

**EFFECTS OF ALTERNATE WETTING AND DRYING
CYCLES ON PEDOGENIC PROCESSES OF SOME
REPRESENTATIVE BANGLADESH SOILS**

MD. FAZLEAH ALI

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**Ph.D. THESIS
DEPARTMENT OF SOIL SCIENCE
UNIVERSITY OF DHAKA
1994**

**EFFECTS OF ALTERNATE WETTING AND DRYING
CYCLES ON PEDOGENIC PROCESSES OF SOME
REPRESENTATIVE BANGLADESH SOILS**

A thesis submitted for the degree of

DOCTOR OF PHILOSOPHY

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UNIVERSITY OF DHAKA

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by



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B.Sc. (Hons), M.Sc. (DU, Dhaka)

May
1994

**DEDICATED TO
MY
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CERTIFICATE

Certified that the thesis entitled "Effects of alternate wetting and drying cycles on pedogenic processes of some representative Bangladesh soils" submitted by Mr. Md. Fazleah Ali in fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in Soil Science of the Faculty of Biological Sciences, Dhaka University, is an original research work. No part of the thesis has been reproduced anywhere for any other degree or diploma.



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I hereby declare that this thesis entitled "Effects of alternate wetting and drying cycles on pedogenic processes of some representative Bangladesh soils" has been composed by myself and all the works presented herein are my own. I further declare that this work has not been submitted anywhere for any academic degree.

May, 1994



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CHAPTER I

INTRODUCTION

CHAPTER - I

INTRODUCTION

Soil is a complex dynamic systems in which almost countless number of processes are taking place. Generally, these processes can be classified into chemical, physical or biological.

The physical, chemical and biological processes in soils collectively represent the pedogenic process in that the reactions ultimately determine the characteristics of the resulting soil (Nikiforoff, 1959). Considerations of pedogenesis have concentrated generally on processes that determine morphologically all significant properties such as horizons of clay or sesquioxide enrichment, leached horizons, or horizons of specific character. Pedogenesis influences functional properties of soils, such as their ability to retain and recycle nutrients.

It is well established that climate is one of several factors that determine the nature of soils. Climate not only exhibits its influence on soil formation by control of some of the chemical and physical reactions taking place in the soil but also by its control of the organic factor and to some extent of the factors of relief and time through erosion and deposition of soil materials (Buol et al, 1980). Of the climatic sub-factors, water plays a dominant role in soil forming processes.

The presence of water in soil influences soil genesis through its effect on biomass production, mineral weathering and clay formation, translocation of colloids within the soil, and removal of soluble products from it (Foth, 1984).

Soils may be saturated or flooded either naturally or artificially. Natural saturation may be caused due to the low lying position of the landscape and artificial saturation may be attributed to man-induced management practices such as irrigation for rice cultivation. The length of duration and depth of flooding largely influences the morphological, electro-

chemical and biological properties of the soils. These provide diagnostic features in pedogenesis and soil classification.

Soil water table strongly influences the biological and chemical processes. In most soils, depth and length of saturation can be correlated with the quantity, nature and pattern of mottles relative to soil horizons, and to structure. The relationship between the quantity, distribution, and colour of mottles is related to oxidation-reduction conditions in soil. Periodic saturation of a soil may result in processes of reduction followed by oxidation when the soil becomes unsaturated. Reduction and removal of reduced materials result in gleying characterized by low chroma colors (Veneman *et al*, 1976). Most soils that have repeated or extended periods of saturation are mottled in the wet part of the profile. The abundance, size, and color of the mottles usually indicate the periodicity of saturation (Parker *et al*, 1985).

Soils of paddy fields or of other fields on which water is impounded will have a tendency to acquire supplementary characteristics of an aquatic moisture regime. The degree of change of the soil moisture regime and the degree to which this change results in the diagnostic properties of soils depend on the soil and water management. It is an established fact that poorly drained low land soils do not change much when used as paddy land but alterations of diagnostic characteristics may take place in the pedons of the rice lands which remain submerged for long periods. Here the sub-surface horizons may develop neutral grey colors due to continuous waterlogging and absence of oxygen. This is seen in double and triple cropped irrigated riceland on fine clayey Inceptisols. Such soils may lose the characteristics required to classify them as Inceptisols, particularly the diagnostic cambic horizon. The changes in diagnostic characteristics under paddy cultivation is more fundamental in moderately well to well drained soils, where a surface and sub-surface gley develops which is not connected continuously with a subsoil gley.

Under wet condition soil also leads to physical changes like expansion and gelation, which again leads to contraction and degelation under drying situation that are extremely

important in structure formation and associated profile differentiation. Besides, rice cultivation under puddling for prolonged periods forms ploughpan in soils, which invites a pedological change on normally nonaquic soils preventing the downward movement of water and impedes the penetration of roots.

Due to flooding of an air dry soil the major electrochemical and chemical changes that occurs are; decrease in redox potential, disappearance of NO_3 , accumulation of NH_4^+ , promotion of N fixation, increase of availability of Fe and P, decrease of availability of S, Zn and Cu, increase in pH of acid soils and decrease in pH of alkaline soils, increase in electrical conductivity, reduction of Fe (III), Mn (IV) and SO_4^{-2} (Ponnamperuma, 1985).

Under aerobic condition most of these electrochemical and chemical changes are reversed with the level of redox-potential and changes in pH. With alternate wetting and drying situations these changes play an important role in determining the pedogenic changes in soils.

The minerals, specially the clay minerals, determine the properties of soil, be it in agriculture, in ceramic or in engineering. The clay minerals being the most reactive constituents of a soil, play a considerable part in the interactions of soil with nutrient ions, water, organic substances etc. Generally, soil management practices depend on the reaction of soil clay minerals with water and fertilizer. These reactions and consequent chemical behavior of the colloid determine, to a large extent, the overall fertility status of a soil. The alteration, transformation and neoformation of clay minerals depend upon the environmental conditions and the intensity and duration of wetting and drying of the soil. The type and dominance of specific clay minerals in soils play an important role in the planning of modern agricultural management as well as in family level classification, which is the most suitable unit for agrotechnology transfer.

Most of the Bangladesh soils are characterized by seasonal flooding and drying which causes different soil forming processes. The floodplain soil formed under alternate seasonal flooding condition comprise about 60 percent of the country's land area. Most of

the floodplain soils are inundated either by heavy rainwater or by floodwater during monsoon and are dried during winter. Of the total cropped area of 13.1 million hectare, 10.4 million hectare of land in Bangladesh is under rice cultivation (Anonymous, 1985). Traditionally aus used to be grown in the nonflooded to shallowly flooded lands, transplanted aman in the shallowly flooded wet lands and deep water aman in the moderately deep to deeply flooded wet lands. Aus/Jute-rabi was the major crop rotation in nonflooded highlands throughout the country except the Barind and old Himalayan piedmont plain areas, where mainly transplanted aman was the mono-crop rotation. But with the introduction of high yielding variety of rice replacing a major part of aus, jute and dry land rabi crops (FAO/UNDP, 1982) during 1960s, the extent of traditional rice gradually decreased and the irrigated area increased through the use of surface and ground water. In the process, the irrigated area increased from 1.2 million hectare to 2.2 million hectares during the last two decades (Bhuiya, 1991) with the implementation of major irrigation and drainage projects like, Dhaka Narayangonj - Demra (DND), Chandpur irrigation project (CIP), Barisal irrigation project (BIP), Ganges - Kobadak Project (GK) in Kushtia, Jessore and Khulna, coastal embankment project - polder-22 in Khulna along with the use of large scale deep tubewells, shallow tubewells and low lift pumps etc.

Due to double and in some case triple HYV rice cultivation under irrigation, the soils remain waterlogged or saturated in most part of the year and this continual man-induced irrigation practice has become an usual phenomenon in Bangladesh causing plausible changes in morphological, physical, chemical and mineralogical properties of the soils.

Although, many research works have been carried out on the chemistry and fertility of floodplain soils but scanty information on the pedogenic relationships of these soils to alternate wetting and drying cycles as well as prolonged saturation period are available. Thus this study on "Effects of alternate wetting and drying cycles on pedogenic processes of some representative Bangladesh soils" has, therefore, been felt and undertaken with the following objectives:-

- To study the morphological, physical, chemical, electrochemical and mineralogical changes that take place due to alternate wetting and drying and prolonged period of saturation of soils by irrigation and to derive their significance in relation to soil properties and development in Bangladesh.
- To classify these soils at the family categoric level.
- To observe likely changes occurring in soil under different water management regimes.

This investigation will help to update the present soil classification into family category according to the USDA system which will be useful to the soil scientists, agronomists, farm research scientists and agricultural extension workers involved in agro-technology transfer programmes. Besides, this will ultimately help the farmers in assessing the extent of deterioration in the fertility of the soils associated with prolonged submergence and adaptation of proper soil management practices to combat the malign changes.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER - II

REVIEW OF LITERATURE

Literature pertaining to the works on morphological, physical, chemical and mineralogical changes that take place due to alternate wetting and drying cycles or seasonal waterlogging of soils has been reviewed. Related information on classification of soils developed on the Ganges and the Brahmaputra alluvium has also been reviewed. They have been arranged in the following pages under different headings.

SOIL RELATED CHARECTERISTICS

MORPHOLOGICAL

The morphological features of soils are of prime importance in the field for identification of soils, because they are a direct result of pedogenic processes. Morphological characteristics included in this review are colour, structure and flood coatings or cutans.

Soil Colour

Soil colour is the most obvious feature of the soil and is one of the most important and useful characteristics for soil identification. Soil scientists commonly use grey colours (chroma ≤ 2) as an indicator of saturated and reduced soil conditions. Various studies (Quespel, 1947; Daniels *et al.* 1973; Evans and Franzmeier, 1986) have indicated that reducing conditions result in grey colours in poorly drained soils or horizons, and oxidizing conditions are responsible for the brighter colours in better drained soils. Studies of water table have shown that soil colours can be used as a general indicator of saturated and reduced conditions (Mackintosh and vander Hulst 1978; Zobeck and Ritche 1984; Pickering and Venemen, 1984; Evans and Franzmeier, 1986).

Daniels *et al.* (1971) found the grey colours generally occurred when the soil was saturated for 50% or more of the time. There are, however, some soils with grey colours but saturated less than 50% of the time. Coventry and Williams (1984) reported a strong relationship between soil colour and current water table. They found that grey colours occurred when there was 5 weeks of saturation, and grey colours were dominant in a mottled subsoil when saturation was for at least 21 weeks.

The relationship between water saturation and soil colour has been explained primarily by the oxidation reduction states of Fe and Mn compounds, which regulate the distribution and forms of these elements within the soil profile (McKeague, 1965; Bonner & 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).

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 Cremeens, (1991) conducted a study on the relationship of saturation and B horizon colour patterns in soils and they related colours of Bt, Btg and Bg horizons to the total percentage of time that the subhorizons were water saturated, and the percentage of time that the sub horizons were saturated 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) recommended that soils containing low ($<1.0\%$) levels of organic matter in horizons below the A₁ or Ap, seasonal saturation and reduction were found to occur in horizons having dominant chromas of 3 or less along ped exteriors, whereas mottled ped interiors had Chromas of 4 or more.

SRDI Staff (1970) during reconnaissance soil survey of Kushtia district (which is Ganges alluvium sediments) found that top soil colour ranged from Pale olive to olive brown in ridges and grey to very dark grey in interr ridge depressions and basins. Subsoil colour ranges from olive to olive brown in ridges and grey to very dark greyish brown in depressions and basin centers.

Soils formed in the old Brahmaputra floodplain have top soil colour range from olive to grey & olive grey in ridges and grey to dark grey in lower slope of ridges and basins. Subsoil colour ranges from brown to mixed brown and grey or dark grey in ridges and grey to mixed dark grey and brown in basins (SRDI staff, 1975).

Soil Structure

The importance of soil structure in soil classification and in influencing soil productivity can scarcely 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.

Alternate wetting and drying situation plays 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 in structure formation and, hence, in profile differentiation with respect to structure. Wetting and drying and expansion and contraction affect structure formation because they affect orientation of the clay particles with respect to one another, with respect to the sand and silt particles, and with respect to the roots (Bear, 1964).

Reid *et al.* (1949) found that soils of saline alkali spots contained low content of waterstable aggregates and a high dispersion ratio, while soils from saline spots were similar to normal saline spots.

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

subsoils with coarser particles are greater than in fine textured soils. SRDI Staff (1974 - 75) found that in old Brahmaputra floodplain the moderately well to imperfectly drained subsoils have weak to moderate prismatic and blocky structure; imperfectly to poorly drained soils have moderate to prismatic structures and poorly to very poorly drained soils have strong prismatic and blocky structure.

SRDI Staff (1970) reported that the young Ganges meander floodplain with loamy to clay subsoils, occupying ridges and inter-ridge depressions have weak to strong prismatic and blocky structure. The clayey soils, occupying infilled channels and small basins, have moderate to strong prismatic and blocky structure. They also found that the loamy to clayey soils occurring on ridges and in inter-ridge depressions, have weak to strong prismatic sometimes lenticular (wedge-shaped) structure. In old Ganges floodplain the loamy to clay soils occurring on ridges and in inter-ridge depressions, have weak to strong prismatic and blocky, sometimes lenticular (wedge shaped) structure. Heavy cracking clays occurring in broad basins and in some infield channels have strong prismatic structure breaking into fine and very fine blocky structure.

Flood Coatings/cutans

Flood coatings is formed mainly in the seasonally flooded lands of Bangladesh. Flood coatings is clearly different from clay skins (argillans), which comprise well oriented fine clay and which are generally regarded as indicating long continued soil development.

FAO (1971) defined flood coatings as the shiny surfaces 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. Brammar, (1971) reported that study of thin sections under the microscope indicates that they comprise clay, fine silt (up to about 30 micron) and humus, and that only the included mica flakes are well oriented, thus he made it clear that they differ from clay skins. The color of the flood coatings is that of the top soil: grey where the topsoil is grey (when wet); dark grey where the top soil is dark grey. This indicates that the material

is derived from the top soil, not from alluvium suspended in the flood water. It also indicates that the coatings are alluvial, not pressure coatings (although they can be modified by pressure in swelling clays such as develop in Ganges alluvium). The floodcoating material is believed to move from the top soil 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 are found 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) proposed the name gleyans for these coatings since the coating material is always gleyed (reduced).

SRDI Staff (1970 and 1974-75) used this flood coatings as cutans in Reconnaissance soil survey reports, Kushtia District and Kishoregonj and Sadar Subdivisions, Mymensingh District.

PHYSICAL PROPERTIES OF SOILS

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

Soil Texture

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

Goel and Agarwal (1959) reported 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. The responsive soils exhibited considerable illuviation of clay from surface downward. Lime content of soil profiles decreased with increase in soil maturation.

Torrent and Nettleton (1979) observed that chemical weathering effects the particle size distribution. They found significant correlation between weathering index (fine silt total silt) and temperature which could be useful in assessing the uniformity of parent material and for comparison purposes.

SRDI Staff (1970) found that on the young Ganges meander floodplain, soils on ridges and interrIDGE depressions are silt loam to silty clay and on the Old Ganges meander floodplain, soils of ridges and inter-ridge depressions are loamy to clay in texture.

SRDI Staff (1974-75) found that most ridge soils in Old Brahmaputra floodplain are silt loam to silty clay loam and in interrIDGE depressions and channels they are mostly silty clay loam to silty clay subsoils. In oldest Brahmaputra flood plain the ridge soils are silt loam to silty clay loam and basin soils are silty clay to clay in subsoil texture.

Bulk density

Bulk density which is a measure of soil weight per unit volume (g cm^{-3}) gives a good estimate of soil porosity. It has great importance in understanding the physical behavior of soils.

Joshua (1983) studied some representative Ganges river floodplain soils of Bangladesh and found that in general, the bulk densities vary from 1.35 gm/cc to 1.5 gm/cc. He reported that the higher bulk densities are frequently associated with the surface horizons of the medium textured soils of the upper slopes. This condition could be attributed to the structural break down and compaction of the soils due to ploughing under

wet conditions. The heavy textured soils show greater variability in their bulk density values, probably due to their swelling and shrinking properties.

SRDI Staff (1986) studied some soils of Old Brahmaputra floodplain and found that the lower bulk density in top silt loam and silt layer ranges from 1.26 to 1.40gm/cc and the higher bulk density which ranges from 1.54gm/cc to 1.62gm/cc are associated with ploughpan which are mostly found in silt loam. He also reported that lower bulk density 1.41 gm/cc to 1.48 gm/cc has been encountered in heavy textured soil and density tends to increase with depth in these soils.

Saturated Hydraulic conductivity of soils

The hydraulic conductivity measures the ability of the soil to conduct water through it. It depends on the nature of the soil and the fluid properties. The soil properties that affect hydraulic conductivity are mainly related to pore size distribution and the soil pores. The hydraulic conductivity is related high in coarse textured soils and low in heavy textured soils (Karim, 1988).

Joshua (1983) measured the saturated hydraulic conductivity of some Ganges river floodplain soils of Bangladesh. On the basis of an average horizontal hydraulic conductivity of the soil horizons of varying textures that are present within the effective depth, he reported that in general, the hydraulic conductivity values of all soils are moderate. Even in the heavy textured Amjupi and Gangni series, the presence of silt loam and silty clay loam horizons in the substratum make the lateral hydraulic conductivity similar to those of the medium textured soils. In soils where these higher textured layers are absent, the hydraulic conductivities will be lower, as would be respected for heavy textured soils.

SRDI Staff (1986) measured hydraulic conductivity of Tippera series on 5cm core soil sample to assess the vertical permeability of soils. They reported that in some soils of Old Brahmaputra alluvium the permeability in the 10-20 cm layer was exceptionally lower than overlying and underlying layer which in fact governs the vertical movement of the

entire soil. They stated that the lower result is due to compactness of this layer as indicated by relatively higher bulk density.

Soil moisture retention capacity

Soil moisture retention is strongly related to the surface area per unit volume of the soil mass and thus is related to the clay and organic matter contents.

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. 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 to 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 (1983) studied soil moisture characteristics with 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 cms of H_2O (PF 1.65). This sharp decrease in moisture content persists upto a tension of 1 atmosphere (1000 cms of H_2O or PF3), during which most of the stored moisture is 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 cms water.

The silty clay and clayey soils have very similar moisture retention curves. These curves do not possess any marked inflection and are very gently sloping, showing uniformity in the pore size distribution. The moisture release is gradual with increase in tension upto 15 atmospheres.

CHEMICAL PROPERTIES OF SOILS

Chemical properties deals with the chemical composition of soil and indicates about the nature and extent of weathering and stage of development of soils. These properties have a direct bearing on nutrient supplying power of soils.

Soil reaction

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

Ponnamperuma (1965 and 1972) found that when an aerobic soil is submerged, it's pH decreases during the first few days, reaches a minimum, and then increases asymptotically to a fairly stable value a few week 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 to increase the pH of acid soils and to depress the pH of sodic and calcareous soils. The increase in pH of most acid mineral soils is due to the reduction of Fe (iii) to Fe (ii) and the decrease in pH of alkaline soils is due to CO₂ accumulation.

Ponnamperuma (1985) reported that the decrease in pH of sodic soils on flooding alleviates Ca and Mn deficiencies. Incorporation of organic matter enhances the flooding effect through CO₂ and acid production. The increase in pH of acid soils increases the

availability of P and Mo. The rise in pH increases the concentration of NH_3 at a given total NH_4^+ concentration, which in turn enhances NH_3 loss from the flood water.

Ponnamperuma (1975) reported that upland soils, unlike submerged soils, are not able to adjust their pH levels to the favorable 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.

Shailendra Kumar *et al.* (1981) found that after one week of submergence the pH of all the hill soils increased and of tarai soil decreased such that after the third week, the pH of all the soils approached neutrality (6.9 to 7.2). The range for initial soil pH of the hill soils was from 6.0 to 6.6 and that of tarai soil was 7.3.

Redox Potential (Eh)

Ponnamperuma (1985) reported that the Eh falls sharply upon flooding, reaches a minimum within a few days, rises rapidly to a maximum, and then decreases asymptotically with time. He found that the presence of organic matter, a low content of NO_3 and MnO_2 , and a temperature of 30-35°C favour Eh decrease. Low Eh favors N-fixation.

Ponnamperuma (1978 and 1982) found that a low Eh increases the availability of P, Fe, Mn and Mo, but decreases that of S and Zn.

Ghildyal (1987) reported that in general, soil Eh decreases with increasing pH.

Patrick *et al.* (1968) observed five ranges of redox conditions in soils depending on the pH values. At pH 7, Oxidized soils are at potentials of + 400 mv, moderately reduced soils at about +100 to +400 mv. reduced soils at -100 to + 100 mv and highly reduced soils at -300 to -100 mv. Again at pH 7, nitrate is reduced at a redox potential of about + 225 mv, manganese (valency 3-4) at about + 200mv, iron (valency) at about + 120 mv and sulphate at about -150 mv.

Ghildyal (1987) demonstrated that the oxidation reduction potential of a soil sample under submerged condition falls gradually, approaching a limiting value that is dependent on the rate of decomposition of organic matter. It is for this reason that the oxidation reduction potential of surface soil samples falls more rapidly, and to a lower level, than in the case of those from lower horizons. The aerobic soils are characterized by high positive Eh values ranging from + 500 to + 700 mv, while flooded soils may exhibit Eh values ranging as low as -400 to -300 mv depending upon the organic matter, the Fe and Mn content and the pH and temperature of the soil.

Aomine (1962) correlated the oxidation reduction potential with some distinct soil colors. Red and brown colours are imparted by ferric iron at $Eh \geq 300$ mv. Similarly, the reduction of ferric iron to ferrous iron imparts grey and blue colours and these soil colours occur at $Eh < 300$ mv.

Alberta (1953) found that the oxidation reduction potential in a gleyed (reduced) soil containing rusty mottles has been found to be 400 mv in these mottles and 170 mv in the surrounding soil.

Electrical conductivity

Ponnamperuma (1978) found that the electrical conductivity of the solution of most soils increases on flooding, attains a maximum, and decline to a fairly stable value that varies with the soil. The increase is due to mobilization of Fe^{2+} and Mn^{2+} , formation of NH_4^+ , HCO_3^- and $RCOO^-$ and displacement of cations for soil Colloids by Fe^{2+} , Mn^{2+} , and NH_4^+ . The subsequent decrease is caused by precipitation of Mn and $MnCO_3$, loss of CO_2 , and conversion of $RCOO^-$ to CH_4 . Ponnamperuma (1985) reported that in a normal submerged soil the peak EC is around 2-4 ds/m, but sandy soils rich in organic matter and some acid sulfate soils may attain values exceeding 4 ds/M, the harmful limit for rice. An Ec of 2 ds/M favours rice growth. Cations displaced by Fe^{2+} , Mn^{2+} , and NH_4^+ while the soil is in the reduced state may be lost in percolating water. On drying, Oxidation of Fe^{2+} and Ntt^+ acidifies the soil.

Shailendra Kumar *et al.* (1981) found that the initial Ec of a hill soil (ranged from 0.16 to 0.50 mmhos per cm) increased during submergence. The range for third week of submergence was 1.05 to 3.15 mmhos cm⁻¹. He reported that this increase in conductance may be attributed to the increase in soluble salts particularly of Ca and Mg by CO₂ and organic acids.

Calcium carbonate

The presence of CaCO₃ in soil is related to water movement and hence to climate (Precipitation). The concentration and position of CaCO₃ accumulations provides an insight into past climate. Movement of soil and water in the profile is slowed down in presence of CaCO₃.

Vinayak *et al.* (1980) while studying some Calcareous (2.4 to 20.5 percent CaCO₃) saline sodic soils, reported that the CaCO₃ with Na⁺ formed the Na₂CO₃ thereby accentuating the sodicity or alkalinity. By this process Na⁺ invariably tended to dominate the exchange complex.

SRDI Staff (1970) during reconnaissance soil survey of Gangetic alluvium soils reported that soil reaction in the surface and subsoils usually ranges from neutral to moderately alkaline in case of calcareous soils and neutral to strongly acid in case of non-calcareous soils. Some soils were found to undergo an appreciable change in soil reaction as a result of drying out from wet or moist field condition, from near-neutral reaction under anaerobic or reduced condition some of the calcareous soils turned somewhat alkaline and non-calcareous soils, particularly having relatively high organic matter content, turned slightly to very strong acid on becoming aerobic or oxidized.

Organic carbon

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 reactions that go on during pedogenesis, are dependent to some degree on the quantity of organic matter present in soils.

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

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 contents in the 0.5 to 1 percent range.

Gupta *et al.* (1952) found organic carbon and total N in decreasing order with depth from 0.57 to .09 and from 0.07 to .008 percent, respectively, while the pH increased with depth in Dhankar grey hydromorphic alluvial soils of lower Gangetic plains of U.P. in India.

Cation exchange capacity

Next to photosynthesis, cation exchange phenomena are the most important reactions in the whole domain of agriculture. The CEC is considered as an index of soil fertility. It plays a great role in the pedogenic processes of soils.

Gupta and Misra (1970) reported CEC values of are Gwalior soils to be 21.3, 16.4, 12.5 and 11.4 me/100q having textures of clay, clay loam, sandy clay loam and sandy loam respectively. Chatterjee and Dalal (1976) reported that the CEC values of Bihar and west Bengal soils decreased with depth (from 10.2 to 4.1 me/100g); while clay increased upto the middle layer following a decrease in the lower horizons.

SRDI Staff (1970) reported an increase in CEC values with the increase of clay contents in the Sara and Ghior soil series.

Pathak and *et al.* (1980) in some salt affected soils of Kaira district of Gujarat found the range of CEC from 11-21 me/100g when clay content ranged from 25.4 to 55.2 percent.

Thawale *et al.* (1991) found that the CEC of the soils of agricultural school farm sawangi ranges from 35.7 to 62.8 C mol (p+) kg⁻¹ indicating montmorillonitic nature of clay minerals.

Exchangeable Cations

Katti (1976) found higher amount of exchangeable Ca⁺ or k⁺ except in the last layer of the pedon where exchangeable Ca⁺⁺ and Mg⁺⁺ was equal to exchangeable Na⁺.

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 ferrous iron displaces cations and the displaced cations are leached.

Janzen (1962) found that exchangeable Ca⁺⁺/Mg⁺⁺ ratios vary from relatively high in the A to very low in the AB and B horizons. Exchangeable Na⁺ is low in upper horizon and high in lower horizons. Exchangeable Ca⁺⁺/Mg⁺⁺ ratios are very high throughout the profile ranging from just over 4 in the upper A to <2 in lower B horizon. The Ca⁺⁺/Mg⁺⁺ ratio decreases with increase in depth.

Islam *et al.* (1974) studied six rice soils of Bangladesh and found that soils calcium concentration increased rapidly with time of submergence and then decreased. He reported that the velocity and magnitude of increase in calcium content varied in different soils. In all soils, the peak values were obtained in the ninth week of submergence followed by a gradual decrease. Magnesium and potassium concentration followed similar trends.

Changes in Soil Nutrient Elements

Nitrogen

Due to alternate wetting and drying of seasonally flooded soils, nitrogen play its role in two forms. Under aerobic situation nitrate is present and in anaerobic situation ammonium is present.

Ponnamperuma (1985) reported that nitrate is rapidly reduced to N_2O and N_2 in the anaerobic bulk of flooded soils. The rate of disappearance of NO_3^- varied markedly with soil and temperature. He found that denitrification (as measured by NO_3^- disappearance) was fastest in pila clay loam (pH 7.1, OC 2.1%), moderate fast in Luisiana clay (pH 4.7, OC 2.1%) and slowest in Keeling silt loam (pH 7.7, OC 3.9%) despite it's high pH and high organic carbon content. In all soils denitrification was hardly detectable at $5^\circ C$ and increased rapidly with increase in temperature.

Ponnamperuma (1985) stated that in tropical rice soils. NO_3^- disappears within a few days of flooding, largely because of denitrification. A survey of 28 philippine wet land rice soils sampled just before flooding for the rice crop revealed the presence of 5-39 mg NO_3^- -N/kg soil with a mean of 13 mg/kg.

Khind and Ponnamperuma (1981) reported that alternate wetting and drying of a soil, carrying a vigorously growing rice crop, does not cause appreciable denitrification.

Islam and Islam (1973) worked with some Bangladesh soils & found a progressive decrease in nitrate concentration with time from the 2nd week of submergence. The rate of decrease was most marked during the first 5 weeks. The decrease was then rather gradual.

Ponnamperuma (1985) reported that the mineralization of organic N in submerged soils stops at the NH_4^+ stage. The velocity of NH_4^+ release is therefore a good index of the capacity of soil to meet the N demands of a rice crop. The kinetics of ammonification varies with the soil, temperature, and pretreatment of the soil.

Sahrawat (1983) found that air-drying 4 peat soils before anaerobic incubation caused in 8 week of 200-500 mg NH_4^+ /kg compared with almost zero for the nondried wet peat soils.

Ponnamperuma (1965) postulated that a considerable proportion of the NH_4^+ mineralized in a submerged soil may be in the solution phase, especially in sandy soils. This form of NH_4^+ is highly mobile and is liable to lose by leaching. A sandy soil well supplied with organic matter built up an NH_4^+ concentration of nearly 70 mg/litre in 75 days while a neutral soil low in organic matter accumulated barely 5mg/litre in the same period.

Phosphorous

Phosphorous is relatively insoluble in soils, but its considerable translocation takes place over the long time spans involved in soil development. In unweathered parent material, P is generally present as apatite and consequently the quantity of P in solution is governed by the weathering of apatite.

The soils PH must drop below approximately 7.5 before significant quantities of P are released. The soluble P is then utilized by plants, leached from the system or precipitated as Ca, Al or Fe-phosphate. Total P tended to progressively decrease as the soils become more weathered, decreasing from 700 to 450 ppm (Smeck, 1963).

Godfrey and Riecken (1954) observed that total P was found to decrease in the profile. The P, measured in B horizon, was less than in A and C horizon. They concluded that a definite relationship exists between quantity and distribution of P and stage of profile development.

Runge and Riecken (1966) reported that available P is high near the surface, decrease to minimum in the lower A or upper B horizon, attains maximum in lower B or upper C horizon and then decreases to a level characteristic to parent material. They explained that high available P at surface was due to the addition of fertilizers and manures or easily mineralized organic P. The minimum was due to constant removal of soluble P by plant roots or eluviation. Maximum P was found within 90 to 180 cm due to illuviation and lack of plant removal. Total P distribution was similar to that of available one.

Ponnamperuma (1985) reported that when a soil is flooded, the concentration of water and acid soluble P increases, and then decreases. He observed that the increase in solubility of P caused by flooding is caused by reduction of $\text{FePO}_4 \cdot 2\text{H}_2\text{O}$ to $\text{Fe}(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, desorption following reduction of Fe (iii) hydrous oxides to Fe (ii), hydrolysis of FePO_4 and AlPO_4 in acid soils, release of occluded p, and anion exchange.

Potassium

Verma and Verma (1968) reported that on individual soil sample basis, available K varied from 0.064 to 4.65 me/100g soil, but on soil group basis its minimum (0.67me) and maximum (1.20me) amounts were found in alluvial and black soils, respectively of M.P. The alluvial soils of Morena ranged in K available content from 0.40 to 0.97 with an average of 0.67 me/100g, which was found to be highly correlated with organic carbon ($r=0.496$).

Islam and Islam (1973) found that potassium concentration increased rapidly with time of submergence. The peak values were reached in 9 weeks of submergence.

Goswami and Bandopadhyaya (1978) demonstrated that the distribution of available K in different soils is a function of the degree of weathering and nature of parent material.

Sulphur

Harward and Reisenauer (1966) reported that the movement of SO_4^- within soils determines the magnitude of losses of the element in drainage water. It may have marked influences on the distribution of available form of the element within the profile and it is a mijor mechanism by which the SO_4^- ion is supplied to the plant root absorption sites.

Neue and Mamaril (1985) postulated that in anaerobic soils, the main change related to S is the reduction of SO_4^{2-} to S by obligate anaerobic bacteria. In neutral to alkaline soils, concentrations of SO_4^{2-} as 1,500 ppm may be reduced to zero within some weeks of submergence. On the basis of various reports, he also reported that S-deficient soils in the humid region possess one or more of the following features: low organic matter content, high content of allophone or oxides, sandy texture, low content of S, frequent burning of vegetation, and absence of pollutants.

Micronutrients

The nature of parent materials and the degree of weathering have a bearing on the micronutrient element status (Graham, 1953); Swaine and Mitchell, 1960; Wells, 1960 and Hodgson, 1963). Whereas pH, Organic matter, soil texture, CaCO_3 and type of clay minerals markedly control the availability of micronutrient in soil. Relatively less weathered desert soils formed on aeolian deposits of fine sand contain low amounts of Cu, Fe, Mn and B but fairly high amounts of Zn.

Oertel (1961) found that micronutrient status of soil profile is closely related not to the composition of parent material but rather to the undermined pedogenic factors whereas Tiller (1963) indicated that the composition of parent material influences the geochemistry of trace elements in the less weathered soils and the pedogenic factors assume greater significance as the soil becomes more strongly weathered.

Sidhu *et al.* (1976) observed that the Fe-Mn concretions are frequently encountered in soil profiles characterized by high pH and subject to alternate oxidation and reduction.

Zinc

Vittal and Gangwar (1974) found that distribution of Zn in the profile was affected by drainage, soil reaction, clay and organic carbon as they affect the mobilization of Zn in soil. Total Zn increased with depth of the soil profile whereas available Zn decreased. John

(1974) observed that total and DTPA extractable Zn, both, decreased with increasing depth of sampling. Extractable Zn was positively correlated with total Zn, organic matter, clay content and CEC while negatively correlated with soil pH, base saturation and sand.

Zinc is generally more available in acid than in alkaline soils (FAO, 1972-73). Viets *et al.* (1954) found that the Zn uptake of plants decrease to about one half when the pH of the soil was increased from 5 to 7. At high pH the formation of insoluble calcium zincates is favored and Zn may be less available. Therefore liming of acid soils decreases the availability of Zn and may produce Zn deficiency (Thorne *et al.* 1951). On the other hand, Zn toxicity may result if soils are acidified to increase the availability of other elements or when Zn fertilization is continued over a long period with Zn rich materials such as sewage sludge (Bear, 1955 and Janick, *et al.* 1968). In soils of sodium alkalinity the availability of Zn may increase with increasing pH due to the formation of relatively soluble sodium zincates (Bear, 1955).

In calcareous soils, such as rendzinas, variations in the calcium carbonate content have been found to have only a minor effect on Zinc availability (Navrot, and Ravikovitch, 1969) whereas the mineralogical composition of these soils plays an important role in influencing both the total content and availability of Zn (Navrot and Gal, 1971). Soils rich in montmorillonite may contain twice as much total Zn as attapulgitic soils but in the former soils, due to stronger Zn bounding to montmorillonite, the content of available Zn may be lower (FAO, 1972-73).

Randhawa *et al.* (1978) reported that Zinc deficiency used to be a very minor problem in the traditional rice-growing areas, but now it is quite widespread in newly reclaimed paddy soils with irrigation under subhumid to semiarid climatic conditions. They found that most soils affected by zinc deficiency are calcareous or saline, and sodic with alkaline pH. Strongly reduced soils in swampy wetlands are also reported to show Zn deficiency.

Ponnamperuma (1985) reported that submergence brings about a decline in Zn availability that is linked to pH changes and formation of insoluble Zn compounds.

Copper

Udo *et al.* (1979) in a study of Nigerian soils observed that total Cu ranged from 7 to 72 ppm with a mean of 35 ppm. The soils formed from basalt had the highest values of Cu while those on coastal plains had the least amount. Total Cu was higher in subsoils.

Ponnamperuma (1985) reported that copper is present in soils as oxides, carbonates, silicates, and sulfides. The chemistry of Cu in submerged soils is similar to that of Zn, forming sparingly soluble sulfides. Precipitation of Cu as hydroxide, carbonate, or phosphate is unlikely below pH 7.

Agrawal and Motiramani (1965) indicated that alluvial soils of Madhya Pradesh contained 1.74 and 22.36 ppm of available and total Cu respectively. Available Cu was significantly correlated with pH ($r = -0.333^*$) and organic carbon ($r = 0.429^*$). Sinha and Joshi (1975) reported 98 percent soils to be deficient in available Cu in some Alluvial and Black Soils of Madhya Pradesh.

Forms of Iron, Aluminium, Silicon, and Manganese in the Soils

Iron

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

Juo *et al.* (1974) reported that the active Fe ratio decreases with the increases of profile depth, suggesting 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.

Chatterjee and Dalal (1976) indicated that Bihar and west Bengal alluvial soils were higher in total Fe in surface (2.1 to 2.5%) than in lower layers (1.3 to 1.4%).

Mitra and Mandal (1983) studied 35 surface soil samples from the rice fields taken from different districts of the 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 cases.

Gotoh and Patrick (1974) found that the increase in water soluble and exchangeable iron were favored by a decrease in both redox potential and pH. They reported that the distribution between water soluble and exchangeable iron fractions was highly pH dependent with a decrease in pH at a given redox potential increasing the relative amount of ferrous iron in the soil solution at the expense of that on the exchange complex.

Karim (1984) studied three typical Bangladesh rice soils i.e. (i) Madhupur, non calcareous dark grey floodplain (Aeric fluvanentic Haplaquepts); (ii) Habigonj, grey floodplain (Fluvaquentic Haplaquepts); and (iii) Kashimpur, shallow red brown terrace (Rhodic paleudults) and found that Fe(ii) ion ranged between 0.92×10^{-4} and 1.94×10^{-4} m L⁻¹. Karim (1984) found that the Habigonj, grey floodplain (Fluvaquentic Haplaquepts) soils contained the largest amount of Fe_d-Fe₀ (goethite), 12.05 mg g⁻¹ soil.

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

Bhattacharyya and Ghosh (1986) studied 14 soil samples 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 in the deferrated soils.

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 of most soils, the released iron is precipitated as oxides, hydroxides, or oxyhydroxides (Garrels and Christ, 1965). Soils contain variable amounts of free oxides and amorphous, or x-amorphous constituents (Ghabru *et al.* 1990).

The amounts of free oxides in soils is very important in evaluating mineral weathering and pedogenic changes in soils (McKeague and Day, 1966; Blume and Schwertmann, 1969; Santos *et al.* 1986).

Motomura and Yokoi (1969) suggested that the different forms of ferrous iron in flooded soils have a physical and chemical influence on the development and stabilization of soil structure, and which in turn exert influence on soil productivity.

Granick (1959) reported that the amount of Fe in soils depends largely on soil pH 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 pH 7, the solubility of Fe (iii) is only 10^{-17} moles per litre, while that of Fe (ii) is 10^{-4} . Katyal (1977) found Fe deficiency symptoms in rice on calcareous soils with about 2 mg Fe^{2+} /litre in the soil solution.

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

Joffe, (1949) stated that the surface enrichment of free iron oxide is possibly due to the fact that, with the recording of the ground water table ferrous iron is oxidized easily to form free iron oxide at the surface, while in the subsoil ferrous iron does not change.

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

Aluminium

Aluminium is a major soil constituent occurring in several chemical forms, arising out of weathering of aluminosilicate minerals under certain conditions.

Dolut (1987) reported that a dynamic equilibrium exists amongst the different forms of aluminum in relation to pedochemical reactions. Forms and amount of aluminium, flocculation, pH surface area, surface charge and also pedogenic processes throughout the profile.

Dolut *et al.* studied the different forms of aluminum and the interrelationship among themselves as well as with some important soil characteristics in relation to pedogenic processes in three Tarai and Teesta alluvial soil profiles of Jalpaiguri District of West Bangal. They found that pyrophosphate extractable Al varies from 125 to 395 ppm and are highest in the surface horizon and show a regular decrease with depth and are intimately related with the organic matter content of the soils. They reported that amorphous Al in soils varies from 1001 to 2881 ppm. Oxalate extractable Al has positive significant correlation with organic carbon. Dithionite extractable Al varied from 1280 to 2910 ppm. Crystalline Al increases upto middle horizon and then decreases below. Moore (1973) stated that it is due to conversion of some alluvial Al into crystalline form on ageing.

Shigeyoshi Gotoh (1976) studied the behavior of Fe, Mn and Al in the soil development of saga polder lands through their distribution in the soil profiles of different reclamation ages. He found that in all the soils, the content of the total and extractable Al_2O_3 showed a rather narrow range from horizon to horizon when compared to that of Fe and Mn. The total Al_2O_3 ranged from 7.96 to 13.22% with a mean of 11.64% constituting the most abundant element in all of the horizons. The profile distribution showed no marked variation with time, exclusive of the soils sampled from two sites where the total Al_2O_3 content generally increased with depth reaching its maximum in the lowest horizons.

Shigeyoshi Gotoh (1976) also found that the extractable Al_2O_3 ranged from 0.091 to 0.243% with a mean of 0.175%. He suggested that a large proportion of the Al content is bound up with the crystal lattice of the constituent soil forming minerals, notably the aluminosilicates. The distribution in the profiles was quite different from that of other elements, in that the extractable Al_2O_3 content generally decreased with depth, attaining the highest contents in the A horizons in the foder soils. He reported that the Al movement in the soil is pH dependent. The pattern of the distribution of the total Al_2O_3 with depth closely resembled that of the distribution of clay.

Karim (1984) reported that formation of goethite was favored by the presence of Al, and the largest amount of goethite was formed at pH 5.8. The influence of Al on the formation of geothite was accentuated at higher temperature. A new Al containing green rust is considered as the possible precursor in the formation of Al goethite from Fe (ii) Al system.

Van Mensvoort *et al.* (1985) reported that aluminum concentrations are directly related to soil pH, and toxic concentrations can occur only at pH values below 5. In most acid wetland soils, the pH rises well above 5 shortly after flooding so that Al toxicity is no problem. In acid sulphate soils, the pH rise may be slower, and Al toxicity may occur even after a period of flooding. Aluminum is probably the most important toxin in the acid sulfate soils in the Bankok Plain (Van Breemen, 1976) and in the Mekong Delta.

Silicon

Silicon is the second most abundant element in the earth's crust. It has a central role in rock weathering and soil development. Silicon in major soil components is lost during weathering and the conversions of silicon to secondary minerals are important aspects of soil development (Tisdale *et al.* 1985). They reported that sandy soils can contain as much as 40% silicon contrasted with as little as 9% silicon in highly weathered tropical soils. The laterite deposits in the tropics, consisting largely of hydrous aluminium and ferric oxides, are left after silicon is removed during intense weathering of soils.

Tisdale *et al.* (1985) also stated that in the usual pH range of soils, H_4SiO_4 or $\text{Si}(\text{OH})_4$ is the principal silicate species in solution. At pH values above 8.5, ionic species such as H_3SiO_4^- contribute significantly to total silicon in solution.

Weaver *et al.* (1968) reported that when soil material containing iron oxides with accumulated silica is deposited where the drainage is poor, reducing condition might be expected to release soluble silica. Since the concentration of $\text{Si}(\text{OH})_4$ of soil solutions appears to be one of the key factors involved in the genesis of montmorillonite in soils (Keller, 1956, Jackson, 1965 and Huang and Jackson, 1968), the release of silica from iron oxides may account for the common occurrence of montmorillonite (Jackson, 1964) in basin sites and in poorly drained soil horizons (Mitchell, 1955; Nye, 1955; Hutcheson *et al.* (1959).

Jones and Handreck (1965) reported that in a wide range of soils of the same pH, the concentration of monosilicic acid in solutions ranged from 3 ppm Si (for a lateritic soil) to 37 ppm Si (for a black clay vertisol).

Hallmark *et al.* (1982) reported that the quality and distribution of Si in soils are influenced by parent material, climate, vegetation, texture, pedogenesis, and intensity of weathering.

Schwertmann and Thalmann (1976) and Karim (1977) found that a small concentration of Si prevents the formation of lepidocrocite during the oxidation of ferrous chloride solutions.

Weaver *et al.* (1968) found that under acid conditions the concentration of Si in the extract is higher than in a neutral extract of soil; that of Fe, Al, and Mg would also be higher in the acid soil system. Given an adequate supply of Al, Fe, and Mg in the soil matrix solution, a sufficiently high concentration of $\text{Si}(\text{OH})_4$ maintained (I) by acidity, (II) by the reduction of free iron oxides or (III) by the hydrolysis of mafic minerals such as

serpentine evidently can lead to the crystallization of expansible layer silicate clays (Wildman *et al.* 1968).

Manganese

Biswas (1953) found uniform distribution of total Mn in older alluvium but either uniform or a slight increase with depth in the recent Indo-Gangetic alluvium. In lower layers CaCO_3 generally acts as a precipitating agent in the accumulation of total Mn. Total Mn also increases with increase in clay content and depth. Active Mn increases slightly with depth whereas exchangeable Mn^{++} is maximum at the surface with uniform or slightly decreasing trend in lower horizons. The amount of total Mn is observed maximum in the zone of accumulation of lime concretions or CaCO_3 which restrict Mn movement. But the accumulation of active Mn is found just above the layer of lime concretions.

Biswas and Gawande (1964) reported that total Mn follows the toposequences. Manganese released during weathering moves partly within the profile and partly towards lateral direction down to the slope. Major portion of total Mn is concentrated in the non clay fractions shows the tendency to increase down the slope.

Vinayaka *et al.* (1964) found that total Mn increased with increase in clay content in saline alkali and normal soil of Rajasthan.

Gupta and Shukla (1975) found that water soluble, exchangeable, reducible and total Mn ranged from traces to 140, 0.1 to 7.1, 15 to 154 and 171 to 741 ppm, respectively. There was no definite depthwise distribution pattern of different forms of Mn in various profiles. But generally readily available form of Mn was more in surface soil than subsoil and reverse was true with total Mn.

FAO, (1972-73) reported that the factors affecting Mn availability, soil pH and the oxidation and reduction conditions may be the most important since the forms in which Mn occurs in soils are strongly related to these factors.

A dynamic equilibrium is believed to exist between the Mn forms so that the tetravalent form is most likely to occur in alkaline soils, the trivalent form is presumably favored by soil pH values near neutrality and the divalent form is found in acid soils (Bould and Hewitt, 1963; Leeper, 1947, and Tisdale and Nelson, 1966).

IRRI (1971) reported that the solubility of manganese increased steeply in aerobic soils as the pH falls below 4.5, while that of iron does not change measurably until a pH of 2.7 to 3.0 is reached. This decrease in pH of an acid soil dramatically, increases the ratio of manganese to iron in the soil solution, leading to manganese toxicity and iron deficiency.

Ponnamperuma (1985) reported that within the first weeks of submergence almost all active Mn in a soil is reduced to Mn^{2+} preceding the reduction of Fe. The reduction of Mn is both chemical and biochemical. Acid soils, high in Mn and organic matter, build up water-soluble Mn concentration of more than 100 mg/litre immediately after submergence. The level declines thereafter to a stable concentration of around 10 mg/litre. He found that Mn deficiency occurs in calcareous soils, sandy soils, and calcareous peat soils.

SOIL FORMING PROCESSES

Major soil forming processes or pedogenic processes pertaining to seasonally flooded or alternate wetting and drying situation are reviewed below:

Oxidation - Reduction

Oxidation is an important geochemical reactions occurring in well aerated rock and soil material where oxygen supply is high and biological demand for it is low. The most important specific reaction is that of ferrous to ferric iron: Oxidation of iron is a disintegrative weathering process in those minerals containing the ferrous ion as part of their structure. The change in size and charge of this element as it is converted to ferric form causes mineral structures to break a part (Buol *et al.* 1980). Examples are those

species of biotite mica containing appreciable amounts of ferrous iron, the mineral glauconite (Commonest mineral in "greensand") (Cools, Pripiat, and Vielvoye 1961) which is rich in ferrous iron, and the iron-bearing species of the hornblendes and pyroxenes in the ferromagnesian primary mineral group. Manganese is likewise released into "free" form by the oxidation of primary minerals.

Reduction in the geochemical environment occurs where the material is water saturated, oxygen supply is low, and biological oxygen demand is high (Buol *et al.* 1980). The effect is to reduce the iron to the highly mobile ferrous form (Cate 1964).

Soil bacteria decomposing the organic matter derive the oxygen they need from oxidized mineral compounds, such as ferric iron, thus converting it to a lower valency form such as ferrous iron. Although iron is the main element affected by reduction, and gives the characteristic grey or bluish grey colour to reduced soil horizons, manganese, sulphur and other elements are reduced at the same time where they are present. The process of iron reduction, being a microbiological process, takes time to operate, and it usually takes about 10-14 days to become thoroughly reduced in seasonally flooded top soil. Reduction plays an important part in the process of ferrolysis (FAO, 1971).

Bouma (1973) reported that soil reduction will take place only when three conditions are met simultaneously by (1) Presence of an organic matter supply (2) absence of an O₂ supply, and (3) Presence of anaerobic micro-organisms in an environment suitable for their growth.

Decalcification and acidification of topsoil

Due to alternate oxidation and reduction cycles in floodplain soils, the top soil becomes acidic. Under the reduced condition the flood plain top soils when flooded, ferrous iron is formed and displaces cations from the clay-humus complex, from where they are removed in the flood water. On re-aeration of the topsoil after the floodwater recedes, the iron changes to the ferric form again and is replaced either by cations provided by

mineral weathering or, where weathering does not release these cations sufficiently rapidly, by hydrogen (and aluminium) in which case the reaction become acid (Brammer, 1971). Thus a floodplain top soil become acidic.

Decalcification means the removal of calcium carbonate from the soil. Ganges alluvium contains about 5-10 percent lime and young lower Meghna estuarine alluvium contains about 1-5 percent. This lime are removed from soils in two ways: laterally and vertically (Brammer, 1971). During seasonal flooding the top soils become reduced. Under reduced condition decomposition of organic mater increases the partial pressure of carbondioxide, allowing calcium bi-carbonate to be formed from the calcium carbonate present (Ponnamperuma, 1966). The bicarbonate, being readily soluble, is dissolved in the floodwater and removed with it. Decalcification also takes place through vertical leaching. This process is very much slower than the lateral leaching; ploughpan interrupt much the vertical leaching of lime.

SRDI Staff (1970) during reconnaissance soil survey found that soils on the old Ganges meander flood plain are usually calcareous at a depth of 30 to 120 cm from the surface or occasionally non-calcareous throughout the profile. Thoroughly calcareous loamy soil occur on higher parts of ridges. They reported that the process of decalcification occurred more rapidly with soils in basins than those on ridges, apparently because of poorer drainage of basin soils and high organic matter content (Brammer, 1968).

Ferrolysis

The term ferrolysis is a hypothesis given by Brinkman (1970). It is a hydromorphic soil forming process in which alternating cycles of reduction and oxidation remove cations from the soil and eventually destroy the soil cation exchange capacity. This process takes place in the seasonally flooded top soils of most Bangladesh flood plain and poorly drained terrace soils, except the Black Terai soils and calcareous soils developed in Ganges alluvium (Brammer 1971).

Brinkman (1970) summarized the ferrolysis process in brief. Iron oxides are reduced to Fe^{2+} during continued microbial decomposition of organic matter after water saturation of the eluvial horizons. The Fe^{2+} displaces exchangeable cations, which are removed by leaching together with part of the ferrous ions. Hydrogen ions consumed during reduction are replaced by the partial neutralization and polymerization of aluminium ions. Next, the pH rises from about 4-5 to 6-7. Part of the aluminium polymers is leached, part is fixed as octahedral fragments or incomplete interlayers between the layers of swelling clay minerals; some Fe^{2+} is trapped and becomes non-exchangeable; the cation exchange capacity of the clay fraction is decreased. Upon the re-entry of oxygen into the eluvial horizons, exchangeable ferrous ions are oxidized again to ferric oxides.

The hydrogen ions during oxidation become exchangeable. The hydrogen clay is rapidly altered to an aluminium and magnesium clay by partial dissolution of cations from the clay minerals. Silica from unsupported tetrahedral sheets is partially dissolved and may reprecipitate in amorphous form when the aluvial horizons dry out part of the silica is removed in solution during the next period of water saturation.

Brinkman (1969) described the following features indicating ferrolysis in the Bangladesh soils.

- A seasonal alternation between an acid soil reaction with the presence of exchangeable Al in dry conditions and a near neutral soil reaction with the presence of exchangeable and soluble Fe^{2+} in wet conditions.
- A net loss of clay from the profile as calculated from texture data as well as from Zr contents of the clay fractions;
- Aluminium interlayering with trapped ferrousion in the interlayers and a low CEC of the clay fractions in the upper horizons;

Moorman (1978) reported that ferrollysis would not occur in carbonate rich soils or in soils receiving ample amounts of basic salts with flood or inter flow waters.

MINERALOGICAL TRANSFORMATIONS

The work done on the mineralogical composition of sand and clay fraction of the Brahmaputra and Ganges alluvium of Bangladesh is reviewed. The literature relating to transformations and neo-formation of clay minerals due to wetness or seasonally flooded and vegetation specially rice cultivation have been reviewed and stated below:

Allen and Fanning (1983) reported that the mineral components of many soils are inherited almost exclusively from the parent material; but in others they have developed mostly in situ during the course of weathering and pedogenesis. In the majority of soils the composition is a result of both inheritance and authogenic formation. Jackson (1964) stated that primary minerals will be understood to mean those formed at high temperatures in igneous and metamorphic rocks and secondary minerals will refer to those formed at lower temperatures in sedimentary rocks and soils. Primary minerals may have been subjected to one or more sedimentary cycles or have been components of previously existing soils.

Allen and Fanning (1983) also demonstrated that the proportion of secondary (authigenic) versus inherited (allogenic) minerals varies greatly among soils. Almost all the clay has developed in situ in some soils, but in others most of it is inherited.

Mineralogy of sand fraction

Huizing (1971) studied the mineralogy of sand fraction (50-500 micron) of some representative floodplain soils of East Pakistan (Present Bangladesh). He found that floodplain deposits contain up to 60% Quartz and 15 to 30 percent feldspars. He also reported that alkali feldspars and plagioclases occur in most samples in about equal amounts. Ganges and young Meghna estuarine alluvia contain 2-9 percent carbonates. The mica content is variable and depends mainly on the grain size of the sediments. Most

samples contain between 5 and 30 percent micas, but in some silty deposits the mica content of the sand fraction can be as high as 80 percent. Huizing demonstrated that in most Ganges deposits, about 40-60 percent of the mica grains are dark colored (biotite and chlorite); in Brahmaputra and Tista deposits, biotite and chlorite grains prevail over muscovite and occupy about 65-73 percent of the total mica fraction.

Saheed (1985) reported that the floodplain deposits are richer in relatively easily weatherable minerals (25-40%) such as feldspars and biotite. The sand mineralogy of the Younger Brahmaputra floodplain deposits has relatively higher mica and lower quartz contents than the Old Brahmaputra floodplain ones. Ganges alluvium contain a considerable amount of calcite.

Khan and Mazumdar (1990) studied the mineralogical composition of sand fractions of two pedons of old Brahmaputra alluvium. They found that the major minerals in Sonatala and Naraibag series of Old Brahmaputra alluvium were muscovite and biotite in coarse fraction (1.0-0.1mm) and quartz, muscovite and biotite in the medium fraction (0.1-0.01mm). They reported that Sonatala and Naraibag soils contained higher amounts of muscovite, biotite and chlorite in the substratum than in the surface layer. Quartz content was found to be higher in the surface than in the substratum in all the soils in all the fractions.

Mineralogy of clay fraction

Saheed (1985) studied the clay mineralogy of some representative soils series i.e. Dhamrai, Sherpur, Silimandi, Singair and Sonatala of the Brahmaputra floodplain and Garuri, Rathuria and Sara of the Ganges meander floodplain of Bangladesh. From the X-ray diffractographic 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 two Dhamrai soils. The other soils of the younger floodplain have traces or small quantities of chlorite and smectite in most of the layers. He stated that apparently most of these kaolinite and vermiculite minerals are parts of the original alluvial deposition, while

chlorite and smectite are the products of in-situ weathering. The relatively older soils of the old Brahmaputra floodplain, with a mild acidic environment in the pedons, have traces of chlorites, but no smectite.

Saheed (1985) demonstrated that Sara and Garuri soils of the Ganges meander floodplain, one being young and calcareous and the other old and partly decalcified, have shown a dominance of mica, closely followed by vermiculite and then kaolinite. The Rathuria soils being relatively younger than sara, have a relatively lesser amount of vermiculite and significantly higher amounts of smectite in comparison with the partly decalcified, strongly acid to neutral layers of the Older Garuri soils and the calcareous, moderately alkaline layers of the Sara soils. These soils persistently show small amounts of chlorite in their surface layers, that decrease with depth. He revealed that their trend might be correlated with the acidic conditions in the topsoils of Rathuria and Garuri soils. But this observation does not hold good in the case of sara topsoil which was calcareous and mildly alkaline in reaction.

Karim *et al.* (1985) reported that Ganges alluvia are calcareous mainly occurring in meander floodplain landscape, ridges, basin and old channels are dominant in mica and vermiculite minerals in clay fractions. The soils of Ganges tidal alluvium are dominated by mica with some kaolinite and smectite. They found that kaolinite and halloysite are the principal minerals in the soils of Brahmaputra alluvium. They contain only little mica and smectite with moderate to highly weathering sequences.

Mia (1990) found that sonatala and Ghatail soil series of Brahmaputra alluvium contain almost equal amount of 1:1 clay and illite (20-40%) in their topsoils, subsoils and substratum. These soils contain trace to small amount (5-20%) of vermiculite and chlorite. He also reported that Sara and Ghior soil series of Ganges alluvium contain 40-60 percent illite, 20-40 percent 1:1 clay in their topsoils, subsoils & substratum. Ghior soils contain small amount (5-20%) of montmorillonite & trace of vermiculite and chlorite throughout the profile. In Sara, trace amount of montmorillonite contents in top and subsoils and while small amount contains in substratum. Chlorite and vermiculite were found in trace in Sara.

White (1985) determined the clay mineral composition of a large number of soils from Bangladesh. He found kaolinite and mica to be present in almost all soils. Vermiculite is present in most of the floodplain soils, but smectites are present mostly in the Gangetic alluvial soils.

Transformations or new-formation of clay minerals due to wetness or seasonally flooded condition and vegetation

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 is believed to be possible in the calcareous Gangetic alluvium because the chemical environment is suitable for their formation. 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, activity of Fe^{2+} increases manifold, it enters in the octahedral layer of smectites by isomorphous substitution. In the soils of Gangetic alluvium, this mechanism might have been operative (Saheed & Hussain, 1992).

Jackson (1965) reported that smectite in soils may occur in any one of the 4 Bs: (i) Basins, (ii) B horizons, (iii) Super B horizons, as in vertisols, and (iv) Beneath basic rocks. Each of these environments has the high Si and basic cation potentials necessary for smectite formation or preservation (Jackson, 1968). Leaching is at a minimum in poorly drained basins most typical of smectite occurrences.

Jackson (1963) demonstrated that an abundance of the exchangeable cations Ca and Mg in silica-rich aqueous (moist) environments favours the formation of freely expansible layer silicate of the montmorillonite series. The most typical occurrences of montmorillonite are: clay of hydromorphic soils in many regions.

Transformation of minerals and formation of smectite (montmorillonite)

Walker (1949) reported that under free drainage conditions, biotite breakdown led to the formation of vermiculite. In the clay fraction of the poorly drained soils of basic origin, the weathering of clay biotite proceeded to the formation of a montmorillonite like freely expanding lattice mineral.

Johnson *et al.* (1963) observed that the montmorillonite was associated with poor drainage and high organic matter content in model soil profiles in several Pennsylvania counties.

Lamoureux *et al.* (1967) studied 11 profiles of mediterranean soils of Lebanon. On basalts, neoformation of montmorillonite through hydrolysis of glasses and silicates eventually led to the formation of kaolinite. On sedimentary rocks, degradation of illite into montmorillonite occurred slowly. There were indication of neoformation of montmorillonite in poorly drained soils.

Vander Merwe *et al.* (1955) reported the dominance of montmorillonite, when internal drainage of South African black clays was poor. Under all circumstances, mature and immature mountain soils derived from basalt were black, and the predominant clay mineral was montmorillonite.

Jackson (1964) reported that an abundance of the exchangeable cations Ca and Mg in silica-rich aqueous (moist) environments favors the formation of freely expansible layer silicates of the montmorillonite series. The most typical occurrences of montmorillonite are: bentonite clay formed from volcanic ash deposits in fresh water; clay formed in marl; clay of hydromorphic soils in many regions; clay in soils formed from basalts and limestones weathered to intermediate stages in humid climates.

Acquaye *et al.* (1992) studied four soil profiles from the Accra Plains of Ghana and found smectite as a dominant clay mineral in all soils. They reported that the presence of

smectite is in agreement with the CEC and swelling properties of the soils. The level to very gently undulating landscape and the semiarid conditions, high pH, and saturation of the soils with water for a period of time may have ensured the accumulation of bases and, therefore, the formation of smectite and other 2:1 clay minerals.

Brady (1974) reported that montmorillonite is favoured by neutral to alkaline conditions and by incomplete leaching of Na, Ca, Mg, K and trace metals. Alteration of other silicate clays, such as chlorite, illite and vermiculite, may also yield montmorillonite. Montmorillonite may be formed by recrystallization from a variety of minerals provided conditions are appropriate.

Cass and Johnston (1985) studied on physical and clay mineralogical properties of some Natal and eastern Transvaal soils. The studied soils were associated with particular management problems such as poor internal drainage, high bulk density or clay dispersive and compact soils had a mixed clay mineralogical composition of smectite, mica and kaolinite.

Vinayak *et al.* (1984) studied on clay minerals of three typical saline-sodic soils of the Indo-Gangetic alluvial plains in Punjab and found illite as a dominant clay mineral in both groups of soils. Smectite was next in order of dominance although it was not detected in the associated cultivated soil, minor amounts of chlorite and kaolinite also present. They commented that presence of smectite was attributed to conversion from illite as a result of imperfect drainage.

Sen and Chatterjee (1957, 1960) reported about the presence of small amount of smectite in Ganges silt. Ghosh and Datta (1974) and Ghosh *et al.* (1974) observed fairly high content of smectite (30-60%) in a few Gangetic alluvial soils of west Bengal.

Ghosh *et al.* (1976) studied some Gangetic alluvial soils of West Bengal and found that the proportion of smectite in many Gangetic alluvial soils is higher than what is found in the "Washings, carried by the Ganges. They interpreted that this changes occurred due

to the pedogenic formation of smectite in these soils. It may be mentioned that the soils contain enough of free R_2O_3 . The studied soils were under rice cultivation which keeps the soils under reducing condition for a part of the year and produce impeded drainage. They commented that hydroxysesquioxide on surfaces of phyllosilicates under reduced condition possibly serve as nucleus for smectite crystal growth in these soils. Subsequent growth of crystal takes place by silication which generates the phyllosilicate layers. Jackson (1965) proposed such type of mechanism of montmorillonite crystal growth. Ghosh (1973) found that rice cultivation induces smectite formation from other 2:1 layer lattice minerals. Ghosh *et al.* (1976) postulated that the smectites in the studied soils appear to have been inherited partly from the alluvium, and partly formed through pedogenic processes under conditions of rice cultivation.

Formation of vermiculite

Walker (1949) reported that under free drainage conditions, biotite breakdown led to the formation of vermiculite.

De Mumbrum (1963) reported rapid conversion of micas to vermiculite by removing K by brief contacts with sodium tetraphenylboron. This procedure simulated the phenomenon of mica weathering and showed the relationship of vermiculite to the parent micas.

Diocahedral vermiculite, apparently resulting from the depotassication of muscovite and /or illite, seems to concentrate in the clay and fine silt fractions; it is rarely observed in >5-um discrete particles (Douglar, 1977). Trioctahedral vermiculite seems to be more common in silts and sands (Alexiades *et al.* 1973; Coffman and Fanning, 1975). It apparently forms by the slow replacement of interlayer K in biotite by hydrated exchangeable cations.

Kangarot *et al.* (1971) reported an increase in vermiculite in Ap horizons, relative to underlying Bt horizons in wisconsin-age loess on terraces in ohio. They also believed

expandable clay (defined as having variable expansion beyond 14 Å upon glycolation) in the Bt, relative to the C horizon, to be pedogenically derived from the illite. Smeck *et al.* (1968) reported evidence of illite alteration to vermiculite in one Ohio Hapludalf.

Vermiculites are found under polar and tropical temperatures, in deserts and in areas of high rainfall. They have been reported in all of the major soil great 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 (Douglas, 1977).

Occurrence and formation of chlorite

Chlorites in soil 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 ferro-magnesian minerals. The abundance and frequency of occurrence of chlorites in soils are relatively low, and the geographic distribution is related to the parent material (Barnhisel, 1977).

Gupta *et al.* (1984) reported that mica and chlorite are mainly inherited from parent rocks and minerals of the soil profile (sand fraction) which have been found rich in mica (both muscovite and biotite) and chlorite.

Weathering of chlorite 2:2 to 2:1 intergrade has been suggested by the acid removal of Fe from the (Fe, Al, Mg) (OH)₂ interlayer (Harrison & Murras, 1959) and by replacement of OH by OH₂ (Droste, 1956). Extensive weathering and soil development under good drainage apparently can rather completely develop interlayer precipitates and approach the 2:2 end member of the series, that is, dioctahedral chlorite (Brydon *et al.* 1961; Glen, 1960 and Theisen *et al.* 1959).

Saheed (1985) reported that soils of the Ganges meander floodplain persistently show small amounts of chlorite in their surface layers, that decrease with depth. He also found traces or small quantities of chlorite in some Young Brahmaputra floodplain soils.

Formation or transformation of Kaolinite

Kaolinite is one of the most widespread clay minerals in soils. It is most abundant in soils of warm moist climates and is prominent constituent of oceanic sediments in the equatorial belt. Kaolinite and halloysite are products of acid weather (Dixon, 1977).

Kaolinite represents a more advanced stage of weathering than does any of the other major types of silicate clays. It is formed from the decomposition of silicates under conditions of moderately to strongly acid weathering which results in the removal of the alkalis and alkaline earth metals. The soluble aluminium and silicon products that are released may recrystallize under proper conditions to form kaolinite. This mineral, in turn, is subjected to decomposition, especially in the tropics, with the formation of iron and aluminum oxides and soluble silica (Brady, 1974).

Schaufelberger (1955) observed that kaolinite clays are formed in base poor acid basin soils, and well drained soils.

Jungerius *et al.* (1964) reported that kaolinite was dominant in all the soils over sedimentary rocks in eastern Nigeria. They reported that the abundance of kaolinite throughout the soil profiles and in the parent sedimentary rocks points to the importance of this mineral being inherited in soils of Nigeria.

Curtin *et al.* (1991) studied six surface soils of Fiji. They reported that all soils were strongly acid, Al being the predominant exchangeable cation in all but the Batiri soils. The highly weathered nature of the soils is evident from their clay mineralogist, which consisted essentially of variable proportions of metal oxides and kaolinite.

Mc Cracken *et al.* (1962) postulated that kaolinite and gibbsite had formed at the expense of the feldspars.

Gupta *et al.* (1984) reported that the presence of kaolinite may be ascribed to its formation through the weathering of feldspars (plagioclase and orthoclase) which have been found to be highly altered in nature.

Occurrence & transformation of illite

The broad group of "micas of argillaceous sediments," containing some domains of 10 Å sequences of structural layers, are often termed hydromica (Hendricks, 1942) or illite (Grim *et al.* 1937). Grim (1953) reported that all gradations can exist between illite and well-crystallized muscovites on the one hand and montmorillonite on the other hand. Yoder (1959) defined illite is a rock term which refers to random interstratification of mica and montmorillonite. Jackson and coworkers (Hellman *et al.* 1943; Jackson *et al.* 1942; and Mehra and Jackson, 1959) have presented extensive evidence that illites are micas with some expanding layers intermixed.

Micas are mainly inherited by soils from soil parent materials and are not known to form to any significant extent in soils. However Juang and Uehara (1969) and Hussain *et al.* (1970) reported the formation of mica during pedogenesis. Micas are abundantly present in many rocks (e.g., shales, slates, phyllites, schists, gneisses, granites) and in sediments derived from these & other rocks (Fanning and Keramidas, 1977).

Folster *et al.* (1963) noted that the formation of illitic clay during the genesis of some Alfisols developed in loess corresponded almost quantitatively to mechanical disintegration of mica minerals originally present in the silt.

White (1951) and Huff (1972) reported a few instances that smectite have apparently been formed from illites. Robert (1973) noted the transformation of glauconites and illites to smectites.

PEDOGENIC CHANGES DUE TO INDUCED WETNESS TO SOIL CLASSIFICATION

Formation of Anthraquic epipedon

Surface water gley soils are seasonally water saturated at least in the upper horizons due to precipitation or flood water low in electrolytes. They are subject to lateral or vertical leaching. There is no accumulation of, for example, iron oxide from elsewhere as occurs in some ground water gley soils (Brammer and Brinkman, 1977). About 1900, the formation of surface water gley soils were described in Russia and was included among the podzols.

They found that surface water gley soils are extremely developed on the seasonally wet landscapes. They are acid, hydromorphic soils with albic horizons containing less clay from the deeper horizons, and with a seasonally fluctuating PH in the surface horizon. Such soils with grey, porous, silty albic horizons to depth ranging from 0.3 to more than 1 meter are extensive over clays on low, level, terrace like pleistocene land forms. The oldest of the Holocene flood plain landscapes have soils in which only the upper 10 or 15 cm have less clay and contain albic material. Soils on younger floodplains where alluvial sedimentation is insignificant have seasonally acid A horizons, without substantial loss of clay. On all landscapes, puddling for rice cultivation apparently accelerates the process give rise to the albic horizon and concentrates them in the ploughed layer and plough pan.

Brammer and Brinkman (1977) reported that surface water gley soil are extensively developed on floodplain and older terrace like landscapes in Bangladesh. The Madhupur and Barind tracts contain a large proportion of surface water gley soils, as do the northern and eastern piedmont plains. 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 only 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 soil in the Jamuna (Young Brahmaputra) floodplain have a seasonally fluctuating pH. in the surface horizon but no evidence of clay loss.

Brammer and Brinkman (1977) correlated surface water gley soils in Bangladesh with hydromorphic soils on terrace landforms occurring widely in southeast Asia (e.g., Moorman, 1961; van der Kevie, 1972), degraded rice soils of Burma (Presently Mianmer), (Karmanov, 1968); paddy soils or Aquarizems, (Kyuma and Kawaguchi, 1966) and with Anthraquic epipedon (Dudal and Moorman, 1964) that forms in a soil long used for seasonal wetland rice cultivation.

When reducing condition due to water saturation, prevails for long period of time, a special soil water regime is defined as the aquic soil moisture regime.

The aquic soil moisture regime implies a reducing regime that is virtually free of dissolved oxygen because the soil is saturated by ground water or by water of the capillary fringe A aquic regime must be a reducing regime (Soil survey staff,1975)

Reduction and gleyzing processes that result from biological activity under anaerobic environments constitute only one of the properties diagnostic of soils with aquic moisture regime (Smith, 1965).

Formation of surface water gley or Pseudogley or inverted gley is the principal Morphological Properties of aquic moisture regime. Koenigs (1950) and Dudal (1964) reported the existence of "inverted gley" in well drained soils that was used for wet rice cultivation when soils that have a non-aquic moisture regime (i.e non flooded highland oxidized soils which are brown in colour) 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 (1964) termed this artificial man-

induced water regime as Anthraquic and the superficial soil horizon that formed under this water regime called " Anthraquic epipedon".

Dudal and Moorman(1964) defined that the Anthraquic epipedon is the surface soil layer altered by ploughing in soils used for wet-land crops, especially rice. It comprises both the cultivated layer and the underlying ploughpan. Both layers are in a puddled state, have grey base colors and are strongly iron stained along root channels. At least the cultivated layer is strongly reduced when waterlogged or flooded. In Bangladesh soil, 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. Based on the above evidences Brammer and Brinkman (1977), correlated surface water gley soils with the anthraquic epipedon. Ali *et al.* (1992) commented that in defining and describing surface water gley soils, Brammer and Brinkman have considered the ferrolysis concept as the central point for all soils of Bangladesh that are seasonally flooded. They reported that soil under Gangetic alluvium land rich in free calcium carbonate do not correlate with ferrilysed soils. But anthraquic epipedon forms in these soils under an imposed aquic moisture regime for prolonged period of rice cultivation.

Karmanov (1966); Wada(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 riceland soils in major and minor alluvial plains of south and East Asia, belonging to various great groups of the Aquent and Aquept suborder will retain their "original" taxonomic classification unchanged. He stated that alteration of diagnostic characteristics may, however, take place locally in the pedons of wet ricelands which remain submerged for long periods. Moorman (1978) also reported that in this case the sub-surface horizon may develop neutral grey colors due to continuous waterlogging and absence of oxygen. This is seen in double and tripple cropped irrigated riceland on fine clayey Inceptisols. Such soil may lose the characteristics required to classify them as Inceptisols, particularly the diagnostic cambic horizon, and they may become Aquents.

Moorman (1980) 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 sub-surface gley develops which is not connected continuously with a subsoil gley. Moorman and van Breeman (1978) termed this specific soil moisture regime as anthraquic. In taxonomic terms it can be defined as periodic man-induced water saturation and ~~reduction~~ of the solum to a depth of at least 40cm without corresponding periodic water saturation and reduction in the horizons below. The soil material in the superficial horizons, submitted to an anthraquic moisture regime shows the same colors of low chrome in the matrix or in mottles as defined for the aquic suborders in soil Taxonomy. The lower horizons, however, do not show these low chroma colours, indicating the absence of longer periods of water saturation and reduction. Moorman(1978) made a tentative proposal to introduce the anthraquic soil moisture regime in soil taxonomy.

SOIL CLASSIFICATION

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 classifications, of which USDA system is widely used and found useful for agrotechnology transfer system. The system is followed in case of Bangladesh soils and as such USDA system of soil classification (1975) related to studied soils is reviewed.

In the USDA classification system, there are 11 orders in the highest level. The orders are recognized by diagnostic horizons, degree of horizonation, presence or absence of certain horizons and gross composition reflecting major difference in the genesis of soils. Moisture regime, temperature, mineralogy and specific kinds of horizons are considered in differentiating suborders within orders. Greatgroups are distinguished within suborders by the presence or absence of characteristic horizons or other features. The range of characteristics are narrowed at the subgroup level. The classification at the family level is

mainly based on soil temperature, texture and mineralogy which have a direct bearing on plant growth and engineering characteristics.

Diagnostic surface horizons: the epipedon: A horizon that forms at the surface is called an epipedon. Seven diagnostic surface horizons were defined by soil survey staff (USDA, 1990) in keys to soil Taxonomy. They are Anthropic, Histic, mollic, Ochric, Melanic, Plaggen & Umbric epipedon.

SRDI staff (1970) reported that the topsoils of most of Ganges alluvium have characteristics derived from continuous ploughing for rice and other crops and alternate seasonal wetting or flooding and drying out. Some of them are gleyed or show iron stains along root channels and at the base of the ploughpan where puddling is a common practice for transplanted rice cultivation. They found that most of these soils having a matrix colour of high value and chroma correlate more or less satisfactory with the ochric epipedon as described in the 7th approximation.

SRDI staff (1975) while surveying the soils of Mymensingh district found that almost all floodplain soils have characteristic top soils which are seasonally wet, gleyed and with prominent iron staining along root channels. These top soils 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 strongly 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 the 7th approximation.

In Inceptisols, soils are usually moist and have weakly developed natural soil horizons that do not represent significant illuviation or eluviation or extreme weathering. Many of these soils are young, although they are always older than Entisols. 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 25⁰C 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).

Brammer (1971) made a nontechnical grouping of Bangladesh soils into 20 general soil types; SRDI staff (1970; 1975) included Sara, in calcareous brown floodplain soil and Pakuria and Ghior in Calcareous darkgrey floodplain soil. Sonatala and Ghatail series were grouped into Grey floodplain and Noncalcareous darkgrey floodplain soil respectively.

Classification of the soils of Ganges alluvium

SRDI staff (1970) after reconnaissance soil survey of Kushtia district clasified the soils having a camic horizon as Inceptisols. These soils were classified into two great groups. Haplaquepts for the dominantly grey soils, and Eutrocrepts for the soils having chroma too high for Aquepts. They classified the soils having more than 60 precent matrix colour with chroma 2 or less as the Typic Haplaquepts and the soils with mottles of chroma higher than 2 covering more than 40 percent of matrix as the Aeric Haplaquepts. They reported that some floodplain soils classified as Haplaquepts have some properties common to all Vertisols. Ghior, Batra, Benapol, Ramdia and Mahespur soils usually have 30 percent or more clay in all layers down to 100 cm, and wedge shaped structure or prominent slickensides, but were not found to develop cracks of 1 cm or more wide at a depth of 50 cm from the surface. These soils, despite their other vertic properties were classified either as Typic or Aeric Haplaquepts.

SRDI staff (1970) correlated Sara, Pakuria and Ghior soil series in the USDA soil classification system as Aeric Haplaquepts.

Zijsvelt (1980) correlated Sara series with Aquic Eutrochrept and Pakuria and Ghior with Aeric Haplaquept in the USDA soil Taxonomy system. He also classified these soils

into following family category on the basis of texture, mineralogy and soil reaction according to Soil Taxonomy.

Soil series: Family

Sara	:	Aquic Eutrochrept, loamy, mixed
Pakuria	:	Aeric Haplaquept, loamy, mixed calcareous
Ghior	:	Aeric Haplaquept, clayey, montmorillonitic, nonacid.

Classification of the soils of Brahmaputra alluvium

SRDI staff (1975) carried out a reconnaissance soil survey in Kishoreganj and Sadar subdivision of Mymensingh districts. The survey covers an extensive area of Brahmaputra alluvium where they reported that the most floodplain 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 mottlings 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 aeric subgroup. They observed that some profiles of Ghatail series have vertic properties. They are clayey down to 100 cm or deeper and have slickensides and wedge shaped peds in the subsoil. These soils could not be classified in the vertic subgroup because slickensides were not close enough to intersect and cracks of one cm or more wide at a depth of 50cm were not found to develop.

SRDI staff (1975) correlated Sonatala and Ghatail soil series as Aeric Haplaquept in the USDA soil Taxonomic system.

Sonatala and Ghatail soils were correlated into family category as loamy, mixed, non-acid Aeric Haplaquept, and clayey, mixed, non-acid Aeric Haplaquept, respectively (Zijsselt, 1980 and Hussain, 1992).

CHAPTER III

MATERIALS AND METHODS

CHAPTER - III

MATERIALS AND METHODS

SELECTION OF SITES FOR THE STUDY

Two parent materials Ganges and Brahmaputra Alluvium were selected for the study (map-1). Kushtia sadar thana (under G.K. project, Phase-1) for Ganges (Map-2) and Mymensingh sadar and Trisal Thana for Brahmaputra alluvium (map-3) were identified as their ideal sites. In identifying and selecting the sites priorities were given to the long term irrigated areas.

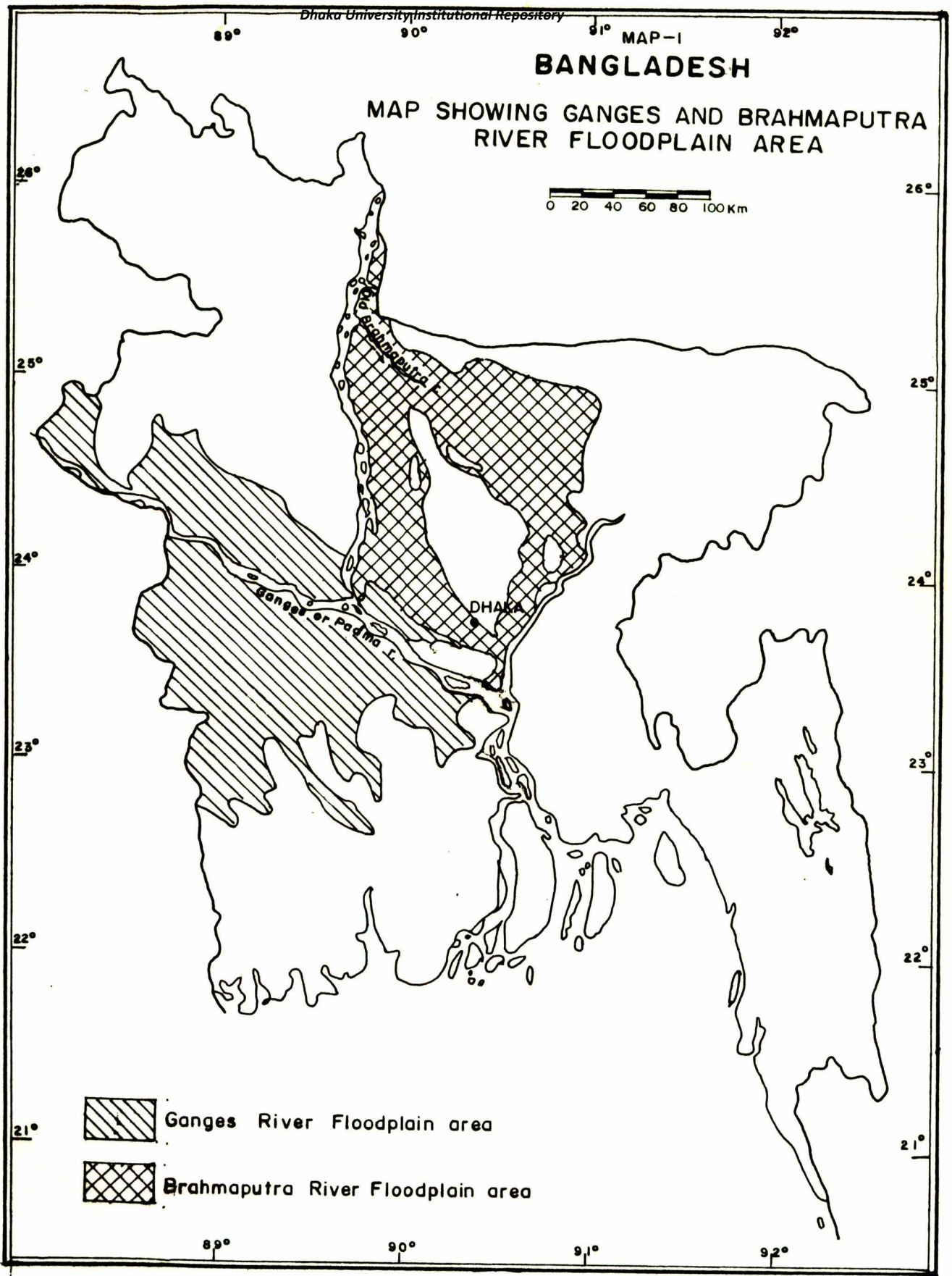
GENERAL DESCRIPTION OF THE AREAS

Location of the studied area in Kushtia

The sampled area for non-irrigated soils (Sara & Pakuria series) lies in Barkhada mouza under Barkhada union, of Kushtia sadar thana. It approximately lies in $23^{\circ}56'1''$ N-latitude and $89^{\circ}06'1''$ E-longitude. The irrigated soils (Sara & Ghior series) were sampled from Charpara-Belgharia mouza under Ziarakhi union of Kushtia sadar thana. It approximately lies in $23^{\circ}51'1''$ N-latitude and $89^{\circ}06'1''$ E-longitude (map -2)

Location of the studied area in Mymensingh district

The sampled area for Sonatala (both non-irrigated and irrigated) and Ghatail (non-irrigated) soils lies in Panghagra and Uparpar mouza respectivity, both under Vhobakhali union of Mymensingh sadar thana. It approximately lies in $24^{\circ}41'1''$ N-latitude and between $90^{\circ}-24'1''$ and $90^{\circ}25'1''$ E-longitude.



89° 00'

89° 05'

89° 10'

Dhaka University Institutional Repository
MAP - 2

KUSHTIA SADAR THANA SHOWING THE LOCATIONS OF STUDIED SOILS

SCALE 1:21,000

LEGEND

Non-irrigated soils

1 ⊙ Pakuria Series, non-irrigated

2 ⊙ Sara Series, non-irrigated

Irrigated soils

3 △ Sara Series, Irrigated

4 △ Ghior Series, Irrigated

CONVENTIONAL SIGNS

- - - District boundary

- - - Thana boundary

— Pacca Road

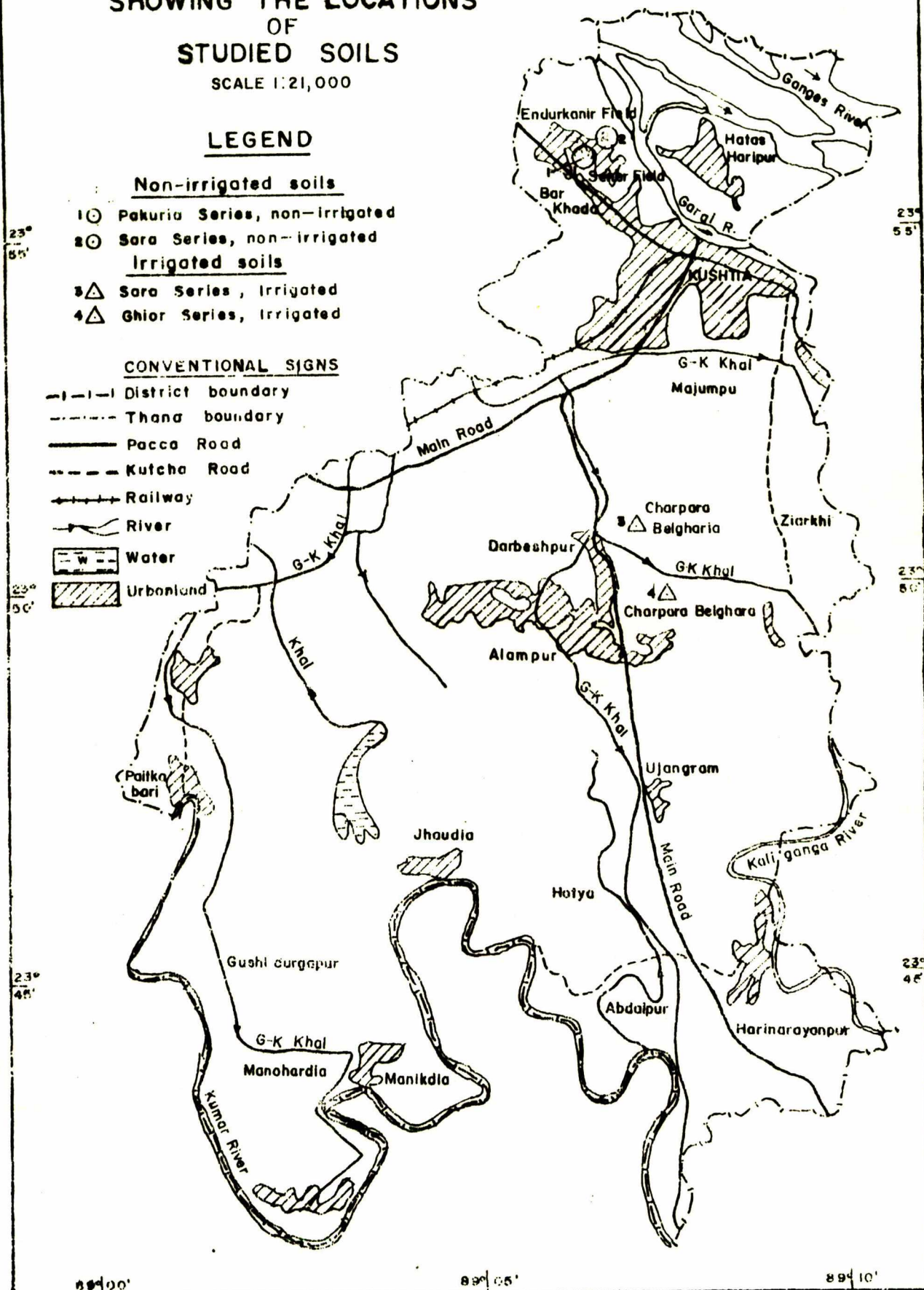
- - - Kutcha Road

+ + + Railway

~ River

[W] Water

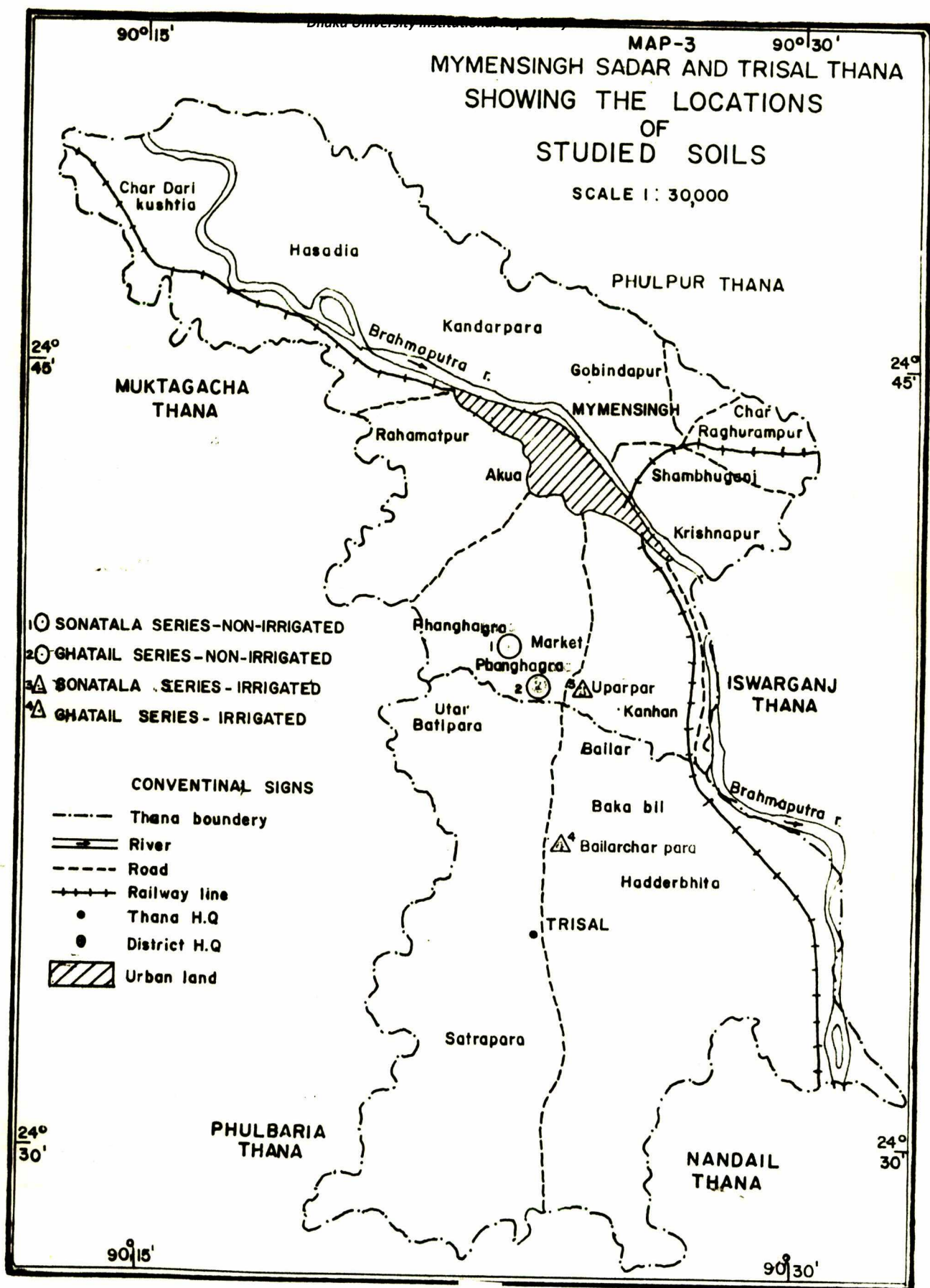
[Hatched] Urbanland



89° 00'

89° 05'

89° 10'



The irrigated Ghatail soils lies in Bailar-charpara mouza under Bailar union of Trisal thana of Mymensingh district. It lies approximately in $24^{\circ}36'1''$ -N latitude and $90^{\circ}25'1''$ E-longitude.

CLIMATE

The climate in the studied areas (Mymensingh and Kushtia) is dominated by the tropical monsoon with high to fairly high rainfall. The rainfall generally occurs during May to September (Table 1a and 1b) with 90 percent of precipitation. The rains are associated with tropical cyclones which forms in the Bay of Bengal. There is short pre-monsoon rainy season from April to May due to nor'westers and thunderstorms. There are three crop seasons in a year. Of which, rabi season includes November to February, pre-kharif season from March to May, while kharif season is the longest and includes June to October. In Mymensingh area the dry months are mostly December, January, February and March, while in Ishurdi it starts from November and lasts upto the end of February.

Table 1a. Temperature and Rainfall data of Mymensingh based on observations from 1980-1989

Month	Temperature ($^{\circ}$ C)			Rainfall (mm)
	Maximum	Minimum	Average	
January	25.07	12.44	19.75	02.0
February	27.20	13.64	20.45	10.8
March	30.93	17.87	24.40	15.0
April	31.52	21.33	26.83	49.0
May	31.33	22.38	26.85	371.0
June	31.55	24.33	27.41	369.0
July	30.97	24.63	27.81	312.0
August	31.47	24.74	28.12	302.0
September	31.07	24.19	27.63	315.0
October	31.23	22.62	26.92	56.0
November	29.42	17.61	23.51	20.0
December	26.07	13.05	19.56	08.0
Range	25.07-31.55	12.44-24.74	19.56-28.12	02-371

1. Mean annual temperature is 24.94°C i.e. $>22^{\circ}\text{C}$.
2. The temperature difference between mean summer and mean winter = $\{(\text{June} + \text{July} + \text{August})/3 - (\text{December} + \text{January} + \text{February})/3\} = \{(27.41 + 27.81 + 28.12)/3 - (19.56 + 19.75 + 20.45)/3\} = 27.78^{\circ}\text{C} - 19.92^{\circ}\text{C} = 7.86^{\circ}\text{C}$, i.e. exceeds 5°C .

Source: Bangladesh Bureau of Statistics (BBS)

Table 1b. Temperature and Rainfall data of Ishurdi (near to Kushtia) based on observations from 1980-1989

Month	Temperature (°c)			Rainfall (mm)
	Maximum	Minimum	Average	
January	24.64	10.66	17.65	00.8
February	27.21	13.01	20.11	06.0
March	30.79	17.41	24.10	25.4
April	35.45	23.24	29.34	70.0
May	33.92	23.54	28.73	215.5
June	33.00	25.77	29.38	309.8
July	31.94	25.74	28.84	338.2
August	31.88	26.09	28.98	237.8
September	32.28	25.69	29.28	210.9
October	31.35	22.76	27.05	59.1
November	29.28	17.17	23.23	02.1
December	25.79	12.59	19.19	00.7
Range	24.64-35.45	10.66-26.09	17.65-29.38	0.7-338.2

1. Mean annual temperature is 25.49°C i.e >22°C.
2. The temperature difference between mean summer and mean winter = {(June + July + August)/3 - (December + January + February /3 } = {(29.38 + 28.84 + 28.98)/3 - (19.19 + 17.65 + 20.11)/3} = 29.07 - 18.98 = 10.09°C, i.e Exceeds 5°C.

Source: Bangladesh Bureau of Statistics (BBS)

In the both Mymensingh and Kushtia area mean annual temperature exceeds 22°C and the temperature difference between mean summer and mean winter is more than 5°C. According to USDA Soil Taxonomy (Soil survey Staff, 1975) this satisfies for hyperthermic soil temperature regime, which is important for soil classification purpose.

Geology

The studied soils in Kushtia were developed from the recent and subrecent unconsolidated Ganges alluvial sediments. Usually moderately coarse to moderately fine textured sediments occur on ridges and fine textured sediments in basins. The deposits are generally calcareous; except where partial or complete decalcification took place in soil profiles occurring on the older deposits (SRDI Staff, 1970).

The Ganges river floodplain divided into young and old floodplain depending on their relative age of deposits. Ganges sediments contain a considerable amount of calcite climate (Saheed, 1985)

The soils of Brahmaputra floodplains were developed from recent and subrecent unconsolidated sediments (SRDI Staff, 1974-75). It has two broad sub-division on the basis of relative age of deposits: the younger Brahmaputra or Jamuna floodplain and the old Brahmaputra floodplain. The sand mineralogy of the younger deposits has relatively higher mica and lower quartz contents than the older ones, indicating a certain amount of weathering of biotite in the latter. Amphibole and epidote are the dominant heavy minerals in the sand fraction of these sediments (Saheed, 1985)

METHOD OF IDENTIFICATION OF SOIL SERIES

Two suitable catena, one irrigated and the other non-irrigated, were identified both in Kushtia and Mymensingh for selecting similar series under different intensity of alternate wetting and drying conditions over different topographical position and time.

The soil survey of the Ganges-kobodak area, ETAP report no. 1071, FAO-Rome, 1970 and Reconnaissance soil survey, Kushtia District, 1970 for Ganges alluvium and Reconnaissance soil survey, Kishorganj and sadar subdivisions, Mymensingh District, 1974-75 for Brahmaputra alluvium were used as base materials. Toposheets and recent aerial photographs of the studied areas were also used for the field works.

To identify the typical soil series from an extensive extent and undisturbed area, a good number of traverses were made in both the areas. Frequent ground checking and field observations were done both in irrigated and non-irrigated land and soils in the adjoining thanas of the studied areas to observe the changes in soil morphological properties.

Two soil series, one medium textured (highland soils) and the other fine textured (medium highland soils), from each catena were identified in both the studied areas. Before selecting the typical soil profiles for the study several mini profiles for each soil series were

studied in fields. Finally four soil profiles under Ganges and Brahmaputra alluvium, both from irrigated and non-irrigated conditions, that have been used for rice cultivation for a long period were identified.

MORPHOLOGICAL STUDY

A pit of 100 cm x 150 cm upto a depth of 200 cm or weathered parent material whichever is shallower was dug for each soil series. Profiles were studied and described according to soil survey manual of USDA (1951) and Key's to Soil Taxonomy of Soil Survey Staff, USDA, SMASS, (1990).

SOIL SERIES UNDER GANGES ALLUVIUM

Sara (Medium textured, highland soils) from non-irrigated and irrigated conditions, Pakuria (fine textured, medium highland soils) from non-irrigated and Ghior (fine textured medium highland soils) from irrigated conditions were identified. Both Pakuria & Ghior are fine textured soils occupying lower position of the catena. As Ghior series was not found under non-irrigated condition, Pakuria series having identical characteristics was selected for the same study. The profiles are described below:

SARA SERIES

Non-irrigated

Location	:	Edurdkanir field, Barakhada Mouza, Union - Barakhada, Thana - Kushtia Sadar, Kushtia.
Relief	:	Summit of undulating ridge.
Drainage	:	Imperfectly drained.
Land use	:	Local Aus-HYV. Transplanted aman - Fallow.
Parent Material	:	Ganges Alluvium.

- Ap₁** 0-11 cm Olive (5y 5/4) moist with common fine distinct greyish brown mottles; Silty clay loam; massive; friable moist; slightly sticky, slightly plastic wet; many very fine and fine tubular pores; moderately calcareous; many very fine and fine roots; few iron staining along root channels; abrupt smooth boundary; pH 8.0
- Ap₂** 11-13 cm Olive (5Y 5/3) moist with common fine distinct dark greyish brown mottles; silty clay loam; massive; firm moist; slightly sticky and slightly plastic wet; many very fine and few fine tubular pores; moderately calcareous; few iron staining along root channels; common very fine and few fine roots; abrupt smooth boundary; pH 8.0
- B_{2w}** 13-26 cm Light olive-brown (2.5Y 5/4) with common fine distinct dark greyish brown mottles; silt loam; moderate coarse and medium prismatic breaking into weak medium prismatic structure; friable moist; slightly sticky and slightly plastic wet; continuous moderately thick dark greyish brown cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; strongly calcareous; iron staining in soil matrix; common very fine roots; clear smooth boundary; pH 8.2
- B_{3w}** 26-41 cm Olive (5Y 5/3) moist with few fine distinct dark brown and prominent strong brown mottles; silt loam; weak very coarse prismatic structure, friable moist; slightly sticky, slightly plastic wet; patchy moderately thick greyish brown cutans along root channels; many very fine tubular pores; strongly calcareous; few iron staining; few very fine roots; clear smooth boundary; pH 8.2
- C₁** 41-57 Olive (5Y 5/3) moist with common fine prominent dark brown mottles; silt loam; remnants of stratification; very friable moist; slightly

sticky, nonplastic wet; many very fine and fine tubular pores; strongly calcareous; few soft black iron-manganese concretions and few small hard CaCO_3 nodules; clear smooth boundary; pH 8.5

C₂ 57-95 Olive (5Y 5/3) moist with common fine prominent dark brown mottles; silt loam; stratified; very friable; slightly sticky, slightly plastic wet; many very fine and fine tubular pores; strongly calcareous; few black soft iron concretions and few small hard CaCO_3 nodules; clear smooth boundary; pH 8.5.

C₃ 95-110 cm+ Olive (5Y 5/3) moist with few fine prominent dark brown mottles; silt loam; stratified; friable moist; slightly sticky, slightly plastic wet; many very fine tubular pores; strongly calcareous; pH 8.5. Ground water not found at 260 cm.

SARA SERIES

Irrigated

Location : Charpara - Belgharia Mouza, Union - Giarakhi, Thana - Kushtia Sadar.

Relief : Upper part of very gently undulating ridge.

Drainage : Imperfectly drained.

Land use : HYV. Aus- HYV. transplanted aman-fallow

Parent Material : Ganges Alluvium.

Ap_{1g} 0-11-cm Dark greyish brown moist (2.5y 4/2) with many very fine distinct olive brown and few fine prominent dark brown mottles; silt loam; massive; slightly firm moist; slightly sticky and slightly plastic wet; many very fine and fine and few medium tubular pores; slightly calcareous;

strongly iron staining along root channels; many very fine and fine roots; abrupt smooth boundary and pH 7.5.

Ap_{2g} 11-15 cm Olive brown moist (2.5y 4.4) with many very fine distinct greyish brown and few fine distinct dark brown mottles; silt loam; massive; slightly firm moist; slightly sticky, slightly plastic wet; many very fine and fine tubular pores; slightly calcareous; strongly iron staining along root channels; many very fine and common fine roots; abrupt smooth boundary; pH 7.5.

B_{21w} 15-33 cm Light olive brown moist (2.5y 5/4) with common fine distinct greyish brown and common fine prominent dark brown mottles; silt loam: moderate coarse and medium prismatic structure breaking into moderate coarse and medium angular blocky structure; friable moist, slightly sticky and slightly plastic wet; many very fine and fine and few medium tubular pores; broken moderately thick dark greyish brown cutans along vertical and horizontal ped faces; moderately calcareous; common very fine and fine roots; abrupt smooth boundary; pH 8.0

B_{22w} 33-50 cm Olive brown moist (2.5y 4/4) with common fine distinct dark brown and few fine prominent strong-brown mottles; Silt loam; moderate very coarse to coarse prismatic structure; friable moist; slightly sticky and slightly plastic wet; many very fine and fine tubular pores; patchy thin dark greyish brown cutans along vertical ped faces and root channels; moderately calcareous; clear smooth boundary; pH 8.0

B_{23w} 50-59 cm Olive brown moist (2.5Y 4/4) with many fine distinct dark brown mottles; siltloam; weak very coarse to coarse prismatic structure; friable moist; slightly sticky and slightly plastic wet; many very fine and

fine tubular pores; patchy thin darkgreyish brown cutans along ped faces; moderately calcareous; clear smooth boundary; pH 8.0

B_{3w} 59-84 cm. Olive brown moist (2.5y 4/4) with common fine distinct dark brown and few strong brown mottles; silt loam; weak very coarse prismatic structure; friable moist; slightly sticky and slightly plastic wet; many very fine and fine tubular pores; patchy thin dark greyish brown cutans along ped faces; moderately calcareous; abrupt smooth boundary; pH 8.0

C₁ 84-97 cm Light olive brown moist (2.5y 5/4) with common fine distinct dark brown mottles; silt loam; remnants of stratification, friable moist; slightly sticky, slightly plastic wet; common very fine and fine tubular pores; moderately calcareous; clear smooth boundary; pH 8.0

C₂ 97-105cm Light olive brown moist (2.5y 5/4) with common fine distinct dark brown and few fine prominent black mottles; silt loam; remnants of stratification; friable moist; slightly sticky, slightly plastic wet; broken thin greyish brown cutans along pores; common very fine and few medium tubular pores; moderately calcareous; pH 8.0 below 105 cm sample was taken by auger.

Pakuria Soil Series

(Non-irrigated)

Location	:	Shaner field, Barakhada Mouza, Union - Barakhada, Kushtia Sadar, Kushtia.
Relief	:	Very gently undulating basin.
Drainage	:	Poorly drained.
Land use	:	Transplanted aman - Fallow

Parent material : Ganges Alluvium.

- Ap_{1g}** 0-13cm. Olive grey (5y 5/2) moist with common very fine and fine distinct dark greyish brown mottles; silty clay; massive; firm moist; sticky, plastic wet; many very fine and fine tubular pores; slightly calcareous; few iron staining along root channels and in the soil mass; cracks at the depth of 20 cm; many very fine and fine roots; abrupt smooth boundary; pH 7.3
- AP₂** 13-17cm. Olive brown (2.5y 4/4) moist with many fine distinct dark grey mottles; silty clay; massive; very firm moist; sticky, plastic wet; common very fine and fine tubular pores; slightly calcareous; gleyance in the soil mass; common very fine and fine roots; abrupt smooth boundary; pH 7.5
- B_{21w}** 17-29cm. Olive brown (2.5y 4/4) moist with many very fine and fine distinct dark greyish brown mottles; clay; strong coarse prismatic breaking into coarse and medium angular and subangular blocky structure; very firm moist; very sticky, very plastic wet; continuous thick dark greyish brown cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; moderately calcareous; many very fine roots; clear smooth boundary; pH 8.0
- B_{22w}** 29-42cm. Olive brown (2.5y 4/4) moist with many very fine distinct dark greyish brown mottles; silty clay; strong coarse prismatic breaking into strong coarse and medium angular blocky structure; firm moist; sticky, plastic wet; continuous thick dark greyish brown cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; moderately calcareous; abrupt smooth boundary; pH 8.2

- IIB_{23w}** 42-59cm. Olive brown (2.5y 4/4) moist with common fine distinct dark greyish brown and prominent dark brown mottles; silty clay loam; moderate coarse prismatic structure; slightly firm moist; sticky, plastic wet; continuous moderately thick dark greyish brown cutans along ped faces; many very fine and fine tubular pores; strongly calcareous; abrupt smooth boundary; pH 8.5
- B_{3w}** 59-83cm. Light olive brown (2.5y 5/4) moist with common fine distinct dark grey and few fine prominent strong brown mottles; silty clay; weak very coarse prismatic structure; slightly firm moist; sticky, plastic wet; continuous moderately thick dark greyish brown cutans along ped faces; many very fine and fine tubular pores; strongly calcareous; abrupt smooth boundary; pH 8.5
- C₁** 83-108cm. Light olive brown (2.5y 5/4) moist with common fine distinct dark grey mottles; clay; remnants of stratification; very firm moist; very sticky; very plastic wet; many very fine and fine tubular pores; strongly calcareous; abrupt smooth boundary; pH 8.5
- C₂** 108-146cm. Light olive brown (2.5y 5/4) moist with common fine distinct olive brown & few medium bluish grey gleyed mottles; ; silty clay; remnants of stratification; firm moist; sticky, plastic wet; many very fine and fine tubular pores; strongly calcareous; earthworm activities; strongly calcareous; pH 8.5 Ground water found at 170 cm; Below 140cm augered.
- C₃** 146-180cm. Light olive brown (2.5y 5/4) moist with common fine distinct olive brown and prominent bluish grey (gleyed) mottles; silty clay; stratified; slightly sticky; slightly plastic; strongly calcareous; pH 8.5

GHIOR SOIL SERIES

IRRIGATED

Location	:	Charpara - Belgharia, Union - Ziarakhi, Kushtia Sadar, Kushtia
Relief	:	Very gently undulating basin.
Drainage	:	Very poorly drained.
Land use	:	Transplanted aus (HYV) - Transplanted aman-Fallow
Parent material	:	Ganges Alluvium.

Ap_{1g} 0-15 cm Olive grey (5y 5/2) moist with common medium prominent (2.5y N3/0) very dark grey mottles; silty clay; massive; slightly sticky, slightly plastic wet; many very fine and fine tubular pores; strongly iron staining along root channels; many very fine, fine and common medium roots; abrupt smooth boundary; pH 7.0

AP_{2g} 15-20 cm Very dark grey, (gleyed) (2. 5Y N. 3/1) moist with few fine prominent light olive brown mottles; clay; massive; firm moist; sticky, plastic wet; many very fine and few fine tubular pores; common very fine roots; strongly iron staining in the root channels; abrupt smooth boundary; pH 7.0

B_{21wg} 20-32 cm Dark greyish brown (2. 5Y 4/1.5) moist with common fine distinct light olive brown mottle; clay; strong coarse prisms breaking into strong fine angular blocky structure; mass friable, individual peds firm moist; very sticky, very plastic wet; many very fine and fine tubular pores; continuous thick very dark grey cutans along vertical and horizontal ped faces; bluish tinge over ped surfaces; pressure faces; slickensides; slightly calcareous; many very fine and fine tubular pores; clear smooth boundary; pH 7.5

- B_{22wg}** 32-57 cm Very dark greyish brown (2.5Y 3/2) moist with many fine distinct light olive brown mottles; clay; strong and medium prismatic structure breaking into fine and very fine angular blocky structure; very firm moist; sticky, plastic wet; continuous thick very dark grey cutans along vertical and horizontal ped faces; many fine and fine tubular pores; slightly calcareous; pressure faces; slickensides; few very fine roots; abrupt smooth boundary; pH 7.5
- B_{3w}** 57-76 cm Olive brown (2.5Y 4/4) moist with many fine distinct olive grey and few very fine prominent dark brown mottles; clay; weak very coarse and coarse prismatic structure; firm moist; sticky, plastic wet; broken moderately thick very dark grey cutans along ped faces; many very fine and common fine tubular pores; abrupt smooth boundary; pH 7.0
- C_{1g}** 76-97 cm Greyish brown (2. 5Y 5/2) moist with common fine distinct olive brown and few medium prominent strong brown mottles; clay; remnants of stratification; firm moist; sticky, plastic wet; continuous moderately thick dark grey cutans along ped faces and pores; many very fine and fine tubular pores; slightly calcareous; iron staining; abrupt smooth boundary pH 7.5
- C_{2g}** 97-140 cm Very dark greyish brown (2. 5Y 3/2) moist with common very fine distinct dark brown and few fine prominent strong brown mottles; clay; remnants of stratification; sticky, plastic; broken moderately thick dark grey cutans along pores; below 135 cm slightly calcareous; iron staining; abrupt smooth boundary; pH 7.5
- C_{3g}** 140-200cm Black (2. 5Y N.2/2) moist with many very fine distinct olive brown and common fine prominent dark brown mottles; clay; stratified; very sticky, very plastic wet; iron staining; pH 6.5 augured.

SOIL SERIES UNDER BRAHMAPUTRA ALLUVIUM

Sonatala (Medium textured, highland soils,) and Ghatail (fine textured, medium highland soils) both from non-irrigated and irrigated conditions were selected and identified for the study. Profiles are described below:

SONATALA SERIES

Non-irrigated

Location	:	Panghagra (near Churkhali market), Union - Vhobakhali, Mymensingh Sadar, Mymensingh
Relief	:	Summit of very gently undulating ridge.
Drainage	:	Imperfectly drained.
Land use	:	Local Aus - HYV. transplanted aman - Fallow
Parent material	:	Old Brahmaputra Alluvium.

Ap ₁	0-11 cm	Olive brown (2.5Y 4/4) moist with many very fine and fine distinct dark greyish brown mottles; silt loam; massive; friable moist; slightly sticky, slightly plastic wet; many very fine and fine tubular pores; many very fine and fine roots; few iron staining along root channels; abrupt smooth boundary; pH 6.0
Ap ₂	11-14 cm	Olive brown (2.5Y 4/4) moist with many fine distinct dark brown and common fine distinct greyish brown mottles; silt loam; friable moist; slightly sticky, slightly plastic wet; many very fine and few fine tubular pores; patchy thin greyish brown cutans along pores; many very fine and few fine roots; abrupt smooth boundary; pH 6.5
B _{21w}	14-33 cm	Olive brown (2.5Y 4/4) moist with few fine distinct greyish brown and prominent dark brown mottles; silt loam; moderate coarse to medium

prismatic structure; friable moist; slightly sticky, slightly plastic wet; many very fine and common fine tubular pores; continuous moderately thick dark grey cutans along vertical and horizontal ped faces; few Krotovinas, many very fine and few fine roots; clear smooth boundary; pH 7.0

B_{22w} 33-50 cm Olive brown (2.5Y 4/4) moist with few fine distinct greyish brown and dark brown mottles; silt loam; moderate coarse prismatic structure; friable moist; slightly sticky, slightly plastic wet; broken moderately thick dark grey cutans along ped faces; many very fine and fine tubular pores; iron staining; few very fine roots; clear smooth boundary; pH 7.0

B_{23w} 50-74 cm Light olive brown (2.5Y 5/4) moist with common fine and medium prominent dark yellowish brown and few fine distinct greyish brown mottles; silt loam; moderate coarse prismatic structure; friable moist; slightly sticky, slightly plastic wet; patchy thin few small dark grey cutans along vertical ped faces: soft iron and manganese concretions abrupt smooth boundary; pH 7.0

AP_{1bg} 74-100 cm Very dark grey (10YR 3/2) moist with common fine distinct olive brown & prominent strong brown & few fine prominent black mottles; clay; weak very coarse prismatic structure; very firm moist, very sticky, very plastic wet; continuous thick very dark grey cutans along ped faces; many very fine and fine tubular pores; clear smooth boundary ; pH 7.0

C_{1g} 100-130 cm Very dark grey (10YR 3/1) moist with common very fine distinct dark yellowish brown and few fine prominent strong brown mottles; clay; very firm moist; very sticky, very plastic wet; many very fine and fine

tubular pores; patchy thin very dark greyish brown cutans along pores; few fine small soft iron and manganese black concretions; abrupt smooth boundary; pH 7.0

C₂ 130-165 cm Light olive brown (2.5Y 5/4) moist with many fine distinct grey mottles; silty clay; friable moist; sticky, plastic wet; many very fine and fine tubular pores; few fine soft iron and manganese black concretions; pH 7.0 Ground water was not found at 250 cm.

SONATALA SERIES

Irrigated

Location : Uparpar, Union -Bhobakhali, Mymensingh Sadar, Mymensingh
Topography : Middle part of gently undulating ridge
Drainage : Poorly drained, highland, water is kept under bound and remains waterlogged for 4-5 months
Land use : HYV Boro-Fallow HYV transplanted Aman
Parent material : Old Brahmaputra Alluvium

AP_{1g} 0-10 cm Dark greyish brown (2.5Y 4/2) moist with many fine distinct olive brown; silt loam. massive; friable moist; slightly sticky, slightly plastic wet; many very fine and common fine tubular pores; many very fine and fine roots; strongly iron staining along root channels; abrupt smooth boundary; pH 7.0

AP_{2g} 10-15 cm Greyish brown (2.5Y 5/2) moist with many fine distinct olive brown mottles; silt loam; massive; firm moist; slightly sticky, slightly plastic wet; many very fine and common fine tubular pores; many very fine roots; strongly iron staining along root channels; abrupt smooth boundary; pH 7.3

- B_{2w}** 15-31 cm Olive brown (2.5Y 4/4) moist with many fine distinct greyish brown mottles; silt loam; moderate coarse and medium prismatic structure; friable moist; slightly sticky, slightly plastic wet; many very fine and fine tubular pores; continuous moderately thick dark grey cutans along vertical and horizontal ped faces; common very fine roots; abrupt smooth boundary; pH 7.0
- IIB_{21w}** 31-51 cm Olive brown (2.5Y 4/4) moist with many fine distinct light olive-brown and few fine prominent dark brown mottles; silty clay; strong coarse and medium prisms breaking into coarse and medium subangular blocky structure; firm moist; sticky, plastic wet; continuous thick very dark grey cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; iron staining along pores; abrupt smooth boundary; pH 7.0
- B_{2wg}** 51-78 cm Dark grey (10YR 4/1) moist with common fine prominent dark yellowish brown and distinct olive brown mottles; silty clay; strong coarse prisms breaking into angular and subangular blocky structure; very firm moist; sticky, very plastic wet; continuous thick dark grey cutans along vertical and horizontal ped faces and pores; many very fine and fine tubular pores; some gleyance in ped surfaces; clear smooth boundary; pH 7.0
- B_{23wg}** 78-108 cm Very dark greyish brown (10YR 3/2) moist with many fine distinct light olive brown and few fine prominent dark brown mottles; silty clay; moderate very coarse and coarse prismatic structure; firm moist; sticky, plastic wet; continuous moderately thick very dark grey cutans along ped faces; many very fine and common fine tubular pores; few small soft iron & manganese concretion; abrupt smooth boundary; pH 7.0

- C₁ 108-130 cm** Light olive brown (2.5Y 5/4) moist with common fine distinct grey and few fine prominent yellowish brown mottles; silty clay loam; weak very coarse prismatic structure ; remnants of stratification; friable moist; slightly sticky, slightly plastic wet; broken moderately thick dark grey cutans along pores; many very fine and fine tubular pores; few small iron & manganese concretions; some sand pockets; abrupt wavy boundary; pH 7.3
- C₂ 130-140 cm** Olive brown (2.5Y 4/4) moist with many fine distinct light olive brown mottles; loam; remnants of stratification; friable moist; slightly sticky, slightly plastic wet; many very fine and fine tubular pores; few small moderately hard black and very dark brown iron & manganese concretions; abrupt smooth boundary; pH 7.5
- C₃ 140-200 cm** Olive grey (5Y 5/2) moist with few fine prominent dark brown mottles; sandy loam; stratified; very friable moist; nonplastic wet; few small moderately hard and soft iron & manganese concretions; pH 7.5
Below 175 augured.

GHATAIL SERIES

(Non-irrigated)

Location	:	Phanghagra, Union - Vhobakhali, Thana - Mymensingh Sadar, Mymensingh
Topography	:	Centre of very gently undulating basin
Drainage	:	Poorly drained.
Land use	:	Local Transplanted Aman - Fallow.
Parent Material	:	Old Brahmaputra Alluvium.

- AP_{1g} 0-10 cm** Dark grey (10YR 4/1) moist with common fine distinct olive brown and dark brown mottles; silty clay; massive; firm moist; sticky, plastic; many very fine and fine tubular pores; iron staining in soil matrix; many very fine and fine roots; few iron staining along root channels; abrupt smooth boundary; pH 5.5
- AP_{2g} 10-13 cm** Dark grey (10YR 4/1) moist with common fine distinct olive brown and dark brown mottles; clay; massive; very firm moist; very sticky, very plastic wet; many very fine and fine tubular pores; few iron staining along root channels; common fine roots; abrupt smooth boundary; pH 6.0
- B_{21wg} 13-20 cm** Dark grey (10YR 4/1) moist with many very fine and fine distinct dark grey and common fine prominent mottles; clay; strong medium prisms breaking into medium angular blocky structure; very firm moist; very sticky, very plastic wet; continuous moderately thick very dark greyish brown cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; few small soft iron and manganese concretions; many very fine and common roots; clear smooth boundary; pH 6.5
- B_{22g} 20-39 cm** Dark grey (10YR 4/1) moist with few fine distinct olive brown mottles; clay; strong medium prisms breaking into medium angular blocky and sub-angular blocky structure; very firm moist; very sticky, very plastic wet; continuous thick very dark grey cutans along vertical and horizontal ped faces and pores; few small soft iron and manganese concretions; few very fine roots; clear smooth boundary; pH 7.5
- B_{23wg} 39-48 cm** Dark greyish brown (10YR 4/2) moist with many fine prominent strong brown and few fine distinct dark brown mottles; clay; strong coarse and medium prisms breaking into coarse and medium angular

blocky and sub-angular blocky structure; very firm moist; very sticky, very plastic wet; continuous thick very dark greyish brown cutans along vertical and horizontal ped faces; many very fine and fine tubular pores; abrupt smooth boundary; pH 7.5

B_{24w} 48-66 cm

Olive brown (10YR 5/4) moist with common fine distinct dark grey and many very fine distinct dark brown mottles; silty clay; strong and moderate coarse prisms breaking into angular & subangular blocky structure; firm moist; sticky, plastic wet; broken moderately thick dark gray cutans along vertical and horizontal ped faces; many very fine and common fine roots; abrupt smooth boundary; pH 7.5

B_{25w} 66-96 cm

Dark brown (10YR 4/3) moist with many very fine distinct dark grey mottles; clay; strong coarse and medium prisms breaking into medium strong angular and sub-angular blocky structure; firm moist; sticky, plastic wet; continuous moderately thick very dark grey cutans along vertical and horizontal ped faces and pores; many very fine and fine tubular pores; few small soft iron and manganese concretions; clear smooth boundary: pH 7.7

B₃ 96-111 cm

Dark brown (10YR 4/3) moist with common fine distinct very dark greyish brown and few prominent strong brown mottles; clay; weak very coarse prismatic structure; very firm moist; very sticky, very plastic wet; patchy thin dark grey cutans along ped faces & in pockets; abrupt wavy boundary; pH 8.0

C₁ 113-133 cm

Yellowish brown (10YR 6/4) moist with common fine distinct dark greyish brown and few fine prominent strong brown mottles; silty clay; weak very coarse prismatic structure; remnants of stratification; very firm moist; very sticky, very plastic wet; patchy thin dark grey cutans

- ## GHATAIL SERIES
- ### IRRIGATED

- AP_{1g} 0-9 cm** Dark grey (10YR 4/1) moist with many very fine distinct olive brown and common fine prominent strong brown mottles; silty clay; massive; firm moist; slightly stick, slightly plastic wet; many very fine and fine tubular pores; strongly iron staining along root channels; many very fine and fine roots; abrupt smooth boundary; pH 5.5

- AP_{2g}** 9-13 cm Dark grey (10YR 4/1) moist with many very fine distinct olive brown and common fine prominent dark brown mottles; silty clay; firm moist, sticky, plastic wet; many very fine and fine tubular pores; strongly iron staining along root channels and pores; many very fine roots; abrupt smooth boundary; pH 7.5
- B2_{1wg}** 13-38 cm Very dark grey (10YR 3/1) moist with many very fine distinct dark brown and few fine prominent strong brown mottles; clay; strong coarse and medium prisms breaking into strong coarse and medium angular blocky structure; very firm moist; very sticky, very plastic wet; continuous thick very dark greyish brown cutans along vertical and horizontal ped faces; common very fine roots; clear smooth boundary; pH 8.0
- B_{22wg}** 38-56 cm Dark grey (10YR 4/1) moist with many very fine and fine distinct olive brown mottles; clay; strong coarse and medium prisms breaking into medium angular blocky structure; firm moist; sticky, plastic wet; continuous thick very dark greyish brown cutans along vertical and horizontal ped faces; few small soft iron and manganese concretions; abrupt smooth boundary; pH 8.0
- B₃** 56-76 cm Light olive brown (2.5Y 5/4) moist with common very fine distinct dark grey mottles; clay; weak very coarse to coarse prismatic structure; firm moist; sticky, plastic wet; broken moderately thick darkgrey cutans along vertical ped faces; many fine and common medium tubular pores; few small soft black concretions; clear smooth boundary; pH 7.5.

- C₁ 76-88 cm Olive brown (2.5Y 5/3) moist with many very fine and fine distinct light olive brown and common fine distinct dark grey mottles; silty clay; remnants of stratification; slightly firm moist, slightly sticky, slightly plastic wet; many very fine and fine tubular pores; few small soft black concretions; abrupt smooth boundary; pH 8.0
- IIC₂ 88-160 cm Light olive grey (2.5Y 6/4) moist with many fine distinct light olive brown mottles, sandy loam; loose moist, non sticky, non plastic wet; pH 8.0.
Below 130 cm. augured samples have been described. Ground water found at 240 cm.

COLLECTION AND PROCESSING OF SOIL SAMPLES

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 airdried under shade. The soil samples were then gently ground with rolling wooden rod and passed through 2 mm sieve and mixed thoroughly. The samples were then preserved in plastic pots for physical, chemical and mineralogical analyses.

Separate bulk surface soil (0-12 cm) samples from each soil series were collected, mixed thoroughly and preserved in large polythene bags for simulation experiment.

PHYSICAL ANALYSIS OF SOILS

Mechanical analysis

The mechanical analysis of the soil samples were done by the Hydrometer method as outlined by Piper (1966), and textural classes determined from the triangular co-ordinates as devised by the USDA (1951).

Moisture percentage

Moisture content of field sample was determined by oven drying at 105°C for 24 hours (Piper, 1950)

Saturated hydraulic conductivity

Saturated hydraulic conductivity of undisturbed soils collected by core sampler were measured by constant water head method as described by Black (1965).

Soil Moisture Characteristics

Soil moisture retention at 0.1, 0.33 and 1.0 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).

Bulk density

Bulk density of soils were determined by core sampling method of Blake (1965).

Particle density

Particle density of soils were determined by pycnometer method of Blake (1965).

Percent pore space

The percent pore space was calculated by using the following formula;

$$\% \text{ Pore space} = 100 - \frac{(\text{Bulk density})}{(\text{Particle density})} \times 100$$

CHEMICAL ANALYSIS OF SOILS

Soil pH

Soil pH was measured by using a pye glass electrode pH meter in 1:2.5 soil: Water ratio and 1: 2.5 soil: 1N Kcl solution.

Measurement of Redox-potential (Eh)

Moist soil samples representing 40 gms on oven dry basis was taken in a 250 ml conical flask and 40 ml distilled water was added and made slurry with the help of a glass rod. N₂ gas was passed carefully into the slurry for 10-15 minutes by means of a plastic pipe. Eh millivolt reading was recorded after keeping the electrode of a PH meter (ELE LTD INTERNATIONAL, England, Model 3070, pH: 0-14-- pH. mv: 0-± 1990 mv) for 5-6 minutes in the slurry.

Electrical conductivity (Ec)

Electrical conductivity was measured in 1:2.5 soil water suspension by using conductivity meter.

Organic Carbon

The organic carbon content of soils was determined volumetrically by wet-oxidation method (Walkley and Black, 1934). The organic matter was calculated by multiplying the percentage of organic carbon with conventional van- Bemmelen's factor of 1.274 (Piper, 1950).

Total nitrogen

The total nitrogen in soils was determined by Kjeldahl's method as described by Jackson (1967).

Available Nitrogen

The available nitrogen in soils was extracted with 2M KCl and determined by steam distillation as described by Jackson (1967).

NH₄-Nitrogen

NH₄-Nitrogen of soil solution (leachate) concentrations was determined by microsteam distillation method without using Devarda's alloy (Black, 1965).

NO₃-Nitrogen

NO₃-Nitrogen of soil solution concentrations (leached) was determined by subtracting the results of ammonium from the result of available nitrogen (i.e. ammonium + nitrate).

Available Phosphorous

Available phosphorous of the soil was extracted by 0.5% NaHCO_3 solution (pH8.5) as proposed by Olsen (1954) and determined by Shimadzu spectrophotometer (Uv-120-02-model) at 470 nm wave length after developing the blue colour with chlorostannous acid as described by Dickman and Bray (1940)

Sulphate sulphur

Sulphate sulphur was determined by turbidimetric method as BaSO_4 after extraction with calcium dihydrogen phosphate solution. The intensity was measured at 420 nm in a Shimadzu spectrophotometer (UV-120-02-model).

Cation exchange capacity and exchangeable cations

The cation exchange capacity of soils was determined with normal NH_4OAc buffered at pH7.0 as of Jackson (1967). In case of calcareous soils, normal sodium acetate solution (pH8.2) was used according to the modified method of Bower *et al.* (Black, 1965).

An aliquate of the ammonium acetate leachate of the soil was used for Ca, mg, Na, & K determination. In case of calcareous soils, exchangeable calcium and magnesium were obtained using BaCl_2 - Triethanolamine (pH 8.1) extract (Puri, 1949). Calcium & Magnesium were determined by pye- Unicam SP-9 Atomic absorption spectrophotometer, while sodium and potassium were analysed by Gallankamp flame photometer (Jackson, 1967).

N/10 Hcl extractable iron, manganese, Zinc and Copper

The soils were extracted with N/10 Hcl (1:10 ratio) and exchangeable iron, manganese, zinc and copper were determined by pye unicam SP-9, Atomic absorption spectrophotometer (Lindsay and cox, 1985).

Total nutrient elements

The total Na, K, Ca, Mg, Fe, Mn, Zn, Cu, and Al content of soils were analysed from nitric-perchloric acid (2:1) extracts. Na & K were determined by Gallan kamp Flame analyser, while Ca, Mg, Fe, Mn, Zn, & Cu by pye-Unicam Sp-9 Atomic absorption spectrophotometer as described by Jackson (1967).

Al was determined colorimetrically by Aluminon method (HSU, 1963; Jayman & Sivasubramaniam, 1974), at 530 nm wave length.

Calcium Carbonate

Rapid titration method was followed (Piper, 1950) for the determination of free calcium carbonate.

Ferrous iron

5 gram soil was extracted with 0.1N H_2SO_4 (1:10 ratio) and ferrous iron was determined colorimetrically by orthophenanthroline method of Arinuskina, 1970. The intensity of colour was measured by Shimadzu spectrophotometer (UV-120-02 model) at 508 nm wavelength.

Total free iron, aluminium, silicon and manganese

Total free iron (Fe_D), aluminum (Al_D), silicon (Si_D) and manganese (Mn_D) were extracted by sodium dithionite, sodium citrate system buffered with sodium bicarbonate as proposed by Mehra and Jackson (1960). Fe and Mn were determined by Pye-Unicam Sp-9 Atomic absorption spectrophotometer, while Al was determined colorimetrically by Aluminon method (HSU, 1963; Jayman and Sivasubramaniam, 1974). Si- Was determined by blue Silicomolybdous acid procedure of weaver et al (1968). The colour intensity was measured spectrophotometrically at 820 nm by spectronic 21/ BUSCH and LOMB.

Acidified ammonium oxalate extractable iron, aluminium and silicon

For determining oxalate soluble iron (Fe_0), aluminium (Al_0) and silica (Si_0), 1 gram soil was taken in 100 ml plastic bottle and 50 ml 0.2M ammonium oxalate solution (adjusted at pH 3.0) was added. The bottles were shaken for 4 hours in the dark in a LAB-LINE, INCUBATOR SHAKER. The solutions were then transferred to polypropylene centrifuge tube and centrifuged for 30 minutes. The procedures of Blakemore *et al* (1987) and USDA - SCS (1972) were followed for the extraction. Fe Al and Si were then determined according to the methods described for total free iron, aluminium and silicon.

Sodium pyrophosphate extractable iron and aluminium

1 gram soil was extracted with 100 ml. 0.1M sodium pyrophosphate. The solution was shaken overnight (16 hours) in LAB-LINE, INCUBATOR SHAKER at room temperature. After centrifugation at 300 rpm for 30 minutes, the supernatant was filtered and transferred to plastic bottles for the determination of Fe_p & Al_p (Blakemore *et al*, 1987; USDA - SCS, 1972). The Fe_p and Al_p were then determined as mentioned earlier.

DETERMINATION OF MINERALOGICAL PROPERTIES OF SOILS

Three soil samples representing top soil, subsoil and substratum from each soil profile were selected for the determination of mineralogical composition in sand and clay fractions.

Separation of sand and clay fractions

After saturating the soils with 1N sodium acetate at pH 5.0 for the removal of free salts, 30% H_2O_2 for the oxidation of organic matter and calgon (sodium hexametaphosphate) for dispersion, the sand fraction was separated by wet sieving method. The clay fraction was separated according to the pipette method of Kilmer and Alexanders (1949) and Day (1956).

Identification of minerals in sand fraction

The sand fraction of representative soil samples were studied under polarizing microscope for the identification of the mineral contents.

Identification of minerals in the clay fraction

Preparation of slides

The clay fraction was rewet and completely dispersed in a beaker by ultrasonic machine. 1 ml of clay suspension was put on clean ceramic tiles placed over the mouth of the flasks over a vacuum pump. The water was sucked by the vacuum pump leaving a thin film of clays on the tiles (mounted tiles). Before scanning, the samples were air dried for about 24 hours.

The clay mineralogical study

The clay mineralogy was studied by X-ray diffraction (XRD) method. Oriented mount clay on 25x38mm sized ceramic tiles were used for XRD analysis in 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.

After air drying, the samples were glycolated and some were heated at different temperature for easy identification of different clay minerals.

Identification of clay minerals were done mainly on the basis of their characteristic basal reflections (Known as Peaks).

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

METHODS FOR COLLECTING RICE ROOT AND SHOOT STUBBLES

Just after harvesting the high yielding variety of transplanted aman, both in Kushtia under Ganges alluvium and Mymensingh (Sadar and Trisal thanas) under Brahmaputra alluvium, rice root and shoot stubbles were collected according to the following procedure:

Five plots (2 meter x 2 meter size) were selected in a randomized system in each land from where the soils were collected both from non-irrigated and irrigated conditions. While choosing the plots the variation in the height of stubbles, growth and yield of rice crops in the lands were also taken into consideration.

A pit was dug in between the crop rows down to the maximum depth of rooting. The roots were isolated initially with stubble scratching on pit walls very gently. They were first cleaned by spraying water on the pit walls, separated and washed in a plastic jar with adequate water. The roots & stubbles collected from each plot were taken separately in polythene bags.

After airdrying, the stubbles were isolated from the roots by cutting them at their adjoining point and oven dried separately at 65°C for 24 hours. The mean oven dried weights of root and stubble from 5 plots were obtained and calculated as ton per hectare.

Oven dried rice root and stubbles at 65°C were ground by a grinder machine and stored in plastic pots for simulation treatments.

SIMULATION EXPERIMENT

The experiment, designed to study the pedogenic condition of rice field, was conducted in the net house of the Department of Soil Science, Dhaka university.

Two types of treatment were adopted for the experiment

1. Addition of different amounts of organic matter from rice root and shoot stubbles with 2kg of soils.
2. Imposition of different water management treatments :
 - i. Alternate wetting and drying situations (15 days alternate wetting & drying)
 - ii) Permanent waterlogging situations for a period of 120 days (standing water-3 cm)

Use of rice root & stubble as different amounts of organic matter

Processed rice roots and stubbles were applied at different doses simulating different levels of organic matter and are shown in Table 2.

The experiment was arranged in a complete randomized block design system with the following organic matter treatments combination.

- S0 R0 = Control
S1 R1 = Initial dose of rice root & stubble.
S2 R2 = Two times increase of initial dose.
S3 R3 = Three times of initial dose .
S4 R4 = Four times of initial dose.

where S = Stubble and R = Root

240 pots={1 x 8 (soils) x 5 organic matter} x 2 (water treatment) x 3 (replications) were arranged for this simulation experiment.

Table 2: Addition of different amount of organic matter (rice root and stubbles) in Simulation Experiment.

Soils	Organic Matter Treatments	Amount of organic matter ton/hac		
		Root	Stubble	Total
SARA, Non-irrigated	S0 R0	-	-	-
	S1 R1	0.46	0.48	0.94
	S2 R2	0.92	0.96	1.88
	S3 R3	1.38	1.44	2.82
	S4 R4	1.84	1.92	3.76
SARA, Irrigated	S0 R0	-	-	-
	S1 R1	0.75	0.44	1.19
	S2 R2	1.50	0.88	2.38
	S3 R3	2.25	1.32	3.57
	S4 R4	3.00	1.76	4.76
PAKURIA, Non-irrigated	S0 R0	-	-	-
	S1 R1	0.47	1.74	2.21
	S2 R2	0.94	3.48	4.42
	S3 R3	1.41	5.22	6.63
	S4 R4	1.88	6.96	8.84
GHIOR, Irrigated	S0 R0	-	-	-
	S1 R1	0.49	2.07	2.56
	S2 R2	0.98	4.14	5.12
	S3 R3	1.47	6.21	7.68
	S4 R4	1.96	8.28	10.24
SONATALA, Non-irrigated	S0 R0	-	-	-
	S1 R1	0.76	0.40	1.16
	S2 R2	1.52	0.80	2.32
	S3 R3	2.28	1.20	3.48
	S4 R4	3.04	1.60	4.64
SONATALA, Irrigated	S0 R0	-	-	-
	S1 R1	0.65	0.23	0.88
	S2 R2	1.30	0.46	1.76
	S3 R3	1.95	0.69	2.64
	S4 R4	2.60	0.92	3.52
GHATAIL, Non-irrigated	S0 R0	-	-	-
	S1 R1	0.44	1.70	2.14
	S2 R2	0.88	3.40	4.28
	S3 R3	1.32	5.10	6.42
	S4 R4	1.76	6.80	8.56
GHATAIL, Irrigated	S0 R0	-	-	-
	S1 R1	0.50	0.27	0.77
	S2 R2	1.00	0.54	1.54
	S3 R3	1.50	0.81	2.31
	S4 R4	2.00	1.08	3.08

120 pots for alternate wetting and drying and the other 120 for permanently waterlogged situations were arranged separately side by side, each pot containing 2kg of airdried processed soil.

The plastic pots were of 16cm height and 15 cm diameter provided with a hole and exit pipe for the collection of leachates, taking all precautions to avoid exit of soil materials and outside leakage of water. The soil in each pot was moistened uniformly using tap water for 2 days prior to organic matter treatment.

Management of water treatments

Tap water was used for the whole period of the experiment. For maintaining fifteen days alternate wetting and drying situations, the relevant post pots were flooded with water at 3 cm level and the ponding situation was allowed to continue for 15 days after collecting the last leachate of this flooded condition, the soil was allowed to go through the drying process for 15 days before resaturating the soil for the next wetting phase. The process was continued for 120 days.

Permanently waterlogged situation (3cm standing water) was maintained by addition of water whenever needed.

Collection of leachates for analysis

The leachates were collected at the intervals of 15, 30, 60 and 120 days for both alternate wetting and drying, and permanently waterlogged conditions. After filtering, the solution concentrations of $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, Ca, mg, Na, K, Fe, Mn, Zn, Cu & ferrous iron were analyzed, as described earlier.

Measurement of pH, redoxpotential (Eh) and Ec of standing water

pH, redoxpotential and Ec of standing water were measured at the intervals of 15, 30, 60 and 120 days under both alternate wetting and drying, and permanently waterlogged situations.

COLLECTION OF SIMULATED SOIL SAMPLES

After completion of 120 days of experimental period the soils were isolated from each pot in polythene sheet and mixed thoroughly. About 500 gm of moist soil was collected, airdried, and ground to pass through 2mm sieve and stored in plastic pots for subsequent laboratory analyses.

Determination of simulated soil colours

Before isolating the soils from pots, the matrix colour was determined in moist condition by using munsell soil color charts and the standard abbreviations were used as described in Soil Survey Manual of USDA (1951).

Analysis of simulated soils

Total nitrogen, pH, Ec, organic carbon, exchangeable Ca, Mg, Na & K of soils were determined according to the methods described earlier.

Fe, Al and Si were determined from acid oxalate extraction of soils as described earlier.

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Investigations were carried out to find out the effects of alternate wetting and drying cycles on the properties and pedogenic processes of some representative Bangladesh soils. The study mainly involved morphological, physical, chemical and mineralogical properties of the soils. Ancillary to this a simulation experiment was conducted with the addition of different amounts of organic matter under alternate wetting and drying, and permanently waterlogged conditions of soils to detect the morphological, electrochemical and chemical changes that took place due to submergence of different periods. The results have been discussed in this chapter.

Morphological Characteristics

Morphological characteristics of the studied soils have been stated in individual soil series descriptions. The studied soil profiles from Ganges alluvium represent Sara (non-irrigated), Sara (Irrigated), Pakuria (non-irrigated) and Ghior (irrigated); while Brahmaputra alluvium represents Sonatala (non-irrigated), Sonatala (irrigated), Ghatail (non-irrigated) and Ghatail (irrigated). Some important morphological characteristics like soil colour, iron staining, soil structure, flood coating, solum depth, effervescence and thickness of ploughpan were recorded in Table 3 and 4 and their results are presented below:

Soil colour

The colour of the surface soil was found to be olive (M.5y5/4) and olive brown (*M.2.5y4/4) in Sara- NI* (Plate-1a) and Sonatala-NI series respectively, while in Sara-I** and Sonatala-I it was dark greyish brown (M.2,5y4/2) (Plate-1b).

NI* = Non-irrigated, I* = Irrigated, M* = Moist state

Olive and olive brown colours were developed due to better drainage of the soils. Their topographical position (highland, ridge) in the landscape (Table-5) are in agreement with these colours. Besides, rice cultivation in these soils under rainfed condition does not hold much water within the land for enough period for which oxidizing condition prevails for longer period, causing brighter colour of the soils. Ouespel (1947); Daniels *et al* (1973) and Evans also reported similar results. Franzmeier (1986) reported that oxidizing conditions are responsible for the brighter colours in better drained soils. SRDI staff (1970, 1975) during reconnaissance soil survey in Kushtia (Ganges alluvium sediments) and Mymensingh (Brahmaputra alluvium sediments) found that the top soil colour in ridges ranged from pale olive to olive brown.

Dark greyish brown colour in the surface soil of Sara-I (Plate-1b) and Sonatala-I was developed due to prolonged period of wetness or saturation by irrigated water for rice cultivation. USDA (Soil Survey Staff, 1975) used a chroma of 2 or less to indicate the reducing condition of soils. Daniels *et al*, (1971), Coventry and Williams (1984) and Mokma and Cremeens (1991) were in agreement with the development of colours caused by water saturation.

This gleying phenomena of the Surface Water Gleys are developed on the seasonally wet landscapes (Brammer and Brinkman, 1977). The surface watergley are known by different names in different parts of the world such as hydromorphic soils in Southeast Asia, (Moorman, 1961; Vander Kevie, 1972), degraded rice soils in Burma (Karmanov, 1968) and Aquarizems in Japan (Kyuma and Kawaguchi, 1966). These soils develop properties diagnostic of soils with aquic moisture regime (Smith, 1965).

The formation of gleying phenomenon due to imposition of aquic moisture regime for rice cultivation on non-aquic soils was called "inverted gley" by Dudal (1964). The soils such as the Sara-I and Sonatala-I can be designated as inverted gley. Moorman and Breemen (1974) termed this man-induced water regime as "anthraquic,"

and the horizon that forms at the surface under this water regime was called "anthraquic epipedon" (Dudal, 1964). In describing the anthraquic epipedon, he stated that it comprises both the cultivated layer and the underlying ploughpan. Both these layers have grey base colours and are strongly iron stained along root channels. However, strongly iron stained root channels were found in the surface horizon and underlying ploughpan of the Sara-I, Sonatala-I, Ghior-I and Ghatail-I soils causing ferrous iron concentration in soils due to continuous irrigation (anaerobic situations).

Under the present investigation dark greyish brown colour (chroma ≤ 2) in the surface horizon of non-aquic soils like Sara-I and Sonatala-I was developed due to prolonged period of wetness or saturations by irrigated water for two high yielding variety of rice cultivation for long period. Strongly iron staining along root channels in surface horizons and underlying ploughpan of Sara-I and Sonatala-I also meet the requirements of Anthraquic epipedon. Current research data provide further requirement of the Anthraquic epipedon as follows:

Anthraquic epipedon includes the plough layer and underlying ploughpan. In Bangladesh condition, where country plough is used for puddling, the thickness of this epipedon is likely to be thinner. In the irrigated Sara-I and Sonatala-I soils the thickness of the anthraquic epipedon was found to be 15 cm.

- Soil matrix colour must be reduced and its chroma should be 2 or less.
- Soils should be saturated or flooded for a long period by irrigated or impounded water under rice culture.
- Presence of strong iron staining along root channels both in the plough layer and in the underlying ploughpan.
- Redox potential of the moist soil should be low (preferably Eh ranged from - 100 to +214 mv).
- Higher concentration of ferrous iron in soils (30 to 40 ppm).
- Absence of $\text{NO}_3\text{-N}$ under wet condition.
- Presence of higher contents of organic matter in the soils (> 1 per cent).

Table 3. Differentiating Morphological Characteristics of the Surface horizon of the Studied Soil Series.

Soil Series	Period of wetness/Saturation (Days)	Depth of flooding and duration	Munsell colour *		Thickness of ploughpan (cm)	Iron staining along root channels
			Matrix (moist)	Mottles (moist)		
GANGES ALLUVIUM SARA (Non-irrigated)	100-110	Non-flooded land, 02-3 cm rain water are usually kept under bund for 30-60 days during rainy season.	M.5y 5/4	5 percent, M.2.5y 5/2 1 percent M.10 YR4/3	2.0	Few iron staining along root channels
SARA, (Irrigated)	210-220	Non-flooded land, 4-5 cm water are kept under bund for 120-130 days.	M.2.5y 4/2	25 percent M.2.5y 4/4 & 1 percent M. 10YR 4/3	4.0	Strongly iron stained along root channels.
PAKURIA, (Non-irrigated)	130-140	10-15 cm for about 80-90 days	M.5y 5/2	15 Percent M.10YR 4/2	3.0	Few iron staining along root channels.
GHIOR, (Irrigated)	260-270	30-45 cm for 120-130 days	M. 5y 5/2	20 percent M.2.5y N3/1	5.0	Strongly iron stained along root channels & some iron staining marks upon ped surfaces

Table 3 (Contd.)

Soil Series	Period of wetness/Saturation. (Days)	Depth of flooding and duration (cm)	Munsell colour *		Thickness of ploughed (cm)	Iron staining along root channels
			Matrix colour (moist)	Mottles (moist)		
BRAHMAPUTRA ALLUVIUM SONATALA (Non-irrigated)	120-130	Above flood level but 3-6 cm rain water are usually kept under bund during rainy season for 40-60 days.	M.2.5y 4/4	22 Percent M.2.5y 4/2	3.0	Few iron staining along root channels
SONATALA, (Irrigated)	230-240	Never flooded but 4-8 cm water are kept under bund by irrigation and rain water for 120-130 days	M.2.5y 4/2	25 percent M.2.5y 4/4	5.0	Strongly iron stained along root channels.
GHATAIL, (Non-irrigated)	175-185	60-90 cm for 90 -100 days. Flooding causes of only rain water.	M.10yr 4/1	15 Percent M.2.5y 4/4 & 2 percent M.10yr 4/3	3.0	Few iron staining along root channels.
GHATAIL, (Irrigated)	270-280	30-60 cm for 80-90 days.	M. 10yr 4/1	22 percent M.2.5y 4/4	4.0	Strongly iron stained along root channels & few iron stain marks upon ped surfaces

* : Standard abbreviations for soil morphological characteristics according to Soil Survey Manual of USDA, Hand book no. 18, 1951 have been used.

Table 4: Differentiating morphological characteristics of subsoil layer of the studied soil series.

Soil series	Depth (cm)	Munsell colour (moist)	Structure	Flood coatings	Effervescence
GANGES ALLUVIUM					
SARA, (Non-irrigated)	13-41	M.2.5y5/4-5y5/3	2c-mpr/ 1mpr to 1vcpr	C ₂ dgb/** vhp & roots-P ₁ gb/roots	ev
SARA, (Irrigated)	15-59	M.2.5y5/4- 4/4	2c-mpr/* 2c-mabk to 2-1vc-cpr	C ₂ dgb/vhp & roots to p ₁ dgb/vp	ev
PAKURIA, (Non-irrigated)	17-59	M.2.5y4/4	3cpr/3c-m abk & sbk to 2-1c-vcpr	C ₃ dgb/ vhp & roots to C ₂ dgb/vp	ev
GHIOR, (Irrigated)	20-76	M.2.5y4/1.5-3/2	3cpr/3vf-fabk/ to 1c-vcpr	C ₃ vdg/ vhp to b ₂ vdg/hp	es
BRAHMAPUTRA ALLUVIUM					
SONATOLA, (Non-irrigated)	14-74	M.2.5y4/4-5/4	2c-mpr	C ₂ dg/hp to br ₂ -p ₁ dg/vp	eo
SONATOLA, (Irrigated)	15-108	M.2.5y4/4 to (10yr4/1-3/2) 2.5y 5/4	2c-mpr to & 3cmpr/3c mabk & sbk-2vc-cpr	C ₂ dg/vhp, C ₃ vdg/vhp, C ₃ dg/vhp,& C ₂ vdg/vp	eo
GHATAIL, (Non-irrigated)	13-111	M.10yr4/1-4/2 to 10yr5/4-4/3	3mpr/mabk, 3mpr/mabk & sbk, 3c-mpr/c-m abk & sbk; 1vcpr	C ₂ dgb/vhp; C ₃ vdg/vhp & pores, b ₂ dg/vhp, C ₂ vdg/vhp & pores & p ₁ dg/vp	eo
GHATAIL (Irrigated)	13-56	M.10yr3/1-4/1 to 2.5y 5/4	3c-mpr/ 3c-mabk & sbk; 1vc-cpr	C ₃ vdgb/vhp to b ₂ dg/vp	eo

*/= Breaking into
**= Along

Note: Standard abbreviations for soil morphological characteristics according to Soil survey Manual of USDA, Hand book no. 18, 1951, have been used.



Plate No.1a. Sara Non-irrigated profile showing ochric epipedon



Plate No.1b. Sara Irrigated profile showing Anthraquic epipedon

Subsoil colour in Sara-NI, Sara-I, Sonatala-NI and Sonatala-I series ranged from olive to olive brown. These colours indicated mostly the non-reducing environments of the soils. Though Sara-I and Sonatala-I were brought under irrigation for prolonged period, their subsoil colour remained brighter as thick ploughpan (Table-3), which prevented vertical water percolation. Besides, these soils, being medium textured, have better internal drainage capability. In these soils the lower horizons reflect free drainage condition of the original profile (Saheed and Hussain, 1992).

In Pakuria-NI and Ghior-I soils, surface colour was found to be olive grey (M.5y5/2) while in Ghatail-NI and Ghatail-I it was dark grey (M.10yr4/1). These colours were developed due to prolonged submergence/saturation of soils. These soils are basically poorly drained. Presently they are occupying medium highland which used to be inundated for a part of the year by rain water and caused the reducing colour of the soils. However, the surface soil colour for irrigation in Ghior-I and Ghatail-I did not change much as the soils were originally poorly drained. Poorly drained low land soils do not change much, when used as paddy land (Karmanov, 1966, Wada, 1973 and Mitsuchi, 1974).

In Pakuria-NI, subsoil colour was light olive brown (M.2.5y4/4) because of free drainage condition, while in Ghior-I it ranged from dark greyish brown to very dark greyish brown (M.2.5y 4/1.5 to 3/2) throughout the subsoil. This was mainly due to rice cultivation under prolonged submergence of soils by irrigation.

The colours of the subsoil in Ghatail-NI and Ghatail-I ranged from dark grey (M.10yr 4/1) to very dark greyish brown/very dark grey (M.10yr 4/2 /M10yr3/1 to 4/1) in the upper part mainly due to prolonged submergence as they occupy the lower position of the landscape and remain inundated for a part of the year during kharif season. The presence of browner colour in the lower part of subsoil indicates the existence of free drainage condition.

Table 5. Some general information on the studied soils.

Soil Series and location	Parent material	Physio-graphy	Topographical position	Land type	Present land use
SARA, (Non-irrigated,) Eduarkanir field, Barkhada mouza, Kushtia sadar, Kushtia.	Ganges alluvium	Ganges flood plain	Summit of undulating ridge.	High land	L. Aus (rainfed) HYV-T.A - fallow
SARA, (Irrigated) Charpara, Belgharia mouza, Giarakhi, Kushtia sadar, Kushtia	do	do	Upper part of very gently undulating ridge.	High land	HYV- TU- HYV-T.A - Fallow.
PAKURIA, (Non-irrigated)	do	do	Middle part of very gently undulating ridge.	Medium high land	HYV-T.A - Fallow.
GHIOR, (Irrigated,) Charpara, Belgharia mouza, Giarakhi, Kushtia sadar, Kushtia.	do	do	Lower part of very gently undulating basin.	Medium high land (presently)	HYV-TU- HYV T.A- Fallow.
SONATALA, (Non-irrigated,) Phanghagra, Vhobakhali, Mymensing, Sadar, Mymensingh.	Old Brahmaputra alluvium	Old Brahmaputra Flood plain	Summit of very gently undulating ridge	High land	Local Aus- HYV- T.A (Rainfed) Fallow
SONATALA, (Irrigated), Uparpar, Vhobakhali, Mymensingh Sadar, Mymensingh.	do	do	Middle part of Gently undulating ridge.	High land	HYV-Boro- Fallow-HYV- T.A.
GHATAIL, (Non-irrigated,) Phanghagra, Vhobakhali, Mymensingh sadar, Mymensingh.	do	do	Centre of very gently undulating basin centre.	Medium high land (presently)	Local T.A- Fallow
GHATAIL (Irrigated,) Bailer, Charpara, Bailer union, Trisal, Mymensingh.	do	do	Lower part of very gently undulating basin.	Medium high land (presently)	HYV-Boro- Fallow -HYV -T.A.

Note: HYV = High yielding variety, T.A= Transplanted aman. Tu: Transplanted aus, L. Aus = Local Aus.

Soil structure

Structure of the soils was massive in all the surface horizon of the studied soil. Structure did not develop in surface as this layer has been ploughed.

Soil series like Sara-NI and Sara-I showed moderate coarse to medium prismatic structure in their subsoil, while medium angular blocky structure was also observed in Sara-I.

Angular and sub-angular blocky structures were exhibited in Pakuria-NI, while in Ghior-I it was very fine to fine angular blocky.

In Sonatala-NI series, moderate coarse and medium prisms structures were found, while in Sonatala-I this was coarse and medium angular and sub-angular blocky. Angular and sub-angular blocky structures were also recorded in Ghatail-NI and Ghatail-I.

Angular and sub-angular blocky structures were developed due to more water movement for long period through the profiles and high clay contents in soils.

It was also observed that relatively weaker structure were present in the lower part of subsoil causing less weathering and as a result less development occurred.

SRDI Staff (1970 and 1975) during reconnaissance soil survey found similar structures in the studied areas.

Considering the overall structural pattern in the studied soil series it was observed that the irrigated soils have relatively finer structures than the non-irrigated ones, which is the indication of more water movement through the profiles following irrigation.

Flood coatings/cutans

Flood coatings are formed in the seasonally flooded lands. It is clearly different from the clay cutans. The shiny surfaces of soil cracks and pores formed by deposition of material washed from the soil surface or the top soil under seasonally flooded conditions were defined as flood coatings (FAO, 1971).

Continuous moderately thick to patchy thin dark greyish brown flood coatings/cutans were observed in Sara-NI and Sara-I profiles, while in Pakuria-NI & Ghior-I it was continuously thick to moderately thick dark greyish brown to very dark greyish brown.

In Sonatala-NI flood coating was continuous moderately thick dark grey, whereas in Sonatala-I it was moderately thick to thick dark grey to very dark grey. Flood cutans were continuous moderately thick to thick very dark grey to very dark greyish brown in Ghatail-NI and Ghatail-I profiles. Thickness of flood coating was caused by continuous leaching of the top soil materials and the darker colour was due to wetness and organic matter contents.

It was observed that the irrigated soils contain relatively thicker and darker flood coatings than the non-irrigated ones due to more leaching of topsoil materials through water movement within the profiles.

Solum depth

Solum is considered as genetic or true soil which is developed by soil building process of biochemical breakdown of weathering and synthesis (Brady, 1990). A soil having higher depth of solum, which includes A and B horizons, indicates the high degree of development and maturity.

Sara-NI series developed a solum depth of 41 cm and as such it is categorized as shallow profile, while Sara-I, Pakuria-NI, Ghior-I, Sonatala-NI and Ghatail-I series were found to have solum depths within 50 to 90 cm and are grouped into moderately deep profile. Sonatala-I and Ghatail-NI series having more than 100 cm solum depth were grouped as deep profiles (USDA, 1951).

Effervescence

Effervescence indicates the presence of free calcium carbonate in soils. The Gangetic soils such as Sara-NI, Sara-I, Pakuria-NI and Ghior-I profiles genetically being calcareous showed effervescence throughout the pedons. In case of Ghior-I strong effervescence below 20 cm indicated the symptom of decalcification in upper part of the profile.

Soils of Brahmaputra alluvium like Sonatala-NI, Sonatala-I, Ghatail-NI and Ghatail-I are genetically non-calcareous and showed no effervescence.

Ploughpan

Ploughpan is a soil layer compacted by tillage and occurs below 5 to 15 cm in the soil depending on the normal depth of ploughing. It is mainly formed due to continuous rice cultivation with irrigation (FAO, 1971). It becomes thicker and harder through continuous practice of irrigated rice cultivation. Ploughpan was found to develop (Table-3) 2 to 3 cm thick in the non-irrigated soils like Sara-NI, Pakuria-NI, Sonatala-NI and Ghatail-NI series. The thickness varied mainly with the variation of soil and time in wetland rice cultivation, while in the irrigated soils like Sara-I, Ghior-I, Sonatala-I and Ghatail-I it ranged from 4 to 5 cm. In irrigated soils relatively thicker ploughpan was found due to cultivation of high yielding variety of rice for long period. However, ploughpan prevents vertical water percolation, restricts aeration and as well as root penetration.

PHYSICAL PROPERTIES OF SOILS

Physical properties does not change their pattern easily as chemical properties and hence impart the most useful contribution in soil classification, management and improvement of cultivated soils.

Under the present investigation the physical properties included mechanical analysis, moisture percentage of soils at field sampling, saturated hydraulic conductivity, soil moisture characteristics (moisture retention) at 0.1, 0.33 and 1.0 bar tension, bulk density, particle density and percent pore space.

Mechanical composition and textural class

The percentage of sand, silt and clay and textural class of soils are very important characteristics of soil profile which reflect the pedogenic and geologic history of a soil.

Soils of Ganges alluvium (Table-6) like Sara-NI and Sara-I were silt loam in texture, while Pakuria-NI and Ghior-I were clayey (SRDI Staff, 1970).

In Sara-NI profile, sand contents increased with the increase of depth (6 to 19%) followed by silt (60 to 73%), while clay decreased (34 to 10%). The distributing pattern of sand, silt & clay in Sara-NI profile indicates non-illuviation of clay and hence the soil is less weathered and relatively less developed.

In Sara-I, an irregular trend with respect to sand contents (ranging from 9 to 17%) was observed, while silt contents closely varied between 66 to 73% upto 123 cm depth then decreased. Clay contents decreased from 25 to 15% upto 59 cm and then gradually increased to 54%. The loss of clay from the upper horizons and their illuviation below 123 cm indicated that the profile was more weathered than Sara-NI. Similar trend in respect to sand and silt contents were observed in Pakuria-NI, while

clay percent increased (53 to 59%) with the increase of depth upto 29 cm and then decreased upto 83 cm. Pakuria-NI, occurring in medium highland, is seasonally flooded or inundated by rainwater /flooding. Due to alternate wetting and drying of soils loss of clay from top soils and their subsequent illuviation in subsoils were observed, causing relatively more weathering of soils and structure development.

In Ghior-I, sand and clay were found to increase from 3 to 18% and 47 to 74% with the increase of depth, while silt contents decreased from 41 to 13%. Ghior-I being the basin soils enriched with clay contents. The loss of clay from the overlying and their illuviation in underlying horizons is the indication of weathering of profile.

The soils of Brahmaputra alluvium such as Sonatala-NI and Sonatala-I were silt loam, while Ghatail-NI and Ghatail-I were clayey in texture (SRDI Staff, 1974-75).

In Sonatala-NI, sand increased (15 to 22%) with the increase of depth upto 50 cm and then decreased, silt contents varied from 66 to 60% upto 84 cm depth and then sharply decreased, while clay increased sharply below 84 cm.

In Sonatala-I sand contents decreased (21 to 14%) with the increase of depth upto 130 cm and then increased, silt increased upto 31 cm and then decreased, while clay increased (21 to 54%) upto 108 cm and then decreased. In case of Ghatail-NI series, an irregular trend in sand and silt contents were observed, while clay contents increased with the increase of depth upto 111 cm and then decreased. In Ghatail-I profile, sand contents ranged from 4 to 10% upto 88 cm which sharply increased (58%), at 88 cm silt contents decreased with the increase of depth, while clay increased upto 56 cm depth and then decreased.

Table 6: Mechanical composition, textural class and moisture per cent of the studied soils

Soils Series	Horizon	depth (cm)	Mechanical composition of soils			Textural class	Moisture % at sampling time (oven dry basis)
			Sand %	Silt %	Clay %		
GANGES ALLUVIUM SARA, (Non-irrigated)	AP ₁	0-11	6	60	34	Sicl	17
	AP ₂	11-13	5	61	34	Sicl	17
	B _{2w}	13-26	15	61	24	Sil	18
	B _{3w}	26-41	13	65	22	Sil	19
	C ₁	41-57	13	73	14	Sil	20
	C ₂	57-95	19	71	10	Sil	19
SARA, (Irrigated)	AP _{1g}	0-11	9	66	25	Sil	25
	AP _{2g}	11-15	13	67	20	Sil	18
	B _{21w}	15-33	8	74	18	Sil	19
	B _{22w}	33-50	16	65	19	Sil	18
	B _{23w}	50-59	12	73	15	Sil	19
	B ₃	59-84	14	62	24	Sil	19
	C ₁	84-97	11	72	17	Sil	20
	C ₂	97-105	9	67	24	Sil	21
	C ₃	105-123	6	72	22	Sil	23
	C ₄	123-148	17	53	30	Sicl	19
	C ₅	148-180	9	37	54	C	19
PAKURIA, (Non-irrigated)	AP _{1g}	0-13	2	45	53	Sic	21
	AP ₂	13-17	5	36	59	Sic	19
	B _{21w}	17-29	10	32	58	C	18
	B _{22w}	29-42	13	43	44	Sic	20
	B _{23w}	42-59	6	55	39	Sicl	20
	B ₃	59-83	7	45	48	Sic	23
	C ₁	83-108	13	32	55	C	25
	C ₂	108-146	8	42	50	Sic	19
	C ₃	146-181	5	43	52	Sic	24
GHIOR, (Irrigated)	AP _{1g}	0-15	3	41	56	Sic	31
	AP _{2g}	15-20	5	22	73	C	25
	B _{21wg}	20-32	12	25	63	C	23
	B _{22wg}	32-57	18	35	47	C	25
	B ₃	57-76	11	20	69	C	24
	C _{1g}	76-97	11	15	74	C	23
	C _{2g}	97-140	15	13	72	C	23

Table 6 (Contd.)

Soils Series	Horizon	depth (cm)	Mechanical composition of soils.			Text- ural class	Moisture % at sampling time (oven dry basis)
			Sand %	silt %	clay %		
BRAHMAPUTR ALLUVIUM SONATALA, (Non-irrigated)	AP ₁	0-11	15	66	19	Sil	21
	AP ₂	11-14	15	64	21	Sil	15
	B _{21w}	14-35	22	66	12	Sil	13
	B _{22w}	35-50	21	60	19	Sil	12
	B _{23w}	50-84	16	60	24	Sil	22
	AP _{1bg}	74-100	13	20	67	C	25
	C _{1g}	100-130	9	13	78	C	22
	C ₂	130-165	14	41	45	Sic	23
SONATALA, (Irrigated)	AP _{1g}	0-10	21	58	21	Sil	26
	AP _{2g}	10-15	19	56	25	Sil	19
	B _{2w}	15-31	14	61	25	Sil	24
	IIB _{21w}	31-51	8	42	50	Sic	25
	B _{22wg}	51-78	5	41	54	Sic	23
	B _{23g}	78-108	9	43	48	Sic	22
	C ₁	108-130	14	52	34	Sicl	23
	C ₂	130-140	26	48	26	L	21
GHATAIL, (Non-irrigated)	C ₃	140-200	53	32	15	Sl	19
	AP _{1g}	0-10	1	41	58	Sic	24
	AP _{2g}	10-13	3	34	63	C	19
	B _{21wg}	13-20	2	33	65	C	19
	B _{22wg}	20-39	4	17	79	C	12
	B _{23wg}	39-48	15	14	71	C	21
	B _{24w}	48-66	6	41	53	Sic	22
	B _{25w}	66-79	11	20	69	C	25
	B ₃	79-96	12	21	67	C	20
	C ₁	96-111	6	34	60	C	20
	C ₂	111-135	12	41	47	Sic	29
	C ₃	135-160	13	44	43	Sic	21
GHATAIL, (Irrigated)	C ₄	160-200	9	55	36	Sicl	21
	AP _{1g}	0-9	4	43	53	Sic	14
	AP _{2g}	9-13	4	41	55	Sic	21
	B _{21wg}	13-38	10	22	68	C	24
	B _{22wg}	38-56	5	24	71	C	21
	B ₃	56-76	6	35	59	C	25
	C ₁	76-88	10	41	49	Sic	22
	IIC ₂	88-160	58	27	15	Sl	24

Sl = Sandy loam, Sil = Silt loam, Sicl = Silty clay loam, Sic = Silty clay, C = Clay.

Considering the overall pattern of sand, silt and clay contents in all profiles it was observed that the more weathered profiles lost clays from the overlying horizons and illuviated in the underlying horizons. The irregular trend of sand, silt and clay percent in soil profiles were due to irregular deposition of sediments at different times. This alluvial nature of soils are in fine agreement with the parent material of the studied soils such as Ganges and Brahmaputra alluvium.

Moisture percentage of soil at field sampling

Data presented in Table-6 showed 17-20, 18-25, 18-25 and 23-31% moisture in the soils of Sara-NI, Sara-I, pakuria (NI) and Ghior-I profiles respectively. In Sonatala-NI, Sonatala-I, Ghatail-NI and Ghatail-I profiles it ranged from 12-25, 19-26, 12-29 and 14-25% respectively.

Moisture in soils at sampling time was found relatively higher in most fine textured soils than the medium textured soils. It was possibly due to the relatively low lying position of the fine textured soils in the landscape (Pakuria-NI, Ghior-I, Ghatail-NI and Ghatail-I) coupled with greater surface area and better structure in soils. Besides, moisture content was observed to be higher with the increase of silt contents in case of medium textured ridge soils like Sara-NI, Sara-I, Sonatala-NI and Sonatala-I, while in basin soils (fine textured soils) relatively more moisture was observed in the lower layers due to rise of ground water through capillary pores in soils.

Saturated hydraulic conductivity

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

In Gangetic alluvium, fine textured soils showed relatively higher hydraulic conductivity (Table-7) than the medium textured soils due to expanding clay contents in

soils. On the other hand, in Brahmaputra alluvium soils hydraulic conductivity was found relatively higher in medium textured soils than the fine textured soils (Table-7). Also Karim (1988) reported that hydraulic conductivity is relatively high in coarse textured soils and low in heavy textured soils.

In most cases irrigated soils were found to have less hydraulic conductivity than non-irrigated soils which may be attributed to compactness due to prolonged irrigation. The results are closely related with the pore space percent of soils (Table-8). Exception was observed in Ghior-I where sub soil have higher hydraulic conductivity (1.55 cm /hr) than Pakuria-NI, due to finer structure in Ghior-I which caused higher permeability of soils.

Moisture retention capacity

Soil moisture retention capacity has the prime importance in soil and water management practices specially for policy planning in irrigation purpose (Velayutham and Raj, 1977).

Moisture contents decreased with the increase of tensions (i.e from 0.1 bar to 1.0 bar) in all studied soil (Table-7). This decrease in moisture contents was slightly faster in medium textured soils like silt loam and silty clay loam than the fine textured soils such as silty clay and clay. Similar results were reported by Joshua (1983). However, in Gangetic soils fine textured soils like Pakuria-NI and Ghior-I were found to retain more moisture in all tensions than the medium textured Sara-NI and Sara-I which was due to the presence of swelling clays in Gangetic soils. While in Brahmaputra alluvium at low tensions (i.e at 0.1 and 0.33 bar) medium textured soils retained slightly higher moisture than the fine textured soils due to higher compactness in fine textured soils like Ghatail-NI and Ghatail-I. The results are in well agreement with the findings of SRDI Staff (1986).

Table 7. Moisture content at different tensions and saturated hydraulic conductivity of the studied soils.

Parent material	Soil series	Depth cm	Texture	Moisture content (vol%)			Hydraulic conductivity in core samples in laboratory. cms/hr
				at.1 bar tension	at.33 bar tension	at 1.0 bar tension	
Ganges Alluvium	Sara, (Non-irrigated)	2-10	Sicl	44.2	40.0	37.5	1.50
		13-20	Sil	42.0	38.5	35.0	1.70
	Sara, (Irrigated)	2-10	Sil	44.0	40.3	37.9	1.29
		24-31	Sil	43.3	38.2	35.1	1.33
	Pakuria, (Non-irrigated)	2-10	Sic	44.3	41.2	39.9	1.67
		29-35	C	45.5	41.5	37.5	0.17
	Ghior, (Irrigated)	2-10	Sic	44.0	41.0	39.5	1.67
		20-32	C	44.2	41.6	40.3	1.55
Brahmaputra Alluvium	Sonatala, (Non-irrigated)	1-10	Sil	47.5	41.5	38.5	1.58
		14-30	Sil	46.0	41.0	37.9	1.00
	Sonatala, (Irrigated)	2-10	Sil	45.5	41.6	37.5	0.80
		15-30	Sil	44.3	41.8	37.7	0.90
	Ghatail, (Non-irrigated)	1-10	Sic	44.5	41.0	38.5	0.20
		13-20	C	43.5	40.8	38.4	0.40
	Ghatail, (Irrigated)	1-9	Sic	44.0	40.8	37.8	0.40
		13-35	C	43.5	40.5	37.5	0.30

Sil = Silt loam, Sicl = Silty clay loam, Sic = Silty clay, C = Clay

Bulk density and particle density

Data presented in Table-8 indicate that the Gangetic alluvium soils like Pakuria-NI and Ghior-I have higher bulk density in top soils than the subsoils, while Sara-NI and Sara-I have slightly lower bulk density in top soil than subsoils. Higher bulk density were associated with compactness and low pore space in soils.

Table 8. Some physical properties of the studied soils

Soils	Depth (cm)	Textural class	Bulk density g/cm ³	Particle density g/cm ³	pore space %
SARA, Non-irrigated	Top soil (0-11)	Sicl	1.44	2.57	43.97
	Sub soil (13-26)	Sil	1.45	2.78	47.84
SARA, Irrigated	Top soil (0-11)	Sil	1.45	2.51	42.23
	Sub soil (15-33)	Sil	1.46	2.49	41.36
PAKURIA, Non-irrigated	Top soil (0-13)	Sic	1.66	2.41	31.12
	Sub soil (17-29)	C	1.42	2.45	42.04
GHIOR, Irrigated	Top soil (0-15)	Sic	1.60	2.27	29.51
	Sub soil (20-32)	C	1.50	2.58	41.86
SONATOLA, Non-irrigated	Top soil (0-11)	Sil	1.48	2.36	37.29
	Sub soil (14-35)	Sil	1.53	2.48	38.30
SONATOLA, Irrigated	Top soil (0-10)	Sil	1.63	2.62	37.79
	Sub soil (15-31)	Sil	1.79	2.66	32.71
GHATAIL, Non-irrigated	Top soil (0-10)	Sic	1.62	2.79	41.93
	Sub soil (13-20)	C	1.64	2.64	37.88
GHATAIL, Irrigated	Top soil (0-9)	Sic	1.64	2.79	41.21
	Sub soil (13-18)	C	1.75	2.82	37.94

Sil = Silt loam, Sicl = Silty clay loam, Sic = Silty clay, C = Clay

In Brahmaputra alluvium soils bulk density was found higher in subsoils than top soils due to compaction resulting through continuous pressure from plough layer to the immediate subsoils. The low pore space percent in soils are in fine agreement with the results.

However, most of the irrigated soils were found to have higher bulk density due to compaction resulting from rice cultivation in wet condition. Joshua (1988) was in

well agreement with this results who reported that higher bulk densities could be attributed to the structural breakdown and compaction of the soils due to ploughing under wet conditions.

Particle density (Table-8) ranged from 2.27 to 2.79 g/cm³ in top soils, while it was observed to vary from 2.45 to 2.82 g/cm³ in subsoils. In almost all soils particle density showed higher values in subsoils than top soils due to higher clay contents.

CHEMICAL PROPERTIES OF SOILS

Chemical analyses of soils for all horizon of the profiles were undertaken with a view to characterize the soils and to find out the changes that took place due to alternate wetting and drying cycles and prolonged saturation with respect to their fertility status and pedogenic changes.

Therefore, horizon wise soil samples from each profile were analyzed for pH, redox-potential (Eh), Electrical conductivity (EC), calcium carbonate, organic carbon, total nitrogen, C/N ratio, available nitrogen, available phosphorous, sulphate sulphur, CEC, exchangeable cations (Ca⁺⁺, Mg⁺⁺, Na⁺, K⁺ and H⁺); exchangeable Fe, Mn, Zn and Cu; nitric-perchloric acid soluble constituents (Na, K, Ca, Mg, Fe, Mn, Zn, Cu and Al); ferrous iron; total free iron, aluminium, silicon and manganese; acid oxalate extractable Fe, Al & Si; and pyrophosphate extractable Fe and Al.

Soil pH

The soil pH plays a very important role in grouping the soils into normal and problematic classes. It has influence in crop growth and hence special emphasis is given on it for soil classification purposes as well as pedogenesis.

The soil pH (water) presented in Table-9 ranged from 7.06 (neutral) to 8.44 (moderately alkaline) in Ganges alluvium soils, while in Brahmaputra alluvium soils it was registered from 4.65 (very strongly acid) to 7.8 (mildly alkaline).

Ganges alluvium soils being calcareous have higher pH value than Brahmaputra alluvium soils. pH in Sara-NI and Sara-I recorded moderately alkaline condition. The pH increased significantly ($r=.927^{**}$) in Sara-NI with the increase of depth and was correlated significantly with CaCO_3 at 1 percent level ($r=.856^{**}$) (Appendix-I).

In Pakuria-NI pH was found to be increased slightly with the increase of depth and recorded moderately alkaline (7.85 to 8.25) upto 108cm and then decreased to mildly alkaline (7.55 to 7.65) level. It was significantly correlated ($r=.903^{**}$) with CaCO_3 contents in Pakuria-NI. In Ghior-I pH increased upto subsoil due to leaching and then decreased significantly with depth ($r=-.697^*$). The value correlated with CaCO_3 significantly ($r=.732^*$). Due to accumulation of high organic matter, decalcification occurred in top soils and consequently low pH was obtained. Lower pH was also observed in the lower horizons in Ghior-I owing to reduced condition induced by ground water as Ghior-I occurred in basin. The results are in fine agreement with the findings of Ponnampetuma (1965 and 1972) who reported that the overall effect of flooding is to increase the pH of acid soils and depress the pH of sodic and calcareous soils. The increase in pH of most acid mineral soils is due to the reduction of Fe (III) to Fe (II) and the decrease in pH of alkaline soils is attributed to CO_2 accumulation.

Soils of Brahmaputra alluvium like Sonatala-NI showed strongly acidic in top soil (pH 5.10) causing leaching loss of bases and then increased and maintained althrough neutral in reaction. While in Sonatala-I it was althrough neutral because of prolonged saturation. But pH decreased significantly ($r=-.578^*$) with the increase of depth and was significantly correlated with CaCO_3 contents ($r=.672^*$) (Appendix-I).

Soil pH in Ghatail-NI was observed at 4.65 to 6.45 (acidic) in the upper 20 cm and then increased upto 7.4 with the increase of depth showing highly significant ($r=.673^{**}$) correlation.

In Ghatail-I profile, pH in top soils upto 13 cm was 5.50 to 6.65 (i.e strongly acid to slightly acidic) which increased significantly ($r=-.691^{*}$) of depth reaching mildly alkaline condition.

Calcium carbonate

The CaCO_3 plays a great role in determining the base status, pH, total soluble salts and drainage condition of soils. The presence of CaCO_3 provides an insight status and past climate of soils.

The Gangetic soils being calcareous in nature contained high CaCO_3 (1.4 to 13.0 percent), while Brahmaputra alluvium as a non-calcareous one ranged nil to 2.9% (Table-9). In Sara-NI of Gangetic soils CaCO_3 was observed throughout the profile and found to increase significantly ($r=.850^{*}$) with the increase of depth. But in other profiles it was registered irregular. The higher amounts of CaCO_3 in Sara-NI and Sara-I may be due to high land ridge topographical position where CaCO_3 accumulates through capillary rise, in addition to higher accounts of silts. On the other hand, Pakuria-NI and Ghior-I soils are saturated or inundated for more periods causing leaching loss of CaCO_3 .

Table 9. Some chemical properties of the studied soils.

Soil Series	Horizon	Depth (cm)	pH (water)	pH (1N KCl)	Δ pH	Ca Co ₃ %	Ec μs/cm
GANGES ALLUVIUM SARA, (Non-irrigated)	AP ₁	0-11	7.98	7.25	-0.73	5.1	385
	AP ₂	11-13	8.00	7.27	-0.73	5.6	185
	B _{2w}	13-26	8.10	7.20	-0.90	6.2	143
	B _{3w}	26-41	8.20	7.34	-0.86	9.4	140
	C ₁	41-57	8.18	7.50	-0.68	13.2	100
	C ₂	57-95	8.28	7.70	-0.58	11.6	102
SARA, (Irrigated)	AP _{1g}	0-11	8.05	7.25	-0.80	8.6	321
	AP _{2g}	11-15	8.25	7.32	-0.93	6.8	182
	B _{21w}	15-33	8.44	7.45	-0.99	10.9	117
	B _{22w}	33-50	8.35	7.34	-1.01	9.7	158
	B _{23w}	50-59	8.41	7.50	-0.91	9.3	109
	B ₃	59-84	8.40	7.40	-1.00	8.7	138
	C ₁	84-97	8.40	7.50	-0.90	8.9	106
	C ₂	97-105	8.41	7.40	-1.01	9.6	128
	C ₃	105-123	8.40	7.52	-0.88	12.5	115
	C ₄	123-148	8.28	7.28	-1.00	8.3	104
	C ₅	148-180	8.28	7.22	-1.06	5.6	146
PAKURIA, (Non-irrigated)	AP _{1g}	0-13	7.85	7.25	-0.60	4.6	302
	AP ₂	13-17	7.98	7.20	-0.78	3.3	203
	B _{21w}	17-29	8.12	7.24	-0.88	6.2	192
	B _{22w}	29-42	8.20	7.20	-1.00	7.0	173
	B _{23w}	42-59	8.24	7.29	-0.95	10.5	168
	B ₃	59-83	8.28	7.29	-0.99	9.3	169
	C ₁	83-108	8.25	7.30	-0.95	10.5	168
	C ₂	108-146	7.55	6.84	-0.71	1.8	130
	C ₃	146-181	7.65	6.91	-0.74	2.8	125
GHIOR, (Irrigated)	AP _{1g}	0-15	7.65	6.85	-0.80	1.3	218
	AP _{2g}	15-20	7.72	6.85	-0.87	1.5	200
	B _{21wg}	20-32	8.20	7.20	-1.00	8.5	158
	B _{22wg}	32-57	8.10	7.19	-0.91	5.7	160
	B ₃	57-76	7.06	6.70	-0.36	1.4	190
	C _{1g}	76-96	7.22	6.75	-0.47	1.7	180
	C _{2g}	96-140	7.20	6.75	-0.45	1.5	160

Table 9 (Contd.)

Soil Series	Horizon	Depth (cm)	pH (water)	pH (1n KCl)	Δ pH*	CaCO ₃ %	Ec μ s/cm
BRAHMAPUTRA ALLUVIUM SONATALA, (Non-irrigated)	AP ₁	0-11	5.10	4.44	-0.66	*-	95
	AP ₂	11-14	6.65	5.48	-1.17	-	72
	B _{21w}	14-35	6.75	5.30	-1.45	-	39
	B _{22w}	35-50	6.86	5.30	-1.56	-	47
	B _{23w}	50-74	7.05	5.47	-1.58	-	55
	AP _{1bg}	74-100	6.77	5.32	-1.45	-	55
	C _{1g}	100-130	6.75	5.22	-1.53	0.9	60
	C ₂	130-165	6.96	5.37	-1.59	2.9	39
SONATALA, (Irrigated)	AP _{1g}	0-10	7.24	6.70	-0.54	2.2	181
	AP _{2g}	10-15	7.34	6.30	-1.04	2.2	92
	B _{2w}	15-31	7.42	6.30	-1.12	2.4	80
	IIB _{21w}	31-51	7.30	6.24	-1.06	2.7	76
	B _{22wg}	51-78	7.05	5.69	-1.36	1.3	63
	B _{23g}	78-108	7.25	5.70	-1.55	1.0	57
	C ₁	108-130	7.20	5.57	-1.63	1.5	60
	C ₂	130-140	7.18	5.50	-1.68	0.4	59
	C ₃	140-200	7.15	5.48	-1.67	0.4	46
GHATAIL, (Non-irrigated)	AP _{1g}	0-10	4.65	4.02	-0.63	-	238
	AP _{2g}	10-13	5.20	4.61	-0.59	-	250
	B _{21wg}	13-20	6.45	5.56	-0.89	-	123
	B _{22wg}	20-39	7.00	5.85	-1.15	0.7	107
	B _{23wg}	39-48	7.30	5.90	-1.40	0.7	80
	B _{24w}	48-66	7.25	5.85	-1.40	0.2	90
	B _{25w}	66-79	7.04	5.71	-1.33	0.7	91
	B ₃	79-96	7.05	5.66	-1.39	-	78
	C ₁	91-111	7.20	5.77	-1.43	0.7	68
	C ₂	111-135	7.30	5.76	-1.54	2.0	83
	C ₃	135-160	7.30	5.71	-1.59	0.0	78
	C ₄	160-200	7.42	5.71	-1.71	-	58
GHATAIL, (Irrigated)	AP _{1g}	0-9	5.50	4.35	-1.15	-	100
	AP _{2g}	9-13	6.35	5.58	-0.77	-	115
	B _{21wg}	13-38	7.57	6.46	-1.11	-	100
	B _{22wg}	38-56	7.65	6.32	-1.33	1.4	92
	B ₃	56-76	7.79	6.30	-1.49	1.8	65
	C ₁	76-88	7.80	6.35	-1.45	2.0	60
	IIC ₂	88-160	7.73	6.10	-1.63	0.7	60

* - = Not found, * Δ pH = (pH_{KCl} - pH_{H2O}).

Calcium carbonate was found absent upto 100 cm of Sonatala-NI but was upto 2% in the lowest layers due to accumulation from the overlying layers. It ranged from 0.4 to 2.4 percent in Sonatala-I profile which increased upto 51cm depth due to vertical leaching and then decreased significantly with depth ($r=-.873^{**}$) (Appendix-I).

In Ghatail-NI and Ghatail-I CaCO_3 was found absent in the upper layers but in the lower layers it was observed in low amounts in an irregular pattern due to vertical leaching from overlying to the underlying horizons.

Electrical conductivity (Ec)

Electrical conductivity (Table-9) in Ganges and Brahmaputra alluvium ranged from 39 to 385 $\mu\text{s}/\text{cm}$ which is non detrimental level for crop. Ganges alluvium showed more EC than Brahmaputra alluvium due to higher electrolytic elements in soils.

Redox-potential (Eh)

Redox potential status reflects the oxidizing and reducing conditions of soils and helps in predicting drainage condition as well as morphological situation specially soil colour.

According to Patrick *et al* (1968) Redox-potential (Table-10) was found moderately reduced throughout the profiles of Sara-NI, Pakuria-NI, Sonatala-NI, Sonatala-I and Ghatail-NI, while in Sara-I, Ghior-I and Ghatail-I it was ranked at reduced level at the surface and then increased gradually upto moderately reduced level. Exception was in topsoil of Ghatail-NI where Eh was in oxidized state.

Eh in reduced level at surface horizon of Sara-I, Ghior-I and Ghatail-I was caused by prolonged saturation of soils through irrigation. The results are in fine agreement with the hypothesis of Ponnampetuma (1985) and Ghildyal (1987) who reported that in general, soils Eh decreases with increasing pH.

It was observed that Eh increased significantly (Appendix-I) at 1 percent level in Sara-I ($r=.799^{**}$) and Ghior-I ($r=.826^{**}$), while in Sonatala-I it increased significantly at 5 percent level ($r=.672^{*}$) with the increase of depth due to more oxidized condition in the underlying layers. It was also revealed that Eh in Ghatail-NI decreased significantly at 5 percent level ($r=-.560^{*}$) with the increase of depth due to ground water saturation in the underlying horizons.

In most cases it was found that Eh increased with the decrease of organic matter in soils. In Sara-I and Ghior-I the increase of Eh correlated significantly at 1 percent level with the decrease of organic matter ($r=-.852^{**}$ and $r=-.84^{**}$, Appendix-I), while it was found at 5% level in Ghatail-I ($r=-.79^{*}$). In case of Ghatail-NI the decrease of Eh correlated significantly at 1 percent level with the increase of organic matter ($r=.671^{**}$). Ponnampuruma (1985) reported that the presence of organic matter favour decrease in Eh.

However, the irrigated soils were found to have relatively low Eh than those of non-irrigated soils in agreement with Alberda (1953) and Aomine (1962).

Organic carbon

The organic carbon content reflects the effect of vegetation in soil genesis.

Results presented in Table-10 was found to indicate that all the profiles contained higher amounts of organic carbon in surfaces than lower horizons (Fig.1a-b). The decrease in organic matter with depth was highly significant in Sara-NI, Pakuria-NI, Ghatail-NI and Ghatail-I, while in Sara-I, Ghior-I, Sonatala-NI and Sonatala-I it decreased significantly with depth (Appendix-I). Similar results were recorded by SRDI Staff (1970 and 1974-75).

The higher amounts of organic carbon in surface layers might be due to maximum root activity, high activity of biomass as well as natural and artificial additions of fresh or partly decomposed organic matter in the form of manure and crop residues. Irregular pattern of organic carbon distribution in lower layers of some profiles was observed with alluvial nature of soils showing deposition of soil mantle at different times.

Table 10. Physico-chemical properties of the studied soils

Soil Series	Horizon	Depth (cm)	Eh (mv)	Organic carbon %	Organic matter %	Total-N %	C/N ratio	Ferrous iron (ppm)
GANGES ALLUVIUM SARA, (Non-irrigated)	AP ₁	0-11	254	0.82	1.41	0.086	9.5	11
	AP ₂	11-13	250	0.66	1.14	0.074	8.9	5
	B _{2w}	13-26	255	0.43	0.74	0.055	7.8	2
	B _{3w}	26-41	263	0.27	0.46	0.043	6.2	2
	C ₁	41-57	250	0.19	0.34	0.025	7.8	1
	C ₂	57-95	249	0.12	0.21	0.017	7.1	17
SARA, (Irrigated)	AP _{1g}	0-11	100	0.90	1.55	0.110	8.2	41
	AP _{2g}	11-15	105	0.43	0.74	0.062	6.9	38
	B _{21w}	15-33	180	0.27	0.46	0.025	10.8	10
	B _{22w}	33-50	240	0.19	0.34	0.021	9.0	5
	B _{23w}	50-59	239	0.19	0.34	0.018	10.8	4
	B ₃	59-84	254	0.23	0.40	0.031	7.4	7
	C ₁	84-97	228	0.27	0.46	0.018	15.0	10
	C ₂	97-105	250	0.16	0.28	0.025	6.4	6
	C ₃	105-123	251	0.16	0.28	0.025	6.4	3
	C ₄	123-148	255	0.19	0.34	0.025	7.8	4
	C ₅	148-180	269	0.16	0.27	0.026	6.1	10
PAKURIA, (Non-irrigated)	AP _{1g}	0-13	263	0.70	1.21	0.099	7.1	75
	AP ₂	13-17	260	0.43	0.74	0.065	6.6	47
	B _{21w}	17-29	265	0.45	0.77	0.074	6.1	29
	B _{22w}	29-42	216	0.43	0.74	0.043	10.0	15
	B _{23w}	42-59	230	0.16	0.44	0.037	7.0	13
	B ₃	59-83	241	0.27	0.47	0.037	7.3	10
	C ₁	83-108	237	0.23	0.40	0.031	7.4	7
	C ₂	108-146	243	0.23	0.40	0.023	10.0	9
	C ₃	146-180	240	0.16	0.27	0.018	8.9	20
GHIOR, (Irrigated)	AP _{1g}	0-15	59	1.13	2.23	0.122	9.3	323
	AP _{2g}	15-20	46	0.82	1.41	0.105	7.8	330
	B _{21wg}	20-32	176	0.95	1.63	0.080	11.9	150
	B _{22wg}	32-57	210	0.47	0.80	0.043	10.9	15
	B ₃	57-76	233	0.35	0.62	0.043	8.1	9
	C _{1g}	76-97	247	0.31	0.53	0.046	6.7	7
	C _{2g}	97-140	245	0.39	0.67	0.046	8.5	14

Table 10 (Contd.)

Soil Series	Horizon	Depth in (cm)	Eh (mv)	Organic carbon %	Organic matter %	Total-N %	C/N ratio	Ferrous iron (ppm)
BRAHMAPUTRA ALLUVIUM	AP ₁	0-11	300	0.90	1.55	0.09	10.0	21
	AP ₂	11-14	285	0.50	0.86	0.055	10.0	12
	B _{21w}	14-35	276	0.25	0.60	0.043	8.1	12
	B _{22w}	35-50	304	0.32	0.63	0.055	6.7	12
	B _{23w}	50-74	302	0.34	0.58	0.043	7.9	15
	AP _{1bg}	74-100	300	0.27	0.58	0.037	7.3	8
	C _{1g}	100-130	298	0.27	0.46	0.049	5.5	9
	C ₂	130-165	308	0.27	0.46	0.029	9.3	12
SONATALA, (Irrigated)	AP _{1g}	0-10	214	0.90	1.55	0.100	9.0	36
	AP _{2g}	10-15	117	0.43	0.74	0.068	6.3	31
	B _{2w}	15-31	220	0.35	0.60	0.065	5.4	18
	IIB _{21w}	31-51	254	0.43	0.74	0.066	6.5	12
	B _{22wg}	51-78	270	0.38	0.65	0.061	6.2	8
	B _{23g}	78-108	289	0.39	0.67	0.062	6.3	9
	C ₁	108-130	300	0.27	0.46	0.043	6.3	10
	C ₂	130-140	270	0.23	0.40	0.043	5.3	10
	C ₃	140-200	265	0.27	0.46	0.025	10.1	11
GHATAIL, (Non-irrigated)	AP _{1g}	0-10	425	1.48	2.54	0.16	9.2	12
	AP _{2g}	10-13	380	0.90	1.54	0.108	8.3	10
	B _{21wg}	13-20	312	0.74	1.27	0.092	8.0	9
	B _{22wg}	20-39	300	0.82	1.41	0.102	8.0	10
	B _{23wg}	39-48	300	0.39	0.67	0.058	6.7	8
	B _{24w}	48-66	315	0.42	0.72	0.062	6.8	5
	B _{25w}	66-79	299	0.54	1.01	0.086	6.9	9
	B ₃	79-96	266	0.62	1.06	0.072	8.6	5
	C ₁	96-111	270	0.45	1.01	0.067	8.8	8
	C ₂	111-135	246	0.71	1.22	0.080	8.9	13
	C ₃	135-160	300	0.27	0.46	0.043	6.3	34
	C ₄	160-200	300	0.23	0.39	0.032	7.2	30
GHATAIL, (Irrigated)	AP _{1g}	0-9	80	1.25	2.15	0.136	9.2	28
	AP _{2g}	9-13	120	0.86	1.48	0.111	7.7	35
	B _{21wg}	13-38	282	0.66	1.13	0.077	8.6	25
	B _{22wg}	38-56	230	0.47	0.81	0.049	9.6	23
	B ₃	56-76	220	0.195	0.33	0.049	4.0	10
	C ₁	76-88	247	0.23	0.39	0.037	6.2	12
	IIC ₂	88-160	250	0.16	0.27	0.025	6.4	15

Fig.1a Distribution of organic carbon and total nitrogen in the studied profiles

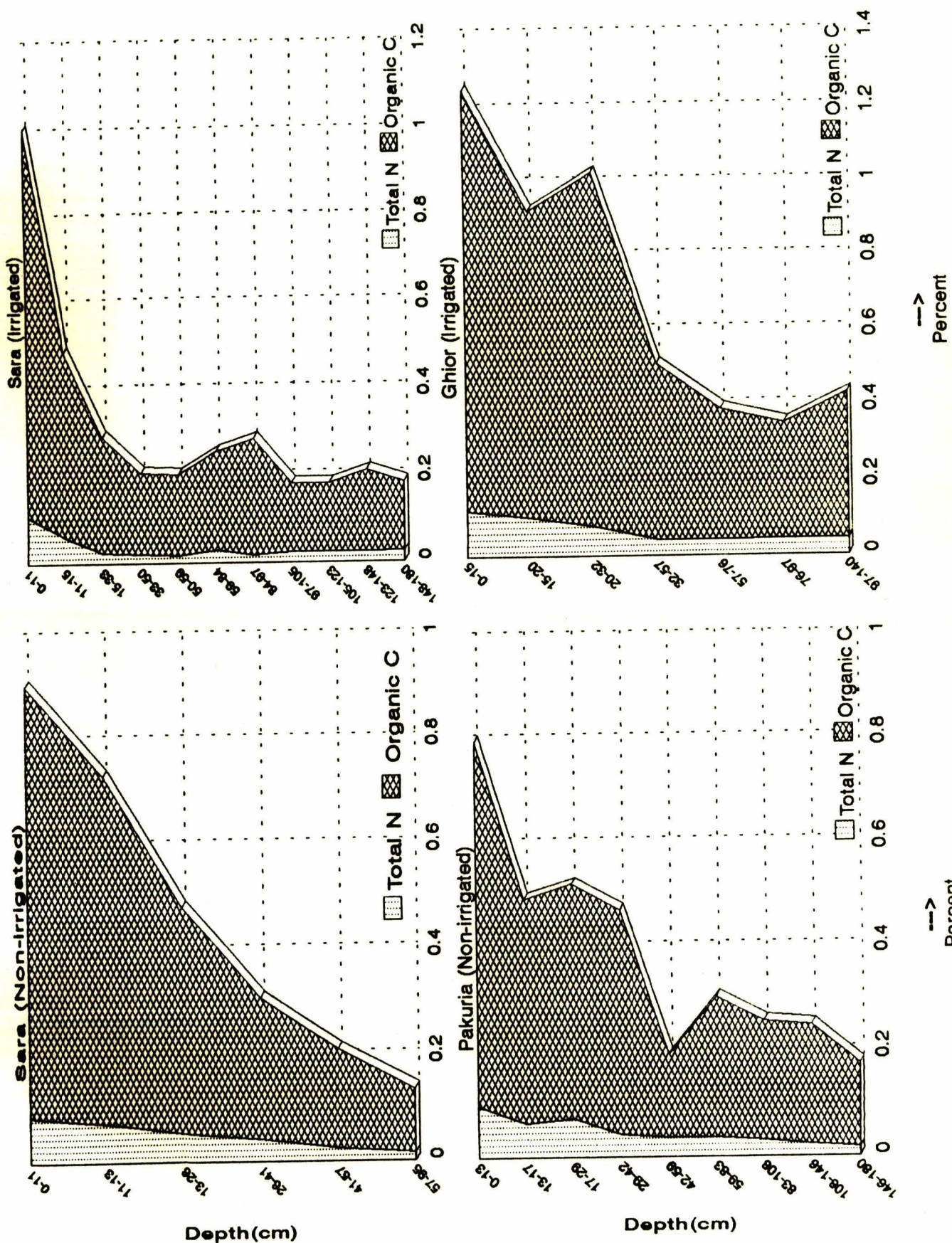
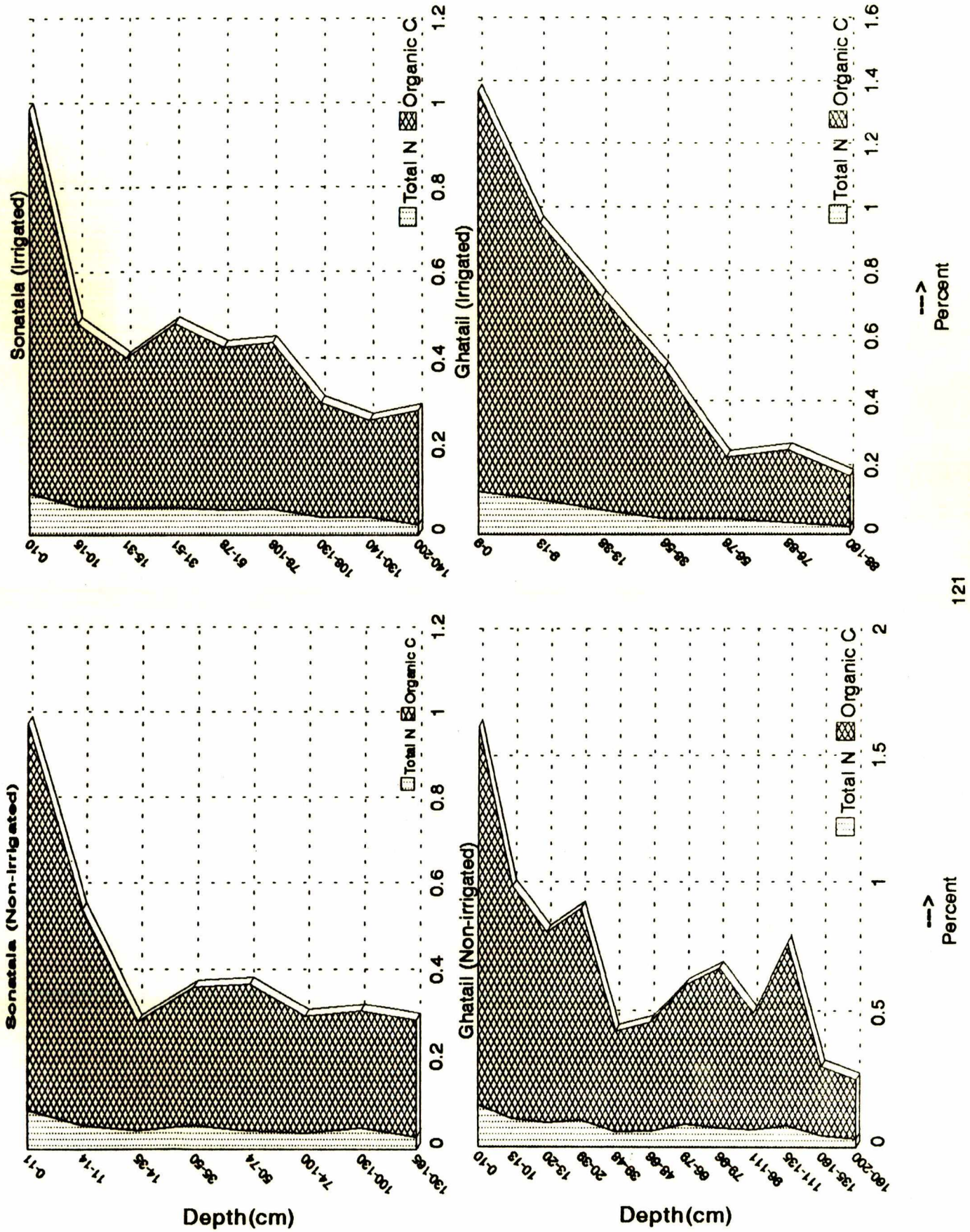


Fig.1.b Distribution of organic carbon and total nitrogen in the studied profiles



Ferrous iron (Fe^{++})

Ferrous iron play an important role in pedogenic processes through physical, chemical and electro-chemical influences on soils.

The results recorded in Table-10 was found to indicate that Ferrous iron decreased with the increase of depth in most of the profiles but in Ghatail-NI it reversed significantly. In Sara-NI, ferrous iron decreased with the increase of depth upto 57 cm but below this depth it increased. The decrease of ferrous iron with the increase of depth was found significant in Sara-I, Pakuria-NI, Ghior-I, Sonatala-I and Ghatail-I (Appendix-I). Ferrous iron was highest in Ghior - I (330 ppm), while it was lowest in Sara-NI (1.0 ppm)

It was observed that almost all profiles contained higher conc. of ferrous iron in surface due to reduction of iron oxides as their surface horizon are flooded for rice cultivation for some part of the year but in Ghatail-NI Fe^{++} was found higher in the lowest layers due to ground water inundation. Ottow (1973) reported that in waterlogged rice soils Fe (II) ions are formed by reducing ferric oxides by different heterotrophic organisms. However, the irrigated soils contained relatively more Fe^{++} than the non-irrigated soils and it was found that the Fe^{++} conc. varied with the intensity & time of submergence of soil.

Total nitrogen

Nitrogen play an important role in soil fertility level as well as in soil genesis and pedogenesis. The results registered in Table-10 indicate that all profiles contained higher amounts of total nitrogen in their surface horizon than the underlying horizons in association with addition of crop residues, green manures and composts etc. It was revealed that total nitrogen decreased with the increase of depth and significantly correlated at 1 percent level in Sara-NI, Pakuria-NI, Sonatala-I, Ghatail-NI and Ghatail-I, while in Sara-I, Ghior-I and Sonatala-NI it decreased significantly with depth at 5 percent level (Appendix-I).

It was also observed that the soils like Ghatail and Ghior occupying the lower position of the landscape contained relatively higher amounts of total nitrogen in their surface horizon than other profiles due to accumulation and decomposition of more crop residues and manures.

Available Nutrients

Available nutrients like nitrogen, phosphorous and sulphur play a vital role in fertility status of soil as well as soil management.

Available nitrogen

Result presented in Table-11 indicate that available nitrogen ranged from 70 to 230 ppm in Gangetic soils, while it ranged from 70 to 290 ppm in Brahmaputra alluvium soils. All profiles contained higher amounts of available nitrogen in their surface horizon due to addition of crop residues, green manures and composts etc.

However available nitrogen was found to decrease significantly at 1 percent level (Appendix-I) with the increase of depth in all the studied profiles.

Available phosphorous

Results recorded in Table-11 revealed that available phosphorous was generally 13 to 68 ppm in Gangetic soils, while in Brahmaputra alluvium soils it ranged from 1 to 20 ppm.

Almost all the profiles of Gangetic and Brahmaputra alluvium soils contained higher amounts of available phosphorous in their surface due to the addition of fertilizers and manures or easily mineralized organic p. Available p decreased with the increase of depth in all the studied profiles due to lack of plant residues in the underlying horizons. The results are in conformity with the report of Runge and Ricecken (1966).

Table 11. Available nitrogen, phosphorus and sulphur contents in the studied soils

Soil Series	Horizon	Depth (cm)	N (ppm)	P (ppm)	S (ppm)
GANGES ALLUVIUM SARA, (Non-Irrigated)	AP ₁	0-11	150	54	6.3
	AP ₂	11-13	130	26	7.6
	B _{2w}	13-26	120	27	36.3
	B _{3w}	26-41	110	20	12.5
	C ₁	41-57	100	19	12.3
	C ₂	57-95	090	21	10.2
SARA, (Irrigated)	AP _{1g}	0-11	170	68	8.4
	AP _{2g}	11-15	120	31	3.9
	B _{21w}	15-33	110	18	.*
	B _{22w}	33-5-	100	27	-
	B _{23w}	50-59	105	18	-
	B ₃	59-84	100	18	-
	C ₁	84-97	090	20	-
	C ₂	97-105	090	20	5.7
	C ₃	105-123	080	34	3.1
	C ₄	123-148	070	34	-
	C ₅	148-200	070	56	-
PAKURIA, (Non-Irrigated)	AP _{1g}	0-13	230	43	39.7
	AP ₂	13-17	140	33	2.4
	B _{21w}	17-29	150	27	0.6
	B _{22w}	29-42	140	25	-
	B _{23w}	42-59	110	23	-
	B ₃	59-83	100	20	0.6
	C ₁	83-108	100	20	-
	C ₂	108-146	105	16	60.0
	C ₃	146-181	100	15	34.2
GHIOR, (Irrigated)	AP _{1g}	0-15	140	59	16.0
	AP _{2g}	15-20	140	49	27.9
	B _{21wg}	20-32	130	44	27.1
	B _{22wg}	32-57	120	40	18.7
	B ₃	57-76	110	40	20.0
	C _{1g}	76-97	110	40	-
	C _{2g}	97-140	100	38	-

Table 11 (Contd.)

Soil Series	Horizon	Depth (cm)	N (ppm)	P (ppm)	S (ppm)
BRAHMAPUTRA ALLUVIUM SONATALA, (Non-irrigated)		0-11	140	14	1.3
	AP ₁	11-14	140	10	.*
	AP ₂	14-35	110	10	-
	B _{21w}	35-50	105	1	-
	B _{22w}	50-74	100	1	-
	B _{23w}	74-100	090	1	-
	AP _{1bg}	100-130	090	3	-
	C _{1g}	130-165	080	1	-
	C ₂				
SONATALA, (Irrigated)	AP _{1g}	0-10	140	15	12.6
	AP _{2g}	10-15	110	10	4.5
	B _{2w}	15-31	100	12	1.6
	IIB _{21w}	31-51	100	12	-
	B _{22wg}	51-78	090	2	-
	B _{23g}	78-108	090	1	-
	C ₁	108-130	080	3	-
	C ₂	130-140	080	2	-
	C ₃	140-200	070	2	-
GHATAIL, (Non-Irrigated)	AP _{1g}	0-10	290	12	24.5
	AP _{2g}	10-13	150	10	22.1
	B _{21wg}	13-20	140	12	0.8
	B _{22wg}	20-39	140	12	3.4
	B _{23wg}	39-48	140	15	-
	B _{24w}	48-66	140	5	-
	B _{25w}	66-79	120	1	-
	B ₃	79-96	110	1	-
	C ₁	96-111	100	2	-
	C ₂	111-135	100	1	-
	C ₃	135-160	090	3	1.3
	C ₄	160-200	080	3	-
GHATAIL, (Irrigated)	AP _{1g}	0-9	170	20	6.8
	AP _{2g}	9-13	130	12	4.5
	B _{21wg}	13-38	100	13	-
	B _{22wg}	38-56	095	2	14.2
	B ₃	56-76	090	4	-
	C ₁	76-88	080	1	-
	IIC ₂	88-160	080	7	-

.* = Not found

It was also observed that irrigated soils contained relatively higher amounts of available p than non-irrigated soils due to saturation or submergence for most part of the year (Ponnamperuma, 1985).

Available p decreased significantly at 1 percent level with the increase of depth in pakuria (NI), Sonatala-NI, Sonatala-I and Ghatal-I profiles and at 5 percent level in Ghior-I profile (Appendix-1).

Available sulphur

Available sulphur (Table-11) was nil to 60 ppm in Gangetic soils, while it ranged from nil to 24.5 ppm in Brahmaputra alluvium soils. Gangetic soils contained relatively higher amounts of available sulphur than Brahmaputra alluvium soils. It was also observed that the irrigated soils contained relatively low amounts of available sulphur of non-irrigated ones in conformity with the hypothesis of Neue and Mamaril (1985). They postulated that in anaerobic soils, the main change related to S is the reduction of So_4^{-2} to S-by obligate anaerobic bacteria. In neutral to alkaline soils concentration of So_4^{-2} as 1,500 ppm may be reduced to zero within some weeks of submergence.

Cation exchange capacity

The CEC is very important for predicating soil fertility level. It also plays a vital role in the pedogenic processes of soils.

The results (Table-12) were found to indicate that fine textured soils contain higher CEC than the medium textured soils due to higher clay contents (Table-6). The increase in CEC values with increasing clay contents in soils was also observed by Gupta and Misra (1970) and Pathak *et al.* (1980).

The CEC in Gangetic soils ranged from 8.70 to 40.20 me/100g, while in Brahmaputra alluvium soils CEC ranged from 8.95 to 40.21 me/100g. CEC was highest in

Ghior-I and Sonatala - N (40.2 me/100g) followed by Ghatail-NI and Ghatail-I, while it was lowest in Sara-NI profile (8.70 me/100g).

It was revealed that Gangetic soils in comparison with Brahmaputra alluvium soils contained higher CEC due to presence of swelling group of clays i.e smectite (Table-19). Thawale *et al.* (1991) found that the CEC of the soils of agricultural school farm sawangi ranged from 35.7 to 6.28 c mol(p+) k⁻¹ indicating montmorillonitic clay mineral.

However, the CEC was found to decrease significantly with the increase of depth in Sara -NI ($r=-.925^{**}$), Ghatail -NI ($r=.819^{*}$) and Ghatail - I ($r=-.708^{*}$) profiles, while it increased significantly with the increase of depth in Sara -I ($r=.601^{*}$) and Sonatala -NI ($r=.708^{*}$) (Appendix-II). In other profiles CEC was found irregular due to variation in clay contents as these soils were developed from alluvial deposits at different times.

Exchangeable Cations

Results on exchangeable cations such as Na⁺, K⁺, Ca⁺⁺, Mg⁺⁺ and H⁺, presented in Table-12 are discussed below:

Sodium

Exchangeable Na⁺ ranged from 0.43 to 1.30 me/100g in Gangetic soils, while in Brahmaputra alluvium soils, it contained from 0.43 to 1.22 me/100g. Highest conc. of Na⁺ was present in the surface horizon of Sara-I (1.30 me/100g), while this was minimum in the lowest layer of Sara-NI and Pakuria-NI due to low weathering from overlying horizons.

Sodium conc. within individual profile was highest at B_{2w}, Ap_{1g}, Ap_{1g}, B_{21wg}, C_{1g}, IIB_{21wg}, B_{22wg} and Ap_{2g} of Sara-NI, Sara-I, Pakuria-NI, Ghior-I, Sonatala-NI, Sonatala-I, Ghatail-NI and Ghatail-I profiles respectively. The high conc. of Na⁺ in subsoils and C horizons may be attributed to leaching from the overlying horizons, while high conc. in the surface layer may be ascribed to lack of weathering loss. It was also observed that Na⁺

illuviated mostly in such layers which contained higher amounts of clay (Table-6) and leaching loss was comparatively slower in such layers. Janzen (1962) reported that exchangeable Na^+ is low in upper horizon and high in lower horizons.

However, Na^+ was found to decrease significantly at 1 percent level with the increase of depth in Pakuria-NI and Ghatail-I, while it reversed in Sonatala-NI and Sonatala-I at 1 Percent level (Appendix-II).

Table 12. Cation exchange capacity and exchangeable cations in the studied soils

Soil Series	Horizon	Depth (cm)	meq/100g soil								BSP
			CEC	Na^+	K^+	Ca^{++}	Mg^{++}	H +	TEB	T E C	
GANGES ALLUVIUM SARA, (Non-irrigated)	AP ₁	0-11	18.20	0.54	0.38	15.03	2.25	-	18.20	-	100
	AP ₂	11-13	19.06	0.54	0.38	15.41	2.18	-	18.50	-	97
	B _{2w}	13-26	14.26	0.65	0.38	16.77	2.72	-	20.50	-	>100
	B _{3w}	26-41	13.50	0.50	0.32	15.32	2.04	-	18.18	-	>100
	C ₁	41-57	9.60	0.43	0.10	12.80	1.90	-	15.20	-	>100
	C ₂	57-95	8.70	0.43	0.13	13.15	1.51	-	15.20	-	>100
SARA, (Irrigated)	AP _{1g}	0-11	15.70	1.30	0.32	7.58	2.18	-	11.38	-	72
	AP _{2g}	11-15	13.60	0.87	0.26	10.44	1.93	-	13.50	-	99
	B _{21w}	15-33	12.07	0.65	0.13	10.30	0.63	-	11.71	-	97
	B _{22w}	33-50	11.60	0.87	0.26	9.00	1.25	-	11.38	-	98
	B _{23w}	50-59	9.70	0.65	0.17	6.69	2.14	-	09.65	-	>100
	B ₃	59-84	13.20	0.76	0.32	9.58	2.39	-	13.05	-	>100
	C ₁	84-97	9.50	0.54	0.17	6.87	1.82	-	09.40	-	99
	C ₂	97-105	13.50	0.65	0.32	12.47	2.68	-	16.12	-	>100
	C ₃	105-123	11.40	0.54	0.19	8.46	1.81	-	11.00	-	96
	C ₄	123-148	17.20	0.54	0.17	12.14	1.56	-	14.41	-	83
	C ₅	148-200	26.15	0.87	0.51	26.26	2.58	-	30.22	-	>100
PAKURIA, (Non-irrigated)	AP _{1g}	0-13	27.10	0.87	0.74	12.29	4.29	-	18.19	-	67
	AP ₂	13-17	30.05	0.73	0.69	8.53	2.50	-	12.45	-	41
	B _{21w}	17-29	28.20	0.87	0.64	7.23	1.48	-	10.22	-	36
	B _{22w}	29-42	22.10	0.76	0.73	16.68	3.83	-	22.0	-	100
	B _{23w}	42-59	18.20	0.65	0.68	13.17	3.60	-	18.10	-	99
	B ₃	59-83	25.10	0.65	0.36	19.96	3.21	-	24.18	-	96
	C ₁	83-108	26.20	0.76	0.36	20.34	4.54	-	26.00	-	99
	C ₂	108-146	27.50	0.65	0.38	23.45	2.44	-	26.92	-	98
	C ₃	146-181	24.20	0.43	0.13	10.11	1.00	-	11.67	-	48
GHIOR, (Irrigated)	AP _{1g}	0-15	32.12	0.76	0.40	10.26	2.57	-	13.99	-	44
	AP _{2g}	15-20	40.20	0.87	0.84	6.49	3.50	-	11.70	-	29
	B _{21wg}	20-32	33.20	0.76	0.74	9.98	2.47	-	13.95	-	42
	B _{22wg}	32-57	28.15	0.98	0.70	8.58	2.82	-	13.00	-	46
	B ₃	57-76	37.20	0.87	0.58	10.33	2.53	-	14.31	-	38
	C _{1g}	76-97	40.20	0.87	0.90	10.85	4.07	-	16.69	-	42
	C _{2g}	97-140	39.80	0.87	0.90	10.83	3.46	-	16.06	-	40

Table 12 (Contd.)

Soil Series	Horizon	Depth (cm)	meq/100g soil								BSP
			CEC	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	H ⁺	TEB	TEC	
BRAHMAPUTRA ALLUVIUM SONATALA, (Non-irrigated)	AP ₁	0-11	12.12	0.70	0.26	2.43	0.92	3.96	4.31	8.27	36
	AP ₂	11-14	13.21	0.78	0.18	1.95	1.48	1.76	4.39	6.15	33
	B _{21w}	14-35	9.65	0.52	0.10	2.54	2.00	1.10	5.16	6.26	53
	B _{22w}	35-50	8.95	0.61	0.13	1.50	1.63	0.60	3.87	4.47	43
	B _{23w}	50-74	14.20	0.70	0.23	2.50	1.48	-	4.91	-	35
	AP _{1bg}	74-100	34.20	1.04	0.41	4.63	3.64	-	9.72	-	28
	C _{1g}	100-130	40.21	1.22	0.23	4.05	2.76	-	8.26	-	21
	C ₂	130-165	22.30	1.20	0.15	3.76	2.28	-	7.39	-	33
SONATALA, (Irrigated)	AP _{1g}	0-10	14.20	0.78	0.10	2.89	1.60	-	5.39	-	38
	AP _{2g}	10-15	13.12	0.87	0.05	1.74	1.15	-	3.81	-	29
	B _{2w}	15-31	12.85	0.96	0.13	2.60	1.73	-	5.29	-	41
	IIB _{21w}	31-51	24.20	1.22	0.20	3.12	2.30	-	6.85	-	28
	B _{22wg}	51-78	23.80	0.96	0.15	3.47	3.62	-	8.20	-	34
	B _{23g}	78-108	24.20	0.87	0.10	2.45	2.39	-	5.81	-	24
	C ₁	108-130	16.15	0.78	0.08	2.59	2.63	-	6.08	-	38
	C ₂	130-140	14.37	0.78	0.10	1.27	2.50	-	4.65	-	32
	C ₃	140-200	10.20	0.61	0.05	1.20	2.26	-	4.12	-	40
GHATAIL, (Non-irrigated)	AP _{1g}	0-10	29.70	0.52	0.26	1.45	1.88	4.0	4.11	8.11	14
	AP _{2g}	10-13	33.00	0.52	0.18	2.02	1.45	3.8	4.17	7.97	13
	B _{21wg}	13-20	33.70	0.43	0.15	2.89	1.48	1.6	4.95	6.55	15
	B _{22wg}	20-39	38.12	0.70	0.20	3.00	1.15	-	5.05	-	13
	B _{23wg}	39-48	34.80	0.61	0.28	4.05	2.24	-	7.18	-	21
	B _{24w}	48-66	26.20	0.52	0.28	2.32	1.64	-	4.76	-	18
	B _{25w}	66-79	34.12	0.73	0.41	3.76	2.32	-	7.22	-	21
	B ₃	79-96	32.20	0.52	0.28	2.77	1.42	-	5.02	-	16
	C ₁	96-111	28.17	0.52	0.23	4.05	3.00	-	7.80	-	28
	C ₂	111-135	22.42	0.61	0.13	5.31	3.54	-	9.41	-	42
	C ₃	135-160	20.05	0.52	0.10	1.73	3.76	-	6.11	-	30
	C ₄	160-200	16.32	0.52	0.08	4.33	3.00	-	7.93	-	49
GHATAIL, (Irrigated)	AP _{1g}	0-9	26.72	0.78	0.15	4.62	2.31	3.2	7.86	10.8	29
	AP _{2g}	9-13	25.05	0.91	0.15	4.39	2.25	1.5	7.70	09.2	31
	B _{21wg}	13-38	33.20	0.78	0.10	2.49	2.18	-	5.55	-	17
	B _{22wg}	38-56	34.80	0.87	0.13	7.51	3.63	-	12.14	-	35
	B ₃	56-76	28.17	0.70	0.10	3.64	2.30	-	6.74	-	24
	C ₁	76-88	23.21	0.70	0.08	2.60	2.08	-	5.46	-	24
	IIC ₂	88-160	10.82	0.61	0.05	3.82	1.68	-	6.16	-	57

Potassium

Exchangeable potassium ranged from 0.13 to 0.90 (me/100g) in Gangetic soils, while in Brahmaputra alluvium soils it ranged from 0.05 to 0.41 me/100g.

The results indicated that Sara-NI, Pakuria-NI and Ghatail-I contained higher K⁺ in their surface horizon than the underlying horizons due to the action of plant roots in

transporting K^+ to the surface (Black, 1968) and addition of organic matter and presence of crop residues. While in Sara-I, Ghior-I, Sonatala-NI, Sonatala-I and Ghatail-NI highest conc. of K^+ was observed in the subsurface and substratum at C_5 , C_{1g} , Ap_{1bg} II B_{21w} and B_{25w} by illuviation processes (Kansal and Sekhon, 1976).

k^+ decreased significantly at 1 percent level with the increase of depth in Sara -NI ($r=-.87^{**}$), Pakuria -NI ($r=-.93^{**}$) and Ghatail -I ($r=-.93^{**}$) (Appendix-II).

Calcium

Exchangeable calcium contents in the Gangetic alluvium soils ranged from 6.69 to 26.26 me/100g, while it ranged from 1.2 to 7.5 me/100g in the soils of Brahmaputra alluvium.

From the results it was observed that all profiles contained lower amounts of Ca^{++} in their surface due to leaching. On the other hand, maximum amounts in B or C horizon was due to illuviation. Ca^{++} increased significantly at 1 percent level in Sara -I ($r=.698^{**}$) and at 5% level in Sonatala -NI ($r=.753^*$) with the increase of depth, due to weathering, while in Sara-NI and Sonatala-I it reversed significantly ($r=-.73^*$ and $r=-.584^*$ respectively) (Appendix-II) due to lack of weathering or leaching. In other profiles, Ca^{++} increased irregularly with the increase of depth due to their development by sediment deposition at different times. In addition, it was revealed that high clay contents slowed down the leaching process.

The higher amounts of Ca^{++} in Gangetic soils compared to Brahmaputra alluvium soils may be attributed to free lime contents in Ganges alluvium.

Magnesium

The results indicated that Gangetic alluvium soils contained relatively more Mg^{++} (0.63 to 4.54 me/100g) than Brahmaputra alluvium soils (0.92 to 3.76 me/100g). It was observed that maximum amounts of Mg^{++} was found in the B or C horizons in almost all profiles due to leaching loss from the overlying horizons. Which was subsequently illuviated in the underlying horizons.

However, it was observed that Mg^{++} increased with the increase of depth which was highly significant in Ghatail -NI ($r=.79^{**}$) and significant in Sonatala -NI ($r=.653^{*}$) profiles, while it reversed significantly in Sara -NI ($r=-.799^{*}$) (Appendix-II). Magnesium in other profiles increased irregularly with depth, linked with their alluvial nature.

Hydrogen (H^{+})

Exchangeable hydrogen was not found in all soils of Gangetic alluvium due to high pH as they were inherently calcareous & contained free $CaCO_3$.

In Brahmaputra alluvium soils, H^{+} was observed in some upper layers of Sonatala-NI, Ghatail-NI and Ghatail-I profiles causing low pH. It was also revealed that the contents of exchangeable H^{+} greatly varied with pH values.

Total exchangeable bases (TEB)

Total exchangeable bases (Table-12) were 9.40 to 30, 22 me/100g in Gangetic alluvium soils, while it ranged from 3.87 to 12.14 me/100g in Brahmaputra alluvium soils. The higher TEB in Gangetic soils may be related to such high Ca^{++} contents. In soils TEB increased significantly with the increase of depth in irrigated profiles like Sara -I ($r=.596^{*}$) and Ghior -I ($r=.781^{*}$), Sonatala -NI ($r=.746^{*}$) and Ghatail -NI ($r=.693^{**}$) (Appendix-II) due to more weathering or leaching, while it reversed in non-irrigated Sara due to lack of weathering.

TEB in Brahmaputra alluvium soils was higher in subsoils of irrigated soils like Sonatala-I and Ghatail-I due to leaching from overlying horizons, while this was higher in C horizons of non-irrigated Sonatala and Ghatail profiles due to weathering.

Base saturation percentage (BSP)

Base saturation percentage of soils are very important for predicting the soil genesis and pedogenesis as well as their weathering.

In Gangetic alluvium soils, BSP (Table-12) ranged from 29 to >100 per cent, while in Brahmaputra alluvium soils it ranged from 13 to 57 per cent. BSP was found higher in

Gangetic alluvium soils due to higher contents of bases specially Ca^{++} . BSP was found higher in the underlying subsoils or substratum due to leaching of bases from the overlying layers.

N/10 HCL Extractable Micronutrients

Micronutrient status is an important parameter for predicting the nature of parent material and degree of weathering as well as the pedogenic factors.

The results presented in Table-13 represent N/10 Hcl extractable Fe, Mn, Zn and Cu.

Iron

Fe ranged from 20 to 50 ppm in Gangetic alluvium soils, while it ranged from 20 to 65 ppm in Brahmaputra alluvium soils.

Results indicated that Sara-NI and Sara-I contained lower exchangeable Fe due to high CaCO_3 contents, while Pakuria-NI and Ghior-I contained relatively higher amounts of ex. Fe due to low contents of calcium carbonate.

Brahmaputra alluvium soils contained relatively more iron than those of Gangetic soils due to low pH (Table-9). It was also revealed that iron increased significantly at 1 percent level (Appendix-II) with the increase of depth in all the studied profiles due to free drainage condition in the underlying layers. The results are in well agreement with Granick (1959)' Katyal (1977) was found Fe deficiency symptoms in rice in calcareous soils with about 2 mg Fe^{2+} /litre in the soil solution.

Manganese

Exchangeable Mn ranged from 1 to 10 ppm in Gangetic alluvium soils, while in Brahmaputra alluvium soils it ranged from 4 to 12 ppm.

Mn decreased significantly with the increase of depth in Ghior-I ($r=-.74^*$) and Sonatala-NI ($r=-.658^*$), while, it increased significantly at 1 percent level with depth in Sonatala-I ($r=.98^{**}$), Ghatail-NI ($r=.915^{**}$) and Ghatail-I ($r=.881^{**}$) profiles (Appendix-II). Similar results were also noticed by Gupta and Shukla (1975).

Table 13. N/10 HCL extractable micronutrient contents in the studied soils.

Soil Series	Horizon	Depth (cm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
GANGES ALLUVIUM SARA, (Non-irrigated)	AP ₁	0-11	20	4	2	- *
	AP ₂	11-13	25	9	2	-
	B _{2w}	13-26	27	6	-	-
	B _{3w}	26-41	27	4	-	-
	C ₁	41-57	30	7	1	-
	C ₂	57-97	35	8	1	-
SARA, (Irrigated)	AP _{1g}	0-11	20	4	-	Tr
	AP _{2g}	11-15	22	7	-	Tr
	B _{21w}	15-33	25	5	-	Tr
	B _{22w}	33-50	26	3	-	Tr
	B _{23w}	50-59	30	6	-	Tr
	B ₃	59-84	30	3	-	-
	C ₁	84-97	32	5	-	-
	C ₂	97-105	35	2	-	-
	C ₃	105-123	38	4	-	-
	C ₄	123-148	40	6	-	-
	C ₅	148-180	40	2	-	-
PAKURIA, (Non-irrigated)	AP _{1g}	0-13	30	6	20	2
	AP ₂	13-17	37	5	3	-
	B _{21w}	17-29	38	5	-	-
	B _{22w}	29-42	39	5	-	-
	B _{23w}	42-59	40	1	-	-
	B ₃	59-83	41	2	-	-
	C ₁	83-108	42	2	-	-
	C ₂	108-146	45	4	-	-
	C ₃	146-181	50	5	-	-
GHIOR, (Irrigated)	AP _{1g}	0-15	20	10	5	4
	AP _{2g}	15-20	33	9	2	3
	B _{21wg}	20-32	40	8	2	2
	B _{22wg}	32-57	42	7	2	-
	B ₃	57-76	45	2	-	-
	C _{1g}	76-97	48	2	1	-
	C _{2g}	97-140	50	5	-	1

Tr : Trace
 - * : Not found

Table 13 (Contd.)

Soil Series	Horizon	Depth (cm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
BRAHMAPUTRA ALLUVIUM						
SONATALA, (Non-irrigated)	AP ₁	0-11	30	5	8	7
	AP ₂	11-14	32	8	9	10
	B _{21w}	14-35	34	5	7	3
	B _{22w}	35-50	35	8	9	8
	B _{23w}	50-74	35	8	11	13
	AP _{1bg}	74-100	45	2	10	9
	C _{1g}	100-130	50	2	8	7
	C ₂	130-165	60	3	7	5
SONATALA, (Irrigated)	AP _{1g}	0-10	20	4	4	7
	AP _{2g}	10-15	20	4	7	3
	B _{2w}	15-31	25	5	4	4
	IIB _{21w}	31-51	28	5	4	4
	B _{22wg}	51-78	30	6	5	5
	B _{23g}	78-108	35	6	6	3
	C ₁	108-130	40	7	9	3
	C ₂	130-140	45	8	10	3
	C ₃	140-200	50	8	7	2
GHATAIL, (Non-irrigated)	AP _{1g}	0-10	32	3	4	15
	AP _{2g}	10-13	35	4	4	14
	B _{21wg}	13-20	40	5	4	10
	B _{22wg}	20-39	42	6	11	9
	B _{23wg}	39-48	45	6	8	8
	B _{24w}	48-66	35	6	8	8
	B _{25w}	66-79	36	6	9	8
	B ₃	79-96	40	6	7	8
	C ₁	96-111	45	6	7	6
	C ₂	111-135	55	8	8	5
	C ₃	135-160	56	10	8	5
	C ₄	160-200	65	12	7	4
GHATAIL, (Irrigated)	AP _{1g}	0-9	40	4	5	11
	AP _{2g}	9-13	45	6	7	7
	B _{21wg}	13-38	50	4	5	3
	B _{22wg}	38-56	55	5	5	2
	B ₃	56-76	56	6	17	2
	C ₁	76-88	60	8	6	3
	IIC ₂	88-160	65	10	5	3

Zinc

In Ganges alluvium soils exchangeable Zn was generally low, ranging upto 5 ppm in all Gangetic soils, except in the surface horizon of Pakuria-NI Series where this was 20 ppm. In Sara-I Zn was not detected throughout the profile. In Brahmaputra alluvium soils exchangeable Zn ranged from 7 to 17 ppm.

Exchangeable Zn decreased significantly with depth in Sara-NI ($r = -.92^*$), while this increased significantly (Appendix-II) in Sonatala-I ($r = .64^*$) with depth.

In Brahmaputra alluvium relatively higher amounts of Zn may be attributed to low CaCa_3 contents (Table-9).

FAO, (1972-73) reported that zinc is more available in acid than in alkaline soils. Viets *et al* (1954) found that the Zn uptake of plant decreased to about one half when the pH of the soil was increased from 5 to 7.

Copper

Exchangeable copper was found nearly nil in most of the Gangetic soils except Ghior-I where 2 to 4 ppm was recorded. The low amounts of Cu was caused of high pH.

In Brahmaputra alluvium soils exchangeable copper was relatively higher (2 to 15 ppm) due to lower pH, being higher in the surface layers. In Ghatail-NI Cu decreased significantly ($r = -.88^{**}$) (Appendix-II) with depth. Agarwal and Motiramani (1965) found that available Cu significantly correlated with pH ($r = -0.333^*$).

Total Elemental Composition of Soils

The data presented in Table-14 are nitric-perchloric acid soluble constituents of soils such as Na, K, Ca Mg, Zn and Cu.

Total Sodium

Total sodium contents in soils of Ganges alluvium ranged from 0.45 to 1.0 percent, while it was 0.15 to 0.93% in Brahmaputra alluvium with the exception of 1.80% in Sonatala-I at a depth of 51 to 78 cm and 1.64% in Sonatala-NI. It was observed that Gangetic soils contained more total sodium than that of Brahmaputra alluvium.

The maximum amounts of total Na was found in subsoils of Sara-I, Pakuria-NI, Ghior-I, Sonatala-NI Sonatala-I and Ghatail-NI. Total Na decreased significantly ($r = -.743^{***}$) (Appendix III) in Pakuria-NI with the increase of depth, while in Sara-NI and Ghior-I total Na was maximum in the substratum. In most other profiles Na decreased irregularly with depth due to their alluvial nature. Higher amounts of Na in subsoils may be attributed to upward movements of soluble salts and also to subsoil clay particles (Gupta, 1981).

Total Potassium

The results indicated that Gangetic soils contained 0.33 to 0.73 percent total potassium, while it ranged from 0.21 to 0.61% in Brahmaputra alluvium soils. Gangetic soils contained relatively higher total potassium than Brahmaputra alluvium soils, presumably due to higher K-bearing minerals.

The total potassium contents decreased significantly at 1 percent level in Sara -NI ($r = -.896^{**}$) and Ghatail -NI ($r = -.709^{**}$) (Appendix-III) with the increase of depth. The

value decreased irregularly with depth in Pakuria-NI, Ghior-I and Ghatail-I due to alluvial nature of the soils. Reversed order was found in Sara-I, Sonatala-NI and Sonatala-I due to leaching.

Kansal and Sekhon (1976) reported that higher concentration of K in the subsoil might be due to illuviation process. Black (1968) demonstrated that the higher conc. of K in surface in comparison to the subsurface layer might be due to the action of plant roots in transporting K to the surface and also addition of organic matter and presence of crop residues.

Total Calcium

Total calcium ranged from 0.50 to 4.90 percent in Gangetic soils, while it ranged from 0.02 to 0.5% in the soils of Brahmaputra alluvium. The higher contents of Ca in Gangetic alluvium soils may be due to high CoCO_3 contents in the original sediments (Parent material).

In most of the profiles total Ca contents were higher in subsoils or substratum due to leaching from the overlying horizons, although in most cases total Ca contents was irregularly located in the profiles due to differences in sediment deposition at different times. However, total Ca increased significantly with depth in Sara -NI ($r=.907^{**}$) and Ghatail - NI ($r=.497^*$) (Appendix-III).

Table 14. Total elemental composition of different soils.

Soil Series	Horizon	Depth in cm	Na %	K %	Ca %	Mg %	Zn %	Cu %
GANGES ALLUVIUM								
SARA, (Non-irrigated)	AP ₁	0-11	0.73	0.40	2.00	0.47	.031	.050
	AP ₂	11-13	0.77	0.46	2.20	0.54	.018	.046
	B _{2w}	13-26	0.86	0.43	2.40	0.51	.080	.019
	B _{3w}	26-41	0.86	0.36	3.60	0.51	.008	.017
	C ₁	41-57	1.00	0.33	5.20	0.57	.005	.006
	C ₂	57-95	0.90	0.30	4.50	0.63	.060	.019
SARA, (Irrigated)	AP _{1g}	0-11	0.91	0.36	3.30	0.60	.014	.028
	AP _{2g}	11-15	0.12	0.45	2.60	0.64	.083	.025
	B _{21w}	15-33	1.00	0.36	4.30	0.64	.067	.017
	B _{22w}	33-50	0.91	0.45	3.80	0.63	.051	.011
	B _{23w}	50-59	0.54	0.38	3.60	0.53	.021	.050
	B ₃	59-84	0.53	0.38	3.40	0.48	.026	.047
	C ₁	84-97	0.67	0.42	3.50	0.57	.022	.029
	C ₂	97-105	0.54	0.54	3.80	0.55	.009	.016
	C ₃	105-123	0.58	0.33	4.90	0.55	.008	.016
	C ₄	123-148	0.75	0.42	3.20	0.57	.005	.009
	C ₅	148-180	0.60	0.60	2.20	0.48	.034	.082
PAKURIA, (Non-Irrigated)	AP _{1g}	0-13	0.92	0.58	1.80	0.59	.014	.032
	AP ₂	13-17	1.00	0.64	1.30	0.64	.007	.009
	B _{21w}	17-29	0.85	0.46	2.40	0.55	.039	.072
	B _{22w}	29-42	1.00	0.60	2.80	0.70	.045	.004
	B _{23w}	42-59	1.00	0.50	4.10	0.59	.018	.033
	B ₃	59-83	0.77	0.54	3.60	0.55	.067	.011
	C ₁	83-108	0.73	0.45	4.20	0.64	.016	.036
	C ₂	108-146	0.90	0.50	0.80	0.66	.028	.069
	C ₃	146-181	0.53	0.65	1.00	0.43	.040	.065
GHIOR, (Irrigated)	AP _{1g}	0-15	0.53	0.60	0.50	0.48	.073	.023
	AP _{2g}	15-20	0.67	0.67	0.60	0.59	.018	.014
	B _{21wg}	20-32	0.50	0.50	3.20	0.51	.020	.041
	B _{22wg}	32-57	0.82	0.73	2.20	0.63	.009	.014
	B ₃	57-76	0.64	0.54	0.60	0.50	.021	.035
	C _{1g}	76-97	0.54	0.64	0.80	0.63	.040	.096
	C _{2g}	97-140	0.45	0.54	0.60	0.60	.030	.050

Table 14 (Contd.)

Soil Series	Horizon	Depth in cm.	Na %	K %	Ca %	Mg %	Zn %	Cu %
BRAHMAPUTRA ALLUVIUM								
SONATALA, (Non-irrigated)	AP ₁	0-11	0.33	0.33	0.17	0.54	.034	.077
	AP ₂	11-14	0.31	0.31	0.06	0.50	.024	.052
	B _{21w}	14-35	0.69	0.31	0.21	0.53	.067	.018
	B _{22w}	35-50	1.64	0.45	0.50	0.64	.033	.072
	B _{23w}	50-74	0.50	0.33	0.15	0.57	.016	.024
	AP _{1bg}	74-100	0.77	0.61	0.19	0.53	.084	.027
	C _{1g}	100-130	0.21	0.36	0.05	0.47	.036	.082
	C ₂	130-165	0.25	0.25	0.08	0.56	.009	.063
SONATALA, (Irrigated)	AP _{1g}	0-11	0.36	0.18	0.18	0.53	.023	.066
	AP _{2g}	10-15	0.67	0.25	0.17	0.56	.023	.046
	B _{2w}	15-31	0.73	0.34	0.14	0.60	.067	.017
	IIB _{21w}	31-51	0.91	0.38	0.18	0.60	.084	.027
	B _{22wg}	51-78	1.80	0.40	0.47	0.68	.034	.074
	B _{23g}	78-108	0.36	0.27	0.04	0.54	.033	.079
	C ₁	108-130	0.33	0.33	0.06	0.56	.014	.021
	C ₂	130-140	0.91	0.27	0.27	0.60	.053	.014
	C ₃	140-200	0.40	0.27	0.10	0.44	.034	.065
GHATAIL, (Non-irrigated)	AP _{1g}	0-10	0.31	0.38	0.02	0.52	.005	.008
	AP _{2g}	10-13	0.27	0.39	0.02	0.57	.016	.034
	B _{21wg}	13-20	0.50	0.35	0.10	0.56	.036	.085
	B _{22wg}	20-39	0.30	0.40	0.02	0.65	.026	.042
	B _{23wg}	39-48	0.31	0.54	0.09	0.54	.023	.050
	B _{24w}	48-66	0.42	0.42	0.12	0.57	.008	.014
	B _{25w}	66-79	0.27	0.36	0.09	0.57	.006	.011
	B ₃	79-96	0.15	0.31	0.04	0.49	.022	.047
	C ₁	96-111	0.15	0.23	0.04	0.48	.022	.015
	C ₂	111-135	0.58	0.21	0.14	0.54	.016	.029
	C ₃	135-160	0.48	0.20	0.08	0.46	.018	.025
	C ₄	160-200	0.20	0.27	0.07	0.47	.016	.027
GHATAIL, (Irrigated)	AP _{1g}	0-9	0.38	0.38	0.06	0.49	.031	.072
	AP _{2g}	9-13	0.27	0.27	0.18	0.58	.088	.028
	B _{21wg}	13-38	0.25	0.25	0.10	0.52	.030	.076
	B _{22wg}	38-56	0.33	0.24	0.10	0.52	.023	.046
	B ₃	56-76	0.31	0.25	0.12	0.45	.078	.021
	C ₁	76-88	0.93	0.21	0.43	0.51	.088	.027
	IIC ₂	88-160	0.46	0.23	0.17	0.52	.058	.019

Total Magnesium

Results indicated that total Mg in Gangetic soils varied from 0.43 to 0.70%, while it ranged from 0.44 to 0.68% in Brahmaputra alluvium. In most of the profiles Mg decreased with depth and this was highly significant in Sara-I ($r=-.687^{**}$) and Ghatail-NI ($r=-.660^{**}$) due to lack of vertical leaching. On the other hand the order reversed significantly at 1 percent level in Sara -NI ($r=.883^{**}$) (Appendix-III) and irregularly in Ghior-I due to intensive leaching.

Kovar & Ricken (1976) found higher amounts of non-exchangeable Mg in the middle layer of some prairie soils and attributed it to a higher content of Mg rich minerals in the sediments at the time of deposition.

Total Zinc

The results (Table-14) indicated that the contents of total Zn ranged from .005 to .083% in Gangetic soils, while it exhibited from .005 to .088 in soils of Brahmaputra alluvium. Almost all the profiles contained maximum amounts of total zinc in their subsoils due to illuviation process, except in surface of Ghior-I presumably due to addition of fertilizer. Total zinc decreased significantly with depth in Sara -I ($r=-.532^{*}$) (Appendix-III) and decreased irregularly with depth in Ghior-I, Sonatala-NI, Sonatala-I and Ghatail-NI mainly due to their alluvial nature. On the other hand, total Zn increased irregularly with depth in Sara-NI, pakuria (NI) and Ghatail-I.

Vittal and Gangwar (1974) reported that distribution of Zn in the profile was affected by drainage, soil reaction, clay and organic carbon as they affect the mobilization of Zn in soil. They also found that total Zn decreased with depth of the soil profile.

Total Copper

Total Cu contents ranged from .004 to .096% in Gangetic soils and from .008 to .085% in the Brahmaputra alluvium soils.

Maximum amounts of total Cu was found in subsoil and subsurface of most of the soil profiles due to illuviation. However, this was higher in the surface of Sara-NI and Ghior-I profile due to lack of leaching.

Udo *et al.* (1979) studied some Nigerian soils and found 7 to 72 ppm total Cu in the soils. They observed that the soils formed from basalt had highest values of Cu, while those on coastal plains had the least amount. They also found higher amounts of total Cu in subsoil.

Total iron, Aluminium and Manganese Contents in Soils

Total Fe, Al and Mn presented in Table-15 (extracted by nitric-perchloric acid) expressed as oxides and are discussed below individually. The contents of Fe in soils and their distribution in the soil profile and within the some horizon reflect the trend and peculiarity of the soil formation processes (Orlov, 1972).

Total Iron

Total iron oxides varied from 1.84 to 4.43 percent in Gangetic soils and ranged from 2.28 to 4.69% in Brahmaputra alluvium soils. In most profiles total Fe_2O_3 was highest in subsoils and substratum and increased with depth due to migration from upper layers. The increase of total Fe_2O_3 with depth was found highly significant in Sonatala -NI ($r=.881^{**}$), while in Sara-I, Pakuria-NI, Ghior-I, Sonatala-I, Ghatail-NI and Ghatail-I it increased irregularly with depth due to irregular leaching and the alluvial nature of the soils. Fe_2O_3 decreased significantly at 1 percent level ($r=-.916^{**}$) (Appendix-III) with the increase of depth in Sara-NI due to lack of weathering and more oxidizing situation in upper layers.

The higher contents of total Fe_2O_3 reflects more weathering and more development of soils.

Juo *et al.* (1974) suggested 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. Chatterjee and Dalal (1976) reported that Bihar and west Bengal alluvial soils contained higher total Fe in surface (2.1 to 2.5%) than lower layers (1.3 to 1.4%).

Table 15. Total Iron, Aluminium and Manganese contents in the studied soils

Soil Series	Horizon	Depth (cm)	Fe ₂ O ₃ %	Al ₂ O ₃ %	MnO ₂ %
GANGES ALLUVIUM					
SARA, (Non-irrigated)	AP ₁	0-11	2.86	1.83	0.040
	AP ₂	11-13	2.93	2.09	0.028
	B _{2w}	13-26	3.01	2.09	0.065
	B _{3w}	26-41	2.78	2.22	0.026
	C ₁	41-57	2.05	1.68	0.043
	C ₂	57-95	1.84	1.08	0.037
SARA, (Irrigated)	AP _{1g}	0-11	2.31	1.64	0.054
	AP _{2g}	11-15	3.03	1.72	0.083
	B _{21w}	15-33	2.82	1.27	0.083
	B _{22w}	33-50	3.10	1.93	0.062
	B _{23w}	50-59	2.58	1.89	0.011
	B ₃	59-84	3.10	2.26	0.050
	C ₁	84-97	2.58	1.93	0.024
	C ₂	97-105	3.24	1.70	0.070
	C ₃	105-123	2.25	1.52	0.011
	C ₄	123-148	2.32	1.76	0.011
	C ₅	148-180	3.71	2.13	0.055
PAKURIA, (Non-irrigated)	AP _{1g}	0-13	3.71	2.09	0.063
	AP ₂	13-17	4.18	1.94	0.076
	B _{21w}	17-29	3.52	2.02	0.112
	B _{22w}	29-42	4.13	1.76	0.076
	B _{23w}	42-59	3.65	2.34	0.054
	B ₃	59-83	3.54	2.30	0.136
	C ₁	83-108	3.47	2.51	0.104
	C ₂	108-146	3.69	2.09	0.054
	C ₃	146-181	4.35	2.22	0.081
GHIOR, (Irrigated)	AP _{1g}	0-15	4.02	1.87	0.055
	AP _{2g}	15-20	4.43	2.13	0.063
	B _{21wg}	20-32	3.40	1.94	0.087
	B _{22wg}	32-57	4.04	2.18	0.089
	B ₃	57-76	3.32	2.09	0.083
	C _{1g}	76-97	4.04	2.34	0.083
	C _{2g}	97-140	3.68	2.34	0.062

Table 15 (Contd.)

Soil Series	Horizon	Depth (cm)	Fe ₂ O ₃ %	Al ₂ O ₃ %	Mno2 %
BRAHMAPUTRA ALLUVIUM					
SONATALA, (Non-irrigated)	AP ₁	0-11	2.58	2.14	0.087
	AP ₂	11-14	2.87	2.13	0.082
	B _{21w}	14-35	2.93	1.76	0.142
	B _{22w}	35-50	3.18	1.53	0.154
	B _{23w}	50-74	3.57	2.13	0.069
	AP _{1bg}	74-100	3.24	2.05	0.069
	C _{1g}	100-130	3.47	2.30	0.026
	C ₂	130-165	3.71	2.18	0.043
SONATALA, (Irrigated)	AP _{1g}	0-10	2.60	1.89	0.040
	AP _{2g}	10-15	3.31	2.13	0.134
	B _{2w}	15-31	3.53	2.28	0.054
	IIB _{21w}	31-51	3.75	2.09	0.089
	B _{22wg}	51-78	3.47	2.13	0.052
	B _{23g}	78-108	3.03	2.13	0.047
	C ₁	108-130	4.17	2.22	0.056
	C ₂	130-140	3.47	2.22	0.047
	C ₃	140-200	2.75	2.13	0.066
GHATAIL, (Non-irrigated)	AP _{1g}	0-10	3.23	2.13	0.046
	AP _{2g}	10-13	3.18	2.13	0.047
	B _{21wg}	13-20	3.61	2.22	0.050
	B _{22wg}	20-39	4.69	1.64	0.067
	B _{23wg}	39-48	3.97	2.02	0.052
	B _{24w}	48-66	3.43	2.09	0.063
	B _{25w}	66-79	3.54	2.13	0.047
	B ₃	79-96	3.18	2.34	0.040
	C ₁	96-111	3.05	2.34	0.070
	C ₂	111-135	3.04	1.73	0.043
	C ₃	135-160	3.05	1.94	0.049
	C ₄	160-200	3.81	2.13	0.102
GHATAIL, (Irrigated)	AP _{1g}	0-9	2.93	2.13	0.028
	AP _{2g}	9-13	3.46	2.18	0.026
	B _{21wg}	13-38	3.05	2.69	0.050
	B _{22wg}	38-56	2.28	2.13	0.050
	B ₃	56-76	4.02	2.05	0.076
	C ₁	76-88	3.63	2.09	0.082
	IIC ₂	88-160	3.05	1.83	0.069

Total Aluminium

Gangetic soils contained 1.08 to 2.51 percent Al_2O_3 , while it ranged from 1.53 to 2.69% in Brahmaputra alluvium soils. Maximum Al_2O_3 contained in subsoils of most of the profiles except in C horizon of Ghior-I.

Dolut *et al* (1987) studied the different forms of aluminium and the interrelationship among themselves as well as with some important soil characteristics in relation to pedogenic process in three Tarai and Teesta west Bengal and found crystalline Al increased upto middle horizon and then decreased below. Moore (1973) stated that it is due to conversion of some alluvial Al into crystalline form on ageing.

Al_2O_3 decreased significantly ($r = -.812^*$) with depth in Sara-NI and was correlated positively with Fe_2O_3 ($r = .875^{**}$) (Appendix-III). In Ghior-I total Al_2O_3 increased significantly ($r = .829^{**}$) with the increase of depth. On the other hand, the increase with depth was irregularly in Sara-I, Pakuria-NI, Sonatala-NI, Sonatala-I and Ghatail-NI, in Ghatail-I it increased upto 38cm and then decreased. Irregularly increasing trend of total Al_2O_3 was due to variation in clay contents as well as due to alluvial nature of the soil. Shigeyoshi Gotoh (1976) also reported that the pattern of the distribution of the total Al_2O_3 with depth closely resembled that of the distribution of clay.

Total Manganese

The results indicated that total MnO_2 contents varied from 0.011 to 0.136% in Gangetic soils, while it ranged from .026 to 0.154% in the soils of Brahmaputra alluvium. Most of the profiles contained Maximum total MnO_2 in their subsoils. Only Ghatail-NI and Ghatail-I contained the highest MnO_2 in the C horizons due to the variation in weathering intensity, clay contents and ageing in soils. On the other hand, in Sonatala-NI MnO_2 decreased significantly ($r = -.658^*$) with the increase of depth, while it

increased with depth significantly in Ghatail -NI ($r=.490^*$) and Ghatail -I ($r=.771^*$) profiles (Appendix-III).

Vinayaka *et al* (1964) found that total Mn increased with increase in clay content in saline alkali and normal soil of Rajasthan.

Free oxides of iron, aluminium, silicon and manganese

The amounts of free oxides in soils are very important in evaluating mineral weathering and pedogenic changes in soils (McKeague and Day, 1966; Blume and Schwertmann, 1969; Santos *et al*, 1986).

The results presented in Table-16 on free Fe, Al, Si, and Mn were expressed as oxides and are discussed below:

Free Iron (Fe_D)

Results indicated that free iron oxide contents varied from 0.4 to 1.3% in Gangetic alluvium soils, while it ranged from .3 to 1.0% in soils of Brahmaputra alluvium.

Non-irrigated profiles contained maximum free iron oxides in their surface horizon and then decreased due to lack of weathering. The decrease with depth was significant in Sara-NI ($r=-.804^*$) and Ghatail-NI ($r=-.611^*$) (Appendix-IV). In irrigated soils like Sara-I, Ghior-I, Sonatala-I and Ghatail-I, free iron (Fe_D) increased significantly and was maximum in subsoils or substratum due to restriction of vertical water movement by thick and hard ploughpan.

Low free iron oxide is neither due to leaching of iron nor to the accumulation of iron in mottles but presumably resulting from reduction (McKeague, 1965). Joffe (1949)

stated 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 at the surface, while in the subsoil ferrous iron does not change.

Table 16. Free oxides of Iron, Aluminium, Silicon and Manganese in the different soils

Soil Series	Horizon	Depth (cm)	Fe ₂ O ₃ %	Al ₂ O ₃ %	SiO ₂ %	MnO ₂ %
GANGES ALLUVIUM						
SARA (Non-irrigated)	AP ₁					
	AP ₂	0-11	0.9	0.11	0.11	0.03
	B _{2w}	11-13	0.9	0.13	0.13	0.03
	B _{3w}	13-26	0.6	0.07	0.18	0.03
	C ₁	26-41	0.4	0.09	0.15	0.03
	C ₂	41-57	0.4	0.13	0.13	0.01
	C ₂	57-95	0.4	0.11	0.13	0.01
SARA (Irrigated)	AP _{1g}	0-11	0.6	0.06	0.11	0.02
	AP _{2g}	11-15	0.7	0.04	0.12	0.03
	B _{21w}	15-33	0.6	0.05	0.09	0.02
	B _{22w}	33-50	0.6	0.07	0.08	0.04
	B _{23w}	50-59	0.6	0.03	0.09	0.02
	B ₃	59-84	0.7	0.08	0.08	0.03
	C ₁	84-97	0.6	0.04	0.09	0.02
	C ₂	97-105	1.1	0.14	0.13	0.04
	C ₃	105-123	0.9	0.09	0.20	0.03
	C ₄	123-148	1.0	0.11	0.19	0.02
	C ₅	148-180	1.3	0.09	0.21	0.04
	C ₅					
PAKURIA (Non-irrigated)	AP _{1g}	0-13	0.7	0.10	0.11	0.01
	AP ₂	13-17	0.5	0.11	0.12	0.02
	B _{21w}	17-29	0.4	0.13	0.12	0.02
	B _{22w}	29-42	0.5	0.08	0.14	0.02
	B _{23w}	42-59	0.6	0.11	0.14	0.05
	B ₃	59-83	0.5	0.09	0.15	0.02
	C ₁	83-108	0.5	0.12	0.12	0.02
	C ₂	108-146	0.5	0.10	0.12	0.02
	C ₃	146-181	0.5	0.10	0.10	0.03
	C ₃					
GHIOR (Irrigated)	AP _{1g}	0-15	0.5	0.14	0.11	0.03
	AP _{2g}	15-20	0.6	0.12	0.09	0.02
	B _{21wg}	20-32	1.3	0.08	0.11	0.02
	B _{22wg}	32-57	0.8	0.09	0.12	0.02
	B ₃	57-76	0.5	0.11	0.13	0.01
	C _{1g}	76-97	0.4	0.10	0.19	0.02
	C _{2g}	97-140	0.6	0.09	0.13	0.01
	C _{2g}					

Table 16 (Contd.)

Soil Series	Horizon	Depth (cm)	Fe ₂ O ₃ %	Al ₂ O ₃ %	SiO ₂ %	MnO ₂ %
BRAHMAPUTRA ALLUVIUM						
SONATALA, (Non-irrigated)	AP ₁	0-11	0.8	0.11	0.17	0.01 0.02
	AP ₂	11-14	0.7	0.15	0.17	0.01
	B _{21w}	14-35	0.5	0.15	0.13	0.01
	B _{22w}	35-50	0.4	0.16	0.14	0.02
	B _{23w}	50-74	0.8	0.13	0.15	0.005
	AP _{1bg}	74-100	0.5	0.11	0.14	0.005
	C _{1g}	100-130	0.5	0.17	0.13	0.01
	C ₂	130-165	0.4	0.09	0.09	
SONATALA, (Irrigated)	AP _{1g}	0-10	0.2	0.10	0.13	0.01
	AP _{2g}	10-15	0.6	0.10	0.13	0.04
	B _{2w}	15-31	0.6	0.07	0.12	0.01
	IIB _{21w}	31-51	0.7	0.08	0.20	0.01
	B _{22wg}	51-78	0.6	0.10	0.12	0.004
	B _{23g}	78-108	0.5	0.07	0.17	0.01
	C ₁	108-130	0.9	0.14	0.16	0.01
	C ₂	130-140	0.8	0.14	0.15	0.003
	C ₃	140-200	0.7	0.13	0.15	0.01
GHATAIL, (Non-irrigated)	AP _{1g}	0-10	0.8	0.09	0.17	0.006
	AP _{2g}	10-13	0.7	0.12	0.12	0.007
	B _{21wg}	13-20	0.6	0.14	0.14	0.005
	B _{22wg}	20-39	0.6	0.14	0.11	0.01
	B _{23wg}	39-48	0.8	0.13	0.16	0.01
	B _{24w}	48-66	0.6	0.10	0.11	0.00
	B _{25w}	66-79	0.6	0.11	0.11	0.00
	B ₃	79-96	0.4	0.10	0.13	0.01
	C ₁	96-111	0.3	0.12	0.09	0.01
	C ₂	111-135	0.4	0.11	0.15	0.01
	C ₃	135-160	0.4	0.09	0.15	0.01
	C ₄	160-200	0.4	0.15	0.14	0.01
GHATAIL, (Irrigated)	AP _{1g}	0-9	0.5	0.12	0.12	0.01
	AP _{2g}	9-13	0.6	0.08	0.14	0.01
	B _{21wg}	13-38	0.7	0.10	0.15	0.01
	B _{22wg}	38-56	0.8	0.12	0.14	0.01
	B ₃	56-76	0.8	0.07	0.15	0.02
	C ₁	76-88	0.9	0.08	0.11	0.01
	IIC ₂	88-160	1.0	0.07	0.10	0.01

Free aluminium (Al_D)

Free Al_2O_3 % varied from 0.03 to 0.14% in Gangetic soils, while in soils of Brahmaputra alluvium it ranged from 0.07 to 0.17% percent.

It was observed that most of the soils (i.e Sara-NI, Sara-I, Pakuria-NI, Sonatala-NI Sonatala-I & also Ghatail-NI under two parent materials contained maximum free aluminium in the subsoils which then decreased with depth. In Ghior-I and Ghatail-I, the free Al_D was maximum in the surface due to low pH.

Dolut *et al* (1987) reported that crystalline Al increased upto middle horizon and then decreased below due to conversion of some illuvial Al into crystalline form on ageing (Moore, 1973). Shigeyoshi Gotoh (1978) found that the extractable Al_2O_3 content generally decreased with depth attaining the highest contents in the A horizons in the folder soils. He also reported that the Al movement in the soil is pH dependent.

Free silicon (Si_D)

The quality and distribution of free Si in soils are influenced by parent material, climate, vegetation, texture, pedogenesis, and intensity of weathering (Hallmark *et al*, 1982).

Results indicated that free silicon varied from 0.08 to 0.21% in Gangetic soils, while in Brahmaputra alluvium soils it ranged from 0.09 to 0.20%.

Most of the profiles contained maximum free silicon in the subsoils but Sara-I and Ghior-I contained the maximum free iron in the C horizons, while it remained in the surface of Sonatala-NI and Ghatail-NI profiles. It increased significantly at 1% level with the increase of depth in Sara -I ($r=.751^{**}$). In Sonatala-NI it reversed significantly at 1 percent level ($r=-.841^{**}$) (Appendix-IV). In other profiles, it was found to increase

(Appendix-IV). In other profiles, it was found to increase irregularly with depth due to alluvial nature as sediments were deposited at different times.

It was reported by Weaver *et al.* (1968) that under acid conditions the Si conc. in the extract is higher than in a neutral extract of soil. Jones and Handreck (1965) reported that in a wide range of soils of the same pH, the conc. of monosilicic acid in solutions ranged from 3 ppm Si (for lateritic soil) to 37 ppm Si (for a black clay vertisol).

Free Manganese (Mn_D)

Results indicated that free MnO_2 varied from 0.01 to 0.04% in Gangetic soils, while it ranged from 0.003 to 0.04% in Brahmaputra alluvium soils.

Free MnO_2 increased with depth in most of the profiles due to leaching. Only in Sara-NI, Ghior-I and Sonatala-NI this decreased with depth due to lack of leaching.

Tisdale and Nelson (1966) demonstrated that a dynamic equilibrium is believed to exist among the forms of Mn so that the tetravalent form is most likely to occur in alkaline soils, the trivalent form is presumably formed by soil pH values near neutrality and the divalent form is found in acid soils. Ponnampetuma (1985) reported that Mn deficiency occurs in calcareous sandy and calcareous peat soils.

Acid oxalate extractable iron, aluminium and silicon.

Oxalate extractable part of Fe_0 , Al_0 and Si_0 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, aluminium and silicon presented in Table-17 expressed as oxides are discussed individually below:

Table 17: Acid oxalate extractable iron, aluminium and silicon in the studied soils

Soil Series	Horizon	Depth (cm)	Al ₂ O ₃ %	Fe ₂ O ₃ %	SiO ₂ %
GANGES ALLUVIUM					
SARA, (Non-irrigated)	AP ₁	0-11	.022	0.98	.105
	AP ₂	11-13	.015	0.91	.103
	B _{2w}	13-26	.008	0.71	.101
	B _{3w}	26-41	.009	0.59	.104
	C ₁	41-57	.020	0.53	.101
	C ₂	57-95	.018	0.56	.068
SARA, (Irrigated)	AP _{1g}	0-11	.022	0.89	.122
	AP _{2g}	11-15	.016	0.87	.106
	B _{21w}	15-33	.020	0.86	.101
	B _{22w}	33-50	.014	0.82	.093
	B _{23w}	50-59	.018	0.98	.101
	B ₃	59-84	.012	0.90	.109
	C ₁	84-97	.014	1.15	.073
	C ₂	97-105	.010	1.05	.124
	C ₃	105-123	.017	1.00	.122
	C ₄	123-148	.016	0.85	.077
	C ₅	148-180	.018	1.33	.126
AKURIA, (Non-irrigated)	AP _{1g}	0-13	.016	1.19	.122
	AP ₂	13-17	.014	1.28	.134
	B _{21w}	17-29	.020	0.88	.134
	B _{22w}	29-42	.018	1.00	.127
	B _{23w}	42-59	.022	1.09	.126
	B ₃	59-83	.018	1.29	.126
	C ₁	83-108	.016	1.20	.134
	C ₂	108-146	.019	1.15	.126
	C ₃	146-181	.020	1.25	.126
GHIOR, (Irrigated)	AP _{1g}	0-15	.016	1.12	.126
	AP _{2g}	15-20	.016	1.17	.101
	B _{21wg}	20-32	.022	1.07	.126
	B _{22wg}	32-57	.020	1.43	.118
	B ₃	57-76	.018	1.31	.101
	C _{1g}	76-97	ND	1.30	ND
	C _{2g}	97-140	ND	1.32	ND

* ND= Not determined

Table 17 (Contd.)

Soil Series	Horizon	Depth (cm)	Al ₂ O ₃ %	Fe ₂ O ₃ %	SiO ₂ %
BRAHMAPUTRA ALLUVIUM					
SONATALA, (Non-irrigated)	AP ₁	0-11	.020	1.58	.124
	AP ₂	11-14	.020	1.66	.104
	B _{21w}	14-35	.012	1.15	.101
	B _{22w}	35-50	.026	1.42	.122
	B _{23w}	50-74	.018	1.30	.105
	AP _{1bg}	74-100	.012	1.10	.122
	C _{1g}	100-130	.018	1.05	.126
	C ₂	130-165	.013	0.97	.105
SONATALA, (Irrigated)	AP _{1g}	0-10	.020	1.57	.134
	AP _{2g}	10-15	.021	1.37	.122
	B _{2w}	15-31	.017	1.70	.109
	IIB _{21w}	31-51	.016	2.26	.118
	B _{22wg}	51-78	.017	1.20	.122
	B _{23g}	78-108	.016	0.98	.124
	C ₁	108-130	.018	0.86	.122
	C ₂	130-140	.013	0.84	.118
	C ₃	140-200	.011	0.90	.105
GHATAIL, (Non-irrigated)	AP _{1g}	0-10	.022	1.17	.101
	AP _{2g}	10-13	.016	1.24	.085
	B _{21wg}	13-20	.018	1.83	.097
	B _{22wg}	20-39	.018	1.69	.112
	B _{23wg}	39-48	.017	1.60	.097
	B _{24w}	48-66	.018	1.53	.126
	B _{25w}	66-79	.018	2.21	.126
	B ₃	79-96	.018	1.50	.126
	C ₁	96-111	.018	1.10	.134
	C ₂	111-135	.012	0.81	.126
	C ₃	135-160	.012	0.70	.124
	C ₄	160-200	.013	0.55	.126
GHATAIL, (Irrigated)	AP _{1g}	0-9	.018	1.60	.102
	AP _{2g}	9-13	.018	0.94	.101
	B _{21wg}	13-38	.021	1.55	.101
	B _{22wg}	38-56	.018	0.98	.122
	B ₃	56-76	.014	0.78	.110
	C ₁	76-88	.013	0.60	.122
	IIC ₂	88-160	.016	0.48	.109

Fig.2a Contents of sodium dithionite, acidified ammonium oxalate and sodium pyrophosphate extractable iron of the studied soils

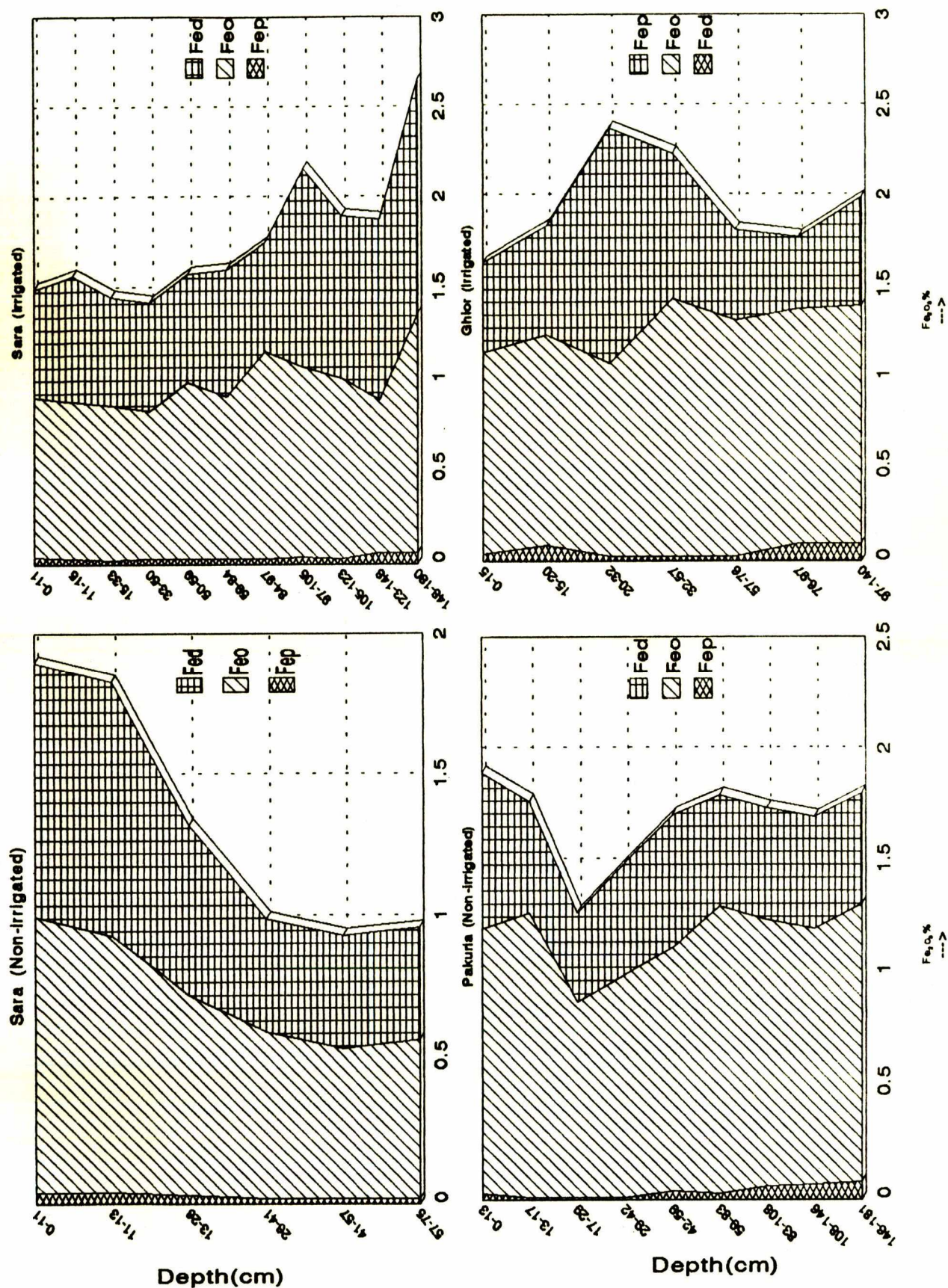
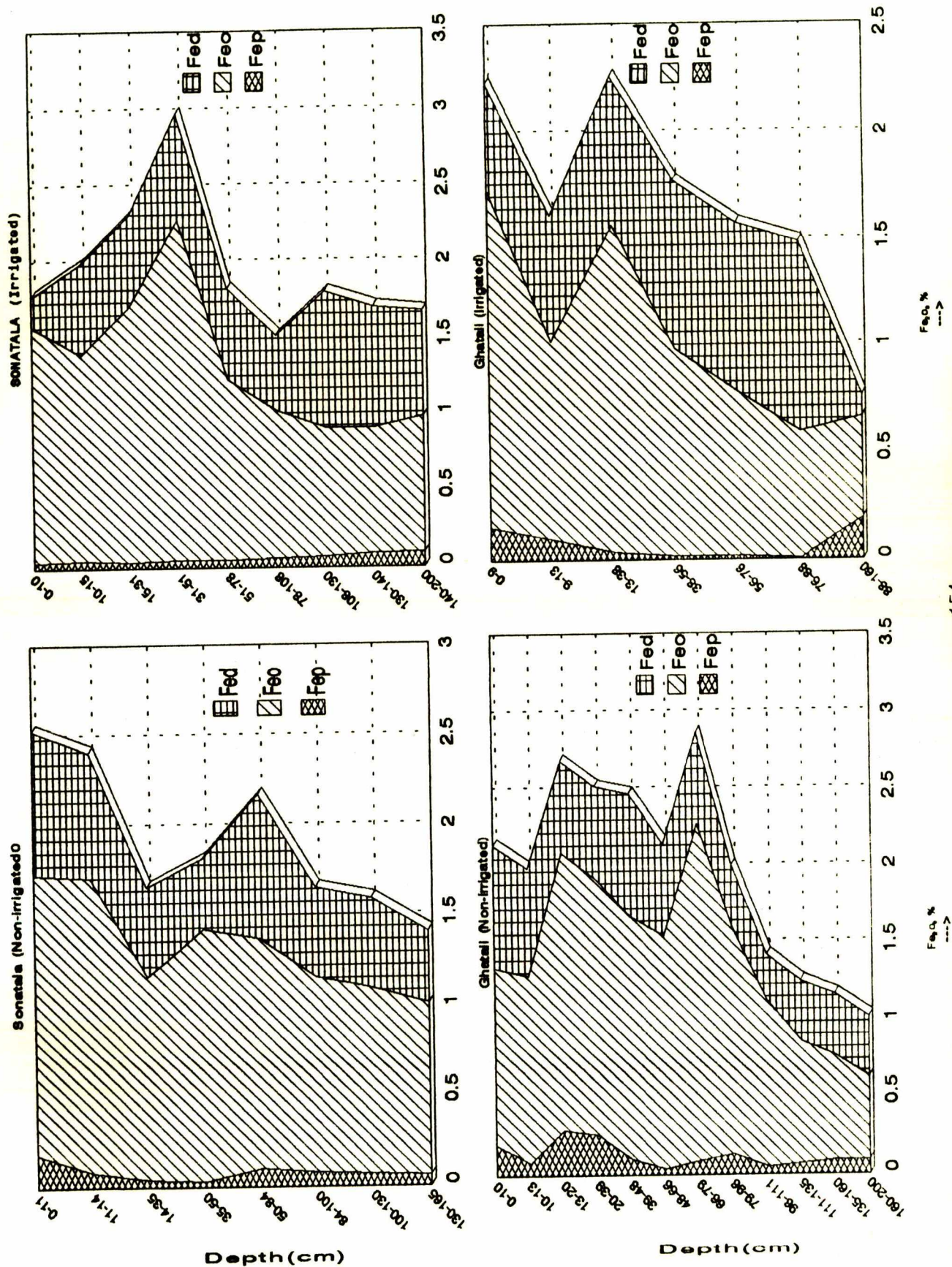


Fig.2.b Contents of sodium dithionite, acidified ammonium oxalate and sodium pyrophosphate extractable iron of the studied soils



Oxalate extractable iron

Results (Table-17) of oxalate extractable Fe_2O_3 ranged from 0.53 to 1.43 percent in Gangetic alluvium soils, and from 0.48 to 2.26% in soils of Brahmaputra alluvium.

It was noted that Sara-NI, Sonatala-NI and Ghatail-I contained maximum Fe_2O_3 in their surface. Fe_0 decreased significantly with the increase of depth in Sara -NI ($r=-.924^{**}$), while it increased significantly with depth in Sara-I ($r=.663^{**}$). It irregularly increased with depth in Pakuria-NI and Ghior-I due to differences in alluvial sediments and leaching. Fe_0 in soils of Brahmaputra alluvium decreased significantly with depth in Sonatala -NI ($r=-.858^{**}$), Sonatala -I ($r=-.715^{**}$), Ghatail -NI ($r=-.557^*$) and Ghatail -I ($r=-.771^*$) (Appendix-IV).

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

It was also found that all the soils under the present investigation contained higher Fe_0 than Fe_D (Fig.2a-b).

Oxalate extractable aluminium

It was observed that both Gangetic and Brahmaputra alluvium soils contained low amounts of Al_0 than Al_D mainly because of high pH of soils. Gangetic soils being calcareous have high pH and the soils of Brahmaputra alluvium also have high pH (above 7.0) except in the top soils of Sonatala-NI, Ghatail-NI and Ghatail-I where they were in acidic level.

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.

Al₀ in most of the soils decreased with the increase of depth and was highly significant in Sonatala -I ($r=-.837^{**}$), Ghatail -NI ($r=-.757^{**}$) and Ghatail -I ($r=-.870^{**}$) (Appendix-IV), while it increased irregularly with depth in pakuria (NI) and Ghior-I.

Dolut *et al.* (1987) studied some soils of Jalpaiguri district of west bengal and reported that oxalate extractable Al is more in illuvial horizons of the profiles due to the deposition of translocated Al-fulvate complex.

Oxalate extractable silicon

The results (Table-17) indicated that oxalate extractable SiO₂ varied from 0.068 to 0.134% in Gangetic soils and ranged from 0.097 to 0.134% in Brahmaputra alluvium soils.

In most of the profiles, Si₀ was found to decrease with the increase of depth, either regularly or irregularly, while in Ghatail-NI and Ghatail-I it reversed. Si₀ decreased significantly ($r=-.864^{**}$) with depth in Sara-NI, while in Ghatail-NI it increased significantly with depth ($r=.750^{**}$) (Appendix-IV).

Pyrophosphate extractable iron and alluminium

Pyrophosphate extractable iron and aluminum, since represent the organically bound form, are highly important for predicting the genetical development as well as the pedogenic condition of soils.

Table 18. Contens of sodium pyrophosphate extractable iron and aluminium of the studied soils

Soil Series	Horizon	Depth (cm)	Fe ₂ O ₃ %	Al ₂ O ₃ %
GANGES ALLUVIUM				
SARA, (Non-irrigated)	AP ₁	0-11	.042	.028
	AP ₂	11-13	.042	.028
	B _{2w}	13-26	.031	.017
	B _{3w}	26-41	.025	.017
	C ₁	41-57	.021	.002
	C ₂	57-95	.019	.002
SARA, (Irrigated)	AP _{1g}	0-11	.039	.028
	AP _{2g}	11-15	.026	.028
	B _{21w}	15-33	.020	.004
	B _{22w}	33-50	.026	.017
	B _{23w}	50-59	.029	.004
	B ₃	59-84	.033	.028
	C ₁	84-97	.034	.017
	C ₂	97-105	.037	.016
	C ₃	105-123	.035	.016
	C ₄	123-148	.059	.017
	C ₅	148-180	.057	.028
PAKURIA, (Non-irrigated)	AP _{1g}	0-13	.030	.042
	AP ₂	13-17	.004	.014
	B _{21w}	17-29	.015	.039
	B _{22w}	29-42	.012	.004
	B _{23w}	42-59	.042	.033
	B ₃	59-83	.027	.028
	C ₁	83-108	.064	.028
	C ₂	108-146	.072	.013
	C ₃	146-181	.079	.016
GHIOR, (Irrigated)	AP _{1g}	0-15	.036	.050
	AP _{2g}	15-20	.094	.044
	B _{21wg}	20-32	.031	.039
	B _{22wg}	32-57	.031	.044
	B ₃	57-76	.034	.050
	C _{1g}	76-97	.100	.057
	C _{2g}	97-140	.100	.054

Soil Series	Horizon	Depth (cm)	Fe ₂ O ₃ %	Al ₂ O ₃ %
BRAHMAPUTRA ALLUVIUM				
SONATOLA, (Non-irrigated)	AP ₁	0-11	.182	.044
	AP ₂	11-14	.080	.028
	B _{21w}	14-35	.036	.013
	B _{22w}	35-50	.026	.013
	B _{23w}	50-84	.026	.011
	AP _{1bg}	74-100	.098	.161
	C _{1g}	100-130	.083	.162
	C ₂	130-165	.072	.164
SONATOLA, (Irrigated)	AP _{1g}	0-10	.036	.039
	AP _{2g}	10-15	.054	.022
	B _{2w}	15-31	.037	.022
	IIB _{21w}	31-51	.047	.083
	B _{22wg}	51-78	.050	.139
	B _{23g}	78-108	.064	.089
	C ₁	108-130	.074	.022
	C ₂	130-140	.094	.020
	C ₃	140-200	.100	.020
GHATAIL, (Non-irrigated)	AP _{1g}	0-10	.205	.008
	AP _{2g}	10-13	.084	.009
	B _{21wg}	13-20	.088	.004
	B _{22wg}	20-39	.056	.004
	B _{23wg}	39-48	.104	.006
	B _{24w}	48-66	.043	.001
	B _{25w}	66-79	.087	.006
	B ₃	79-96	.126	.018
	C ₁	96-111	.046	.009
	C ₂	111-135	.069	.008
	C ₃	135-160	.089	.004
	C ₄	160-200	.094	.001
GHATAIL, (Irrigated)	AP _{1g}	0-9	.163	.009
	AP _{2g}	9-13	.099	.008
	B _{21wg}	13-38	.044	.012
	B _{22wg}	38-56	.020	.010
	B ₃	56-76	.025	.004
	C ₁	76-88	.015	.004
	IIC ₂	88-160	.205	.001

Iron (Fe_p)

Results (Table-18) indicated that Gangetic soils contained .004 to .10% Fe_p , while it ranged from .015 to .205% in Brahmaputra alluvium soils. The Fe_p was observed much lower than Fe_0 and Fe_D (Fig.2a-b) due to less weathering of soils.

It was observed that Fe_p decreased significantly with the increase of depth in Sara -NI ($r=-.8970^{**}$) due to lack of leaching, while it increased with depth significantly in Sara -I ($r=.792^{**}$), Pakuria -NI ($r=.9065^{**}$) and Sonatala -I ($r=.9245^{**}$) (Appendix-IV) due to intensive leaching and illuviation processes. It was also indicated that Fe_0 irregularly increased with depth in Ghior-I, while decreased in Sonatala-I, Ghatail-NI and Ghatail-I profiles. It was also revealed that most of the irrigated soils contained higher Fe_p in their underlying horizons due to more leaching than those of non-irrigated soils.

Aluminium (Al_p)

Results presented in Table-18 indicated that Al_p in Gangetic soils varied from .002 to .057 percent, and ranged from .001 to .164 $Al_2O_3\%$ in soils of Brahmaputra alluvium.

Gangetic soils contained relatively low Al_p than Brahmaputra alluvium soils presumably due to their high pH value. Soils like Sara-NI, Sara-I and Pakuria-NI contained maximum Al_p in the surface horizons than the underlying horizons due to relatively low pH of the surface horizon.

It was indicated that Al_p decreased significantly with depth in Sara -NI ($r=-.9087^{**}$) and Ghatail -I ($r=-.777^{*}$) (Appendix-IV). Al_p also decreased irregularly with

depth in Sara-I, Pakuria-NI, Sonatala-NI, Sonatala-I and Ghatail-NI, while it reversed in Ghior-I.

The maximum concentration of Al_p in the upper layers was due to lack of leaching and low pH.

Dolut *et al.* (1987) found that pyrophosphate extractable aluminium varied from 125 to 395 ppm in the soils of Jalpaiguri district of west Bengal. They also reported that the highest concentration of pyrophosphate extractable aluminium was found near the surface of the soils.

Mineralogical Properties of Soils

Under the present investigation the mineralogical properties included mineralogical composition of sand and clay fraction in topsoil, subsoil and substratum of the studied profiles. The results are summarized and discussed below:

Mineralogical composition of sand fraction ($>50\mu m$)

The results presented in Table-19 indicate that the sand fraction of the both Gangetic and Brahmaputra alluvia contain mainly quartz, feldspars and mica as major primary mineral. Quartz was found to be the dominant mineral followed by mica and feldspars. In Gangetic soils the contents of quartz, feldspars, and mica ranged from 52 to 98%, 1.0 to 11% and 2.0 to 27% respectively. In Brahmaputra alluvium soils quartz, feldspar and Mica ranged from 61.0 to 89%, 2 to 7% and 1.0 to 24% respectively.

It was also observed that Gangetic alluvium soils like Ghior-I contained nearly 1% magnetite, while in Brahmaputra alluvium soils it contained upto 4% magnetite. Both soils were observed to contain some coloured minerals.

The floodplain deposits of Bangladesh contain upto 60% quartz and 15 to 30% feldspars, while mica content is variable and depends mainly on the grain size of the sediments (Huizing, 1971).

It was observed that Gangetic soils like Sara-NI contained lower amounts of quartz in surface than the underlying subsoil and substratum due to variation in sediment deposition at different times. The higher amounts of feldspars and mica in surface than the subsoil are in conformity of less weathering of Sara-NI soil. Sara-I, Pakuria-NI and Ghior-I contained higher amounts of quartz in the surface. Lower amounts of feldspars and mica in their surface are related to relatively more weathering of the soils, and hence these soils are more developed than Sara-NI.

In case of Brahmaputra alluvium, it was observed that all the profiles contained higher amounts of quartz and lower amounts of mica in their surface than subsoil due to weathering. It was also revealed that Sonatala-NI and Ghatail-NI contained higher feldspar in their surface than the subsoil. Feldspar being the more weatherable minerals, lower amounts of it in surface of all irrigated profiles indicated that they are more weathered than the non-irrigated ones. Saheed (1985) reported that the floodplain deposits are richer in relatively easily weatherable minerals (25-40%) such as feldspars and biotite. He also stated that the younger Brahmaputra floodplain deposits has relatively higher mica and lower quartz than the old Brahmaputra flood plain area.

The presence of magnetite in Ghior-I, Sonatala-I and Ghatail-NI indicated that the soils are more weathered than others and hence more developed.

The presence of hornblende in Sonatala-NI, Sonatala-I, Ghatail-NI and Ghatail-I presumably reflects the acidic background of soils.

Table 19: Mineralogical composition of the sand fraction (>50 μ m) of the studied soils

Soil series	Horizon	Depth (cm)	Mineralogical composition expressed as percent											
			Quartz	Feldspar	Mica	Organic matter	Rock fragments	Magnetite	Hematite	Hornblende	Tourmaline	Garnet	Coloured mineral	Unidentified
GANGES ALLUVIUM	Ap ₁ B _{2w} C ₂	0-11	66.44	5.37	27.52	-*	-	-	-	-	-	-	0.67	-
		13-26	74.53	4.62	12.50	-	7.87	-	-	-	-	-	.046	-
		57-97	80.35	5.95	13.39	-	-	-	-	-	-	-	-	-
SARA (Non-irrigated)	Ap _{1g} B _{21w} C ₃	0-11	84.35	6.95	5.22	-	-	-	-	-	-	3.48	-	
		15-33	78.52	11.33	8.20	-	-	-	-	-	-	-	1.95	-
		148-180	77.46	3.76	17.37	-	-	-	-	-	-	-	1.41	-
PAKURIA (Non-irrigated)	Ap _{1g} B _{22w} C ₁	0-13	82.23	2.00	10.60	4.29	0.85	-	-	-	-	-	-	-
		29-42	51.69	0.78	26.63	15.66	4.96	-	-	-	-	-	.26	-
		83-108	97.68	1.32	3.31	11.92	17.21	-	-	-	-	-	1.65	-
GHIOR. Irrigated	Ap _{1g} B _{21wg} C _{1g}	0-15	75.43	0.65	1.73	11.30	-	0.43	-	-	-	-	-	0.21
		20-32	65.41	1.07	1.60	28.95	-	-	-	-	-	-	1.34	-
		76-97	69.87	1.86	12.42	5.90	-	0.93	-	-	-	-	0.31	0.93
BRAHMAPUTRA ALLUVIUM	Ap ₁ B _{21w} C ₂	0-11	85.32	5.36	3.97	-	-	-	-	4.76	-	-	-	-
		14-35	71.97	3.18	23.57	-	-	-	-	1.27	-	-	-	-
		130-165	60.96	6.15	17.91	-	-	-	-	-	-	-	14.97	-
SONATALA. Non-irrigated	Ap _{1g} B _{2w} C ₃	0-10	82.37	6.88	6.42	-	-	4.13	-	-	-	-	-	-
		15-31	79.83	6.91	8.84	0.55	-	-	-	-	-	-	3.87	-
		140-200	83.93	5.36	5.95	-	-	4.16	-	0.60	-	-	-	-
GHATAIL. Non-irrigated	Ap _{1g} B _{21wg} C ₃	0-10	86.31	3.42	5.87	.24	0.49	-	-	1.22	1.22	-	-	-
		13-20	84.77	2.46	9.43	.82	0.41	.41	-	0.41	1.29	-	-	-
		135-160	88.93	1.95	0.65	.65	2.281	1.30	2.28	-	-	-	-	-
GHATAIL. Irrigated	Ap _{1g} B _{21wg} 11C ₂	0-9	84.95	3.76	5.91	-	-	-	-	-	-	5.38	-	-
		13-38	73.40	4.26	19.50	-	-	-	-	-	-	-	2.84	-
		88-160	75.37	8.09	13.97	-	-	-	-	0.37	1.46	0.74	-	-

- = Not identified

Mineralogical composition of the clay fraction

The clay minerals were identified by X-ray diffractogram method, (Fig.3-6) and their relative abundance were calculated from the individual peak areas and were expressed as percent.

The data presented in Table-20 indicated that Gangetic alluvium soils contained clay minerals like smectite, illite, chlorite and kaolinite.

It was found that Gangetic alluvium soils were highly dominant in smectite (56-75%) with some illite, chlorite and kaolinite. Their contents widely varied with respect to soil, horizon and management.

It was observed that in Brahmaputra alluvium soils, the major clay minerals were illite, chlorite and kaolinite. Sonatala-I and Ghatail-NI soils contained small amounts of vermiculite in their subsoil. Small amounts of smectite were also observed in the subsoil of Sonatala-I and Ghatail-I profiles.

Considering the vertical distribution of the clay minerals with respect to topsoil, subsoil and substratum, it was observed that Sara-NI contained maximum smectite in the surface.

It was also observed that irrigated Sara-I and Ghior-I contained relatively higher amounts of smectite than the non-irrigated Sara-NI. There may be two types of smectities in the present soils. These are allogenic (minerals present in the parent material) and authigenic (synthesized). It appears that some of the smectites are of pedogenic origin. The likely pathways of the formation of smectite in the irrigated rice soils is outlined below (Fig. 7):

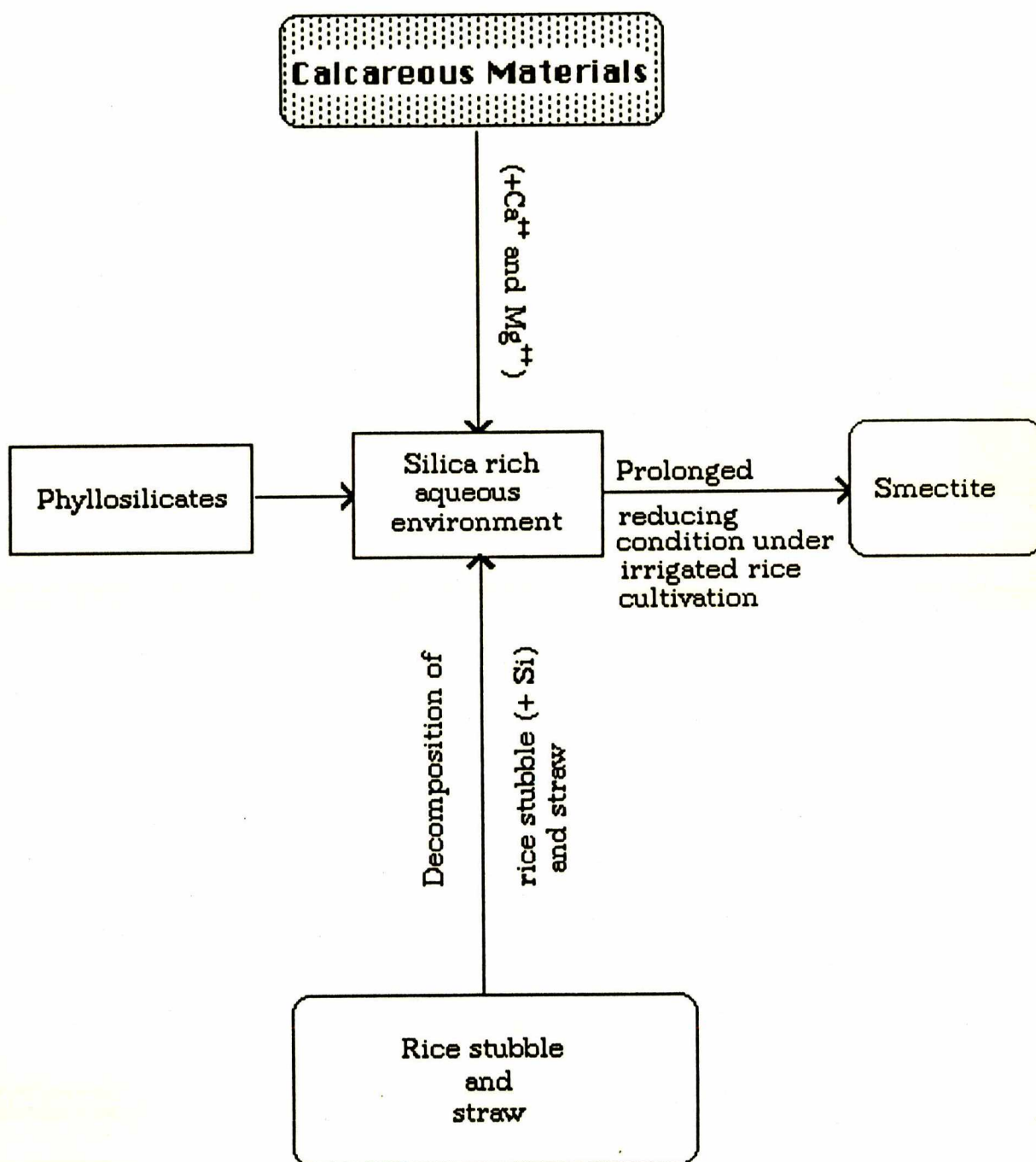


Fig.7: Likely pathways of the formation of smectite in the irrigated rice soils

The pathways (Fig. 7) of the formation of smectite in the irrigated soils under rice cultivation are based on the following evidences:

- 1) Presence of large amounts of hydrosesquioxides in the profile of the prolonged reduced soil (Sara-I, Sonatala-I, Table-16).
- 2) Calcareous materials (sediments) contain large amounts of Ca^{++} and Mg^{++} , (Table-9), more particularly in the Gangetic alluvial soils (ranged from 6.69 to 26.26 me/100g Ca and .63 to 4.54 me/100g Mg) with dominance of smectite (Table-20).
- 3) No smectite was found in the non-irrigated Brahmaputra alluvium soils, where the exchangeable Ca^{+} and Mg^{++} was less than Gangetic alluvial soils (Table-12). But small amounts of smectite was found in the reduced soils under irrigated rice cultivation (Sonatala-I and Ghatail-I, Table-20).
- 4) Rice straw is rich in silica, its decomposition in situ under prolonged irrigated rice cultivation would release a larger quantity of soluble silica in soil environments. This has been observed in the simulated experiment (Table-33).
- 5) Presence of larger amounts of smectite in the Gangetic alluvial soils, with a tendency to increase intensity in the more reduced soils under prolonged cultivation of irrigated rice.

Sen and Chatterjee (1957 and 1960) reported about the presence of small amounts of smectite in Ganges silt. Saheed (1985) reported the presence of some smectites in Gangetic soils like Sara and Rathuria series. Karim (1985) stated that Ganges alluvia are calcareous and mainly occur in the meander floodplain landscape, ridges, basin and old channels and are dominant in mica and vermiculite minerals in clay fractions. The soils of Ganges tidal alluvium are dominated by mica with some kalonite and smectite. White (1985) studied a large number of soils from Bangladesh and reported that smectites are mostly present in the Gangetic alluvial soils but he did not mention the abundance of it. Mia (1990) reported that Sara and Ghior series of Ganges

alluvium contained small amounts (5-20%) of montmorillonite throughout the profile. Ghosh and Datta (1974) and Ghosh *et al.* (1974) found 30 to 60% of smectite in a few Gangetic alluvial soils of west Bengal. Ghosh *et al.* (1976) observed that the proportion of smectite in many Gangetic alluvial soils is higher than what is found in the washings carried by the Ganges and interpreted that this changes occurred due to the pedogenic formation of smectite in the soils. They reported that the studied soils were under rice cultivation which keeps the soils under reducing condition for a part of the year and produce impeded drainage. They also clarified that hydrosesquioxide on surface of phyllosilicates under reduced condition possibly serve as nucleus for smectite crystal growth in these soils. The subsequent growth of crystal takes place by silication which generates the phyllosilicate layers. Jackson (1965) proposed such type of mechanism of montmorillonite crystal growth. Ghosh (1973) found that rice cultivation induces smectite formation from other 2:1 lattice minerals. Ghosh *et al.* (1976) postulated that the smectites in their studied soils appear to have been inherited partly from the alluvium and partly formed through pedogenic process under condition of rice cultivation. The formation of smectites are favored by poor drainage, high pH and the presence of high Ca^{++} and Mg^{++} . The findings under the present investigation are in agreement with those of Johnson *et al.* (1963), Vander Merwe *et al.* (1965); Jackson (1964); Brady (1974) Vinayak *et al.* (1984) and Acquaye *et al.* (1992).

Although Brahmaputra alluvium have no smectite, the presence of 7% smectite was observed in the subsoils of Sonatala-I and 8% at 88 cm of Ghatail-I. It was due to double HYV rice cultivation for long period under irrigated condition, which favoured pedogenic changes.

The presence of small amounts of illite, chlorite, and kaolinite (Table-20) in Gangetic soils are presumably because of inherent clay minerals of the original sediments. However, in most of the Gangetic alluvium soils illites were found to decrease with the increase of smectite possibly due to transformation to smectite. Robert (1973) reported the transformation of glauconites and illites to smectite.

Table 20: Mineralogical composition of clay fraction (<2 μ m) of the studied soils.

Soil series	Horizon	Depth (cm)	Clay mineral composition (percent)				
			Smectite	Illite	Chlorite	Kaolinite	Vermiculite
GANGES ALLUVIUM							
SARA, Non-irrigated	Ap ₁	0-11	67	10	12	11	-
	B _{2w}	13-26	64	10	18	8	-
	C ₂	57-97	56	18	12	14	-
SARA, Irrigated	Ap _{1g}	0-11	69	11	7	13	-
	B _{21w}	15-33	72	14	6	8	-
	C ₅	148-180	74	6	11	9	-
PAKURIA, Non-irrigated	Ap _{1g}	0-13	65	15	4	16	-
	B _{22w}	29-42	66	9	15	10	-
	C ₁	83-108	71	8	11	10	-
GHIOR, Irrigated	Ap _{1g}	0-15	69	9	14	8	-
	B _{21wg}	20-32	69	17	3	11	-
	C _{1g}	76-97	75	8	10	7	-
BRAHMAPUTRA ALLUVIUM							
SONATOLA, Non-irrigated	Ap ₁	0-11	-	46	18	36	-
	B _{21w}	14-35	-	50	22	28	-
	C ₂	130-165	-	40	10	50	-
SONATOLA, Irrigated	Ap _{1g}	0-10	-	27	29	44	-
	B _{2w}	15-31	7	31	15	42	5
	C ₃	140-200	-	53	11	33	-
GHATAIL, Non-irrigated	Ap _{1g}	0-10	-	28	21	51	-
	B _{21wg}	13-20	-	28	16	49	7
	C ₃	135-160	-	33	16	51	-
GHATAIL, Irrigated	Ap _{1g}	0-9	-	26	24	50	-
	B _{21wg}	13-38	-	27	24	49	-
	IIC ₂	88-160	9	41	15	31	4

- = Not identified

Barnhisel (1977) reported that chlorites are largely inherited as primary minerals found in metamorphic and igneous rocks or occur as alteration products from minerals such as hornblende, biotite and other ferro-magnesian minerals. Its occurrence in soils is relatively low and distribution is related to the parent material. Gupta *et al.* (1984) also demonstrated that mica and chlorite are mainly inherited from parent materials.

Dixon (1977) postulated that kaolinite is one of the most widespread clay minerals in soils and are the products of acid weathering. Brady (1974) reported 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 moderately to strong acid weathering which results from the removal of the alkalis and alkaline earth metals. McCracken *et al.* (1962) and Gupta *et al.* (1984) were of the opinion that kaolinite is formed through the weathering of feldspars.

Under the present investigation it was observed that the soils of Brahmaputra alluvium contained 27 to 53% illite, 10 to 29% chlorite and 31 to 51% kaolinite. The minerals are mainly the inherent component of parent material.

However, the higher amounts of illite in Sonatala-NI is presumably due to less weathering. The higher amounts of kaolinite in surface of Ghatail-NI and Ghatail-I in comparison with other soils were due to acidic reaction (Table-9) and hence of pedogenic product.

The presence of small amounts of vermiculite in the subsoil of Sonatala-I and Ghatail-NI were pedogenic products (Smeck *et al.* 1968 and Douglas, 1977).

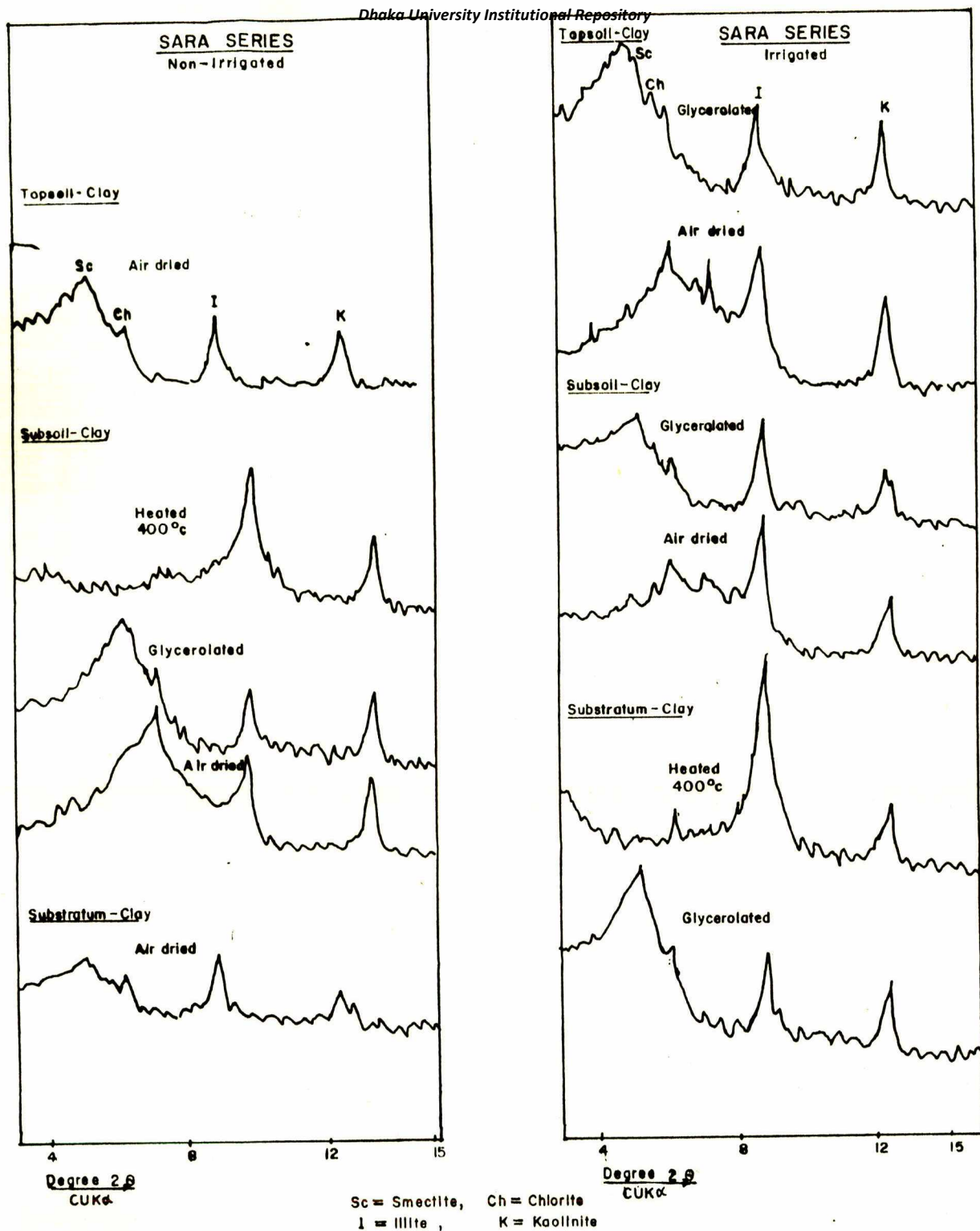


Fig. 3. X-ray diffractograms of topsoil, subsoil and substratum-clays from Sara, non-irrigated and irrigated profiles

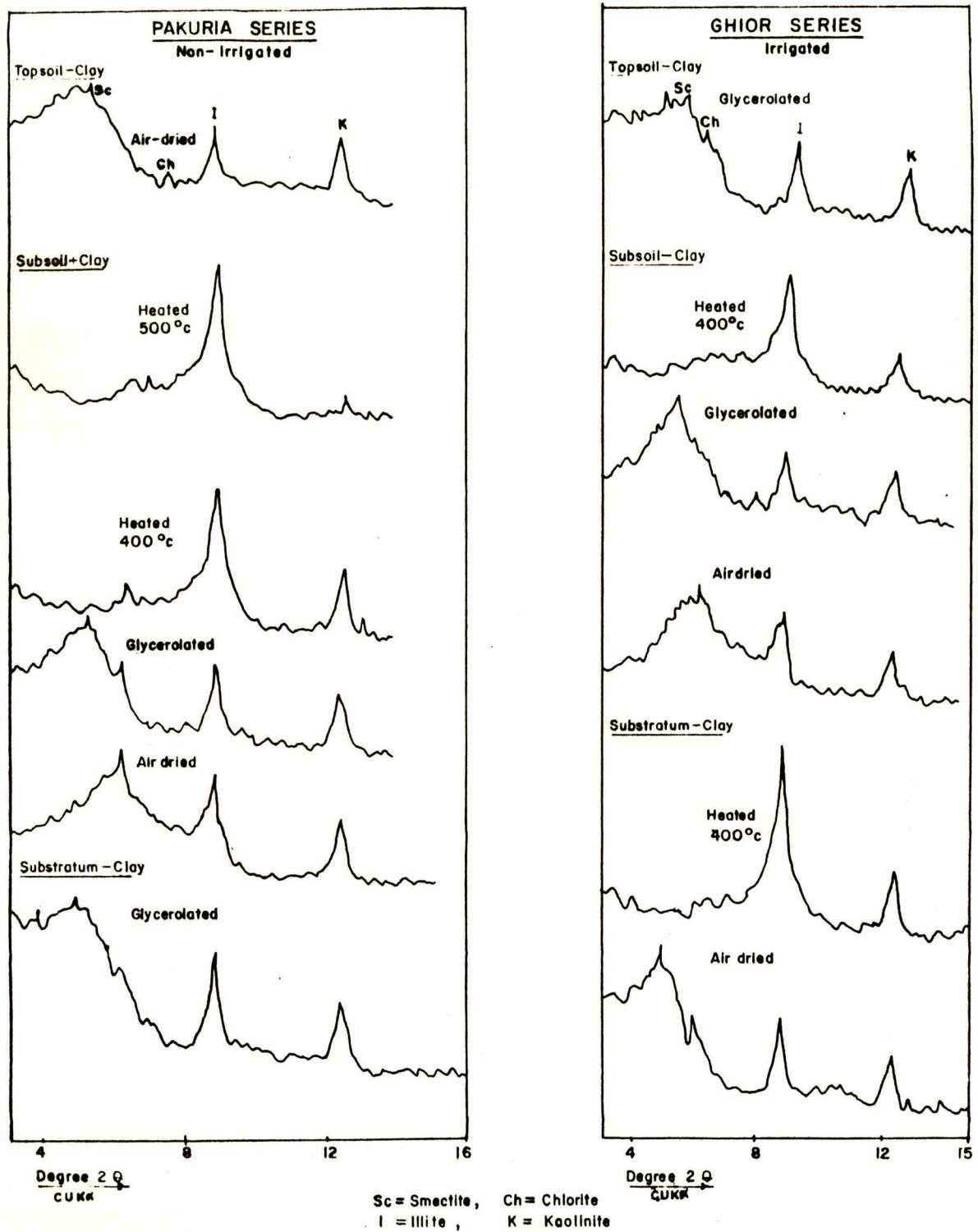


Fig. 4. X-ray diffractograms of topsoil, subsoil and substratum-clays from Pakuria, non-Irrigated and Ghior-irrigated profiles

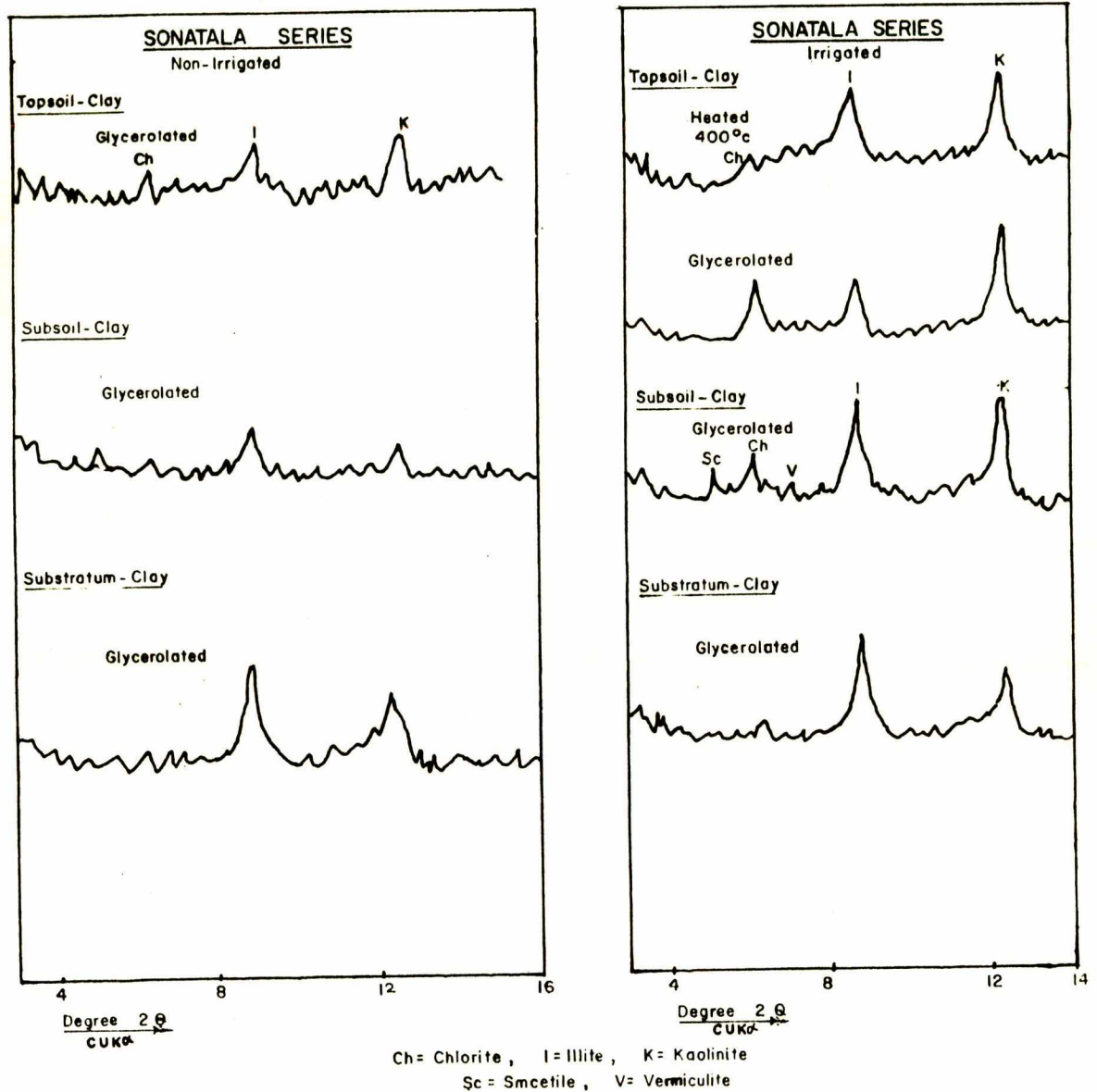


Fig 8. X-ray diffractograms of topsoil, subsoil and substratum-clays from Sonatala non-irrigated and irrigated profiles

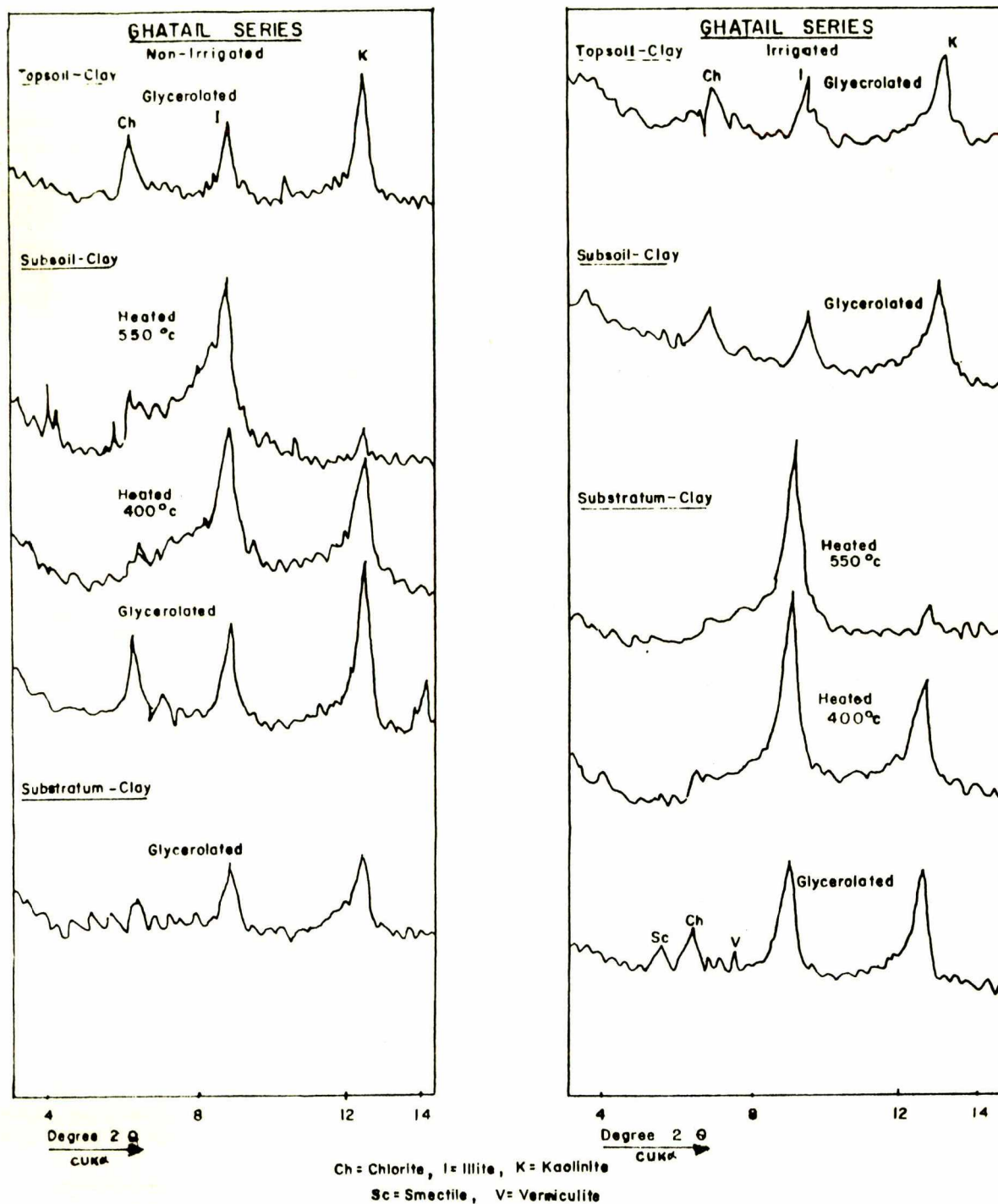


Fig 6 X-ray diffractograms of topsoil, subsoil and substratum-clays from Ghatail non-irrigated and Irrigated profiles

SOIL CLASSIFICATION

In the present investigation, one of the important objectives was to classify the studied soils in the family category of USDA system (Soil survey staff, 1975) on the basis of their inherent characteristics. The results of the morphological, physical, chemical and mineralogical properties of the studied soils profiles as presented in the previous chapters revealed that there was a variation in surface and subsoil colours, texture, structure, pH, calcium carbonate, base saturation percentage, ESP, effervescence and clay mineral composition. The variation of the above properties in the profiles was considered very important in differentiating the soils into order, suborder, greatgroup, subgroup and family. The studied soil series from the Ganges (Sara-NI, Sara-I, Pakuria-NI and Ghior-I) and the Brahmaputra alluvium (Sonatala-NI, Sonatala-I, Ghatail-NI and Ghatail-I) have been characterized on the basis of the results presented in Table-21.

Results presented in the above table show that structures (Prismatic or blocky) have developed in the subsoils of all the studied profiles, which indicates the destruction of alluvial stratification and their alteration. The leaching loss of CaCO_3 , exchangeable bases and sesquioxides from the surface to the underlying horizons and the gradual decrease of organic carbon from the upper layers to the lower layers proved that sufficient alteration has taken place in these soil profiles (Table-9, 12, 16 and Fig. 1a, 1b, respectively). Hence it was assumed that cambic horizon has developed in all the studied profiles. Therefore, the Sara, Pakuria, Ghior, Sonatala, and Ghatail soils may be placed in the Inceptisols order.

Inceptisols are subdivided into suborders on the basis of differences in soil moisture regime, climatic parameter and some extreme physical and chemical properties. The studied soils on the basis of their relevant properties as presented in Table-21 can be placed into two suborders, Aquepts and Ochrepts. The soil series like Sara-I, Pakuria-NI, Ghior-I, Sonatala-I, Ghatail-NI and Ghatail-I fall in the Aquept suborder due to their reduced colour (chroma ≤ 2), and Sonatala-NI can also be placed tentatively in the same suborder. While Sara-NI due to high chroma fall into the Ochrept suborder. The Sara-I and Sonatala-I due to their man-induced irrigation and prolonged period of rice culture are found to acquire some aquic properties in their surface

horizons, which has been called "anthraquic epipedon" in the present investigation. It can be noted that in the USDA system the surface soil having high chroma (i.e ≥ 3.5 moist) are classed as Ochric epipedon, but the greyer surface soils that forms under poor drainage condition have not as yet been classed.

The Ochrepts formed from calcarious parent material have calcium carbonate in the cambic horizon or in the C horizon or have base saturation that is 60 per cent or more by (NH_4OAc method) in some sub-horizon that occur between 25 and 75 cm below the soil surface were classed in Eutrocrepts great group. Among the studied soils only Sara-NI fall within Eutrocrepts great group. But other calcareous soils having grey colours do not fit well in any other great group. Sonatala-NI soil fit into Haplaquept great group as it has high chroma surface soil colour. Other greyer soils such as Sonatala-I, Ghatail-NI and Ghatail-I also can be tentatively placed into this great group.

However, at the subgroup level, the Sara-NI, Sara-I and Pakuria-NI fit in the aquic Eutrocrepts subgroup as they have calcium carbonate within 75 cm depth, > 60 per cent base saturation, mottles with chroma 2 within 60 cm depth and organic carbon contents that decreases regularly with depth (Fig 1a and 1b). SRDI Staff (1970) correlated Sara, Pakuria and Ghior in the Aeric Haplaquepts subgroup.

The studied soils like the Sonatala-NI, Sonatala-I, Ghatail-NI, Ghatail-I and Ghior-I fit in the Aeric Haplaquepts sub group as they have hyperthermic temperature regime, <15 per cent sodium saturation and horizon with chroma >2 within 75 cm depth.

It should be noted here that all the above soils have hyperthermic temperature regime (Table-21).

Table 21. Derived values for soil classification

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Soil Series	Surface soil colour (moist)	Subsoil colour (moist)	Subsoil texture	Subsoil structure	Organic carbon (decreased from top to substratum)	CaCO ₃ (In profile)	ESP	BSP upto 75 cm depth	pH range upto 50 cm depth	Ec mmhos/cm	Effervescence (In profile)	Temperature regime	Clay mineralogy class
Sara-NI	Olive (M.5y5/4)	Light olive brown to olive (M.2.5y5/4 5y/3)	Silt loam	Moderate coarse prism	.82-.12	5.1-13.2	2.97	97 to >100	7.98-8.20	<1	Effervescence	Hyperthermic	Smectitic
Sara-I	Dark greyish brown (M.2.5y5/2)	Light olive brown to olive brown (M.2.5y5/4-4/4)	Silt loam	Moderate coarse to medium prisms breaks into angular blocky	.90-.16	5.6-10.9	8.28	72 to >100	8.05-8.35	<1	Effervescence	Hyperthermic	Smectitic
Pakuria-NI	Olive grey (M.5y5/2)	Olive brown (M.2.5y4/4)	Clay	Strong coarse to medium prisms breaks into angular blocky	.70-.16	1.8-10.5	3.21	36 to 100	7.85-8.24	<1	Effervescence	Hyperthermic	Smectitic
Ghior-I	Olive grey (M.5y5/2)	Dark greyish brown (M.2.5y4/1.5)	Clay	Strong coarse to medium prisms breaks into very fine to fine angular blocky	1.13-.31	1.3-8.5	2.37	29 to 49	7.65-8.10	<1	Effervescence	Hyperthermic	Smectitic
Sonatala-NI	Olive brown M.2.5y4/4)	Olive brown (M.2.5y4/4-5/4)	Silt loam	Moderate coarse & medium prisms	1.55-.46	0.9-2.9 (below 100 cm)	5.77	33 to 53	5.10-6.86	<1	No effervescence	Hyperthermic	Mixed
Sonatala-I	Dark greyish brown (M.2.5y4/2)	Olive brown (M.2.5y4/4)	Silt loam	Strong coarse to medium prisms breaks into angular and sub angular blocky	1.55-.40	0.4-2.7	5.49	29 to 41	7.24-7.42	<1	No effervescence	Hyperthermic	Mixed
Ghatal-NI	Dark grey (M.10yr4/1)	Dark grey to dark brown (M.10yr4/1 to M.10yr5/4-4/3)	Clay	- Do -	2.54-.39	0.2-2 (below 200 cm)	1.75	13 to 21	4.65-7.30	<1	No effervescence	Hyperthermic	Mixed
Ghatal-I	Dark grey (M.10yr4/1)	Very dark grey to olive brown (10yr3/1-4/1 to 2.5y5/4)	Clay	- Do -	2.15-.27	0.7-2.0 (below 38 cm)	2.92	17 to 35	5.50-7.65	<1	No effervescence	Hyperthermic	Mixed

On the basis of calcareous and reaction classes the Ghior-I may be classed as calcareous, while Sonatala-NI, Sonatala-I, Ghatail-NI and Ghatail-I can be placed under the non-acid class.

On the basis of mineralogy classes Sara-NI, Sara-I, Pakuria-NI and Ghior-I soils can be designated as smectitic (as they have >50% smectite mineral in the clay fraction). Sonatala-NI, Sonatala-I, Ghatail-NI and Ghatail-I are classed as mixed as they do not have any particular clay mineral, which is more than 50%.

Thus the studied soils were found to fit into one order (Inceptisols), two suborder (Aquepts and ochrepts), two great groups, (Eutrocrepts and Haplaquepts), two sub groups (Aquic Eutrocrepts and Aeris Haplaquepts) and five families (Table-22).

SRDI Staff (1970, 1975) tentatively classified these soils of Bangladesh upto the subgroup level mainly on the basis of their morphological properties. Zijssvelt (1980) extended the classification of these soils upto the family category depending on SRDI reconnaissance soil survey reports. These were also mainly based on morphological properties. He made the mineralogy classes on theoretical basis.

Table 22. Classification of the studied soils at the family level*.

Order	Sub-order	Great-group	Sub-group	Family	Series
Incepti-sols	Ochrepts	Eutrocrepts	Aquic Eutrocrepts	Loamy, smectitic, hyperthermic, Aquic eutrocrepts	Şara-NI and Sara-I
				Clayey, smectitic, hyperthermic, Aquic eutrocrepts	Pakuria-NI
	Aquepts	Haplaquepts	Aeric Haplaquepts	Clayey, smectitic, hyperthermic, calcareous, Aeric Haplaquepts	Ghior-I
				Loamy, mixed, non-acid, hyperthermic Aeric haplaquepts	Sonatala-NI and Sonatala-I
				Clayey, mixed, non-acid, hyper thermic, Aeric Haplaquepts	Ghatail-NI and Ghatail-I

* USDA Soil Taxonomy (Soil Survey Staff, 1975 and 1992)

SIMULATION EXPERIMENT

To observe the major chemical and electrochemical changes that took place in soils at alternate wetting and drying and permanently waterlogged situations with the addition of different amounts of organic matter, some important chemical parameters like $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, Na, K, Ca, Mg, Fe Mn, Zn, Cu and ferrous iron of soil solution and the electrochemical properties such as PH, redoxpotential and Ec of standing water after 15, 30, 60, and 120 days were analyzed. Besides, after 120 days, simulated soils were analysed for total nitrogen, organic carbon, exchangeable Na^+ , K^+ , Ca^{++} , Mg^{++} and oxalate extractable Fe, Al & Si, electrical conductivity (Ec) and pH of simulated soils were measured and the colour of the simulated soils were also recorded to detect the possible changes that took place in soils. The results obtained from the above mentioned parameters are summarized and discussed below under the following sub headings. (The correlation values obtained for different parameters are given in Appendix-V-X1).

Chemical Changes in Soil Solution

Soil solution were analyzed for $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, Ca, Mg, Na, K, Fe, Mn, Zn, Cu and ferrous iron.

The results on these elements presented in different tables are summarized and discussed below:

Changes in $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ in soil solution

$\text{NH}_4\text{-N}$

The data presented in Table-23 indicated that $\text{NH}_4\text{-N}$ concentration in soil solution increased under submergence. It was also indicated that $\text{NH}_4\text{-N}$ concentration at permanently waterlogged condition was found higher than alternate wetting and drying situations.

Table 23. Changes in NH₄-N and NO₃-N contents in soil solution with the addition of different amounts of organic matter at alternate wetting and drying and permanently waterlogged condition with time.

Soils	Organic matter treatments	NH ₄ -N (ppm)								NO ₃ -N (ppm)							
		Alternate wetting and drying condition				Permanently waterlogged condition				Alternate wetting and drying condition				Permanently waterlogged condition			
		Days from start				Days from start				Days from start				Days from start			
		15	30	60	120	15	30	60	120	15	30	60	120	15	30	60	120
SARA Non-irrigated	S0R0	0.6	1.4	1.5	2.4	0.6	4.0	3.1	4.0	1.0	0.6	0.5	-	1.0	.*	-	-
	S1R1	0.8	1.8	1.2	3.0	1.0	4.2	4.3	4.3	2.0	1.0	0.6	-	2.0	-	-	-
	S2R2	1.2	2.4	1.2	4.2	1.4	4.3	2.8	4.5	1.6	1.0	1.8	-	1.0	-	-	-
	S3R3	1.6	2.4	2.6	4.1	1.6	4.4	3.6	4.6	2.0	1.4	1.0	-	2.0	-	-	-
	S4R4	1.8	2.2	2.6	4.0	2.2	4.0	4.3	4.0	1.6	1.5	1.2	-	2.0	-	-	-
SARA, Irrigated	S0R0	0.6	1.0	1.6	3.3	1.0	4.1	1.8	4.2	1.1	1.0	1.0	-	1.2	-	-	-
	S1R1	1.6	2.5	2.6	3.4	1.8	4.3	4.3	4.6	1.2	1.2	1.2	-	1.3	-	-	-
	S2R2	1.6	1.8	2.2	3.6	2.0	4.5	3.0	4.5	1.4	1.4	1.4	-	1.4	-	-	-
	S3R3	1.6	2.4	2.6	3.7	2.2	3.6	2.8	4.5	1.6	1.4	1.8	-	1.5	-	-	-
	S4R4	2.0	2.8	3.2	4.5	2.5	4.6	3.7	4.7	2.0	1.5	1.8	-	2.0	-	-	-
PAKURIA, Non-irrigated	S0R0	2.1	2.2	2.3	2.5	2.3	4.3	3.1	4.7	1.2	1.0	-	-	1.2	-	-	-
	S1R1	2.6	2.9	3.1	3.3	2.8	5.5	3.2	5.8	1.4	1.0	-	-	1.3	-	-	-
	S2R2	3.0	3.1	3.3	3.7	3.4	5.6	3.7	5.9	1.5	1.0	-	-	1.5	-	-	-
	S3R3	3.0	3.2	3.4	3.6	3.4	5.5	3.5	5.9	1.7	1.0	-	-	1.7	-	-	-
	S4R4	3.0	3.4	3.4	3.8	3.6	5.7	3.1	5.9	2.2	1.0	-	-	2.4	-	-	-
GHIOR, Irrigated	S0R0	2.2	2.4	2.5	3.0	2.4	3.7	2.1	4.0	1.0	1.0	-	-	1.0	-	-	-
	S1R1	2.5	2.8	2.7	3.3	2.8	3.8	2.2	4.2	1.4	1.0	-	-	1.4	-	-	-
	S2R2	2.6	2.8	3.0	3.9	3.0	3.8	2.2	4.5	1.6	1.0	-	-	1.5	-	-	-
	S3R3	3.0	3.2	3.3	4.4	3.1	4.0	2.5	4.7	2.0	1.0	-	-	2.0	-	-	-
	S4R4	3.1	3.4	3.5	4.6	3.2	4.0	2.9	5.0	2.6	1.0	-	-	2.5	-	-	-
SONATALA Non-irrigated	S0R0	1.0	1.3	2.4	3.0	1.2	3.5	1.8	4.0	1.0	0.8	1.0	-	1.0	.*	-	-
	S1R1	1.4	1.6	2.8	4.0	1.4	4.5	2.2	4.5	2.0	1.0	1.0	-	2.0	-	-	-
	S2R2	1.6	1.8	3.0	4.5	1.5	5.5	3.1	5.5	2.0	1.2	1.0	-	1.8	-	-	-
	S3R3	1.8	2.0	3.2	4.6	1.6	6.5	3.2	6.6	2.5	1.0	1.2	-	2.5	-	-	-
	S4R4	1.8	2.2	3.6	4.8	2.0	6.6	3.5	6.7	3.0	1.0	1.3	-	3.0	-	-	-
SONATALA Irrigated	S0R0	1.2	1.5	2.8	3.0	1.4	3.7	2.5	5.0	1.0	1.0	1.0	-	1.0	-	-	-
	S1R1	1.4	1.6	3.0	4.2	1.5	4.8	1.8	5.8	1.2	1.0	1.0	-	1.1	-	-	-
	S2R2	1.6	2.0	3.2	4.5	1.9	4.8	3.2	5.3	1.4	1.0	1.0	-	1.4	-	-	-
	S3R3	2.0	2.4	3.4	4.8	2.0	6.2	3.8	6.8	1.6	1.0	1.0	-	1.6	-	-	-
	S4R4	2.2	3.0	3.6	5.0	2.5	6.5	4.0	8.5	1.7	1.0	1.0	-	1.8	-	-	-
GHATAIL, Non-irrigated	S0R0	3.0	3.2	3.6	3.8	3.0	5.6	3.1	7.0	1.4	1.0	-	-	1.3	-	-	-
	S1R1	3.0	3.4	4.0	4.2	3.0	6.5	2.5	6.6	1.6	1.0	-	-	1.5	-	-	-
	S2R2	3.1	3.6	4.2	4.5	3.0	7.0	3.7	7.6	1.7	1.0	-	-	1.8	-	-	-
	S3R3	3.2	3.5	4.6	5.0	3.5	8.0	3.2	8.9	1.8	1.0	-	-	2.0	-	-	-
	S4R4	3.4	3.8	4.8	5.4	3.6	8.7	3.8	9.0	2.2	1.0	-	-	2.4	-	-	-
GHATAIL, Irrigated	S0R0	3.0	3.2	3.4	4.1	2.8	5.6	2.5	7.0	1.4	1.0	-	-	1.3	-	-	-
	S1R1	3.2	3.8	4.0	4.2	3.2	6.5	3.6	8.0	1.8	1.0	-	-	1.6	-	-	-
	S2R2	3.4	4.0	4.4	4.9	3.4	6.8	3.8	8.5	2.0	1.0	-	-	1.8	-	-	-
	S3R3	3.6	4.1	4.8	5.2	3.6	7.0	4.5	9.2	2.2	1.0	-	-	2.0	-	-	-
	S4R4	3.6	4.3	5.0	5.6	4.0	7.5	5.1	9.0	2.6	1.2	-	-	2.5	-	-	-

.* = Not detected

It was also observed that peak values of $\text{NH}_4\text{-N}$ at alternate wetting and drying situations were obtained at 120 days. While $\text{NH}_4\text{-N}$ concentration under submergence was found to increase sharply upto 30 days and then decreased upto 60 days which again gradually increased and reached upto a peak value at 120 days and this value was found to sustain near to 30 days value.

Ponnamperuma (1985) reported that the mineralization of organic N in submersed soils stops at the $\text{NH}_4\text{-N}$ stage and hence it accumulates in soils due to submergence. He reported that the kinetics of ammonification varies with the soil, temperature and pretreatment of the soil.

It was observed that $\text{NH}_4\text{-N}$ conc. was increased with the increase of organic matter in soil solution both at alternate wetting and drying (AWD) and permanently waterlogged (PWL) situations. The increase of $\text{NH}_4\text{-N}$ with the increase of organic matter at AWD was found mostly significant (Appendix-V) in case of Sara-NI at 30 and 120 days period, while it was highly significant at all stages in Ghior-I, Sonatala-NI, Sonatala-I, Ghatail-NI and Ghatail-I.

Under PWL condition of $\text{NH}_4\text{-N}$ conc. increased with the increase of organic matter and found highly significant at 15 days for Sara-NI, Sara-I, and Pakuria-NI. Highly significant (Appendix-V) were observed at all stages of PWL situation for other soils.

$\text{NO}_3\text{-N}$

$\text{NO}_3\text{-N}$ at AWD situations decreased slowly upto 60 days for Sara-NI, Sara-I, Sonatala-NI and Sonatala-I and then disappeared. It disappeared after 30 days in Pakuria-NI, Ghior-I, Ghatail-NI and Ghatail-I soils. At AWD situation the medium textural soils were found to retain $\text{NO}_3\text{-N}$ for more days than fine textured soils because of slow denitrification.

Under PWD situation $\text{NO}_3\text{-N}$ disappeared after 15 days due to denitrification. The $\text{NO}_3\text{-N}$ increased with the increase of organic matter and was highly significant (Appendix-V) mostly at 15 days for all soils at AWD and PWD situations. While in case of AWD situations the increase of $\text{NO}_3\text{-N}$ was highly significant at 30 days in Sara-NI and Sara-I,

$\text{NO}_3\text{-N}$ increase was found highly significant in Sara-I and Sonatala-NI at 60 days (Appendix-V).

Ponnamperuma (1985) found that in tropical rice soils $\text{NO}_3\text{-N}$ disappeared within a few days of flooding because of denitrification and the rate of disappearance of $\text{NO}_3\text{-N}$ varied with soil and temperature. He also reported that denitrification (as measured by $\text{NO}_3\text{-N}$ disappearance) was fastest in case of clay and slowest in silt loam.

Islam and Islam (1973) worked with some Bangladesh soils and found that $\text{NO}_3\text{-N}$ decreased after 2nd week of submergence. Khind and Ponnamperuma (1981) reported that alternate wetting and drying of a soil, carrying a vigorously growing rice crop, does not cause appreciable denitrification.

Changes in Calcium, magnesium, sodium and potassium in soil solution.

Calcium

The data showed in Table-24 indicated that Ca concentration in soil solution decreased at alternate wetting and drying situations. While it increased at permanently waterlogged conditions upto certain period. The decrease of Ca conc. at AWD situations was mainly due to mineralization, immobilization and evaporation loss.

Islam *et al.* (1974) found that calcium concentration increased rapidly with time of submergence and then decreased. He also reported that in all soils, the peak values were obtained in the ninth week of submergence followed by a gradual decrease.

It was registered that Ca.conc. at AWD situations increased with the increase of organic matter in case of Ganges alluvium soils due to release of Ca from added rice stubble and roots as they contained high calcium. In case of Brahmaputra alluvium soils (a non-calcareous soils low Ca conc.) no definite trend was observed.

Under PWD condition, Ca conc. was found to increase with the increase of organic matter in most cases of Gangetic soils, while in Brahmaputra alluvium soils it increased mainly at 60 days period of PWL condition presumably due to solubilization of Ca that contained in added rice root and stubble.

However, at AWD the increase of Ca conc. with the increase of organic matter was significant (Appendix-VI) at 120 days for Sara-NI, at 15 days for Pakuria-NI, at 15,60 and 120 days for Ghior-I and at 30 days for Sonatala-NI. Whereas, it decreased significantly at 60 days for Pakuria and at 120 days for Sonatala-NI. Under PWD condition Ca conc. increased with the increase of organic matter and was significant (Appendix-VI) at 60 days for Sara-NI, at 30 days for Sara-I and Pakuria-NI, at 30 and 60 days for Ghior-I, at 60 and 120 days for Sonatala-NI and at 60 days for Ghatala-NI and Ghatala-I.

Magnesium

The data exhibited in Table-24 revealed that Mg conc. in soil solution increased at both AWD and PWL conditions of soils. At AWD situations peak values reached at 60 days and then decreased. At PWD condition Mg conc. sharply increased after 30 days and reached upto the maximum level at 120 days in case of Gangetic alluvium soils, while in Brahmaputra alluvium soils it reached upto a maximum value at 60 days and then sharply decreased.

It was also observed that Mg conc. under PWL condition was appreciably higher than those of AWD situations due to solubilization.

Islam *et al.* (1974) demonstrated that magnesium increased with time of submergence and found the peak values at 9th week of submergence and then decreased. He also reported that it varied widely in different soils.

Table 24.

Changes in calcium and magnesium contents in soil solution after addition of different amounts of organic matter at alternate wetting and drying and permanently waterlogged conditions with time

Soils	Organic matter treat-ments	Calcium (ppm)								Magnesium (ppm)							
		Alternate Wetting and drying condition				Permanently Waterlogged condition				Alternate Wetting and drying condition				Permanently Waterlogged condition			
		Days from start				Days from start				Days from start				Days from start			
		15	30	60	120	15	30	60	120	15	30	60	120	15	30	60	120
GANGES ALLUVIUM SARA, Non-irrigated	S0 R0	35	36	33	30	35	40	45	32	5.4	7.0	7.5	5.1	4.2	4.1	10.5	11
	S1 R1	39	35	29	35	39	41	50	40	5.2	7.0	7.5	5.2	4.1	4.2	11.0	11
	S2 R2	38	30	31	35	21	30	52	30	5.4	7.0	7.6	5.2	4.1	4.2	13.5	12
	S3 R3	38	33	27	36	26	32	55	28	5.4	7.0	7.5	5.3	4.2	4.2	10.0	13
	S4 R4	38	32	30	36	25	35	53	27	5.5	7.0	7.6	5.1	4.2	4.4	15.0	14
SARA, Irrigated	S0 R0	43	40	28	36	44	50	60	40	4.5	7.0	7.4	5.0	4.0	4.1	9.5	9
	S1 R1	45	41	34	36	46	60	65	45	5.1	7.0	7.5	5.1	4.0	3.9	9.5	10
	S2 R2	46	42	34	36	50	63	70	45	5.6	7.0	7.5	5.2	4.0	4.2	4.0	11
	S3 R3	42	40	31	35	44	65	75	40	5.2	7.0	7.6	5.1	4.1	4.1	10.0	11
	S4 R4	35	36	30	30	38	67	69	43	5.6	7.0	7.6	5.1	4.1	4.2	10.5	12
PAKURIA, Non-irrigated	S0 R0	59	37	33	45	58	70	80	60	5.0	7.0	7.5	5.2	4.0	4.0	11.3	11
	S1 R1	66	42	36	34	65	80	85	61	6.1	7.0	7.5	5.3	4.1	4.4	11.0	11
	S2 R2	67	42	36	46	67	82	90	62	6.3	7.0	7.5	5.3	4.1	4.1	12.0	12
	S3 R3	70	31	27	31	68	85	95	60	6.3	7.0	7.6	5.2	4.2	4.3	12.0	13
	S4 R4	71	31	16	28	72	90	100	65	7.1	7.0	7.5	5.0	4.2	4.2	15.0	14
GHIOR, Irrigated	S0 R0	40	40	30	32	41	45	50	40	5.4	7.0	7.6	5.2	4.2	4.1	14.0	12
	S1 R1	35	31	30	38	36	55	60	35	7.5	7.0	7.6	5.3	4.2	4.2	11.0	11
	S2 R2	60	56	35	40	61	70	75	50	7.7	7.0	7.7	5.2	4.2	4.5	14.0	14
	S3 R3	62	54	40	45	61	75	80	53	7.8	7.0	7.7	5.3	4.1	4.4	16.0	16
	S4 R4	60	54	40	52	62	70	83	50	7.7	7.0	7.7	5.3	4.1	4.2	16.0	16
BRAHMAPUTRA ALLUVIUM SONATALA, Non-irrigated	S0 R0	34	12	13	11	30	35	40	25	5	7	7	5	5	4	11	3
	S1 R1	35	13	15	10	34	38	42	27	5	7	7	5	4	4	10	3
	S2 R2	35	17	18	8	31	38	44	26	7	7	7	5	4	4	12	4
	S3 R3	35	17	11	8	35	38	45	28	7	7	7	5	4	4	12	4
	S4 R4	31	20	9	6	29	36	50	30	6	7	7	5	4	4	10	4
SONATALA, Irrigated	S0 R0	27	23	24	22	25	30	33	20	6	7	7	5	4	4	13	4
	S1 R1	26	27	27	30	24	25	30	21	7	7	7	5	4	4	11	4
	S2 R2	24	21	25	20	24	25	35	18	6	7	7	5	4	4	16	5
	S3 R3	27	24	23	21	30	28	40	22	6	7	7	5	4	4	17	5
	S4 R4	27	20	25	21	25	27	42	20	7	7	7	5	4	4	12	5
GHATAIL, Non-irrigated	S0 R0	26	24	24	17	34	38	40	25	5	7	7	5	4	5	15	4
	S1 R1	24	22	21	20	28	39	45	26	5	7	7	5	4	5	14	4
	S2 R2	22	22	21	20	20	36	46	25	5	7	7	5	4	5	15	4
	S3 R3	21	20	20	19	22	37	47	20	5	7	7	5	4	5	16	4
	S4 R4	24	22	21	20	28	33	48	25	6	7	7	5	4	4	15	4
GHATAIL, Irrigated	S0 R0	17	16	15	14	17	22	35	18	4	7	6	5	4	5	16	4
	S1 R1	16	15	15	15	17	18	37	20	5	7	7	5	4	4	18	4
	S2 R2	16	15	14	14	20	24	36	19	5	7	7	5	4	4	20	4
	S3 R3	13	12	12	11	20	21	37	18	5	7	6	5	4	4	15	4
	S4 R4	20	17	18	16	19	28	38	20	6	7	7	5	4	4	16	4

Mg conc. at AWD situations increased slightly in all soils with the increase of organic matter at 15 days mainly. At PWL condition it increased at 60 and 120 days for Gangetic soils but in case of Brahmaputra alluvium soils it increased at 60 days only.

Sodium

The data recorded in Table-25 indicated that Na conc. in soil solution increased with the increase of time at AWD situations, while it increased under submergence upto certain period. Na conc. in soil solution was higher at PWL condition than AWD situations. It was also observed that Na conc. in soil solution increased slightly both at AWD and PWL conditions with the increase of organic matter but in most cases it was irregular.

At AWD situations the peak values were observed at 120 days. The increasing trend was registered rapid at 60 days for medium textured Sara and Sonatala soils and it was comparatively slow in case of fine textured Pakuria, Ghior and Ghatail soils and reached upto a maximum level at 120 days.

Under PWL condition Na concentration in soil solution increased with time and reached to a peak values at 60 days and then decreased. The increase of Na conc. under submergence was presumably due to solubilization and decreasing trend was related to leaching loss.

However, at AWD situations the increase of Na conc. with the increase of organic matter was found significant (Appendix-VII) at 15, 60 and 120 days for Ghior-I, at 30 days for Sonatala-NI, at 60 days for Sonatala-I, and at 30, 60 and 120 days for Ghatail-I. In case of PWL conditions, the increase of Na conc. with the increase of organic matter was found significant (Appendix-VII) at 60 days for Sara-NI, at 30 days for Sara-I, at 60 and 120 days for Pakuria, at 60 days for Ghior and at 120 days for Sonatala-NI and Sonatala-I.

Table 25. Contents of sodium and potassium contents in soil solution with the addition of different amount of organic matter at alternate wetting and drying and permanently waterlogged conditions with time.

Soils	Organic Matter Treatments	Sodium (ppm)								Potassium (ppm)							
		Alternate Wetting and drying condition				Permanently Waterlogged condition				Alternate Wetting and drying condition				Permanently Waterlogged condition			
		Days from start				Days from start				Days from start				Days from start			
		15	30	60	120	15	30	60	120	15	30	60	120	15	30	60	120
SARA, Non-irrigated	S0 R0	57	63	66	66	60	64	75	55	8	5	4	5	7	10	11	7
	S1 R1	58	61	63	64	59	64	77	58	8	4	4	5	7	10	12	6
	S2 R2	60	63	69	70	63	76	75	60	8	5	4	4	7	11	12	8
	S3 R3	59	61	64	63	60	75	80	60	8	5	4	5	8	10	14	8
	S4 R4	57	60	66	64	59	71	85	59	7	5	5	5	6	9	11	8
SARA, Irrigated	S0 R0	42	49	56	62	43	75	82	45	8	4	4	4	7	11	12	7
	S1 R1	46	55	57	59	45	67	75	43	9	4	3	4	8	12	13	8
	S2 R2	46	51	58	61	45	74	77	45	8	4	3	4	8	12	14	8
	S3 R3	44	55	60	61	46	72	77	43	8	4	3	4	9	11	14	8
	S4 R4	46	53	54	57	48	72	75	40	10	5	3	4	11	13	15	9
PAKURIA, Non-irrigated	S0 R0	61	59	62	65	55	60	66	50	11	5	6	7	10	12	15	10
	S1 R1	64	62	63	65	65	66	74	60	12	9	7	8	11	13	16	11
	S2 R2	63	62	67	67	65	66	73	62	11	8	7	7	10	13	16	9
	S3 R3	60	58	62	60	64	72	74	61	11	7	7	8	11	14	18	12
	S4 R4	63	60	54	59	66	66	78	63	11	7	6	8	12	15	19	10
GHIOR, Irrigated	S0 R0	56	60	58	56	64	65	66	62	16	10	7	9	15	17	18	10
	S1 R1	56	60	58	58	64	72	74	60	15	10	8	9	14	18	20	11
	S2 R2	57	59	61	59	57	65	73	55	16	11	9	9	16	19	22	11
	S3 R3	57	68	61	62	63	64	74	58	15	11	10	10	16	20	23	12
	S4 R4	58	60	61	63	66	70	78	58	15	12	9	10	16	20	24	11
SONATALA, Non-irrigated	S0 R0	43	48	59	63	44	61	72	40	9	10	11	5	10	13	15	7
	S1 R1	47	49	59	63	48	68	68	41	9	10	12	6	10	14	18	8
	S2 R2	52	50	63	60	50	64	68	43	11	11	13	6	11	15	18	8
	S3 R3	46	53	79	47	48	65	74	42	11	10	14	6	12	16	19	9
	S4 R4	46	53	56	54	50	56	67	45	10	12	12	5	13	18	20	10
SONATALA, Irrigated	S0 R0	51	61	66	63	51	70	79	50	10	11	11	8	9	13	13	6
	S1 R1	51	64	66	71	55	73	80	51	11	11	10	9	10	14	15	7
	S2 R2	50	74	67	68	56	67	68	52	12	13	12	9	11	16	17	7
	S3 R3	63	65	67	71	55	65	72	52	11	13	11	10	12	18	18	8
	S4 R4	46	69	67	67	44	70	78	53	12	14	12	11	12	20	19	8
GHATAIL, Non-irrigated	S0 R0	54	61	61	64	52	60	78	50	17	15	16	10	18	20	22	12
	S1 R1	61	61	66	66	59	57	67	48	19	18	17	11	20	22	23	12
	S2 R2	55	68	66	65	64	60	66	60	15	17	17	12	20	25	27	13
	S3 R3	58	68	67	52	57	63	72	55	16	18	18	13	21	26	30	12
	S4 R4	61	66	66	65	65	58	61	60	17	20	19	14	22	26	29	14
GHATAIL, Irrigated	S0 R0	59	58	61	64	57	61	70	50	9	8	7	6	8	12	14	7
	S1 R1	60	59	61	65	56	64	72	52	8	7	7	6	7	13	15	7
	S2 R2	61	64	65	67	62	74	77	55	9	9	8	7	8	15	18	7
	S3 R3	62	65	65	69	68	62	68	60	9	10	10	8	9	16	20	8
	S4 R4	63	64	65	69	60	62	72	58	10	12	10	8	10	18	21	9

Potassium

The data in Table-25 indicated that at AWD situations K concentration in soil solution decreased, while at PWL condition it increased rapidly under submergence upto certain period (at 60 days) and then decreased and reached upto a minimum level at 120 days. K conc. in soil solution was higher under PWL than AWD situations. The decrease of K conc. at AWD was due to mineralization and leaching loss. Under PWL condition K conc. increased due to solubilization. The findings are in well conformity with Islam and Islam (1973).

It was also found that K conc. increased with the increase of organic matter in most cases under both AWD and PWL situations. However, at AWD situations it was found that K conc. increased significantly (Appendix-VII) at 30, 60 and 120 days with the increase of organic matter in Ghior-I, at 30 and 120 days for Sonatala-I, at 30 and 60 days for Ghatail-NI and at 30, 60 and 120 days for Ghatail-I. Under PWL condition, it was significant at 15, 60, and 120 days in Sara-I, at 30 and 60 days in Pakuria-NI and Ghior-I, at 15, 30, 60, and 120 days in Sonatala-NI, Sonatala-I and Ghatail-I and at 15, 30 and 60 days in Ghatail-NI.

Iron

Results (Table-26) indicated that Iron conc. in soil solution at AWD conditions was only trace at 15 and 30 days in all soils which then disappeared. Under PWL conditions, it was not detected at all at any stage. The addition of organic matter did not show any response in any soil at any situations.

Ponnamperuma (1985) reported that the average concentration of water soluble iron was higher in acid sulfate soils with a high content of reactive Fe (III) hydrous oxides and lowest in alkaline soils low in organic matter.

Table 26: Changes in Iron and Manganese contents in Soil solution with the addition of different amount of organic matter at alternate wetting and drying and permanently waterlogged conditions with time.

Soils	Organic Matter Treatments	Iron (ppm)								Manganese (ppm)							
		Alternate wetting and drying condition				Permanently Waterlogged condition				Alternate wetting and drying condition				Permanently Waterlogged condition.			
		Days from start				Days from start				Days from start				Days from start			
		15	30	60	120	15	30	60	120	15	30	60	120	15	30	60	120
SARA, Non-irrigated	S0 R0	Tr	Tr	-	-	-	-	-	-	-	Tr	-	-	-	Tr	.07	-
	S1 R1	Tr	Tr	-	-	-	-	-	-	-	Tr	-	.75	-	.10	.07	-
	S2 R2	Tr	Tr	-	-	-	-	-	-	-	Tr	-	1.0	-	.08	.06	-
	S3 R3	Tr	Tr	-	-	-	-	-	-	-	Tr	-	1.0	-	.07	.05	-
	S4 R4	Tr	Tr	-	-	-	-	-	-	-	Tr	-	1.0	-	.10	.07	-
SARA Irrigated	S0 R0	Tr	Tr	-	-	-	-	-	-	-	Tr	-	Tr	-	.08	.07	-
	S1 R1	Tr	Tr	-	-	-	-	-	-	-	Tr	-	-	-	.07	.06	-
	S2 R2	Tr	Tr	-	-	-	-	-	-	-	Tr	-	Tr	-	.07	.07	-
	S3 R3	Tr	Tr	-	-	-	-	-	-	-	Tr	-	1.4	-	.08	.07	-
	S4 R4	Tr	Tr	-	-	-	-	-	-	-	Tr	-	1.25	-	.08	.06	-
PAKURIA Non-irrigated	S0 R0	Tr	Tr	-	-	-	-	-	-	-	Tr	-	1.0	-	.08	.07	-
	S1 R1	Tr	Tr	-	-	-	-	-	-	-	Tr	-	Tr	-	.12	.08	-
	S2 R2	Tr	Tr	-	-	-	-	-	-	-	Tr	-	Tr	-	.09	.08	-
	S3 R3	Tr	Tr	-	-	-	-	-	-	-	Tr	-	1.0	-	.07	.08	-
	S4 R4	Tr	Tr	-	-	-	-	-	-	-	Tr	-	1.0	-	.09	.07	-
GHIOR Irrigated	S0 R0	Tr	Tr	-	-	-	-	-	-	-	Tr	-	Tr	-	.09	.07	-
	S1 R1	Tr	Tr	-	-	-	-	-	-	-	Tr	-	1.0	-	.08	.05	-
	S2 R2	Tr	Tr	-	-	-	-	-	-	-	Tr	-	1.0	-	.07	.07	-
	S3 R3	Tr	Tr	-	-	-	-	-	-	-	Tr	-	1.0	-	.10	.08	-
	S4 R4	Tr	Tr	-	-	-	-	-	-	-	Tr	-	-	-	.07	.08	-
SONATALA Non-irrigated	S0 R0	Tr	Tr	-	-	-	-	-	-	-	Tr	2.5	3.0	-	.11	.07	-
	S1 R1	Tr	Tr	-	-	-	-	-	-	-	Tr	3.25	Tr	-	.10	.07	-
	S2 R2	Tr	Tr	-	-	-	-	-	-	-	Tr	3.0	3.0	-	.08	.12	-
	S3 R3	Tr	Tr	-	-	-	-	-	-	-	Tr	4.5	Tr	-	.09	.10	-
	S4 R4	Tr	Tr	-	-	-	-	-	-	-	Tr	5.0	1.0	-	.09	.09	-
SONATOLA Irrigated	S0 R0	Tr	Tr	-	-	-	-	-	-	-	Tr	1.4	2.5	-	.09	.08	-
	S1 R1	Tr	Tr	-	-	-	-	-	-	-	Tr	4.0	4.0	-	.07	.07	-
	S2 R2	Tr	Tr	-	-	-	-	-	-	-	Tr	4.0	3.25	-	.07	.06	-
	S3 R3	Tr	Tr	-	-	-	-	-	-	-	Tr	2.2	1.0	-	.07	.07	-
	S4 R4	Tr	Tr	-	-	-	-	-	-	-	Tr	2.0	1.5	-	.11	.07	-
GHATAIL, Non-irrigated	S0 R0	Tr	Tr	-	-	-	-	-	-	-	Tr	1.5	2.0	-	.07	.08	-
	S1 R1	Tr	Tr	-	-	-	-	-	-	-	Tr	1.0	3.0	-	.18	.09	-
	S2 R2	Tr	Tr	-	-	-	-	-	-	-	Tr	0.4	1.5	-	.10	.09	-
	S3 R3	Tr	Tr	-	-	-	-	-	-	-	Tr	1.45	Tr	-	.08	.08	-
	S4 R4	Tr	Tr	-	-	-	-	-	-	-	Tr	1.0	Tr	-	.07	.09	-
GHATAIL, Irrigated	S0 R0	Tr	Tr	-	-	-	-	-	-	-	Tr	1.3	2.5	-	-	.09	-
	S1 R1	Tr	Tr	-	-	-	-	-	-	-	Tr	1.75	Tr	-	-	.07	-
	S2 R2	Tr	Tr	-	-	-	-	-	-	-	Tr	0.9	Tr	-	-	.09	-
	S3 R3	Tr	Tr	-	-	-	-	-	-	-	Tr	0.6	Tr	-	-	.09	-
	S4 R4	Tr	Tr	-	-	-	-	-	-	-	Tr	1.5	Tr	-	-	.08	-

- = Not detected

Tr = Trace

Table 27: Changes in Zinc and Copper contents in Soil solution with the addition of different amount of organic matter at alternate wetting and drying and permanently waterlogged conditions with time.

Soils	Organic Matter Treatments	Zinc (ppm)								Copper (ppm)							
		Alternately wetting and drying condition				Permanently water logged condition				Alternate wetting and drying condition				Permanently waterlogged condition.			
		Days from start				Days from start				Days from start				Days from start			
		10	30	60	120	10	30	60	120	10	30	60	120	10	30	60	120
SARA Non-irrigated	S0 R0	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S1 R1	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S2 R2	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S3 R3	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S4 R4	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
SARA Irrigated	S0 R0	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S1 R1	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S2 R2	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S3 R3	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S4 R4	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
PAKURIA Non-irrigated	S0 R0	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S1 R1	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S2 R2	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S3 R3	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S4 R4	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
GHIOR Irrigated	S0 R0	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S1 R1	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S2 R2	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S3 R3	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
	S4 R4	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
SONATOLA, Non-irrigated	S0 R0	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S1 R1	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S2 R2	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S3 R3	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S4 R4	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SONATOLA, Irrigated	S0 R0	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S1 R1	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S2 R2	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S3 R3	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S4 R4	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GHATAIL, Non-irrigated	S0 R0	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S1 R1	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S2 R2	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S3 R3	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S4 R4	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GHATAIL, Irrigated	S0 R0	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S1 R1	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S2 R2	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S3 R3	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S4 R4	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Tr = Trace

- = Not detected

Manganese

Table-26 indicates that Mn conc. in soil solution increased with time at AWD situations, while it decreased at PWL condition. It was also revealed that the addition of organic matter in soils did not show any response at all stages and situations. Mn conc. in soil solution was recorded upto 1 ppm in case of Gangetic alluvium soils, while in Brahmaputra alluvium soils, it was 5 ppm.

Zinc and copper

Data presented in Table-27 recorded that Zinc in soil solution was detected only in trace amounts in all soils at 30 days at AWD situations. Under PWL condition it was not detected.

Copper in soil solution at AWD conditions was found in trace amounts in Gangetic soils but not in Brahmaputra alluvium. Under PWL condition it was detected at all in any soil (at any stage). It was also revealed that the effect of organic matter on Zn & Cu did not show any response at any stage possibly due to short period of experiment (120 days).

Ferrous iron in soil solution

The results (Table-28) indicated that at AWD situations ferrous iron was not observed, while with the increase of organic matter it increased slightly in all soils of Ganges (1 to 2 ppm) and Brahmaputra alluvium (1 to 4 ppm) except Sonatala-NI where 1.00 ppm was recorded at all stages.

Table-28. Changes in ferrous iron and electrical conductivity in soil solution after the addition of different amounts of organic matter at alternate wetting and drying and permanently waterlogged conditions with time

Soils	Organic Matter Treatments	Ferrous Iron (ppm)					Electrical conductivity Ec (μ s/cm)														
		Alternate wetting and drying conditions					Permanently waterlogged conditions					Alternate wetting and drying conditions					Permanently waterlogged conditions				
		Days from start					Days from start					Days from start					Days from start				
		15	30	60	120	15	30	60	120	15	30	60	120	15	30	60	120				
		0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
SARA, Non-irrigated	S0 R0	0	0	0	0	0	1	3	4	1060	820	850	1040	1080	1120	1000					
	S1 R1	1	1	1	1	1	3	6	6	1080	800	900	1050	1010	1100	1000					
	S2 R2	1	1	1	1	1	4	7	8	1160	850	920	1130	1160	1200	1050					
	S3 R3	1	1	1	1	1	6	8	10	1100	840	850	1100	1150	1200	1060					
	S4 R4	2	2	2	2	2	8	10	12	1170	870	900	1150	1180	1230	1070					
SARA, Irrigated	S0 R0	0	0	0	0	0	2	3	4	970	900	900	950	1020	1060	900					
	S1 R1	1	1	1	1	1	3	6	7	1000	930	900	1020	1030	1070	920					
	S2 R2	1	1	1	1	1	4	8	9	1180	890	850	1150	1150	1180	950					
	S3 R3	1	1	1	1	1	5	6	12	1180	980	950	1160	1100	1170	960					
	S4 R4	2	2	2	2	2	8	10	14	1030	980	850	1050	1200	1250	970					
PAKURIA, Non-irrigated	S0 R0	0	0	0	0	0	1	2	4	1220	780	845	1200	1260	1300	1100					
	S1 R1	1	1	1	1	1	3	4	6	1300	970	880	1280	1310	1310	1110					
	S2 R2	1	1	1	1	1	5	7	8	1300	960	900	1290	1350	1360	1120					
	S3 R3	1	1	1	1	1	6	9	12	1350	970	980	1320	1360	1350	1150					
	S4 R4	2	2	2	2	2	8	12	14	1450	1020	740	1400	1450	1490	1180					
GHITOR, Irrigated	S0 R0	0	0	0	0	0	2	3	5	1450	1050	950	1440	1480	1500	1200					
	S1 R1	1	1	1	1	1	4	5	7	1500	1070	650	1490	1500	1560	1250					
	S2 R2	1	1	1	1	1	6	8	10	1360	1100	1000	1350	1400	1550	1260					
	S3 R3	1	1	1	1	1	8	10	12	1400	1130	1050	1410	1460	1580	1270					
	S4 R4	2	2	2	2	2	8	12	14	1350	1140	1050	1360	1400	1580	1290					

Table-28 (Contd.)

Table-28 (Contd.)

Soils	Organic Matter Treatments	Ferrous Iron (ppm)						Electrical conductivity Ec (μ s/cm)									
		Alternate wetting and drying conditions						Permanently waterlogged conditions									
		Days from start						Days from start									
		15	30	60	120	15	30	60	120	15	30	60	120				
SONATALA, Non-irrigated	S0 R0	0	0	0	0	0	4	4	4	860	600	570	700	870	860	960	850
	S1 R1	1	1	1	1	1	6	8	9	950	650	630	780	940	960	1000	900
	S2 R2	1	1	1	1	1	7	10	13	970	670	730	730	960	1000	1060	910
	S3 R3	1	1	1	1	1	10	12	16	1050	700	560	500	1040	1050	1090	910
	S4 R4	1	1	1	1	1	15	18	20	1080	720	560	560	1070	1080	1100	980
SONATALA, Irrigated	S0 R0	0	0	0	0	0	4	34	5	1120	750	700	700	1110	1120	1150	1100
	S1 R1	1	1	1	1	1	6	10	12	1100	800	700	880	1120	1150	1180	1110
	S2 R2	1	1	3	2	1	8	12	17	1088	780	710	890	1090	1160	1190	1100
	S3 R3	2	1	3	3	2	12	19	19	1110	750	720	900	1100	1170	1200	1100
	S4 R4	2	2	4	3	2	18	20	22	1200	800	725	880	1150	1180	1200	1120
GHATAIL, Non-irrigated	S0 R0	0	0	0	0	0	3	4	6	1050	800	700	850	1060	1090	1100	1040
	S1 R1	1	1	1	1	1	7	8	10	950	820	710	900	940	1100	1130	1000
	S2 R2	1	2	2	2	1	10	12	16	1080	850	780	950	1070	1030	1120	1050
	S3 R3	2	3	3	1	2	12	16	19	1100	870	730	950	1100	1120	1160	1040
	S4 R4	3	3	2	1	2	19	20	23	1120	880	700	850	1110	1180	1200	1050
GHATAIL, Irrigated	S0 R0	0	0	0	0	0	2	3	3	1220	700	500	500	1210	1280	1300	1120
	S1 R1	1	1	2	1	1	4	8	10	1125	730	600	550	1120	1200	1310	1100
	S2 R2	2	2	2	1	1	7	12	15	1300	740	600	650	1250	1260	1350	1100
	S3 R3	3	3	2	1	2	11	15	20	1340	700	650	600	1320	1360	1350	1150
	S4 R4	3	3	2	1	2	15	18	25	1390	750	580	650	1360	1380	1400	1210

Soil materials that are submerged only from time to time to short periods of saturation show little or no mobility of the Fe. Therefore, the high chroma of the matrix is preserved (Stoops and Eswaram, 1985). They also reported that when the soil material remains completely wet during several months, much of Fe and Mn is removed from the profile.

At permanently waterlogged condition, ferrous iron increased with the increase of time due to Fe (III) reduction. It was also observed that with the increase of organic matter ferrous iron increased at all stages in all soils of Ganges and Brahmaputra alluvium. Ponnampetuma, (1985) reported that during soil submergence the concentration of water soluble Fe^{++} increased to a Peak Value and then declined. Those changes varied with the pH and organic matter content of the soil.

Electrochemical Changes in Soil Solutions

The electrochemical properties of simulated soil solution like pH, Eh and Ec were measured to observe the changes that took place after the addition of different amounts of organic matter at AWD and PWL conditions of soils. Their results are summarized and discussed individually below:

pH in soil solution

Results (Table-29) indicated that pH in soil solution of Gangetic alluvium soils decreased at AWD situations with the increase of frequency. It was also observed to decrease sharply at 60 days followed by a slow decrease. In case of Brahmaputra alluvium, it increased at 30 days and then decreased.

Under permanently waterlogged condition, pH in soil solutions decreased in all soils with time. Lowest values were found at 30 days, in almost all cases except Sonatala-NI where it was noticed at 60 days.

Table 29. Changes in pH and redox potential in soil solution after the addition of different amounts of organic matter under alternate wetting and drying and permanently waterlogged conditions with time

Soils	Organic Matter treat-ments	pH					Redox Potential (mv)									
		Alternate Wetting and drying condition		Permanently Waterlogged contition			Alternate Wetting and drying condition		Permanently Waterlogged condition							
		Days from start					Days from start									
		15	30	60	120	15	30	60	120	15	30	60	120			
SARA, Non-irrigated	S0 R0	7.45	7.69	7.16	7.15	7.40	7.00	7.10	7.12	141	133	135	136	140	10	-50
	S1 R1	7.43	7.91	7.14	7.13	7.42	6.92	7.15	7.14	135	132	142	138	134	15	-60
	S2 R2	7.42	7.36	7.14	7.14	7.41	6.95	7.20	7.16	141	138	141	138	140	8	-70
	S3 R3	7.44	7.74	7.16	7.14	7.44	6.83	7.25	7.20	143	133	134	135	145	7	-90
	S4 R4	7.42	7.44	7.12	7.13	7.41	6.75	7.20	7.18	140	138	139	140	147	7	-95
SARA, Irrigated	S0 R0	7.32	7.47	7.12	7.13	7.30	6.96	7.10	7.11	171	132	135	136	165	15	-60
	S1 R1	7.35	7.35	7.10	7.12	7.34	6.99	7.20	7.16	159	131	138	135	149	10	-70
	S2 R2	7.37	7.65	7.10	7.11	7.32	7.06	7.15	7.15	154	135	140	138	135	11	-80
	S3 R3	7.40	7.35	7.10	7.12	7.20	7.13	7.14	7.15	154	134	141	140	145	8	-85
	S4 R4	7.42	7.50	7.10	7.09	7.01	7.08	7.04	7.06	146	137	143	142	145	7	-90
PAKURIA, Non-irrigated	S0 R0	7.40	7.75	7.20	7.18	7.30	7.2	7.10	7.13	138	134	143	140	130	6	-60
	S1 R1	7.39	7.55	7.16	7.17	7.29	6.85	7.15	7.14	138	132	144	145	130	5	-65
	S2 R2	7.40	7.42	7.16	7.13	7.2	6.86	7.06	7.04	136	134	144	150	120	2	-70
	S3 R3	7.38	7.38	7.12	7.09	7.30	6.91	7.16	7.14	135	136	134	140	125	3	-80
	S4 R4	7.27	7.60	7.17	7.16	2.20	6.86	7.10	7.09	140	138	135	145	130	5	-100
GHIOR, Irrigated	S0 R0	7.33	7.50	7.16	7.14	7.25	6.90	7.06	7.08	145	132	140	135	130	8	-70
	S1 R1	7.40	7.20	7.10	7.10	7.25	7.0	7.11	7.11	144	140	139	140	140	9	-80
	S2 R2	7.43	7.21	7.12	7.13	7.20	7.06	7.06	7.09	136	140	145	150	130	10	-85
	S3 R3	7.34	7.25	7.13	7.14	7.30	7.16	7.12	7.11	140	139	144	145	135	15	-90
	S4 R4	7.38	7.12	7.14	7.13	7.22	7.17	7.11	7.10	138	131	142	135	135	18	-105

Table 29 (Contd.)

Soils	Organic Matter treatments	pH				Redox Potential (mv)											
		Alternate Wetting and drying condition		Permanently Waterlogged condition	Alternate Wetting and drying condition		Permanently Waterlogged condition										
		Days from start			Days from start												
		15	30	60	120	15	30	60	120	15	30	60	120				
SONATALA Non-irrigated	S0 R0	7.51	7.93	7.14	7.16	7.35	6.9	7.15	7.25	118	137	146	135	116	10	-40	-70
	S1 R1	7.53	7.60	7.13	7.13	7.45	7.18	7.10	7.15	119	135	147	140	117	8	-50	-70
	S2 R2	7.64	8.12	7.14	7.12	7.50	7.11	7.09	7.15	106	119	152	145	108	7	-55	-75
	S3 R3	7.50	8.0	7.16	7.15	7.45	6.98	7.12	7.11	120	133	149	145	111	6	-60	-80
	S4 R4	7.56	8.1	7.14	7.16	8.35	7.13	7.10	7.00	137	138	153	150	135	5	-63	-95
SONATALA, Irrigated	S0 R0	7.59	7.87	7.18	7.17	7.40	6.78	7.18	7.10	150	122	135	130	120	15	-40	-60
	S1 R1	7.40	7.85	7.19	7.18	7.20	6.90	7.20	7.18	116	133	140	135	112	10	-50	-70
	S2 R2	7.54	7.90	7.24	7.20	7.50	6.90	7.15	7.30	106	131	138	140	103	8	-56	-75
	S3 R3	7.50	8.18	7.20	7.15	7.50	6.75	7.15	7.20	112	119	148	135	110	8	-70	-70
	S4 R4	7.52	7.88	7.20	7.18	7.50	6.78	7.20	7.25	105	125	140	130	107	7	-73	-80
GHATAIL, Non-irrigated	S0 R0	7.38	8.0	7.18	7.15	7.36	7.01	7.30	7.25	127	122	145	230	125	30	-30	-60
	S1 R1	7.74	8.45	7.16	7.13	7.70	7.06	7.65	7.50	118	116	146	130	115	25	-40	-40
	S2 R2	7.50	8.46	7.19	7.15	7.50	6.97	7.30	7.20	109	116	145	135	106	10	-25	-60
	S3 R3	7.51	8.00	7.19	7.19	7.50	6.95	7.35	7.25	106	121	144	136	104	10	-60	-70
	S4 R4	7.46	8.08	7.19	7.16	7.98	7.01	7.15	7.30	108	123	147	133	105	11	-75	-80
GHATAIL, Irrigated	S0 R0	7.49	8.08	7.17	7.20	7.48	6.92	7.35	7.37	125	122	140	130	120	10	-30	-70
	S1 R1	7.52	8.12	7.16	7.12	7.50	6.96	7.20	7.25	105	120	145	132	105	8	-50	-75
	S2 R2	7.54	8.52	7.18	7.21	7.52	6.97	7.14	7.23	108	125	140	130	100	7	-60	-60
	S3 R3	7.52	8.0	7.25	7.23	7.50	7.10	7.32	7.34	110	135	142	135	109	6	-80	-50
	S4 R4	7.45	8.0	7.20	7.18	7.44	7.06	7.40	7.25	118	132	138	133	115	5	-90	-40

Ponnamperuma (1977) reported that the overall effect of flooding is to increase the pH of acid soils and to depress the pH of sodic and calcareous soils. The increase in pH of most acid soils is due to reduction of Fe (III) to Fe (II) and the decrease in pH of alkaline soils is due to CO_2 accumulation.

It was also observed that pH in soil solution at AWD in Gangetic alluvium soils decreased in most soils with the increase of organic matter. At PWL condition it decreased initially and then increased slightly at some stages.

At AWD situations pH in soil solution in Brahmaputra alluvium soils increased slightly with the increase of organic matter at the initial stage (i.e at 15 and 30 days) but then decreased. However, in Sara-I pH was found to increase significantly at 15 days and decreased significantly at 120 days (Appendix-IX) with increasing organic matter supply.

Redox potential (Eh) in soil solution

The data (Table-29) indicated that redoxpotential in soil solution at AWD situations did not change much and remained at moderately reduced level (+100 to +400mv). On the other hand, under PWL condition it was observed to fall sharply after 15 days and reached to a highest negative value within reduced level (-100 to +100mv) at 120 days in almost all cases.

It was also observed that at 15 days of AWD situation Eh decreased slightly with the increase of organic matter mainly at 15 days and then showed a slightly increasing trend in most cases due to evolving of CO_2 . Under PWL condition Eh decreased significantly (Appendix-IX) with the increase of organic matter in almost all cases at 30, 60, and 120 days.

Ponnamperuma (1985) and Ghildyal (1989) reported that Eh falls rapidly after flooding and the decrease of Eh is dependent on the rate of decomposition of organic matter.

Electrical conductivity in soil solution (Ec)

Results presented in Table-28 indicate that electrical conductivity in soil solution at AWD situations decreased due to loss of salts through immobilization and leaching. At PWL condition it was increased with time due to solubilization of salts from soils and organic matter. The peak values were obtained in almost all cases at 60 days. It was also observed that the level of Ec obtained in both AWD and PWL conditions was below 2 mmhos/cm and hence found to be non-detrimental to agricultural crops.

Ec increased in soil solution with the increase of organic matter both at AWD and PWL conditions due to solubilization of salts contained in soils and organic matter. The electrical conductivity of the soil solution in most soils increased on flooding due to mobilization of Fe^{2+} and Mn^{2+} , formation of NH_4^+ and displacement of cations (Ponnamperuma, 1978). Shailendra Kumar *et al* (1981) demonstrated that the increase in Ec may be attributed to the increase in soluble salts particularly of Ca and Mg by CO_2 and organic acids.

The increase of Ec in soil solution with the increase of organic matter was found significant to highly significant both at AWD and PWL conditions (Appendix-VIII).

Changes in Simulated Soils

To observe the changes in soils after 120 days of alternate wetting and drying and permanently waterlogged conditions with the addition of different amounts of organic matter in soils, specially soil colour, pH, Ec, organic carbon, total nitrogen, exchangeable

calcium, magnesium, sodium and potassium and oxalate extractable iron, aluminium and silicon were determined. The results presented in different tables are summarized and discussed below:

Changes in soil colour

The data recorded in Table-30 indicate that soil colour without organic matter was not changed after 120 days under both AWD and PWL conditions. On the other hand, after addition of organic matter (rice root + stubble Table-2) at the rate of 4.76 ton/ha in Sara-I, and 10.24 ton/ha in Ghior-I, soil colour specially chroma reduced from 2 to 1.5 and in Ghatail-NI it changed from 1 to 2 with 8.86 ton/ha at AWD situations.

After 120 days of PWL condition of soil, soil colour was found to be reduced in all soils of Gangetic alluvium, mostly with higher doses of organic matter. In Brahmaputra alluvium, soil colour value was found to reduce from 4 to 3 in Sonatala-NI with all doses of organic matter and reduced in chroma from 2 to 1.5 with the highest dose of organic matter in Sonatala-I.

It was also observed that the non-irrigated soils (Sara -NI and Sonatala -NI having relatively browner colours) were reduced more than the irrigated greyer soils. This reduction might be the cause of anaerobic condition associated with organic matter (Bouma, 1983). Vepraskas and Wilding (1983) demonstrated the influence of organic matter in saturated soils for reducing soil colours.

Table 30. Changes in soil colours with the addition of different amount of organic matter under alternate wetting and drying and permanently waterlogged conditions after a period of 120 days.

Soils	Original soil colour (matrix)	Organic matter treatments	Munsell colour	
			(matrix colour of soils)	
			Alternate wetting and drying conditions	Permanently waterlogged conditions
GANGES ALLUVIUM SARA, Non-irrigated	M.5y 5/4	So R0 S1 R1 S2 R2 S3 R3 S4 R4	M.5y 5/4 M.5y 5/4 M.5y 5/4 M.5y 5/4 M.5y 5/4	M.5y5/4 M.5y5/4 M.5y4/4 M.5y4/4 M.5y4/4
SARA, Irrigated	M.2.5y 4/2	S0 R0 S1 R1 S2 R2 S3 R3 S4 R4	M.2.5y 4/2 M.2.5y 4/2 M.2.5y 4/2 M.2.5y 4/2 M.2.5y 4/1.5	M.2.5y 4/2 M.2.5y 4/2 M.2.5y 4/2 M.2.5y 4/1.5 M.2.5y 4/1.5
PAKURIA, Non-irrigated	M.5y 5/2,	S0 R0 S1 R1 S2 R2 S3 R3 S4 R4	M.5y 5/2 M.5y 5/2 M.5y 5/2 M.5y 5/2 M.5y 5/2	M.5y 5/2 M.5y 5/2 M.5y 5/2 M.5y 4/2 M.5y 4/2
GHIOR, Irrigated	M.5y 5/2,	S0 R0 S1 R1 S2 R2 S3 R3 S4 R4	M.5y 5/2 M.5y 5/2 M.5y 5/2 M.5y 5/2 M.5y 5/1.5	M.5y 5/2 M.5y 5/2 M.5y 5/2 M.5y 5/2 M.5y 4/2
BRAHMAPUTRA ALLUVIUM SONATOLA, Non-irrigated	M.2.5y 4/4	S0 R0 S1 R1 S2 R2 S3 R3 S4 R4	M.2.5y 4/4 M.2.5y 4/4 M.2.5y 4/4 M.2.5y 4/4 M.2.5y 4/4	M.2.5y 4/4 M.2.5y 3/4 M.2.5y 3/4 M.2.5y 3/4 M.2.5y 3/4
SONATOLA, Irrigated	M.2.5y 4/2	S0 R0 S1 R1 S2 R2 S3 R3 S4 R4	M.2.5y 4/2 M.2.5y 4/2 M.2.5y 4/2 M.2.5y 4/2 M.2.5y 4/2	M.2.5y 4/2 M.2.5y 4/2 M.2.5y 4/2 M.2.5y 4/2 M.2.5y 4/1.5
GHATAIL, Non-irrigated	M.10yr 4/1	S0 R0 S1 R1 S2 R2 S3 R3 S4 R4	M.10yr 4/1 M.10yr 4/1 M.10yr 4/1 M.10yr 4/1 M.10yr 4/2	M.10yr 4/1 M.10yr 4/1 M.10yr 4/1 M.10yr 4/1 M.10yr 3/1
GHATAIL, Irrigated	M.10yr 4/1	S0 R0 S1 R1 S2 R2 S3 R3 S4 R4	M.10yr 4/1 M.10yr 4/1 M.10yr 4/1 M.10yr 4/1 M.10yr 4/1	M.10yr 4/1 M.10yr 4/1 M.10yr 4/1 M.10yr 4/1 M.10yr 4/1

Note: Standard abbreviations for soil morphological characteristics according to Soil Survey Manual of USDA. Hnad book no. 18, 1951 have been used.

Electrochemical Changes in Simulated Soils

Electrochemical parameters such as pH and Ec in simulated soils were measured to detect the possible changes that took place after 120 days of AWD and PWL conditions. The results are summarized and discussed below:

pH in simulated soil

The results registered in Table-31 indicated that after 120 days of alternate wetting and drying of soils pH in comparison to original soil pH (Table-9), decreased in all Gangetic soils due to leaching and immobilization of CaCO_3 , while in Brahmaputra alluvium changes in pH was not observed presumably due to short period of experiment. It was also observed that in Gangetic soils after 120 days of permanently waterlogged condition pH decreased due to loss of CaCO_3 and bases through leaching, while it increased appreciably (i.e about a unit) in most of the soils of Brahmaputra alluvium, specially in acidic Sonatala-NI, Ghatail-NI and Ghatail-I, presumably due to solubilization of soluble salts and reductions of Fe (III) to Fe (II). The findings are in well agreement with Ponnampereuma (1965 and 1972).

pH in soils increased with the increase of organic matter at both AWD and PWL situations presumably due to solubilization of bases from added organic residues in soils. It was also observed that pH of alkaline soils increased more at AWD situations than PWL condition, while it reversed in acidic soils like Sonatala-NI, Ghatail-NI and Ghatail-I. However, the increase of pH due to the increase of organic matter was found significant in Sara-I, Sonatala-NI and Ghatail-NI at AWD situations (Appendix-X).

EC in simulated soils

Electrical conductivity in simulated soils (Table-31) increased over original values (Table-9) after 120 days of AWD and PWL situations due to solubilization of salts and reduction of Fe (III) to Fe (II) specially in PWL condition. The increase was higher at

PWL than AWD conditions due to higher reduction of Fe (III) to Fe (II) and $\text{NH}_4\text{-W}$ accumulation under anaerobic condition (Ponnamperuma, 1978).

It was also revealed that Ec increased in almost all soils with the increase of organic matter after 120 days of AWD and PWL situations of soils due to release of cations from soils and organic residues. However, in all cases EC was less than 1 mmhos/cm and hence nondetrimental to the agricultural crops, although this increase with organic matter was significant (Appendix-X) in the soils of Gangetic and Brahmaputra alluvium for both AWD and PWL conditions.

Chemical Changes in Simulated Soils

Organic carbon

The data recorded in Table-31 indicate that organic carbon in original soil (Table-10) decreased in all cases after 120 days of alternate wetting and drying and permanently waterlogged conditions due to leaching. The decrease in organic carbon at PWL was slightly higher than AWD situations.

It was also observed that organic carbon in soil increased with the increase of organic matter (rice root + stubble) in all soils after 120 days for both AWD and PWL treatments.

Soils simulated with organic matter at AWD situations contained slightly higher organic carbon than at PWL due to rapid decomposition of organic residues at AWD situations.

The increase of organic carbon with the increase of organic matter (Table-2) was highly significant with all doses (Appendix-X) after 120 days from both AWD and PWL conditions.

Table 31. Changes in pH, organic carbon, total nitrogen and electrical conductivity of soils after addition of different amounts of organic matter after 120 days of alternate wetting and drying and permanently waterlogged conditions

Soils	Organic matter treatments	pH (water)		Organic carbon %		Total nitrogen %		Electrical conductivity ms/cm	
		A*	P**	A	P	A	P	A	P
GANGES ALLUVIUM SARA, Non-Irrigated	S0 R0	7.70	7.50	0.77	0.75	.09	.085	390	502
	S1 R1	8.30	8.15	0.88	0.80	.11	.085	400	460
	S2 R2	8.50	8.20	1.02	0.85	.12	.090	420	540
	S3 R3	8.40	8.20	1.15	1.00	.11	.100	440	630
	S4 R4	8.40	8.10	1.20	1.05	.12	.110	463	682
SARA, Irrigated	S0 R0	7.90	7.80	0.85	0.84	.11	.100	340	522
	S1 S1	8.10	8.15	1.05	0.90	.10	0.09	366	552
	S2 R2	8.09	8.02	1.20	1.00	.13	.090	380	659
	S3 R3	8.30	8.10	1.32	1.02	.14	.120	400	670
	S4 R4	8.25	8.20	1.40	1.10	.15	.13	420	690
PAKURIA, Non-Irrigated	S0 R0	7.77	7.50	0.68	0.70	.10	.100	310	613
	S1 R1	8.10	8.00	0.89	0.80	.11	.090	360	650
	S2 R2	8.30	5.10	1.10	0.89	.11	.100	390	700
	S3 R3	8.30	8.00	1.30	0.95	.12	.110	400	730
	S4 R4	8.20	7.93	1.35	1.00	.13	.120	420	800
GHIOR, Irrigated	S0 R0	7.60	7.45	1.08	1.02	.12	.110	322	574
	S1 R1	7.90	7.60	1.25	1.10	.13	.120	350	600
	S2 R2	7.70	7.65	1.30	1.15	.13	.110	370	630
	S3 R3	7.65	7.50	1.45	1.20	.14	.120	380	660
	S4 R4	7.60	7.50	1.55	1.30	.15	.130	400	700

Table 31 (Contd.)

Soils	Organic matter treatments	pH		Organic carbon %		Total nitrogen %		Electrical conductivity ms/cm	
		A*	P**	A	P	A	P	A	P
BRAHMAPUTRA ALLUVIUM SONATALA, Non-Irrigated	S0 R0	5.20	6.60	0.76	0.73	.10	.07	93	418
	S1 R1	6.20	6.78	0.80	0.78	.10	.07	100	544
	S2 R2	5.98	6.10	0.95	0.90	.12	.08	120	540
	S3 R3	6.10	6.10	1.08	1.00	.12	.09	120	540
	S4 R4	6.43	6.80	1.15	1.10	.13	.11	75	857
SONATALA Irrigated	S0 R0	7.10	7.00	0.85	0.81	.10	.08	134	468
	S1 S1	7.20	7.50	0.90	0.88	.11	.09	150	408
	S2 R2	7.30	7.40	1.0	0.90	.12	.09	175	353
	S3 R3	7.20	7.30	1.12	1.03	.12	.10	200	380
	S4 R4	7.20	7.20	1.20	1.08	.13	.11	230	312
GHATAIL Non-Irrigated	S0 R0	4.60	5.50	1.25	1.20	.15	.13	227	322
	S1 R1	5.84	6.75	1.40	1.35	.18	.15	270	296
	S2 R2	6.00	6.25	1.60	1.40	.17	.14	280	420
	S3 R3	6.15	6.75	1.75	1.60	.20	.15	300	634
	S4 R4	6.10	6.50	1.85	1.65	.21	.16	350	465
GHATAIL Irrigated	S0 R0	5.50	6.50	1.17	1.15	.14	.12	109	287
	S1 R1	6.30	6.70	1.25	1.20	.16	.12	132	396
	S2 R2	6.35	6.75	1.40	1.25	.16	.13	150	350
	S3 R3	6.30	6.50	1.45	1.45	.15	.14	180	276
	S4 R4	6.10	6.50	1.65	1.50	.16	.15	240	409

A* = Alternate wetting and drying condition

**P = Permanently waterlogged condition

Total nitrogen

From the results (Table-31) it was found that original total nitrogen values in soil (Table-10) decreased after 120 days of PWL condition in almost all soils due to leaching.

Also total nitrogen increased in soils with the increase of organic matter after 120 days for both AWD and PWL, the increase being higher in case of AWD situations due to rapid decomposition of added residues. However, this increase of total nitrogen was highly significant in most of the soils (Appendix-X) for both AWD and PWL situations.

Exchangeable Calcium, Magnesium, Sodium and Potassium in Simulated Soils

The exchangeable cations like Ca^{++} , Mg^{++} , Na^{+} and K^{+} were determined after 120 days of AWD and PWL conditions following simulating soils with different doses of organic matter to find out the effects of the two management systems. The results presented in Table-32 are summarized below:

Exchangeable Ca^{++} in simulated soils

Ca^{++} contained in the original soils decreased after 120 days for both AWD and PWL due to leaching. The decrease of Ca^{++} was higher at AWD situations. Brinkman (1970) suggested that the reduction of free iron to ferrous iron during alternate anaerobic periods displaced cations like Ca^{++} .

It was also observed that Ca^{++} with the increase of organic matter decreased after 120 days of AWD situations presumably due to reduction of free iron during frequently wetting phase with concurrent oxidation of organic matter and hence ferrous iron displaced more Ca^{++} and leached from soils (Brinkman, 1970). On the other hand, increase of organic matter in most cases of PWL increased Ca^{++} , specially in Gangetic alluvium soils, presumably due to release of Ca^{++} from added organic residues.

Exchangeable Magnesium in Simulated Soils

Mg⁺⁺ from original soils (Table-10) decreased (Table-32) after 120 days of AWD in most of the soils due to leaching associated with immobilizations under PWL conditions. Mg⁺⁺ increased in all soils due to release of Mg⁺⁺ from the soil minerals.

It was also observed that with the increase of organic matter in soils Mg⁺⁺ increased after 120 days of AWD in majority of the simulated soils presumably due to release of Mg⁺⁺ from added organic residues. The increase of Mg⁺⁺ was significant in Sara-I ($r=.898^*$) (Appendix-XI). However, it decreased slightly in some soils like Ghior-I, Sonatala-NI and Ghatail-I soils possibly due to leaching loss. The decrease of Mg⁺⁺ was highly significant in Sonatala-NI ($r=-.955^{**}$).

Exchangeable sodium in simulated soils.

Na⁺⁺ contained in original soils increased after 120 days of both AWD and PWL in almost all soils (Table-31). The soils simulated under PWL contained higher Na⁺ than AWD situations due to release of Na⁺ from soil materials.

With the increase of organic matter Na⁺ increased after 120 days of AWD in majority of soils due to release of Na⁺ from organic residues during decomposition. However, it decreased slightly in some soils like Sara-NI, Sara-I and Sonatala-NI as a result of leaching from the medium textured soils.

Exchangeable potassium in simulated soils

The data presented in Table-31 indicated that K⁺ from original soils (Table-12) decreased after 120 days of AWD in most of the soils, while after 120 days of PWL it increased in majority of the soils due to release of K from organic residues.

Table 32. Changes in the contents of exchangeable calcium, magnesium, sodium, and potassium of soils after addition of different amounts of organic matter after 120 days of alternate wetting and drying and permanently waterlogged conditions.

Soils	Organic matter treat-ments	Meq/100g							
		Ca ₊₊		Mg ₊₊		Na ₊		K ₊	
		A*	P**	A	P	A	P	A	P
SARA, Non-Irrigated	S0 R0	6.40	6.72	2.25	3.94	0.87	1.32	0.29	0.43
	S1 R1	6.48	7.94	2.34	3.65	0.87	1.23	0.36	0.40
	S2 R2	5.86	7.15	3.65	3.88	0.71	1.17	0.35	0.45
	S3 R3	5.78	7.00	2.26	4.11	0.72	1.43	0.35	0.45
	S4 R4	2.21	6.79	2.42	0.87	0.81	1.37	0.37	0.43
SARA, Irrigated	S0 R0	6.96	8.50	1.50	4.54	0.91	1.69	0.29	0.64
	S1 R1	4.95	8.53	1.50	5.89	0.91	1.45	0.30	0.65
	S2 R2	6.58	9.31	1.65	6.20	0.96	1.71	0.31	0.68
	S3 R3	6.61	6.18	1.67	5.28	0.82	1.43	0.28	0.62
	S4 R4	6.07	6.67	1.67	5.50	0.68	1.39	0.31	0.73
PAKURIA, Non-Irrigated	S0 R0	5.16	5.66	2.37	3.9	0.97	1.37	0.65	0.51
	S1 R1	5.62	5.13	3.17	2.88	1.09	1.07	0.68	0.46
	S2 R2	4.14	6.05	2.57	2.82	0.88	1.14	0.62	0.45
	S3 R3	5.19	6.54	2.94	3.00	1.13	1.21	0.64	0.48
	S4 R4	4.97	6.66	2.52	3.16	1.31	1.27	0.66	0.47
GHIOR, Irrigated	S0 R0	4.51	8.58	2.62	4.50	0.79	1.41	0.60	0.64
	S1 R1	4.60	7.93	3.07	4.43	0.76	1.39	0.57	0.66
	S2 R2	4.10	11.52	2.41	5.64	0.90	1.26	0.63	0.65
	S3 R3	3.49	7.05	2.36	4.82	1.05	1.23	0.67	0.69
	S4 R4	3.28	8.77	2.47	5.72	0.87	1.47	0.68	0.73
SONATALA, Non-Irrigated	S0 R0	1.00	1.27	1.36	2.17	0.75	0.78	0.14	0.15
	S1 R1	0.90	0.87	1.37	2.12	0.72	0.79	0.14	0.18
	S2 R2	0.85	0.70	1.30	1.67	0.77	0.83	0.13	0.23
	S3 R3	0.90	0.72	1.25	1.75	0.80	1.06	0.14	0.23
	S4 R4	0.75	0.82	1.17	1.39	0.83	1.06	0.14	0.23
SONATALA, Irrigated	S0 R0	1.19	0.83	0.72	2.22	0.85	0.96	0.11	0.19
	S1 R1	1.00	1.20	0.67	3.99	0.74	0.87	0.10	0.16
	S2 R2	1.00	1.54	0.67	1.95	0.75	0.81	0.11	0.14
	S3 R3	0.95	1.15	1.41	3.32	0.73	0.89	0.17	0.18
	S4 R4	0.50	1.85	0.62	2.37	0.76	0.69	0.10	0.16
GHATAIL, Non-Irrigated	S0 R0	1.50	1.95	1.33	4.32	0.89	0.90	0.25	0.24
	S1 R1	1.00	1.63	1.47	3.63	0.97	0.90	0.28	0.25
	S2 R2	1.00	1.55	1.44	4.54	0.92	1.03	0.27	0.27
	S3 R3	1.00	2.22	1.57	3.90	0.96	1.06	0.27	0.27
	S4 R4	0.90	1.52	1.36	3.49	0.83	1.00	0.18	0.27
GHATAIL, Irrigated	S0 R0	1.44	2.36	2.10	4.37	0.82	1.05	0.16	0.19
	S1 R1	0.58	1.70	2.27	4.00	0.80	1.00	0.17	0.19
	S2 R2	0.57	1.58	2.21	4.09	0.83	1.04	0.19	0.19
	S3 R3	0.54	1.60	1.72	4.48	0.84	0.89	0.15	0.19
	S4 R4	0.40	1.59	2.05	4.17	1.10	1.09	0.18	0.19

A* = Alternate wetting and drying condition

P** = Permanently waterlogged condition

With the increase of organic matter K⁺ increased significantly ($r=.887^{**}$) after 120 days of AWD in Ghior-I and after 120 days of PWL conditions it also increased significantly in Ghior -I ($r=.911^{*}$), Sonatala -NI ($r=.894^{*}$) and Ghatail -NI ($r=.894$) (Appendix-XI).

Oxalate extractable iron, aluminium and silicon in simulated soils

Oxalate extractable Fe, Al & Si from simulated Sara-I and Sonatala-I were determined to observe the changes that took place after 120 days of AWD and PWL conditions with the increase of organic matter in Soils.

The results (Table-33) indicated that Fe_0 contained in original soils (Table-17) decreased after 120 days of AWD and PWL conditions due to leaching. It decreased more in Sara-I than Sonatala-I under PWL condition due to high pH of Sara-I as this is a lime rich Gangetic soil. After 120 days of AWD & PWL condition both Al_0 and Si_0 decreased in soils.

With increasing organic matter supply (rice root + stubble) Fe_0 in Sara-I decreased after 120 days of AWD possibly due to more oxidized state that favoured conversion of some Fe_0 to free iron oxides, while after 120 days of PWL it increased due to reduction. In case of Sonatala-I Fe_0 increased with the increase of organic matter at AWD due to low pH, while it decreased at PWL condition.

No regular trend was observed with respect to Al_0 possibly due to short simulation period of soils.

Oxalate extractable silicon (Si_0) in original soils decreased after 120 days of both AWD and PWL conditions. However, Si_0 with the increase of organic matter at both AWD and PWL situations increased presumably due to release of Si from added rice root

and stubble. But the increased in SiO_2 in Sonatala-I soils was slightly higher under PWL condition than AWD situation which facilitates the pedogenic formation of smectite in soils.

Table 33: Contents of acidified ammonium oxalate extractable iron, aluminium and silicon of simulated soils under alternate wetting and drying and permanently waterlogged conditions.

Soils	Organic Matter Treat-ments	Fe_2O_3 %		Al (ppm)		SiO_2 %	
		A	P	A	P	A	P
SARA, Irrigated	S0 R0	.858	.543	11	7	.09	.09
	S1 R1	.686	.558	7	11	.12	.12
	S2 R2	.786	.615	7	4	.12	.12
	S3 R3	.758	.558	Nd	4	.13	.13
	S4 R4	.815	.558	43	Nd	.13	.13
SONATALA, Irrigated	S0 R0	1.36	1.416	4	Nd	.13	.13
	S1 R1	1.33	1.359	9	Nd	.13	.14
	S2 R2	1.46	1.330	9	7.43	.13	.14
	S3 R3	1.33	1.387	7	Nd	.13	.14
	S4 R4	1.54	1.301	7	Nd	.14	.14

Nd= Not detected

A = Alternate wetting and drying conditions.

B = Permanently waterlogged conditions.

CHAPTER V

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

The present investigations were undertaken to study the morphological, physical, chemical, electrochemical and mineralogical properties of soils to find out the changes that took place due to alternate wetting and drying and prolonged period of saturation of soils.

Ancillary to the above investigation a simulation experiment was also carried out with the addition of different amounts of organic matter under alternate wetting and drying, and permanently waterlogged conditions of soils to ascertain associated morphological, electrochemical and chemical changes of the soils.

The study was carried out with two extensive parent materials, the Ganges and Brahmaputra alluvium. For Gangetic alluvium, soils series like Sara and Pakuria from Non-irrigated lands, Sara and Ghior from irrigated ones were studied, while Sonatala and Ghatail under both non-irrigated and irrigated situations represented Brahmaputra alluvium for the study.

The soils were studied morphologically and detail profile descriptions were recorded.

Surface soil colour of non-irrigated highland soils like Sara-NI and Sonatala-NI was olive to olive brown (M.5y5/4 to M.2.5y4/4), while it was dark greyish brown (M.2.5y4/2) in Sara-I and Sonatala-I under irrigated situations for HYV-rice cultivation although they were occupying the same position of the landscape. Their subsoil colour ranged from olive to olive brown. Surface soil colours of poorly drained soils like Pakuria-NI and Ghior-I was olive grey (5.5y5/2) and it was dark grey (M.10yr4/1) in Ghatail-NI and Ghatail-I. Subsoil colour in Pakuria-NI was light olive brown, (M.2.5y4/4), while it ranged from dark greyish brown to very dark greyish brown in Ghior-I (M.2.5y4/1.5 to 3/2). In Ghatail-NI and Ghatail-I subsoil colour ranged from dark grey (M.10yr4/1) to very dark greyish brown/very dark grey (M.10yr4/2 to M.10yr3/1 - 4/1) in the upper part and it was brower in the lower

parts. Sara-I and Sonatala-I although occupied highland ridges, the surface soil colour reduced to dark greyish brown at chroma 2 due to prolonged period of induced wetness or saturation by irrigated water for rice cultivation.

The irrigated soils like Sara-I, Ghior-I, Sonatala-I and Ghatail-I were strongly iron stained, while the non-irrigated Sara-I, Pakuria-NI, Sonatala-NI and Ghatail-NI had few iron staining along root channels.

Dark greyish brown colour (at chroma 2) in the surface horizon of non-aquic soils like Sara-I and Sonatala-I and the strongly iron staining along root channels in their surface and underlying ploughpan due to prolonged period of rice cultivation meet the requirements of Anthraquic epipedon. Present study provides further requirement of the Anthraquic epipedon as follows:

Anthraquic epipedon includes the plough layer and underlying ploughpan. In Bangladesh condition, where country plough is used for puddling, the thickness of this epipedon is likely to be thinner. In the irrigated Sara-I and Sonatala-I soils the thickness of the anthraquic epipedon was found to be 15 cm.

- Soil matrix colour must be reduced and its chroma should be 2 or less.
- Soils should be saturated or flooded for a long period by irrigated or impounded water under rice culture.
- Presence of strong iron staining along root channels both in the plough layer and in the underlying ploughpan.
- Redox potential of the moist soil should be low (preferably Eh ranged from - 100 to +214 mv).
- Higher concentration of ferrous iron in soils (30 to 40 ppm).
- Absence of $\text{NO}_3\text{-N}$ under wet condition.
- Presence of higher contents of organic matter in the soils (> 1 per cent).

In all the studied profiles soil structures were formed in subsoil or B horizon. The irrigated soils had relatively finer structures than the non-irrigated ones due to more water movement through the profiles following irrigation. Irrigated soils also contained relatively thicker and darker flood coatings than the non-irrigated ones due to more leaching of topsoil materials through water movement within the profiles.

As per solum depth soil profiles like Sara-NI was shallow, while Sara-I, Pakuria-NI, Ghior-I, Sonatala-NI and Ghatail-I were moderately deep and Sonatala-I and Ghatail-NI were deep.

Gangetic soils being calcareous showed effervescence throughout the profiles and the Brahmaputra alluvium soils showed no effervescence, being genetically non-calcareous.

Ploughpan was found relatively thicker in irrigated soils than the non-irrigated ones due to cultivation of high yielding variety of rice for long period.

Under the present investigation the physical properties included mechanical analysis, moisture percentage of soil at field sampling, saturated hydraulic conductivity, soil moisture characteristics (moisture retention) at 0.1, 0.33 and 1.0 bar tension, bulk density, particle density and percent pore space.

The textural class of the immediate subsoil (below plough lower) of the studied series was silt loam in Sara-NI, Sara-I, Sonatala-NI and Sonatala-I, while it was clay in Pakuria-NI, Ghior-I, Ghatail-NI and Ghatail-I.

Most of the irrigated soils were found to have less hydraulic conductivity as well as less pore space per cent than Non-irrigated soils which may be attributed to compaction due to prolonged irrigation. Exceptionally, Ghior-I had higher hydraulic conductivity in its subsoil due to finer structure.

The fine textured soils like Pakuria-NI, Ghior-I, Ghatail-NI and Ghatail-I occupying relatively low lying position of the landscape had higher moisture at sampling time than the medium textured soils.

In Gangetic alluvium, fine textural soils like Pakuria-NI and Ghior-I retained more moisture in all tensions than the medium textured Sara-NI and Sara-I due to presence of swelling clays.

Most of the irrigated soils were found to have higher bulk density due to compaction resulting from rice cultivation. In most cases particle density showed higher values in subsoils than top soils due to higher clay contents.

Horizon wise soil samples from each profile were analyzed for pH, redox-potential (Eh), Ec, calcium carbonate, total nitrogen, available nitrogen, available phosphorous, sulphate sulphur, CEC, exchangeable cations (Ca^{++} , Mg^{++} , Na^+ , K^+ and H^+) exchangeable Fe, Mn, Zn, Cu, nitric-perchloric acid soluble constituents (Na, K, Ca, Mg, Fe, Mn, Zn, Cu, and Al); Ferrous iron, total free Fe, Al, Si, and Mn; acid oxalate extractable Fe, Al, Si and pyro-phosphate extractable Fe, and Al.

Ganges alluvium soils being calcareous had higher pH value than Brahmaputra alluvium soils. The soil pH in Gangetic alluvium soils ranged from 7.06 (neutral) to 8.44 (moderately alkaline), while in Brahmaputra alluvium it was 4.65 to 7.8 (very strongly acid to mildly alkaline). Relatively low pH in surface horizon of Ghior-I was due to high organic matter accumulation and decalcification in top soil. Low pH in lower horizons of Ghior-I was due to reduced condition induced by ground water as it occurred in basin. pH in top soil of Sonatala-NI, Ghatail-NI and Ghatail-I was acidic due to leaching loss of bases.

The Gangetic soils being calcareous contained high CaCO_3 (1.4 to 13.0 percent), while Brahmaputra alluvium as a non-calcareous one represented nil to 2.9 percent. In Gangetic alluvium soils, CaCO_3 was observed throughout the profiles. In case of

Brahmaputra alluvium soils, CaCO_3 was not observed in the surface layers in most cases due to leaching.

Electrical conductivity (Ec) in all studied soils ranged from 39 to 385 $\mu\text{s}/\text{cm}$. (i.e <1 mmhos/cm), which is non-detrimental level to agricultural crops. Ganges alluvium soils showed more electrical conductivity than Brahmaputra alluvium soils due to higher electrolytic elements in soils.

Redox potential (Eh) was in moderately reduced level throughout the profiles of Sara-NI, Pakuria-NI, Sonatala-I and Ghatail-NI, while it was at reduced level at the surface of Sara-I, Ghior-I & Ghatail-I and moderately reduced level in the underlying layers. Irrigated soils were found to have relatively low Eh than non-irrigated soils. The minimum Eh value was found in Ap_1 and Ap_2 layers of all irrigated profiles due to saturation/wetness.

Gangetic alluvium soils contained 0.12 to 1.13 percent organic carbon, while it ranged from .16 to 1.48 percent in Brahmaputra alluvium soils. All the studied profiles contained higher amounts of organic carbon in the surfaces, decreasing significantly with depth.

In almost all profiles ferrous iron conc. was higher in the surfaces due to reduced condition associated with rice cultivation. However, in Ghatail-NI it was found higher in the lowest layer due to ground water inundation. The irrigated soils contained relatively more Fe^{++} than the non-irrigated soils and its concentration varied with the intensity and time of submergence of soil.

All the studied profiles contained higher amounts of total nitrogen in the surface which decreased significantly with depths. The soils like Ghatail and Ghior occupying the lower position of the landscape contained relatively higher amounts of total -N in the

surface horizon than other profiles due to accumulation and decomposition of more crop residues and manures.

Available nitrogen and phosphorus were higher in surfaces of all the soils of Gangetic and Brahmaputra alluvium and decreased significantly with depth. Irrigated soils like Sara-I, Ghior-I, Sonatala-I and Ghatail-I contained relatively higher amounts of phosphorus than non-irrigated soils.

Available sulphur in Gangetic alluvium soils ranged from nil to 60 ppm and in Brahmaputra alluvium soils it was nil to 24.5 ppm. Most of the irrigated soils contained relatively low amounts of available sulphur than non-irrigated ones.

Fine textured soils like Pakuria-NI, Ghior-I, Ghatail-NI and Ghatail-I contained higher cation exchange capacity than the medium textured soils and varied greatly with the variation of clay contents in soils.

In most of the profiles exchangeable Na was higher in the underlying horizons due to leaching from above. Na^+ illuviated mostly in such layers which contained higher amounts of clay and leaching loss was comparatively slower in such layers.

Gangetic alluvium soils contained relatively higher amounts of exchangeable K^+ , Ca^{++} and Mg^{++} than the Brahmaputra alluvium soils. Soils of Ganges alluvium contained exceptionally higher amounts of Ca^{++} , being genetically a calcareous alluvium. Most of the profiles specially the irrigated soils contained relatively higher amounts of K^+ in the subsurface or substratum due to illuviation. In all profiles Ca^{++} content was higher in the underlying horizons due to leaching from the overlying horizons. Mg^{++} was higher in the very C horizons because of the same reason.

Exchangeable H^+ was not found in all the Gangetic profiles due to high pH as they were inherently calcareous. In Brahmaputra alluvium soils H^+ was found in the upper layers of Sonatala-NI, Ghatail-NI and Ghatail-I as the layers were acidic.

Gangetic alluvium soils contained higher total exchangeable bases (TEB) than the Brahmaputra alluvium soils mainly due to high Ca^{++} contents. In all the profiles higher TEB was observed in the underlying B or C horizons due to leaching from the overlying horizons.

Base saturation percentage (BSP) was higher (29 to >100%) in Gangetic soils than the Brahmaputra alluvium soils (13 to 57%). Sara-NI and Sara-I contained more BSP than Pakuria-NI and Ghior-I due to higher Ca^{++} and other bases. Most of the irrigated soils contained higher BSP in the B or C horizons due to illuviation.

Gangetic alluvium soils contained relatively lower exchangeable Fe (20 to 50 ppm) than Brahmaputra alluvium soils (20 to 65 ppm) due to high $CaCO_3$ contents. Exchangeable Fe increased significantly with depth due to free drainage condition in the underlying layers.

Gangetic alluvium soils contained relatively low amounts of exchangeable Mn, Zn and Cu than brahmaputra alluvium soils due to high pH.

Soils of Ganges alluvium contained relatively higher amounts of total Na, K, Ca and Mg than Brahmaputra alluvium soils. Total Ca contents were exceptionally higher in Gangetic soils due to calcareous nature of soils associated with free $CaCO_3$. These elements were found higher in the underlying B or C horizons of most of the profiles. However, no definite trend with depth was observed due to alluvial nature of the soils.

Total Zn, and Cu were present in lower amounts (< than .1 per cent) in all the studied soils. They were even relatively lower in Gangetic soils due to calcareousness and relatively higher in the subsoils and substratum in almost all the profiles.

Gangetic soils contained relatively low amount of total iron oxides (1.84 to 4.43%) than Brahmaputra alluvium soils (2.28 to 4.69%). In most profiles total Fe_2O_3 was higher in subsoils and substratum due to migration from the upper layers. However, in Sara-NI it decreased with depth. Higher conc. of Fe_2O_3 reflects oxidizing situation and more weathering of soils.

Total aluminium oxides were higher in Brahmaputra alluvium (1.5 to 2.69%) than Gangetic alluvium soils (1.08 to 2.51%). Total Al_2O_3 was maximum in subsoils of most of the profiles. But in Sara-NI, it decreased with depth..

Total MnO_2 was relatively lower in Gangetic alluvium soils than Brahmaputra alluvium soils. In most of the profiles it was higher in subsoils and substratum. However, in Sonatala-NI, MnO_2 decreased significantly with depth, while in Ghatail-NI and Ghatail-I it increased significantly with depth.

Non-irrigated profiles such as Sara-NI, Pakuria-NI, Sonatala-NI and Ghatail-NI contained maximum free Fe_2O_3 in their surface horizon and then decreased. On the other hand, in the irrigated profiles like Sara-I, Ghior-I, Sonatala-I and Ghatail-I, this was maximum in subsoils or substratum due to restriction of vertical water movement by thick and hard ploughpan.

Free Al_2O_3 was found maximum in subsoils of most of the profiles such as Sara-NI, Sara-I, Pakuria-NI, Sonatala-NI, Sonatala-I and also Ghatail-NI, which then decreased. However, in Ghior-I and Ghatail-I this was maximum in the surface horizon.

Free SiO_2 was found maximum in subsoils of most of the profiles but in Sara-I and Ghior-I this was maximum in C horizon, while this was maximum in the surface of Sonatala-NI and Ghatail-NI profiles.

Free MnO_2 increased with depth in most of the profiles. Only in Sara-NI, Ghior-I and Sonatala-NI it decreased with depth.

Gangetic alluvium soils contained relatively low oxalate extractable Fe_2O_3 (i.e. Fe_0 , .53 to 1.43%) than Brahmaputra alluvium soils (.48 to 2.26%). Fe_0 decreased significantly with depth in all profiles of Brahmaputra alluvium due to lower pH in the upper layers. In Gangetic soils, it decreased significantly with depth in Sara-NI, while it increased significantly in Sara-I profile. In other profiles, Fe_0 increased irregularly with depth.

All the studied profiles contained higher Fe_0 than Fe_D (Free Fe_2O_3), while these profiles had lower Al_0 (oxalate extractable Al_2O_3) than Al_D (Free Al_2O_3) mainly because of high pH of soils. However, Al_0 in most of the profiles decreased with depth and was highly significant in Sonatala-I, Ghatail-NI and Ghatail-I.

Oxalate extractable Si (Si_0) was found to decrease either regularly or irregularly with depth in most of the profiles but in Ghatail-NI and Ghatail-I this increased with depth.

The soils contained much lower pyrophosphate extractable Fe, (Fe_P) than Fe_D and Fe_0 due to less weathering of soils as well as lower organic matter contents. Most of the irrigated soils contained higher Fe_P in their underlying horizons due to more leaching than non-irrigated soils.

Gangetic alluvium soils contained relatively low (.002 to .057) pyrophosphate extractable Al, (Al_P) than Brahmaputra alluvium soils (.001 to .164) due to the high pH values.

Mineralogical composition of sand and clay fraction in topsoil, subsoil and substratum were investigated.

In the sand fraction both Gangetic and Brahmaputra alluvium soils contained mainly quartz, feldspars and mica as major primary minerals. Quartz found the dominant mineral followed by mica and feldspar. In Gangetic soils, the contents of quartz, feldspars and mica ranged from 52 to 98%, 1.0 to 11% and 2.0 to 27%, while in Brahmaputra alluvium soils they ranged from 61.0 to 89%, 2 to 7% and 1.0 to 24% respectively.

The contents of quartz varied in different horizons and profiles mainly due to variation in sediment deposition at different times.

Feldspars being the more weatherable minerals, the lower amounts of it in surfaces of all irrigated profiles like Sara-I, Ghior-I, Sonatala-I and Ghatail-I indicate that they are more weathered than non-irrigated ones.

The presence of magnetite in Ghior-I, Sonatala-I and Ghatail-NI indicates that the soils are more weathered and hence more developed.

The presence of hornblende in Sonatala-NI, Sonatala-I, Ghatail-NI and Ghatail-I reflects the Mg rich background of soils.

The Gangetic alluvium soils were found to contain clay minerals like smectite, illite, chlorite and kaolinite. While it was found dominant in smectite (56-75%). Their contents varied with respect to soil, horizons and management.

In Brahmaputra alluvium soils, the major clay minerals were illite, chlorite and kaolinite. Small amounts of vermiculites were found in subsoil of Sonatala-I and Ghatail-NI. Small amounts of smectite were also observed in the subsoil of Sonatala-I and Ghatail-I profiles.

Considering the vertical distribution of the clay minerals it was observed that Sara - NI contained maximum smectite in the surface. Irrigated Sara - I and Ghior-I contained relatively higher amounts of smectite of pedogenic origin than the non-irrigated Sara-NI. The likely pathways of the formation of smectite in the irrigated rice soils is outlined in Fig. 7.

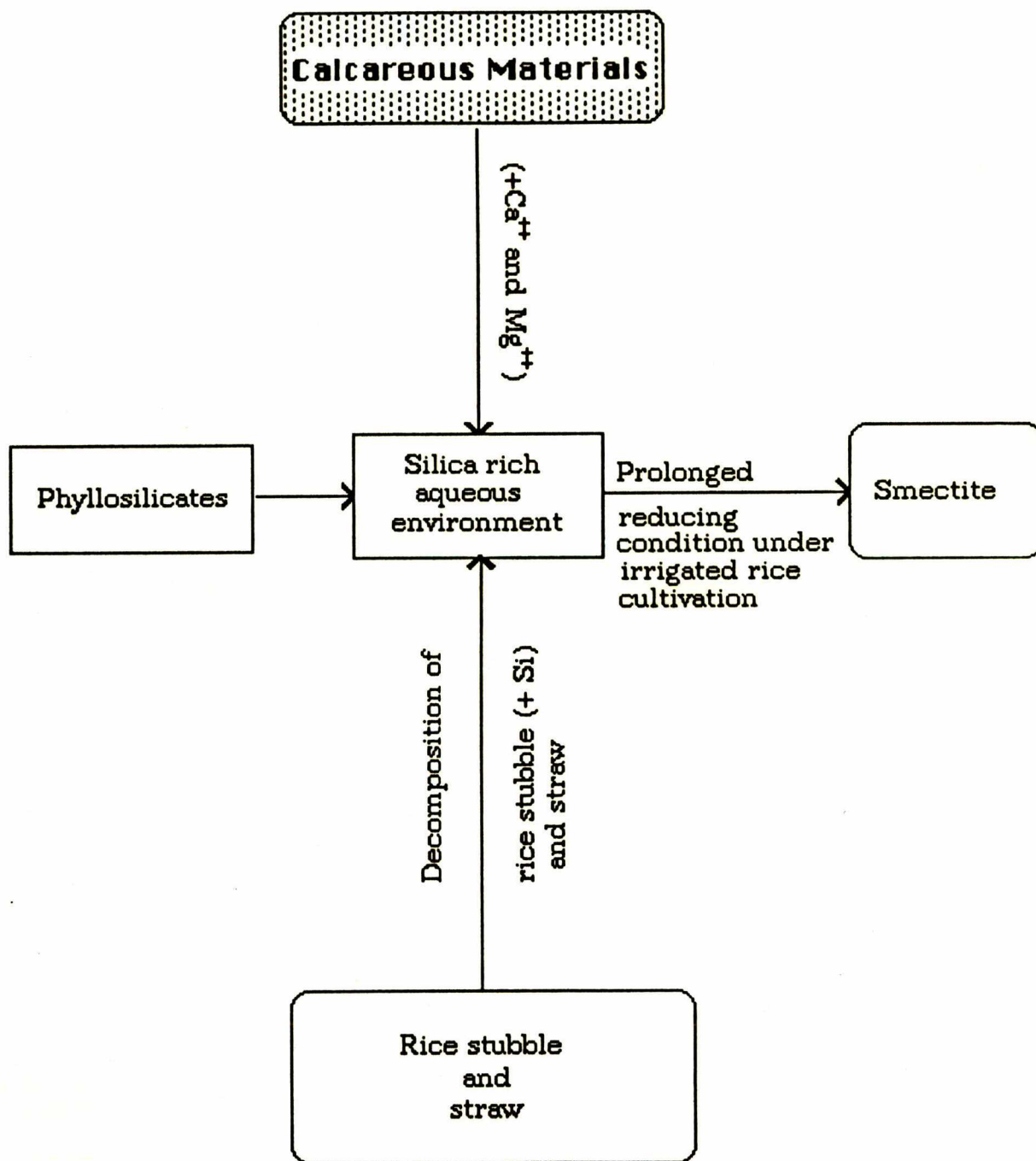


Fig.7: Likely pathways of the formation of smectite in the irrigated rice soils

Although Brahmaputra alluvium have no inherent smectite, the presence of 7% smectite in the subsoil of Sonatala-I and 8% at 88 cm of Ghatail-I profile was due to double HYV rice cultivation for long period under irrigated condition which favoured pedogenic changes.

In Gangetic alluvium soils, the presence of small amounts of illite, chlorite and kaolinite are presumably because of inherent clay minerals of the original sediments. However, illites in most of the Gangetic alluvium soils were found to decrease with the increase of smectite possibly due to transformation to smectite. The soils of Brahmaputra alluvium were found to contain 27 to 53% illite, 10 to 29% chlorite and 31 to 51% kaolinite, the minerals being the inherent component of parent martials. However, the higher amounts of illite in Sonatala-NI is presumably due to less weathering. The higher amounts of kaolinite in surface of Ghatail-NI and Ghatail-I in comparison with other profiles were due to acidic reaction and hence of pedogenic change.

On the basis of morphological, physical, chemical and mineralogical properties, the studied soils have been classified and were found to fit into one order (Inceptisols), two suborder (Aquepts and ochrepts), two great groups, (Eutrocrepts and Haplaquepts), two sub groups (Aquic Eutrocrepts and Aeris Haplaquepts), and five families, such as (i) Loamy, smectitic, hyperthermic, Aquic eutrocrepts (ii) Clayey, smectitic, hyperthermic, Aquic eutrocrepts (iii) Clayey, smectitic, hyperthermic, calcareous, Aeris Haplaquepts (iv) Loamy, Mixed, non-acid, hyperthermic Aeris Haplaquepts and (v) Clayey, mixed, non-acid, hyperthermic, Aeris Haplaquepts..

Under the simulation experiment some important chemical parameters like $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, Na, K, Ca, Mg, Fe, Mn, Zn, Cu and ferrous iron of soil solution and the electrochemical properties such as pH, redoxpotential (Eh) and Ec were analyzed in the treatments of organic matter incorporated soils after 15, 30, 60 and 120 days of standing water and under alternate wetting and drying conditions. Besides, after 120 days, simulated soils were analyzed for total nitrogen, organic carbon, exchangeable Na^+ , K^+ , Ca^{++} ,

Mg^{++} and oxalate extractable Fe, Al and Si; Ec and pH and change in soil colour also recorded to detect possible changes taking place in the soils. The results are summarized below:

NH_4 -N concentration in soil solution (leachate) increased under submergence i.e. PWL and alternate wetting and drying i.e. AWD conditions. At AWD situations peak values of NH_4 -N conc. was obtained at 120 days. On the other hand, under PWL condition, NH_4 -N conc. increased sharply upto 30 days and then decreased upto 60 days, which again gradually increased and reached upto a peak value at 120 days and found to sustain near to 30 days value. NH_4 -N under PWL condition was found higher than AWD situations. NH_4 -N conc. in soil solution increased significantly with the increase of organic matter for all water treatments, being highly significant in all stages of PWL conditions.

NO_3 -N at AWD situations decreased slowly, while at PWL conditions it disappeared readily. At AWD situations NO_3 -N was found to disappear from medium textured Sara-NI, Sara-I, Sonatala-NI and Sonatala-I soils after 60 days, while it disappeared after 30 days from fine textured Pakuria-NI, Ghior-I, Ghatail-NI and Ghatail-I soils. Under PWL conditions NO_3 -N disappeared from all soils after 15 days. At 15 days of water treatments NO_3 -N increased with the increase of organic matter and was highly significant for all soils at both AWD and PWL situations. while at AWD situations the increased amount to NO_3 -N continued to exist upto 60 days with some medium textured soils, at PWL conditions it ceased to exist after 15 days, irrespective of organic matter doses.

Calcium and potassium in soil solution (leachate) without incorporation of organic matter in most cases decreased at AWD situations due to leaching loss. On the other hand, they were found to increase significantly at PWL conditions. With the increase of organic matter in soils Ca and Mg in soil solution increased significantly in most cases under both AWD and PWL conditions. However, the increase of these elements under PWL condition was higher than AWD situations due to solubilization. Sodium in soil solution without incorporation of organic matter increased at both AWD and PWL conditions. This was also

found to increase significantly with the increase of organic matter in most cases, being higher under PWL condition.

In the leachate from AWD treatments iron was found in trace amount, while with the increase of organic matter it increased slightly in all soils of Ganges and Brahmaputra alluvium. On the other hand, at PWL condition ferrous iron conc. increased with the increase of time due to Fe (III) reduction and it increased significantly in almost all stages with the increase of organic matter, in all soils.

At AWD situations, Mn and Cu in solution (leachate) of both Gangetic and Brahmaputra alluvium soils were either not present or found in trace amounts at different time intervals. Under PWL conditions these were totally absent. On the other hand, at AWD situations Mn was noticed in trace amounts < 1 ppm at 30 days which slightly increased at 120 days in almost all soils. Under PWL condition, this was > 1 ppm at 30 and 60 days period only. The addition of organic matter in soils did not show any response possibly due to short period of the experiment (120 days).

pH in soil solution of organic matter treated Gangetic alluvium soils (calcareous) decreased with water treatment frequency at AWD situations, while in Brahmaputra alluvium soils it increased at 30 days and then decreased. Under PWL condition, pH in soil solution decreased in all soils with time, although lowest values were found at 30 days in almost all cases.

With the increase of organic matter, pH in soil solution at AWD in most Gangetic alluvium soils decreased and at PWL it decreased initially and then increased slightly at some stages. While in Brahmaputra alluvium soils at AWD situations this increased slightly at the initial stage (15 and 30 days) but then decreased.

Redox potential (Eh) in soil solution at AWD situations did not change much and remained at moderately reduced level (+100 to +400 mv). But under PWL condition it was

reduced sharply after 15 days and reached to the highest negative value (-100 to +100 mv) at 120 days in almost all cases. With the increase of organic matter redox potential (Eh) at AWD decreased slightly mainly at 15 days and then showed a slightly increasing trend in most cases due to evolving of CO₂. Under PWL condition Eh decreased significantly with the increase of organic matter in almost all case at 30, 60 and 120 days.

Electrical conductivity (Ec) in soil solution at AWD situations decreased, although at PWL condition it increased with time due to solubilization of salts from soils and organic matter. Ec in soil solution increased significantly with the increase of organic matter in soils at both AWD and PWL conditions. In all situations the level of Ec was below 2 mmhos/cm and hence found non-detrimental to agricultural crops.

Changes in soil colour without organic matter was not found after 120 days under both AWD and PWL conditions. But after addition of organic matter (rice root + stubble) at the rate of 4.76 ton/ha in Sara-I, and 10.24 ton/ha in Ghior-I, soil colour specially chroma reduced from 2 to 1.5 and in Ghatail-NI it changed from 1 to 2 with 8.86 ton/ha at AWD situations. On the other hand, after 120 days of PWL condition, soil colour was found to be reduced in all soils of Gangetic alluvium, mostly with higher doses of organic matter. In soils of Brahmaputra alluvium like Sonatala-NI, soil colour value reduced from 4 to 3 with all doses of organic matter (root + stubble) and in Sonatala-I chroma reduced from 2 to 1.5 and in Ghatail-NI colour value reduced from 4 to 3 with the highest dose of organic matter. However, non-irrigated highland soils like Sara-NI and Sonatala-NI having relatively browner colours were reduced more than the irrigated greyer soils.

After 120 days of both AWD and PWL conditions the simulated soils having high pH (>7.0) were reduced to a lower pH value, while it was unchanged in acidic Sonatala-NI, Ghatail-NI and Ghatail-I after same period of AWD but increased after 120 days of PWL condition. pH in soils increased with the increase of organic matter (rice root + stubble) after 120 days, under both AWD and PWL conditions presumably due to solubilization of bases from added organic residues.

Electrical conductivity in soils increased over original values after 120 days of AWD and PWL situations. The increase was higher at PWL than AWD conditions due to higher reduction of Fe (III) to Fe (II) and $\text{NH}_4\text{-N}$ accumulation under anaerobic conditions. Ec increased in almost all soils with increasing dose of organic matter application after 120 days of AWD and PWL situations of soils due to release of cations from soils and organic residues. However, in all cases it was below 1 mmhos/cm. and hence non-detrimental to the agricultural crops.

Organic carbon in original soil decreased after 120 days of AWD and PWL conditions due to leaching. The decrease of organic carbon at PWL was slightly higher than AWD situations. Organic carbon in soils increased significantly with the increase of organic matter supply (rice root + stubble) in all soils after 120 days of AWD and PWL treatments. Soils simulated with organic matter at AWD situations contained slightly higher organic carbon than at PWL.

Total nitrogen values in original soils decreased almost in all soils after 120 days of PWL due to leaching. Total nitrogen increased significantly in soils with increasing supply of organic matter after 120 days for both AWD and PWL, the increase being higher in case of AWD situations.

Exchangeable Ca^{++} in original soils decreased after 120 days for both AWD and PWL due to leaching. Increase of organic matter, in most cases of PWL, increased Ca^{++} presumably due to release of Ca^{++} from added organic residues.

Na^+ contained in original soils increased after 120 days of both AWD and PWL in almost all soils. It was higher at PWL than AWD situations due to release of Na^+ from soil materials.

Mg^{++} and K^+ from original soils decreased in most of the soils after 120 days of AWD conditions, while they were found to increase after 120 days of PWL condition. With the increase of organic matter in soils, Mg^{++} and K^+ increased significantly in most of the cases under both AWD and PWD conditions.

Oxalate extractable Fe, Al and Si i.e Fe_0 , Al_0 and Si_0 contained in original soils decreased after 120 days of AWD and PWL due to leaching. Fe_0 decreased in Sara-I with increasing organic matter (rice root + stubble) after 120 days of AWD possibly due to more oxidized state that favoured conversion of some Fe_0 to free iron oxides, while after 120 days of PWL Fe_0 increased due to reduction. The effect of organic matter was not noticed with respect to Al_0 . On the other hand, Si_0 increased with the increase of organic matter after 120 days at both AWD and PWL situations, presumably due to release of silicon from added rice root and stubbles. But the increase of Si_0 in soils was slightly higher under PWL condition which facilitates the pedogenic formation of smectite in soils.

From the above investigations the following conclusions are drawn:

1. Anthraquic epipedon, a diagnostic surface horizon, is formed on some non-aquic soils of Ganges and Brahmaputra alluvium under long term irrigated rice cultivation.
2. Thicker ploughpan is developed in irrigated soils due to cultivation of high yielding variety of rice for prolonged period, which prevents vertical water percolation, restricts aeration as well as root penetration.

3. Low hydraulic conductivity, less pore space per cent and higher bulk density may also emanate from compactness resulting from prolonged irrigation for rice cultivation.
4. Gangetic soils contain higher total exchangeable bases as well as base saturation percentage than Brahmaputra alluvium soils.
5. Gangetic soils contain relatively lower exchangeable Fe, Mn, Zn and Cu; total Zn, Cu, Fe, Al and Mn and pyrophosphate extractable Fe and Al than the Brahmaputra alluvium soils.
6. Irrigated soils have relatively lower Eh, lesser amounts of available sulphur and higher ferrous iron than non-irrigated soils. They vary with the intensity and time of submergence.
7. The sand fraction of both Gangetic and Brahmaputra alluvium soils contain mainly quartz, feldspars and mica as primary mineral, quartz being the dominant one followed by mica and feldspars.
8. The Gangetic alluvium soils contain clay minerals like smectite, illite, chlorite and kaolinite, although the soils are dominantly smectitic (56-75% of the clay fraction). On the other hand, the major clay minerals in Brahmaputra alluvium soils are illite, chlorite and kaolinite.
9. The higher amounts of smectite in irrigated soils has been attributed to the effect of long term HYV-rice cultivation under irrigated management.

10. On the basis of morphological, physical, chemical and mineralogical properties, the studied soils are classified into family category according to USDA system (1975) as follows:

Ganges alluvium soils:

<u>Soil series</u>		<u>Family category</u>
Sara-NI	-	Loamy, smectitic, hyperthermic, Aquic Eutrocrepts.
Sara-I	-	Loamy, smectitic, hyperthermic, Aquic Eutrocrepts.
Pakuria-NI	-	Clayey, smectitic, hyperthermic, Aquic Eutrocrepts.
Ghior-I	-	Clayey, smectitic, hyperthermic, Calcareous, Aeric Haplaquepts.

Brahmaputra alluvium soils:

<u>Series</u>		<u>Family name</u>
Sonatala-NI	-	Loamy, mixed, non-acid, hyperthermic, Aeric Haplaquepts.
Sonatala-I	-	Loamy, mixed, non-acid, hyperthermic, Aeric Haplaquepts.
Ghatail-NI	-	Clayey, mixed, non-acid, hyperthermic, Aeric Haplaquepts.
Ghatail-I	-	Clayey, mixed, non-acid, hyperthermic, Aeric Haplaquepts.

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APPENDICES

Appendix-I

Correlation coefficients of soil properties (r=value)

Soil Series	Depth VS			pH VS	Depth VS				Eh VS	Depth VS	
	Ph (Water)	CacO ₃	CacO ₃		Eh	Organic Carbon (O.C)	Total-N	Ferrous Iron		Available -N	Av.P
SARA (Non-irrigated)	.927**	.850**	.856**	-	-	-.878**	-.929**	-	-	-.955**	-
SARA (Irrigated)	-	-	-	.799**	-	-.625*	-.547*	-.615*	-.852**	-.855**	-
PAKURIA (Non-irrigated)	-	-	.903**	-	-	-.821**	-.843**	-.601*	-	-.709*	-.848**
GHIOR (Irrigated)	-.697*	-	.732*	.826**	-	-.803*	-	-.799*	-.840**	-.958**	-.793*
SONATALA (Non-irrigated)	-	-	-	-	-	-.683*	-.694*	-	-	-.882**	-.743*
SONATALA (Irrigated)	-.578*	-.873**	.672*	.672*	-	-.663*	-.895**	-.711*	-	-.864**	-.827**
GHATAIL (Non-irrigated)	.673**	-	-	-.56*	-	-.69**	-.768**	.695**	.671**	-.734**	-.74**
GHATAIL (Irrigated)	.691*	-	-	-	-	.837**	-.867**	-.748*	-.793*	-.819**	-

- = Non significant
 * = Significant at 5%
 ** = Significant at 1%

Appendix-II

Correlation coefficients of soil properties (r=value)

Soil Series	Depth VS						Depth Vs			
	CEC	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	TEB	Ex.Fe	Ex.Mn	Ex.Zn	Ex.Cu
SARA (Non-irrigated)	-.925**	-.764*	-.872**	-.730*	-.799*	-.807*	.957**	-	-.917*	-
SARA (Irrigated)	.601*	-	-	.698**	-	.596*	.981**	-	-	-
PAKURIA (Non-irrigated)	-	-.811**	-.927**	-	-	-	.936**	-	-	-
GHIOR (Irrigated)	-	-	-	-	-	.781*	.870**	-.74*	-	-
SONATALA (Non-irrigated)	.708*	.877**	-	.753*	.653*	.746*	.974**	-.658*	-	-
SONATALA (Irrigated)	-	-	-	-.584**	-	-	.99**	.98**	.638*	-
GHATAIL (Non-irrigated)	-.819**	-	-	-	.790**	.693**	.864**	.915**	-	-.881**
GHATAIL (Irrigated)	-.708**	-.82**	-.925**	-	-	-	.962**	.881**	-	-

- = Non significant

* = Significant at 5%

** = Significant at 1%

Appendix-III

Correlation coefficients of soil properties (r=value)

Soil Series	Depth Vs total elements:										Total Al ₂ O ₃ VS
	Na	K	Ca	Mg	Zn	Cu	Fe ₂ O ₃	Al ₂ O ₃	MnO ₂	Total Fe ₂ O ₃	
SARA (Non-irrigated)	-	-.896**	.907**	.883**	-	-	-.916**	-.812*	-	.875*	Dhaka University Institutional Repository
SARA (Irrigated)	-	-	-	-.687**	-.532*	-	-	-	-	-	
PAKURIA (Non-irrigated)	-.743**	-	-	-	-	-	-	-	-	-	
GHIOR (Irrigated)	-	-	-	-	-	-	-	.829**	-	-	
SONATALA (Non-irrigated)	-	-	-	-	-	-	.881**	-	-.658**	-	
SONATALA (Irrigated)	-	-	-	-	-	-	-	-	-	.638*	
GHATAIL (Non-irrigated)	-	-.709**	.497*	-.66**	-	-	-	-	.49*	-	
GHATAIL (Irrigated)	-	-	-	-	-	-	-	-	.771*	-	

- = Non significant
 * = Significant at 5%
 ** = Significant at 1%

Appendix-IV

Correlation coefficients of soil properties (r=value)

Soil Series	Depth VS free oxides					Depth VS oxalate extractable			Depth VS pyrophosphate extractable	
	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂	MnO ₂		Fe ₂ O ₃	Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃
SARA (Non-irrigated)	-.828*	-	-	-.863**		-.924**	-	-.864**	-.897**	-.9087**
SARA (Irrigated)	.836**	.612*	.751**	-		.663**	-	-	.792**	-
PAKURIA (Non-irrigated)	-	-	-	-		-	-	-	.907**	-
GHIOR (Irrigated)	-	-	-	-.736*		-	-	-	-	-
SONATALA (Non-irrigated)	-	-	-.841**	-		-.858**	-	-	-	-
SONATALA (Irrigated)	.649*	.63*	-	-		-.715**	-.837**	-	.925**	-
GHATAIL (Non-irrigated)	-.809*	-	-	-		-.557*	-.757**	.75**	-	-
GHATAIL (Irrigated)	.958**	-	-	-		-.771*	-.87**	-	-	-.777**

- = Non significant
 * = Significant at 5%
 ** = Significant at 1%

Appendix-V

Correlation coefficients of soil solution concentrations of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ ($r=\text{value}$)

Soil Series	Organic matter doses (rice root + stubble) VS days at alternate wetting and drying (AWD) & permanently waterlogged condition (PWL)											
	NH ₄ -N at AWD						NH ₄ -N at PWL					
	15	30	60	120	15	30	15	30	60	120	15	30
SARA (Non-irrigated)	-	.8023*	-	.8512*	.99**	-	-	-	.965**	-	-	-
SARA (Irrigated)	.849*	-	.857*	.90**	.95**	-	-	.972**	.949**	.9723**	.914**	-
PAKURIA (Non-irrigated)	.8751*	.925**	.853*	.871*	.9396**	-	-	.955**	-	-	.93**	-
GHIOR (Irrigated)	.9825**	.973**	.997**	.989**	.95**	.943**	.918*	.985**	-	-	.981**	-
SONATALA (Non-irrigated)	.945**	.996**	.9899**	.92**	.959**	.977**	.962**	.959**	-	.894**	.944**	-
SONATALA (Irrigated)	.991**	.975**	.999**	.924**	.971**	.965**	.864*	.994**	-	-	.992**	-
GHATAIL (Non-irrigated)	.945**	.919**	.993**	.998**	.886*	.996**	-	.959**	-	-	.993**	-
GHATAIL (Irrigated)	.970**	.939**	.985**	.982**	.989**	.964**	.982**	.989**	-	-	.983**	-

- = Non significant
 * = Significant at 5%
 ** = Significant at 1%

Appendix-VI

Correlation coefficients of soil solution concentrations of Ca and Mg (r=value)

Soil Series	Organic matter doses (rice root + stubble) VS days at alternate wetting and drying (AWD) and permanently waterlogged condition (PWL)											
	Ca at AWD				Ca at PWL				Mg at AWD			
	15	30	60	120	15	30	60	120	15	30	60	120
SARA (Non-irrigated)	-	-	-	.819*	-	-	.872*	-	-	-	.866*	.970
SARA (Irrigated)	-	-	-	-	.924**	-	-	-	.803*	-	.945**	.971
PAKURIA (Non-irrigated)	.937**	-	-.805*	-	.961**	-	-	-	.923**	-	.945**	.970
GHIOR (Irrigated)	.825*	-	.949**	.986**	.882*	-	.966**	-	-	-	.866*	.901
SONATALA (Non-irrigated)	-	.967**	-	-.973**	.838*	-	.965**	.904*	-	-	-	.866*
SONATALA (Irrigated)	-	-	-	-	-	-	.894*	-	-	-	-	-
GHATAIL (Non-irrigated)	-	-	-	-	-.824*	-	.914*	-	-	-	-	-
GHATAIL (Irrigated)	-	-	-	-	-	-	.832*	-	.894*	-	-	-

- = Non significant
 * = Significant at 5%
 ** = Significant at 1%

Appendix-VII

Correlation coefficients of soil solution concentrations of Na and K (r=value)

Soil Series	Organic matter doses (root + stubble) VS days at alternate wetting and drying (AWD) and permanently waterlogged condition (PWL)														
	Na at AWD					Na at PWL					K at AWD				
	15	30	60	120	15	30	60	120	15	30	60	120	15	30	60
SARA (Non-irrigated)	-	-	-	-	-	-	.862*	-	-	-	-	-	-	-	-
SARA (Irrigated)	-	-	-	-	-	.957**	-	-	-	-	-	-	.938**	-	.971**
PAKURIA (Non-irrigated)	-	-	-	-	-	-	.871*	.811*	-	-	-	-	-	.971**	.962**
GHIOR (Irrigated)	.9449**	-	.866*	.988**	-	-	.871*	-	-	.945**	.832*	.866*	-	.970**	.985**
SONATALA (Non-irrigated)	-	.961**	-	-	-	-	-	.904*	-	-	-	-	.970**	.986**	.930**
SONATALA (Irrigated)	-	-	.866*	-	-	-	-	.971**	-	.943**	-	.971**	.970**	.9939**	.985**
GHATAIL (Non-irrigated)	-	-	-	-	-	-	-	-	-	.870*	.971**	-	.960**	.943**	.932**
GHATAIL (Irrigated)	-	.878*	.866*	.971**	-	-	-	.920**	-	.904*	.938**	.949**	.832*	.993**	.985**

- = Non significant
 * = Significant at 5%
 ** = Significant at 1%

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Appendix-VIII

Correlation coefficients of soil solution concentrations of Ferrous iron and electrical conductivity (r =value)

Soil Series	Organic matter doses (rice root + stubble) VS days at alternate wetting and drying (AWD) and permanently waterlogged condition (PWL)											
	Fe ⁺⁺ at AWD				Fe ⁺⁺ at PWL				Ec at AWD			
	15	30	60	120	15	30	60	120	15	30	60	120
SARA (Non-irrigated)	.894*	.894*	.894*	.894*	.894*	.995**	.977**	.999**	-	.819*	.884*	.894*
SARA (Irrigated)	.844*	.894*	.894*	.894*	.894*	.962**	.956**	.998**	.935**	.881*	.946**	.476**
PAKURIA (Non-irrigated)	.894*	.894*	.894*	.894*	.894*	.995**	.998**	.991**	.955**	.821*	.963**	.967**
GHIOR (Irrigated)	.894*	.894*	.894*	.894*	.894*	.970**	.997**	.997**	-	.987**	.866*	.941**
SONATALA (Non-irrigated)	-	-	-	-	-	.961**	.977**	.996**	.981**	.984**	.974**	.921**
SONATALA (Irrigated)	.945**	.894*	.962**	.971**	.945**	.969**	-	.972**	-	.971**	.915**	-
GHATAIL (Non-irrigated)	.971**	.970**	.832**	-	.945**	.979**	1.00**	.990**	-	.988**	.933**	-
GHATAIL (Irrigated)	.970**	.970**	-	-	.945**	.991**	.993**	.997**	.841*	-	.958**	-

- = Non significant
 * = Significant at 5%
 ** = Significant at 1%

Appendix-IX

Correlation coefficients of soil solution concentrations of pH and redox-potential - Eh (r=value)

Soil Series	Organic matter doses (rice root + stubble) VS days at alternate wetting and drying (AWD) and permanently waterlogged (PWL) condition											
	pH at AWD				pH at PWL				Eh at AWD			
	15	30	60	120	15	30	60	120	15	30	60	120
SARA (Non-irrigated)	-	-	-	-	-	-.935**	-	.900*	-	-	-.986**	-.915**
SARA (Irrigated)	.998**	-	-	-.834*	-	.874*	-	-	-.945**	.861*	.985**	.939**
PAKURIA (Non-irrigated)	-	-	-	-	-	-	-	-	-	.832*	-	-
GHOR (Irrigated)	-	-	-	-	-	.977**	-	-	-	-	.956**	-.977**
SONATALA (Non-irrigated)	-	-	-	-	-	-	-	-.947**	-	-	.986**	-.915**
SONATALA (Irrigated)	-	-	-	-	-	-	-	-	-.801*	-	-.887*	-.853*
GHATAIL (Non-irrigated)	-	-	-	-	-	-	-	-	-.899*	-	-.827*	-
GHATAIL (Irrigated)	-	-	-	-	-	.886*	-	-	-	.857*	-.986**	.939**

- = Non significant
 * = Significant at 5%
 ** = Significant at 1%

Appendix-X

Correlation coefficients of simulated soil properties (r=value)

Soil Series	Organic matter treatments VS pH, organic carbon (OC), total nitrogen, and Electrical conductivity (Ec) at alternate wetting and drying (AWD) and permanent waterlogged (PWL) condition.							
	pH		Organic carbon		Total nitrogen		Ec	
	AWD	PWL	AWD	PWL	AWD	PWL	AWD	PWL
SARA (Non-irrigated)	-	-	.991**	.977**	-	.948**	.992**	.916**
SARA (Irrigated)	.906*	-	.986**	.987**	.915**	-	.997**	.944**
PAKURIA (Non-irrigated)	-	-	.984**	.989**	.971**	.832*	.961**	.992**
GHIOR (Irrigated)	-	-	.990**	.991**	.971**	-	.988**	.997**
SONATALA (Non-irrigated)	.798*	-	.980**	.994**	.943**	.945**	-	.843*
SONATALA (Irrigated)	-	-	.993**	.978**	.971**	.899*	.995**	-.916**
GHATAIL (Non-irrigated)	.809*	-	.994**	.983**	.927*	.832*	.972**	-
GHATAIL (Irrigated)	-	-	.984**	.965**	-	.970**	.968**	-

- = Non significant

* = Significant at 5%

** = Significant at 1%

Appendix-XI

Correlation coefficients of simulated soil properties (r=value)

Soil Series	Organic matter treatments VS exchangeable Ca ⁺⁺ , Mg ⁺⁺ , Na ⁺ and K ⁺ after alternate wetting & drying (AWD) and permanently waterlogged (PWL) condition of soils.							
	Ca ⁺⁺		Mg ⁺⁺		Na ⁺		K ⁺	
	AWD	PWL	AWD	PWL	AWD	PWL	AWD	PWL
SARA (Non-irrigated)	-.806 [*]	-	-	-	-	-	-	-
SARA (Irrigated)	-	-	.898 [*]	-	-	-	-	-
PAKURIA (Non-irrigated)	-	.852 [*]	-	-	-	-	-	-
GHIOR (Irrigated)	-.951 ^{**}	-	-	-	-	-	.887 ^{**}	.911 [*]
SONATALA (Non-irrigated)	-.870 [*]	-	-.955 ^{**}	-.936 ^{**}	.887 [*]	.914 ^{**}	-	.894 [*]
SONATALA (Irrigated)	-.882 [*]	.804 [*]	-	-	-	-.811 [*]	-	-
GHATAIL (Non-irrigated)	-.795 [*]	-	-	-	-	-	-	.894 [*]
GHATAIL (Irrigated)	-.805 [*]	-	-	-	-	-	-	-

- = Non significant

* = Significant at 5%

** = Significant at 1%