DRAFT

BANGLADESH FLOOD ACTION PLAN

FAP 16 Environmental Study

Special Studies Program

10

EFFECTS OF FLOOD PROTECTION ON THE FERTILITY OF SOILS AT THE CHANDPUR IRRIGATION PROJECT

July 1993

ISPAN IRRIGATION SUPPORT PROJECT FOR ASIA AND THE NEAR EAST

Funded by the U.S. Agency for International Development

in collaboration with
BANGLADESH INSTITUTE OF NUCLEAR AGRICULTURE

BANGLADESH AGRICULTURAL RESEARCH COUNCIL

DRAFT

BANGLADESH FLOOD ACTION PLAN

FAP 16 Environmental Study

Special Studies Program

EFFECTS OF FLOOD PROTECTION ON THE FERTILITY OF SOILS AT THE CHANDPUR IRRIGATION PROJECT

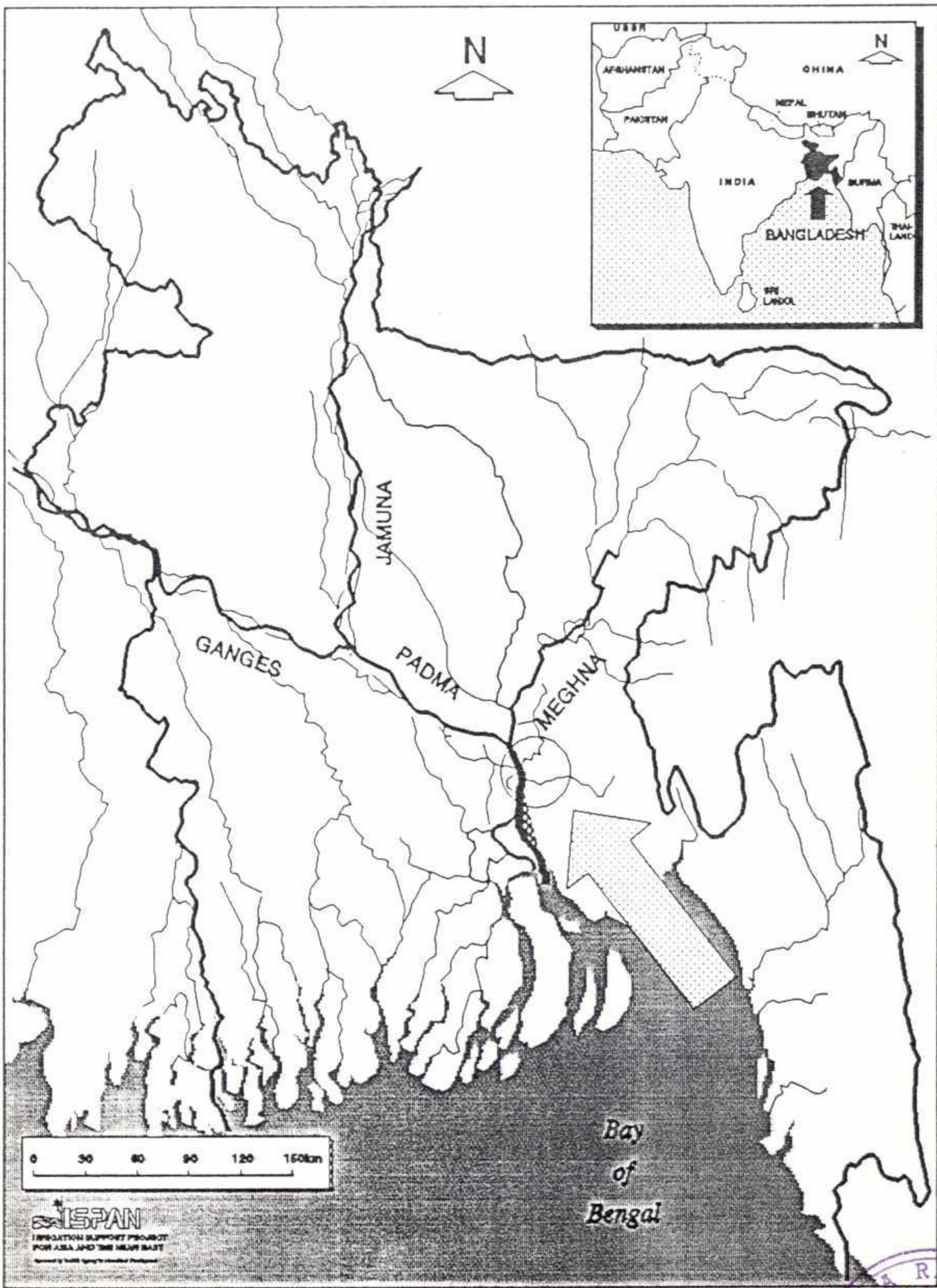
July 1993

ISPAN IRRIGATION SUPPORT PROJECT FOR ASIA AND THE NEAR EAST

Funded by the U.S. Agency for International Development

in collaboration with
BANGLADESH INSTITUTE OF NUCLEAR AGRICULTURE

BANGLADESH AGRICULTURAL RESEARCH COUNCIL



Frontispiece. Location of Chandpur Irrigation Project

TABLE OF CONTENTS

TABLE OF CONTENTS continued

List of Tables

List of Figures

List of Figures continued

List of Maps

List of Annexes

SUMMARY

Rice productivity in Bangladesh is low compared with that of other rice-growing areas of the world because of poor soil fertility, limited use of costly fertilizers, risk of flood damage, and only moderate achievements in irrigation. Past attempts to ameliorate this situation have placed 30 percent of the country under flood control, drainage and irrigation (FCD/I) projects, intended to improve hydrologic conditions for the benefit of crop production. These FCD/I projects generally impede flooding during the monsoon season and prevent deposition of river-borne sediments on soils within protected areas.

Although the linkage between flooding and soil fertility has long been recognized, previous investigations of pedological changes in flood-protected areas have been limited. Those studies, however, indicate the likelihood of widespread deficiencies in elements such as zinc and sulphur, possibly due to the intense cultivation of rice following flood protection. This report, on a study of soil fertility in one project area, adds to this knowledge base. Prior to this study there had been no systematic investigation of the effects on soils of excluding the annual deposition of river-borne sediments.

This report presents the results of a one-year comparative study of flood-protected and flood-exposed soils in the Chandpur Irrigation Project (CIP). The objectives of the study were to compare nutrient characteristics of soils inside and outside the protective embankment, measure the nutrient qualities of deposited sediments, and examine the soil nutrient relationships of other potentially significant factors such as blue-green algal (BGA) distribution and abundance, dissolved nutrient levels of river and irrigation water, and the effects of fertilization and changes in cropping patterns.

Eight sites were selected and sampled twice each in a balanced sampling design based on river frontage (Meghna or Dakatia rivers), protection (outside or inside the embankment), relative elevation (medium highlands or medium lowlands), and timing relative to monsoon flooding (pre-monsoon and post-monsoon). At each site in each period, 20 topsoil samples were collected. Twenty sediment sampling trays were placed in flood exposed sites prior to the monsoon flooding and collected after floods had subsided. Soil and sediment samples were assayed for texture, pH, organic matter, electrical conductivity, and available nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, zinc, iron, copper, boron, and manganese. Water samples also were collected on four occasions from four open river and canal sites and one site inside the CIP during the monsoon period, and from a number of internal irrigation canals during the dry season. Water samples were analyzed for pH, total dissolved solids (TDS), electrical conductivity (EC), and available nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, zinc, iron, copper, boron, and manganese. BGA samples were taken from rice plants and surface water in the sampling sites and subjected to microscopic examination for identification and volumetric assessment of BGA abundance. Among the other data collected from the sample areas were cropping patterns, rates of fertilizer application and crop production.

Little or no sedimentation occurred in the sampling sites along the Dakatia River because floodwater there was mainly sediment-free rainwater. Sediment deposition along the Meghna was probably lower than normal because of the abnormally low flooding intensities and water levels of 1992. The sediment samples from the Meghna sites were sandy loams and had a different texture than the local soils, which are loams and clay loams. The deposited sediments obviously were translocated soils from elsewhere, and were probably a combination of agricultural soils eroded from the upper Meghna and upper Padma basins and transported to the CIP sites. Their physical and chemical composition was quite different from that of the local

Madna and Chandpur soils, making it unlikely that they were locally translocated.

The study showed that deposited sediments along the Meghna River in the vicinity of the CIP have a high nutritive value for crop production. The value of the sediments lies in their worth as substrates for crop production and their high content of nitrogen and potassium, both normally deficient in local soils. The high nitrogen content is probably attributable to particulate organic allochthonous material and algal biomass, both of which are high in flood water draining large expanses of previously inundated lands. The nitrogen content of the sediment was low in relation to levels of fertilizer normally applied, and probably low in relation to the amounts of nitrogen fixed by the abundant BGA populations. The sediments also were found to be substantially higher in EC, organic matter, calcium, sulphur, potassium, and manganese than local soils, but significantly lower in copper and zinc. Nutrient concentrations in lower-elevation sediments were significantly higher than in those deposited at upper elevations. The higher clay content of lower elevation deposits may contribute to the higher nutrient content through higher proportions of adsorbed ions.

The study showed that soil nutrients are affected by many factors in an area subjected to flooding and flood protection, some of these being: types of crops grown, types and rates of fertilizer applications, elevation of the soils relative to the local flooding levels, and the sediment content of the rivers supplying the floodwaters.

Meghna River water, the analysis found, is high in TDS — probably sodium, chlorides, and bicarbonates — but contains only moderate amounts of dissolved calcium; low levels of magnesium, potassium, and other inorganic soil nutrients; and only traces of ammonium nitrogen. Dakatia River water had similar potassium and sulphur content but was lower in calcium, magnesium, phosphorus, manganese, and especially TDS. Soil nutrients contributed as dissolved forms in incoming floodwater were probably slight by comparison to those transported in the form of sediments.

A principal components analysis indicated that protection from flooding brings about a discernible shift in nutrient content, but an even greater shift occurs in protected soils during the monsoon rains. Monsoon flooding and associated changes in cropping, the study found, lower the pH and the organic matter, calcium, magnesium, iron, and manganese content of most soils. Levels of potassium, nitrogen, phosphorus and sulphur increase because of fertilizer applications inside the embankment, and fertilizer applications and sediment deposition outside the embankment. No flooding-induced changes in zinc levels were found.

The major difference between the protected and unprotected areas was in flood protection and associated crop production: within the embankments production was two to three times higher than it was outside because of the protection provided and because of associated changes in cropping patterns and the use of high yielding varieties (HYVs). Such increases in production required high rates of fertilizer application, which are necessary for such crops as potatoes, HYV *boro* and HYV transplanted *aman*. The high crop production rates of the protected areas could probably not be obtained in flood prone areas, even with the annual deposition of nutritive sediments.

Levels of potassium, nitrogen, phosphorous, sulphur, boron, copper, zinc, and electrical conductivity all rose in protected soils on the Meghna side of the CIP after the monsoon cropping and harvesting season. All of these nutrients, with the exception of copper and boron, were present in the fertilizers applied, principally Triple Sulphur Phosphate (TSP), Single Super Phosphate (SSP), muriate of potash (MP) and zinc sulphate. The rise in electrical conductivity was associated with the high levels of calcium, potassium, and ammonium cations and sulphate and chloride anions in the dissolving fertilizer applications.

Nutrient depletion within the CIP is high overall, and is especially so in upper elevation soils, which support crops of potatoes, HYV *boro*, and HYV *aman*. Fertilizer additions replace most of nutrients removed by cropping, but potassium is applied in quantities too low to adequately replace what is used and is notably deficient in all soils in the CIP. Soils in the unprotected areas support less nutrient-exhaustive crops and produce lower yields. These soils are supplemented with fertilizers as well as high amounts of organic manure. Local farmers are of the opinion that crop production within the CIP is becoming increasingly dependent on high application rates of fertilizers.

Based on the findings of this study, river-borne sediments are valuable sources of soil nutrients and their exclusion from agricultural lands by embankments is a major potential negative impact of flood control developments. The potential loss of nutrient sediments in such developments should be balanced against the fact that flood protection permits more intensive cropping and higher crop production. The study also demonstrated that sedimentation of agricultural lands from river-derived floodwater is heterogenous, occurs mainly in areas close to the mainstem rivers, and may be minimal or absent in areas flooded by smaller rivers.

Controlled flooding appears to be an appropriate way to take advantage both of the increased production associated with flood protection and the free nutrient content of deposited sediments. Through controlled flooding, sediment rich water could potentially be permitted access to agricultural lands at key periods in the cropping cycle, but could be excluded during subsequent periods when crops are susceptible to flood damage and when sediment concentrations may be declining due to subsiding flood levels. It would seem desirable, however, to examine the efficiency of sediment deposition on lands when flood waters enter primarily via regulators rather than overbank spills, since restrictive canal and regulator openings are likely to act as sediment traps.

The report recommends that controlled flooding be further examined as an option for flood control in agricultural areas and that ways be specifically sought to ensure effective transfer of river-borne sediments to agricultural lands at key periods in the cropping cycles. It suggests that the nutritive value of sediment deposition be quantified in an economic sense to permit its consideration in project cost-benefit analysis. It further recommends that consideration be given to repeating the soil comparison study in other regions in Bangladesh, especially in the upper Meghna, Jamuna and Ganges basins, where different sedimentary regimes and local geochemistry might produce different information and conclusions from those arrived at here.

STUDY PARTICIPANTS

The study was designed and managed by Abu Md. Ibrahim of ISPAN. The report was prepared by Stanley M. Hirst and A.M. Ibrahim of ISPAN, Dr. Z. Karim of the Bangladesh Agricultural Research Council (BARC), and Drs. Md. Idris Ali and A.K. Podder of the Bangladesh Institute of Nuclear Agriculture (BINA).

Chemical analysis of soil samples was undertaken under the direction of Dr. Md. Idris Ali of BINA, while Dr. A.K. Podder of BINA and Dr. A. Aziz of Dhaka University undertook the examination and analysis of blue-green algal samples. Dr. Stanley M. Hirst of ISPAN carried out the statistical analyses. Dr. Z. Karim of BARC served as study advisor.

Md. Faruque of ISPAN collected soils samples and land use and cropping data, and maintained liaison with cooperating farmers in the study area. Assistance in collection of field data was given by Md. Masuduzzaman, Shah Newaz Siddiqi, Golam Monowar Kamal and Raguibuddin Ahmed of ISPAN.

ACKNOWLEDGEMENTS

The helpful advice of Dr. Keith Pitman, Mr. Mujibul Huq, Mr. Hugh Brammer, Dr. Firouz Rooyani and Mr. William Hurlbut during the study is acknowledged with appreciation. ISPAN acknowledges the valuable assistance of the farmers in the Chandpur study areas who permitted access to their lands for soil, water and algal sample collection and who provided detailed data on their cropping and land management practices. The Executive Engineer (O&M) and other officials of the BWDB, Chandpur, are thanked for their support during the field work.

Chapter 1

INTRODUCTION

Bangladesh has a total area of 148,393 km^2, of which about 90 percent comprises one of the largest deltaic plains in the world, formed by the confluence of the Brahmaputra (Jamuna), Ganges and Meghna rivers. The remaining 10 percent is comprised of the undulating, forested Hill Tracts. About two-thirds of the national area is cultivable, and of this about 60 percent is subject, on average, to seasonal flooding from river overbank spillage as well as heavy rainfall (World Bank 1992).

Agriculture is highly attuned to seasonal flooding, and the linkage between flooding and soil fertility has long been recognized. The Bengali term *barsha* refers to normal, beneficial flooding of agricultural land which does not significantly affect homes and villages. Bentley (1925) compared situations in east and west Bengal and was the first on record to claim that embankments reduced soil fertility by preventing flooding.

Water control measures, many at a small scale, have been extensively developed to reduce sporadic flooding damage to agricultural crops and property, and to improve drainage and irrigation. Large-scale destructive floods such as occurred in 1987 and 1988 are comparatively rare, but of sufficient negative impact to infrastructure and livelihoods as to have prompted an international response in the form of the Bangladesh Flood Action Plan (FAP) which seeks to reduce flood damages through construction of protective embankments and related water control measures.

At present about 30 percent of the net cultivated area in Bangladesh is covered by flood control, drainage and irrigation (FCD/I) projects (World Bank 1992). The most flood prone soils are either on active floodplains within and close to river channels, in the northern and eastern areas which receive flash floods from neighboring hills, and/or in flood plain basins. FCD/I projects aim at improving the hydrologic regime of these flood prone soils for the benefit of crop production. Rice productivity in Bangladesh is low compared to other rice-growing areas of the world; responsible factors cited are poor soil fertility, limited use of costly fertilizers and a lack of irrigation (Sattar 1991). Irrigation permits the growing of high yielding varieties (HYV) of rice in the dry season. HYVs plus fertilizers have led to 37 percent rise in agricultural production since 1970 (MOEF 1991), but in the past decade average HYV yields have remained static or have decreased. Possible reasons cited for this (MOEF 1991) are year-round waterlogging of soils leading to the formation of toxic compounds, and the loss of zinc and sulphur through deep percolation. About 3.9 million ha land are presently deficient in sulphur, and 1.74 million ha deficient in zinc (MOEF 1991).

FCD/I projects generally reduce both the depth and duration of seasonal flooding and thereby increase the surface area in the highland and medium highland categories. FCD/I projects located near the major rivers generally impede river water flooding during the monsoon season, and hence soils within the protected areas do not receive fresh river-borne sediments. Finer sediments are commonly looked upon by local farmers as nutrient sources (ISPAN 1991, 1992), in contrast to coarse sands which are detrimental to crop production and which have to be removed from lands following flooding.

The pedological effects of FCD/I development so far undertaken in Bangladesh have been subjected to only limited investigation. Zinc and sulphur deficiencies are documented in intensively cultivated soils of the Chandpur Irrigation Project (CIP), Dhaka-Narayanganj-Demra Project (DNDP) and the Ganges-Kobadak Project (Andriesse 1982). This is suggested to be due, at least partly, to the higher extraction of trace elements that takes place under high cropping intensities with HYV's, and partly due to elements being less available for uptake by plant roots under submerged conditions of higher frequency and longer duration, i.e. less fallow conditions.

Soil analyses in the CIP indicate an adequate supply of potassium, while phosphates are deficient and the nitrogen content very low (CIRDAP 1987). Most sampled areas have sufficient supplies of calcium, magnesium and iron, but sulphur, boron, manganese and zinc contents are low. Both Andriesse (1982) and CIRDAP (1987) refer to the high iron content of soils, believed to be related to a low soil pH. These two studies were confined to investigations inside flood-protected areas only, which limits the scope of understanding the effects of flood protection measures on the physical and chemical characteristics of these soils.

FCD/I development may affect soil fertility in one or more ways:

- reducing or eliminating the periodic addition of new sediments;
- eliminating or reducing topsoil flooding and the associated topsoil chemical changes which may affect nutrients;
- increasing or decreasing the extent of waterlogging and the associated physiological changes to root efficiency;
- bringing about changes from natural flood-associated soil moisture regimes to irrigation-induced soil moisture regimes; and/or
- leading to cropping intensification and the associated increased use of inorganic fertilizers.

Because of heterogeneous soil characteristics in flood plains, such changes of environmental factors may have different effects on the availability of nutrients in different areas.

Increased development of FCD/I projects is expected to take place under the FAP with consequent wide-reaching implications for soil fertility, crop production and land management. The potential effects of such flood control on soil fertility, through the restriction of sediment inputs and possibly other changes, has been indicated as a major concern by FAP participants (e.g. ISPAN 1991, BCEOM *et al.* 1993).

The study reported here was undertaken by ISPAN in collaboration with the Bangladesh Institute for Nuclear Agriculture (BINA) and the Bangladesh Agricultural Research Council (BARC) to provide additional data, information and insights into soil fertility status and its relationship to flooding and sediment deposition. Time and budgetary constraints within the FAP 16 Environmental Study limited the study effort to a one-year examination of soil fertility in one major location only. After consideration of a number of potential study sites, the Chandpur Irrigation Project (see frontispiece) was selected because of the presence of two major rivers providing sediment, one carrying heavy sediment loads (Meghna) and the other relatively lighter loads (Dakatia), the availability of flood-protected and flood-exposed locations within the same soil series, the availability of background soils data, and the willing cooperation of local farmers. It was recognized from the outset that this would not provide general answers to all queries related to FCD/I and soil fertility because of the reported wide-ranging variations in soil and flooding conditions in Bangladesh.

Chapter 2

BACKGROUND

2.1 Soil Development in the Bangladesh Floodplain

The Bengal Lowlands are one of the oldest alluvial plains in the world. The recent alluvial lowland is divided into two regions - the Brahmaputra-Jamuna floodplain and the Ganges floodplain, with the Barind formation between them (Umitsu 1987). The youngest surfaces lie adjacent to the present rivers.

Sediments in the Brahmaputra-Jamuna floodplain are mainly sandy with a gravel bed at a depth of 50 to 100m (probably late Quaternary). The formations above this are coarse sand and gravel mixes at the lower levels and finer silts at the upper levels. Variations in sediment characteristics are due to changes in the sedimentary environment and changes in the upper reaches of the rivers. The uppermost part of the sediments is made up of oxidized alluvium (Umitsu 1987). The plains are formed of riverine sediments and are generally of dark and loose material with a high water content and a variable organic matter content.

The morphology of the river plain is distinctive and consists of a series of ridges and depressions, river levees, slopes and swamps, braided streams, meander scars and typical river channels. On the micro scale the topography is highly variable, but macroscopic slopes are very slight (Murray *et al.* 1992). Six broad morphological types are distinguishable (Brammer 1989):

- Active young floodplains (chars) along major river channels; experience bank erosion and new deposition of seasonal alluvium; have mixed silty/sandy deposits; undergo severe flooding 2-5m in depth.
- River meander floodplains, characterized by basin and ridge topography such as haors, baors, backswamps and beels; heavy clays and silts dominate; seasonal flooding with rainwater up to 5m, 1-2m on ridges.
- Estuarine floodplains; level relief and few channels; deep silty deposits; seasonally flooded by rainwater; soils and estuary waters become saline in dry season.
- Tidal floodplains; level basins drained by tidal creeks; clay soils; flooded at high tide by river and/or rainwater; saline soils.
- Alluvial fans and piedmont plains; deposition occurs after flash flooding events, silt-bearing water leads to sand, loam and clay patterns of soil development.
- Major floodplain basins; flooding to 5m occurs seasonally; central haors are wet year-round; rainwater flooding with flash flooding brings silts.

River alluvia along the Ganges and in the estuarine zone contain lime (Murray *et al.* 1992). Ganges tidal, Brahmaputra river and estuarine alluvia are neutral to moderately alkaline but not calciferous, while alluvial fans and Brahmaputra river deposits are slightly acidic. Both Meghna and Jamuna floodplain soils are typically neutral to slightly alkaline (Whitton *et al.* 1988a), although the Jamuna floodplain receives much more silt.

Topsoils which do not receive annual depositions of alluvium are generally acidic, while alluvium-rich soils are neutral or calcareous (Murray *et al.* 1992). In dry periods redox reactions in topsoils lead to acidification. This is permanent except where biological activity brings a constant new supply of material to the surface or alluvial deposition occurs. During ponding and submergence soils are neutralized and leaching occurs rapidly. Only active floodplains and surrounding areas receive significant depositions of silts on an annual basis.

2.2 Sediments and Sediment Deposition

Rahman *et al.* 1990 estimate the mean annual discharge of the Brahmaputra to be 19,200 m^3/s and the mean annual sediment runoff to be 1370 tonnes/km^2. For the Ganges the mean annual discharge is 11,610 m^3/s and mean annual sediment runoff 492 tonnes/km^2. The estimated mean discharge for the Meghna is 3513 m^3/s. Sediment runoff has not been estimated for the Meghna. From these data Murray *et al.* (1992) estimate a net overall annual deposition in the delta of 2 billion tonnes, calculated roughly from input-output comparisons. This translates into an average annual deposition rate of 0.8 cm. The suspended sediment load of the Brahmaputra-Ganges systems is characterized by coarser fractions in the Himalayan tributaries and finer material downstream.

Rivers tend to deposit sediments on their beds and along their banks at low or falling discharges, and to resuspend these sediments at high or rising discharges. For some rivers such as the Mississippi in the U.S.A., seasonal changes in water level and river slope are factors leading to remobilization of suspended sediments; there are as yet no data on these phenomena for the Brahmaputra, Ganges and Meghna systems (Murray *et al.* 1992)

Sediment deposition on cultivable lands varies regionally, according to the main river sediment source (Brahmaputra, Ganges or Meghna) and the subsidiary sources, the distance from the river banks, and probably a number of other, as yet undetermined, factors. For a deepwater rice area at Manikganj, supplied with floodwaters from the Brahmaputra (Jamuna), Whitton *et al.* (1988a) recorded sediment deposition occurring from early July to the first week in November. Sediment deposition was highest in July (215 g/m^2/week) and lowest by November (35 g/m^2/-week). Whitton *et al.* (1988a) found measured annual sediment deposition to range from a low of 36 g/m^2 at Daudkandi on the Meghna River (recorded twice in separate years) to 5353 g/m^2 at Mohadebpur near the Jamuna-Ganges confluence. The median deposition for all sites was 408 g/m^2 ($\sim$4 tonnes/ha). Sites near the Meghna had the lowest deposition (36 to 187 g/m^2), while sites near the Jamuna had the highest deposition.

The nutritive value of deposited sediments remains contentious. For most world rivers, suspended sediments absorb a number of aqueous ionic constituents (Meade 1988, Milliman 1991, cited by Murray *et al.* 1992) and thus play a major role in geochemical cycling by transporting these ions through the hydrological system. The amounts and rates of sediment transportation via adsorption are affected by various factors, including deforestation, farming practices and damming, as well as the effects of local embankments. Bangladeshi farmers almost unanimously extol the virtues of new silts deposited on their lands as sources of nutrients. However, Brammer (1976) suggests river alluvium is probably relatively infertile as it contains little organic matter or nutrients which are available to crops in the short-term. He indicates three alternative sources of soil fertility arising from seasonal flooding:

- nitrogen-fixing activities of blue-green algae (BGA);
- decomposition of deep water rice plants and other submerged vegetation; and
- nutrient release resulting from shifts from acid or alkaline reactions (dry soils) to neutral ones (submerged soils).

Particulate organic carbon (POC) is a commonly measured component of river water, and Depetris *et al.* (1991, cited by Murray *et al.* 1992) note that POC is positively correlated with suspended solids, especially during rising river stages; increased discharges cause dilution of POC concentrations.

2.3 Water-Soluble Nutrients

Dissolved ions in river waters are a potential source of nutrients to flooded soils. The upland zones of the Ganges and Brahmaputra basins are dominated by calcium, magnesium and bicarbonates, while sodium, potassium, sulfates and chlorides come from the lower basins (Degens *et al.* 1991, cited by Murray *et al.* 1992). Chloride concentrations tend to be higher in the Ganges, which is roughly twice as saline as the Brahmaputra, and are derived from flooded soils. Dissolved solids in the Ganges average 178 mg/l, and in the Brahmaputra 100 mg/l; the Ganges transports 70 million tonnes/year dissolved solids, while the Brahmaputra moves 60 million tonnes/year (Murray *et al.* 1992). Despite these large masses of transported nutrients, suspended solids still dominate over dissolved solids in the major river systems entering Bangladesh, e.g. a 10:1 ratio between suspended and dissolved solids was measured in the Brahmaputra at Gauhati in India (Subramanian and Ittekot 1991, cited by Murray *et al.* 1992).

Dissolved organic carbon (DOC) is a commonly measured and interpreted component of the dissolved solids loading of river water, and Depetris *et al.* (1991, cited by Murray *et al.* 1992) note that DOC concentrations increase with increasing discharge, especially during intensive floods. A significant source of DOC is amino acids and carbohydrates derived from biological activity on the floodplains.

Karim *et al.* (1991) measured the amounts of nutrients in irrigation water from the major Bangladesh rivers and found it to vary with the river and with the crop in question. For *boro* rice, about 55 percent of the potassium requirement (59 kg/ha) was provided by Ganges irrigation water. The contributions were lower for transplanted *aman* (35 percent) and for wheat (33 percent). The contribution to the phosphorus requirement for *boro* varied from 5 kg/ha from the Ganges to 7 kg/ha from the Meghna. Supply of sulphur to *boro* crops was similar for the Jamuna (33 kg/ha) and Ganges (31 kg/ha).

2.4 Biological Nitrogen Fixation

Biological nitrogen fixation (BNF) of aerobic nitrogen by microorganisms, especially blue-green algae (BGA), has been credited with being a major source of nutrient nitrogen for floodplain crops in Bangladesh, especially rice. Martinez and Catling (1982) estimated that BGA growing in paddy fields could fix up to 30 kg nitrogen/ha, a substantial proportion of the nitrogen requirements of rice. Murray *et al.* (1992) calculated that nitrogen fixed through BGA in the Bangladesh floodplain (possibly 180,000 tonnes/year) may be 35-40 percent of the amount applied as nitrogenous fertilizer. BGA are not dominant organisms in the Bangladesh soil or aquatic environment, and have been found to comprise <2 percent of total algal populations in surveyed samples (Khan and Venkataraman 1991). Highest numbers are found in alkaline soils, with much lower densities in acidic soils (Watanabe and Roger 1984, Khan and Venkataraman 1991). Thirty three species of BGA belonging to 22 genera have been identified from 25 deepwater rice sites within the Jamuna, Meghna and Ganges floodplains (Catling *et al.* 1981). *Anabaena, Gloeotricha, Oscillatoria, Nostoc, Carococcus* and *Lyngbya* spp. are most abundant. Fourteen genera were found to be rare. Many species are epiphytic on leaf sheaths, others on nodal roots. BGA are typically less common in water samples. Catling *et al.* (1981) found BGA to decline in numbers when floods receded in October and standing waters became cloudy, malodorous and anaerobic. They note that deepwater rice areas are likely to have more BGA than others due to the large expanse of stem area under well-oxygenated, clear water.

Rother *et al.*(1988), one of the few groups of workers to actually examine the role of BGA in nitrogen fixation under Bangladesh conditions, found that nitrogen fixation is less important during the actual flood season than in moist soils in the period immediately preceding flooding. More than twice as much nitrogen was fixed in the pre-flooding period at their study site at Manikganj. They also found that BGA were much more abundant in fallow fields than in flooded paddy fields. Despite its value as a nitrogen source, fixation by BGA was not responsible for all nitrogen available in deepwater rice areas (Rother *et al.*1988). They estimated that soluble nitrogen in floodwater contributed ~6 percent of deepwater rice requirements (on an areal per ha basis), and BGA on soils in the area contributed ~11 percent. They speculated that the remainder of the required nitrogen came from lateral transport from fallow areas (where BGA are very abundant) or some other nitrogen-fixing system. BGA growth in flooded paddy fields appear to be favored by higher contents of magnesium and calcium in the water (Whitton *et al.* 1988b).

Chapter 3

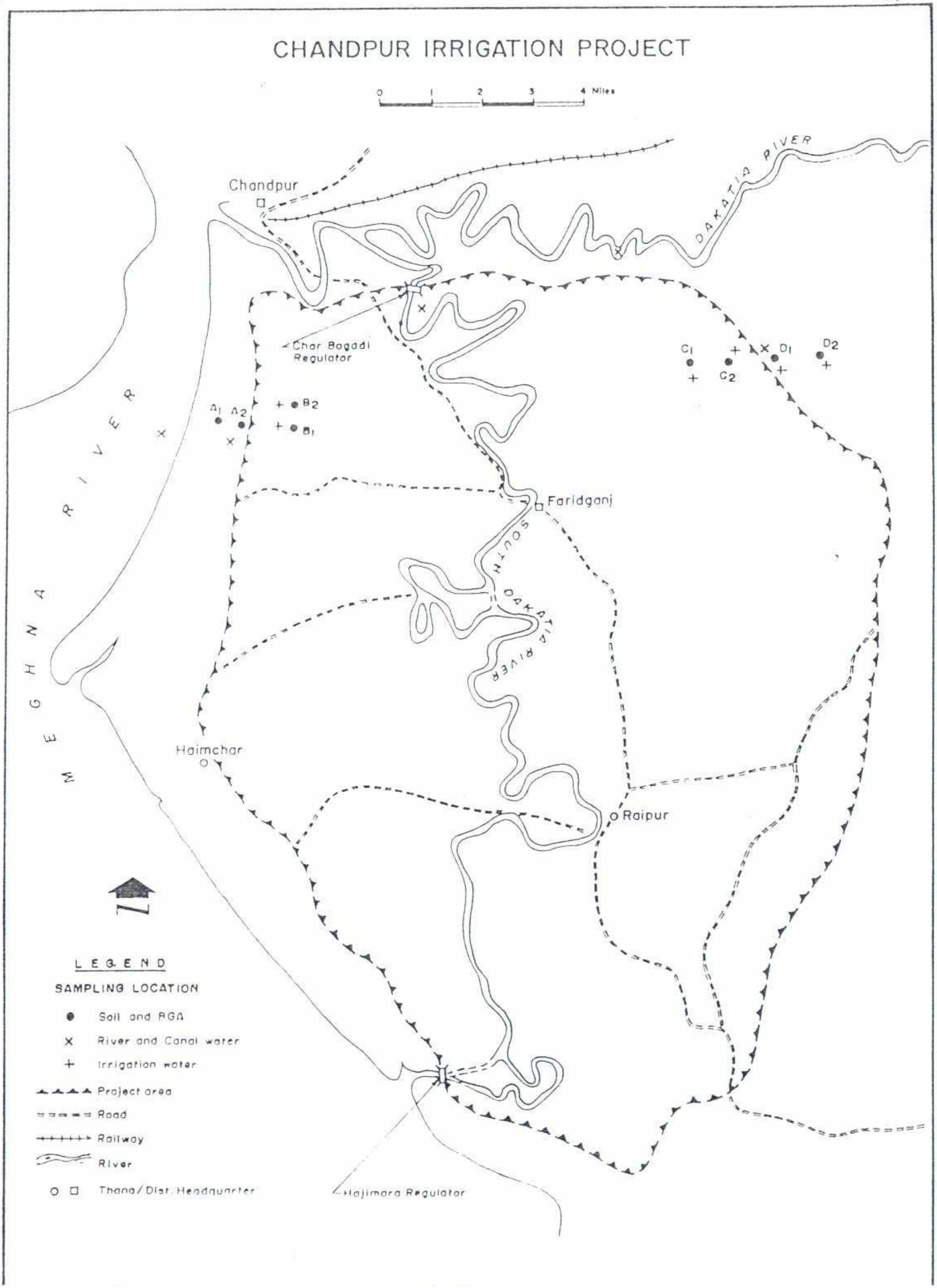
STUDY AREA

The Chandpur Irrigation Project (CIP) is a major FCD/I project located on the left bank of the Meghna River, south of Chandpur town in the districts of Chandpur and Laksmipur (Map 1, Annex 1). The CIP comprises an area of 53,000ha on both sides of the South Dakatia river. Gross cultivable area is estimated at 36,000ha, with a total irrigable area of 29,000ha.

The project effectively started in 1975 and includes flood protection, drainage and irrigation, as well as other infrastructural improvements such as navigation facilities, roads and agricultural extension services. The project area is protected from the Meghna and Dakatia rivers by 101km of flood control embankment of average height of 3-4m. Drainage facilities include two regulators at Char Bagadi with reversible pumps of capacity 35 m^3/s used for both drainage and irrigation. The southern regulator at Hajimara has a capacity of 652 m^3/s and provides drainage only. Irrigation water is first lifted into the south Dakatia River which then feeds a network of tributaries, khals and irrigation canals. Lifting of irrigation water is via low-lift pumps hired out to farmers' groups in units of 16ha each.

Total population in the project area in 1976 was measured at 658,000, with 102,000 farm families (Andriesse 1976). About 77 percent of the farmers owned their land, 17 percent were owners/tenants, and 6 percent were purely tenants. The average gross farm area at that time was about 0.4ha, with a net cultivable area of 0.3ha per farm. In 1976 about 50 percent of the farms were smaller than 0.2ha, 20 percent were between 0.2 and 0.4ha, and 15 percent were between 0.4 and 0.6ha. Homesteads and tanks covered 25 percent of the area. Based on national growth rates, it is calculated that the 1992 population density in the area is about 906,000 persons (density 1700/km^2), with farm families totalling about 150,000. Gross farm area is estimated to average only 0.3ha, with average cultivable area of about 0.2ha.

The area has 220-230 days of kharif (wet season) growing period, 120-145 days of rabi (dry season) growing period and 40-50 days of pre-kharif transition period. The area remains under a minimum temperature of $< 15°C$ for about 50-70 days during the dry season.


CHANDPUR IRRIGATION PROJECT
0 1 2 3 4 Miles
Chandpur
DAKATIA RIVER
Char Bagadi Regulator
MEGHNA RIVER
A1 A2
B2
B1
C1
C2
D1
D2
Faridganj
SOUTH DAKATIA RIVER
Haimchar
Raipur
Hajimara Regulator
LEGEND
SAMPLING LOCATION
Soil and RGA
River and Canal water
Irrigation water
Project area
Road
Railway
River
Thana/Dist. Headquarter

Chapter 4

METHODS

4.1 Study Design

A two-fold approach to the examination of the role of sediment deposition on soil nutrient quality was employed, i.e.

- comparison of soils from flood-protected and flood-exposed areas which are otherwise similar in pedogenesis, elevation, land use and other factors; and
- collection and examination of sediments deposited on flood prone areas.

The desirable requirement for effective statistical treatment of comparative samples is to hold all "treatments" (i.e. soil uses, fertilizer applications, cropping uses, period of sampling, etc.) constant in the sampled locations, while varying only the factor to be tested (i.e. addition of deposited sediment). In practice, such a situation is almost impossible to find in an intensively cropped region such as Bangladesh, except under very tightly controlled situations where the land is under the full and long-term control of the study team. As soon as flood control measures are implemented, as at CIP, land use, cropping and associated practices of fertilization usually change to make use of the flood protection status. The alternative approach is to measure the associated treatments such as cropping patterns, fertilizer applications, etc. and to account for resultant changes in soil nutrient status through statistical comparison and analysis (covariance analysis).

4.2 Field Sampling

Reconnaissance

A reconnaissance field study was carried out inside and outside the CIP project area from 10th to 15th March, 1992. Potential sampling sites were visited along a transact extending across both protected and unprotected areas from the highest to the lowest point, and crossing all major soil series and land types in the area. Two sampling blocks were selected, one on either side of the CIP representing sites exposed to the high-sediment Meghna River environment, and to the low sediment Dakatia River environment respectively. At each location, blocks were divided into two, one part outside the existing embankment and one inside. Furthermore, two sub-locations were selected within each block, one at higher elevations in medium highland/-highland land types, and another at lower elevations in medium lowland/lowland land types. Protected and unprotected blocks occurred within one of four soil series - Chandpur, Madna, Tippera and Burichang - occurred both inside and outside the embankment. These were dissimilar in physical and chemical characteristics and represented different toposequences. After field examination and consultation with local BWDB project officials, sampling sites in each block were chosen, representing lands belonging to from two to seven individual farmers each.

Soils

Collection of soil samples from eight sampling blocks within the four sampling sites (Meghna inside and outside, Dakatia inside and outside) was undertaken from 17 March 1992 to 15 April 1992 (pre-monsoon samples), and repeated again from 7 through 24 December (post-monsoon samples). Each soil sample was a composite sample drawn from a combination of 25 sub-samples taken from the topsoil (0-10cm depth) within the same fields (Annex 2). Sampling was replicated 20 times within the same soil series and land types in adjacent fields of 8-10 m^2 each. The number of samples collected totalled 320 (2 river sources x 2 flood protection situations x 2 elevations x 2 seasons x 20 replications in each). Samples were placed in heavy duty polyethylene bags, sealed, and transported via ricksha to Faridganj from where they were transferred to the BINA laboratories in Mymensingh for chemical and physical analysis.

Sediments

Within each flood exposed sampling block, a series of five specially constructed wooden trays was place at ground level and securely anchored. Each tray measured 50cm x 50cm and was equipped with a plastic liner and a 10cm high lip to hold deposited sediment whiles excluding soil moving laterally across the ground surface under the moving flood waters. Trays were placed *in situ* 1 and 2 August 1992 and retrieved in November following flood water subsidence. Land owners were paid a moderate fee to guard trays and prevent their unauthorized removal. Collected sediment samples were treated the same as soil samples.

Water

Water samples were collected at three depths (surface, 1m and 2m depths) from the Meghna River, Dakatia River and the three inlets nearest to the study area on 4-5 August, 25-26 August, 16-17 September, and 5-6 October 1992. Samples contained suspended sediments at the time of collection, these were filtered out at the laboratory so that analytical results reflected only dissolved nutrients.

Irrigation water samples were collected during the *boro* irrigation season (March and April). Replicate samples of water just below the surface were taken from the irrigation canals closest to the respective soil sampling sites. All water samples were sealed and transported to BINA for chemical analysis.

Blue Green Algae

The abundance and diversity of BGA on the soil surface in standing water and on rice stems were monitored through the monsoon season. Samples of water and rice stems at water level were collected separately at 20 day intervals in each of the fields from which soil samples are taken. Three replicate samples each of water and rice stems at water level were collected from each sampling block on 4-5 August, 25-26 August, 16-17 September and 6-7 October 1992, and on 19-20 March and 24-25 April 1993.

Each field was subdivided into three equal parts and at least four or five samples (both water and rice plant) were collected from each part and combined into a composite sample. Approximately 100ml per composite water sample was collected in polythene bags and 4 percent formalin added as a preservative. Tillers of rice plants sample were randomly selected starting from the margin of a field to the centre. The plant was collected by cutting from the soil surface up to water level and placed in a polythene bag with 4 percent formalin solution. With few exceptions, the method for collecting BGA samples was similar to that described by Klarer and Hickman (1975).

Other Data Collection

Land use and crop management data covering the current and past three years for each sampling blocks were collected by interviewing the farmers in the sample areas during April and May 1992. Information collected included cropping patterns, crop yields, management practices (tillage, irrigation), type and quantity of fertilizers used, manuring practices, insecticides used, depth and duration of seasonal inundation and sediment deposition within each of the sampling blocks.

4.3 Laboratory Analyses

Soil and Water Samples

Physical and chemical analyses were carried out on soil, sediment and water samples by the laboratories of BINA, using standard techniques (Hunter 1984). Soil and sediment samples were analyzed for texture, pH, organic matter, available nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, zinc, iron, copper, boron, manganese and electrical conductivity. Water samples were analyzed for pH, total dissolved solids, available nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, zinc, iron, copper, boron, manganese and electrical conductivity. All chemical analyses on soils, sediment and water samples were done following standard procedures. Soil and sediment pH was measured using a glass electrode in 1:2.5 soil:water suspension. Electrical conductivity was measured using a conductivity bridge. NH_4 nitrogen, calcium and magnesium were determined on 1N potassium chromate extracts, with a calorimetric procedure for NH_4 nitrogen, and atomic absorption spectrophotometry on the others. Sulphur and boron were determined on calcium phosphate extracts using a turbidimetric procedure for sulphur and a calorimetric measurement for boron. Organic matter was determined by the wet oxidation procedure (Walkley 1946). Phosphorus, potassium, iron, manganese and zinc were determined on sodium EDTA extracts (0.25 N Na HCO_3 / 0.01M EDTA / 0.01 N NH_4F with 0.5g Superfloc 127 per 10 liters). Phosphorus was measured calorimetrically and the other nutrients by atomic absorption spectrophotometry. Measurement of nutrients in water samples was done following ASI procedures, and dissolved solids were determined following Standard Methods for Analysis for Soils, Plant Tissues, Water and Fertilizers (1990).

Blue Green Algae

In the laboratory BGA samples were scraped from the plants and placed in glass vials in which the total volume was made up to 20 ml. with 4 percent formalin. From the shaken sample 0.1ml was transferred to a slide, covered by a cover glass and examined. Five such slides were prepared from each vial. Within each slide five randomly selected microscopic fields were studied at a magnification of 300 and a mean estimate of filament density made.

Nitrogen fixation by BGA in topsoils and in surface waters was not measured since this is already well established and would involve sophisticated experimental and laboratory installation beyond the scope of this study.

4.4 Statistical Analyses

A total of 320 soil samples were collected from the CIP and analyzed for 14 soil nutrient parameters. Equal numbers of replicate samples (20) were collected in each location subjected to a combination of two alternative treatments for each of four factors, i.e. rivers (Meghna, Dakatia), river flood protection status (protected, not protected), site elevation (upper, lower elevations) and time of collection relative to the monsoon period (pre-, post-). Data for each of the measured nutrients were examined for statistical distributions and generally found close enough to normal distributions for the application of standard robust parametric analytical procedures. Small numbers of outliers and extreme cases were detected by the statistical analyses, but were too few in number to significantly affect the interpretation of the statistical results.

Soil samples were compared using analysis of covariance (ANOCOVA) based on a general least squares model; river environment (Meghna and Dakatia), site elevation (upper, lower), protection status (outside, inside embankment) and period (pre- and post-monsoon) were used as treatments, with equal numbers of replicates (20) within each class. Rates of fertilizer application in each field from which the soil sample had been collected were treated as continuous covariates. Manure application to fields prior to sampling had been recorded in a qualitative way only (applied, not applied), and this was entered into the ANOCOVA as a categorical variable.

There were no replicate water samples collected in the sampling design, but following examination of the variances and means pooled alternatively for collection site within period and period within collection site, it was decided that the samples from the separate depth strata could be treated as replicates from one sampling site.

The statistical significance of any of the four factors (rivers, protection, elevation and period) in relation to the soil nutrient contents was determined in each case by reference to a four-way ANOCOVA in which the size of the mean square attributable to the factor in question was tested against the mean square error while the effects of all other factors and covariates were held constant.

In addition to the specific comparisons for each sampled nutrient, global comparisons of soils and sediments in terms of their nutrient content were made using principal components analysis (PCA). PCA is a statistical method whereby a matrix of highly correlated variables (soil nutrient concentrations in this case) is reduced to a smaller matrix by computation of principal components based on the extent of correlation between and among the variables. There is no correlation between principal components themselves. The first two components extracted accounted for approximately 60 percent of total variation observed in the set of 14 variables, and were used to plot two-dimensional comparisons between various soils and between soils and deposited sediments.

Chapter 5

SOILS AND LAND TYPES

5.1 Soils

The project area falls within Agroecological Zone (AEZ) 17 (Lower Meghna River Floodplain), with minor areas in AEZ 18 (Young Meghna Estuarine Floodplain) and AEZ 19 (Old Meghna Estuarine Floodplain (Map 2). Four subregions of AEZ 17 occur in the CIP and contain either calcareous flood protected (17a) or non-flood protected (17b) soils, or non-calcareous flood protected (17c) or non-flood-protected (17d) soils. Soils in subregions 17a and 17b are slightly calcareous because of the admixture of Ganges river alluvium with the Meghna sediments. Soils on highlands and medium highlands are lighter in texture and consistence than those in adjoining medium lowlands and depressions. Most higher elevation soils are olive silt loams, with grey gleyans along subsoil cracks. Lower elevation soils are mainly olive silty clay loams with dark grey gleyans. Soils in the extreme south show slightly saline patches in the dry season, while elsewhere soils are non-saline. Soils of AEZ 18 are grey to olive, finely stratified, calcareous, silty alluvium which becomes saline in the dry season. AEZ 19 soils occupy deeply flooded sections, and are partly protected by the CIP embankment. Raised cultivation platforms, constructed from both calcareous and non-calcareous materials, are numerous in the south and centre.

Soil survey data for the CIP are based on a survey carried out in 1966-67 by the Soil Resources Development Institute (SRDI 1966), and updated in 1984 (Ibrahim 1984) for inclusion in the Agroecological Zones report (FAO 1988) (Map 3). The *Madna* series occupies the higher elevation sites (A_1 and B_1) in the Meghna floodplain. The soils are characterized by a light grey to grey mottled brown, friable, loam topsoil overlying an olive to olive-grey, friable, sandy loam subsoil with weak coarse prismatic and subangular blocky structure. This is underlain by a partially stratified olive to olive grey silt loam to sandy loam substratum. The *Chandpur* series occurs in the lower elevation sites (A_2 and B_2) in the floodplain, and soils are characterized by an olive, firm loam topsoil overlying a grey to olive, firm, silty loam with moderately thick grey cutans. This is underlain by an olive to grey , friable, silt loam substratum. The *Tippera* series lies within the higher elevations of the old Meghna estuarine floodplain (C_1 and D_2), where soils have olive to olive grey mottled yellowish brown, friable, loam and silty loam topsoils overlying olive grey mottled yellowish brown, silt loam with moderate coarse prismatic and blocky structure. At the lower elevations the *Burichang* series occurs (C_2 and D_1), characterized by dark to dark grey loam topsoil overlying very dark grey silty clay loam subsoil with strong coarse prismatic and blocky structure and dark grey cutans. A comparative soil classification for the various series appears in Table 5.1. Texture analyses for soil samples taken from the sample plots (two integrated samples per location) are shown in Figure 5.1 and compared to the texture of the deposited sediments (Meghna outside embankment only).

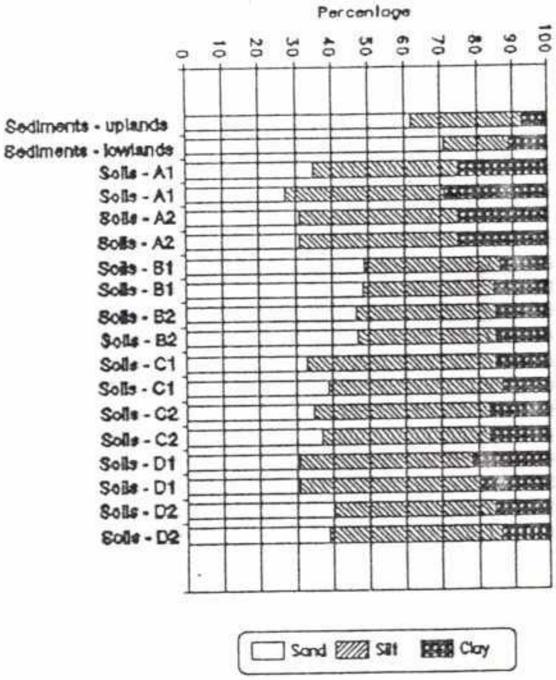


Figure 5.1. Texture of soil and sediment samples, CIP.

5.2 Land Types and Seasonal Flooding

Before the implementation of the CIP, major soils of the area were typically flooded to depths of 90-200cm by rain- and river water for 4-6 months during the monsoon season. Since 1976, the soils inside the project area have been protected against floods. Surface inundation depths in the sampling sites (B_1, B_2, C_1, C_2) now typically reach only 30-90cm during the monsoon period. Soils outside the project area on the Meghna River front (sampling sites A_1 and A_2) are still subject to seasonal tidal inundation during the period mid-June to the end of October. The area is exposed to erosion by the Meghna River, and topsoils receive a deposition of fresh sediments each year. The area outside the embankment on the Dakatia River side is flooded mainly by rain water. Summary data on flooding, land types and soil phases of the sampling sites are shown in Table 5.2.

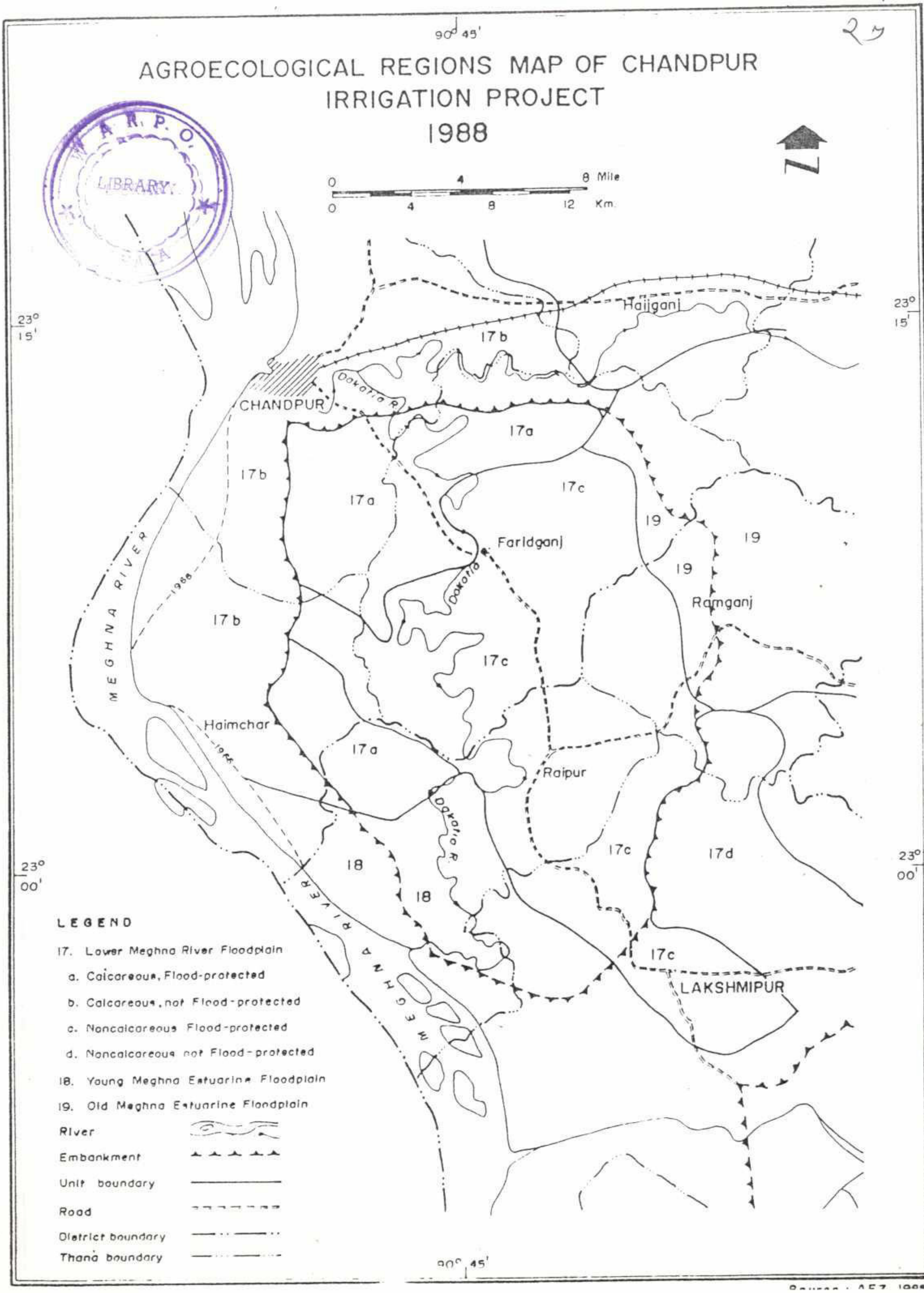
Table 5.1. Soil Classification of Soil Series of Sampling Sites

Soil Series	Parent Material	General Soil Type	FAO Soil Unit	USDA Soil Family
Madna	Lower Meghna River Alluvium	Calcareous grey flood- plain soil	Chromi Calcaric Gleysols	Aeric Haplaquept
Chandpur	Lower Meghna River Alluvium	Calcareous grey flood- plain soil	Chromi Calcaric Gleysols	Aeric Haplaquept
Tippera	Old Meghna Estuarine Alluvium	Noncalcareous dark grey floodplain soil	Chromi Eutric Gleysols	Aeric Haplaquept
Burichang	Old Meghna Estuarine Alluvium	Noncalcareous dark grey floodplain soil	Chromi Eutric Gley-sols	Aeric Haplaquept

Source: FAO/UNDP (1988)

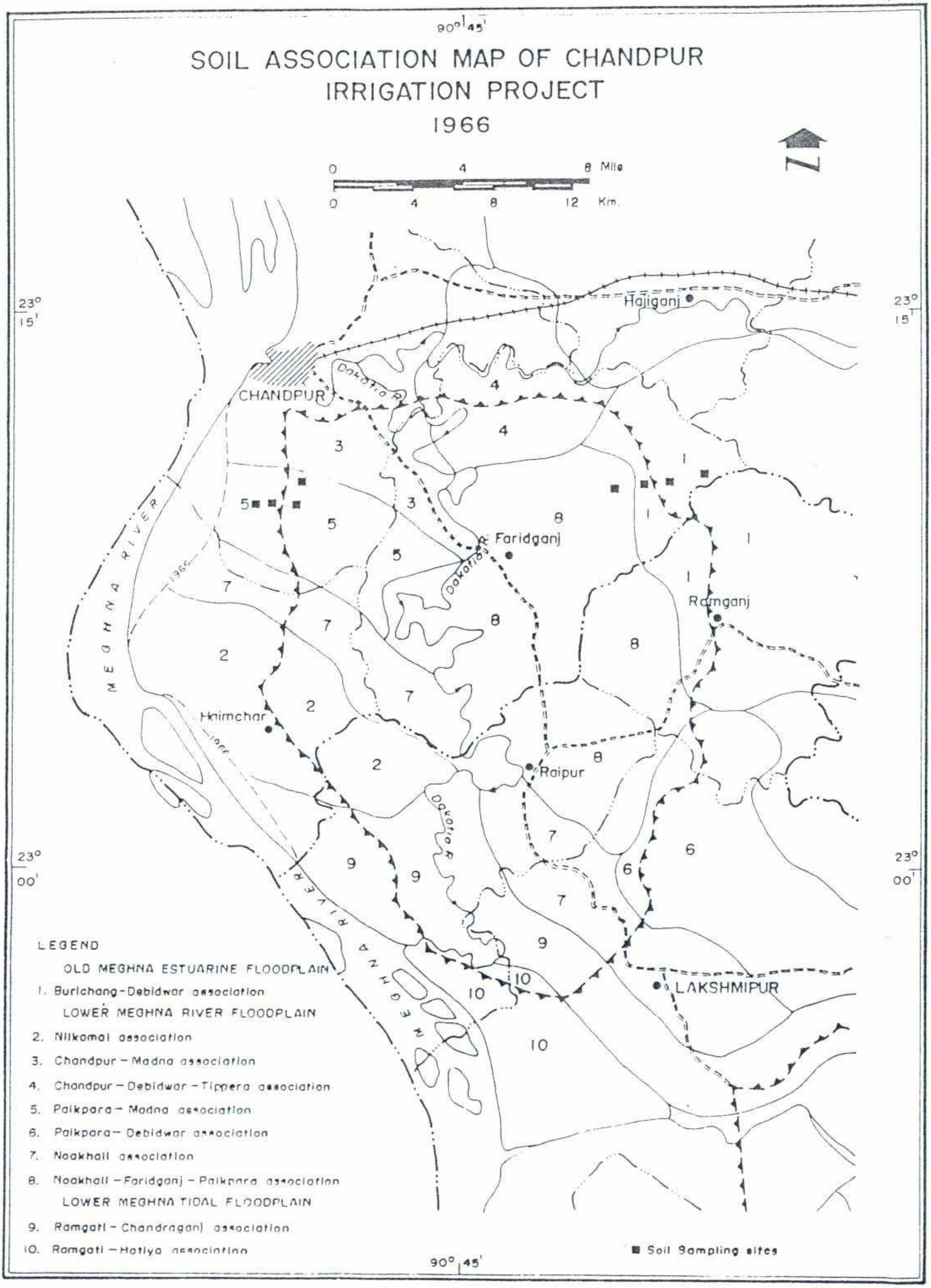
Table 5.2. Land Types and Flooding Depths and Duration in Sampled Sites at CIP.

Sample Site	Soil Series	Land Type	Flooding Depth (cm)	Flooding Duration in 1993	
				From	Until
A_1	Madna	Medium highland	80-95	10 June-20 June	15 Oct - 30 Oct
A_2	Chandpur	Medium low-land	110-120	5 June-15 June	20 Oct - 1 Nov
B_1	Madna	Medium highland	20-30	20 June-1 July	30 Sept - 15 Oct
B_2	Chandpur	Medium highland	40-60	15 June-25 June	15 Oct - 30 Oct
C_1	Tippera	Medium highland	40-70	10 June-20 June	20 Oct - 30 Oct
C_2	Burichang	Medium highland	80-90	8 June-20 June	20 Oct - 30 Oct
D_2	Tippera	Medium low-land	100-120	7 June 15 June	15 Oct - 25 Oct
D_1	Burichang	Lowland	170-210	30 May-10 June	20 Oct - 30 Oct



Source : AEZ 1988

Map-3



Source : SRDI.

Chapter 6

CROPPING PATTERNS AND CROP PRODUCTION

6.1 Cropping Patterns

Before implementation of the CIP the major cropping pattern of the area was mixed *aus* and *aman*, followed by dryland crops in the winter, practiced on an estimated 60 percent of the cultivable area. Jute was grown instead of *aus* on about 10 percent of the cultivable area. In areas that did not drain quickly after monsoon floods, i.e. the lower elevations in the old Meghna estuarine floodplain, B. *aman* was the main crop; the soils were usually left fallow in the dry season. On higher parts of the landscape, mainly in the south, T. *aman* was grown, preceded by B. *aus*, and followed usually by dryland *rabi* crops. This latter cropping pattern occupied 30 percent of the cultivable area. Before 1975, *boro* was virtually non-existent in the project area. Cropping intensity prior to CIP implementation was about 160 percent.

Since project implementation there has been a rapid increase in *boro* cultivation. The increase in boro area has taken place at the cost of *rabi* and *aus* crops in the area. The dryland rabi area decreased from about 21,870ha to 7695ha over the period 1975 to 1981. Chillies and pulses declined while cultivation of potato and wheat increased. Areas under jute decreased from 3645ha in 1976 to 1013ha in 1982.

Reduced flood depths inside the project area have eliminated the use low yielding varieties of B. *aman* in favor of introduced T. *aman* crops, but the area of high yielding variety (HYV) T. *aman* still comprises only about 30 percent of total area under T. *aman*. HYVs may be constrained by drainage problems that still occur over considerable areas. Cropping intensity of the project in 1981 was about 177 percent.

Cropping practices outside the project area have also changed significantly. Boro is cultivated on about 15-20 percent of the cultivable area on the Meghna side of the embankment, and has become one of the major crops in the deeply flooded areas outside the embankment on the Dakatia side. On the Meghna side, transplanted deepwater (T.D.) *aman* is grown in the area where previously B. *aman* was grown. Cropping intensity outside the areas increased since the implementation of the project.

Present cropping patterns in the soil sampling blocks are shown in Figure 6.1. Irrigated cropping patterns are practiced in all the sampling sites except in A_1 and A_2. Inside the project areas, high cropping intensities were observed in blocks B_1 and B_2 (200-300 percent). BR-11, BR-14 and IR-8 are the HYVs grown in the *aman* and *boro* cropping seasons.

6.2 Crop Production

Crop production inside the project areas is satisfactory by national standards (Table 6.1). Annual paddy production in the B_1 and B_2 blocks ranges between 9.5-10.5 tonnes/ha. Production outside the embankment in blocks A_1 and A_2 ranges between 1.5-2.5 tonnes/ha. Higher production inside the areas is mainly due to the use of HYVs. Crop production in blocks C_1 and C_2 is not as high (7.2-8.5 tonnes/ha) as in B_1 and B_2, but the figure is significantly higher than outside in blocks D_1 and D_2 (5.0-6.5 ton/ha).

Crop production is constrained at the lower elevations in C_2 by heavy rainfall in the monsoon season, when T. *aman* is damaged by drainage congestion. Farmers usually attempt a second transplantation to recover the loss. Existing flood depths do not permit HYV practice in the *aman* season. Crops are frequently damaged outside the project area towards the Dakatia side. Farmers of block D_1 do not cultivate *kharif* crops because of the risk of crop damage by floods. Farmers report losses of B. *aman* crops by flood in block D_2.

Based on information collected from farmers in the area, the yield levels of boro crops inside the CIP are fairly stable, except in B_1 where they

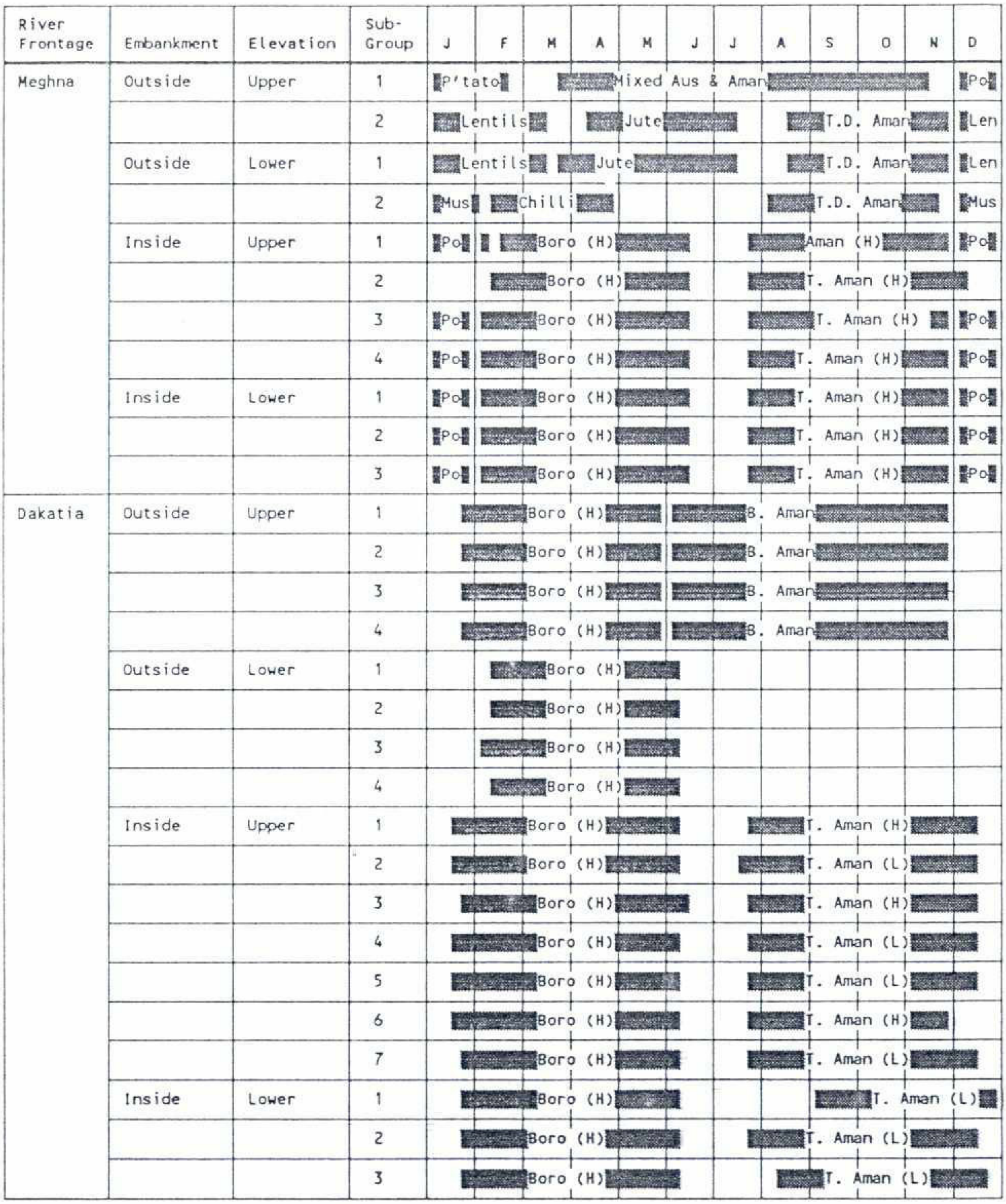


Figure 6.1. Present cropping patterns in sampled areas, CIP.

are decreasing slightly. A slight upward trend is reported for D_1 and D_2. Although T. *aman* production in 1992 was good due to favorable agroclimatic conditions, data for other years have shown a declining trend in yield levels.

Table 6.1. Crop Yields (tonnes/ha) in Sampled Areas at CIP Study Sites.

	Meghna				Dakatia			
	Upper		Lower		Upper		Lower	
	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside
Mixed aus and aman	1.5	-	-	-	-	-	-	-
T.D.aman	2.5	-	2.1-2.4	-	-	-	-	-
B.aman	-	-	-	-	1.4-1.6	-	-	-
T.aman (H)	-	3.9-4.3	-	4.5-4.7	-	1.8-3.4	-	-
T.aman (L)	-	-	-	-	-	2.6-2.7	-	2.5-3.1
Boro (H)	-	4.9-6.1	-	5.9-6.1	4.9-5.1	4.6-5.1	5.0-5.1	5.9-6.1
Jute	2.7	-	2.2	-	-	-	-	-
Potatoes	22.1	19.3-22.1	-	19.5-21.0	-	-	-	-
Mustard	-	-	1.8	-	-	-	-	-
Chilli	-	-	1.3	-	-	-	-	-
Lentils	0.8	-	1.3	-	-	-	-	-

Chapter 7

AGRICULTURAL PRACTICES AND INPUTS

7.1 Agricultural Practices

Soils inside the project area are intensively used for agriculture. In blocks B_1, B_2 and C_1 sites are cultivated by tractors and spades, while in C_2 only country ploughs are used for land preparation. Soils in the study area are tilled 3-4 times in preparation for boro, jute and potato crops, and 2-3 times for T. *aman* crops. Minimum land tilling was noted to take place in preparation for mustard and chili crops. Soils outside the embankment are tilled by country plough and spades. In the A_1 and A_2 blocks no land preparation was made for pulses, and seeds were simply broadcast into standing *aman* crops. Boro and jute crops were weeded 3-4 times in most cases, T. *aman* twice, and potato only once throughout the growing period.

After harvesting of crops, plant residues in the fields are mixed with the soil as organic manure or burned and added as ash (A_2 block only). In the B_1 and B_2 blocks most of the crop remains were removed and very little remained to be mixed with the soil.

7.2 Fertilizer and Manure Applications

Chemical fertilizers were applied by farmers for all the crops of the sampling sites of the study area (Figure 7.1 to 7.6). Fertilizers were used more inside the project area than outside beacsue of the higher cropping intensities and preponderance of HYVs. The B_2 block has the highest record of fertilizer use, while minimum fertilizer applications were recorded for A_2. Urea, triple super phosphate (TSP), single super phosphate (SSP), muriate of potash (MP), and zinc sulphate were commonly applied in most blocks. Manure, in the form of cow dung, and ash were applied to a limited number of fields.

The rate and timing of application of fertilizers varied from site to site. Major fertilizer applications were observed for potato crops, both inside and outside the project. In the B_1 and B_2 blocks, application of urea ranged between 328-642 kg/ha, SSP between 822-1316 kg/ha and MP 198-395 kg/ha. Farmers used these high application rates to carry over nutrients for their next major *boro* crop. During *boro* cultivation, only urea and zinc sulphate were applied at the rate of 66-132 and 16-25 kg/ha respectively at the transplanting period of this crop. In *boro* fields not preceded by potatoes, amounts of urea ranging from 197-330 kg/ha were applied in three installments at intervals of 20 days each. TSP, MP and zinc sulphate were applied once only, along with the first application of urea at rates of 166-370, 91-99 and 8-12 kg/ha respectively.

Fertilizers were applied in smaller quantitities to T. *aman* crops which are grown only inside the CIP area. HYV T. *aman* received 110-264 kg/ha of urea. Other fertilizers were not applied. For local T. *aman* crops, 70-110 kg/ha of urea were applied. Use of TSP and MP in very low doses was recorded in some plots. Farmers also used fertilizer on seedbeds of HYV crops.

Jute crops in sites A_1 and A_2 received fairly high doses of fertilizers. Applications of urea ranged between 132-189, TSP between 118-132 and MP 118 kg/ha. Cow dung and ash were also added as manure. T.D. *aman* received only urea fertilizer at the rate of 33 - 118 kg/ha.

7.3 Insecticides

B.*aus* crops in site A_1 were badly damaged by stem borer (*majra*) and the yield from such damaged crops was only 0.2 tons/ha. In other sites damage due to insects was observed to be slight. Common insect pests on the *boro* crop were Hispa (*pamri*) and stem borers. Farmers generally applied Azodin and Dimecron at rates of 0.90 kg/ha and 1.16 kg/ha respectively during March and April. The rates and timing of application of insecticides were more or less the same both inside and outside the project.

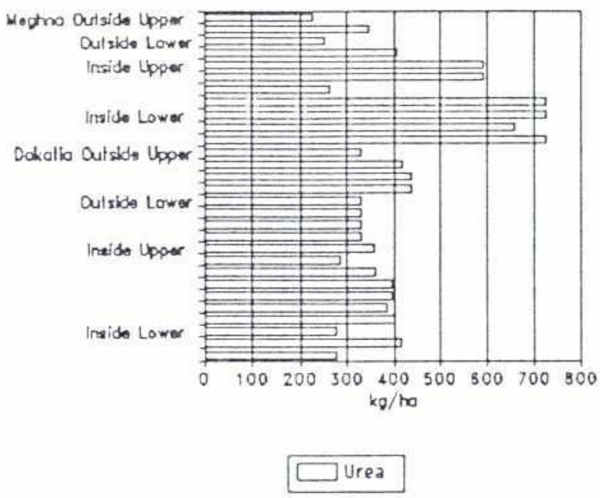


Figure 7.1. Rates of urea application to sampled areas, CIP.

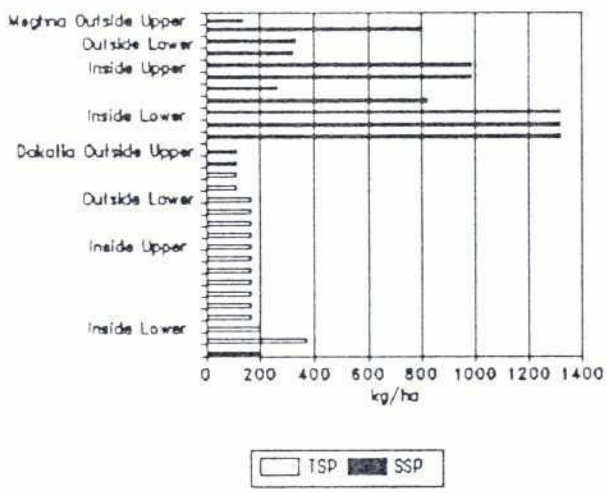


Figure 7.2 Rates of phosphate application to sampled areas, CIP.

Swarming caterpillar (*leda poka*), stem borers and grass hoppers (*faring*) were the insects most observed in T. aman crops. Azodin, Dimecron and Marshall were applied in fields at the rate of 0.9 kg/ha, 0.9-1.1 kg/ha and 0.4 kg/ha respectively. T.D. *aman* crops were infested with insects locally known as *tut*, *meoa* and *jara*. To control these insects, Dimecron at the rate of 0.80 kg/ha and Furadan at the rate of 16 kg/ha were used. Common insects on B. *aman* crops were Hispa and stem borers, for which farmers applied Dimecron at the rate of 0.87 kg/ha.

7.4 Irrigation

Irrigation water was mainly used on *boro* crops. Boro transplantation started as soon as the irrigation water was available in the field. During the growing period, water was applied 4-6 times to the fields.

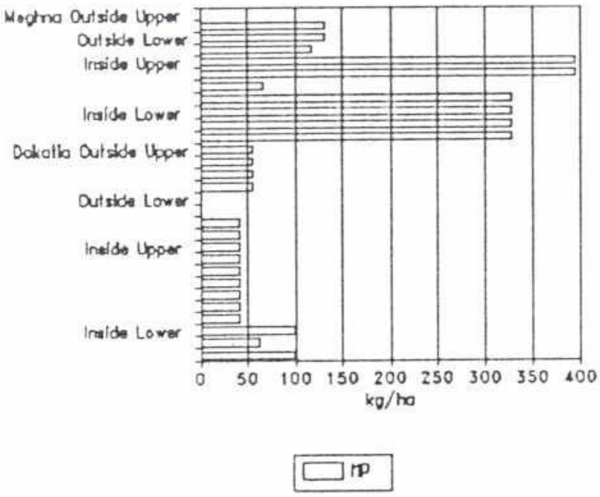


Figure 7.3. Rates of application of muriate of potash to sampled areas, CIP.

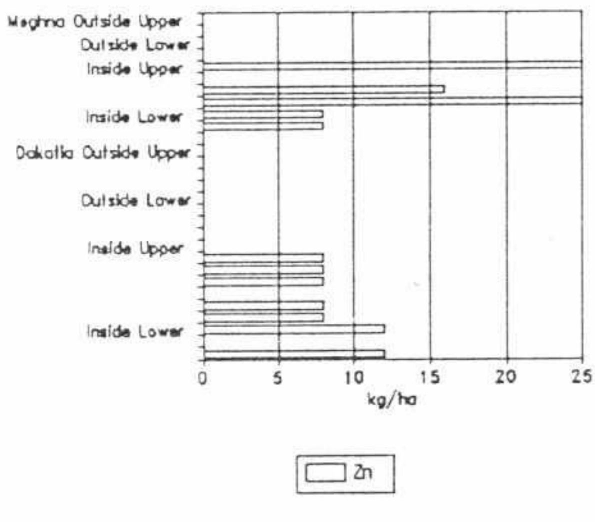


Figure 7.4. Rates of application of zinc fertilizer to sampled areas, CIP.

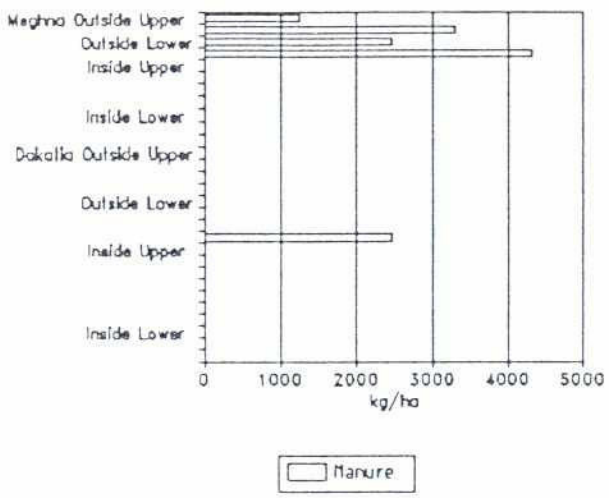


Figure 7.5. Rates of manure application to sampled areas, CIP.

Chapter 8

DISSOLVED NUTRIENTS

8.1 River Water During Monsoon

The complete set of monsoon season surface water samples from the study area comprised 60 individual samples (Annex 3) collected from five locations (two on the Meghna, two on the Dakatia and one inside the embankment from the main drainage canal). Each site was sampled four times during the monsoon period, one sample drawn from each of three depth strata. No significant differences were detected between strata for any of the 14 parameters (Annex 4), and these were thus treated as replicate samples for each sampling site. Results of the water sample analyses are shown in Figures 8.1 to 8.11. Levels of ammonium nitrogen, copper and boron in the samples were at or below detectable limits.

All waters in the vicinity of the study area were neutral to very slightly acidic (Figure 8.1). Statistically significant differences occurred between sampling periods but not between sites. Meghna River water was high in total dissolved solids (TDS) (Figure 8.2), but contained only moderate amounts of dissolved calcium and low levels of magnesium and potassium ions (Figures 8.3, 8.6 and 8.9). The bulk of the TDS thus probably consisted of sodium, chlorides and bicarbonates, which are generally high in the Ganges/Brahmaputra basin (Murray *et al.* 1992), and possibly dissolved organic carbon (DOC) which is typically high in large rivers during floods (Depetris *et al.* 1992, cited by Murray *et al.* 1992). Other dissolved inorganic soil nutrients were low in the Meghna waters, although during the late monsoon, when river levels were subsiding, zinc concentrations in the Meghna doubled and iron levels in both the Meghna and the Dakatia rose about five-fold, suggesting runoff of leachates at this period.

In comparison to Meghna River water, Dakatia waters were significantly lower in calcium, magnesium, phosphorus, manganese and especially TDS, but not in potassium and sulphur. The relatively lower levels of most dissolved elements was indicative of the high rainwater and local drainage content of the Dakatia, as opposed to the extensive floodplain-derived runoff which made up the bulk of the Meghna waters.

The results of the water analyses indicated that for most soil nutrients considered in this study, the inputs from the Meghna River in the form of dissolved ions were moderate for calcium and low for others. The highest inputs were in dissolved forms which were not specifically analyzed, possibly DOC, bicarbonates and

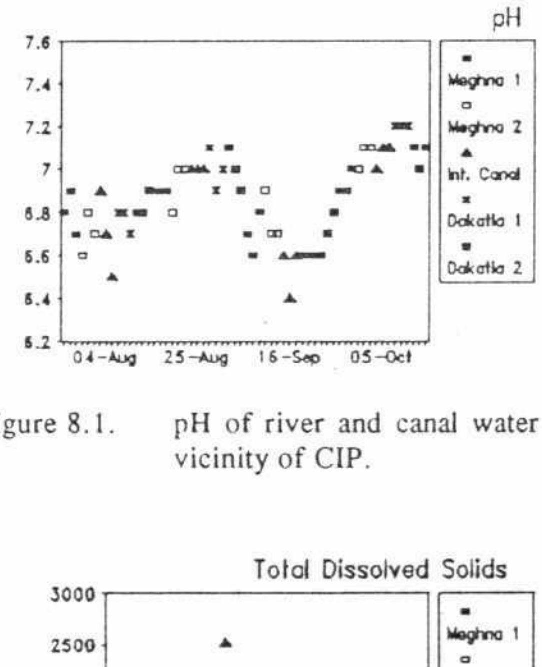


Figure 8.1. pH of river and canal water in vicinity of CIP.

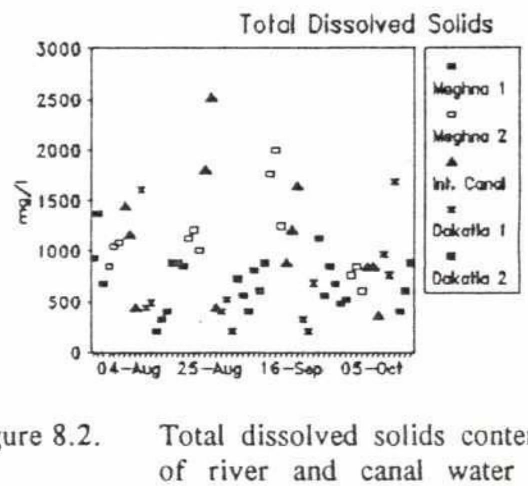


Figure 8.2. Total dissolved solids contents of river and canal water in vicinity of CIP.

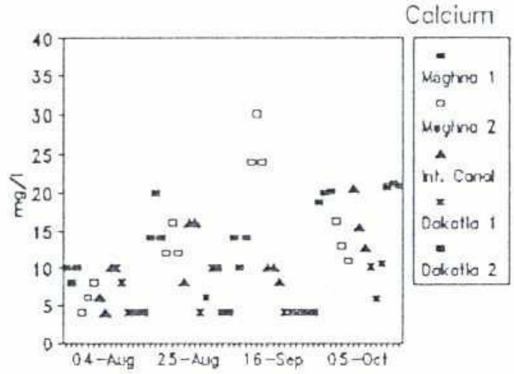


Figure 8.3. Calcium content of river and canal water from vicinity of CIP.

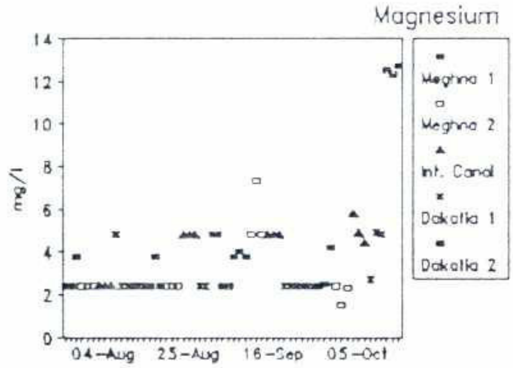


Figure 8.4. Magnesium content of river and canal water from vicinity of CIP.

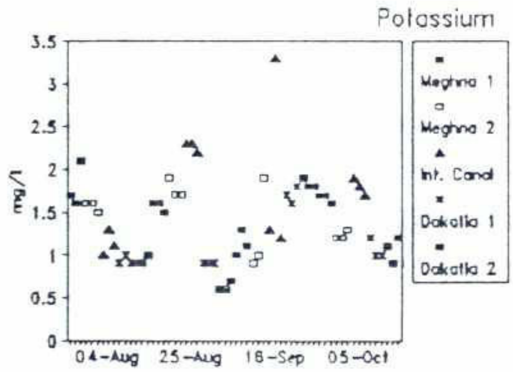


Figure 8.5. Potassium content of river and canal water in vicinity of CIP.

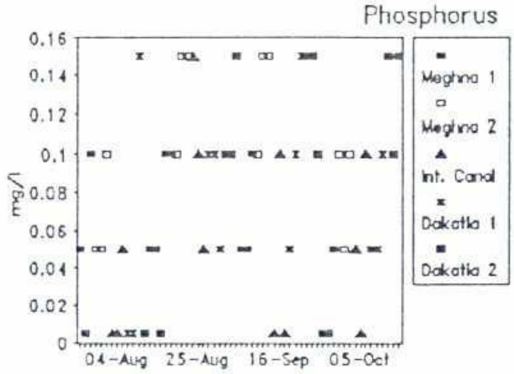


Figure 8.6. Phosphorus content of river and canal water in vicinity of CIP.

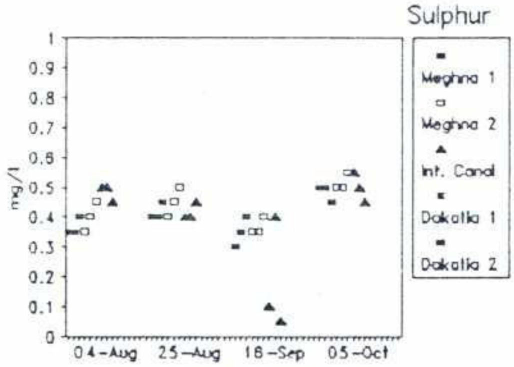


Figure 8.7. Sulphur content of river and canal water in vicinity of CIP.

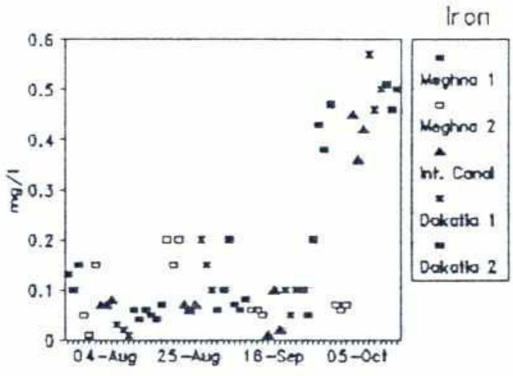


Figure 8.8. Iron content of river and canal water in vicinity of CIP.

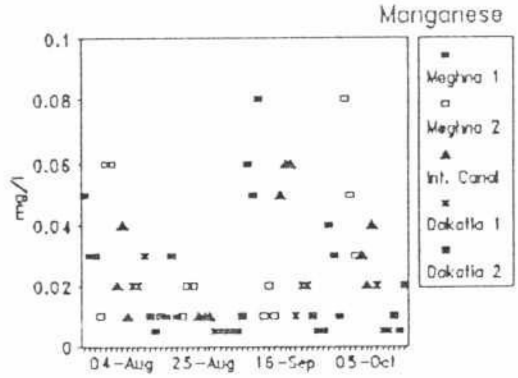


Figure 8.9. Manganese content of river and canal water in vicinity of CIP.

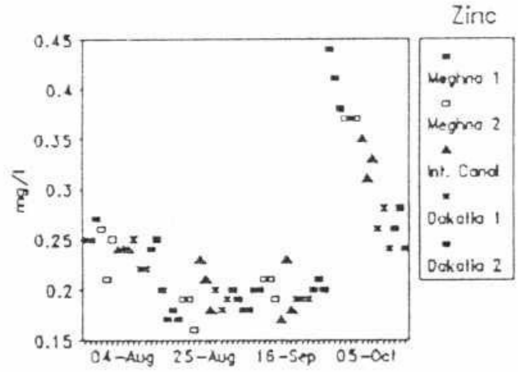


Figure 8.10. Zinc content of river and canal water in vicinity of CIP.

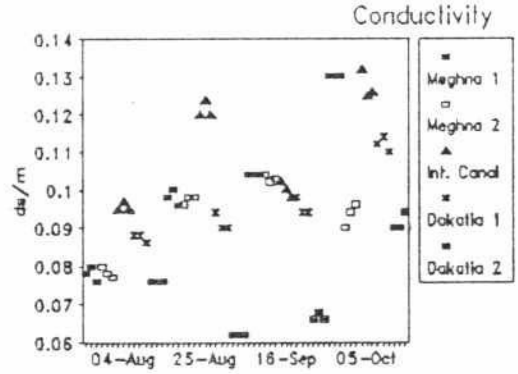


Figure 8.11. Electrical conductivity of river and canal water in vicinity of CIP.

chlorides. Dissolved nitrogen inputs were very low. Dissolved nutrient inputs from the Dakatia were significantly lower than the Meghna for all nutrients except potassium and sulphur.

8.2 Dry Season Irrigation Water

Two sets of dry season irrigation water samples were collected, in March and April 1993 (Annex 3). These were collected from irrigation canals supplying water to the plots where soil samples were collected (with the exception of those outside the embankment on the Meghna side, where no irrigation was practiced). Water in the irrigation canal was pumped from the Dakatia River and delivered to feeder canals via gravity.

Irrigation water was slightly more alkaline than outside river water (Figure 8.12) and had considerably lower total dissolved solids content (Figure 8.13), and a lower electrical conductivity (Figure 8.23). Most nutrients were present in higher concentrations than in river water (Figures 8.14 to 8.22), which suggests that differences in dissolved solids was due to lower concentrations of chlorides, sulphates and sodium in the irrigation water. Ammonium nitrogen was detected in the irrigation canals but only in non-quantifiable traces. Copper was found in small concentrations in the irrigation water, but was not previously detected in measurable quantities in outside river water.

The general pattern for calcium, copper, potassium and magnesium was to increase in concentration during the irrigation period. Other nutrients remained at approximately the same concentrations throughout the dry season. All nutriments were present in higher concentrations than in the outside river water. Some of these nutrients were present in fertilizer applications (calcium, potassium) and water concentrations may have been the result of run-off or direct fertilizer application to the water surface. However, many of the nutrients were not present in fertilizers, suggesting that the increased concentrations were due to topsoil leaching.

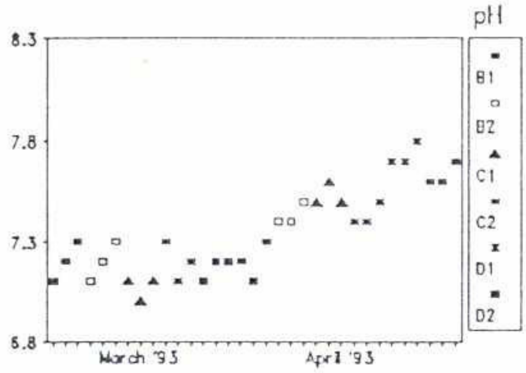


Figure 8.12. pH of dry-season irrigation water in CIP. Legends indicate sampling area supplied by irrigation water.

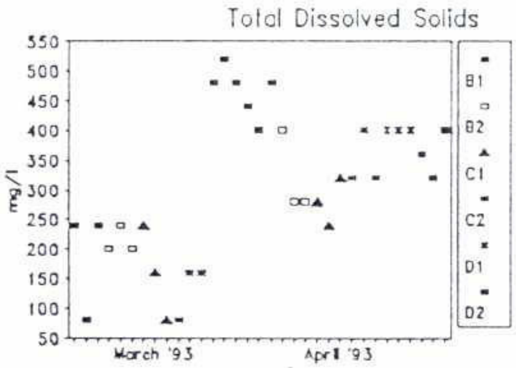


Figure 8.13. Total dissolved solids content of dry-season irrigation water in CIP.

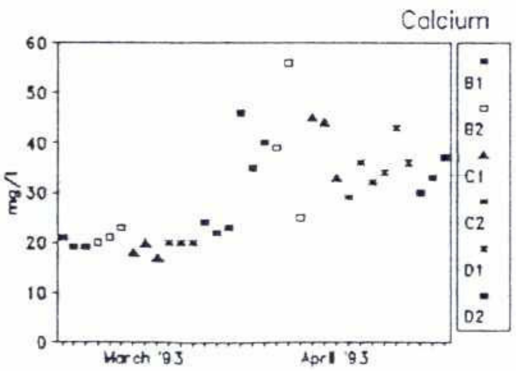


Figure 8.14. Calcium content of dry-season irrigation water in CIP.

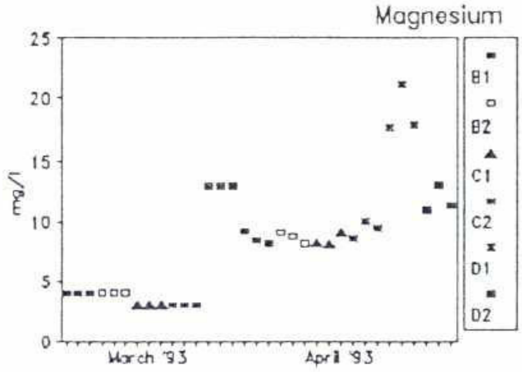


Figure 8.15. Magnesium content of dry-season irrigation water in CIP.

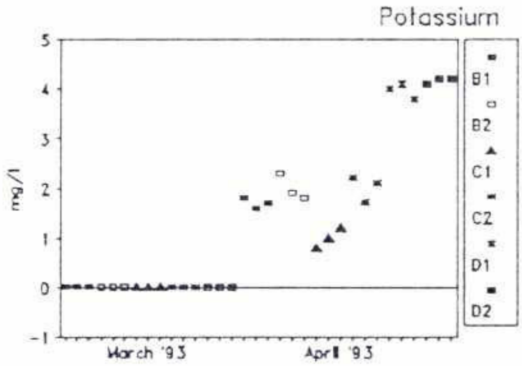


Figure 8.16. Potassium content of dry-season irrigation water in CIP.

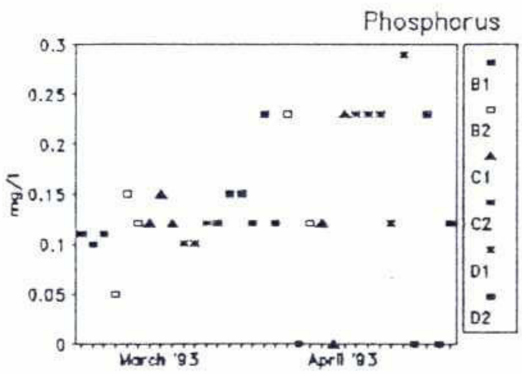


Figure 8.17. Phosphorus content of dry-season irrigation water in CIP.

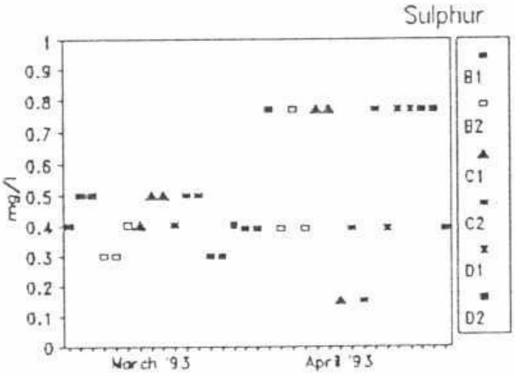


Figure 8.18. Sulphur content of dry-season irrigation water in CIP.

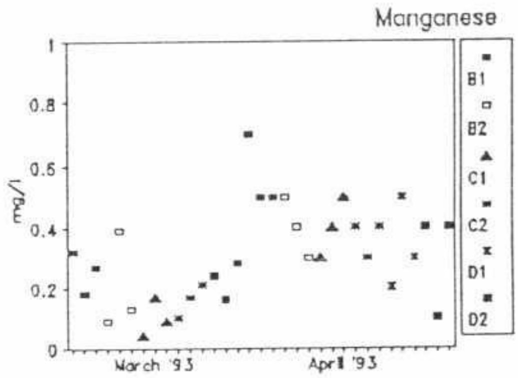


Figure 8.21. Manganese content of dry-season irrigation water in CIP.

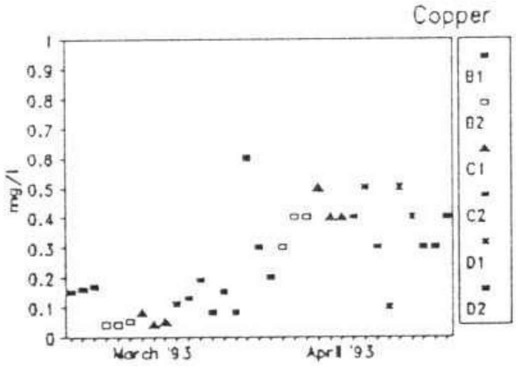


Figure 8.19. Copper content of dry-season irrigation water in CIP.

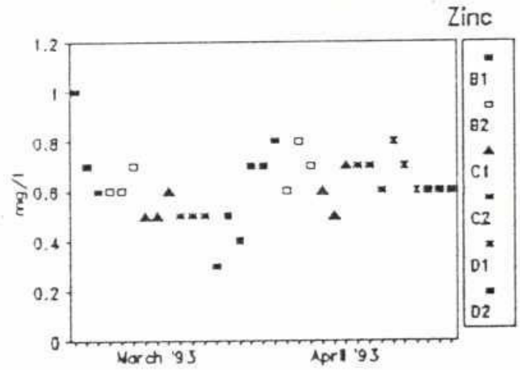


Figure 8.22. Zinc content of dry-season irrigation water in CIP.

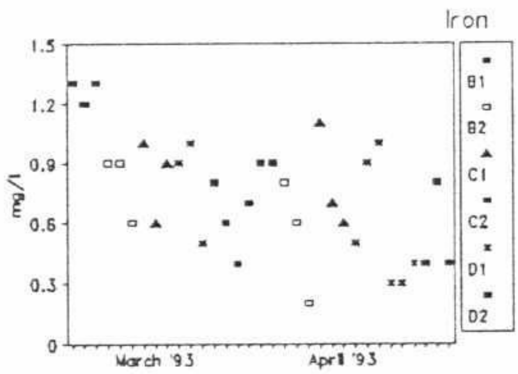


Figure 8.20. Iron content of dry-season irrigation water in CIP.

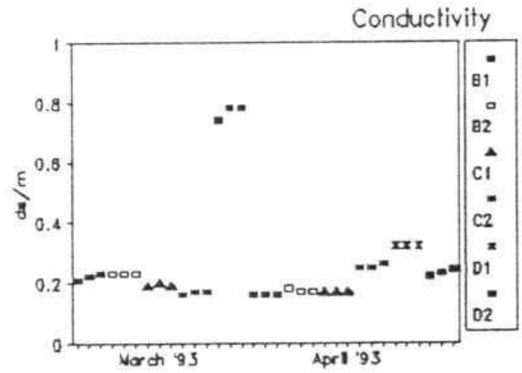


Figure 8.23. Electrical conductivity of dry-season irrigation water in CIP.

Chapter 9

BLUE-GREEN ALGAL DISTRIBUTION AND ABUNDANCE

With few exceptions, BGA were found to be abundant in all sampled sites and in all of the four sampled periods during the monsoon (Figures 9.1, 9.2). Exceptions to this were samples of floating BGA which were not found in water samples inside the embankment in October, and it likely that by this time floating BGA had all settled in the paddies and were attached to some form of substrate.

A total of 16 species belonging to 7 genera of nitrogen fixing BGA were identified from both flood-protected and unprotected fields (Annex 5). The numbers of filaments of different species varied widely from location to location. Some genera occurred throughout the flood period, i.e. *Aulosira*, *Nostoc*, *Anabaena* and *Gloeotrichia*. A gradual increase in the number of BGA, both floating and attached, was recorded from the beginning of flooding, and attained a maximum after about 80 days (total 2927 filaments) of the 130 days total flood period. Thereafter the numbers of BGA filaments gradually declined in the unprotected areas.

BGA filament numbers were higher when occurring free in water samples than when attached to rice plants. The relative abundance of BGA genera and species recorded from the Dakatia River sites was higher in the unprotected areas (total filaments 2927) than in the protected areas (total filaments 1446) during September, probably because flood water contained higher nutrient concentrations than rain water. A similar situation was observed in the Meghna River sites, where 1006 filaments were recorded in the unprotected area and 575 filaments in the protected area during the same period. Heterocystous BGA filaments were encountered in negligible numbers in the *boro* season (March-April)

Overall BGA abundance was greater in the Dakatia River sites than the Meghna River sites due to the clearer water which permitted more efficient photosynthesis. BGA abundance from area to area may also have differed because of soil tillage practices.

The occurrence of flowing sediment laden waters outside the embankment on the Meghna side appeared to have little effect on BGA abundance when they were attached to plant substrates, but floating BGA were relatively much less abundant on the Meghna side than on the Dakatia side of the study area, likely because of the greater volumes of water and the relatively greater dilution factors.

The biological nitrogen fixation by BGA could not estimated in this experiment due to shortage of time, equipment and field facilities. It is difficult to calculate the actual amount of nitrogen fixation by BGA in particular ecological situations since many biotic and environmental factors are involved. In most sampling periods the total number of BGA filaments was much higher in unprotected areas than in protected areas, so it was likely that the fixation of atmospheric nitrogen was higher there as well. A rough calculation based on literature data indicates that atmospheric nitrogen fixation in the unprotected areas along the Dakatia River could have approximated 16-20 kg N/ha. This amount of nitrogen addition to rice fields is fairly small compared to chemical fertilizer applications, but the long-term effect on soil quality is superior to that of chemical fertilizers because of the absence of soil and water pollution and the associated contribution to the humus content of the soil.

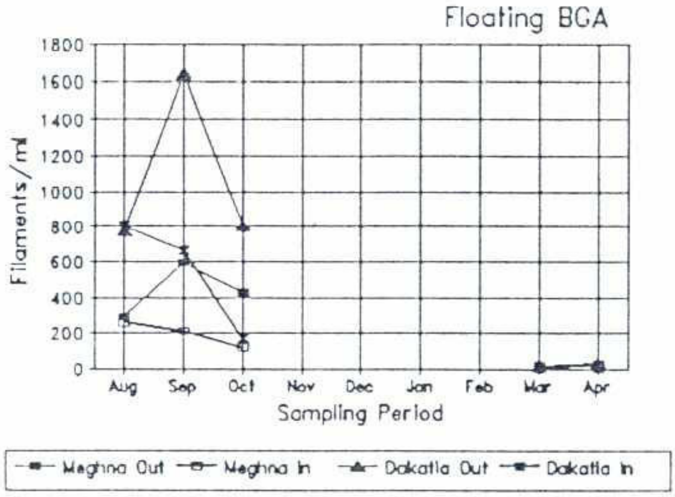


Figure 9.1. Abundance of floating BGA in water samples, CIP.

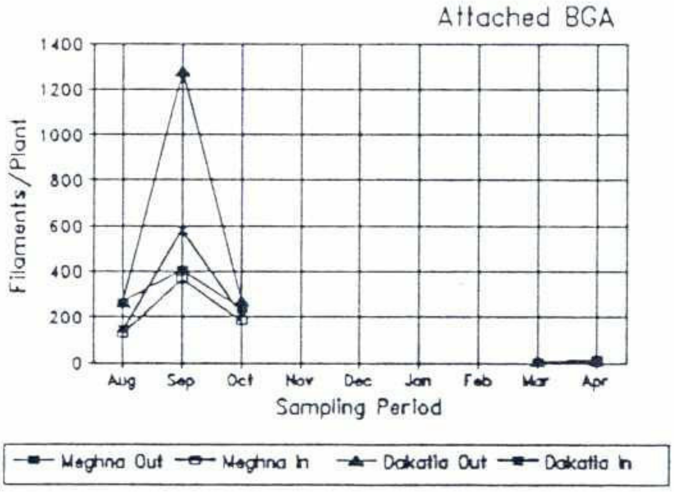


Figure 9.2. Abundance of attached BGA on rice culms, CIP.

Chapter 10

NUTRIENT CONTENT OF DEPOSITED SEDIMENTS

A major finding of the study was that there were little or no deposited sediments along the Dakatia side of the CIP embankment, as evidenced by a lack of deposited sediments in the collection trays, and thus it was concluded that most flooding was derived from sediment-free rainwater. This is probably the most common phenomenon in this area, as confirmed by the views of local farmers. Dakatia River flooding, with some sediment deposition may occur in years of exceptionally high floods, however, hence occasional deposition of river-borne sediments cannot be completely discontinued.

Sampling intensity of sediments deposited within the unprotected areas by the Meghna River was lower than planned for two reasons. The 1992 flood year was an exceptionally low one, and little flooding occurred in some sections, with little or no sediment deposition in the collection trays. Several collection trays were removed by local people before they could be recovered by the study team. A total of nine deposited sediment samples were eventually retrieved along the Meghna side of the embankment, five at the lower elevations within the medium lowlands and four in the medium highlands. Recovered sediment samples were all sandy loams.

Table 10.1. Texture of Deposited Sediments along Meghna River, CIP.

Location	Percent		
	Sand	Silt	Clay
Upper Elevations	62	31	7
Lower Elevations	71	18	11

In terms of nutrient content, deposited sediment samples were substantially higher in some nutrients than the surrounding soils on which they were deposited, substantially lower for others and intermediate between pre- and postmonsoon soil nutrient levels in a few (Table 10.1). Calcium and sulphur (in sediments deposited at lower elevations), and potassium, manganese and nitrogen were significantly higher in deposited sediments than in soils, the latter two substantially so. By contrast, copper and zinc contents of the sediments at the upper elevations were quite significantly lower than those in the soils. The conductivity and organic matter content of sediments recovered at the lower elevations were significantly higher than that in the surrounding soils. Iron, magnesium, sulphur (upper elevations) and zinc (lower elevations) concentrations in sediments were intermediate between levels measured in soils during the pre- and postmonsoon periods respectively, suggesting that addition of these sediments was likely responsible for the elevation of soil concentrations over the flooding period.

With the exception of copper and phosphorus, nutrient concentrations of sediments deposited at the lower elevations was significantly higher than those deposited at upper elevations. The duration of flooding at the various elevations varied by a few days at most (Table 5.1), hence this was not likely to have been a causative factor in nutrient deposition. Differential textural analysis (Table 10.1) indicates a higher sand and higher clay content of sediments deposited at lower elevations. It is possible that the higher clay content may have contributed to the increased concentrations of nutrients at lower elevations because of the adsorbed ions.

Principal components analysis using the first two extracted components (Figures 10.1, 10.2) confirms the considerable differences between the nutrient content of deposited sediments and the nutrient contents of the Chandpur and Madna soils on which they were deposited, and confirms that the deposited sediments were indeed introduced from outside the area and were not simply local soils redeposited by moving flood waters.

Table 10.2. Comparison of Soil Nutrient Concentrations in Deposited Sediments and in Soils in Unprotected Areas Adjacent to Meghna River.

	Pre-Monsoon	Deposited Sediments	Post-Monsoon
Number of Samples			
Upper Elevations	20	5	20
Lower Elevations	20	4	20
pH			
Upper Elevations			
Mean	5.8	6.6	5.7
SD	0.2	0.1	0.1
Minimum	5.5	6.5	5.6
Maximum	6.1	6.7	5.8
Lower Elevations			
Mean	5.6	6.3	5.3
SD	0.1	0.0	0.1
Minimum	5.4	6.3	5.1
Maximum	5.8	6.4	5.5
Organic Matter %			
Upper Elevations			
Mean	3.0	2.4	2.3
SD	0.2	0.4	0.2
Minimum	2.7	1.7	2.0
Maximum	3.3	2.9	2.9
Lower Elevations			
Mean	3.0	5.1	2.6
SD	0.2	0.5	0.3
Minimum	2.5	4.4	2.1
Maximum	3.3	5.8	3.1
Calcium meq/100g			
Upper Elevations			
Mean	10.1	9.4	9.0
SD	0.5	0.3	0.7
Minimum	9.0	8.9	8.0
Maximum	10.7	9.9	10.2
Lower Elevations			
Mean	10.3	12.0	11.0
SD	0.4	1.4	2.5
Minimum	8.9	10.6	8.3
Maximum	10.8	14.0	17.0
Magnesium meq/100g			
Upper Elevations			
Mean	5.7	3.5	3.0
SD	0.4	0.4	0.3
Minimum	4.8	3.1	2.6
Maximum	6.2	4.3	3.5
Lower Elevations			
Mean	4.4	4.5	2.3
SD	0.3	0.5	0.2
Minimum	3.8	4.0	2.0
Maximum	4.8	4.9	2.6
Potassium meq/100g			
Upper Elevations			
Mean	0.19	0.27	0.15
SD	0.03	0.04	0.04
Minimum	0.15	0.22	0.10
Maximum	0.25	0.32	0.26
Lower Elevations			
Mean	0.18	0.44	0.21
SD	0.03	0.07	0.06
Minimum	0.15	0.35	0.12
Maximum	0.25	0.53	0.35
Nitrogen µg/g			
Upper Elevations			
Mean	17.0	55.0	17.5
SD	7.3	29.2	3.6
Minimum	10	25	14
Maximum	30	100	23
Lower Elevations			
Mean	23.0	193.8	18.4
SD	8.1	27.2	3.6
Minimum	10	150	14
Maximum	40	225	23
Phosphorous µg/g			
Upper Elevations			
Mean	20.8	20.8	18.8
SD	9.7	1.2	4.0
Minimum	10	20	13
Maximum	43	23	28
Lower Elevations			
Mean	17.1	19.8	23.6
SD	3.7	3.3	2.5
Minimum	10	16	20
Maximum	22	25	28
Sulphur µg/g			
Upper Elevations			
Mean	47.9	44.2	41.2
SD	9.2	27.9	7.3
Minimum	29	23	29
Maximum	59	97	57
Lower Elevations			
Mean	31.1	156.8	51.7
SD	7.4	4.7	10.4
Minimum	17	150	38
Maximum	44	162	71
Boron µg/g			
Upper Elevations			
Mean	0.7	0.8	0.8
SD	0.2	0.4	0.2
Minimum	0.4	0.2	0.6
Maximum	0.9	1.3	1.0
Lower Elevations			
Mean	0.4	1.0	0.8
SD	0.3	0.3	0.2
Minimum	0.1	0.7	0.6
Maximum	0.9	1.3	1.0
Copper µg/g			
Upper Elevations			
Mean	10.7	6.8	12.4
SD	0.7	2.2	1.7
Minimum	9.5	3.6	10.0
Maximum	12.0	10.2	17.1
Lower Elevations			
Mean	10.9	6.1	14.5
SD	0.8	0.9	2.2
Minimum	8.7	5.4	11.2
Maximum	12.0	7.6	19.2
Iron µg/g			
Upper Elevations			
Mean	527	300	302
SD	135.3	116.9	125.7
Minimum	330	197	80
Maximum	775	505	511
Lower Elevations			
Mean	616	706	838
SD	63.8	198.0	115.5
Minimum	505	398	574
Maximum	756	937	1100

Continued

Table 10.2.Continued.

	Pre-Monsoon	Deposited Sediments	Post-Monsoon
Manganese µg/g			
Upper Elevations			
Mean	62.5	129.4	30.0
SD	22.5	62.4	8.7
Minimum	23	47	13
Maximum	88	226	50
Lower Elevations			
Mean	78.4	427.3	50.2
SD	17.0	190.7	7.5
Minimum	41	141	38
Maximum	105	653	65
Zinc µg/g			
Upper Elevations			
Mean	4.8	2.5	3.5
SD	0.3	0.6	1.5
Minimum	4.1	1.7	1.0
Maximum	5.5	3.1	6.3
Lower Elevations			
Mean	3.5	3.8	4.3
SD	1.0	0.6	1.7
Minimum	1.7	2.9	1.9
Maximum	5	4.7	7.3
Conductivity ds/m			
Upper Elevations			
Mean	0.35	0.22	0.12
SD	0.10	0.06	0.02
Minimum	0.14	0.16	0.08
Maximum	0.58	0.33	0.17
Lower Elevations			
Mean	0.18	0.50	0.15
SD	0.02	0.09	0.04
Minimum	0.13	0.41	0.09
Maximum	0.21	0.62	0.27

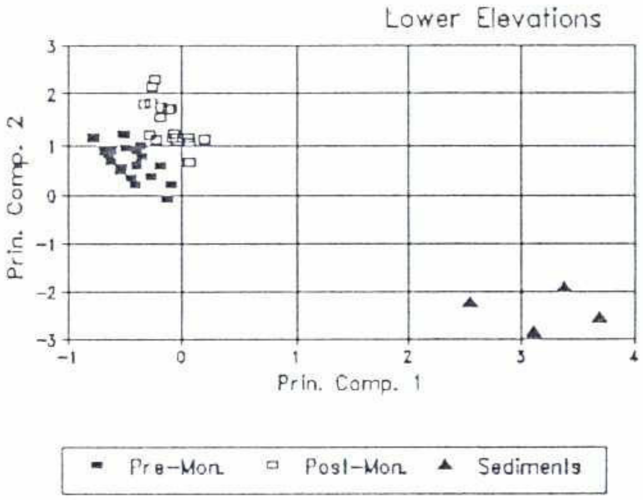


Figure 10.1. Principal components comparison of nutrient content of deposited sediments and surrounding soils in lower elevation areas adjacent to Meghna River, CIP.

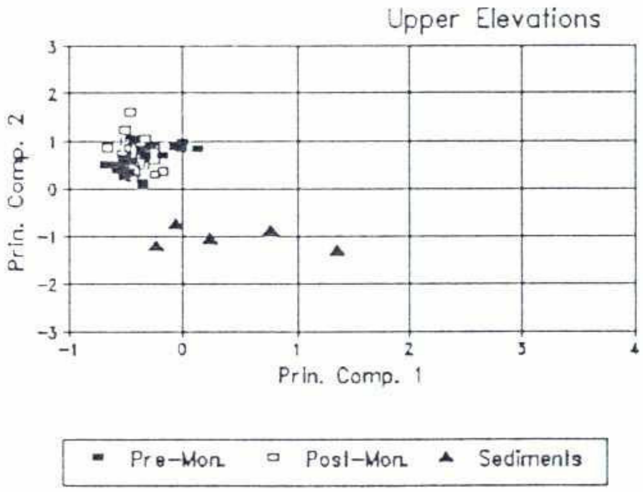


Figure 10.2. Principal components comparison of nutrient content of deposited sediments and surrounding soils in upper elevation areas adjacent to Meghna River, CIP.

Chapter 11

NUTRIENT STATUS OF SOILS

Summary statistics for the results of the analyses are presented in Annexes 6, 7 and 8.

Soil nutrient concentrations were highly correlated with each other (Annex 9). Most nutrients were positively correlated with other, but notable exceptions were iron and manganese, which although positively correlated to each other, were negatively correlated with other nutrients. Soil organic matter and soil pH were also negatively correlated with soil nutrient contents, but soil pH was positively correlated with iron content. Soils on the Dakatia side of the study area were higher in iron content than on the Meghna side, especially soils at lower elevations in the medium lowlands.

The patterns of change in soil nutrient concentrations from the pre- to the post-monsoon period were noted to be similar in both protected and unprotected areas on the Meghna side of the study area. Where soil concentrations rose after flooding (e.g. calcium, potassium, phosphorus, sulphur, boron, copper and zinc) or declined after flooding (e.g. magnesium and manganese), these directional changes occurred on both sides of the embankment.

Most of the fertilizer levels applied were correlated to each other (Annex 9); urea, TSP and MP applications were positively correlated to each other, but negatively related to manure and ash applications, which were made only in the areas outside the embankment on the Meghna side where phosphate, MP and urea applications were much lower than on the inside (Figures 7.1 to 7.6.

pH

No significant differences were found between the mean pH of soils on the Meghna side (range 5.1-6.5) and on the Dakatia side (range 5.4-7.1) of the study area (Figure 11.1). Soil pH was slightly but significantly higher inside the embankments (mean 5.9) than outside (mean 5.7) because of the prolonged wetness of the inside soils, and significantly lower after monsoon flooding (mean 5.6) than before (mean 6.0), probably because of soil oxidation. The pH of river and canal water supplying the cropped areas was only slightly acidic (Annex 3), much less acidic than the soils, and became significantly less acidic (neutral in fact) as the monsoon season progressed. There were no statistically significant differences in the pH of water in the various locations in the study area. The soil pH in lands receiving urea fertilization prior to sampling was significantly higher (6.0 and higher in plots receiving $\geq$197 kg/ha urea) than in those not receiving urea (mean 5.8). Similarly TSP application increased soil pH slightly but significantly ($\geq$6 in plots receiving TSP, mean of 5.8 in others). The pH in lands receiving manure applications prior to sampling was slightly but significantly lower (mean 5.7) than those not receiving it (mean 5.9). Other fertilizer applications had no detectable effect on soil pH. Deposited sediments had a significantly higher pH (6.3-6.7) than the soils on which they were deposited (5.1-6.1). Thus, every treatment to which the soils were subjected (water, sediments, fertilizers) tended to reduce acidity, which remained fairly low, probably due to redox reactions.

Organic Matter

Organic matter content of soils was measured to be significantly higher on the Dakatia side of the study area (mean 3.7 percent) than on the Meghna side (mean 3.0 percent). It was higher inside the embankments (mean 3.8 percent) than outside (mean 3.0 percent), higher in lower elevation soils (mean 3.6 percent) than in higher elevation soils (mean 3.2 percent), and lower after the monsoon period (from mean of 3.6 to 3.2 percent). Fertilizer applications had no measurable effect on soils organic content, with the exception of lands which received manure which were found to have a lower organic matter content (mean 3.0 percent) than those not

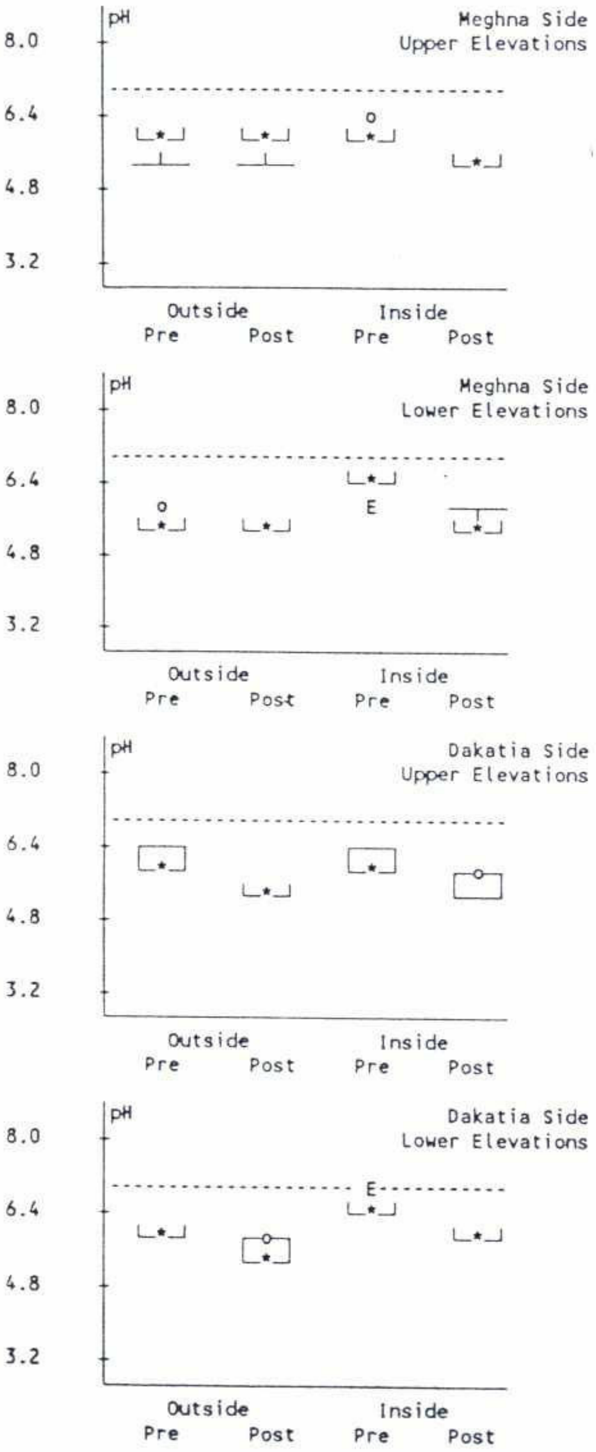


Figure 11.1. pH of soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme. Horizontal lines demarcate acidic and alkaline ranges.

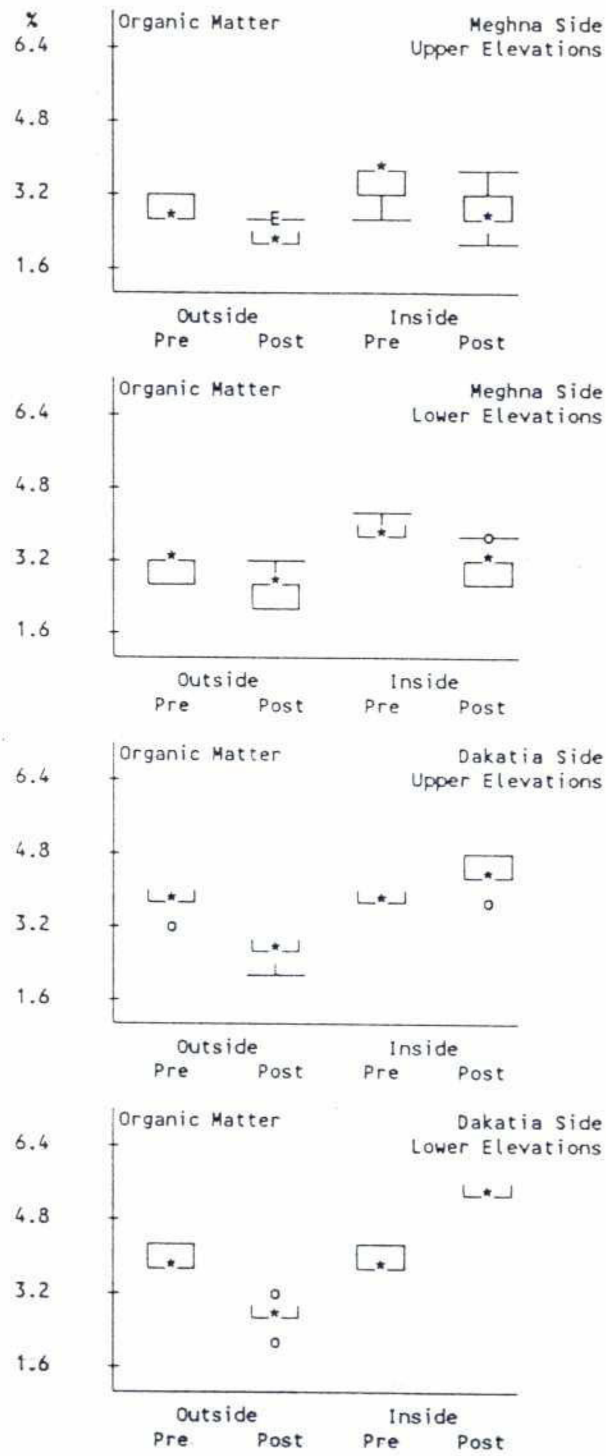


Figure 11.2. Organic matter content of soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value.

receiving it (mean 3.5 percent). Manured areas were all outside the Meghna embankment. The rates of crop production were much higher within the embanked area than outside, based on the cultivation of high yielding T. *aman* and *boro* paddy and potatoes, and consequently the build-up of organic residues would be expected to be higher in these locations.

The organic matter content of the deposited sediments was significantly higher than that of the surrounding soils at the lower elevational sites (mean of 5.1 percent, compared to 2.6-3.0 percent for soils), but not significantly different at the higher elevations (mean of 2.4 percent, compared to 2.3-3.0 percent for soils). The locational differences in organic matter content, the relatively low organic content of soils outside the embankments despite the inputs via the sediments, and the positive correlation between sediment organic content and sediment nitrogen content, suggest that the organic materials in the sediments were labile, probably particulate organic materials such as algae and allochthonous fragments, and soluble nitrogenous materials such as amino acids, which are broken down rapidly within the soil biological environment.

Calcium

The calcium content of soils on the Meghna side of the study area was measured to be markedly higher (mean 10.3 meq/100g) than those on the Dakatia side (mean 6.3 meq/100g), which is consistent with the distribution of calciferous gleysolic soils in the area. Soils at the lower elevations, inside and outside the embankments on either side of the study area, respectively, had similar calcium concentrations, but higher elevation soils inside the embankment were significantly higher in calcium than higher elevational soils outside. Calcium content was higher in soils at lower elevations (mean 9.0 meq/100g) than in upper elevation soils (mean 7.6 meq/100g), and was lower after the monsoon (mean 8.0 meq/100g) than before (mean 8.6 meq/100g). All measured calcium concentrations were well within the optimum ranges for crop nutrition.

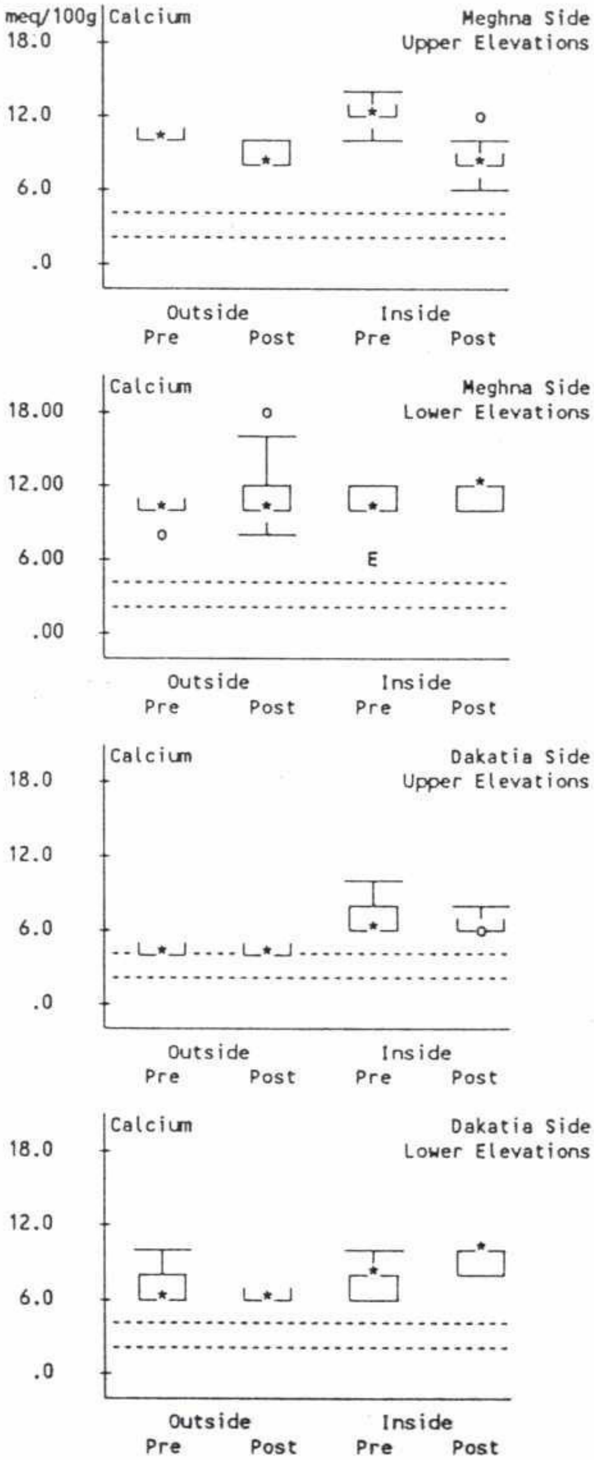


Figure 11.3. Calcium concentrations in soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value. Horizontal lines demarcate low, medium and optimum ranges for crop nutrition.

The calcium content of deposited sediments along the Meghna was little different to that of the surrounding soils. The inundating water derived from the Meghna River and the associated irrigation canals was high in dissolved calcium, and significantly higher than that in the Dakatia and its associated irrigation supply system.

Soil calcium content was significantly higher in all samples from fertilized plots, with the exception of those receiving urea applications. Samples from plots receiving SSP and TSP were higher (4-13 meq/100g) than those not receiving it (mean 6.9 meq/100g), higher in plots receiving MP (4-13 meq/100g) than those not receiving it (mean 7.7 meq/100g), higher in manured lands (mean 10.2 meq/100g) than in non-manured lands (mean 8.1 meq/100g), higher in lands receiving zinc fertilizer (7-13 meq/100g) than others (mean 8.1 meq/100g), and higher in lands receiving ash applications (mean 10.0 meq/100g) than those not receiving it (mean 8.3 meq/100g).

Deposited sediments along the Meghna are calcareous in nature and, combined with the high dissolved calcium content of the Meghna water, appear to be responsible for the higher calcium content of the Chandpur and Madna soils. The calcium content of these soils at the locally higher elevations is further boosted by applications of calcium-containing fertilizers such as TSP and inorganic ash.

Magnesium

Magnesium concentrations were quite significantly higher in the Madna and Chandpur soils on the Meghna side (mean 3.4 meq/100g) than in Tippera and Burichanga soils on the Dakatia side (mean 2.4 meq/100g). No significant differences were detected in protected and unprotected soils in any treatment plots or in soils at different elevations. Soils were significantly lower in magnesium after the monsoon (mean 2.1 meq/100g) than before (mean 3.7 meq/100g). Except for some post-monsoon samples on the Dakatia side, outside the embankment, all measured magnesium concentrations were within the optimum range for crop production.

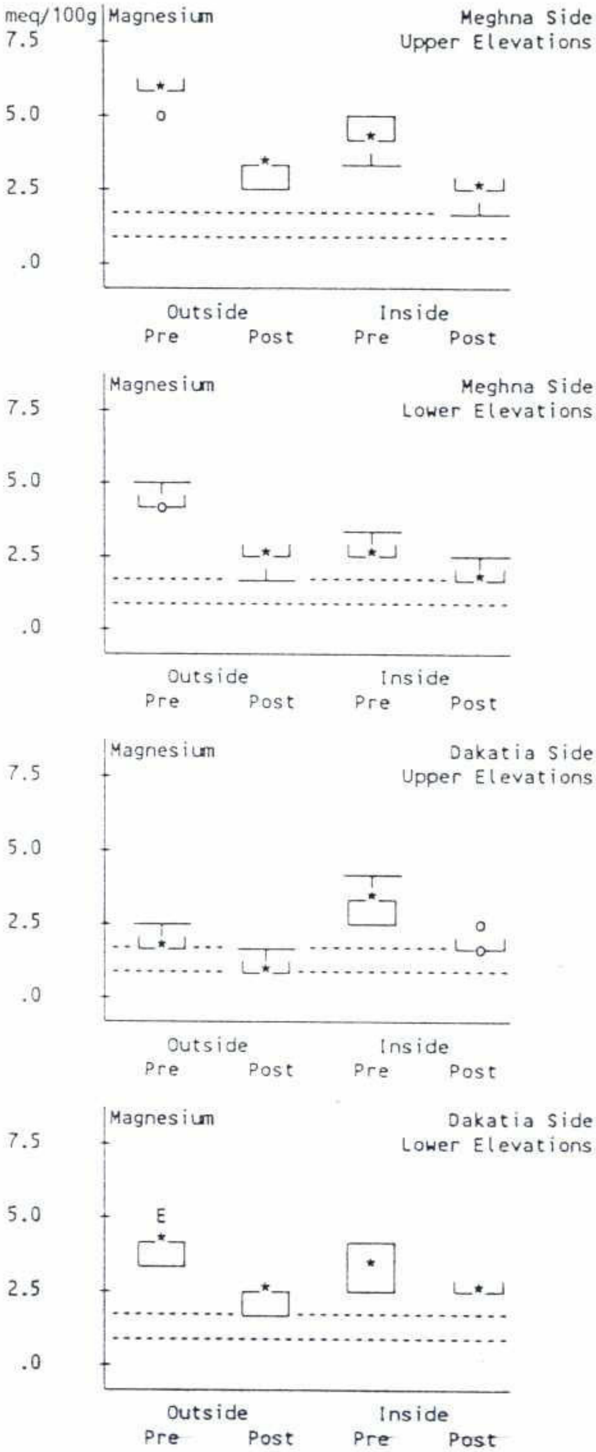


Figure 11.4. Magnesium concentrations in soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value. Horizontal lines demarcate low, medium and optimum ranges for crop nutrition.

Plots receiving TSP prior to sampling had higher magnesium concentrations (range 2-5 meq/100g) than those not receiving it (mean 2.1 meq/100g) as did soils receiving zinc fertilizers (range 3-4 meq/100g as against a mean of 2.7 meq/100g in plots not receiving zinc). Magnesium concentrations were much higher (mean 5.0 meq/100g) in manured fields than in non-manured ones (mean 2.6 meq/100g).

Potassium

As with magnesium, potassium concentrations were much higher in soils on the Meghna side (mean 0.24 meq/100g) than in those on the Dakatia side (0.09 meq/100g). They were slightly higher inside the embankments (mean 0.19 meq/100g) than outside (0.14 meq/100g), higher in lower elevation soils (mean 0.20 meq/100g) than upper elevation soils (mean 0.13 meq/100g), and much higher after the monsoon period (mean 0.24 meq/100g) than before (mean 0.09 meq/100g). They were higher in soils fertilized with MP (range 0.04-0.24 meq/100g versus a mean of 0.13 meq/100g) and with TSP (range 0.06-0.78 meq/100g versus a mean of 0.14 meq/100g). Manured soils were slightly but significantly higher in potassium (mean 0.18 meq/100g versus 0.16 meq/100g). Potassium concentrations in soils on the Dakatia side of the CIP, both in- and outside the embankment were in the range of potential deficiency in terms of crop nutrition. Soils on the Meghna side were mainly in the moderate range, i.e. deficiencies could have been problematical for some crops.

Nitrogen

All soil samples were found to be very low in nitrogen content, and generally deficient in terms of crop nutritive capabilities. Soils of the Meghna side of the study area were quite significantly higher in ammonium nitrogen (mean 26 ppm) than those on the Dakatia side (mean 16 ppm), and soils protected by the embankments were similarly quite significantly higher in nitrogen (mean 25 ppm than unprotected soils (mean 18 ppm). These differences correlated well with the higher applications of urea on the Meghna side and in the areas inside the CIP. However, samples from urea-treated soils were not statisti-

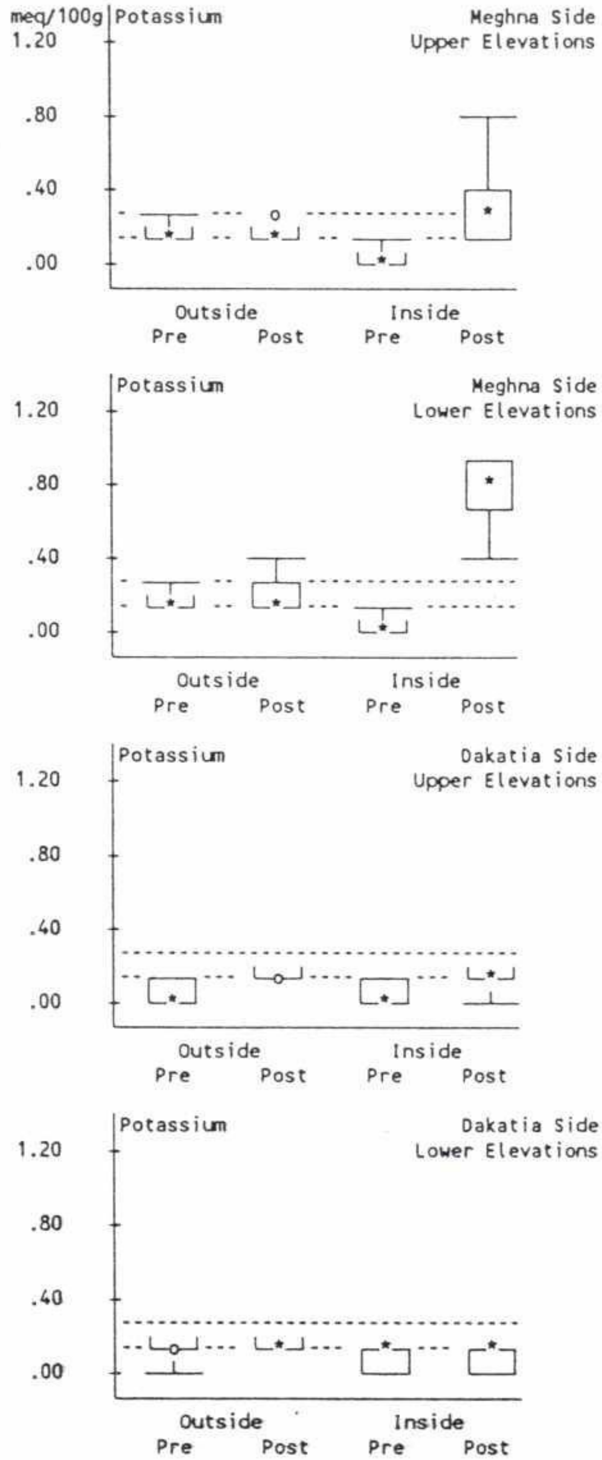


Figure 11.5. Potassium concentrations in soil samples from CIP. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value. Horizontal lines demarcate low, medium and optimum ranges for crop nutrition.

cally different in nitrogen concentrations from soils not receiving urea. Lower elevation Chandpur and Burichanga soils were much higher in nitrogen (mean 27 ppm) than upper elevation Madna and Tippera soils (mean 15 ppm). Post-monsoon samples were significantly higher (mean 26 ppm) than pre-monsoon samples (17 ppm).

Nitrogen was much higher in TSP-treated soils (range 13-96 ppm versus a mean of 15 ppm in non-treated soils) and in MP-treated soils (range of 9-70 ppm versus mean of 16 ppm in non-treated soils). Manured soils were slightly but significantly lower in nitrogen (mean 20 ppm) than non-manured soils (mean 21 ppm).

Phosphorus

The general statistical distribution of soil phosphorus concentrations was similar to that for soil nitrogen, i.e. much higher on the Meghna side (mean 36 ppm) than on the Dakatia side (mean 22 ppm), much higher in lower elevation soils (mean 39 ppm) than upper elevation soils (20 ppm), and much higher after the monsoon (mean 36 ppm) than before (mean 22 ppm). Fertilizer treatments also had statistical effects similar to those seen in the case of nitrogen - soil phosphorus appeared not to be affected by urea treatments but was significantly higher in TSP-treated soils (range 12-115 ppm versus mean of 22 ppm in untreated soils) and MP-treated soils (range 12-32 ppm versus mean of 23 in untreated samples). Manured soils were much lower in phosphorus (mean 19 ppm) than non-manured ones (mean 31 ppm), and soils receiving ash were slightly lower (mean 23 ppm) than those not receiving it (mean 29 ppm). These differences were ascribed to the generally lower application rates of other fertilizers in plots which received manure and ash.

Sulphur

Although overall soil sulphur concentrations were much higher in samples from the Meghna side of the study area (mean 54 ppm) than in those from the Dakatia side (mean 17 ppm), the difference was not shown to be significant in the analysis of variance, likely because of strong

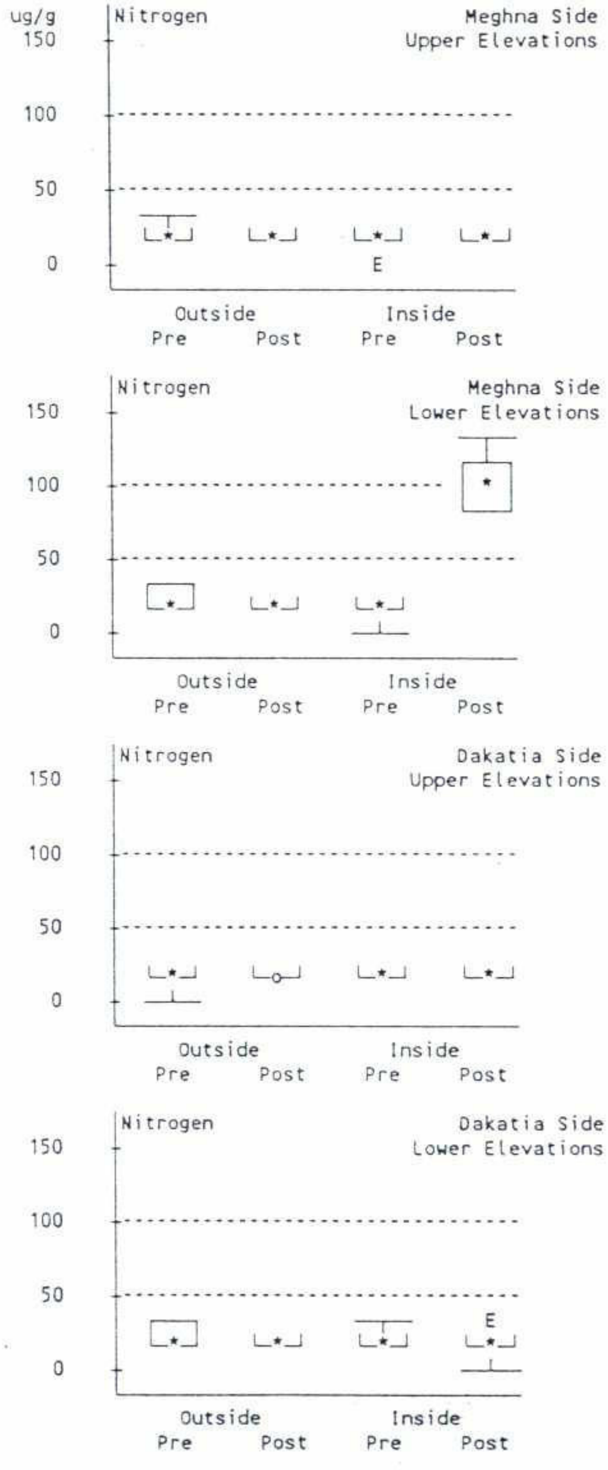


Figure 11.6. Nitrogen concentrations in soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value. Horizontal lines demarcate low, medium and optimum ranges for crop nutrition.

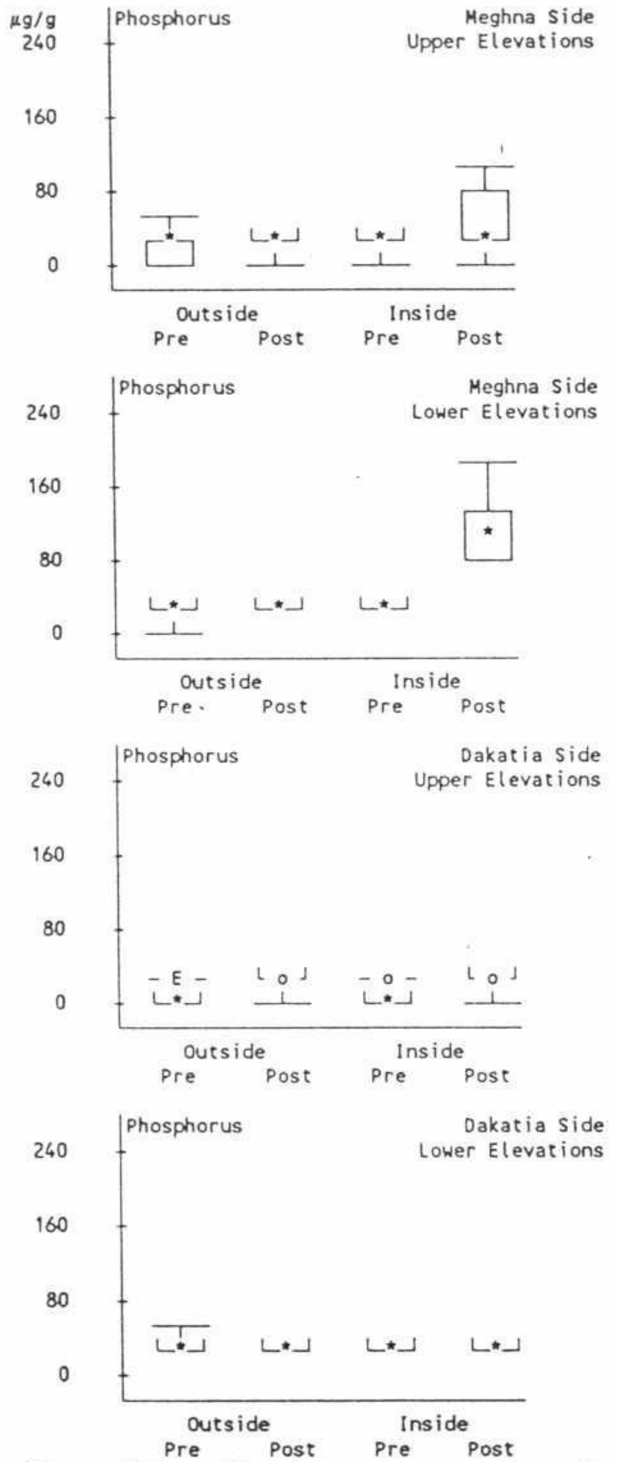


Figure 11.7. Phosphorus concentrations in soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value.

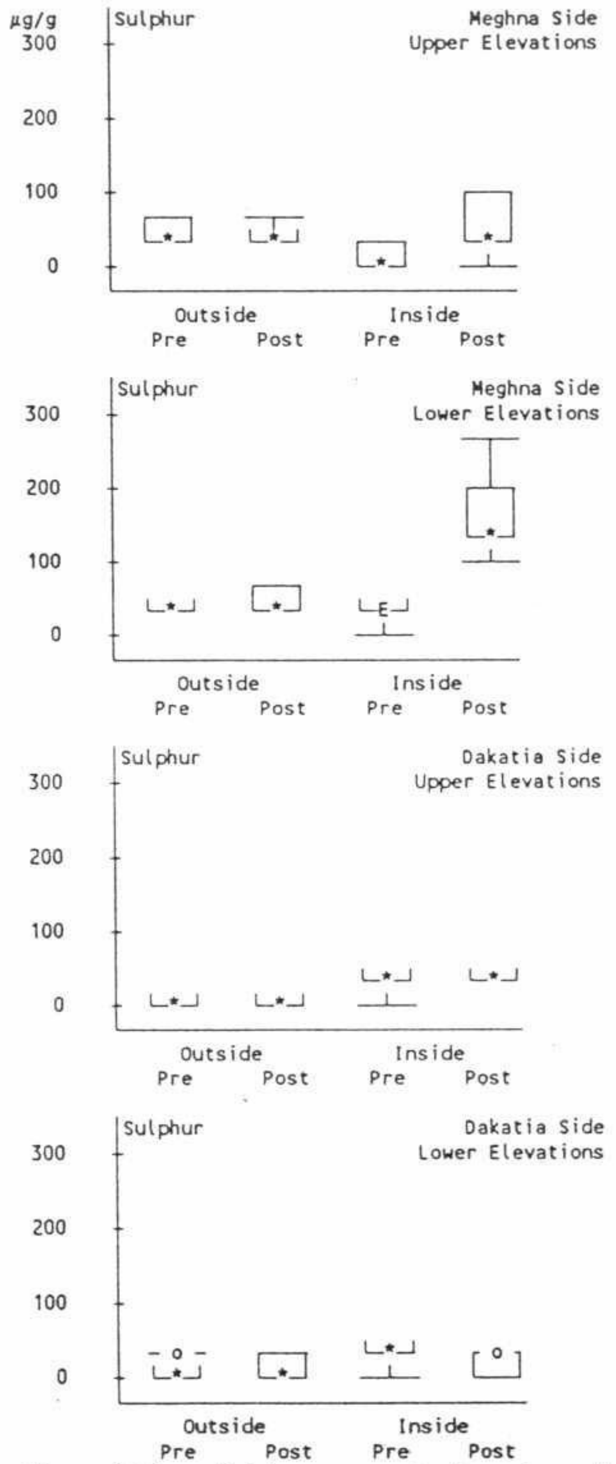


Figure 11.8. Sulphur concentrations in soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value.

interactions between the factors (rivers, protection, elevations, periods) and the covariates (fertilizer treatments) tested. Soils inside the embankments were much higher in sulphur (mean 44 ppm) than those outside (mean 27 ppm), lower elevation soils were much higher (mean 43 ppm versus 29 ppm), and post-monsoon samples were much higher (mean 49 ppm versus 23 ppm).

With the exception of zinc-treated samples (mean concentration of sulphur at 39 ppm in untreated soils was higher than range of 11-28 ppm in treated soils), all other fertilizers appeared to have a positive effect on sulphur concentrations. TSP-treated soils were higher (range 8-167 ppm versus mean of 26 ppm) as were MP-treated soils (range 8-134 ppm versus 29 ppm), manured soils (mean of 40 ppm versus mean of 35 ppm) and soils receiving ash (mean of 51 ppm versus mean of 35 ppm).

Boron

Soil boron concentrations were significantly higher inside the embankments (mean 1.0 ppm) than outside (mean 0.6 ppm), higher in the lower elevation Chandpur and Burichanga soils (mean 0.9 ppm) than the higher elevation Madna and Tippera soils (mean 0.8 ppm), and higher after the monsoon (mean 1.0 ppm) than before (0.6 ppm). TSP- and MP-treated soils were significantly higher in boron (ranges of 0.4-2.0 ppm and 0.4-1.8 ppm compared to respective means of 0.8 ppm for untreated soils), but soils receiving other fertilizers were slightly lower in boron (e.g. manured soils 0.6 ppm versus 0.8 ppm for non-manured ones). Many soil samples were found to be on the borderline of deficiency in terms of their boron content.

Copper

Copper concentrations in soils were similar to the nutrients discussed above in terms of the effects of protection (higher (mean 12.2 ppm) at lower elevations than higher elevations (mean 9.6 ppm) and higher after the monsoon (mean 13.5 ppm than before mean 8.3 ppm). However, copper was notably different from many other nutrients in that concentrations in soils

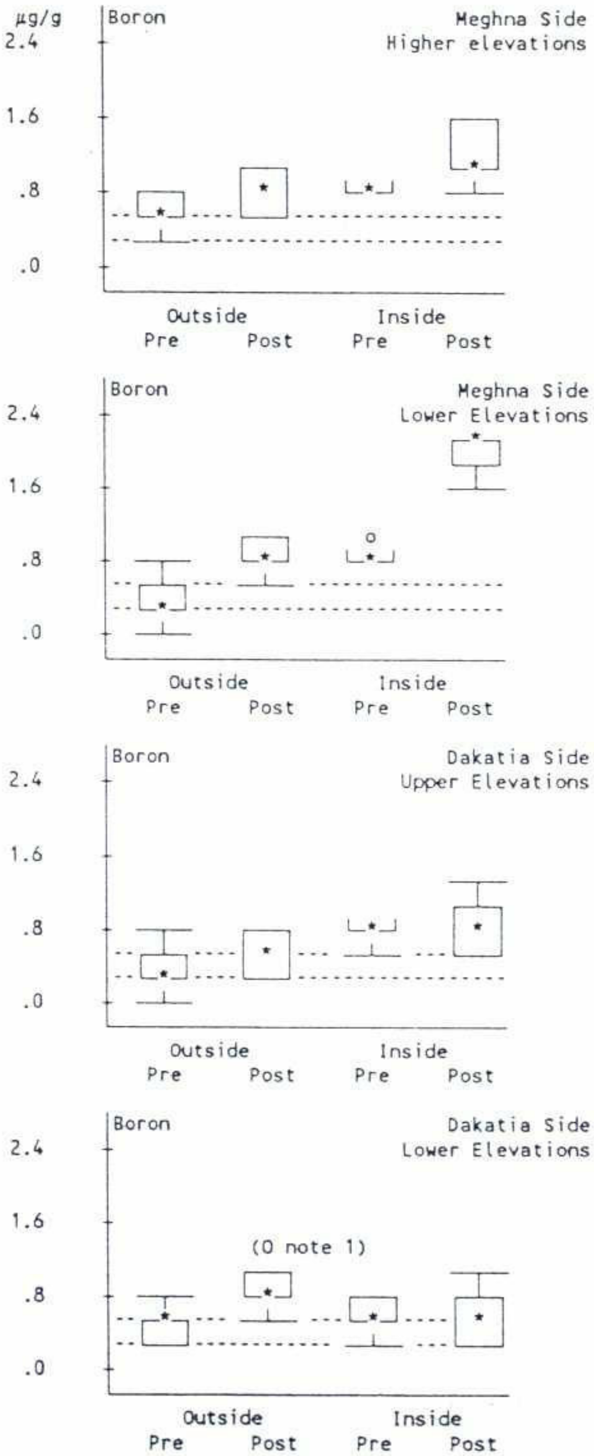


Figure 11.9. Boron concentrations in soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier. Horizontal lines demarcate low, medium and optimum ranges for crop nutrition.

unprotected from river flooding were significantly higher (mean 11.2 ppm) than those within the embankments (mean 10.5 ppm), although actual differences were relatively small, usually ≤0.5 ppm). No significant effects were found for fertilizer treatments in respect of copper concentrations.

Iron

Soil iron concentrations were much higher on the Dakatia side of the study area (mean 780 ppm) than on the Meghna side (mean 490 ppm). As with copper, iron concentrations were higher outside the embankments (mean 752 ppm) than inside (519 ppm), but they followed the general pattern of distribution for other nutrients in being significantly higher at lower elevations (mean 798 ppm) than upper elevations (mean 472 ppm). A significant variation from other nutrients was noted in that iron concentrations in post-monsoon samples were markedly lower (mean 467 ppm) than in pre-monsoon samples (804 ppm).

Apart from a relatively small number of ash-treated soils which were higher in iron (mean 854 ppm) than untreated ones (mean 628 ppm), and from samples of urea-treated soils which were not different to untreated ones in respect of iron concentrations, other fertilizer-treated soils were lower in iron concentrations than untreated soils (i.e. TSP-treated ranged from 408-1220 ppm compared to 437 ppm for untreated, MP-treated soils ranged from 330-1030 ppm compared to 579 for untreated, manured soils had a mean of 571 ppm compared to a mean of 644 ppm for non-manured).

Manganese

Soil manganese concentrations were significantly higher on the Meghna side (mean 41 ppm) than on the Dakatia side (mean 27 ppm), higher outside the embankments (mean 44 ppm) than inside (mean 25 ppm), higher in lower-elevation soils (mean 40 ppm) than others (mean 29 ppm), and lower after the monsoon (mean 25 ppm) than before (44 ppm). Fertilizer treatments had no significant effect on soil manganese, except for manured soils which had very much higher

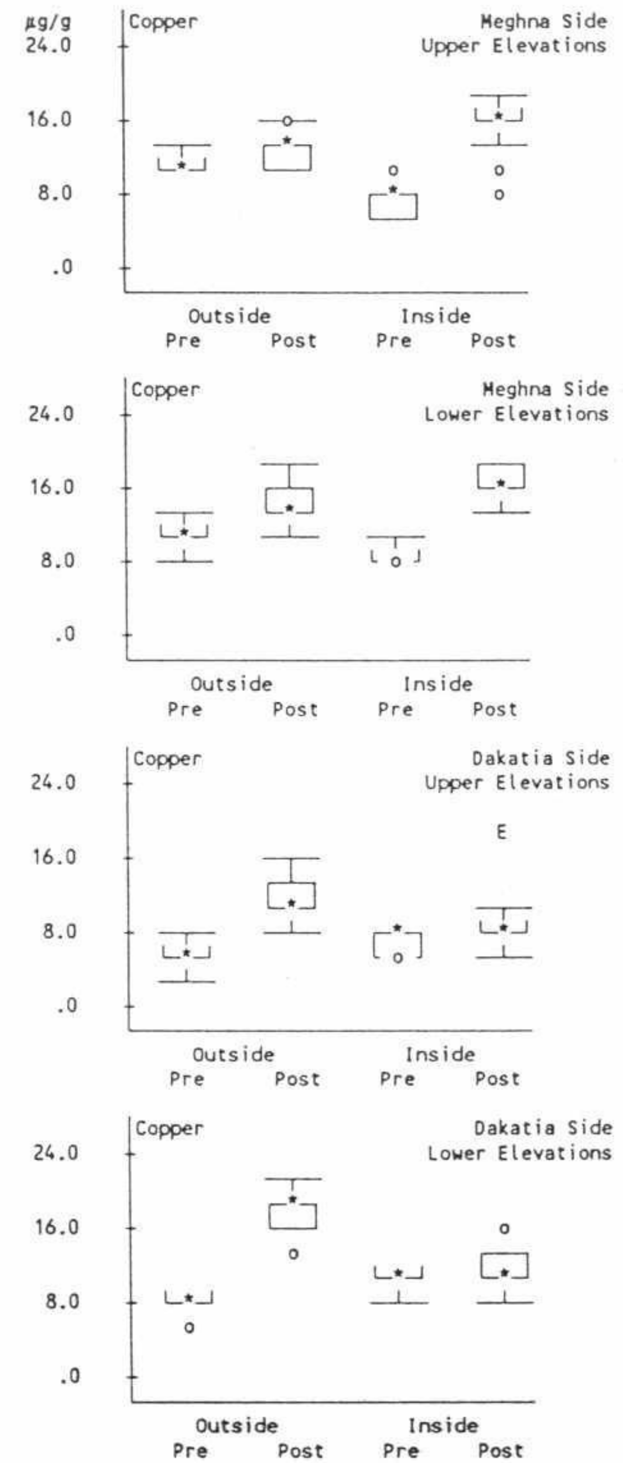


Figure 11.10. Copper concentrations in soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value.

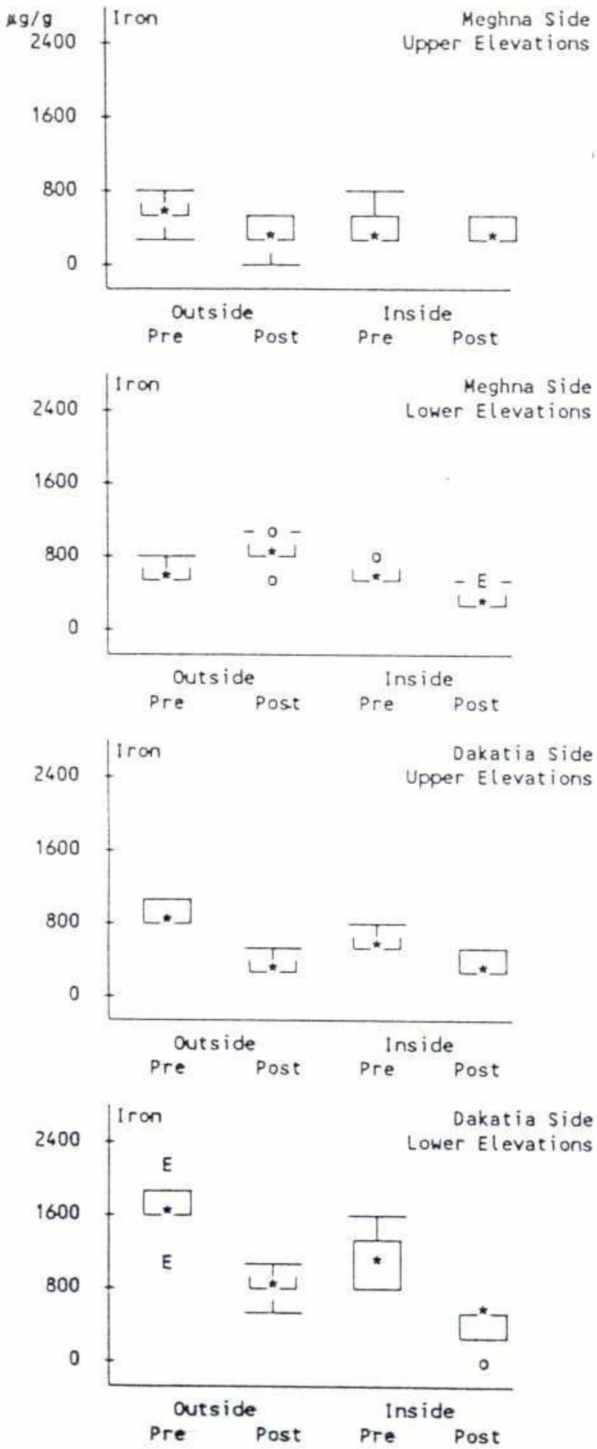


Figure 11.11. Iron concentrations in soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value.

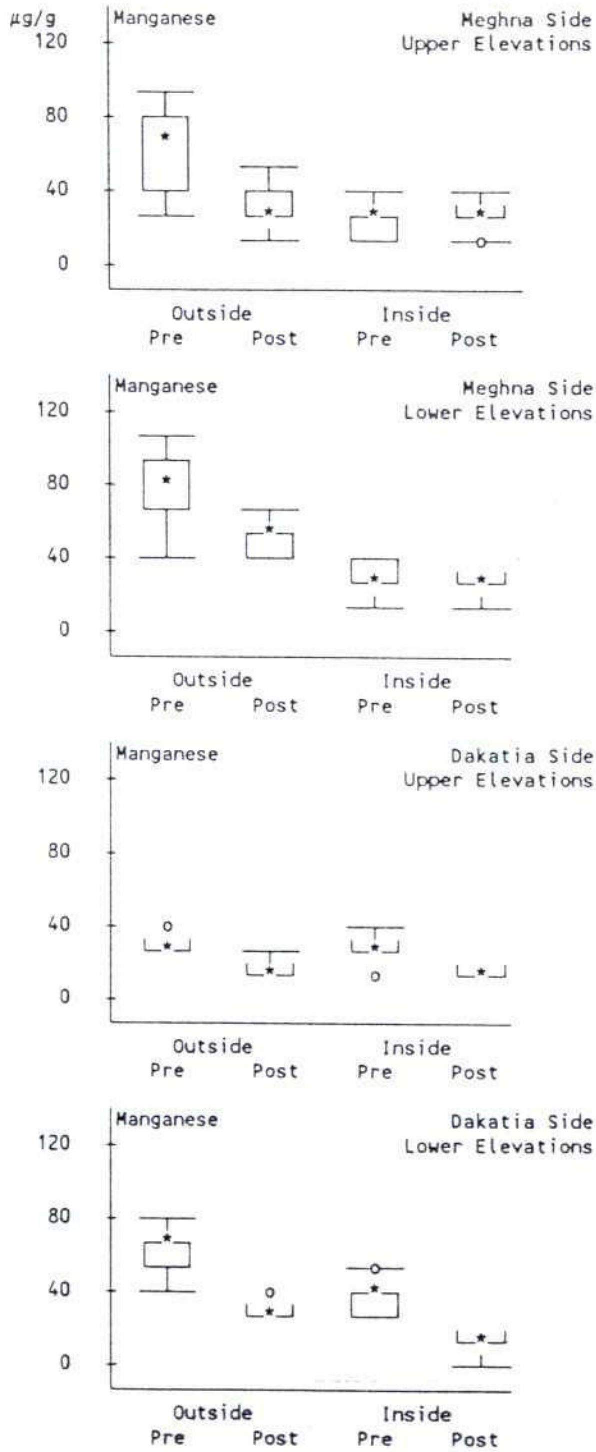


Figure 11.12. Manganese concentrations in soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value.

concentrations (mean 70 ppm) than others (mean 29 ppm).

Zinc

Meghna River side soils were significantly higher in zinc (mean 4.0 ppm) than Dakatia side soils (mean 2.3 ppm). Embankment-protected soils were slightly but significantly higher (mean 3.3 ppm) than unprotected ones (mean 3.0 ppm). Contrary to the situation with most other measured nutrients, zinc concentrations were found to be significantly higher in upper elevation Madna and Tippera soils (mean 3.4 ppm) than lower elevation soils; (mean 2.9 ppm). No significant changes in zinc concentrations were detected following monsoon inundation. Manured soils were notably higher in zinc (mean 4.1 ppm) than non-manured ones (mean 3.0 ppm).

The analysis of covariance indicated soil zinc concentrations to be significantly related to the levels of application of zinc fertilizers to soils prior to sampling. However, the relationship was not linear. Soils receiving zinc fertilization at levels of 16-20 kg/ha prior to sampling were found to have mean zinc levels of 4.2 ppm, compared to a mean level of 3.2 ppm in untreated soils. However soils receiving small to moderate zinc applications of 4-12 kg/ha had zinc concentrations lower than untreated soils (mean of 2.0 to 3.1 ppm) and soils receiving the highest rates of zinc fertilizer (>28 kg/ha) had lower concentrations (mean 2.7 ppm) than untreated soils. Numbers of zinc-treated samples were relatively small (total of 52) compared to samples from untreated soils (268), and the results must be treated with circumspection.

Electrical Conductivity

River-flood protected soils had significantly higher rates of electrical conductivity (mean 0.27 ds/m) than unprotected soils (mean 0.19 ds/m), and soils receiving manure had slightly lower ECs (mean 0.23 ds/m) than non-manured ones (mean 0.26 ds/m). No other significant effects could be found.

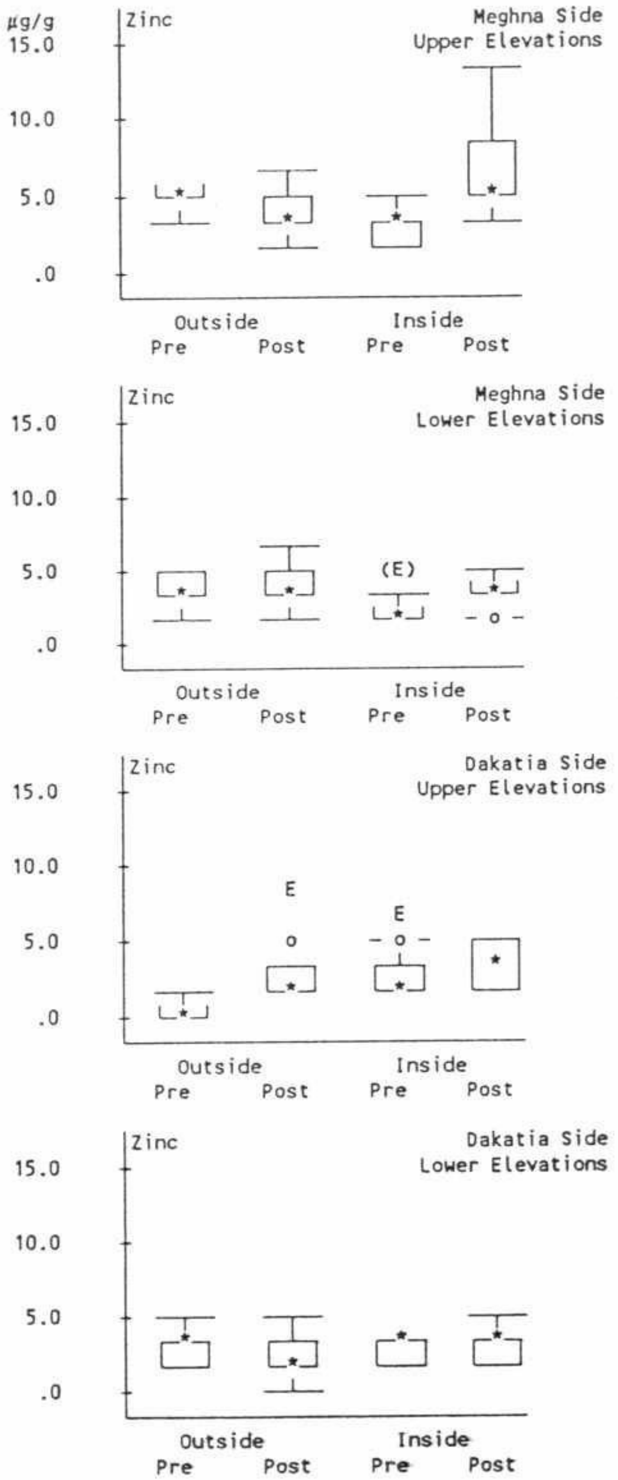


Figure 11.13. Zinc concentrations in soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value.

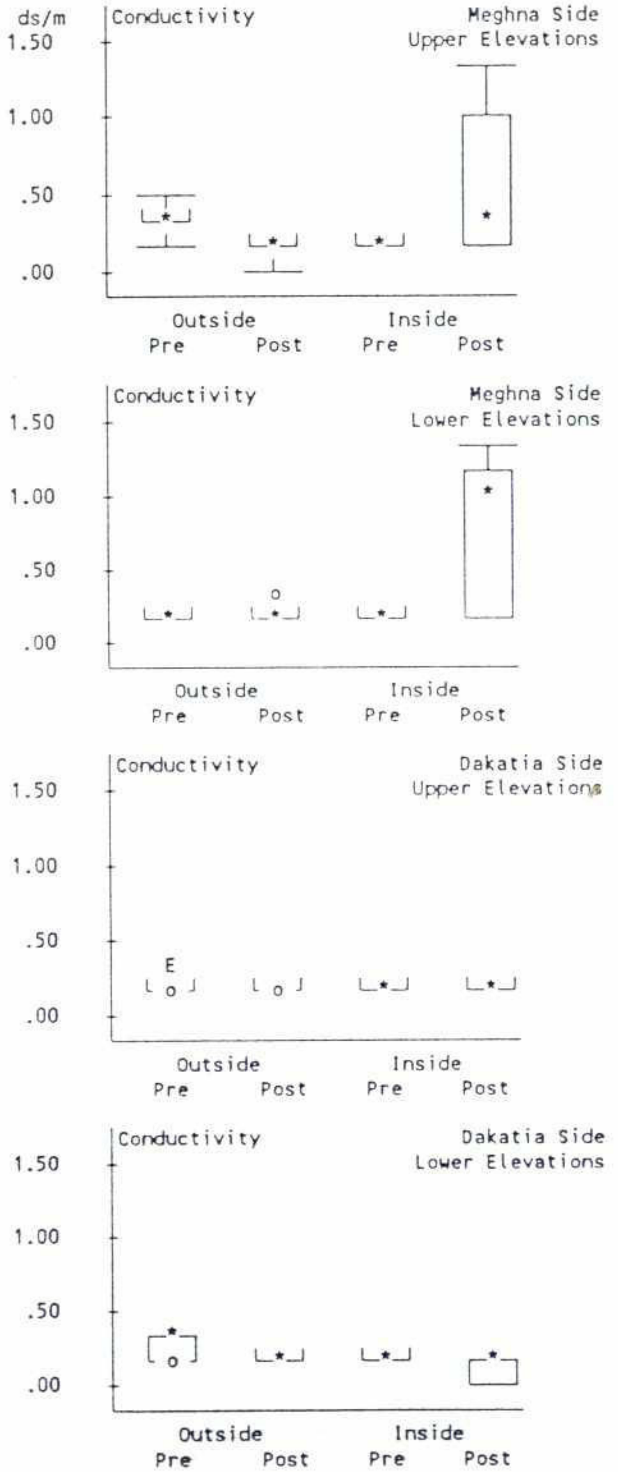


Figure 11.14. Electrical conductivity in soil samples from CIP study area. Data blocks shown are normal ranges and 95 percent confidence intervals; * = median, o = outlier, E = extreme value.

Chapter 12

DISCUSSION

In accordance with the basic objectives of the study, the key questions to be considered are to what extent flood protection by the embankment at the CIP has changed the nutrient status of the soils, and to what extent the exclusion of annual sediment deposition within the CIP has contributed to any such changes. As pointed out earlier in the report, protection of agricultural lands induces marked changes in cropping practices and associated uses of agricultural inputs, especially fertilizers and crop types, and hence there are a number of additional questions which must be addressed in order to adequately consider the primary questions. These are to what extent changes in cropping and fertilizing have changed the nutrient status of protected soils, and to what extent factors other than sediment deposition, e.g. dry season irrigation, have changed the topsoils. These questions are addressed by a series of comparisons between the nutrient contents of soils in protected and unprotected sites, in different localities within the study area, at different times relative to the monsoon flooding periods, and in relation to their respective cropping and fertilizing treatments.

12.1 Effects of Flood Protection on Soil Fertility

Soils inside the CIP differed quite significantly from those on the outside. They contained significantly less clay and more sand than on the outside, were slightly less acidic, had a slightly higher organic matter content, and were higher in potassium, nitrogen, phosphorus, sulphur, boron and zinc. They contained less copper, iron and manganese. No significant differences could be found in respect of calcium and magnesium content. Significant differences in soil nutrient content could however also be ascribed in part to differences in soil series, elevation and timing relative to the monsoon inundation periods. The differences due to these various factors are not always in the same direction, i.e. one factor may induce a higher level in a nutrient while another induces a lower level.

Madna and Chandpur soils along the Meghna River were similar in acidity to those on the Dakatia side, and contained notably lower concentrations of copper, iron and organic matter, but all other nutrients were significantly higher than in the Tippera and Burichanga soils along the Dakatia. Monsoon flooding and associated changes in cropping tended to lower the pH, organic matter, calcium, magnesium, iron and manganese content of most soils, but levels of potassium, nitrogen, phosphorus, sulphur, boron and copper were increased. No flooding-induced changes in zinc levels were detected. The effects of the various factors - river flood protection, elevation and monsoon flooding - could not be isolated in the study design, and there doubtless exist many complex interactions between them. An overall comparison between soil samples based on a principal components analysis using the first two extracted components (Figure 12.1) indicates that in the Meghna soils, protection from river flooding has caused a discernible shift in nutrient content, but a much greater fluctuation is caused during the monsoon flooding period, probably because of fertilizer applications and soil tillage practices (see below). In the Dakatia soils (Figure 12.2), protection from river flooding has also caused a discernible shift in overall nutrient content.

The major differences inside and outside the CIP embankment along the Meghna River are the cropping practices and the associated levels of use of some fertilizers. Fertilizer applications within and outside the CIP are not uniform and, in many cases, they are unbalanced. Some cropping sequences, e.g. potato-*boro* (H)-T.*aman* (H) within the CIP along the Meghna River received very high rates of fertilizers, while in similar situations on the Dakatia side they received much less. Some (but not all) plots in the protected areas received TSP and SSP applications up to twice as high, and MP applications up to three times as high as those in the unprotected plots on the river side of the embankment because of the high *boro* cropping intensity.

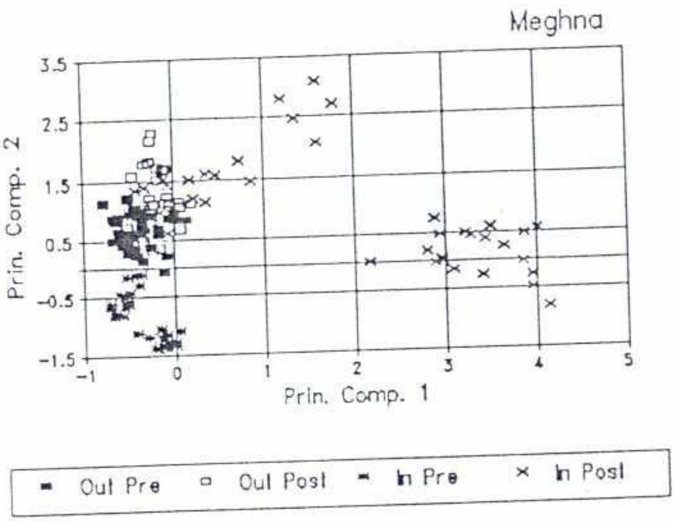


Figure 12.1. Principal components comparison of soil samples collected on the Meghna River side of the CIP.

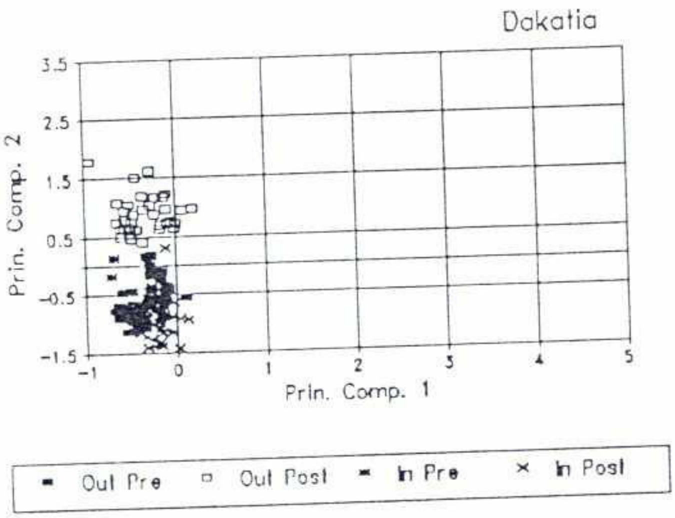


Figure 12.2. Principal components analysis of soils samples collected on the Dakatia River side of the CIP.

Unprotected areas on the Meghna side conversely received high applications of manure (1-4 tonnes/ha). The slightly lower soil pH outside the Meghna embankment may have been due to these manure applications (significant association through covariance analysis).

Levels of potassium, nitrogen, phosphorous, sulphur, boron, copper, zinc and electrical conductivity all rose appreciably in protected soils on the Meghna side after the monsoon cropping and harvesting season. All of these nutrients, with the exception of copper and boron, were present in the fertilizers applied, principally TSP, SSP, MP and zinc sulphate. The rise in electrical conductivity was associated with the high levels of calcium, potassium and ammonium cations, and sulphate and chloride anions in the dissolving fertilizer applications.

The patterns of nutrient differences between river flood and unprotected protected soils on the Dakatia side of the CIP were unlike those on the Meghna side in several respects. There were no major differences in fertilizer applications between protected and unprotected areas on the Dakatia side since there were no major differences in cropping patterns between the two areas. There were consequently no increases in concentrations of zinc, conductivity, boron, phosphorus, potassium or nitrogen in the post-monsoon period.

The origin of the higher boron and copper levels in post-monsoon samples in the flood protected Meghna soils is not clear. Boron is a micronutrient which is normally present in very small amounts in soils and water. The concentrations in water were too low to be accurately quantified by standard laboratory techniques, but levels may have been quite high enough in the flood waters to cause elevated soil levels. It may have been present in sufficient quantities in either irrigation water within the CIP or even in fertilizers applied. The higher copper levels require further investigation.

An estimate of the annual balance of the basic nutrients - nitrogen, phosphorus, potassium and sulphur -in the protected and unprotected areas was computed (Tables 12.1, 12.2) through consideration of the rates of fertilizers applied and the amounts of biomass removed during cropping. Both annual uptake and addition of fertilizer nutrients are much higher in the protected than in the unprotected areas on the Meghna River sites, but nutrient depletion within the CIP is high in all cases. The depletion of nutrients in the upper elevation soils which support crops of potatoes, *boro* (H) and T. *aman* (H) is especially high. Fertilizer additions appeared in most cases to replace the nutrients removed by cropping, with the exception of potassium, which was added in quantities too low to adequately replace that which was removed, and potassium is notably deficient in all soils in the CIP (see chapter 11). Soils in the unprotected area supported less nutrient-exhaustive crops producing lower yields, and these soils were supplemented with fertilizers as a well as high amounts of organic manure. Similar situations exist in the lower elevation areas along the Dakatia River, where the nutrient depletion rates were also quite high.

Local farmers were of the opinion that crop production within the CIP was increasingly dependent on higher application rates of fertilizers, and this is borne out by the observations in this study. HYV *aman* production in the low elevation soils in the CIP near the Dakatia River was measured at only 1.8 tonnes/ha, probably because of soil nutrient deficiencies, including potassium and nitrogen.

12.2 Role of Deposited Sediments in Soil Fertility

The sediments deposited in the agricultural lands along the Meghna River outside of the CIP embankment proved to be productive soils in their own right. Sediments deposited on the medium highlands and medium lowlands were all sandy loams, with nutrient concentrations similar to those of the underlying soils in the case of calcium, magnesium, phosphorous, boron, iron and zinc. They were substantially higher in potassium, manganese and nitrogen then the local soils, and significantly lower in copper. Sediments on the medium highlands had organic matter content similar to local soils, but those deposited in the medium lowlands were significantly higher in organic content.

Deposited sediments were obviously sandy soils translocated from elsewhere, and were probably a combination of agricultural soils eroded from the upper Meghna and upper Padma basins, and transported to the CIP sites. Their physical and chemical composition was quite different from that of the local Madna and Chandpur soils, making it unlikely that they were locally translocated.

The value of the deposited sediments lies in their immediate value as substrates for crop production outside the embankment. Their specific value lies in their high content of nitrogen and potassium, both of which are deficient normally in local soils. All potassium-based fertilizers in Bangladesh are imported at considerable cost, while nitrogenous fertilizers are both imported

Table 12.1. Estimated Uptake and Depletion of Combined Major Nutrients (N,P,K,S) in CIP Sample Areas.

Cropping patterns	Annual Crop Uptake (kg/ha)	Addition of Fertilizer Nutrient (kg/ha)
Meghna: Unprotected		
Upper Elevations (A_1)		
Potato-Mixed aus & aman		
Lentil-Jute -T.D. aman	329	256
Lower Elevations (A_2)		
Lentil-Jute-T.D. aman		
Chili-T.D.aman-Mustard	463	279
Meghna: Protected		
Upper Elevations (B_1)		
Potato-Boro(H)-T.aman (H)	669	551
Lower Elevations (B_2)		
Potato-Boro(H)- T.aman (H)	666	744
Dakatia: Unprotected		
Upper Elevations (D_2)		
B.aman-Boro (H)	306	242
Lower Elevations (D_1)		
Boro (H)	239	205
Dakatia: Protected		
Upper Elevations (C_1)		
T. aman (L)-Boro (H)		
T. aman (H)-Boro (H)	373	229
Lower Elevations (C_2)		
T. aman (L)-Boro (H)	394	215

Table 12.2. Estimated Nutrient Uptake and Fertilizer Supplementation of Selected Nutrients in CIP Study Plots.

Frontage	Protection Status	Elevation	Plot No.	Nutrient Uptake (kg/ha)				Fertilizer Addition (kg/ha)			
				N	P	K	S	N	P	K	S
Meghna	Outside	Upper	A_1	144	26	142	17	132	44	33	48
		Lower	A_2	207	33	198	25	152	26	62	39
	Inside	Upper	B_1	258	44	339	28	250	61	148	91
		Lower	B_2	257	44	338	27	319	103	164	158
Dakatia	Outside	Upper	D_2	117	19	158	12	192	22	28	-
		Lower	D_1	93	15	122	09	151	32	22	-
	Inside	Upper	C_1	142	24	192	15	175	32	22	-
		Lower	C_2	150	25	204	15	128	37	50	-

and manufactured locally, but also at high cost to agricultural production.

The source of the high nitrogen content in the sediments was probably particulate organic allochthonous material and algal biomass, all of which are high in flood waters draining large expanse of previously inundated lands. It should be noted that the sediment value lies in its nature as a substrate, not simply as added fertilizing medium. Although high by local standards, the nitrogen content of the added sediment is low in relation to levels of added fertilizer normally applied. Using estimates of sediment deposition calculated for the Meghna River by Whitton *et al.* (1988a), nitrogen addition from deposited sediments amounts to something like 100-150g/-ha, compared to 50-60kg/ha nitrogen for a typical urea application. This is also probably orders of magnitude lower than the amounts of nitrogen added locally to the soils by the abundant BGA (see below).

Despite the deposited sediments having higher nutrient contents than local soils in many cases, it was also observed that post-monsoon soil samples taken outside the embankment along the Meghna River had similar or even lower nutrient concentrations after the subsidence of the floods than before. Nutrient depletion though crop uptake was one factor responsible, and was probably a major cause in the case of potassium which has a high crop uptake rate and was deficient in most soils. For other elements, notably nitrogen, crop uptake plus chemical breakdown may have played a role in depleting post-monsoon soil concentrations. Noting that lower elevation soils often had higher nutrient levels than upper elevation soils in the post-monsoon period (e.g. calcium, potassium, phosphorus, sulphur, copper, manganese and zinc), and that this was not always explained by higher fertilizer applications at the lower elevations, it is possible that leaching of soil nutrients by moving and subsiding flood waters may have been a factor in reducing nutrient levels in unprotected soils. Late season concentrations of iron and zinc in Meghna River water were noted to rise sharply as the flooding season progressed, possibly indicating that leaching was taking place.

The concentrations of various soil nutrients in deposited sediments were quantified in the study but not the actual amounts of sediment deposited. Determination of the latter was constrained by time, resources and, most importantly, lack of full control over the management of the study sites. It was clear, however, that sedimentation was a significant edaphic factor along the Meghna River but not the Dakatia. The distribution of sediments over the agricultural lands along the Meghna prior to the construction of the embankment is unknown. It may have been extensive, or may have been limited to a relatively narrow band along the river. This is an important item of knowledge to be obtained from further research, since the extent of sedimentation prior to flood control embanking obviously determines the extent of impact of flood control on soil quality and agricultural production. Moreover, the amounts of sediment deposited in various sites and at various elevations relative to the river source need to be quantified for computation of total nutrient loadings and comparison to agricultural crop requirements and required fertilizer supplementation.

12.3 Role of Water Soluble Nutrients in Soil Fertility

The waters inundating the flooded sites outside the CIP were high in TDS, but contained only moderate to low concentrations of the key plant nutrients. Calcium was present in moderate quantities in Meghna River water and probably contributed to the characteristically high calcium content of Meghna River soils. Ammonium nitrogen was detected in traces only. Nitrate and nitrite nitrogen contents were not assayed. Dakatia River water was generally low in most dissolved nutrients, reflecting the high proportion of local runoff and rainwater in that river. Study results suggested that soluble nutrients were added to soils in moderate to small quantities, but the significance was small in relation to particulate and adsorbed nutrients carried by the sediments themselves.

12.4 Role of BGA in Soil Fertility

The major finding of the study was that BGA were abundant in water and attached to rice plants in both flood-protected and flood-exposed situations. They were much more abundant in the clear waters near the Dakatia sampling sites than in the more turbid Meghna waters. Differences between the different river sites were much greater than differences between protected and exposed sites on the same river frontage. BGA was in fact slightly more abundant outside the Meghna embankment than inside it. The data suggest that the role of BGA in supplying nitrogen through biological fixation was probably not significantly different in protected and exposed sites along the Meghna or the Dakatia respectively.

12.5 Nutrient Depletion in Flood Protected Lands

The study results point out the significant increases in crop production which follow on the use of HYVs and triple cropping patterns, both practices made possible by flood protection. However, there is a associated high rate of extraction of soil nutrients which is not balanced (in the case of the CIP at least) by the use of fertilizers. Rice crops cover over 80 percent of the CIP and annually remove a large amount of nutrients, particularly potassium which is a key nutrient in river-borne sediments. The long-term implications to soil quality, sustainability of production and economic gains are obvious. The present cropping system in the CIP needs to be made more diverse in terms of crops, and should include more pulses and oilseeds. There is an obvious need to increase the use of green manuring crops.

Chapter 13

CONCLUSIONS AND RECOMMENDATIONS

The study proved that deposited sediments along the Meghna River in the vicinity of the CIP have a high nutritive value for crop production. The conventional wisdom frequently voiced by farmers, i.e. that sediment deposition within agricultural lands is desirable for soil fertility, was essentially substantiated for the area under study. The study further showed that soil nutrients are affected by many factors in an area subjected to flooding and flood protection, including the types of crops grown, the types and rates of fertilizer applications, the elevation of the soils relative to the local flooding levels, and the sediment content of the rivers supplying the floodwaters. BGA were found to be abundant during the monsoon season and likely contribute significantly to nitrogen fixation in both flood-protected and flood exposed soils.

Crop production within the flood protected area was two to three times higher than that outside the embankments because of the protection provided and because of associated changes in cropping patterns and the use of HYVs. Such increases in production required high rates of fertilizer application. Such high crop production rates could not be obtained in flood prone areas, even with the annual deposition of nutritive sediments, such as occurs along the Meghna River at CIP.

The appropriate way to gain advantage from both positive factors, i.e. increased production from flood protection and the benefits of sediment deposition (which is essentially free nutrient substrate) would appear to be some form of controlled flooding, where sediment rich water is permitted access to agricultural lands at key periods in the cropping cycle, but is held out during subsequent periods when crops are susceptible to flood damage and when sediment concentrations may be declining due to subsiding flood levels. Controlled flooding is a key concept in the Flood Action Plan, primarily via the compartmentalization approach which relies on controlled flooding and associated water management practices by local farmers and community groups. It would seem desirable however to examine the efficiency of sediment deposition on lands when flood waters enter primarily via regulators rather than overbank floods, since restrictive canal and regulator openings are likely to act as sediment traps.

The results reported in this study refer to the CIP area where the samples were collected. Care should be taken in extrapolating from the situation in the relatively low sediment environment of the lower Meghna River to the higher sedimentary environment of the Jamuna, or from the lower Meghna, which receives sediments from a wide variety of sources, to the upper reaches of the country which may receive sediment from more limited sources and sources closer to the eroding foothills in India. However, the widespread view held by farmers in all parts of Bangladesh that normal seasonal flooding (*barsha*) and associated sediment deposition is beneficial suggests that sediments are valuable sources of soil nutrients in other regions.

The study findings indicate that river-derived sedimentation is an important factor in soil fertility in the Bangladesh floodplain. It should be taken into full consideration in water resource development, especially where there is a likelihood of its exclusion by embankments. The extent of sedimentation is probably a result of several factors, including suspended sediment concentrations in river water, maximum flood stage, duration of maximum flood stage and local topography. In order to properly include the benefits of sediment deposition in pre-project assessment and to fully address the negative impacts of its exclusion from the post-project situation, it would be necessary to know the amounts of sediment deposited in various sites and in which sites it is not an important pre-project consideration because of distance from the flood source, local topography, etc. Measurement of all these factors would be impractical for every environmental impact assessment of a flood control, drainage and/or irrigation project. A better understanding of the process in various flooding cases would permit assessment of likely impacts in any specific case, based on observations of average river stage during flooding, project area topography, spatial relationship of the project area to the mainstem river, and the quantity and quality of suspended sediments in the main rivers at various stages of the flood cycle.

It is recommended that:

a. controlled flooding be further examined as an option for flood control in agricultural areas and that ways be specifically sought to ensure effective transfer of river-borne sediments to agricultural lands at key periods in the cropping cycles;
b. consideration be given to repeating the soil comparison study in other regions in Bangladesh, especially in the upper Meghna and Jamuna basins where different sedimentary regimes and local geochemistry might produce different information and conclusions from those made here; and
c. consideration be given to undertaking specific studies with a view to enlarging the overall knowledge of river-derived sedimentation of agricultural lands to establish the cause-and-effect links between the spatial aspects of sediment deposition and the quantifiable hydrological and topographic parameters of flooding.

Chapter 14

LITERATURE CITED

Andriesse, W. 1982. Changes in land use and soil in major irrigation and drainage projects areas in Bangladesh. FAO/UNDP Agricultural Development Adviser Project. Dhaka.

BCEOM/Compagnie Nationale du Rhone/Euroconsult/Mott MacDonald International/Satec Dèveloppement. 1993. Flood Action Plan. FAP 3 North Central Regional Study. Supporting report V. Environment. Dhaka.

Bentley, C. A. 1925. Malaria and agriculture in Bengal: how to reduce malaria in Bengal by irrigation. Public Health Department, Government of Bengal. Calcutta.

Bhuiyan, Z.H., MA. Hashem and A.K.M.N. Islam. 1980. Isolation and identification of dominant nitrogen fixing blue-green algae from Bangladesh soils. Current Perspectives in Nitrogen Fixation. Australian Acad. Sci. Canberra.

Brammer, H. 1967. Possible influences of flood protection, drainage and irrigation on the soil of East Pakistan. Soil Survey Project of Pakistan, FAO.

Brammer, H. 1976. Nutrient supply in flooded soils. Soil Survey Interpretation Project, UNDP, Dhaka.

Brammer, H. 1983. Agriculture and food production in polder areas. A case study in Bangladesh. Water International 8: 74-81.

Brammer, H. 1989. Floods in the agroecology of Bangladesh. Int. Seminar on Bangladesh Floods: Regional and Global Environmental Perspectives, Dhaka.

Brammer, H. 1990. Floods in Bangladesh - flood mitigation and environmental aspects. The Geographical Journal 156,2: 158-165.

Catling, H.D., M.R. Martinez and Z. Islam. 1981. Survey of algae associated with deepwater rice in Bangladesh. Cryptogamie, Algologie 11: 109-121.

CIRDAP. 1987. The impact of flood control, drainage and irrigation (FCDI) projects in Bangladesh. Benchmark survey and initiation of a monitoring and evaluation system (MES). CIRDAP Study Series 90. Dhaka.

Degens, E.T., S. Kempe and J.E. Richey (eds.) 1991. Biogeochemistry of major world rivers. SCOPE/UNEP Publication 42. John Wiley & Sons, New York.

Depetris, P.J., and J.E. Paolini. 1991. Biogeochemical aspects of South American rivers: the Parana and Orinoco. In Degens, E.T., S. Kempe and J.E. Richey (eds.) 1991. Biogeochemistry of major world rivers. SCOPE/UNEP Publication 42. John Wiley & Sons, New York.

FAO/UNDP (Food and Agricultural Organization/United Nations Development Program). 1988. Land resources appraisal of Bangladesh for agricultural development, Reports 2 and 5, Ministry of Agriculture, Government of the People's Republic of Bangladesh.

FPCO (Flood Plan Coordination Organization). 1992a. Guidelines for environmental impact assessment. Ministry of Irrigation, Water Development and Flood Control, Dhaka.

FPCO (Flood Plan Coordination Organization). 1992b. Guidelines for project assessment. Ministry of Irrigation, Water Development and Flood Control, Dhaka.

GOB (Government of Bangladesh). 1992. Environment policy 1992 and implementation. Dhaka. *In Bangla*.

Holeman, J.N. 1968. Sediment yield of major rivers of the world. Water Resources Res. 4: 737-747.

Hunter, A.H. 1984. Laboratory and greenhouse techniques for nutrient survey studies to determine the soil amendments required for optimum plant growth. Soil Fertility Analytical Services in Bangladesh. BARC.

Hunting Technical Services. 1991. FAP 12 FCD/I Agricultural study, draft final report, summary and recommendations. Dhaka.

Ibrahim, A.M. 1984. Changes in flood level in Bangladesh. FAO/UNDP Agriculture Development Advisor Project.

IRRI (International Rice Research Institute). 1980. Blue-green algae and rice. Los Banos, Philippines.

ISPAN (Irrigation Support Project for Asia and the Near East). 1991. Bangladesh flood action plan. FAP 16 Environmental Study. Environmental position paper. Dhaka.

ISPAN (Irrigation Support Project for Asia and the Near East). 1992a Bangladesh flood action plan. FAP 16 Environmental Study. Environmental impact assessment case study: Surma-Kushiyara Project. Dhaka.

ISPAN (Irrigation Support Project for Asia and the Near East). 1992b. Bangladesh Flood Action Plan. Manual for environmental impact assessment (EIA). Dhaka

ISPAN (Irrigation Support Project for Asia and the Near East). 1992c. Bangladesh flood action plan. FAP 16 Environmental Study/ FAP 19 Geographic Information System - Environmental impact assessment case study: Compartmentalization Pilot Project. Banani, Dhaka.

Ittekot, V., and R. Arain. 1986. Nature of particulate organic matter in river Indus, Pakistan. Geochim. Cosmochim. Acta 50: 1643-1653.

Ittekot, V., S. Safiullah, B. Mycke and R. Seifert. 1985. Seasonal variability and geochemical significance or organic matter in the river Ganges, Bangladesh. Nature 317:800-802.

Jenkinson, D.S. 1973. Organic matter and nitrogen in soils of the Rothamsted classical experiments. J. Sci. Food Agric. 24: 11-29.

Karim, Z. (ed.). 1989. Fertilizer recommendation guide. Soils Publ. 32. Bangladesh Agricultural Research Council.

Karim, Z., S. Razia and N.I. Bhuyan. 1991. Contribution of river water to soil fertility in irrigated agriculture of Bangladesh. J. Bangladesh Academy of Sciences 15,1: 47-52.

Khan, Z.U.M., and G.S. Venkataraman. 1991. Distribution of nitrogen fixing blue-green algae in rice soils of Bangladesh. J. Nature Study 1: 31-36.

Klarer, D.M., and M. Hickman. 1975. The effect of thermal effluent upon the standing crop of an epiphytic algal community. Int. Rev. ges. Hydrobiol. 60,1:17-62.

Kulasooriya, S.A., P.A. Roger, W.L. Barraquio and I. Watanabe. 1981. Epiphytic nitrogen fixation on deepwater rice. Soil Sci. Plant Nutr. 27: 19-27.

Martinez, M.R., and H.D. Catling. 1982. Contribution of algae to the nutrition of deepwater rice. Pages 201-214 in Proc. 1981 Intern. Deepwater Rice Workshop, Intern. Rice Res. Inst., Los Banos, Philippines.

Matsuguchi, T., B. Tangcham and S. Patiyuth. 1970. Nitrogen fixing microflora and its activity in paddy soils of Thailand. I. Nitrogen-fixing microflora and some soil;s environmental conditions. In Proc. First ASEAN Soil Conference, Bangkok.

Matsuo, H. 1976. Nitrogen-fixing blue-green algae in paddy soils. Review Series 1. Soil Survey Interpretation Project, Bangladesh.

Milliman, J.D., and R.H. Meade. 1983. World-wide delivery of river sediment to the oceans. J. Geol. 91:1-21.

Milliman, J.D. 1991. Flux and rate of fluvial sediment and water in coastal seas. In R.F.C. Mantoura, J.M. Martin and R. Wollat (eds.). Ocean margin processes in global change. John Wiley & Sons, New York.

MOEF (Ministry of Environment and Forest). 1991. Bangladesh country report for United Nations Conference on Environment and Development (UNCED), Brazil. Dhaka.

MOEF (Ministry of Environment and Forest). 1991. Towards sustainable development: the national conservation strategy of Bangladesh. Government of the People's Republic of Bangladesh, Dhaka.

MPO (Master Plan Organization). 1986. Agriculture system. Technical Report No. 14. Ministry of Irrigation, Water Development and Flood Control, Government of the People's Republic of Bangladesh. Dhaka.

Murray, F.E.S., L. Lovison-Golob and P. Rogers. 1992. Flood fertility study. Nutrient cycling and the relationship to soil fertility. Div. Applied Sciences, Harvard Univ. Cambridge, Mass., U.S.A.

Podder, A.K., A.K.M. Habibullah and A.R.M. Solaiman. 1983. Importance of biological nitrogen fixation by non-legumes in Bangladesh. ADAB News, March April 1983: 41-45.

Rahman, A.A., S.Huq and G.R. Conway. 1990. Environmental aspects of surface water systems of Bangladesh. University Press, Dhaka.

Rashid, Md. Shahedur. 1992. Environmental impact of flood control, drainage and irrigation project on soils. A case study of Meghna-Dhonagoda FCDI Project. M.Sc. thesis, Jahangirnagar University, Dhaka.

Rother, J.A., and B.A. Whitton. 1988. Ecology of deepwater rice-fields in Bangladesh. 5. Mineral composition of the rice plant and other aquatic macrophytes. Hydrobiologia 169: 57-67.

Rother, J.A., Aziz, N.H. Karim and B.A. Whitton. 1988. Ecology of deepwater rice-fields in Bangladesh. 4. Nitrogen fixation by blue-green algal communities. Hydrobiologia 169: 43-56.

Sattar, M.A. 1991. Rice based BNF research in Bangladesh: problems and prospects. In S.K. Dutta and C. Sloger (eds.). Biological nitrogen fixation associated with rice production. Oxford and IBH Publ. Co., New Delhi.

SRDI (Soil Resources Development Institute). 1966. Reconnaissance soil survey of Noakhali district and Sadar north, Sadar south and Chandpur subdivisions of Comilla district. Dhaka.

Standard Methods of Analysis for Soil, Plant Tissue, Water and Fertilizer. 1980. Philippine Council for Agricultural and Resources Research, Los Banos.

Subramanian, V., and V. Ittekot. 1991. Carbon transport by the Himalayan rivers. In Degens, E.T., S. Kempe and J.E. Richey (eds.) 1991. Biogeochemistry of major world rivers. SCOPE/UNEP Publication 42. John Wiley & Sons, New York.

Umitsu, M. 1987. Late quaternary sediment environment and landform evolution in the Bengal Lowland. Geogr. Rev. Japan, Series B, 60: 164-178.

Venkataraman, G.S. 1981. Blue-green algae for rice production. A manual for its promotion. FAO/UNDP Field Doc. 2(RAS/75/004). Food and Agriculture Organization of the United Nations.

Walkley, A. 1946. A critical examination of rapid methods for determining organic carbon in soils. Effects of variations in digestion conditions and inorganic soil constituents. Soil Sci. 63: 251-263.

Watanabe, A. 1959. Distribution of nitrogen fixing blue-green algae in various areas of south and east Asia. J. gen. appl. Microbiol. 5: 21-29.

Watanabe, I., nd P.A. Roger. 1984. Nitrogen fixation in wetland rice fields. In N.S. Subba Rao (ed.). Current Developments in Biological Nitrogen Fixation. Oxford and IBH Publ. Co., New Delhi.

Whitton, B.A., A. Aziz, P. Francis, J.A. Rother, J.W. Simon and Z.N. Tahmida. 1988a. Ecology of deepwater rice-fields in Bangladesh. 1. Physical and chemical environment. Hydrobiologia 169: 3-22.

Whitton, B.A., J.A. Rother and A.R. Paul. 1988. Ecology of deepwater rice-fields in Bangladesh. 2. Chemistry of sites at Manikganj and Sonargaon. Hydrobiologia 169: 23-30.

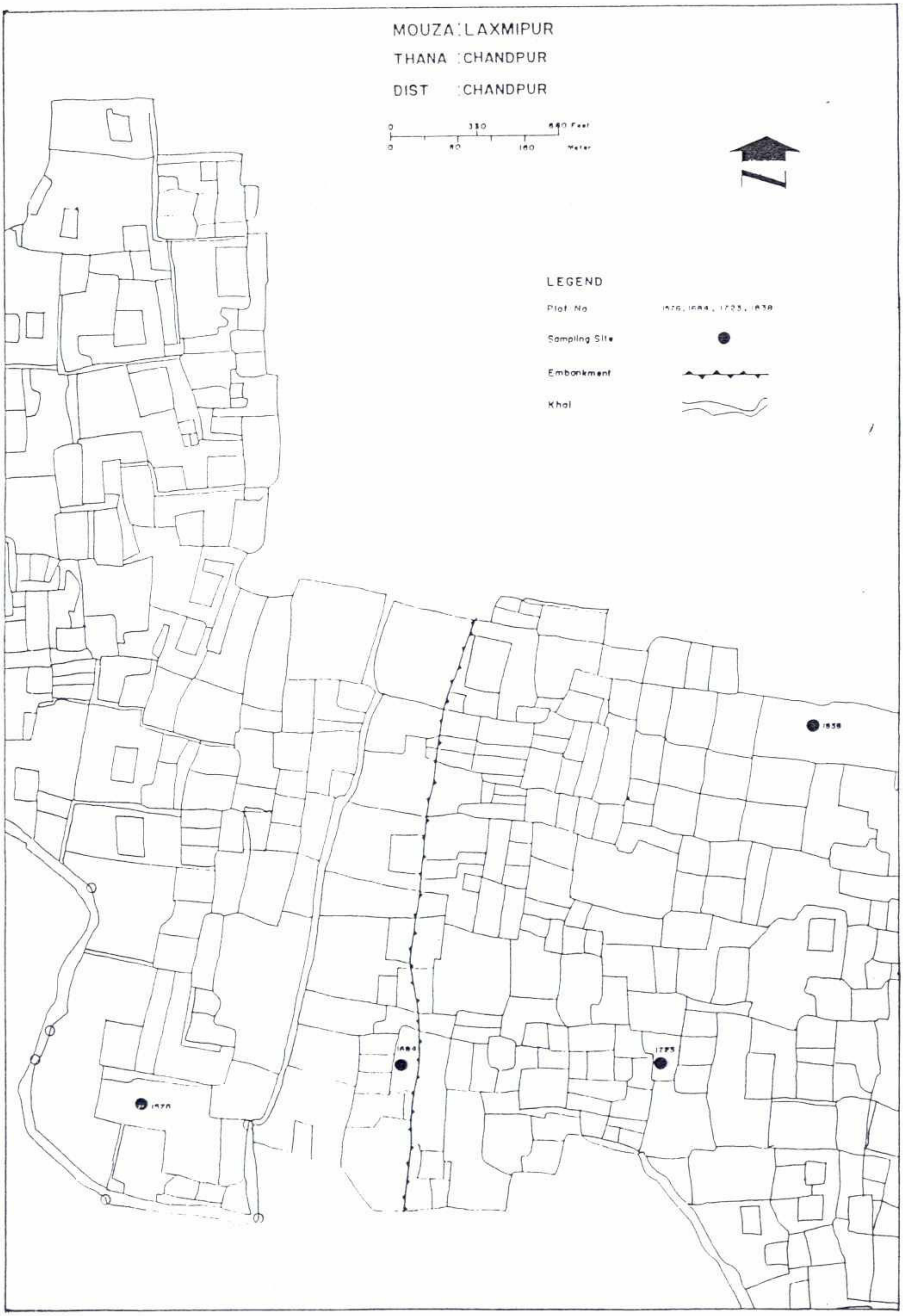
Whitton, B.A., A. Aziz, B. Kawecka and J.A. Rother. 1988b. Ecology of deepwater rice-fields in Bangladesh. 3. Associated algae and macrophytes. Hydrobiologia 169: 31-42.

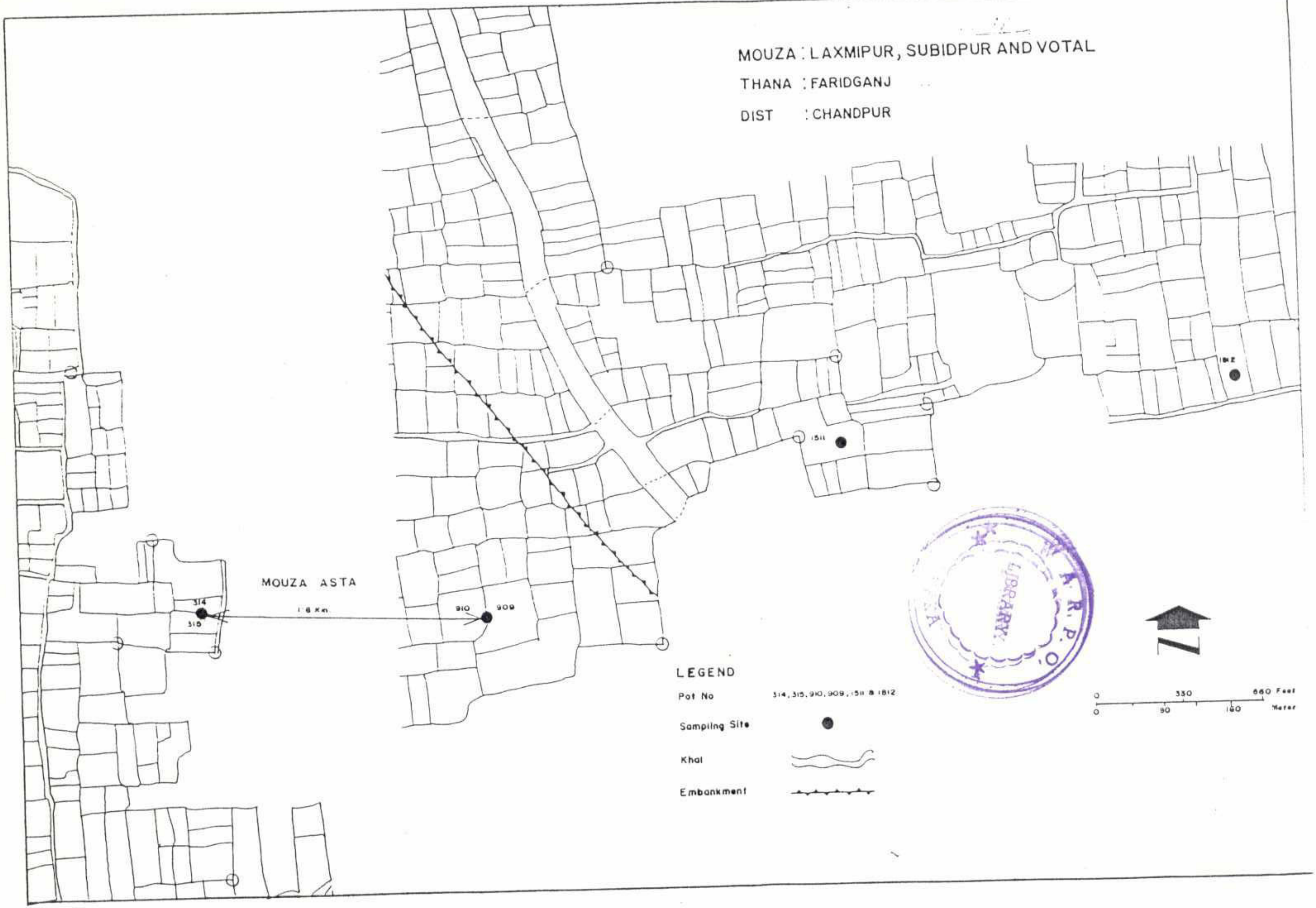
World Bank. 1991. Bangladesh Action Plan for Flood Control. The 1990 annual report. Asia Region, Technical Department, Washington D. C., U.S.A.

World Bank. 1992. Bangladesh Action Plan for Flood Control: achievements and outlook - an update. Dhaka.

Annex 1

Location of Soil Sampling Plots, Chandpur Irrigation Project


MOUZA: LAXMIPUR
THANA : CHANDPUR
DIST : CHANDPUR
0 330 660 Feet
0 80 160 Meter
N
LEGEND
Plot No 1576, 1684, 1723, 1838
Sampling Site
Embankment
Khal

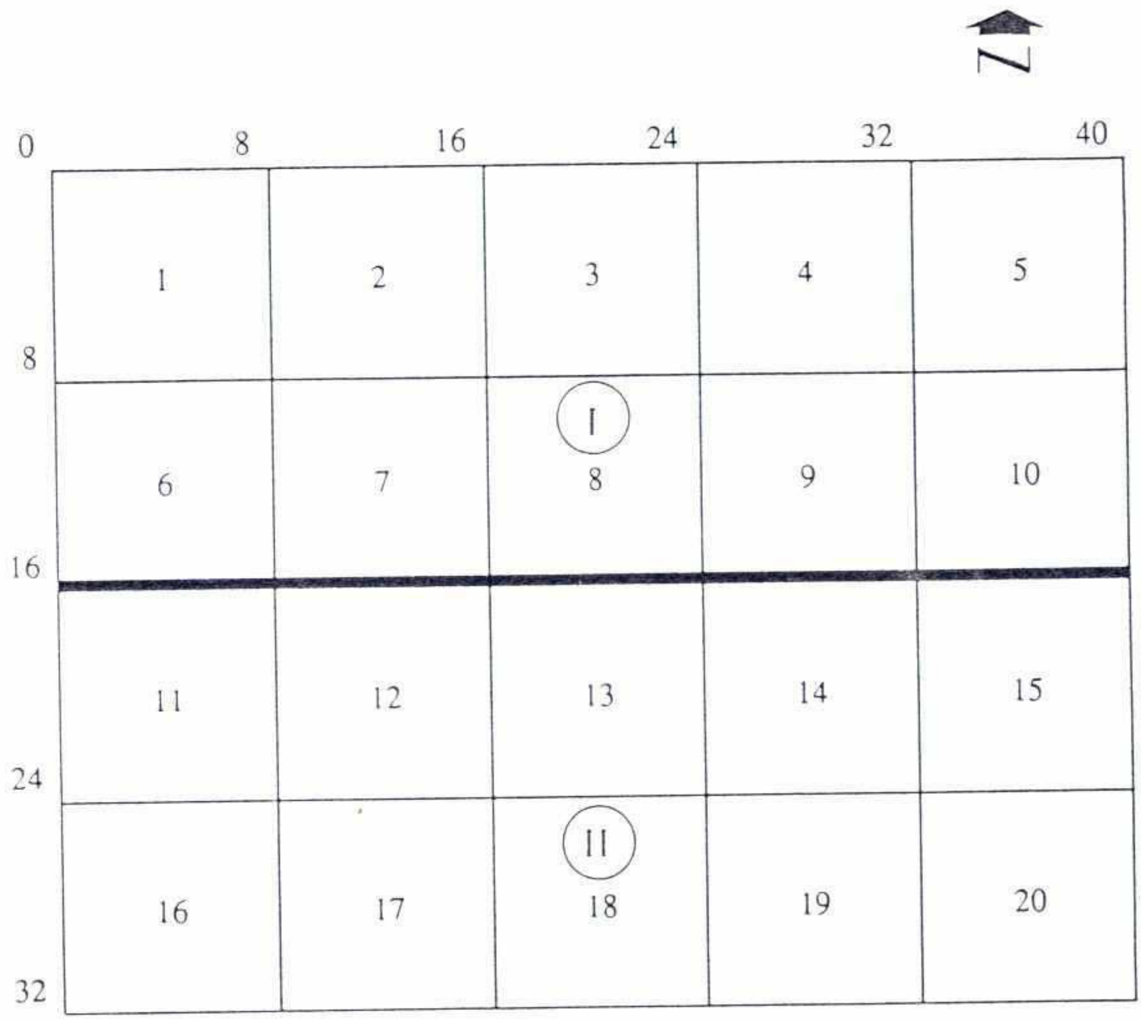

MOUZA : LAXMIPUR, SUBIDPUR AND VOTAL
THANA : FARIDGANJ
DIST : CHANDPUR
MOUZA ASTA
1·6 Km
314
315
910
909
1511
1812
LEGEND
Pot No 314, 315, 910, 909, 1511 & 1812
Sampling Site
Khal
Embankment
0 330 660 Feet
0 90 180 Meter

Annex 2

Soil Sampling Designs at the Chandpur Irrigation Project

SOIL SAMPLING DESIGN FOR A_1

Meter



A. Location
Village: Laksmipur, Mouza: Laksmipur
Union: Sakhua, Thana: Chandpur

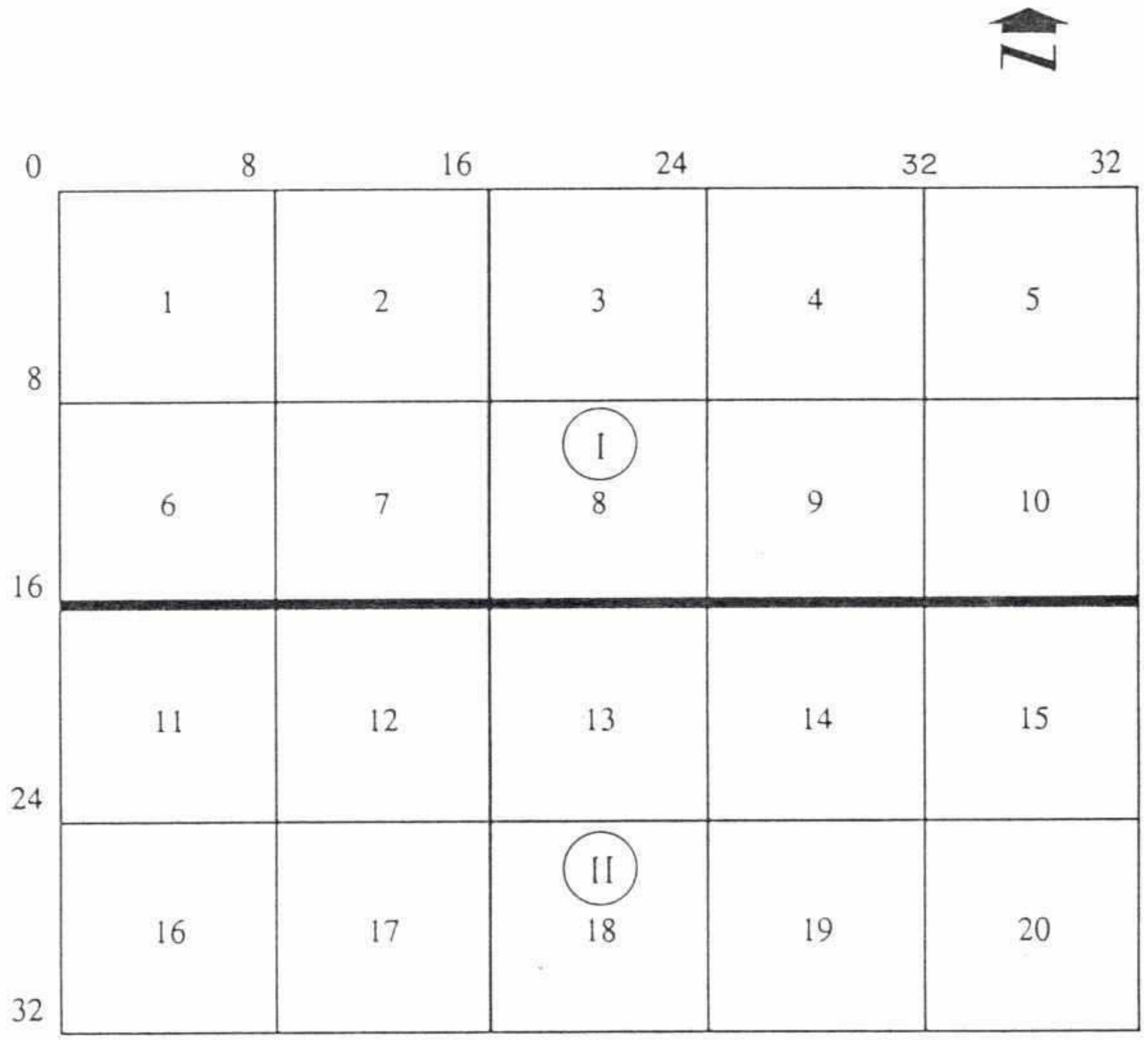
B. Land owner:

I. Md. Rahman Khan
S/o. Late Hashem Khan

II. Abdul Halim Khan
S/o. Late Haji Umed Khan

SOIL SAMPLING DESIGN FOR A_2

Meter



A. Location:
Village: Laksmipur, Mouza: Laksmipur (sheet-4)
Union: Shakhua, Thana: Chandpur
Dist.: Chandpur

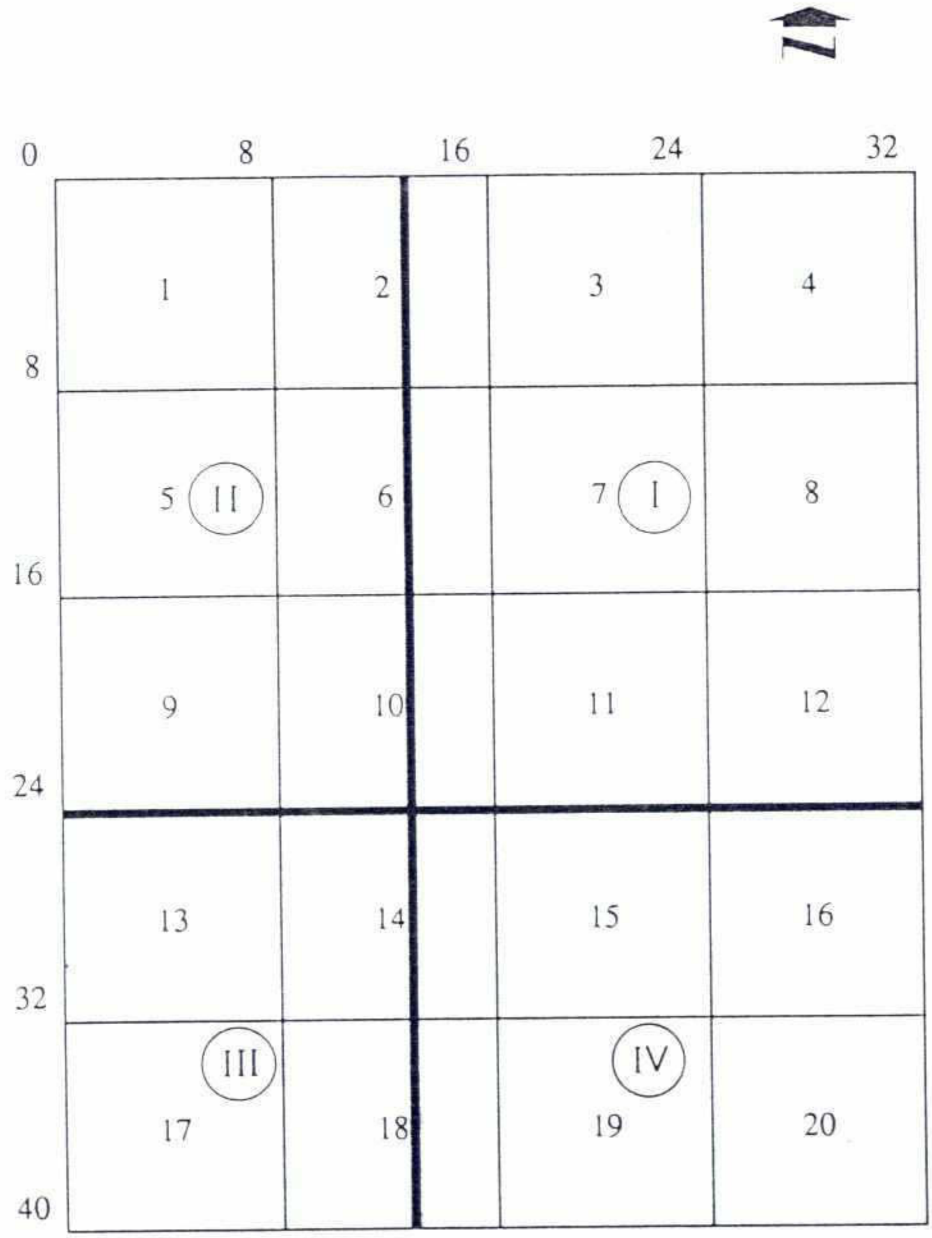
B. Land owner:

I. Amir Hossain Khan
S/o. Late Abdul Gafur Khan

II. Anwarullah Gazi
S/o. Late Mana Gazi

SOIL SAMPLING DESIGN FOR B_1

Meter



A. Location:
Village: Laksmipur, Mouza: Laksmipur (sheet-4)
Union: Shakhua, Thana: Chandpur
Dist.: Chandpur

B. Land owner:

I. Yunus Khan
S/o. Late Hussain Khan

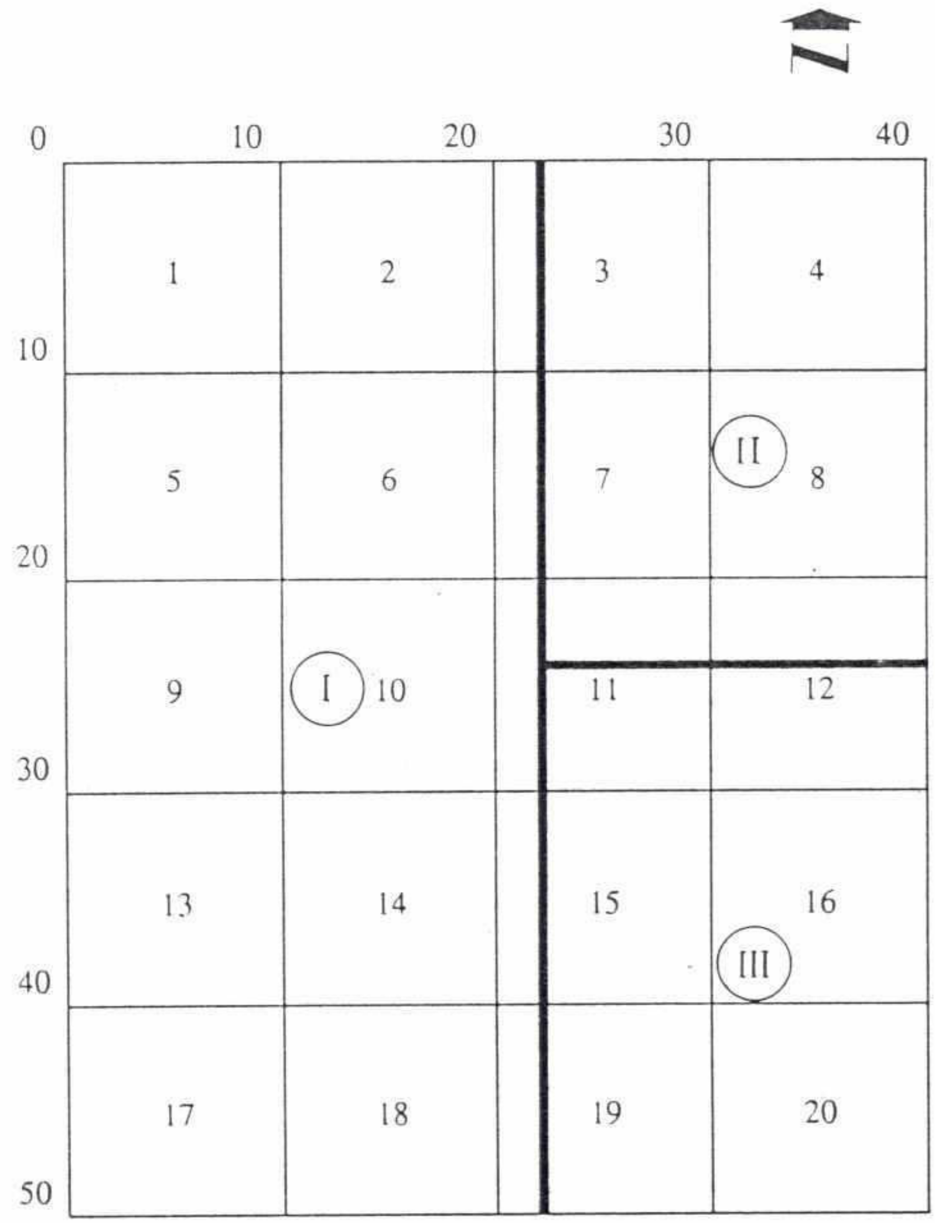
II. Sattar Mridha
S/o. Late Mantazuddin Mridha

III. Hakim Khan
S/o. Late Gafur Khan

IV. Khairun Nesa
Husband: Md. Waliullah

SOIL SAMPLING DESIGN FOR B_2

Meter



A. Location
Village: Laksmipur, Mouza: Laksmipur (sheet-4)
Union: Shakhua, Thana: Chandpur
Dist.: Chandpur

B. Land owner:

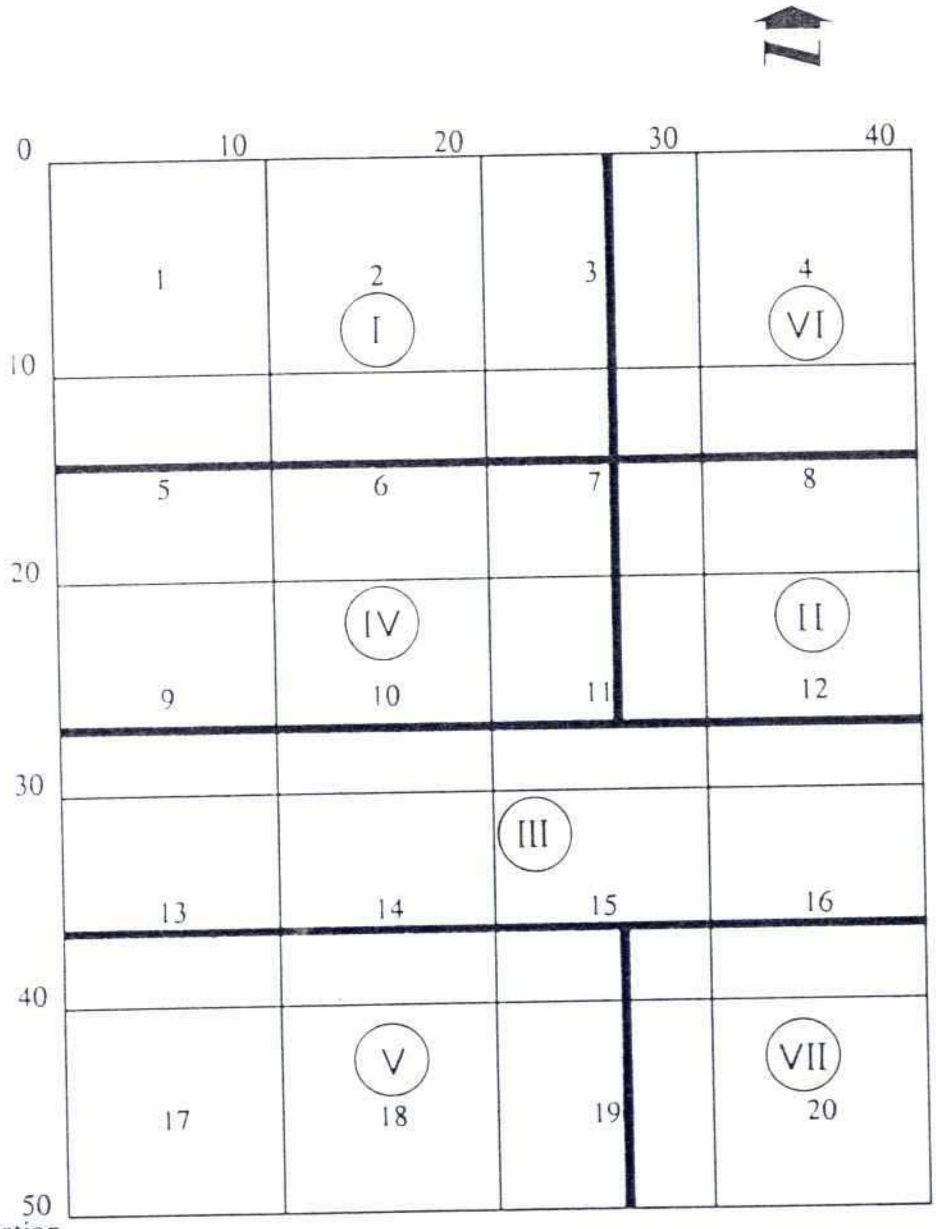
I. Momtazuddin Ukil
S/o. Late Jamaluddin Ukil

II. Serazul Ukil
S/o. Late Samsuddin Ukil

III. Ilias Ukil
S/o. Late Samsuddin Ukil

SOIL SAMPLING DESIGN FOR C_1

Meter



A. Location
Village: Votal, Mouza: Votal
Union: Guptieast (5 no.), Thana: Faridganj
Dist.: Chandpur

B. Land owner:

I. Abdul Satter
S/o. Late Munsur Ali

II. Anamia Bepari
S/o. Late Salimuddin Bepari

III. Abul Bashar
S/o. Late Sobhan Ali

IV. Samsul Haque
S/o. Late Rehanuddin

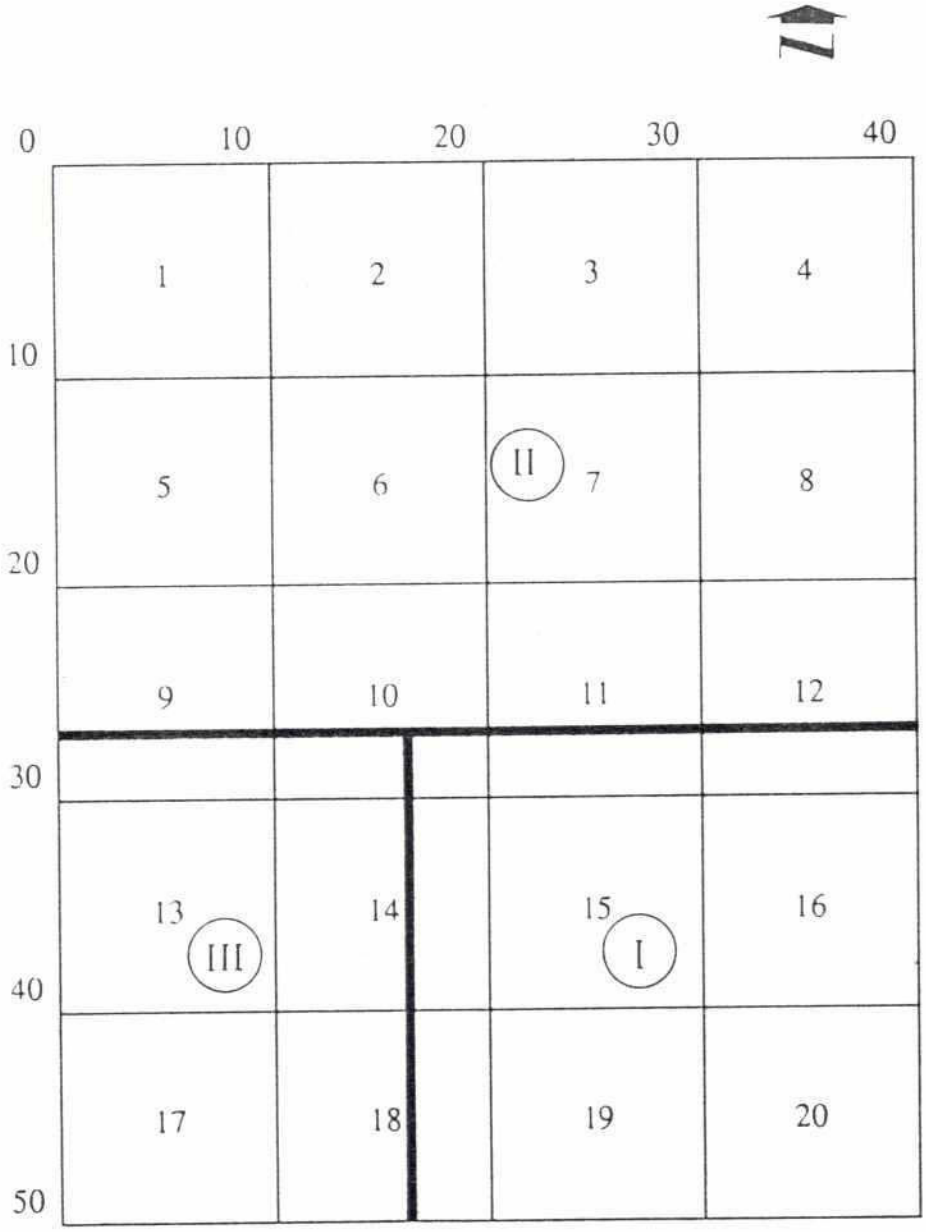
V. Sona Mia Bapari
S/o. Late Salimuddin

VI. Noor Mohammad
S/o. Late Abdul Hashem

VII. Siddique Mia
S/o. Late Abdul Aziz

SOIL SAMPLING DESIGN FOR C_2

Meter



A. Location
Village: Subidpur, Mouza: Subidpur
Union: Subidpur, Thana: Faridganj
Dist.: Chandpur

B. Land owner:

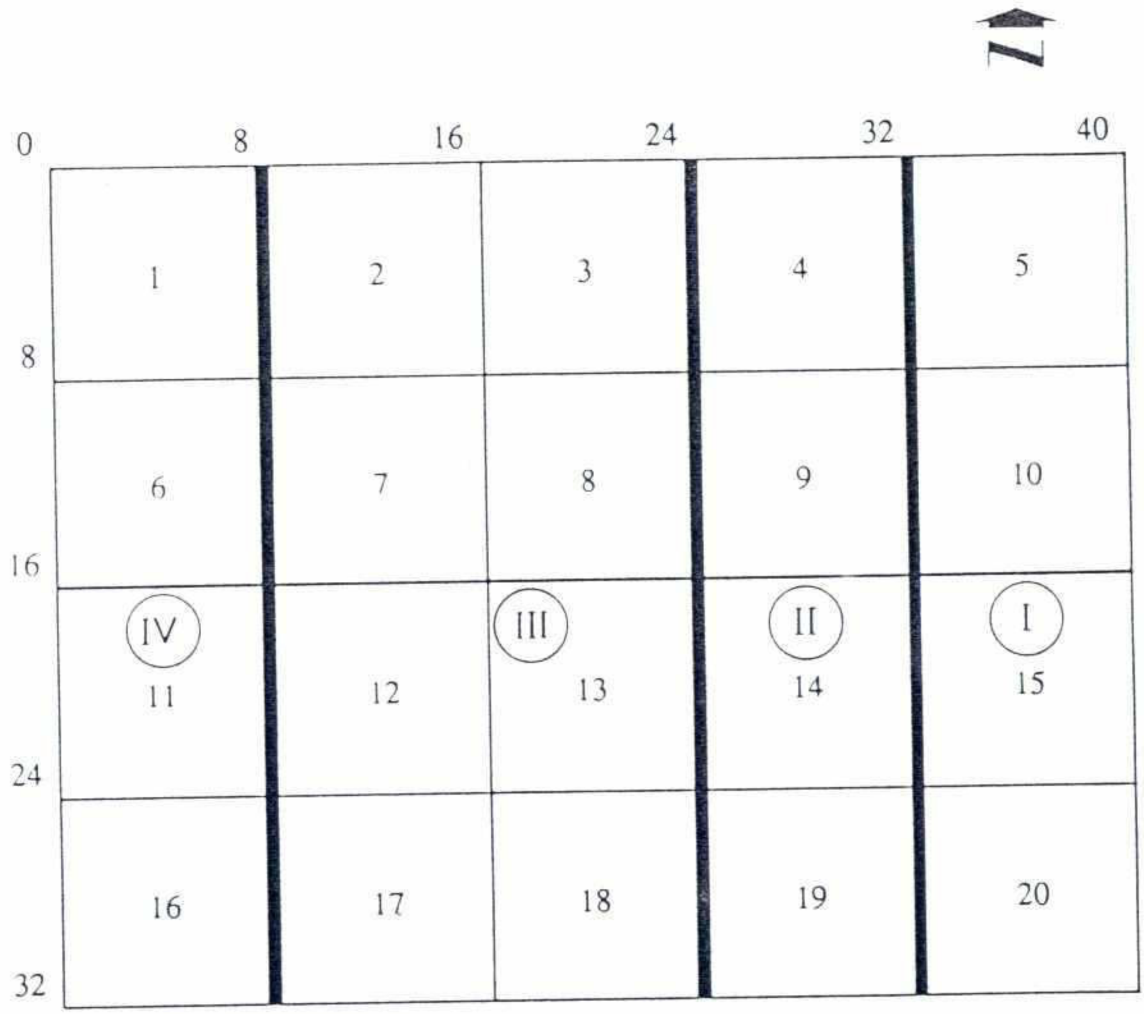
I. Shafiullah Bhuiyan
S/o. Late Elahi Box Bhuiyan

III. Shahidullah Bhuiyan
S/o. Late Jinnat Ali Bhuiyan

II. Altaf Bhuiyan
S/o. Late Aminuddin Bhuiyan

SOIL SAMPLING DESIGN FOR D_1

Meter



A. Location
Village: Subidpur Mouza: Subidpur
Union: Guptieast, Thana: Faridganj
Dist.: Chandpur

B. Land owner:

I. Sobhan Master
S/o. Late Ahmed Bepari

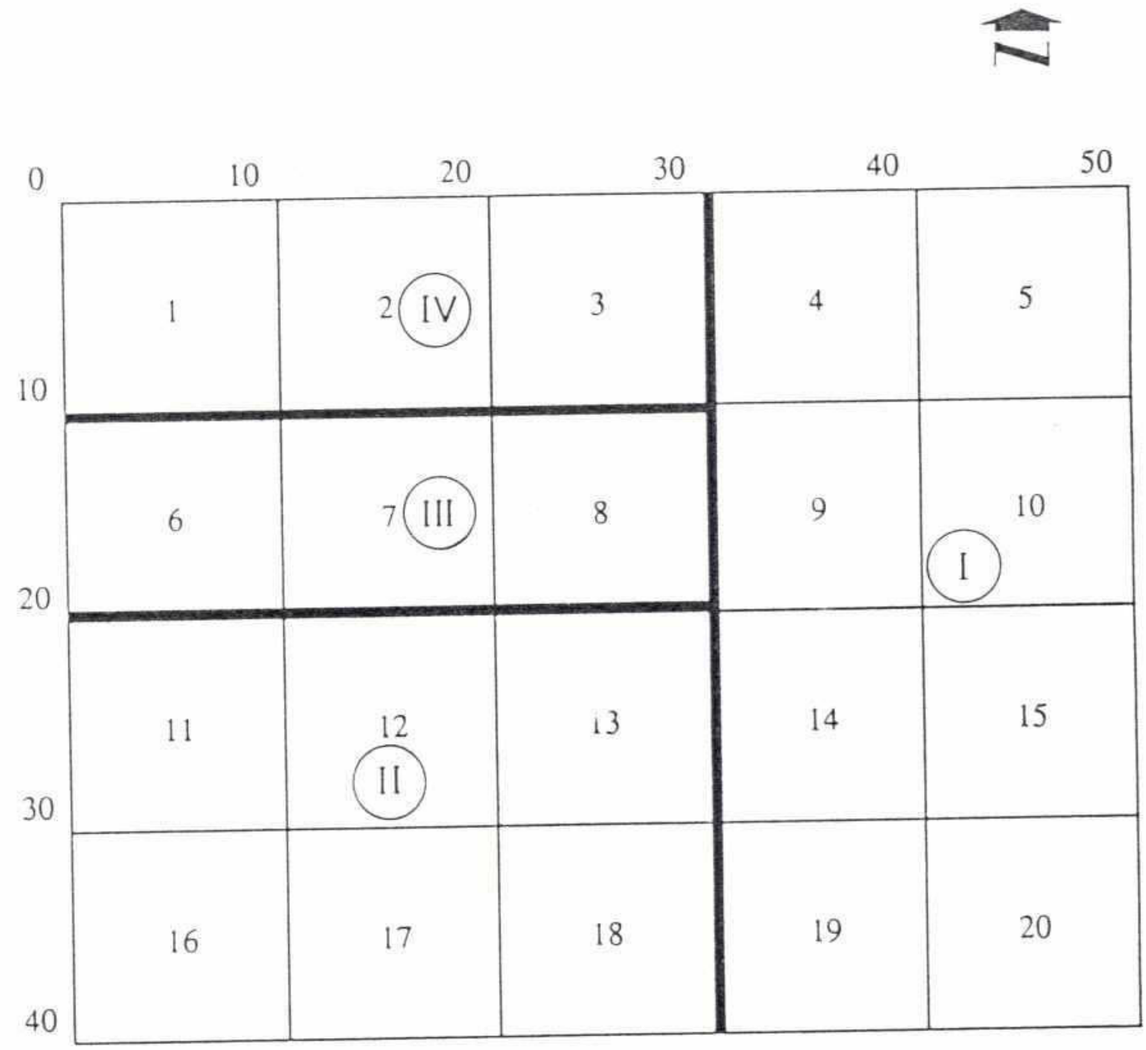
II. Yousuf Ali
S/o. Late Ahmed Bepari

III. Nurul Hoque Sarder
S/o. Late Ayub Ali Sarder

IV. Md. Rafique
S/o. Hafizuddin Bepari

SOIL SAMPLING DESIGN FOR D_2

<u>Meter</u>



A. Location
Village: Laksmipur, Mouza: Laksmipur
Union: Guptieast, Thana: Faridganj
Dist.: Chandpur

B. Land owner:

I. Md. Ibrahim
S/o. Late Abdul Mazid

II. Ruhul Amin
S/o. Late Hamid Bepari

III. Md. Ibrahim
S/o. Md. Bepari

IV. Abul Khaer
S/o. Md.Bepari

Annex 3

Crop Nutrient Content of Surface Water Samples, CIP

Annex 3.1. Monsoon Season

Site		Date		pH	EC ds/m	Ca mg/l	Mg mg/l	K mg/l	NH4N mg/l	P mg/l	S mg/l	B mg/l	Cu mg/l	Fe mg/l	Mn mg/l	Zn mg/l	
Meghna River	1	05-Aug-92	Mean	6.8	0.1	9.3	2.9	1.8	0.0	0.1	0.4	0.0	0.0	0.1	0.0	0.3	987
			Std	0.1	0.0	0.9	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	282
	1	26-Aug-92	Mean	6.9	0.1	16.0	2.9	1.6	0.0	0.1	0.4	0.0	0.0	0.1	0.0	0.2	867
			Std	0.0	0.0	2.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19
	1	17-Sep-92	Mean	6.7	0.1	12.7	3.9	1.1	0.0	0.1	0.4	0.0	0.0	0.1	0.1	0.2	760
			Std	0.1	0.0	1.9	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	118
	1	10-Oct-92	Mean	6.9	0.1	19.6	3.0	1.7	0.0	0.0	0.5	0.0	0.1	0.4	0.0	0.4	560
			Std	0.0	0.0	0.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	86
Meghna River	2	04-Aug-92	Mean	6.7	0.1	6.0	2.4	1.6	0.0	0.1	0.4	0.0	0.0	0.1	0.0	0.2	987
			Std	0.1	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	105
	2	25-Aug-92	Mean	6.9	0.1	13.3	2.4	1.8	0.0	0.1	0.5	0.0	0.0	0.2	0.0	0.2	1107
			Std	0.1	0.0	1.9	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	82
	2	16-Sep-92	Mean	6.8	0.1	26.0	5.6	1.3	0.0	0.1	0.4	0.0	0.0	0.1	0.0	0.2	1667
			Std	0.1	0.0	2.8	1.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	317
	2	05-Oct-92	Mean	7.1	0.1	13.3	2.1	1.2	0.0	0.1	0.5	0.0	0.1	0.1	0.1	0.4	733
			Std	0.0	0.0	2.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
Inside CIP at Regu-lator	3	04-Aug-92	Mean	6.7	0.1	6.7	2.4	1.1	0.0	0.0	0.5	0.0	0.0	0.1	0.0	0.2	1013
			Std	0.2	0.0	2.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	421
	3	25-Aug-92	Mean	7.0	0.1	13.3	4.8	2.3	0.0	0.1	0.4	0.0	0.0	0.1	0.0	0.2	1587
			Std	0.0	0.0	3.8	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0	0.0	0.0	863
	3	16-Sep-92	Mean	6.5	0.1	9.3	4.8	1.9	0.0	0.0	0.2	0.0	0.3	0.0	0.1	0.2	123
			Std	0.1	0.0	0.9	0.0	1.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0	312
	3	05-Oct-92	Mean	7.1	0.1	16.2	5.0	1.8	0.0	0.1	0.5	0.0	0.0	0.4	0.0	0.3	680
			Std	0.0	0.0	3.3	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	226
Dakatia River	4	04-Aug-92	Mean	6.8	0.1	7.3	3.2	0.9	0.0	0.1	-	0.0	0.0	0.0	0.0	0.2	840
			Std	0.0	0.0	2.5	1.1	0.0	0.0	0.1	-	0.0	0.0	0.0	0.0	0.0	538
	4	25-Aug-92	Mean	7.0	0.1	6.7	3.2	0.9	0.0	0.1	-	0.0	0.0	0.2	0.0	0.2	373
			Std	0.1	0.0	2.5	1.1	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	132
	4	16-Sep-92	Mean	6.6	0.1	4.0	2.4	1.7	0.0	0.1	-	0.0	0.0	0.1	0.0	0.2	400
			Std	0.0	0.0	0.0	0.0	0.1	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	204
	4	05-Oct-92	Mean	7.2	0.1	8.8	4.1	1.1	0.0	0.1	-	0.0	0.0	0.5	0.0	0.3	1133
			Std	0.0	0.0	2.1	1.0	0.1	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	395
Dakatia River	5	04-Aug-92	Mean	6.8	0.1	4.0	2.4	0.9	0.0	0.0	-	0.0	0.0	0.1	0.0	0.2	307
			Std	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	82
	5	25-Aug-92	Mean	7.0	0.1	6.0	3.2	0.6	0.0	0.1	-	0.0	0.0	0.1	0.0	0.2	560
			Std	0.1	0.0	2.8	1.1	0.0	0.0	0.0	-	0.0	0.0	0.1	0.0	0.0	131
	5	16-Sep-92	Mean	6.7	0.1	4.0	2.4	1.8	0.0	0.1	-	0.0	0.0	0.1	0.0	0.2	840
			Std	0.1	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0	0.1	0.0	0.0	229
	5	05-Oct-92	Mean	7.1	0.1	21.0	12.5	1.1	0.0	0.1	-	0.0	0.0	0.5	0.0	0.3	627
			Std	0.0	0.0	0.2	0.2	0.1	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	197

Annex 3.2. Nutrient Content of Dry Season (March) Surface Water Samples from CIP Study Area

Sample Site	pH	EC ds/m	Ca mg/l	Mg mg/l	K mg/l	NH_4 mg/l	P mg/l	S mg/l	B mg/l	Cu mg/l	Fe mg/l	Mn mg/l	Zn mg/l	TDS mg/l
B1R1	7	0.21	0.2	0	0	Trace	0.1	4	Trace	0.15	1.3	0.32	1	240
B1R2	7	0.22	0.2	0	0	Trace	0.1	5	Trace	0.16	1.2	0.18	0.7	80
B1R3	7	0.23	0.2	0	0	Trace	0.1	5	Trace	0.17	1.3	0.27	0.6	240
B2R1	7	0.23	0.2	0	0	Trace	0	3	Trace	0.04	0.9	0.09	0.6	200
B2R2	7	0.23	0.2	0	0	Trace	0.2	3	Trace	0.04	0.9	0.39	0.6	240
B2R3	7	0.23	0.2	0	0	Trace	0.1	4	Trace	0.05	0.6	0.13	0.7	200
C1R1	7	0.19	0.2	0	0	Trace	0.1	4	Trace	0.08	1.0	0.04	0.5	240
C1R2	7	0.20	0.2	0	0	Trace	0.2	5	Trace	0.04	0.6	0.17	0.5	160
C1R3	7	0.19	0.2	0	0	Trace	0.1	5	Trace	0.05	0.9	0.09	0.6	80
C2R1	7	0.17	0.2	0	0	Trace	0.1	5	Trace	0.13	1.0	0.17	0.5	160
C2R2	7	0.17	0.19	0	0	Trace	0.12	5	Trace	0.19	0.5	0.21	0.5	160
C1R3	7	0.16	0.21	0	0	Trace	0.1	4	Trace	0.11	0.9	0.01	0.5	80
D2R1	7	0.74	0.2	0.1	0	Trace	0.1	3	Trace	0.08	0.8	0.24	0.3	480
D2R2	7	0.78	0.2	0.1	0	Trace	0.2	3	Trace	0.15	0.6	0.16	0.5	520
D2R3	7	0.78	0.2	0.1	0	Trace	0.2	4	Trace	0.08	0.4	0.28	0.4	480

Annex 3.3. Nutrient Content of Dry Season (April) Surface Water Samples from CIP Study Area

Sample Site	pH	EC ds/m	Ca mg/l	Mg mg/l	K mg/l	NH4 mg/l	P mg/l	S mg/l	B mg/l	Cu mg/l	Fe mg/l	Mn mg/l	Zn mg/l	TDS mg/l
B1R1	7.2	0.16	46	9.20	1.80	Trace	0.12	0.39	Trace	0.6	0.7	0.7	0.7	440
B1R2	7.1	0.16	35	8.50	1.60	Trace	0.23	0.39	Trace	0.3	0.9	0.5	0.7	400
B1R3	7.3	0.16	40	8.20	1.70	Trace	0.12	0.77	Trace	0.2	0.9	0.5	0.8	480
B2R1	7.4	0.18	39	9.10	2.30	Trace	0.23	0.39	Trace	0.3	0.8	0.5	0.6	400
B2R2	7.4	0.17	56	8.80	1.90	Trace	Trace	0.77	Trace	0.4	0.6	0.4	0.8	280
B2R3	7.5	0.17	25	8.20	1.80	Trace	0.12	0.39	Trace	0.4	0.2	0.3	0.7	280
C1R1	7.5	0.17	45	8.20	0.80	Trace	0.12	0.77	Trace	0.5	1.1	0.3	0.6	280
C1R2	7.6	0.17	44	8.10	1.00	Trace	Trace	0.77	Trace	0.4	0.7	0.4	0.5	240
C1R3	7.5	0.17	33	9.10	1.20	Trace	0.23	0.15	Trace	0.4	0.6	0.5	0.7	320
C2R1	7.4	0.25	29	8.60	2.20	Trace	0.23	0.39	Trace	0.4	0.5	0.4	0.7	320
C2R2	7.4	0.25	36	10.09	1.70	Trace	0.23	0.15	Trace	0.5	0.9	0.3	0.7	400
C2R3	7.5	0.26	32	8.50	2.10	Trace	0.23	0.77	Trace	0.3	1.0	0.4	0.6	320
D1R1	7.7	0.32	34	17.70	4.00	Trace	0.12	0.39	Trace	0.1	0.3	0.2	0.8	400
D1R2	7.7	0.32	43	21.10	4.10	Trace	0.29	0.77	Trace	0.5	0.3	0.5	0.7	400
D1R3	7.8	0.32	36	17.90	3.80	Trace	Trace	0.77	Trace	0.4	0.4	0.3	0.6	400
D2R1	7.6	0.22	30	11.00	4.10	Trace	0.23	0.77	Trace	0.3	0.4	0.4	0.6	360
D2R2	7.6	0.23	33	13.10	4.20	Trace	Trace	0.77	Trace	0.3	0.8	0.1	0.6	320
D2R3	7.7	0.24	37	11.40	4.20	Trace	0.12	0.39	Trace	0.4	0.4	0.4	0.6	400

ANNEX 4

Analysis of Variance: Water Samples from Chandpur

All effects assessed simultaneously, each effect adjusted for all other effects.

A. Examining Differences Between Samples Taken From Different Strata

Variable: pH

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0023	.0012	.0308	.9697
Within Groups	57	2.1570	.0378		
Total	59	2.1593			

Variable: Ca

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.5320	.2660	.0062	.9938
Within Groups	57	2447.1640	42.9327		
Total	59	2447.6960			

Variable: Mg

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.1120	.0560	.0097	.9903
Within Groups	57	327.4840	5.7453		
Total	59	327.5960			

Variable: K

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0810	.0405	.1593	.8531
Within Groups	57	14.4930	.2543		
Total	59	14.5740			

Variable: NH4N

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0000	.0000		
Within Groups	57	.0000	.0000		
Total	59	.0000			

Variable: P

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0126	.0063	2.6508	.0793
Within Groups	57	.1357	.0024		
Total	59	.1484			

Variable: S

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0072	.0036	.3235	.7259
Within Groups	33	.3683	.0112		
Total	35	.3756			

Variable: B

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0000	.0000		
Within Groups	57	.0000	.0000		
Total	59	.0000			

Variable: Cu

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0144	.0072	1.0392	.3603
Within Groups	57	.3953	.0069		
Total	59	.4098			

Variable: Fe

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0137	.0069	.2601	.7719
Within Groups	57	1.5022	.0264		
Total	59	1.5159			

Variable: Mn

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0000	.0000	.0129	.9872
Within Groups	57	.0239	.0004		
Total	59	.0240			

Variable: Zn

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0022	.0011	.2574	.7739
Within Groups	57	.2469	.0043		
Total	59	.2491			

Variable: EC

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	.0000	.0000	.0152	.9849
Within Groups	57	.0192	.0003		
Total	59	.0192			

Variable: TDS

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	299253.3333	149626.6667	.6490	.5264
Within Groups	57	13141680.00	230555.7895		
Total	59	13440933.33			

B. Examining Differences Between Samples Taken From Different Sites at Different Periods

Variable: pH

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	1.615	7	.231	28.839	.000
SITE	.054	4	.014	1.698	.170
PERIOD	1.561	3	.520	65.028	.000
2-way Interactions	.224	12	.019	2.337	.022
SITE PERIOD	.224	12	.019	2.337	.022
Explained	1.839	19	.097	12.101	.000
Residual	.320	40	.008		
Total	2.159	59	.037		

Variable: Ca

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	1206.771	7	172.396	25.937	.000
SITE	582.699	4	145.675	21.917	.000
PERIOD	624.072	3	208.024	31.297	.000
2-way Interactions	975.058	12	81.255	12.225	.000
SITE PERIOD	975.058	12	81.255	12.225	.000
Explained	2181.829	19	114.833	17.277	.000
Residual	265.867	40	6.647		
Total	2447.696	59	41.486		

Variable: Mg

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	97.574	7	13.939	22.273	.000
SITE	37.826	4	9.456	15.110	.000
PERIOD	59.748	3	19.916	31.823	.000
2-way Interactions	204.989	12	17.082	27.295	.000
SITE PERIOD	204.989	12	17.082	27.295	.000
Explained	302.563	19	15.924	25.445	.000
Residual	25.033	40	.626		
Total	327.596	59	5.552		

Variable: K

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	1.641	5	.328	2.113	.099
SITE	.684	2	.342	2.202	.132
PERIOD	.957	3	.319	2.054	.133
2-way Interactions	2.412	6	.402	2.589	.045
SITE PERIOD	2.412	6	.402	2.589	.045
Explained	4.052	11	.368	2.372	.037
Residual	3.727	24	.155		
Total	7.779	35	.222		

Variable: NH4N

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	.000	5	.000		
SITE	.000	2	.000		
PERIOD	.000	3	.000		
2-way Interactions	.000	6	.000		
SITE PERIOD	.000	6	.000		
Explained	.000	11	.000		
Residual	.000	24	.000		
Total	.000	35	.000		

Variable: P

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	.039	5	.008	5.063	.003
SITE	.022	2	.011	7.076	.004
PERIOD	.017	3	.006	3.721	.025
2-way Interactions	.009	6	.001	.924	.495
SITE PERIOD	.009	6	.001	.924	.495
Explained	.048	11	.004	2.806	.017
Residual	.037	24	.002		
Total	.085	35	.002		

Variable: S

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	.194	5	.039	9.026	.000
SITE	.009	2	.005	1.081	.355
PERIOD	.185	3	.062	14.323	.000
2-way Interactions	.078	6	.013	3.016	.024
SITE PERIOD	.078	6	.013	3.016	.024
Explained	.272	11	.025	5.748	.000
Residual	.103	24	.004		
Total	.376	35	.011		

Variable: B

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	.000	7	.000		
SITE	.000	4	.000		
PERIOD	.000	3	.000		
2-way Interactions	.000	12	.000		
SITE PERIOD	.000	12	.000		
Explained	.000	19	.000		
Residual	.000	40	.000		
Total	.000	59	.000		

Variable: Cu

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	.089	7	.013	3.660	.004
SITE	.044	4	.011	3.175	.023
PERIOD	.045	3	.015	4.306	.010
2-way Interactions	.182	12	.015	4.372	.000
SITE PERIOD	.182	12	.015	4.372	.000
Explained	.271	19	.014	4.110	.000
Residual	.139	40	.003		
Total	.410	59	.007		

Variable: Fe

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	1.078	7	.154	95.953	.000
SITE	.081	4	.020	12.577	.000
PERIOD	.997	3	.332	207.120	.000
2-way Interactions	.374	12	.031	19.401	.000
SITE PERIOD	.374	12	.031	19.401	.000
Explained	1.452	19	.076	47.604	.000
Residual	.064	40	.002		
Total	1.516	59	.026		

Variable: Mn

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	.011	7	.002	10.577	.000
SITE	.007	4	.002	12.286	.000
PERIOD	.004	3	.001	8.298	.000
2-way Interactions	.008	12	.001	4.465	.000
SITE PERIOD	.008	12	.001	4.465	.000
Explained	.018	19	.001	6.716	.000
Residual	.006	40	.000		
Total	.024	59	.000		

Variable: EC

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	.015	7	.002	619.470	.000
SITE	.009	4	.002	657.923	.000
PERIOD	.006	3	.002	568.198	.000
2-way Interactions	.004	12	.000	95.375	.000
SITE PERIOD	.004	12	.000	95.375	.000
Explained	.019	19	.001	288.462	.000
Residual	.000	40	.000		
Total	.019	59	.000		

Variable: Zn

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	.194	7	.028	86.313	.000
SITE	.015	4	.004	11.697	.000
PERIOD	.179	3	.060	185.801	.000
2-way Interactions	.042	12	.003	10.858	.000
SITE PERIOD	.042	12	.003	10.858	.000
Explained	.236	19	.012	38.657	.000
Residual	.013	40	.000		
Total	.249	59	.004		

Variable: TDS

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	3490586.667	7	498655.238	3.467	.005
SITE	3038666.667	4	759666.667	5.281	.002
PERIOD	451920.000	3	150640.000	1.047	.382
2-way Interactions	4196746.667	12	349728.889	2.431	.018
SITE PERIOD	4196746.667	12	349728.889	2.431	.018
Explained	7687333.333	19	404596.491	2.813	.003
Residual	5753600.000	40	143840.000		
Total	13440933.333	59	227812.429		

Annex 5.2. Samples Collected September 1992

Species	Meghna River Sites		Dakatia River Sites	
	Outside Embankment	Inside Embankment	Outside Embankment	Inside Embankment
1. Floating BGA (filaments/ml.)				
a) *Aulosira Prolifica* (20-70 cells/fil)	0	14	116	137
b) *Anabaena Oscillarioides* (25-50 cells/fil)	137	13	75	49
c) *Anabaena fuellebornii* (15-25 cells/fil)	53	42	10	117
d) *Cylindrospermum maius* (60-70 cells/fil)	111	10	120	12
e) *Scytonema mirabile* (100-125 cells/fil)	112	10	160	140
f) *Scytonema subtile* (50-60 cells/fil)	43	11	7	80
g) *Nostoc linckia* (35-60 cells/fil)	142	110	1157	133
2. Attached BGA (filaments/plant)				
a) *Nostoc punctiforme* (15-20 cells/fil)	140	117	123	133
b) *Gloeotrichia pilgerii* (15-25 cells/fil)	19	60	118	110
c) *Gloeotrichia natans* (20-30 cells/fil)	137	115	10	111
d) *Microchaete uberrima* (30-50 cells/fil)	112	73	1031	224

Annex 5.3. Samples Collected October 1992

Species	Meghna River Sites		Dakatia River Sites	
	Outside Embankment	Inside Embankment	Outside Embankment	Inside Embankment
1. Floating BGA (filaments/ml.)				
a) *Aulosira prolifica* (20-70 cells/fil)	43	-	111	-
b) *Anabaena affinis* (30-35 cells/fil	20	-	165	-
c) *Anabaena oscillarioides* (25-50 cells/fil)	72	-	32	-
d) *Cylindrospermum maius* (60-70 cells/fil)	116	-	113	-
e) *Scytonema subtile* (50-60 cells/fil)	0	-	69	-
f) *Nostoc linckia* (35-60 cells/fil)	113	47	212	118
g) *Anabaena cylindrica* (60-70 cells/fil)	61	71	100	54
2. Attached BGA (filaments/plant)				
a) *Nostoc punctiforme* (15-20 cells/fil)	111	141	88	40
b) *Gloeotrichia pilgerii* (15-25 cells/fil)	72	18	72	112
c) *Gloeotrichia natans* (20-30 cells/fil)	54	22	110	62

Annex 5.4. Samples Collected March 1993

Species	Meghna River Sites		Dakatia River Sites	
	Outside Embankment	Inside Embankment	Outside Embankment	Inside Embankment
1. Floating BGA (filaments/ml.)				
a) *Anabaena affinis* (30-35 cells/fil	-	2	5	3
b) *Anabaena oscillarioides* (25-50 cells/fil)	-	4	3	1
c) *Scytonema subtile* (50-60 cells/fil)	-	8	8	6
2. Attached BGA (filaments/plant)				
a) *Nostoc punctiforme* (15-20 cells/fil)	-	3	4	2
b) *Gloeotrichia natans* (20-30 cells/fil)	-	2	3	1

Annex 5

Relative Abundance of Blue Green Algae in CIP Sampling Areas

Annex 5.1. Samples Collected August 1992

Species	Meghna River Sites		Dakatia River Sites	
	Outside Embankment	Inside Embankment	Outside Embankment	Inside Embankment
1. Floating BGA (filaments/ml.)				
a) *Aulosira prolifica* (20-70 cells/fil)	92	2	239	321
b) *Nostoc linckia* (35-60 cells/fil)	154	129	4	173
c) *Nostoc spongiaeforme* (30-35 cells/fil)	1	3	295	108
d) *Anabaena cylindrica* (60-70 cells/fil)	8	67	18	19
e) *Anabaena sphaerica* (30-80 cells/fil)	1	3	33	101
f) *Cylindrospermum maius* (60-70 cells/fil)	4	12	32	10
g) *Anabaena volzii* (25-35 cells/fil)	11	7	35	0
h) *Scytonema mirabile* (100-125 cells/fil)	14	8	81	10
i) *Scytonema subtile* (50-60 cells/fil)	3	11	2	48
j) *Gloeotrichia natans* (20-30 cells/fil)	3	4	11	15
k) *Anabaena affinis* (30-35 cells/fil)	0	13	28	0
2. Attached BGA (filaments/plant)				
a) *Nostoc spongiaeforme* (30-35 cells/fil)	115	9	36	30
b) *Nostoc microscopicum* (40-50 cells/fil)	150	111	203	106
c) *Microchaete uberrima* (30-50 cells/fil)	2	6	25	10

Annex 5.5. Samples Collected April 1993

Species	Meghna River Sites		Dakatia River Sites	
	Outside Embankment	Inside Embankment	Outside Embankment	Inside Embankment
1. Floating BGA (filaments/ml.)				
a) *Anabaena proloifica* (30-35 cells/fil	-	4	10	5
b) *Anabaena affinis* (25-50 cells/fil)	-	4	4	3
c) *Anabaena oscillariodes* (25-50 cells/fil)	-	6	5	6
d) *Scytonema subtile* (50-60 cells/fil)	-	10	9	5
2. Attached BGA (filaments/plant)				
a) *Nostoc punctiforme* (15-20 cells/fil)	-	6	7	8
b) *Gloeotrichia natans* (15-25 cells/fil)	-	4	3	3

Annex 6

Soil Fertility Comparisons: CIP Sample Sites

Parameter		Meghna River Side: Outside Embankment Upper Pre-	Post	Lower Pre-	Post	Inside Embankment Upper Pre-	Post	Lower Pre-	Post	Dakatia River Side: Outside Embankment Upper Pre-	Post	Lower Pre-	Post	Inside Embankment Upper Pre-	Post	Lower Pre-	Post
pH	Mean	5.8	5.7	5.6	5.3	6.1	5.5	6.4	5.5	6.1	5.5	6.0	5.6	6.1	5.7	6.3	6.1
	SD	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3
	Minimum	5.5	5.6	5.4	5.1	5.9	5.3	6.0	5.4	6.0	5.4	5.8	5.5	6.0	5.6	6.2	5.9
	Maximum	6.1	5.8	5.8	5.5	6.3	5.6	6.5	5.7	6.2	5.6	6.1	6.0	6.3	6.0	6.4	7.1
Organic Matter %	Mean	3.0	2.3	3.0	2.6	3.4	2.7	3.9	3.1	3.5	2.6	4.0	2.8	3.7	4.5	4.0	5.4
	SD	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.3	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.1
	Minimum	2.7	2.0	2.5	2.1	2.9	2.4	3.5	2.5	3.3	2.3	3.8	2.3	3.5	4.0	3.6	5.2
	Maximum	3.3	2.9	3.3	3.1	3.6	3.5	4.2	3.9	3.8	2.9	4.2	3.3	3.8	4.6	4.4	5.4
Calcium meq/100g	Mean	10.1	9.0	10.3	11.0	11.9	8.6	10.6	11.3	4.1	3.7	7.2	5.7	7.1	6.4	7.4	9.1
	SD	0.5	0.7	0.4	2.5	0.7	1.2	1.1	0.7	0.2	0.4	1.0	0.5	1.2	0.4	1.1	0.6
	Minimum	9.0	8.0	8.9	8.3	10.8	6.8	6.4	9.7	3.8	3.2	5.9	5.1	5.7	5.4	5.7	8.1
	Maximum	10.7	10.2	10.8	17.0	13.3	12.0	11.6	12.5	4.7	4.8	9.1	6.7	10.7	7.2	9.0	10.4
Magnesium meq/100g	Mean	5.7	3.0	4.4	2.3	4.4	2.4	2.8	2.0	1.9	1.0	3.8	2.2	3.0	1.9	3.3	2.5
	SD	0.4	0.3	0.3	0.2	0.5	0.3	0.2	0.1	0.2	0.2	0.5	0.2	0.4	0.1	0.5	0.2
	Minimum	4.8	2.6	3.8	2.0	3.4	1.8	2.5	1.8	1.6	0.8	3.3	1.9	2.3	1.6	2.3	2.2
	Maximum	6.2	3.5	4.8	2.6	5.2	2.8	3.3	2.2	2.2	1.4	5.3	2.4	4.0	2.1	3.9	2.9
Potassium meq/100g	Mean	0.19	0.15	0.18	0.21	0.05	0.32	0.05	0.78	0.06	0.11	0.09	0.14	0.06	0.11	0.07	0.09
	SD	0.03	0.04	0.03	0.06	0.02	0.23	0.02	0.16	0.02	0.02	0.02	0.03	0.02	0.03	0.01	0.02
	Minimum	0.15	0.10	0.15	0.12	0.02	0.12	0.01	0.44	0.03	0.07	0.06	0.09	0.03	0.03	0.05	0.06
	Maximum	0.25	0.26	0.25	0.35	0.14	0.80	0.10	1.00	0.09	0.14	0.15	0.19	0.10	0.17	0.09	0.14
Ammonia Nitrogen µg/g	Mean	17	17	23	18	11	14	13	97	13	14	21	16	16	17	19	11
	SD	7.3	3.6	8.1	3.6	3.0	2.5	3.9	13.5	4.0	1.9	5.9	4.5	3.8	3.5	7.2	6.9
	Minimum	10	14	10	14	5	11	5	80	5	11	10	11	10	11	10	8
	Maximum	30	23	40	23	20	17	20	125	20	17	30	23	22	23	30	41
Phosphorus µg/g	Mean	21	19	17	24	22	44	31	115	12	16	34	34	10	16	31	23
	SD	9.7	4.0	3.7	2.5	8.1	32.3	5.7	29.2	3.0	1.7	5.2	3.1	4.8	3.0	5.2	2.7
	Minimum	10	13	10	20	10	13	19	70	7	13	24	26	5	13	19	19
	Maximum	43	28	22	28	37	104	39	182	20	20	40	38	24	27	39	27
Sulphur µg/g	Mean	48	41	31	52	14	59	23	167	8	10	14	15	24	29	19	21
	SD	9.2	7.3	7.4	10.4	4.3	31.1	7.0	51.4	1.4	2.8	2.5	3.1	4.5	5.2	2.7	6.5
	Minimum	29	29	17	38	9	14	49	107	6	5	9	9	15	24	13	14
	Maximum	59	57	44	71	23	94	49	275	10	14	20	19	29	38	23	38

Continued

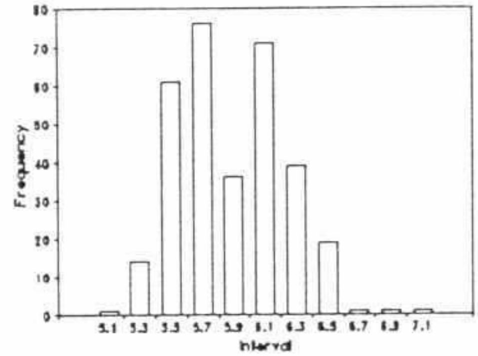
Annex 6 (Continued)

Parameter		Meghna River Side								Dakatia River Side							
		Outside Embankment				Inside Embankment				Outside Embankment				Inside Embankment			
		Upper		Lower		Upper		Lower		Upper		Lower		Upper		Lower	
		Pre-	Post	Pre-	Post	Pre-	Post	Pre-	Post	Pre-	Post	Pre-	Post	Pre-	Post	Pre-	Post
Boron µg/g	Mean	0.7	0.8	0.5	0.8	0.9	1.3	0.9	2.0	0.4	0.6	0.5	0.9	0.8	0.8	0.6	0.6
	SD	0.2	0.2	0.3	0.2	0.1	0.3	0.1	0.3	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2
	Minimum	0.4	0.6	0.1	0.6	0.7	0.8	0.7	1.1	0.1	0.3	0.2	0.6	0.5	0.6	0.3	0.4
	Maximum	0.9	1.0	0.9	1.0	0.9	1.7	0.9	2.2	0.8	0.8	0.7	1.4	0.9	1.4	0.9	1.0
Copper µg/g	Mean	10.7	12.4	10.9	14.5	6.9	15.3	8.5	16.6	4.9	11.2	7.6	17.7	6.7	8.3	10.0	11.6
	SD	0.7	1.7	0.8	2.2	1.2	2.4	0.6	1.6	0.8	1.9	0.5	1.3	1.0	2.7	1.0	1.9
	Minimum	9.5	10.0	8.7	11.2	4.9	8.5	6.9	13.5	3.4	7.5	6.3	14.6	4.5	5.3	7.8	7.8
	Maximum	12.0	17.1	12.0	19.2	10.3	19.2	9.6	19.7	6.7	15.1	8.4	20.0	8.5	18.5	11.7	15.8
Iron µg/g	Mean	527	302	616	838	427	366	550	295	899	311	1714	809	596	351	1102	462
	SD	135	126	64	116	106	109	68	104	82	135	179	128	92	93	227	155
	Minimum	330	80	505	574	303	216	453	158	749	136	1131	530	471	186	787	121
	Maximum	775	511	756	1100	675	612	726	647	1057	625	2067	1098	824	518	1507	650
Manganese µg/g	Mean	62	30	78	50	25	28	31	26	27	15	61	29	30	12	36	11
	SD	22.5	8.7	17.0	7.5	7.0	5.3	8.0	3.4	3.8	1.9	12.1	3.7	5.9	1.7	7.7	2.8
	Minimum	23	13	41	38	13	17	15	17	20	12	36	24	13	8	25	5
	Maximum	88	50	105	65	41	28	43	32	36	20	83	37	39	15	53	15
Zinc µg/g	Mean	4.8	3.5	3.5	4.3	3.3	6.9	2.1	3.3	0.7	2.4	2.7	2.0	2.4	3.1	2.6	2.8
	SD	0.3	1.5	1.0	1.7	1.1	2.9	0.9	0.7	0.1	1.6	1.0	1.1	1.3	1.3	0.6	0.7
	Minimum	4.1	1.0	1.7	1.9	2.0	3.9	1.4	1.6	0.5	1.0	1.0	0.7	1.0	1.0	1.5	1.6
	Maximum	5.5	6.3	5.0	7.3	5.7	13.6	5.7	4.5	1.0	8.4	4.2	4.3	6.3	5.4	3.9	4.3
Conductivity ds/m	Mean	0.35	0.12	0.18	0.15	0.18	0.58	0.16	0.69	0.21	0.14	0.27	0.15	0.14	0.16	0.13	0.10
	SD	0.10	0.02	0.02	0.05	0.02	0.47	0.03	0.50	0.03	0.03	0.05	0.02	0.03	0.02	0.02	0.03
	Minimum	0.14	0.17	0.13	0.09	0.15	0.09	0.11	0.11	0.15	0.11	0.12	0.11	0.11	0.12	0.11	0.07
	Maximum	0.58	0.17	0.21	0.27	0.22	1.40	0.21	1.30	0.31	0.19	0.33	0.18	0.22	0.20	0.17	0.18

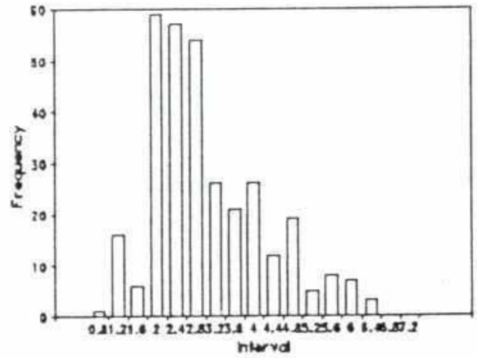
ANNEX 7

Frequency Distributions of Soil Nutrient Concentrations

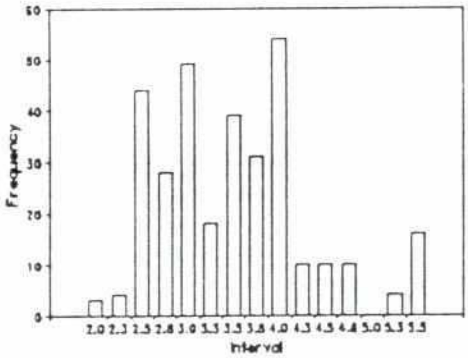
pH



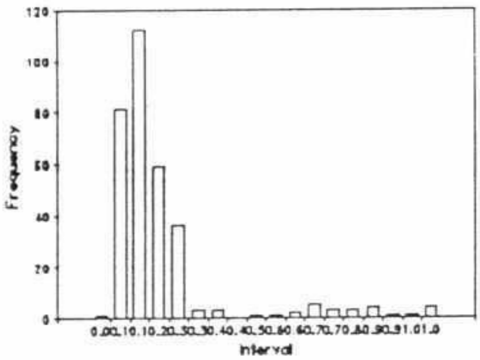
Magnesium



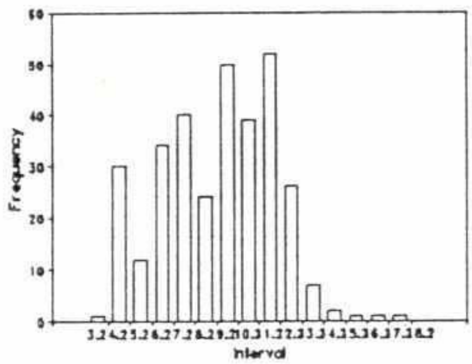
Organic Matter



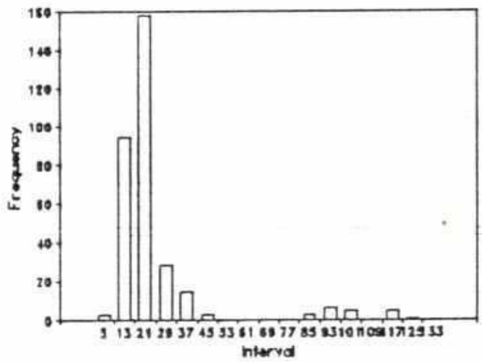
Potassium



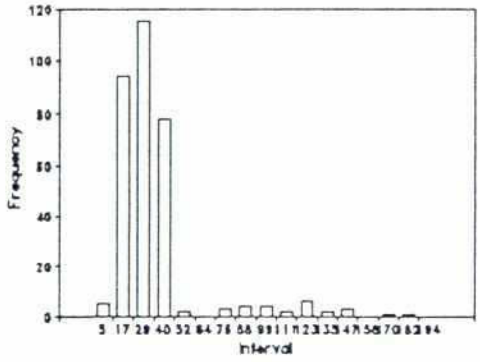
Calcium



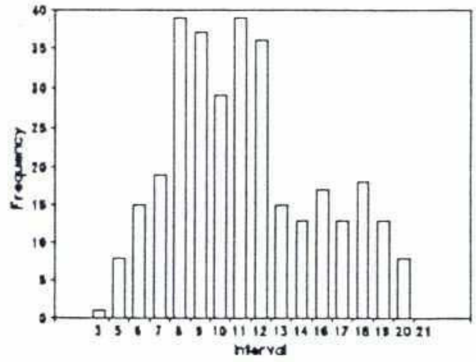
Nitrogen



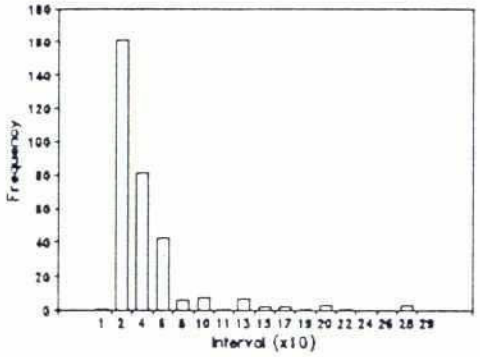
Phosphorus



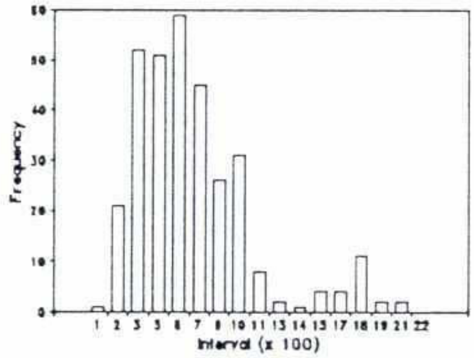
Copper



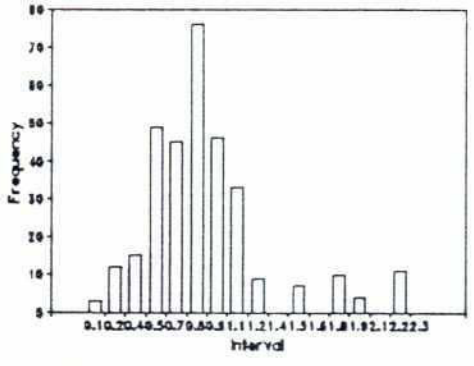
Sulphur



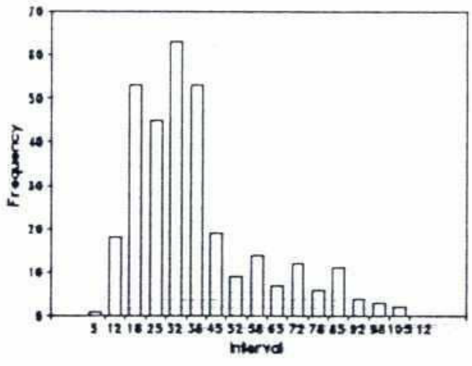
Iron



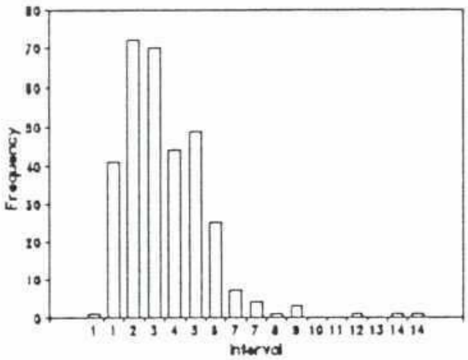
Boron



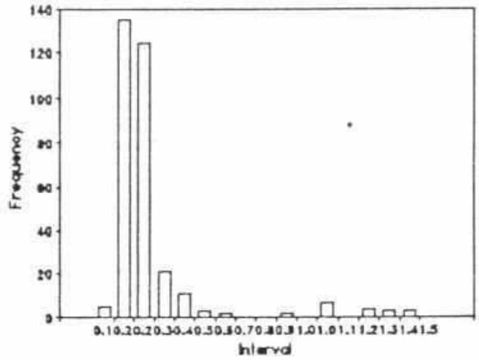
Manganese



Zinc



Conductivity



2 06

Annex 8

Analysis of Covariance: Soil Samples from CIP Sample Sites

All effects assessed simultaneously, each effect adjusted for all other effects.

Variable: pH

Source of Variation		Sum of Squares	DF	Mean Square	F	Signif of F
Covariates		3.455	6	.576	30.505	.000
UREA		.152	1	.152	8.059	.005
TSP/SSP		.415	1	.415	21.998	.000
MP		.020	1	.020	1.077	.300
MANURE		1.507	1	1.507	79.830	.000
ZINC		.041	1	.041	2.166	.142
ASH		.031	1	.031	1.644	.201
Main Effects		2.658	4	.664	35.196	.000
RIVER		.024	1	.024	1.262	.262
PROT		.189	1	.189	10.015	.002
ELEV		.192	1	.192	10.195	.002
PERIOD		1.595	1	1.595	84.495	.000
2-way Interactions		5.490	6	.915	48.468	.000
RIVER	PROT	.728	1	.728	38.560	.000
RIVER	ELEV	.729	1	.729	38.600	.000
RIVER	PERIOD	1.301	1	1.301	68.928	.000
PROT	ELEV	2.708	1	2.708	143.433	.000
PROT	PERIOD	.242	1	.242	12.801	.000
ELEV	PERIOD	.189	1	.189	10.020	.002
Explained		30.631	16	1.914	101.412	.000
Residual		5.720	303	.019		
Total		36.351	319	.114		

Variable: Organic Matter

Source of Variation		Sum of Squares	DF	Mean Square	F	Signif of F
Covariates		26.598	6	4.433	78.188	.000
UREA		.072	1	.072	1.263	.262
TSP/SSP		.036	1	.036	.636	.426
MP		.017	1	.017	.294	.588
MANURE		14.622	1	14.622	257.908	.000
ZINC		.000	1	.000	.001	.971
ASH		.018	1	.018	.320	.572
Main Effects		25.731	4	6.433	113.458	.000
RIVER		.940	1	.940	16.573	.000
PROT		2.109	1	2.109	37.203	.000
ELEV		10.794	1	10.794	190.391	.000
PERIOD		4.507	1	4.507	79.502	.000
2-way Interactions		48.945	6	8.158	143.881	.000
RIVER	PROT	16.822	1	16.822	296.699	.000
RIVER	ELEV	.678	1	.678	11.952	.001
RIVER	PERIOD	25.844	1	25.844	455.841	.000
PROT	ELEV	1.225	1	1.225	21.605	.000
PROT	PERIOD	41.075	1	41.075	724.468	.000
ELEV	PERIOD	.173	1	.173	3.051	.082
Explained		191.058	16	11.941	210.616	.000
Residual		17.179	303	.057		
Total		208.237	319	.653		

Annex 8 (Continued)

Variable: Calcium

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Covariates	80.730	6	13.455	12.431	.000
UREA	.002	1	.002	.002	.963
TSP/SSP	20.810	1	20.810	19.226	.000
MP	8.587	1	8.587	7.933	.005
MANURE	20.703	1	20.703	19.127	.000
ZINC	3.081	1	3.081	2.846	.093
ASH	18.660	1	18.660	17.240	.000
Main Effects	599.474	4	149.869	138.461	.000
RIVER	460.985	1	460.985	425.895	.000
PROT	2.220	1	2.220	2.051	.153
ELEV	166.579	1	166.579	153.899	.000
PERIOD	6.732	1	6.732	6.219	.013
2-way Interactions	140.817	6	23.469	21.683	.000
RIVER PROT	92.582	1	92.582	85.535	.000
RIVER ELEV	11.572	1	11.572	10.691	.001
RIVER PERIOD	25.809	1	25.809	23.845	.000
PROT ELEV	17.499	1	17.499	16.167	.000
PROT PERIOD	19.641	1	19.641	18.146	.000
ELEV PERIOD	29.717	1	29.717	27.455	.000
Explained	1864.094	16	116.506	107.638	.000
Residual	327.964	303	1.082		
Total	2192.059	319	6.872		

Variable: Magnesium

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Covariates	11.087	6	1.848	15.551	.000
UREA	.005	1	.005	.046	.831
TSP/SSP	6.483	1	6.483	54.566	.000
MP	3.985	1	3.985	33.539	.000
MANURE	3.166	1	3.166	26.648	.000
ZINC	2.077	1	2.077	17.478	.000
ASH	.394	1	.394	3.315	.070
Main Effects	13.610	4	3.402	28.635	.000
RIVER	7.869	1	7.869	66.225	.000
PROT	.247	1	.247	2.078	.150
ELEV	.011	1	.011	.092	.762
PERIOD	10.675	1	10.675	89.841	.000
2-way Interactions	78.518	6	13.086	110.137	.000
RIVER PROT	8.436	1	8.436	71.003	.000
RIVER ELEV	65.096	1	65.096	547.865	.000
RIVER PERIOD	.786	1	.786	6.618	.011
PROT ELEV	7.152	1	7.152	60.190	.000
PROT PERIOD	.292	1	.292	2.461	.118
ELEV PERIOD	.024	1	.024	.201	.654
Explained	414.147	16	25.884	217.848	.000
Residual	36.002	303	.119		
Total	450.148	319	1.411		

Annex 8 (Continued)

Variable: Potassium

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Covariates	1.812	6	.302	38.812	.000
UREA	.017	1	.017	2.129	.146
TSP/SSP	.278	1	.278	35.770	.000
MP	.177	1	.177	22.729	.000
MANURE	1.139	1	1.139	146.403	.000
ZINC	.000	1	.000	.021	.885
ASH	.000	1	.000	.021	.884
Main Effects	1.341	4	.335	43.068	.000
RIVER	.048	1	.048	6.189	.013
PROT	.536	1	.536	68.883	.000
ELEV	.298	1	.298	38.349	.000
PERIOD	.811	1	.811	104.228	.000
2-way Interactions	3.020	6	.503	64.660	.000
RIVER PROT	.692	1	.692	88.908	.000
RIVER ELEV	.257	1	.257	33.060	.000
RIVER PERIOD	2.030	1	2.030	260.792	.000
PROT ELEV	.122	1	.122	15.698	.000
PROT PERIOD	.002	1	.002	.306	.581
ELEV PERIOD	.033	1	.033	4.249	.040
Explained	8.975	16	.561	72.068	.000
Residual	2.358	303	.008		
Total	11.333	319	.036		

Variable: Nitrogen

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Covariates	27418.382	6	4569.730	41.159	.000
UREA	6.618	1	6.618	.060	.807
TSP/SSP	10131.671	1	10131.671	91.254	.000
MP	4395.888	1	4395.888	39.593	.000
MANURE	8656.215	1	8656.215	77.965	.000
ZINC	2.084	1	2.084	.019	.891
ASH	1540.401	1	1540.401	13.874	.000
Main Effects	17831.344	4	4457.836	40.151	.000
RIVER	2424.739	1	2424.739	21.839	.000
PROT	3135.800	1	3135.800	28.244	.000
ELEV	10252.023	1	10252.023	92.338	.000
PERIOD	4898.694	1	4898.694	44.122	.000
2-way Interactions	41329.258	6	6888.210	62.041	.000
RIVER PROT	3887.690	1	3887.690	35.016	.000
RIVER ELEV	11299.121	1	11299.121	101.769	.000
RIVER PERIOD	21212.741	1	21212.741	191.059	.000
PROT ELEV	4207.970	1	4207.970	37.900	.000
PROT PERIOD	.452	1	.452	.004	.949
ELEV PERIOD	189.646	1	189.646	1.708	.192
Explained	102337.663	16	6396.104	57.609	.000
Residual	33641.184	303	111.027		
Total	135978.847	319	426.266		

Annex 8 (Continued)

Variable: Phosphorus

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Covariates	26205.418	6	4367.570	22.106	.000
UREA	84.223	1	84.223	.426	.514
TSP/SSP	7936.272	1	7936.272	40.168	.000
MP	3426.905	1	3426.905	17.345	.000
MANURE	11467.660	1	11467.660	58.042	.000
ZINC	444.703	1	444.703	2.251	.135
ASH	1062.926	1	1062.926	5.380	.021
Main Effects	37627.136	4	9406.784	47.611	.000
RIVER	1326.917	1	1326.917	6.716	.010
PROT	9802.428	1	9802.428	49.613	.000
ELEV	24206.977	1	24206.977	122.520	.000
PERIOD	7844.204	1	7844.204	39.702	.000
2-way Interactions	38805.668	6	6467.611	32.735	.000
RIVER PROT	14775.627	1	14775.627	74.784	.000
RIVER ELEV	527.044	1	527.044	2.668	.103
RIVER PERIOD	25611.337	1	25611.337	129.628	.000
PROT ELEV	3551.210	1	3551.210	17.974	.000
PROT PERIOD	88.915	1	88.915	.450	.503
ELEV PERIOD	93.554	1	93.554	.474	.492
Explained	165735.993	16	10358.500	52.428	.000
Residual	59865.557	303	197.576		
Total	225601.550	319	707.215		

Variable: Sulphur

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Covariates	64185.596	6	10697.599	28.043	.000
UREA	10.977	1	10.977	.029	.865
TSP/SSP	22725.192	1	22725.192	59.573	.000
MP	11710.212	1	11710.212	30.698	.000
MANURE	29318.737	1	29318.737	76.858	.000
ZINC	4478.375	1	4478.375	11.740	.001
ASH	1637.669	1	1637.669	4.293	.039
Main Effects	49145.249	4	12286.312	32.208	.000
RIVER	625.016	1	625.016	1.638	.202
PROT	23401.024	1	23401.024	61.345	.000
ELEV	12064.593	1	12064.593	31.627	.000
PERIOD	18964.031	1	18964.031	49.713	.000
2-way Interactions	122404.144	6	20400.691	53.480	.000
RIVER PROT	9606.215	1	9606.215	25.182	.000
RIVER ELEV	19188.369	1	19188.369	50.302	.000
RIVER PERIOD	73389.114	1	73389.114	192.387	.000
PROT ELEV	5957.134	1	5957.134	15.616	.000
PROT PERIOD	5.667	1	5.667	.015	.903
ELEV PERIOD	2781.331	1	2781.331	7.291	.007
Explained	405077.778	16	25317.361	66.368	.000
Residual	115584.469	303	381.467		
Total	520662.247	319	1632.170		

Annex 8 (Continued)

Variable: Boron

Source of Variation		Sum of Squares	DF	Mean Square	F	Signif of F
Covariates		5.742	6	.957	18.237	.000
UREA		.018	1	.018	.352	.553
TSP/SSP		1.162	1	1.162	22.136	.000
MP		1.166	1	1.166	22.217	.000
MANURE		2.858	1	2.858	54.457	.000
ZINC		.458	1	.458	8.731	.003
ASH		.339	1	.339	6.461	.012
Main Effects		9.043	4	2.261	43.082	.000
RIVER		.170	1	.170	3.235	.073
PROT		6.740	1	6.740	128.447	.000
ELEV		.549	1	.549	10.460	.001
PERIOD		2.560	1	2.560	48.784	.000
2-way Interactions		8.210	6	1.368	26.077	.000
RIVER	PROT	3.955	1	3.955	75.369	.000
RIVER	ELEV	.670	1	.670	12.762	.000
RIVER	PERIOD	5.767	1	5.767	109.894	.000
PROT	ELEV	.042	1	.042	.800	.372
PROT	PERIOD	1.256	1	1.256	23.934	.000
ELEV	PERIOD	.538	1	.538	10.248	.002
Explained		40.924	16	2.558	48.744	.000
Residual		15.900	303	.052		
Total		56.824	319	.178		

Variable: Copper

Source of Variation		Sum of Squares	DF	Mean Square	F	Signif of F
Covariates		772.405	6	128.734	48.439	.000
UREA		3.646	1	3.646	1.372	.242
TSP/SSP		2.827	1	2.827	1.064	.303
MP		2.895	1	2.895	1.089	.297
MANURE		391.691	1	391.691	147.383	.000
ZINC		3.468	1	3.468	1.305	.254
ASH		1.110	1	1.110	.418	.519
Main Effects		944.965	4	236.241	88.891	.000
RIVER		2.162	1	2.162	.813	.368
PROT		135.318	1	135.318	50.917	.000
ELEV		532.331	1	532.331	200.302	.000
PERIOD		368.230	1	368.230	138.555	.000
2-way Interactions		758.756	6	126.459	47.583	.000
RIVER	PROT	324.235	1	324.235	122.001	.000
RIVER	ELEV	117.000	1	117.000	44.024	.000
RIVER	PERIOD	333.069	1	333.069	125.325	.000
PROT	ELEV	9.484	1	9.484	3.569	.060
PROT	PERIOD	409.622	1	409.622	154.130	.000
ELEV	PERIOD	43.497	1	43.497	16.367	.000
Explained		4115.423	16	257.214	96.783	.000
Residual		805.265	303	2.658		
Total		4920.688	319	15.425		

Annex 8 (Continued)

Variable: Iron

Source of Variation		Sum of Squares	DF	Mean Square	F	Signif of F
Covariates		2296815.913	6	382802.652	19.011	.000
UREA		44418.800	1	44418.800	2.206	.139
TSP/SSP		459982.567	1	459982.567	22.843	.000
MP		169716.490	1	169716.490	8.428	.004
MANURE		425471.167	1	425471.167	21.130	.000
ZINC		758020.792	1	758020.792	37.644	.000
ASH		274094.015	1	274094.015	13.612	.000
Main Effects		14980128.987	4	3745032.247	185.984	.000
RIVER		1104163.994	1	1104163.994	54.834	.000
PROT		2022364.216	1	2022364.216	100.434	.000
ELEV		6766293.950	1	6766293.950	336.024	.000
PERIOD		1960175.967	1	1960175.967	97.345	.000
2-way Interactions		8038825.397	6	1339804.233	66.537	.000
RIVER	PROT	5548.762	1	5548.762	.276	.600
RIVER	ELEV	1953303.112	1	1953303.112	97.004	.000
RIVER	PERIOD	561764.724	1	561764.724	27.898	.000
PROT	ELEV	2056723.600	1	2056723.600	102.140	.000
PROT	PERIOD	695027.235	1	695027.235	34.516	.000
ELEV	PERIOD	661032.808	1	661032.808	32.828	.000
Explained		41068132.288	16	2566758.268	127.469	.000
Residual		6101304.699	303	20136.319		
Total		47169436.988	319	147866.574		

Variable: Manganese

Source of Variation		Sum of Squares	DF	Mean Square	F	Signif of F
Covariates		4434.122	6	739.020	7.867	.000
UREA		45.434	1	45.434	.484	.487
TSP/SSP		345.154	1	345.154	3.674	.056
MP		202.041	1	202.041	2.151	.144
MANURE		2310.654	1	2310.654	24.597	.000
ZINC		78.067	1	78.067	.831	.363
ASH		31.630	1	31.630	.337	.562
Main Effects		14501.870	4	3625.468	38.594	.000
RIVER		1215.559	1	1215.559	12.940	.000
PROT		3088.952	1	3088.952	32.882	.000
ELEV		10417.654	1	10417.654	110.897	.000
PERIOD		1313.311	1	1313.311	13.980	.000
2-way Interactions		14042.647	6	2340.441	24.914	.000
RIVER	PROT	20.905	1	20.905	.223	.637
RIVER	ELEV	86.202	1	86.202	.918	.339
RIVER	PERIOD	3469.211	1	3469.211	36.930	.000
PROT	ELEV	6070.304	1	6070.304	64.619	.000
PROT	PERIOD	2.644	1	2.644	.028	.867
ELEV	PERIOD	1376.067	1	1376.067	14.648	.000
Explained		108992.279	16	6812.017	72.515	.000
Residual		28463.768	303	93.940		
Total		137456.047	319	430.897		

Annex 8 (Continued)

Variable: Zinc

Source of Variation		Sum of Squares	DF	Mean Square	F	Signif of F
Covariates		62.576	6	10.429	5.510	.000
UREA		8.171	1	8.171	4.317	.039
TSP/SSP		.546	1	.546	.289	.592
MP		.687	1	.687	.363	.547
MANURE		10.930	1	10.930	5.774	.017
ZINC		19.880	1	19.880	10.504	.001
ASH		.383	1	.383	.203	.653
Main Effects		110.376	4	27.594	14.579	.000
RIVER		38.824	1	38.824	20.512	.000
PROT		28.357	1	28.357	14.982	.000
ELEV		17.939	1	17.939	9.478	.002
PERIOD		.293	1	.293	.155	.694
2-way Interactions		148.266	6	24.711	13.056	.000
RIVER	PROT	3.123	1	3.123	1.650	.200
RIVER	ELEV	48.504	1	48.504	25.627	.000
RIVER	PERIOD	17.229	1	17.229	9.103	.003
PROT	ELEV	52.382	1	52.382	27.675	.000
PROT	PERIOD	.022	1	.022	.012	.914
ELEV	PERIOD	9.204	1	9.204	4.863	.028
Explained		515.106	16	32.194	17.009	.000
Residual		573.498	303	1.893		
Total		1088.604	319	3.413		

Variable: Conductivity

Source of Variation		Sum of Squares	DF	Mean Square	F	Signif of F
Covariates		1.527	6	.255	7.744	.000
UREA		.007	1	.007	.215	.643
TSP/SSP		.129	1	.129	3.916	.049
MP		.125	1	.125	3.807	.052
MANURE		1.104	1	1.104	33.580	.000
ZINC		.079	1	.079	2.415	.121
ASH		.042	1	.042	1.264	.262
Main Effects		1.180	4	.295	8.978	.000
RIVER		.011	1	.011	.345	.557
PROT		1.043	1	1.043	31.728	.000
ELEV		.018	1	.018	.538	.464
PERIOD		.321	1	.321	9.772	.002
2-way Interactions		4.075	6	.679	20.662	.000
RIVER	PROT	1.652	1	1.652	50.257	.000
RIVER	ELEV	.004	1	.004	.122	.727
RIVER	PERIOD	1.981	1	1.981	60.283	.000
PROT	ELEV	.003	1	.003	.079	.778
PROT	PERIOD	.042	1	.042	1.277	.259
ELEV	PERIOD	.000	1	.000	.006	.936
Explained		8.515	16	.532	16.192	.000
Residual		9.959	303	.033		
Total		18.473	319	.058		

Annex 9

Correlation Matrices for Soil Nutrients, CIP.

A. Between soil nutrients

	pH	OM	Ca	Mg	K	N
pH	1.0000	.5889**	-.0591	.2225**	-.4476**	-.2671**
OM	.5889**	1.0000	-.0561	.0004	-.2841**	-.1158
Ca	-.0591	-.0561	1.0000	.5017**	.3135**	.2701**
Mg	.2225**	.0004	.5017**	1.0000	-.1704*	-.1585*
K	-.4476**	-.2841**	.3135**	-.1704*	1.0000	.8066**
N	-.2671**	-.1158	.2701**	-.1585*	.8066**	1.0000
P	-.2270**	-.1058	.3381**	-.1745**	.8338**	.7886**
S	-.3826**	-.2243**	.4379**	-.0913	.8911**	.8175**
B	-.3063**	-.2035**	.3312**	-.2185**	.6794**	.6390**
Cu	-.5965**	-.4034**	.1758**	-.2296**	.5460**	.3681**
Fe	.2409**	.2003**	-.2004**	.1815**	-.2649**	-.1472*
Mn	-.1581*	-.2408**	.2954**	.6120**	-.0044	.0224
Zn	-.3834**	-.2304**	.3242**	.1721*	.3227**	.0255
EC	-.2453**	-.1705*	.1692*	-.0342	.6541**	.4145**

	P	S	B	Cu	Fe	Mn
pH	-.2270**	-.3826**	-.3063**	-.5965**	.2409**	-.1581*
OM	-.1058	-.2243**	-.2035**	-.4034**	.2003**	-.2408**
Ca	.3381**	.4379**	.3312**	.1758**	-.2004**	.2954**
Mg	-.1745**	-.0913	-.2185**	-.2296**	.1815**	.6120**
K	.8338**	.8911**	.6794**	.5460**	-.2649**	-.0044
N	.7886**	.8175**	.6390**	.3681**	-.1472*	.0224
P	1.0000	.8427**	.6472**	.4773**	-.0697	-.0560
S	.8427**	1.0000	.6856**	.4586**	-.2863**	.0005
B	.6472**	.6856**	1.0000	.4965**	-.3619**	-.1990**
Cu	.4773**	.4586**	.4965**	1.0000	-.2154**	-.0058
Fe	-.0697	-.2863**	-.3619**	-.2154**	1.0000	.4300**
Mn	-.0560	.0005	-.1990**	-.0058	.4300**	1.0000
Zn	.2188**	.2965**	.1986**	.3288**	-.1792**	.1599*
EC	.5834**	.4944**	.4434**	.3033**	-.1016	.0310

	Zn	EC
pH	-.3834**	-.2453**
OM	-.2304**	-.1705*
Ca	.3242**	.1692*
Mg	.1721*	-.0342
K	.3227**	.6541**
N	.0255	.4145**
P	.2188**	.5834**
S	.2965**	.4944**
B	.1986**	.4434**
Cu	.3288**	.3033**
Fe	-.1792**	-.1016
Mn	.1599*	.0310
Zn	1.0000	.3998**
EC	.3998**	1.0000

N of cases: 320   1-tailed Significance: * - .01 ** - .001

Annex 9 (Continued)

B. *Between soil nutrients and rates of fertilizer application*

	Urea	*TSP*	*MP*	*Manure*	*Zinc*	*Ash*
pH	.4698**	.0506	.0180	-.1742**	.1352*	-.2693**
OM	.1349*	-.0724	-.0873	-.1795**	.0027	-.1877**
Ca	.3234**	.5418**	.4705**	.2630**	.2639**	.1129
Mg	.2102**	.0824	-.0083	.6819**	.3814**	-.1102
K	.0468	.4237**	.4387**	.0383	-.1305*	.0767
N	.1613*	.4545**	.4238**	-.0187	-.0663	-.0194
P	.2436**	.5265**	.5213**	-.1447*	-.1206	-.0425
S	.0901	.4543**	.4494**	.0339	-.1517*	.0687
B	.1572*	.5095**	.4945**	-.2256**	-.1119	-.0209
Cu	-.3683**	.0654	.1083	-.0075	-.2212**	.1562*
Fe	.1463*	-.1811**	-.2073**	-.0629	-.0656	.1025
Mn	.0240	-.0838	-.0870	.6566**	.2083**	.0977
Zn	-.1293	.1032	.1455*	.2061**	-.0426	.0546
EC	.1625*	.3362**	.3665**	.0490	-.1036	-.0345

N of cases: 320 1-tailed Significance: * - .01 ** - .001

C. *Between rates of fertilizer applications to sampled areas*

	Urea	TSP	MP	Manure	Zinc	Ash
Urea	1.0000	.7748**	.7598**	-.1660*	.2521**	-.0626
TSP	.7748**	1.0000	.9328**	-.1776**	.3019**	.0966
MP	.7598**	.9328**	1.0000	-.1581*	.1679*	.1098
Manure	-.1660*	-.1776**	-.1581*	1.0000	.2282**	-.0679
Zinc	.2521**	.3019**	.1679*	.2282**	1.0000	-.0694
Ash	-.0626	.0966	.1098	-.0679	-.0694	1.0000

N of cases: 320 1-tailed Significance: * - .01 ** - .001