

**EVALUATION OF SOIL SALINITY PROBLEMS ASSOCIATED WITH  
SUGARCANE PRODUCTION UNDER IRRIGATION AT TANGANYIKA  
PLANTING COMPANY (TPC) ESTATES, MOSHI**

**BY**



**ANTERY ANTONY KIWALE**



**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE  
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## ABSTRACT

In Tanzania the problem of salinity and sodicity is common and widespread especially in irrigation schemes, the Tanganyika Planting Company Ltd in Arusha Chini- Moshi (TPC) being one of them. A detailed study was carried out to investigate the distribution, origin and characteristics of salt affected soils in TPC. The objectives were to categorize the soils in terms of the salinity problem; to investigate the sources of salt accumulation and assess the quality of irrigation and underground waters in the study area.

A preliminary survey of the irrigated fields was done and experimental fields were selected on the basis of the available information, crop growth performance and visual appearance of soil and plants. Soil characterization was based on physical and chemical properties. Detailed laboratory characterization was done on the salt affected soils, irrigation and underground waters.

A soil morphology study revealed that the soils are young profiles, of deep alluvial deposits.

The soils were classified according to the FAO (1988) soil classification system and found to be Humic Cambisols; Eutric Gleysols and Calcic Fluvisols in South, North and West areas of TPC respectively.

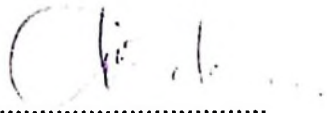
The main categories of soils in TPC were observed to be generally: Normal soils in north and west areas; Saline (fields 19A and 21d) and sodic (80%) soils in South area; Saline sodic soils in field R8 in West area.

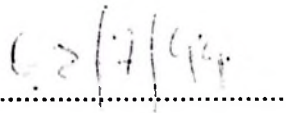
Kikuletwa river water showed a potential to cause soil salinity with electric conductivity values of 0.95 and 0.48 dS/m in first and second water sampling respectively. Ruvu and Weruweru waters were found to have medium and low salinity levels, values being 0.35,0.16 and 0.07,0.1dS/m respectively. As far as sodium content of water is concerned, all the three rivers were found to have low sodium. Values are 19.71, 11.9 and 3.33mg/kg in Kikuletwa, Ruvu and Weruweru rivers respectively.

Other causes of salts in TPC soils were found to be seepage from Kikuletwa river, high water tables and poor soil drainage.

**DECLARATION**

I, ANTERY ANTONY KIWALE, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work and that it has not been submitted, in whole or in part, for a degree in any other University.

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## **DEDICATION**

This dissertation is dedicated to my parents. My father Mr. Antony Kiwale and my mother Mrs. Jonofeva Antony, through whose love and tireless efforts I got my education.

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**ABBREVIATIONS**

|       |   |
|-------|---|
| TPC   | = Tanganyika Planting Company                             |
| B.D   | = Bulk density  |
| BS    | = Base saturation   |
| C     | = Clayey  |
| SC    | = Sandy clay  |
| SCL   | = Sandy clay loam   |
| LS    | = Loamy sand  |
| SiCL  | = Silt clay loam  |
| SiC   | = Silt clay   |
| SiL   | = Silt loam   |
| L     | = Loam  |
| CEC   | = Cation exchange capacity                                |
| DTPA  | = Diethylene triamine pentaacetic acid                    |
| EC    | = Electrical conductivity                                 |
| SAR   | = Sodium adsorption ratio                                 |
| ESP   | = Exchangeable sodium percent                             |
| FAO   | = Food and Agriculture organization of the United Nations |
| NORAD | = Norwegian Agency for Development co-operation           |
| O.C   | = Organic carbon  |

ppm = parts per million

USDA = United States Department of Agriculture

## CHAPTER ONE

### INTRODUCTION

The Sugar industry in Tanzania plays an important role in the national economy. At the national level, sugar production does not only earn the nation foreign currency, but also reduces the national expenditure on importing it. Tanzania exports 10,000 metric tons of sugar annually to European Economic Community (EEC). Molasses, an important by-product of sugar industry is widely used in the production of industrial ethyl alcohol and acetone (Ministry of Agriculture, 1993). The sugar industry in Tanzania also plays an important role in reducing unemployment problems (Senkoro, 1988). It employs more than 20,000 workers at national level. Tanganyika Planting Company alone employs more than 5000 people on permanent terms.

Decline in sugar production in Tanzania has caused concern to the government and researchers for a long time now. During 1992 production season, TPC recorded a decline in sugar production from 37,750 to 36,500 tones (Ministry of Agriculture, 1993). The causes for the ever decreasing sugar production in Tanzania and similar countries include decrease in soil fertility, low agricultural technology, increased land degradation which, together with the ever increasing unreliability of the rainfall, have contributed to the decrease in the acreage of potential agricultural land. One of the solutions which

Tanzania has adopted to solve the above mentioned problems is increased acreage through irrigated agriculture.

Currently production from the irrigated lands, which constitute about 17 percent of the total arable lands, accounts for 35 percent of the global food harvests (Rhoades *et al.*, 1992). Indeed many countries will adopt irrigated agriculture as the only reliable means to increase production on a sustainable basis. However, poorly designed and / or managed irrigation, is a major cause of salinisation and alkalization in developed and developing countries (Barrow, 1991).

In Tanzania, about 3.6 million hectares of land have salt problems of one type or another (Massoud, 1977). A report by De Pauw (1984) shows the occurrence of these soils to be most extensive in areas with arid and semi-arid climates where precipitation is usually insufficient to meet the evapotranspiration (ET) needs of plants. Since ET greatly exceeds precipitation most of the year, essentially no water percolates through the soil under natural condition. As a result, salts are not leached from the soil; instead they accumulate in the profile in amounts and / or types detrimental to plants. On irrigated lands salinisation is the major cause of the land being lost to production and is one of the most prolific adverse environmental impacts associated with irrigation (Dougherty and Hall, 1995).

Problems of salinity and sodicity of varying degrees are common in irrigation schemes of sugar estates such as Tanganyika Planting Company (TPC), Mtibwa and Kilombero. Others are rice irrigation schemes such as Lower Moshi, Ndungu, Ruvu and Kapunga. Salt affected soils cause considerable problems to the natural environment, the national economy and hinder agricultural production.

Despite the availability of ample literature with sound information on salt affected soils (Richards, 1954; Gupta and Gupta, 1987 and Sharma *et al.*, 1987), there are far too many failures of efforts to reclaim salt affected soils (Abrol *et al.*, 1988). These failures are largely due to lack of proper characterization of these soils and subsequent use of incorrect reclamation methods which result in losses of both money and potential increases in crop production (Abrol *et al.*, 1988). According to some reports there is a problem of salinity in soils of TPC (Kinyali, 1975; Frisby, 1979; Slood, 1987). However, some studies have been done mainly to improve soil physical properties (Slood, 1987). Studies have also been directed on ways of reclaiming salt affected soils at TPC (Kinyali, 1975; Slood, 1987). Unfortunately, comprehensive and systematic studies that include the identification and characterization of the salinity problem have not been undertaken at TPC. Consequently, information regarding the type of salinity, its distribution and origin of salts is lacking. This information would be of vital importance in planning and managing these soils. The general objective of the study therefore was to determine the extent of soil salinity problems affecting sugarcane production at TPC. The specific objectives were to:

- (i) Characterize the soils in terms of their physical and chemical properties.
- (ii) Categorize the soils in terms of the salinity problem.
- (iii) Determine the sources of salt in the study area
- (iv) Assess the quality of irrigation and ground waters.

## CHAPTER TWO

### 2.0.LITERATURE REVIEW

#### 2.1 General aspects of salt affected soils.

Researchers have defined salt affected soils based on their content of soluble salts in relation to plant growth. They have been defined as soils having excessive concentrations of soluble salts or adsorbed sodium or both (Reeve and Fireman, 1967); or those adversely modified for the growth of most crops by the presence or action of soluble salts (James *et al.*, 1982 and Arunin 1984) or those containing accumulated salts into the root zone to the level that affects crop yield (FAO, 1985). Salts occur in the soil in one of the following three forms: Salt ions dissolved in the soil water; cations adsorbed on the negatively charged surface of the soil particles, and precipitated salts (Smedema and Rycroft, 1983). The main ions found in the soil solution of salty soils are potassium, sodium, calcium magnesium, chloride, sulphate, carbonate, bicarbonate and nitrate (FAO, 1985).

According to Verhoeven (1972), soil salinity can be categorized into three classes as follows: Saline soils, sodic soils and saline-sodic soils. Saline soils are soils which have soluble salts in such quantity that they interfere with the growth of most crop plants. Sodic soils have sufficient exchangeable sodium to interfere with the growth of most crop plants, either with or without appreciable quantities of soluble salts. Saline-sodic soils are have sufficient exchangeable sodium to interfere with the growth of most crop plants and have

appreciable quantities of soluble salts. It is important to know the different categories of salt affected soils because the type and strategies for reclamation depend on the type of problem in question, that is, saline, sodic or saline – sodic.

## **2.2 Characteristics of salt affected soils**

The most important characteristics of salt affected soils are the physical and chemical characteristics.

### **2.2.1 Physical characteristics**

Saline soils are usually friable (Rhoades *et al.*, 1992). The presence of excess salts keeps the clay in saline soils in flocculated state (James *et al.*, 1982, Rhoades *et al.*, 1992). The permeability of these soils to water and air and other physical characteristics are generally comparable to those of normal soils (Abrol *et al.*, 1988). In the field, saline soils can be recognized by the spotty growth of crops and the presence of salty white crusts on the surface (Gupta and Gupta, 1987; Abrol *et al.*, 1988).

Sodic soils have columnar or prismatic structure in the B horizon (Raheje, 1966). Excess exchangeable sodium and high pH result in the dispersion of clay and the soils have an unstable structure (Abrol *et al.*, 1988; FAO, 1985). As the proportion of exchangeable sodium increases, the soils tend to become dispersed, less permeable to water and air (FAO, 1985), and physical properties of the soil become worse. The infiltration and

hydraulic conductivity decrease to the extent that little or no water movement occurs, the soil becomes plastic and sticky when wet, hard when dry and soil crusting develops (Allison, 1964; FAO, 1985). Dispersed organic matter may accumulate at the surface of poorly drained areas and impart a black color hence the common name "black alkali" (Bohn *et al.*, 1985).

The morphology, appearance and properties of saline-sodic soils are generally similar to those of saline soils, as long as excess salts are present and clays do not swell or become dispersed (Soil Survey Staff, 1951). When leached, the soluble salts are removed more rapidly than the exchangeable sodium. This causes conversion to sodic soils with all its attendant problems.

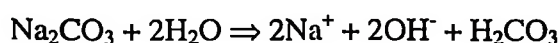
### **2.2.2 Chemical characteristics**

The most important chemical properties of salt affected soils are the pH, the electrical conductivity (EC<sub>e</sub>), the exchangeable sodium percentage (ESP), and the sodium adsorption ratio (SAR) of the saturation extract. These properties are widely accepted criteria for grouping salt affected soils into different categories (Gupta and Gupta, 1987; Abrol *et al.*, 1988; Rhoades, 1993).

Saline soils are dominated by neutral soluble salts consisting of chlorides and sulphates of sodium, calcium and magnesium (Abrol *et al.*, 1988). Sodium ion in saline soils seldom

comprises more than half of the soluble cations and, therefore it is not adsorbed to any significant extent in the soil exchange complex (Allison, 1964). However, in certain saline soils, sodium may become the most predominant adsorbed cation (Allison, 1964). The presence of compounds such as gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) and lime ( $\text{CaCO}_3$ ,  $\text{CaMg}(\text{CO}_3)_2$ ) in saline soils is common (James *et al.*, 1982). Saline soils have an electric conductivity of the saturated soil extract (ECe) of greater than 4 dS/m at 25°C and exchangeable sodium percent (ESP) of less than 15 (James *et al.*, 1982; Abrol *et al.*, 1988). The pH of the saturated soil paste is usually less than 8.5 (Rhoades *et al.*, 1992). According to Abrol *et al.* (1988), the pH for saline soils is less than 8.2. However, soils with a pH range of 7.5 to 8.5 have been included in the category of saline soils (Gupta and Gupta, 1987).

In sodic soils, sodium is the dominant soluble cation while the anions present consists mostly of chlorides, sulphates and bicarbonates with small to moderate amounts of carbonates depending on the pH of the soil (Allison, 1964). Raheje (1966) reported carbonate and bicarbonate to be the predominant anions in sodic soils. Sodic soils have ECe generally less than 4 dS/m at 25°C and the pH is more than 8.2 (Abrol *et al.*, 1988). The pH increases with increasing amounts of sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) and may be as high as 10 to 10.5. Increase in pH is due to the high solubility of sodium carbonate and therefore the greater potential for hydrolysis (Abrol *et al.*, 1988), as represented by the following chemical equation.



Gupta and Gupta (1987), reported the pH range of sodic soils in saturation extract to be 8.2 to 10.0 while that of soil water suspension (1:2) ranged from 9.0 to 10.8.

However, it has also been shown that a sodic soil does not necessarily have a high pH, but may even show an acidic reaction (Van Beek and Van Breemen, 1973).

In the saline-sodic soils, chlorides, sulphates and carbonates predominate while sodium and calcium occur in high and low proportions respectively (Raheje, 1966). Saline-sodic soils have been found to contain large quantities of both soluble sodium carbonate and exchangeable sodium (Abrol and Dahuja, 1974). Saline-sodic soils have ESP of greater than 15, ECe of greater than 4 dS/m at 25<sup>0</sup>C and pH which are usually less than 8.5 (James *et al.*, 1982; Gupta and Gupta, 1987). If gypsum is present in appreciable quantities, the pH of saline-sodic soils may be as low as 8.2 (Allison, 1964). ECe values greater than 2 dS/m and SAR greater than 15 were also reported by Bohn *et al.*, (1985) in this group of soils.

High salinity may also interfere with the growth and activity of the soil's microbial population and thus indirectly affect the transformation and availability of some essential plant nutrients. Nitrogen transformation reactions are most affected in this regard. Both nitrification and symbiotic N<sub>2</sub> fixation are reported to be reduced in saline soils due to toxic effects of salts on the bacteria which bring about these reactions (Gupta and Gupta, 1987).

Rai and Prasad (1991), worked with on the effect of soil salinity on soil microbes and

noted that *Azospirillum* spp. And their associates were adversely affected. Among salts tested, bicarbonates were the most toxic strains followed by sulphate and chloride.

## **2.3 Genesis of salt affected soils**

### **2.3.1 Origin of salts**

The primary source of salts in soil and waters is the ever-continuing geochemical weathering of rocks that form the upper strata of the earth's continental crust (Abrol *et al.*, 1988; Kenneth, 1990). Rock materials are highly variable in their elemental composition and some materials are higher in salts than others. Some of the elements contained in rocks are sodium, potassium, magnesium and calcium in the form of silicates; chlorides, sulphur, sulphides or sulphates are rarely encountered (Van der Molen, 1984). Shales, especially those of marine origin, can supply large quantities of soluble salts when traversed by water (Abrol *et al.*, 1988). Thus the kinds of geologic formations through which the drainage water passes significantly influence the composition and total concentration of salts. During the process of chemical weathering which involves hydrolysis, hydration, solution, oxidation, carbonation and other processes, the soil constituents are gradually released and made soluble (Van der Molen, 1984; Abrol *et al.*, 1988). Concomitantly, the salt constituents of the rocks are released and made soluble. The reagents involved in geochemical weathering include atmospheric water, oxygen and carbon dioxide (Van der

Molen, 1984). Organic matter serves as a reducing agent and as a source of organic acids, which promote weathering and cation migration through complexation.

Salts released through weathering in the arid regions with limited rainfall are usually deposited at some depth in the soil profile. The depth depends on such factors as the water retention capacity of the soil, seasonal and maximum rainfall, etc. (Yaalon, 1965). If the salts are deposited beyond the rooting zone of most crops, they rarely affect the crops adversely unless they are redistributed and accumulate in the surface soil layers.

### **2.3.2 Factors influencing the accumulation of salts in soils**

The accumulation of salts in soils is influenced by many factors (Szabolcs, 1984). The most important ones are nature of parent materials (Dubey *et al.*, 1986; Sharma *et al.*, 1987), climate (Kenneth, 1990), topography and drainage (Landon, 1984), surface water, chemical composition and depth of ground water table, capillary rise of water table (Yadav and Pathak, 1967; Bhargava *et al.*, 1981), irrigation (James *et al.*, 1982; Szabolcs, 1984), and nature of the characteristics of the soil (Soil Survey Staff, 1951).

#### **2.3.2.1 Climate**

The intensity and extent of the weathering reactions strongly reflect the influence of climate although weathering is a universal and continuous process and it occurs

universally, (Kenneth,1990). The presence of water is most important to the weathering process. It serves as a reactant in mineral transformation and is a medium that transports dissolved and suspended matter from the system (Bresler *et al.*, 1982). The transport of the weathering products depends on sufficient rainfall to move the soluble salts through the surface soil into the ground water, eventually into rivers, and, ultimately, the oceans (Kenneth,1990).

On the other hand, during low precipitation there is high evaporation of water which causes salts to remain in the soil (Van der Molen, 1984). Saline and sodic soils occur in areas with an annual average precipitation of less than 500mm (James *et al.*,1982)

### **2.3.2.2 Topography and drainage**

The slope of the land surface determines the drainage pattern, hence, the distribution of salts on the land surface (Chapman, 1966). The work by Ballantyne (1963) revealed that there is a definite increase in salt content and in water soluble sodium and magnesium percentage where the slope changes from 8 to 2%. According to Abrol *et al.*, (1988), soluble salts move from higher to lower elevations where they accumulate.

Restricted drainage is a factor that usually contributes to the salinization of soils and it may involve the presence of a high ground water table or low permeability of soil or both (Hesse, 1971).

### 2.3.2.3 Soil characteristics

A soil that initially possesses a high proportion of clay or silt as compared to sand fraction, will be much more unsatisfactory in the presence of sodium and magnesium. It is also more difficult to remove the excess alkali from such soils (Chapman, 1966). Therefore, unfavorable soil texture or structure or presence of indurate layers could affect soil permeability resulting into poor soil drainage, hence contributing to salinization (Richards, 1954).

Slight differences in texture in the soil may result in unequal movements of salt water and hence cause or result into large differences in salt accumulation (Soil Survey Staff, 1951). Smectites account for the high CEC in the soil. According to Van Hoorn (1971), the higher the CEC the greater is the risk of salinization and alkalization in the presence of water rich in salts.

### 2.3.2.4 Water

Rhoades *et al* (1992) reported that the common source of salts in soils is surface and ground waters. Both of them contain dissolved salts, the concentration of which depends upon the salt content of the soil and geologic materials with which the water has been in contact (Richards, 1954). Surface water adds salts to soils under natural conditions by flooding low lying areas (Arar, 1971). In many areas, saline and fresh subsurface waters exist in close proximity. When fresh ground water is pumped from aquifers that are in

hydraulic connection with sea water, the change in gradient as a result of pumping may result in a flow of salt water from the sea towards the well. Salt transport and accumulation is greatly influenced by the phenomena of seepage and capillary rise (Arar, 1971). The ground water rises sharply soon after intensive irrigation or rainfall and drops back very slowly, hence causing soil salinisation through capillary action (Arar, 1971). This is especially true of arid climates where there is low rainfall and high evaporation. Ground water is not recharged so frequently as in humid climates. The nearer to the surface is the ground water table, the greater is the chance of salinization to occur (Chang *et al.*, 1985). Where water table exists within 1.2 to 1.5m of the soil surface there is a likelihood of development of saline soils because of upward movement of saline ground water and its subsequent evaporation (Richards 1954; Allison, 1964)

The quality of surface and ground waters is an important consideration in any appraisal of salinity or alkalinity in an irrigated area (Arar, 1971; Gupta and Gupta, 1987). Both the total concentration and the type of constituent ions must be evaluated. The most common cations in irrigation waters are  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$  and  $\text{K}^+$ , while the most important anions are  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ , and  $\text{CO}_3^{2-}$ . The most important water quality parameter is the water's total salt concentration, most commonly measured as the electrical conductivity (EC).

Water quality or suitability is judged on the potential severity of problems that can be expected to develop during long term use (FAO, 1985). The problems that result vary both

in kind and degree and are modified by soil, climate and crop, as well as by the skill and knowledge of the water user. In this respect, there is no set limit on water quality, rather its suitability for use is determined by the conditions of use which affect the accumulation of the water constituents and which may restrict crop yield (FAO, 1985). However, there have been a number of different useful water quality guidelines related to irrigated Agriculture. Unfortunately, none has been entirely satisfactory because of the wide variability in field conditions (FAO, 1985). Based on the electrical conductivity of water, Richards (1952), established four classes of salinity hazard. Accordingly, water with EC values of 0.1 to 0.25, 0.25 to 0.75, 0.75 to 2.25 and 2.25 to 5 dS/m is regarded as low, medium, high and very high salinity water respectively. Gupta (1979), established the following water salinity categories: normal (0.2-1.5 dS/m), low (1.5-3 dS/m), medium (3-5 dS/m), high (5-10) and very high salinity water (>10) dS/m. FAO, (1985), suggested more practical values for evaluating and managing water quality related problems of irrigated agriculture as being < 0.7, 0.7-3 and >3 dS/m for none, slight to moderate and severe salinity water respectively. The specific ion of most concern to general water quality appraisal is sodium. The sodium adsorption ratio (SAR) is the best known index for irrigation water sodium hazard (Bresler *et al.*, 1982). FAO (1985), established sodicity hazard categories based on the SAR of the irrigation water as being none (< 3), slight to moderate (3-9) and severe (>9). Richards (1954), considered water with SAR values of 0-10, 10-18, 18-26 and 26-31 to be low, medium, high and very high sodicity water respectively.

FAO (1985) evaluated the quality of irrigation water based on the bicarbonate and chloride content. Waters having bicarbonates below 1.5, 1.5 to 8.5 and above 8.5 m/l were considered as none, slight to moderate and severe hazard water respectively, while waters having chloride ions below 4, 4-10 and above 10 mg/l, were regarded as none, slight to moderate and severe water respectively.

#### **2.3.2.5 Man**

Soils made saline by mankind are of major historic and economic importance (Kenneth, 1990). In the past, saline and alkaline soils were most often formed as a result of salt accumulation due to natural causes such as floods, impaired drainage and the evaporation of salty ground waters (Reeve and Fireman, 1967). In recent centuries, vast areas of salt affected soils have developed from man made causes such as industrialization and irrigation (Kenneth, 1990). Industrialization has increased the atmospheric loading of gaseous nitrogen and sulphur component both of which increase the salt concentration in the atmosphere and result in acidic fallout, which intensifies the soil mineral weathering rate (Kenneth, 1990). Energy related mining activities have in some places brought to the surface saline and sodic materials, which had they been left in the ground , would have had little effect on the environment (Kenneth, 1990). On the other hand, irrigation has a dramatic effect on the introduction of salts to the terrestrial system. All irrigation waters contain salts in varying amounts and differing types (Rhoades *et al.*, 1992). During evapotranspiration, essentially pure water is used by the plant and the salt that is left behind

is added to the salt already present in the rhizosphere (Kenneth, 1990). Among all factors which influence salinization of soils, irrigation alone accounts for the formation of many millions of hectares of saline or alkaline soils in different parts of the world (Szabolcs, 1984). More specifically irrigation adds salts to soils through:

(1) Saline seeps. These are a result of excessive leaching that results from reduced evapotranspiration, usually after changes in land use e.g. from a natural forest vegetation to a cereal grain crop or a shift in cropping pattern such as the introduction of a fallow season in a grain farming system (Bressler, 1982). The percolating water may pass through saline sediments. When such water is intercepted by impermeable horizontal layers, it is conducted laterally to landscape depressions causing extensive soil salinization (Doering and Sandoval, 1976).

(2). Transportation of water from over-irrigated areas and seepage water from irrigation channels to poorly irrigated areas. These new additions to the ground water will raise the subsoil water level or may form a perched water table (Bressler, 1982). Once the water table is within 1 to 2 m of the soil surface it contributes significantly to evaporation from the soil surface and therefore to root zone salinisation. The severity of the salinisation problem which may result depends on the salinity status of the ground water (Bressler, 1982).

(3). Under-irrigation. Under-irrigation especially with relatively saline irrigation water can also result in salt accumulation in soils. In this case, the salt accumulation occurs as the salt concentration of the soil solution is increased when water is removed during plant

growth. Such accumulations can be avoided by adopting irrigation regimes which include periodic irrigation with water in excess of plant needs, in order to leach accumulated salts from the root zone (Bressler, 1982).

## **CHAPTER THREE**

### **3.0. MATERIALS AND METHODS**

#### **3.1 The environment of the studied area**

##### **3.1.1 Location and Topography**

TPC is located in Arusha chini Moshi-rural district, Kilimanjaro region (Fig.1). It lies approximately between latitude  $30^{\circ}32'$  south of the equator and longitude  $37^{\circ}20'$  east of Greenwich. The altitude of the central factory area is around 700 m above sea level. The whole of the estate area declines gently (1%) towards the south.

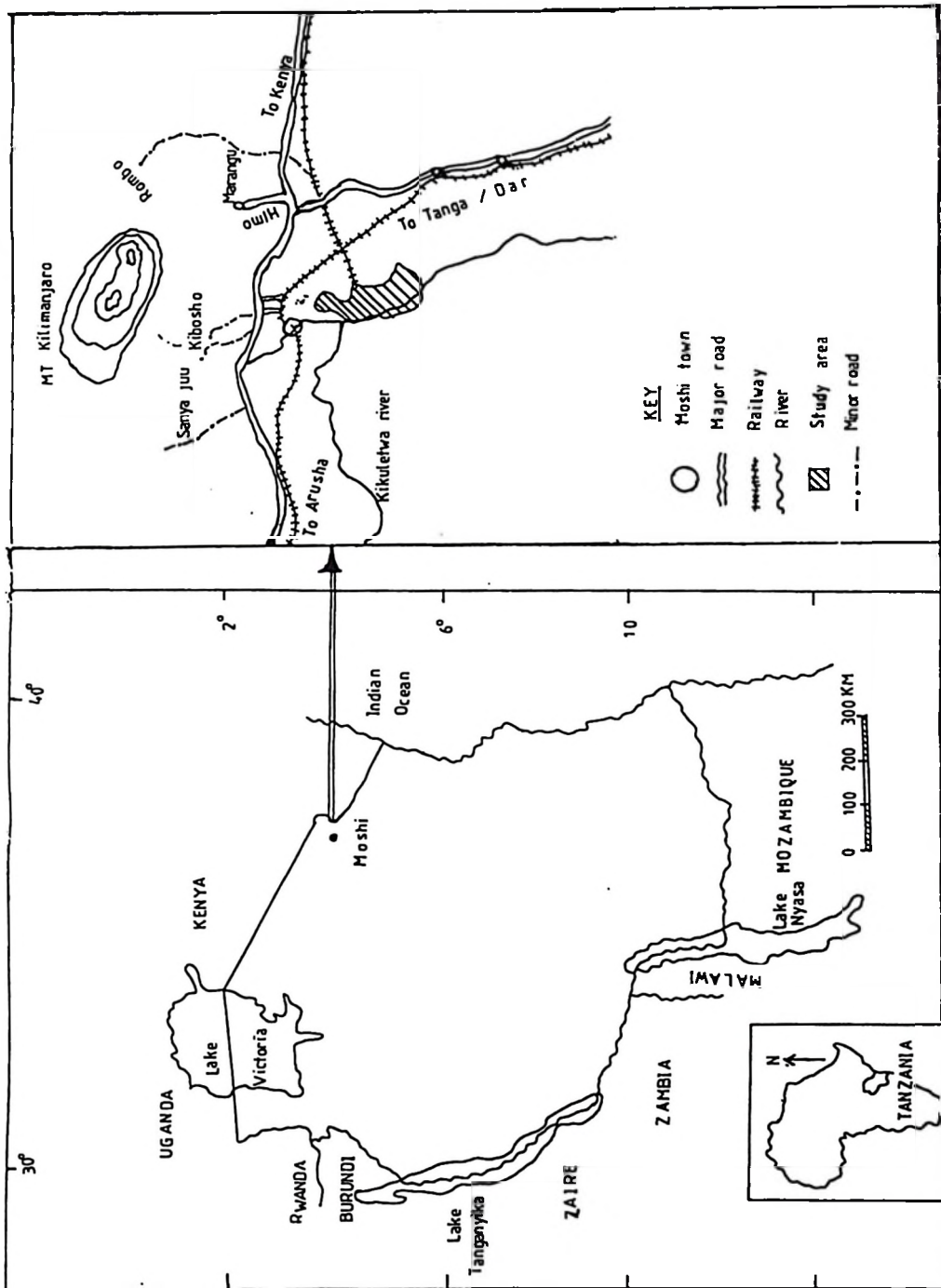


Figure 1: Location of the study area

### **3.1.2 Geology**

The soil is a mixture of fluvial, lacustrine and eolic (ash) sedimentation (Sloot, 1987). The origin is volcanic, from the Kilimanjaro mountain in the north. The eroded materials have been deposited relatively recent. The East African soil map indicates them as being quaternary sediments. The volcanic material was brought down from the slopes of the Kilimanjaro by air and water. It is assumed that the alluvium filled up an old lake or swamp which existed in between the Lelatema mountains in the west and the Pare mountains in the east. The differences in soil type are mainly due to variations in parent material and the different ways of transport and deposition. Time has been too short to significantly influence the soil profile. The horizontal strata that can be found are the results of volcanic outbursts (ashes and tuffs) or fluvial and lacustrine sedimentation. The hardpans found on the estate show more signs of vertical migration of soil particles.

### **3.1.3 Drainage pattern**

The drainage pattern is sub-parallel. Most rivers flow in a north-south direction with the exception of the spring fed Kikuletwa which flows eastwards to join the Weruweru at the border of the estate. The Weruweru, Rau and Pangani have dissected the plain by rather deep canyons which become less pronounced towards the south. The whole area in between the mountain area of Kilimanjaro, Pare and Lelatema drains on the Pangani river. There are signs of underground water flows to the estate, i.e. seepage from the mountain

slopes, resulting in the natural springs of Miwaleni and Kikuletwa. With the prevailing climatic condition of TPC, seepage can easily be associated with dangers of salinisation.

#### **3.1.4 Climate**

The climatic data of the study area (TPC) is presented in Figure 2a, 2b and Appendix 1. The area experiences low rainfall which is unevenly distributed and cannot suffice the high water demanding Sugarcane crop. Therefore irrigation becomes imperative. The mean annual precipitation averages about 540mm. There are two rainy seasons. The long season extends between March and May while the short one is experienced between November and December. The period extending from June to October is dry in most years. However, it is important to note that considerable differences occur within the large area of the estate. Northern fields are usually wetter and may receive rainfall as high as 700 mm/year, whereas areas in the far Southeast may get hardly half of it. As far as climate is concerned, moisture, temperature and light are the principal factors that affect sugarcane growth (Humbert, 1968).

Mean annual temperature is 24.6°C. Sunshine hours range from 5.3 in July to 8.7 per day in January. Optimum temperatures for sugarcane production is 28-30°C which at TPC is often reached. Light is also not a restricting factor except during the rainy months.

Temperature plays an important role in salinity build-up and leaching (Sloot, 1987). The prolonged dry period in TPC, likely aggravates the salinity problem due to high evaporative demand. It is also the very period when salts are added to the soil by irrigation.

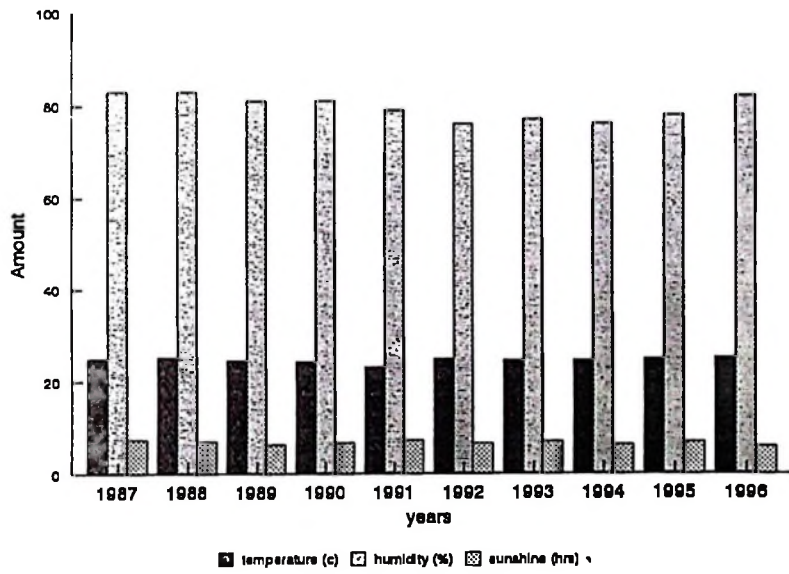
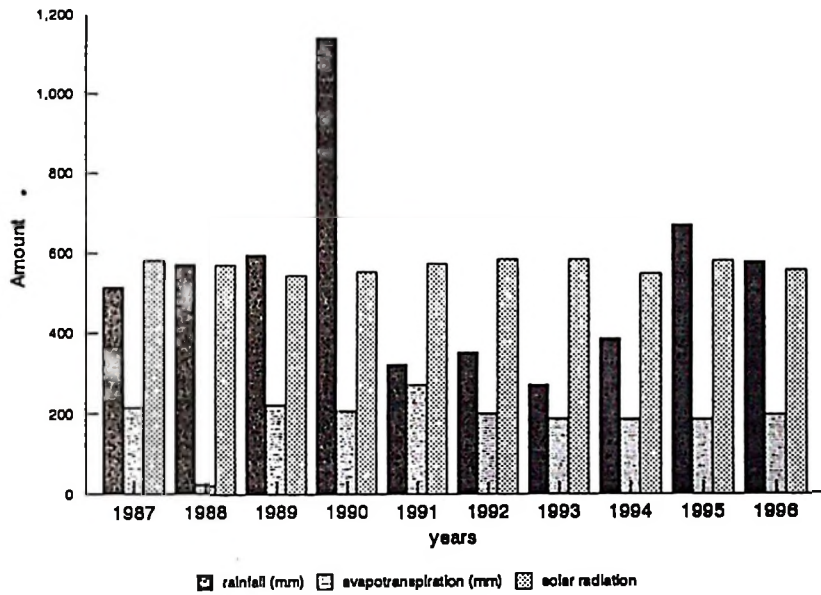


Figure 2:TPC climatic data

### **3.1.5 Vegetation**

The natural vegetation is an open woodland savannah with some areas covered with shrubs. Towards the south the vegetation changes from savannah bush into a typical salt-bush. The dominant species are *Acacia Zanthropica*, *Eleusina Indica* and *Setaria Verticillata*.

## **3.2 The field work**

### **3.2.1. Site selection**

The available information of TPC fields (Sloot, 1987), coupled by a preliminary survey of the irrigated fields were used to select experimental fields. The basis used were crop growth performance, and visual appearance of soil and plants. The fields affected by salts were recognized by the presence of white crusts on the surface and spotty growth of crops. Sugarcane growth on the salt affected fields appeared to be stunted and the leaves were generally smaller and darker green in color than the normal leaves. According to these criteria, the southern area of the TPC fields was observed to be more severely affected whereas the eastern and western areas were moderate and the northern area was low. In each of the three categories (severe, moderate, low) ten fields from each area (appendix.2) were selected by judgement sampling technique. One field (Donga A in south area) which has never been under production was also sampled for comparison.

### **3.2.2 Soil sampling and profile description**

#### **(i) Composite samples**

Soil sampling was done randomly by using an auger at 0-30cm, 30-60cm and 60-90cm depths. Each field was represented by one composite sample made up of 18 thoroughly mixed sub-samples.

#### **(ii) Profile samples**

Selection of soil profile locations was done based on the existing soil information (Sloot, 1987) coupled with auger observations. Three representative profiles, one from each area (severe, moderate, low) were then dug for soil characterization. The profiles were designated as TPC.SP, TPC.EWP and TPC.NP in South, Central and North areas respectively and described according to FAO (1990). Disturbed and undisturbed soil samples were collected from each horizon for bulk density determination and soil classification purposes in accordance with the guidelines laid down by FAO, (1979).

### **3.3. Sampling of water from the irrigation sources**

Water samples were taken from the rivers used for irrigation at two periods of the year so as to cover the distinctive periods of the year with respect to the water volume in the drainage system. The 1<sup>st</sup> sampling was done in December during the heavy rains while the 2<sup>nd</sup> one was done in April in the dry season. The water samples were refrigerated at about 4°C until analysis. They were analyzed for  $K^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Na^+$ ,  $CO_3^{2-}$ ,  $HCO_3^-$ ,  $SO_4^{2-}$ ,  $Cl^-$

and  $\text{NO}^-$ . Also determined were the indicators of irrigation water quality, being electrical conductivity (EC), sodium adsorption ratio (SAR), and residual sodium carbonate (RSC) Gupta and Gupta, (1987).

### **3.3. Physical and chemical characterisation of the soils**

The parameters analyzed for and the methods used are given in Tables 1 and 2.

### **3.4. Soil classification**

The studied soils as presented in table 6, were classified using their physical, chemical and morphological characteristics in accordance with the principles established by FAO (1988) and USDA (1990). They were also categorized in terms of types of salt effects following the criteria established by Richards (1954).

**Table 1: Methods used for physical and chemical analysis of the soils.**

| S/No | Parameter   | Method of analysis  | Reference                    |
|------|---|---|------------------------------|
| 1.   | Particle size analysis  | Hydrometer method   | Juo (1979)                   |
| 2.   | Bulk density  | Metallic core procedure   | Blake and Hartage (1986)     |
| 3.   | Soil pH   | Potentiometric, using glass electrode pH meter in 1:2.5 soil water suspension   | Mclean (1982)                |
| 4.   | Sulphate (SO <sub>4</sub> <sup>2-</sup> ) anions  | Turbidimetric method  | Bower and Wilcox, (1965)     |
| 5.   | Carbonate (CO <sub>3</sub> <sup>2-</sup> ) and bicarbonate (HCO <sub>3</sub> <sup>2-</sup> ) anions | Titrimetric using a known volume of the extract with standard sulphuric acid (H <sub>2</sub> SO <sub>4</sub> )        | Richard (1954)               |
| 6.   | Chloride (Cl <sup>-</sup> ) anions  | Titrimetric using the same sample used 5 above; with silver nitrate solution  | Hesse (1971)                 |
| 7.   | K <sup>+</sup> , Ca <sup>2+</sup> , Mg <sup>2+</sup> , Na <sup>+</sup>                              | In neutral ammonium acetate extract, then determined by atomic absorption spectrophotometer                           | National Soil Service (1987) |
| 8.   | Cation + exchange capacity (CEC)  | Samples with pH < 7.5, by ammonium acetate saturation method; those with pH >7.5, by sodium acetate saturation method | Hesse (1971)                 |
| 9.   | Water soluble cations   | In distilled extract then determined by atomic absorption spectrophotometer   | Rhoades (1982)               |
| 10.  | Organic carbon  | Wet combustion  | Walkley and Black (1934)     |
| 11.  | Total N   | Semi-micro Kjeldahl procedure   | Bremner and Mulvaney (1982)  |
| 12.  | Available P   | Olsen method  | Olsen et al, 1954            |
| 13.  | Available Zn, Cu, Fe and Mn   | Extraction using DTPA and then determined by Atomic absorption spectrophotometer                                      | Lindsay and Norvel (1978)    |
| 14.  | Electrical conductivity   | Electric conductivity meter method  | Van Reeuwijk (1987)          |

**Table 2: Parameter and methods used for water analysis**

| S/N | Parameter   | Method of analysis  | Reference          |
|-----|---|---|--------------------|
| 1.  | PH  | Potentiometrically by pH-meter  | Mclean (1982)      |
| 2.  | Total soluble salts   | Electrical conductivity method  | Rhoades (1982b)    |
| 3.  | Soluble cations (Ca <sup>2+</sup> , Mg <sup>2+</sup> , Na <sup>+</sup> , K <sup>+</sup> ) | Atomic absorption spectrophotometer   | Rhoades (1982a)    |
| 4.  | Sodium adsorption ratio   | By calculation using the formula:<br>$SAR = \frac{Na^+}{((Ca^{2+} + Mg^{2+})/2)^{1/2}}$ | Bohn et al. (1985) |

## CHAPTER FOUR

### 4.0. RESULTS AND DISCUSSION

#### 4.1 Soil characterisation

##### 4.1.1 Soil morphological properties

Detailed information on the sites and representative soil profile descriptions and analytical data of TPC soils are presented in Table 3, and appendices 3.1, 3.2 and 3.3. The morphological characteristics of soils from all three areas indicate that they are deep and occupy the alluvial plain at the footslopes of mountain Kilimanjaro with a slope of less than 1% towards the south, and without surface stoniness or rock outcrops. The soils are young in which the development of genetic horizons has only just begun. In these relatively little weathered soils the influence of the parent material is still dominant. Allophane and weatherable primary minerals as forsterite as well as pyroxenes are still present (at least in the sub-soil) (Sloot, 1987). Sodium and potassium contents are very high (usually in the form of feldspars) which also corresponds closely to the alkaline, volcanic and pyroclastic parent material. The soils are mainly brown alluvials with a texture varying from clay loam, silt clay and silt clay loam to sand clay loam in few fields. The problem of hardpan was noticed in profile TPC.SP located in the south area. At the depth of 70 – 95cm, the presence of hardpan or duripan is a result of salt accumulation in the soil and hence of retarded plant growth. This observation is consistent with findings by Sloot (1987), who pointed out that hardpan or duripan extends over an area of approximately 1,000 ha of

cultivated land, mainly in the east and south areas of TPC. The most probable cause of the hardpan is associated with mineralogical composition of the soil (Moberg, 1981). The relatively high contents of allophane, Zeolite and silicates in the clay fraction and the high presence of Na - Ca feldspars in the sand fraction is the most striking difference between horizons closer to the surface. Silicate components of the hardpan have been brought in by water and, perhaps, ash deposition into a matrix of carbonates and K - feldspars. The cementing agents are mainly present in the form of allophane and Zeolite (Moberg, 1981).

**Table 3. Diagnostic features and horizons of the studied soils**

| Profile | Area  | Diagnostic features/properties  | Diagnostic horizon |
|---------|-------|---|--------------------|
| TPC.SP  | South | Sodic properties<br>Calcareous<br>(Ustic soil moisture regime)<br>Isohyperthermic soil temperature regime | Umbric A horizon   |
| TPC.NP  | North | Calcareous<br>(Ustic soil moisture regime)<br>Isohyperthermic soil temperature regime                     | Cambic B horizon   |
| TPC.EWP | West  | Calcareous Fluvic properties<br>(Ustic soil moisture regime)<br>Isohyperthermic soil temperature regime   | Ochric A horizon   |

#### **4.1.2 Soil physical properties**

The data pertaining to laboratory soil physical properties for the profiles studied are indicated in Appendix 3 and their trend with soil depth for all the three profiles is graphically presented in Figure 3. Physical properties for the auger samples from the sugarcane fields are given in Tables 4a, 4b and 4c.

#### **Soil texture**

Data from composite auger soil samples from the severely salt affected south area showed that about 60% of top soils (0-90) cm are clay loam while profile samples from the south (No.TPC.SP) were predominantly silt clay loam and silt loam. The soil separates that is, percentage sand, silt and clay generally varied in a non systematic manner with soil depth. Soils of North area which are represented by profile No.TPC.NP had their texture predominated by clay loam. Auger composite samples showed that this area has a texture varying from clay loam, silt clay, silt clay loam to loam and sand loam. There was no systematic trend on the change of the soil separates.

The moderately salt affected areas were represented by profile No TPC.EWP. The top soil was sand clay loam while it was loam sand in the sub surface horizon (75 cm). Auger composite samples showed that these soils are varying from clay loam and loam to silt clay and silt clay loam. Although Sugarcane grows in a wide range of soils, the loamy and clay

loamy soils provide the best rooting medium for this crop and it requires little management to minimise possible reduction in yields due to poor soil conditions (Yates, 1977; ILLACO, 1981). Therefore, generally TPC soils appear to have favourable soil texture for sugarcane. On the other hand, it is stated that a soil that initially possesses a high proportion of clay or silt as compared to sand fraction, will be much more unsatisfactory in the presence of sodium and magnesium. It is also more difficult to remove the excess alkali from such soils (Chapman, 1966). Therefore with TPC soils which are predominated by clay and silt fractions, it is likely that this texture is contributing high alkalinity problem.

### **Bulk density**

The results showing bulk density levels are indicated in appendix 3 and the variation with soil depth is graphically presented in Figure 3. It ranged from 1.01 to 1.7 g/cm<sup>3</sup>. In all the profiles bulk density increased with soil depth. This trend may be caused by decrease in soil organic matter with soil depth. Clay content does not seem to contribute significantly to this trend since it was changing in a non systematic manner with soil depth. Also it may be reflecting the effect of heavy agricultural machinery such as Camaco, (cane machinery construction) which performs various operations like deep ploughing, harrowing and loading. For sugarcane growth, bulk density values of less than 1.4 g/cm<sup>3</sup> are recommended (Trouser and Humbert, 1961). West and North areas which had low salinity status recorded relatively high bulk density values 1.55-1.7 g/cm<sup>3</sup>) as compared with South area which had high salt status. This is inconsistent with the results presented by Gupta and

Gupta (1987) showing that bulk densities of salt affected soils whether saline or alkaline are generally higher than in those of normal soils. It is because salt affected soils over a long period of time lie barren and uncared for (Gupta and Gupta, 1987). However, this reason can not be true for TPC soils since the land is continuously under production. Bulk density values between 1.4 and 1.6 g/cm<sup>3</sup> are critical for sugarcane growth for they limit plant root growth (Juang, 1972). Higher bulk densities in low and moderately affected areas (1.55-1.7 g/cm<sup>3</sup>) areas may limit plant root growth, aeration, water movement and drainage which have negative effect on yield and quality of sugarcane produced. Deep ploughing can improve soil aeration.

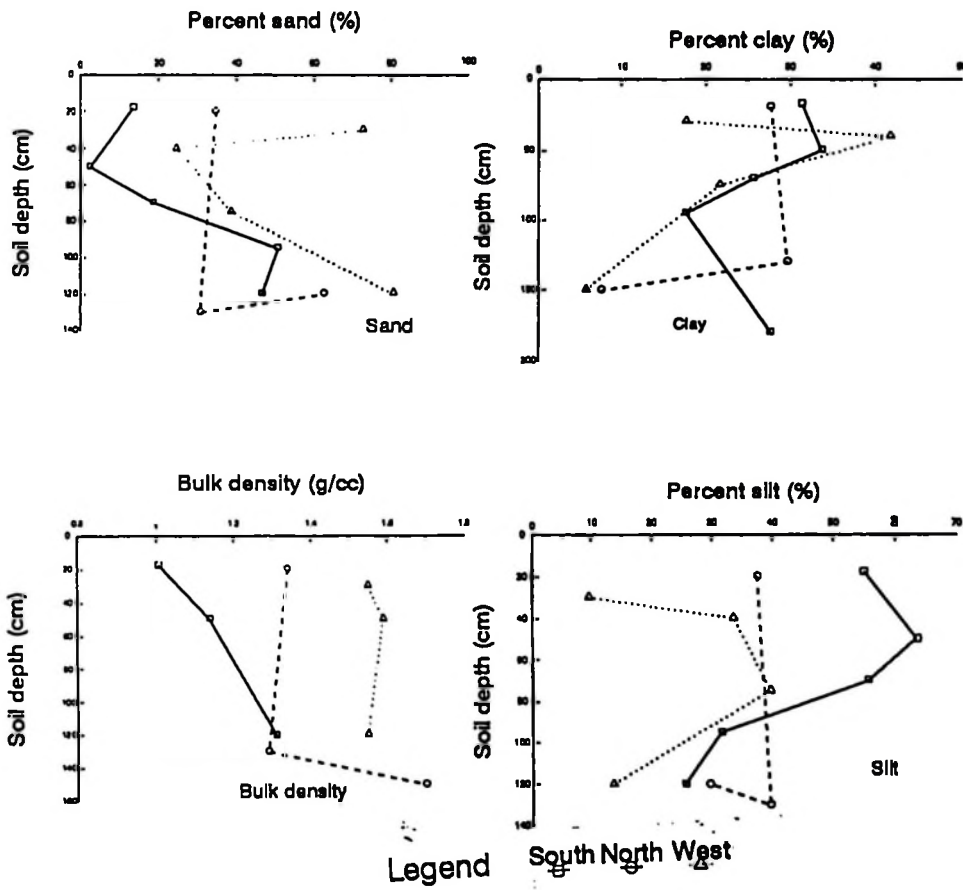


Figure 3. Particle size distribution and bulk density of the soil profiles

### 4.1.3 Soil chemical properties

Results showing some chemical data of composite auger soil samples are given in Tables 4a, 4b, 4c, 5a, 5b, and 5c. Selected chemical parameters for the profile samples are graphically presented in Figures 4 and 5.

Total nitrogen was rather low ranging from 0.001 - 0.18 %, 0.01 - 0.15 % and 0.001 - 0.12 % in severe, moderate and low salt affected areas respectively. Generally total N contents both in composite and profile samples decreased with depth, except for north and west profiles where the opposite trend was observed (Figure 4). The low content of total nitrogen in TPC is attributed to the highly sodic soils especially in South area. Sodic soils have generally low organic matter content (Rao and Batra, 1983). Furthermore, due to low infiltration rate the surface layers of these soils remain nearly saturated for prolonged periods following irrigation or rain resulting in temporary anaerobic conditions. This situation leads to elemental nitrogen losses through denitrification. Considerable losses of nitrogen in ammonia form also occur in these soils due to their high pH (Rao and Batra, 1983). Nitrogen is a very important nutrient for plant growth (ILLACO, 1981), and sugarcane is known to be a heavy feeder of this nutrient. Demeterio (1960), found that critical N concentration in soils for Sugarcane in Philippines was 0.3%. Therefore, for optimum production of Sugarcane in this estate, nitrogen should be supplied in form of fertilizers.

**Table 4a. Some physico-chemical properties of soils of south area**

| Field no | Depth (cm) | Soil separates (%) |       |       | Text. class | Olsen-P (mg/kg) | OC (%) | Total N (%) | ECe (dS/m) | pH (1:2.5) (H <sub>2</sub> O) |
|----------|------------|--------------------|-------|-------|-------------|-----------------|--------|-------------|------------|-------------------------------|
|          |            | Silt               | Clay  | Sand  |             |                 |        |             |            |                               |
| 12       | 0-30       | 27.76              | 24.3  | 47.94 | SCL         | 60.0            | 2.43   | 0.09        | 0.36       | 7.9                           |
|          | 30-60      | 53.2               | 31.56 | 15.24 | SiCL        | 16.2            | 1.39   | 0.08        | 0.27       | 8.0                           |
|          | 60-90      | 43.6               | 27.6  | 28.6  | CL          | 3.0             | 0.20   | 0.07        | 0.23       | 8.5                           |
| 10K      | 0-30       | 39.4               | 29.94 | 30.66 | CL          | 16.9            | 0.89   | 0.06        | 0.58       | 9.1                           |
|          | 60-60      | 19.4               | 41.94 | 38.66 | C           | 7.1             | 0.74   | 0.05        | 0.41       | 9.3                           |
|          | 60-90      | 31.76              | 32.3  | 35.94 | CL          | 6.8             | 2.11   | 0.02        | 0.37       | 9.5                           |
| 19A      | 0-30       | 35.2               | 35.56 | 29.24 | CL          | 34.9            | 1.32   | 0.08        | 6.68       | 7.5                           |
|          | 30-60      | 29.76              | 28.3  | 41.94 | CL          | 7.8             | 0.43   | 0.03        | 2.38       | 7.8                           |
|          | 60-90      | 37.4               | 31.94 | 30.66 | CL          | 3.5             | 0.63   | 0.001       | 1.25       | 8.3                           |
| 3C       | 0-30       | 45.76              | 36.3  | 17.94 | SiCL        | 26.0            | 1.85   | 0.06        | 0.37       | 8.2                           |
|          | 30-60      | 51.4               | 43.94 | 4.66  | SiCL        | 9.0             | 0.55   | 0.06        | 0.37       | 8.8                           |
|          | 60-90      | 27.4               | 25.94 | 46.66 | SCL         | 5.7             | 0.32   | 0.01        | 0.3        | 9.2                           |
| 4D       | 0-30       | 43.76              | 28.3  | 27.94 | CL          | 97.6            | 2.65   | 0.18        | 0.36       | 8.4                           |
|          | 30-60      | 51.04              | 37.22 | 11.74 | SiCL        | 55.6            | 0.47   | 0.08        | 0.4        | 8.7                           |
|          | 60-90      | 49.2               | 41.56 | 9.24  | SiC         | 15.2            | 0.32   | 0.08        | 0.46       | 7.6                           |
| 4F       | 0-30       | 23.2               | 23.56 | 53.24 | SCL         | 17.7            | 1.58   | 0.09        | 0.31       | 8.4                           |
|          | 30-60      | 33.04              | 31.22 | 35.74 | CL          | 8.6             | 0.43   | 0.04        | 0.32       | 8.7                           |
|          | 60-90      | 35.4               | 27.94 | 36.66 | CL          | 14.7            | 0.51   | 0.02        | 0.37       | 8.9                           |
| 6        | 0-30       | 41.2               | 31.56 | 27.24 | CL          | 80.8            | 1.74   | 0.13        | 0.39       | 8.5                           |
|          | 30-60      | 33.4               | 39.94 | 26.66 | CL          | 34.9            | 1.08   | 0.09        | 0.75       | 8.8                           |
|          | 60-90      | 41.4               | 27.94 | 30.66 | L           | 14.1            | 0.01   | 0.06        | 0.43       | 9.1                           |
| 21d      | 0-30       | 45.76              | 32.3  | 21.94 | CL          | 54.9            | 1.83   | 0.06        | 2.72       | 7.2                           |
|          | 30-60      | 43.4               | 29.94 | 26.66 | CL          | 20.6            | 0.47   | 0.04        | 4.6        | 7.3                           |
|          | 60-90      | 39.76              | 42.3  | 17.94 | C           | 21.8            | 0.47   | 0.02        | 2.88       | 7.8                           |
| G5       | 0-30       | 45.76              | 40.3  | 13.94 | SiL         | 75.9            | 1.20   | 0.09        | 0.29       | 8.1                           |
|          | 30-60      | 25.4               | 25.94 | 48.66 | SCL         | 66.9            | 1.08   | 0.06        | 0.28       | 8.2                           |
|          | 60-90      | 27.2               | 31.56 | 41.24 | CL          | 21.1            | 1.52   | 0.06        | 0.29       | 8.5                           |
| 15b      | 0-30       | 37.2               | 29.56 | 33.24 | CL          | 75.0            | 1.39   | 0.13        | 0.18       | 8.0                           |
|          | 30-60      | 37.76              | 24.3  | 37.94 | L           | 68.8            | 0.7    | 0.05        | 0.19       | 7.8                           |
|          | 60-90      | 33.76              | 28.3  | 37.94 | CL          | 33.1            | 0.32   | 0.02        | 0.1        | 7.5                           |
| Donga A  | 0-30       | 43.4               | 41.94 | 14.66 | SiC         | 33.4            | 1.35   | 0.08        | 1.0        | 8.8                           |
|          | 30-60      | 45.4               | 43.94 | 10.66 | SiC         | 12.7            | 0.82   | 0.05        | 1.86       | 8.1                           |
|          | 60-90      | 57.4               | 35.94 | 6.66  | SiCL        | 18.3            | 0.94   | 0.03        | 2.08       | 8.5                           |

**Table 4b. Some physico-chemical properties of soils of the North area**

| Field no | Depth (cm) | Soil separates (%) |       |        | Text. class | Olsen-P (mg/kg) | OC (%) | Total N (%) | ECe (dS/m) | pH (1:2.5) (H <sub>2</sub> O) |
|----------|------------|--------------------|-------|--------|-------------|-----------------|--------|-------------|------------|-------------------------------|
|          |            | Silt               | Clay  | Sand   |             |                 |        |             |            |                               |
| N3I      | 0-30       | 37.616             | 5.688 | 56.696 | SL          | 75.             | 1.39   | 0.06        | 0.11       | 7.8                           |
|          | 30-60      | 51.76              | 32.3  | 15.94  | SiCL        | 18.0            | 1.16   | 0.09        | 0.10       | 7.9                           |
|          | 60-90      | 21.2               | 17.56 | 61.24  | SL          | 17              | 0.85   | 0.001       | 0.09       | 7.4                           |
| N42      | 0-30       | 45.2               | 45.56 | 9.24   | SiC         | 89.8            | 1.65   | 0.09        | 0.15       | 7.0                           |
|          | 30-60      | 35.76              | 32.3  | 31.94  | CL          | 87.9            | 0.77   | 0.05        | 0.11       | 7.1                           |
|          | 60-90      | 29.76              | 34.3  | 35.94  | CL          | 78.1            | 0.7    | 0.04        | 0.11       | 7.1                           |
| N7I      | 0-30       | 37.04              | 35.22 | 27.74  | CL          | 46.9            | 1.27   | 0.34        | 0.14       | 7.1                           |
|          | 30-60      | 45.76              | 38.3  | 15.94  | SiCL        | 31.5            | 1.2    | 0.06        | 0.06       | 7.3                           |
|          | 60-90      | 17.2               | 25.56 | 57.24  | SCL         | 15.1            | 0.59   | 0.02        | 0.06       | 7.0                           |
| N66      | 0-30       | 39.2               | 37.56 | 23.24  | CL          | 54.7            | 1.16   | 0.07        | 0.05       | 6.8                           |
|          | 30-60      | 35.2               | 35.56 | 29.24  | CL          | 21.2            | 0.93   | 0.05        | 0.04       | 6.3                           |
|          | 60-90      | 25.76              | 34.30 | 39.94  | CL          | 4.4             | 0.77   | 0.03        | 0.03       | 6.4                           |
| N22      | 0-30       | 37.76              | 38.3  | 23.94  | CL          | 69.4            | 1.85   | 0.12        | 0.08       | 7.4                           |
|          | 30-60      | 37.2               | 37.56 | 25.24  | CL          | 22.8            | 1.08   | 0.05        | 0.06       | 7.7                           |
|          | 60-90      | 51.4               | 33.94 | 14.66  | SiCL        | 30.0            | 0.85   | 0.03        | 0.05       | 6.8                           |
| N60      | 0-30       | 15.2               | 33.56 | 53.24  | SCL         | 58.2            | 2.58   | 0.11        | 0.07       | 7.1                           |
|          | 30-60      | 37.4               | 39.94 | 22.66  | CL          | 52.0            | 0.97   | 0.08        | 0.09       | 7.3                           |
|          | 60-90      | 39.76              | 26.3  | 33.94  | L           | 49.5            | 0.51   | 0.02        | 0.25       | 6.6                           |
| N93      | 0-30       | 41.2               | 43.56 | 15.24  | SiC         | 91.4            | 1.31   | 0.08        | 0.07       | 6.9                           |
|          | 30-60      | 41.2               | 49.56 | 9.24   | SiC         | 82.4            | 0.59   | 0.06        | 0.04       | 6.7                           |
|          | 60-90      | 37.76              | 34.3  | 27.94  | CL          | 81.8            | 0.47   | 0.03        | 0.05       | 6.5                           |
| N51      | 0-30       | 48.04              | 47.22 | 4.74   | SiC         | 41.4            | 1.77   | 0.1         | 0.06       | 7.0                           |
|          | 30-60      | 45.76              | 50.3  | 3.94   | SiC         | 12.0            | 0.97   | 0.05        | 0.04       | 6.1                           |
|          | 60-90      | 25.2               | 21.56 | 53.24  | SCL         | 47.5            | 0.55   | 0.02        | 0.16       | 6.6                           |
| N80      | 0-30       | 23.2               | 27.56 | 49.24  | SCL         | 16.5            | 2.23   | 0.08        | 0.06       | 7.0                           |
|          | 30-60      | 31.2               | 27.56 | 41.24  | L           | 41.4            | 1.46   | 0.07        | 0.04       | 7.5                           |
|          | 60-90      | 23.2               | 29.56 | 47.24  | SCL         | 27.6            | 1.27   | 0.04        | 0.04       | 7.2                           |
| N100     | 0-30       | 31.04              | 17.22 | 51.74  | L           | 25.7            | 1.35   | 0.07        | 0.08       | 7.0                           |
|          | 30-60      | 45.2               | 47.56 | 7.24   | SiC         | 97.6            | 0.89   | 0.05        | 0.08       | 7.2                           |
|          | 60-90      | 47.2               | 49.56 | 3.24   | SiC         | 37.2            | 0.70   | 0.05        | 0.05       | 7.0                           |

**Table 4c. Some physico-chemical properties of soils of the East and West area**

| Field no | Depth (cm) | Soil separates (%) |       |       | Text. Class | Olsen-P (mg/kg) | OC (%) | Total N (%) | Ecc (dS/m) | pH (1:2.5) (H <sub>2</sub> O) |
|----------|------------|--------------------|-------|-------|-------------|-----------------|--------|-------------|------------|-------------------------------|
|          |            | Silt               | Clay  | Sand  |             |                 |        |             |            |                               |
| Q3       | 0-30       | 33.4               | 19.94 | 46.66 | L           | 15.1            | 1.62   | 0.15        | 0.13       | 7.5                           |
|          | 30-60      | 37.4               | 39.94 | 22.66 | CL          | 11.1            | 0.36   | 0.08        | 0.23       | 7.5                           |
|          | 60-90      | 45.04              | 27.22 | 27.74 | L           | 17.5            | 0.51   | 0.06        | 0.29       | 7.4                           |
| R3       | 0-30       | 45.76              | 36.3  | 17.94 | SiCL        | 53.9            | 0.7    | 0.13        | 0.66       | 7.2                           |
|          | 30-60      | 49.76              | 44.3  | 9.94  | SiC         | 2.6             | 0.7    | 0.05        | 0.6        | 7.1                           |
|          | 60-90      | 47.4               | 27.94 | 24.66 | CL          | 25.2            | 0.47   | 0.03        | 0.67       | 7.9                           |
| L4       | 0-30       | 43.2               | 35.56 | 21.24 | C           | 98.8            | 2.31   | 0.12        | 0.12       | 5.9                           |
|          | 30-60      | 35.4               | 15.94 | 48.66 | L           | 22.2            | 0.51   | 0.09        | 0.09       | 6.1                           |
|          | 60-90      | 43.2               | 27.56 | 29.24 | CL          | 30.3            | 0.78   | 0.07        | 0.06       | 5.9                           |
| R8       | 0-30       | 33.4               | 23.94 | 42.66 | L           | 15.5            | 1.16   | 0.11        | 7.56       | 9.5                           |
|          | 30-60      | 27.4               | 23.94 | 48.66 | SCL         | 26.1            | 0.55   | 0.08        | 1.88       | 8.9                           |
|          | 60-90      | 37.4               | 31.94 | 30.66 | CL          | 48.2            | 0.59   | 0.03        | 0.67       | 8.8                           |
| M6       | 0-30       | 45.2               | 33.56 | 21.24 | CL          | 98.5            | 2.00   | 0.16        | 0.14       | 6.9                           |
|          | 30-60      | 35.2               | 29.56 | 35.24 | CL          | 56.6            | 1.47   | 0.11        | 0.07       | 6.1                           |
|          | 60-90      | 45.2               | 29.56 | 25.24 | CL          | 22.5            | 1.12   | 0.11        | 0.08       | 6.5                           |
| KI       | 0-30       | 29.04              | 29.22 | 41.74 | CL          | 63.6            | 2.56   | 0.13        | 0.11       | 7.0                           |
|          | 30-60      | 29.76              | 26.3  | 43.94 | L           | 33.3            | 0.7    | 0.09        | 0.17       | 7.3                           |
|          | 60-90      | 41.76              | 26.3  | 31.94 | L           | 27.0            | 0.7    | 0.04        | 0.19       | 7.3                           |
| K8       | 0-30       | 31.2               | 27.56 | 41.24 | L           | 86.9            | 1.85   | 0.01        | 0.66       | 7.7                           |
|          | 30-60      | 31.76              | 26.3  | 41.94 | L           | 50.7            | 1.32   | 0.07        | 0.51       | 7.2                           |
|          | 60-90      | 21.04              | 29.22 | 49.74 | SCL         | 47.7            | 0.89   | 0.05        | 0.45       | 6.9                           |
| M2       | 0-30       | 41.76              | 46.3  | 11.94 | SiCL        | 72.0            | 1.93   | 0.12        | 0.12       | 6.2                           |
|          | 30-60      | 43.2               | 21.56 | 35.24 | L           | 16.1            | 1.2    | 0.09        | 0.06       | 7.3                           |
|          | 60-90      | 35.76              | 26.3  | 37.94 | L           | 19.1            | 1.21   | 0.09        | 0.07       | 7.1                           |
| b02      | 0-30       | 35.2               | 33.56 | 31.24 | CL          | 65.2            | 1.54   | 0.04        | 0.14       | 7.0                           |
|          | 30-60      | 51.4               | 33.94 | 14.66 | SiC         | 52.3            | 1.04   | 0.06        | 0.12       | 7.2                           |
|          | 60-90      | 39.4               | 39.94 | 20.66 | CL          | 56.8            | 0.79   | 0.06        | 0.25       | 7.7                           |
| d28      | 0-30       | 45.76              | 47.3  | 6.94  | SiC         | 39.8            | 1.27   | 0.08        | 0.23       | 7.5                           |
|          | 30-60      | 49.56              | 47.94 | 2.50  | SiC         | 34.8            | 0.59   | 0.05        | 0.32       | 7.7                           |
|          | 60-90      | 39.4               | 43.94 | 16.66 | C           | 96.4            | 0.74   | 0.04        | 0.38       | 7.7                           |

Organic carbon content in the soils ranged from 0.36 - 2.56 %, 0.47 - 2.58 % and 0.01 - 2.65 % in west, north and south areas respectively. Most of the organic carbon was concentrated in the surface horizons and generally decreased with depth in south and north profiles and most auger samples. The soil profile of west area showed an opposite trend

where organic carbon increased with depth (Figure 4). This trend may be explained by the fact that these soils were formed from different cycles of deposition of soil material and stratification is an evident morphological feature of the profile. These features are referred to as fluvic properties (FAO, 1988).

The organic matter content in this soil was generally very low for sugarcane growth. Yates (1977) reported 2 to 4% organic matter (about 1.2-2.3% organic carbon) in soil to be the appropriate range for the crop. The low organic carbon in these soils could be attributed to the practice of sugarcane burning during harvesting. Smith, (1970) found that large amounts of soil organic matter were lost from the profile in 15 months after severe burning. Therefore, where possible the practice of burning should be discouraged in order to get rid of its harmful effects. Addition to the soil of organic materials such as filter mud which is produced in hundreds of tons in every season, will improve and maintain the organic matter level in the soils.

The Olsen extractable P ranged from 2.6 to 98.8, 4.4 to 97.6 and 3 to 97.6 mg/kg in west, north and south areas respectively. Except for fields 12 and 19A in the South area which had low P content in their subsoil, TPC soils had extractable P values greater than the critical value of 4.25 mg/kg (Olsen) as reported by Jones *et al.*, (1982) in soils of Punjab, India.

Since the organic carbon content of these soils was generally low, it is not likely that organic matter contributed much to the high content of extractable P. It seems therefore that the minerals in these soils were rich in P. Common P minerals found in calcareous soils are dicalcium phosphate ( $\text{CaHPO}_4$ ) and dicalcium phosphate dihydrate ( $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$ ). On the other hand, studies by Chhabra *et al* (1981), demonstrated that sodic soils like those at TPC, contain high amounts of extractable P which occurs mostly as soluble sodium phosphate.

The CEC ranged from 8 - 32, 9.2 - 44.4 and 5.1 - 60.4  $\text{cmol}(+)/\text{kg}$  soil in north, west and south areas respectively. The variation of CEC with soil depth showed no systematic trend as it was also the case with clay. The high CEC in south area as compared to north and west areas may be due to the influence of soil texture and the type of clay minerals. Rhoades (1982) reported that, clayey soils have higher CEC than sandy soils mainly due to charges that result from isomorphous substitution in clay minerals. Uriyo *et al* (1979) also showed that the 2:1 clays eg. montmorillonite have higher CEC than the 1:1 clays like kaolinite. According to Van Hoorn (1971), the higher the CEC the greater is the risk to salinization and alkalization in the presence of water rich in salts. It shows therefore that TPC soils have reasonably high CEC especially in south area. Hence they relatively stand greater risks of salinity and sodicity.

The data pertaining to exchangeable bases are given in tables 5a, 5b and 5c. The ranges of exchangeable bases were  $\text{Ca}^{2+}$  : 0.34 - 14 cmol(+)/kg soil (mean = 8.5), 0.45 - 13.71 cmol(+)/kg soil (mean = 8.4) and 1.16 - 26.77 cmol(+)/kg soil (mean = 14.5) in west, north and south areas respectively. Ca content increased non systematically with soil depth for profiles in north and south areas (Figure 4). Ca content for samples from the west profile however decreased with soil depth. It has been observed that sugarcane growing in soils with exchangeable Ca concentration of more than 3.5 cmol(+)/kg cannot respond to Ca fertilization (Bates, 1977). Therefore, TPC soils seem to contain sufficient Ca for sugarcane production.

Magnesium ranges were, 0.03 - 11.8 cmol(+)/kg soil (mean = 3.29), 1.07 - 11.47 cmol(+)/kg soil (mean = 3.37) and 0.06 - 13.2 cmol(+)/kg soil (mean = 3.72) in west, north and south areas respectively. South area recorded relatively high levels of Mg. South and East/West profiles had their Mg values decreasing non systematically with soil depth whereas increase in Mg with soil depth was observed in North area (Figure 4). The irregular decrease in Mg with soil depth is related to the fluvic properties observed in west area.

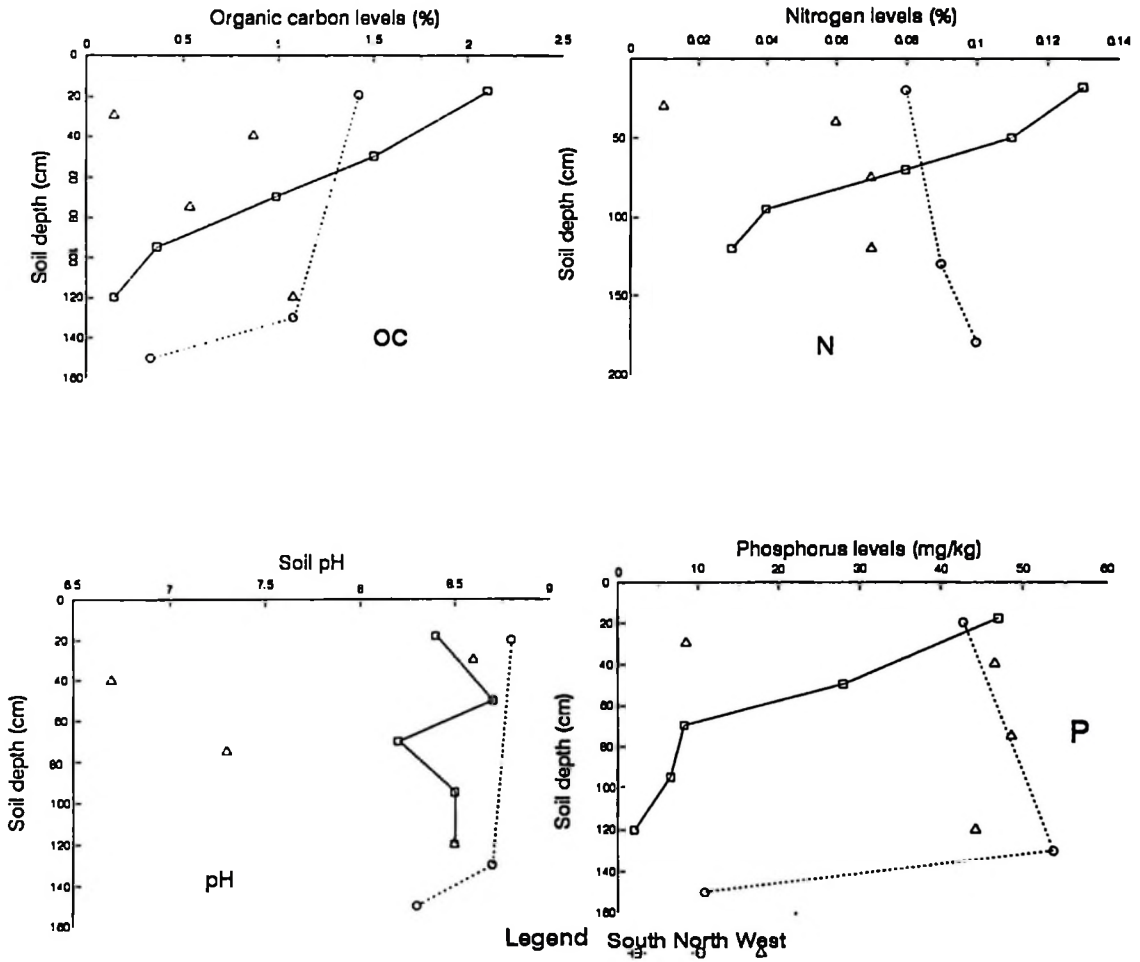


Figure 4. Selected chemical properties of the profiles

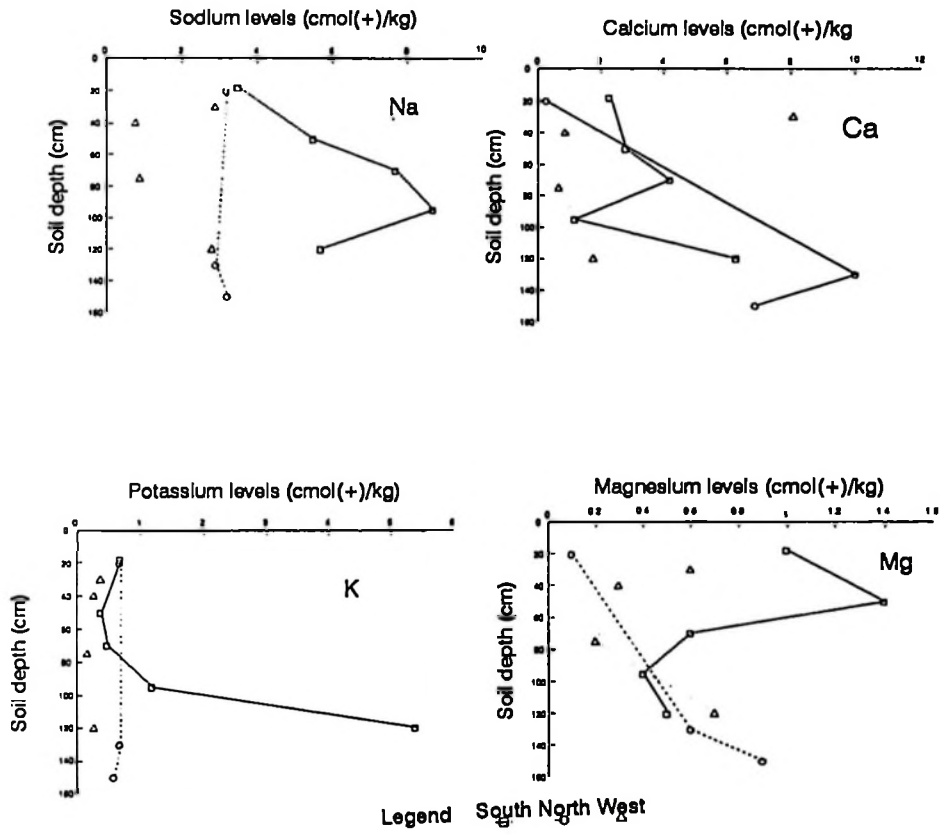


Figure 5. Distribution of exchangeable bases in the soil profile

**Table 5a. Exchangeable bases, CEC and base saturation of the south area.**

| Field No | Depth (cm) | Exchangeable bases (cmol(+)/kg soil) |      |      |      | CEC                 |      | %    |
|----------|------------|--------------------------------------|------|------|------|---------------------|------|------|
|          |            | Ca                                   | Mg   | Na   | K    | Cmol(+)/k<br>g soil | ESP  | BS   |
| 12       | 0-30       | 12.2                                 | 6.2  | 2.25 | 5.16 | 28.2                | 7.9  | 91.5 |
|          | 30-60      | 6.46                                 | 5.99 | 1.89 | 1.66 | 27.0                | 7.0  | 59.3 |
|          | 60-90      | 17.07                                | 6.59 | 5.71 | 3.89 | 33.6                | 16.9 | 98.9 |
| 10K      | 0-30       | 12.16                                | 0.42 | 3.10 | 1.13 | 17.7                | 40.3 | 94.9 |
|          | 30-60      | 13.33                                | 0.82 | 2.5  | 0.69 | 18.9                | 28.1 | 91.7 |
|          | 60-90      | 4.82                                 | 1.23 | 4.1  | 0.83 | 15.1                | 80.4 | 72.7 |
| 19A      | 0-30       | 10.08                                | 3.96 | 4.6  | 0.23 | 19.2                | 34.4 | 98.3 |
|          | 30-60      | 10.56                                | 2.27 | 4.69 | 2.52 | 20.8                | 22.5 | 96.3 |
|          | 60-90      | 11.0                                 | 2.30 | 5.0  | 1.1  | 19.8                | 25.3 | 97.9 |
| 3C       | 0-30       | 12.58                                | 4.84 | 3.42 | 4.16 | 25.5                | 13.4 | 98.0 |
|          | 30-60      | 1.88                                 | 0.41 | 5.9  | 0.19 | 22.5                | 26.2 | 37.2 |
|          | 60-90      | 1.84                                 | 0.06 | 7.5  | 0.53 | 21.7                | 34.6 | 47.8 |
| 4D       | 0-30       | 20.03                                | 1.29 | 5.08 | 6.85 | 35.8                | 14.2 | 92.9 |
|          | 30-60      | 11.66                                | 5.54 | 8.54 | 7.21 | 33.2                | 25.7 | 99.2 |
|          | 60-90      | 13.34                                | 3.66 | 10.5 | 2.73 | 31.7                | 33.1 | 95.4 |
| 4F       | 0-30       | 5.4                                  | 1.2  | 5.9  | 4.5  | 27.4                | 21.5 | 62.0 |
|          | 30-60      | 3.16                                 | 0.67 | 5.1  | 3.27 | 19.3                | 26.4 | 63.2 |
|          | 60-90      | 9.17                                 | 1.18 | 6.2  | 4.00 | 29.3                | 21.2 | 70.1 |
| 6        | 0-30       | 15.79                                | 4.20 | 5.85 | 3.66 | 32.2                | 18.2 | 91.6 |
|          | 30-60      | 3.03                                 | 0.56 | 4.5  | 0.29 | 18.8                | 23.9 | 44.6 |
|          | 60-90      | 1.16                                 | 0.86 | 5.6  | 0.42 | 19.1                | 29.3 | 42.1 |
| 21D      | 0-30       | 10.77                                | 5.63 | 3.17 | 5.22 | 27.2                | 11.7 | 91.1 |
|          | 30-60      | 11.16                                | 6.58 | 4.7  | 4.94 | 25.8                | 18.2 | 94.5 |
|          | 60-90      | 15.54                                | 7.22 | 5.77 | 4.74 | 33.6                | 24.4 | 99.0 |
| G5       | 0-30       | 14.73                                | 5.63 | 2.73 | 5.98 | 29.4                | 9.3  | 98.9 |
|          | 30-60      | 8.51                                 | 0.45 | 3.1  | 0.77 | 18.3                | 16.9 | 70.1 |
|          | 60-90      | 15.41                                | 5.79 | 4.87 | 7.00 | 34.0                | 14.3 | 97.3 |
| 15B      | 0-30       | 21.85                                | 3.86 | 3.15 | 7.42 | 42.8                | 7.4  | 84.8 |
|          | 30-60      | 26.77                                | 3.2  | 4.03 | 8.19 | 44.0                | 9.2  | 86.8 |
|          | 60-90      | 18.99                                | 5.63 | 5.52 | 4.65 | 60.4                | 9.1  | 57.6 |
| Donga A  | 0-30       | 7.35                                 | 0.16 | 0.4  | 0.75 | 9.6                 | 4.2  | 90.2 |
|          | 30-60      | 5.23                                 | 6.34 | 1.10 | 0.44 | 21.0                | 2.9  | 62.4 |
|          | 60-90      | 13.48                                | 4.61 | 3.75 | 2.02 | 28.1                | 4.3  | 84.9 |

**Table 5b. Exchangeable bases, CEC and base saturation of soils of North area**

| Field No | Depth (cm) | <u>Exchangeable bases (cmol(+)/kg soil)</u> |       |      |      | CEC             |      | %    |
|----------|------------|---|-------|------|------|-----------------|------|------|
|          |            | Ca  | Mg    | Na   | K    | cmol(+)/kg soil | ESP  |      |
| N31      | 0-30       | 11.48                                       | 2.71  | 1.22 | 3.53 | 23.2            | 5.26 | 81.6 |
|          | 30-60      | 11.47                                       | 1.29  | 1.32 | 3.43 | 20.4            | 6.5  | 85.8 |
|          | 60-90      | 11.45                                       | 4.57  | 1.72 | 2.73 | 25.2            | 6.8  | 81.2 |
| N42      | 0-30       | 9.52  | 3.78  | 0.31 | 3.1  | 16.8            | 31.2 | 99.5 |
|          | 30-60      | 7.65  | 3.29  | 0.73 | 1.95 | 14.8            | 4.9  | 92.0 |
|          | 60-90      | 8.74  | 5.24  | 0.76 | 1.77 | 32.0            | 2.4  | 51.6 |
| N71      | 0-30       | 8.82  | 2.81  | 0.53 | 1.99 | 16.0            | 3.3  | 88.4 |
|          | 30-60      | 7.63  | 4.06  | 0.19 | 0.93 | 14.8            | 1.28 | 86.6 |
|          | 60-90      | 6.71  | 3.23  | 1.31 | 1.03 | 15.0            | 8.7  | 81.9 |
| N66      | 0-30       | 13.29                                       | 1.07  | 0.07 | 3.53 | 18.0            | 0.5  | 99.7 |
|          | 30-60      | 5.45  | 3.36  | 0.41 | 1.34 | 14.4            | 2.8  | 70.4 |
|          | 60-90      | 6.6   | 6.69  | 0.5  | 1.2  | 15.0            | 3.3  | 99.9 |
| N22      | 0-30       | 0.45  | 2.42  | 0.02 | 3.13 | 19.0            | 0.11 | 31.7 |
|          | 30-60      | 7.85  | 6.18  | 0.31 | 2.15 | 18.6            | 2.12 | 88.7 |
|          | 60-90      | 3.79  | 4.66  | 0.13 | 1.79 | 13.2            | 0.98 | 78.6 |
| N60      | 0-30       | 8.77  | 4.57  | 0.49 | 2.41 | 19.6            | 2.5  | 82.9 |
|          | 30-60      | 6.69  | 4.14  | 4.09 | 1.7  | 17.0            | 27.3 | 97.8 |
|          | 60-90      | 6.60  | 2.55  | 1.82 | 1.49 | 13.8            | 13.2 | 90.3 |
| N93      | 0-30       | 8.06  | 4.22  | 0.32 | 2.04 | 15.6            | 2.5  | 93.8 |
|          | 30-60      | 6.15  | 9.28  | 0.39 | 0.89 | 17.0            | 3.5  | 98.3 |
|          | 60-90      | 5.59  | 8.97  | 0.86 | 0.66 | 18.4            | 10.2 | 87.4 |
| N51      | 0-30       | 5.33  | 5.38  | 0.32 | 1.85 | 13.0            | 2.46 | 99.1 |
|          | 30-60      | 10.84                                       | 7.38  | 1.19 | 2.76 | 24.0            | 6.26 | 92.4 |
|          | 60-90      | 13.71                                       | 11.47 | 0.44 | 2.67 | 30.0            | 2.7  | 94.3 |
| N80      | 0-30       | 9.91  | 2.49  | 0.49 | 2.17 | 17.0            | 2.88 | 88.6 |
|          | 30-60      | 9.6   | 8.51  | 0.22 | 1.41 | 19.9            | 1.16 | 99.2 |
|          | 60-90      | 8.64  | 2.80  | 0.18 | 1.73 | 15.00           | 1.4  | 89.0 |
| N100     | 0-30       | 8.46  | 4.26  | 4.05 | 2.01 | 19.5            | 20.8 | 96.8 |
|          | 30-60      | 6.79  | 2.84  | 0.52 | 1.19 | 12.0            | 4.3  | 94.5 |
|          | 60-90      | 6.26  | 3.34  | 0.10 | 1.09 | 19.4            | 0.52 | 55.6 |



Potassium ranges were 0.05 - 5.08 cmol(+)/kg soil (mean = 2.13), 0.66 - 3.53 cmol(+)/kg soil (mean = 2.58) and 0.19 - 8.19 cmol(+)/kg soil (mean = 4.73) in west, north and south areas respectively. Except for South profile, there is no much change in K content with soil depth (Figure 4). Since the exchangeable potassium in these soils (mean values) is above the optimal range of 0.2 to 0.64 cmol(+)/kg soil (Sanchez, 1976), Sugarcane response to K fertilization is therefore unlikely.

Sodium ranges were, 0.11 - 11.27 cmol(+)/kg soil (mean = 2.15), 0.02 - 4.05 cmol(+)/kg (mean = 0.78) and 1.89 - 10.5 cmol(+)/kg soil (mean = 4.13) in west, north and south areas respectively. There was no systematic trend in Na levels with soil depth (Figure 4). The exchangeable sodium percent (ESP) ranges were 0.5 to 39.2, 0.11 to 31.2 and 2.9 to 80.4 in west, north and south areas respectively. South area demonstrated highest values of ESP as compared to west and north areas. Sugarcane is known to tolerate ESP values of up to 15% (ILLACO, 1981). Therefore, values greater than 15% observed in South area likely to affect sugarcane growth.

The results from this study indicate that among the exchangeable bases,  $\text{Ca}^{2+}$  was the most abundant followed by  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ , and lastly  $\text{K}^+$ . They further reveal that in the south area where the soils are severely affected by salts,  $\text{Ca}^{2+}$  and  $\text{Na}^+$  are more abundant than in west and north areas. Where exchangeable calcium dominated, the content of exchangeable

magnesium was also relatively high. Consequently, the content of exchangeable divalent bases (Ca + Mg) in most fields exceeded that of monovalent bases (K+ Na).

More than 80% of the studied soils in TPC have high base saturation percentage (>60), according to Landon's (1984) classification. The remaining soils (16%) fall under medium range (20-60). Therefore, it can generally be stated that TPC soils have sufficient levels of exchangeable bases which are important for sugarcane production.

**Table 6. Classification of the studied soils**

| Profile | Area  | Soil classification |                       |
|---------|-------|---------------------|-----------------------|
|         |       | FAO (1988)          | USDA (1990)           |
| TPC.SP  | South | Humic Cambisols     | Typic Ustults         |
|         |       | Sodic phase         |                       |
| TPC.NP  | North | Eutric Gleysols     | Typic Ustochrepts     |
|         |       | Sodic phase         |                       |
| TPC.WP  | West  | Calcaric Fluvisols  | Fluventic Ustochrepts |
|         |       | Sodic phase         |                       |

#### 4.1.4 Micronutrient contents of the studied soils

The status of some micronutrients in the soils of TPC is summarized in appendices 4a, 4b and 4c. The distribution of the four micronutrients in the top and subsoil is graphically presented in Figure 6. DTPA extractable Zn of the top soil ranged from 0.51 - 3.48 mg/kg, 0.21 - 4.22 mg/kg and 0.52 - 2.38 mg/kg in west, north and south areas respectively. Levels of Zn decreases with soil depth in all the three areas. The top soils had more Zn than the subsoils which is normally attributed to the influence of soil organic matter (Mitchell, 1971). Zn levels in many of the soils except in fields Q3, M6 (west), 4D (south) and N100, N93, N60 (north) are considered inadequate for sugarcane growth as compared to the critical level for Zn by DTPA method which is estimated at 0.2-2.0 mg/kg (Sims and Johnson, 1991). Therefore, it is likely that TPC soils will develop Zn deficiency. South area recorded lowest Zn levels with mean value of 0.99mg/kg as compared to west and north which had mean values of 1.05mg/kg and 1.18 respectively. This is probably due to high salinity and/or sodicity effects in these soils. The availability of Zinc decreases with increasing pH (Tisdale *et al.*, 1993). At high pH levels, Zn precipitates as insoluble amorphous soil Zinc, ( $ZnFe_2O_4$  and/or  $ZnSiO_4$ ). It has also been revealed that high  $CaCO_3$  content in soils could reduce Zn in solution due to adsorption on the surface of  $CaCO_3$  (Tisdale *et al.*, 1993). It is no wonder therefore that, Zn deficiency has been widely reported in crops grown in sodic soils (Singh *et al.*, 1982).

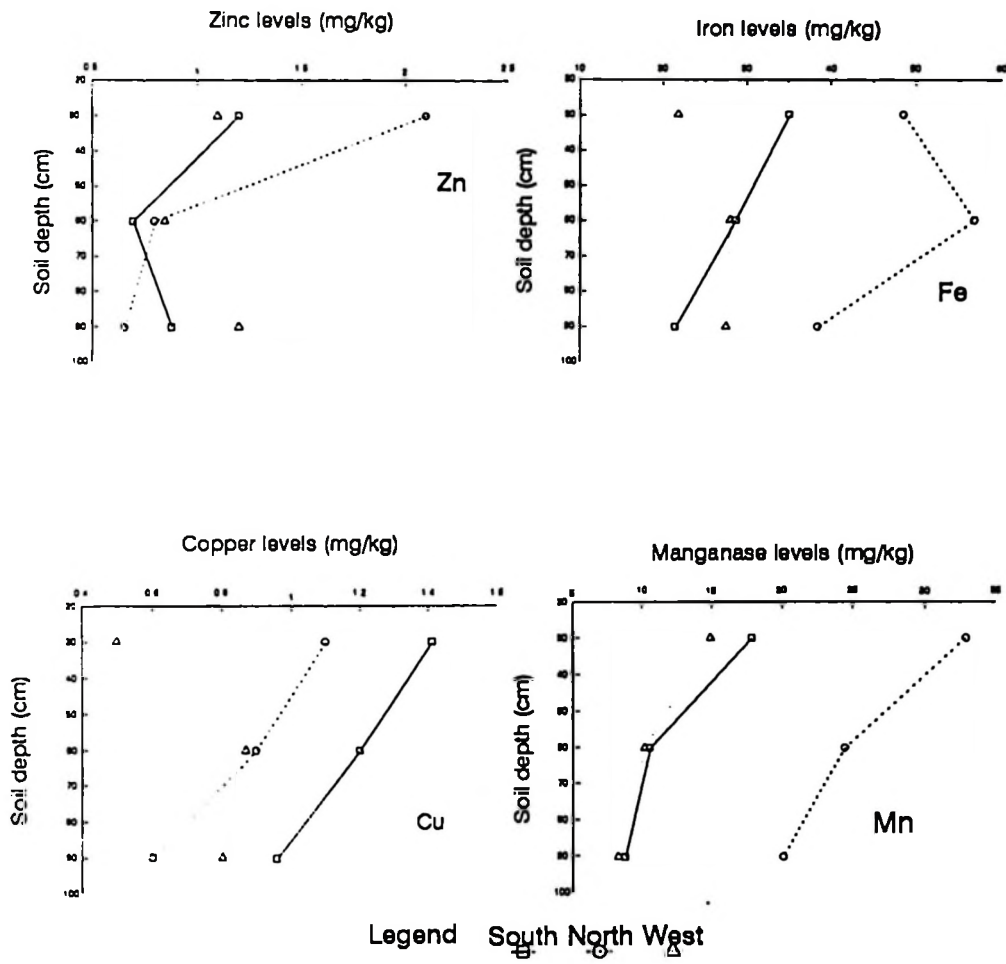


Figure 6. Distribution of micronutrients of the soil profile

The levels of Fe in top soils ranged from 10.34 - 73.9 mg/kg. South area had Fe values decreasing with soil depth whereas in West and North areas there was no systematic trend . These levels are higher than the critical range of 2.5-5.0 mg/kg (Sims and Johnson, 1991). North area measured the highest levels of Fe whereas the lowest were recorded in South area. This is probably due to high pH values measured in the south area. Fe deficiency is most often observed in soils with high pH due to Fe precipitation (Tisdale *et al.*, 93).

The levels of Mn in top soils ranged from 2 to 71 mg/kg and increased with soil depth in all the areas. These levels are generally above the critical level of 1.0-5.0 mg/kg (Sims and Johnson, 1991). Highest levels were measured in North area while the lowest were in West area. This is probably attributed to the pH values in west area (Tisdale *et al.*, 1993). Values greater than 140 to 200 mg/kg are regarded as excessive (Sillampaa, 1982). Therefore, TPC soils will not suffer from excess or deficiency of Mn.

High levels of Fe and Mn found in these soils are most likely due to high content of the same in the parent material and flooding effects. The volcanic material brought from the slopes of Mount Kilimanjaro are composed of halloysites and Feldspars with some silicates of Fe and Mg which are high in Fe and Mn (Sloot, 1987).

Copper levels ranged from 0.2 - 2.9 mg/kg in all of the top soils studied with north area demonstrating the highest value. South and North areas had their Cu values decreasing with soil depth while the opposite trend was observed in West area. Generally, TPC soils have adequate levels of copper. According to Sims and Johnson (1991), the critical level for copper by DTPA method ranges from 0.12 to 0.25 mg/kg. It is generally stated that Cu decreases with increasing pH, and its supply to plants is reduced because of decreased solubility and increased adsorption (Tisdale *et al.*, 1993). Ironically, this is not true with South area soils which had comparatively high pH values. This could probably be associated with the parent materials from which these soils are derived. However, as the parent materials were not analyzed, this remains an area that may need further research.

#### **4.2. Properties and categories of salt affected soils in TPC**

The properties which are characteristic of salt affected soils include pH of the saturated soil paste extract (pH), electric conductivity of the saturated soil paste extract (Ece), exchangeable sodium percent (ESP), and water soluble bases and anions. These are presented and discussed for the TPC soils in the following sections.

##### **4.2.1 pH, electric conductivity and exchangeable sodium percent of the soils**

The pH varied from 6.1 to 8.9, 6.1 to 7.9 and 7.2 to 9.5 in west , north and south areas respectively (Tables 4a, 4b and 4c). More than 50% of the studied soils had their pH values

increasing with soil depth. Since the pH values of all the studied fields in south area is above 7.0, it shows that these soils are alkaline in nature (Richards, 1954). This is also true with some fields such as (N31) and (Q3, R8 & d28) in north and west areas respectively. The increase of pH with soil depth in nearly all the fields, coincides with the presence of relatively high proportion of carbonates and bicarbonates which are capable of undergoing hydrolysis and hence increase the pH (Allison, 1964; Abrol *et al.*,1988). Hamad (1992) working with soils of major rice growing areas in Zanzibar associated the variation of soil pH with soil depth with the leaching of bases in the upper horizons.

On the basis of the established ranges of pH for grouping of soils with different degrees of salinity and sodicity levels (Richards, 1954; Allison, 1964; Reeve and Fireman, 1967), fields 10k, 3C and 6 in south area and R8 in west area exhibit sodic or saline - sodic properties. Their pH in the root zone is above 8.5. The remaining fields do not exhibit sodic or saline - sodic properties. The high pH in these soils may affect plant growth indirectly by lowering the availability of some essential plant nutrients. Studies by Geraldson, (1957) indicated that the solubility of Ca and Mg in the soil solution is reduced as the pH increases due to the formation of insoluble Ca and Mg carbonates. He also noted that availability to plants of other plant nutrients e.g. iron, manganese and zinc tend to be reduced at high pH. This scenario is also observed in TPC soils where south area which is more sodic measured low values of the above mentioned nutrients.

North and west areas had relatively low Ece values ranging from 0.04 to 0.16 and 0.06 to 0.7 dS/m respectively. However, field R8 in west area recorded a higher value of 7.56 dS/m in the top soil. South area measured higher Ece values ranging from 0.1 to 6.68 dS/m. Fields 19a and 21d are the most affected in terms of salinity. About 70% of the studied soils had Ece variation with soil depth conforming to that of pH values which implies an increase in salt content with depth.

The low Ece values observed in the north and west areas indicate a low accumulation of soluble salts while the presence of high values of Ece in south area correspond to high accumulation of soluble salts. Increased Ece values in the upper layers in some fields is an indication of favourable conditions for salt accumulation at or near the soil surface, such as evaporation (Mediratta *et al.*, 1985; More *et al.*, 1988). On the other hand increased Ece values with soil depth in other soils is due to increased magnesium and sodium salts in the lower horizons which is supported by the fact that rains had persisted substantially to enhance leaching of bases from top soil. When reference is made to already established categories of salinity based on Ece values (FAO, 1988; Abrol *et al.*, 88), all the studied fields in north and west areas, except field R8, are considered as non saline, while fields 19a and 21d in the south area have slight to moderate salinity. However, since all the samples were taken during the rainy season (El Nino fuelled rains), there is a high possibility of the soluble cations to have been leached to deeper horizons. Hence the salinity problem might be more severe than it has been reported herein.

The levels of ESP varied appreciably among the soils studied. The lowest levels were measured in the north and west areas with values ranging from 0.11 to 27.3 and 0.5% to 39.2% respectively (Tables 5a, 5b and 5c). The south area recorded the highest value ranging from 7.0 to 80.4%. In most of the fields studied ESP values increased with soil depth. The ESP values of all the fields studied in north/east and most of the fields in west areas are below the 15% limit within 30 cm of the soil surface. Therefore these soils do not have sodic properties while the opposite is true for south and some fields (L4,M6,M2,K1,K8 &bo2) in west areas (FAO, 1988). On the basis of the criteria developed by Abrol *et al.*, (1988), all the studied fields in North and west areas have none to slightly sodicity hazard except Q3, R3 & R8 which have slight to moderate and moderate to high sodicity hazard respectively. The area affected by sodium is estimated to be more than 60% of the studied fields.

Nearly all the fields in south area have light to moderate and moderate to high sodicity hazards. The increased ESP values in the subsoil coincides with increased exchangeable sodium in the corresponding horizons. Higher proportion of sodium as compared to calcium causes permeability problems. The rate of water infiltration into and through the soil is reduced to such an extent that the crop is not adequately supplied with water and yield is reduced (Gupta and Gupta, 1987).

When pH, Ece and ESP values are examined together, four categories of salt affected soils are identified in the study area as follows:

(1) Soils low in pH, Ece and ESP values (2) soils low in pH and ESP but high in Ece (3) Soils with very high pH and ESP but low in Ece (4) Soils with high pH, Ece and ESP. Soils in north and west areas except R8, correspond to the first category while fields 19a and 21d in south area correspond to the second category. The remaining fields in south area are typical examples of the third category whereas category four is represented by only field R8 in west area. Hence nearly all soils of the north and west areas are normal soils while 19a and 21d are considered as saline soils. Eighty percent of the studied soils in the south area are sodic soils. Field R8 in west area is a saline sodic soil.

#### **4.2.2 Distribution of water soluble cations and anions in the studied soils**

The content of sodium ranged from 0.2 to 2.3 (mean 0.26), 0.11 to 0.46 (mean 0.27) and 0.5 to 14.7 (mean 2.47) cmol(+)/kg soil in west, north and south areas respectively (Tables 7a, 7b & 7c). Sodium content exceeded that of other cations in most of the soils. Soluble potassium levels were the least of all bases and had mean values of 0.14, 0.12 and 0.21 cmol(+)/kg soil in west, north and south areas respectively. Chloride content dominated the anions in all the soils. It ranged from 0 to 829, 0 to 446.5 and 0 to 2494 mg/kg soil in west, north and south areas respectively. As compared to carbonates, bicarbonates recorded higher values which ranged from 30.5 to 259, 30.5 to 218.1 and 15.3

to 244 mg/l in west, north and south areas respectively; whereas carbonates ranged from trace to 180, trace to 30 and trace to 24mg/l in west, north and south areas respectively. More than 60% of the studied fields in north and west areas recorded only trace amounts of carbonates as compared to only 30% recorded in the south area. The distribution of carbonates and bicarbonates with soil depth followed a similar pattern as the pH and soluble sodium nearly in all soils. The sulphates contents of the salts of the soil was comparatively low in all soils ranging from 0.02 to 1.34, 0.03 to 2.1 and 0.05 to 6.36 mg/kg in west north and south areas respectively. Therefore, sodium was the most dominant water soluble cation while, chlorides and bicarbonates dominated in the case of anions.

The high amount of soluble sodium and chloride in the soils studied could probably be explained by assuming that the conditions which favor the increase in concentration of the two ions are optimal in the water catchment influencing the soils. The solubility product of other compounds such as carbonates of calcium and magnesium could be another reason which accounts for the dominance of sodium in the soils studied. Appreciable amounts of carbonates and bicarbonates contained in water get precipitated as calcium carbonate ( $\text{CaCO}_3$ ) (Vinayak *et al.*, 1981). The precipitation of  $\text{CaCO}_3$  causes an increase in soluble sodium which tends to dominate the exchange complex.







### **4.3 Possible causes for the accumulation of salts in some areas of TPC**

The causes for the accumulation of salts in soils of TPC are explained in terms of the principle sources of salts and factors which influence their accumulation and distribution.

Soil properties, irrigation and ground waters are in this regard examined.

The main sources of irrigation water are the rivers. The rivers are Kikuletwa, Ruvu and Weruweru. Ruvu is a tributary of Kikuletwa and Weruweru rivers which in TPC is referred to as old intake. In TPC both river and borehole waters are used for irrigation and the methods of application are mainly furrow and overhead irrigation.

#### **4.3.1 Quality of Irrigation water from Rivers**

The chemical composition of water is a major factor determining its quality (FAO, 1985).

The chemical composition of water from the three rivers is presented in Table 8. The important criteria used to characterize the salt in irrigation water were water reaction (pH), electrical conductivity (E<sub>cw</sub>), sodium adsorption ratio (SAR) and content of cations and anions.

##### **4.3.1.1 pH, E<sub>c</sub> and SAR of the studied waters**

Kikuletwa river recorded the highest pH with values of 7.8 and 8.8 in the first and second sampling respectively (Table 8). Ruvu and Weruweru rivers had pH levels in the first and

second sampling of 7.6, 8.1 and 7.2 and 7.9 respectively. These high pH may be attributed to the presence of  $\text{Na}^+$  and hence an indicator of alkalinity problem in the irrigated fields.

Electrical conductivity of all irrigation waters was low. Values were; Kikuletwa, 0.95 and 0.48 dS/m; Ruvu 0.35 and 0.16 dS/m; Weruweru, 0.07 and 0.1 dS/m in first and second water sampling respectively. The Ece values of Kikuletwa river show that there is a potential of its water to cause soil salinity. According to Landon (1984), this water has a degree of restriction on its use as slight to moderate. Ruvu water according to Richards (1954), is classified as  $\text{C}_2$ . This means that it is of medium salinity and can be used for irrigation purposes without much problems if moderate amount of leaching occurs. Plants with moderate salt tolerance, like sugarcane, can be grown in most instances without special practices for salinity control. According to Landon (1984) and Rhoades (1992), Ruvu and Weruweru waters have limited potential to cause salinity and / or sodicity to soils.

**Table 8. pH, Electric conductivity, SAR and chemical composition of the irrigation water**

| Source    | Sampling date | pH  | Ec <sub>w</sub><br>(dS/m) | Soluble cations (mg/l) |       |      |       |      | TDS<br>mg/l |
|-----------|---------------|-----|---------------------------|------------------------|-------|------|-------|------|-------------|
|           |               |     |                           | K                      | Na    | Ca   | Mg    | SAR  |             |
| Kikuletwa | 30/12/97      | 7.8 | 0.95                      | Nd                     | nd    | nd   | nd    | n.d  | 608         |
|           | 6/4/98        | 8.8 | 0.48                      | 1.42                   | 19.71 | 0.66 | 14.49 | 7.17 | 307.2       |
| Ruvu      | 30/12/97      | 7.6 | 0.35                      | Nd                     | Nd    | nd   | nd    | n.d  | 224.0       |
|           | 6/4/98        | 8.1 | 0.16                      | 1.26                   | 11.9  | 0.34 | 8.96  | 5.52 | 102.4       |
| Weruweru  | 30/12/97      | 7.2 | 0.07                      | Nd                     | Nd    | nd   | nd    | n.d  | 44.86       |
|           | 6/4/98        | 7.9 | 0.10                      | 0.36                   | 3.33  | 0.05 | 0.72  | 5.37 | 4.0         |

nd = not determined

Sodium adsorption ratio (SAR) values, show that there differences arise between sampling periods. According to the classification guidelines by Richards (1954), all sources of water, i.e. Kikuletwa, Ruvu and Weruweru contain low sodium. Such water can be used for irrigation on almost all soils with little danger to cause build-up of harmful levels of exchangeable sodium. The same water is placed under slight to moderate category for sodicity build-up (FAO, 1985). Kikuletwa had the highest SAR value of 7.17 while 5.52 and 5.37 were measured in Ruvu and Weruweru rivers respectively. Total dissolved solids (TDS) values for the two sampling periods were 44.8 & 64.0, 102.4 & 224.0 and 307.2 &

608mg/l in Weruweru, Ruvu and Kikuletwa rivers respectively. Kikuletwa river had the highest value and is related to the higher values of electric conductivity in Kikuletwa river.

Because of the fact that rains had started when sampling was done, the effect of dilution cannot be ignored. Hence, it is expected that during dry periods higher concentrations of salts may be encountered than have been reported. However, sodium levels observed in these waters suggest that river waters used for irrigation is one of the sources of the highly sodic soils in some of the fields due to continued irrigation.

#### **4.3.1.2 Cation and anion composition of the river waters**

The concentration of soluble cations and anions is presented in Tables 8 and 9. The concentration of  $\text{Ca}^{2+}$  and  $\text{K}^+$  in the water was the least in all of the water sources analyzed. Kikuletwa recorded highest values of 0.82 and 1.6 mg/kg, while Ruvu had values of 0.34 and 1.26 mg/kg of calcium and potassium respectively. Weruweru which is considered to be of low salinity had the lowest levels of Calcium and potassium (  $\text{Ca} = 0.21\text{cmol}(+)/\text{kg}$ ;  $\text{K} = 0.66\text{ cmol}(+)/\text{kg}$ ). The content of sodium and magnesium was relatively high. Sodium had averages of 22.3, 8.6 and 5.9  $\text{cmol}(+)/\text{kg}$  while magnesium had 15.1, 5.6 and 2.9 $\text{cmol}(+)/\text{kg}$  in Kikuletwa, Ruvu and Weruweru rivers respectively. The high levels of Na and Mg could probably be due to high levels of the same in the geologic formations through which these waters pass through (Abrol *et al.*, 1988). Na and Mg as far as the specific toxic ions are concerned constitute the major toxicants. Most annual and biannual

crops like sugarcane are not so sensitive to low concentrations of Na, but may be affected by higher concentrations (Gupta and Gupta, 1987). On the other hand, high Mg levels in waters affect plant growth mainly by reducing Ca uptake and causing Ca deficiency. However, due to high concentration of Ca in TPC soils, specific ion effect of Mg is therefore unlikely to occur (Meiri and Shalhevet, 1973).

Bicarbonates dominated over the rest of the anions in all water sources studied. The concentration of this anion at the first and second sampling was as follows: (average values in bracket). 556.6 and 346.2 mg/l; 207.4 and 102.48 mg/l; 35.1 and 47.58 mg/l in Kikuletwa Ruvu and Weruweru respectively. The concentration of this anion varied considerably with sampling period. Except for Weruweru, values of this anion in waters which was sampled in late December, 1997 were higher than those of waters sampled in early April, 1998. This is due to dilution effect which was brought about by heavy rains which started in December 1997. The carbonate anion was recorded only in Kikuletwa river with values in first and second sampling not varying considerably (7.5 and 9.0 mg/l). Like sulphates, the value of the second sampling was much higher than the first sampling. This could probably be due to presence n more higher concentrations of carbonates than other anions in rain water. The other rivers that is, Ruvu and Weruweru had only trace concentrations. According to FAO (1985), all waters used for irrigation in TPC falls under severe hazard water as far as bicarbonates is concerned.

Ranges of Residual sodium carbonate (RSC) of the first sampling were 547.5, 198.1 and 29.7 in Kikuletwa, Ruvu and Weruweru rivers respectively. There was a significant decrease in RSC in the second sampling in all the rivers except Weruweru where opposite behavior was observed. This opposite behavior is probably attributed to the high levels of sodium and carbonates discharged into the rivers by run off water. As far as RSC is concerned, it has been noted that waters from all the three rivers are considered as unsuitable for irrigation (Gupta and Gupta, 1987). Eaton (1950) pointed out that the development of alkali soils may be expected when irrigation water containing  $\text{CO}_3 + \text{HCO}_3$  higher than  $\text{Ca} + \text{Mg}$  is used for irrigation. Hence there is high risk of development of a high sodicity hazards. The relative domination of soluble sodium over calcium and magnesium in all water sources correspond with a relatively high content of residual sodium carbonate. Consequently, soils which are irrigated by these waters are prone to be highly affected by sodium and bicarbonates and /or carbonates.

Chloride was the second most dominant anion after bicarbonates. Values showed no much difference with sampling period. The average values were 8.6, 4.45 and 1.8 mg/l in Kikuletwa, Ruvu and Weruweru respectively. Weruweru waters according to FAO (1985), is regarded as having no chloride hazards. Kikuletwa and Ruvu waters was found to contain slight to moderate chloride hazards (FAO, 1985). Hence the high content of chlorides measured in some fields is probably due to irrigation waters from Kikuletwa and Ruvu.

Sulphates averaged values of 2, 1.1 and 1.2 mg/kg in Kikuletwa, Ruvu and Weruweru rivers respectively. According to FAO, (1985), these waters are within the usual range and they are not likely to pose a sulphate problem.

Nitrates content was low in all of the waters analyzed. Values were 0.002 mg/l, 0.002 mg/l and 0.0018 mg/l in Kikuletwa, Ruvu and Weruweru rivers respectively. The nitrate content of 2.5 to 5.0 mg/l in the waters. has been observed to cause beneficial effect on plant growth and partly helps in the substitution for nitrogenous fertilizers (Gupta, 1979). On the other hand, in amounts higher than 10.0mg/l, (Gupta, 1979) nitrates have been observed to cause toxic effect to the plant growth. However, in all of the waters analyzed, both scenarios were not encountered. Hence, as far as nitrates levels in waters are concerned, all the water sources have no potential to cause toxic effects.

**Table 9. Soluble anions and RSC of the irrigation water (1<sup>st</sup> and 2<sup>nd</sup> water sampling)**

| Source    | sampling date | Soluble anions                     |                                    |                      |                                   |                                   | RSC   |
|-----------|---------------|------------------------------------|------------------------------------|----------------------|-----------------------------------|-----------------------------------|-------|
|           |               | HCO <sub>3</sub> <sup>-</sup> mg/l | CO <sub>3</sub> <sup>2-</sup> mg/l | Cl <sup>-</sup> mg/l | SO <sub>4</sub> <sup>-</sup> mg/l | NO <sub>3</sub> <sup>-</sup> mg/l |       |
| Kikuletwa | 30/12/97      | 556.6                              | 7.5                                | 9.5                  | 1.78                              | nd                                | 547.5 |
|           | 6/4/98        | 346.2                              | 9.0                                | 7.65                 | 41.56                             | 0.02                              | 340.1 |
| Ruvu      | 30/12/97      | 207.4                              | trace                              | 5.1                  | 0.13                              | nd                                | 198.1 |
|           | 6/4/98        | 102.48                             | trace                              | 3.83                 | 17.58                             | 0.002                             | 100.1 |
| Weruweru  | 30/12/97      | 35.1                               | trace                              | 2.34                 | 0.47                              | nd                                | 29.7  |
|           | 6/4/98        | 47.58                              | trace                              | 1.28                 | 18.69                             | 0.0018                            | 46.8  |

## CHAPTER FIVE

### 5.0 CONCLUSIONS AND RECOMMENDATIONS

#### 5.1. Conclusions

The following conclusions can be drawn from this study:

The soils occurring in the south, north and west areas of TPC were classified as Typic Ustult (Humic Cambisols with sodic phase; Typic Ustochrept (Eutric Gleysol with sodic phase) and Fluventic Ustochrepts (Calcaric Fluvisol with sodic phase), respectively.

The existence of a hardpan was noticed in the south area. This causes a perched high water tables and poor drainage as it was typically the case in the estate. The hardpan is an increasing cause of salt accumulation in the soil.

Bulk density was found to be high in the north and west areas and this was associated with the use of heavy agricultural machinery in different operations consequently resulting in soil compaction.

Organic carbon was generally low probably because of the burning practise.

Soil texture which is dominated by clay and silt fraction, likely aggravates the problem of the observed highly sodic soils in the South area.

The major categories of salt affected soils found in the study area were as follows:

- (i) Normal soils in the north area
- (ii) Saline soils (fields 19A and 21d) in north area
- (iii) Sodic soils in the South area.
- (iv) Saline sodic soils in field R8 of the West area.

However, the actual area affected by salinity may have been underestimated due to perseverance of El Nino rains which might have caused leaching of soluble salts to the subsurface horizons.

The study on irrigation waters indicate that, Kikuletwa and Ruvu waters are of high and medium salinity respectively, and hence of poor irrigation quality. Weruweru water is of low salinity and hence it is of good quality.

The findings from this study indicate that the possible source of salinity and sodicity in the estate is irrigation waters. Furthermore, a number of factors seem to be aggravating the problem. These were identified as being unfavourable soil texture, seepage and presence of hardpans.

## **5.2. Recommendations**

(1) Alleviating the problem of high bulk densities observed in the study area, deep ploughing is imperative. Cultivation and other mechanical operations should be carried out under ideal soil moisture regime to avoid further soil compaction. Perched water table will also be taken care of by this operation.

(2) Filter mud, which is produced in hundreds of tonnes in each production season, should be incorporated into the soil to improve soil structure.

(3) The multi-factorial nature of salt affected soils in TPC calls for integrated approaches to alleviate the problem as recommended below:

(a) Construction of drains and leaching will reduce or eliminate the salinity problem. Seepage interceptor drains can be used to control the seepage in the study area. Nevertheless, a thorough study on its workability with respect to TPC conditions is essential before adopting this practise.

(b) With sodic soils, neutralisation of the alkalinity by use of gypsum which is locally available in the region in combination with subsurface drainage will ensure removal of exchangeable sodium. The saline sodic soils in field R8 require a combination of measures like addition to the soil of chemical amendment (gypsum), which will neutralise the excess sodium, addition of enough water to the soil which will leach and drain salts from the root zone.

(c) Increase of irrigation efficiency by land grading will permit uniform water distribution. Salts accumulate in the high spots which have too little penetration and leaching while water accumulates in low lying areas which causes water logging and potential water drainage problem. Under and over - irrigation should be avoided as much as possible. To achieve this small and frequent irrigation practises can be applied.

(d) Blending of water supplies before or during irrigation is another viable recommendation. Soil dilution which involves alternating of good and poor quality water is simpler than network dilution because it does not involve use of blending equipment.

(e) For optimum crop production in these saline and sodic soils, special fertiliser management practises different from those usually recommended for unaffected soils should be applied. Thus fertilisation programmes should aim at: (i) Supplementing nutrients that are present in sufficient amounts; and/or (ii) Supplementing nutrients that, although present in sufficient amounts, are not taken up in adequate amounts due to antagonistic effect.

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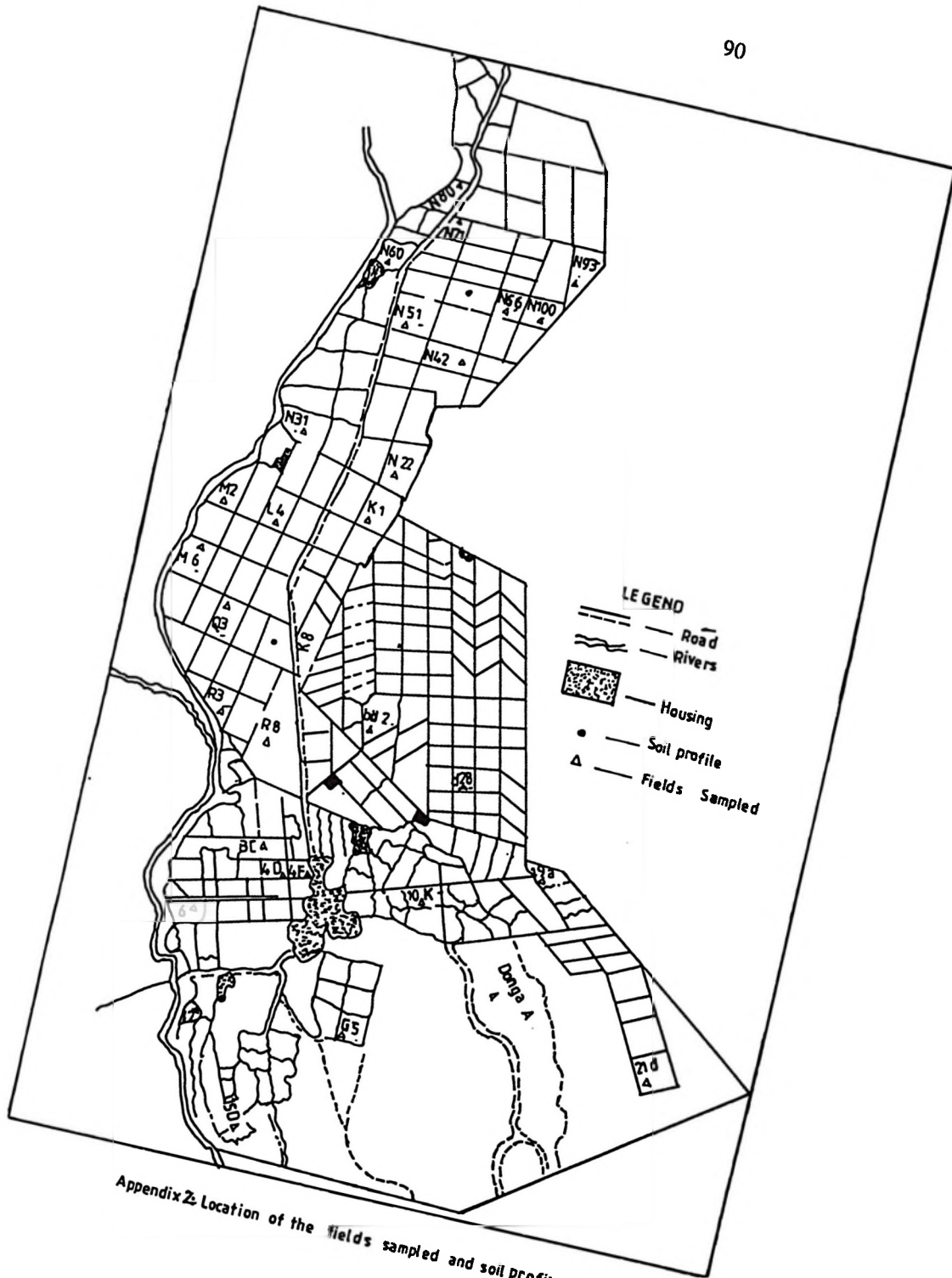
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## APPENDICES

## Appendix 1. Mean annual Climatic data, TPC area

| Year | Rainfall<br>(mm) | Temp.<br>(c <sup>o</sup> ) | Hum.<br>(%) | S/shine<br>(hrs) | Evap.<br>(mm) | Solar<br>rad. |
|------|------------------|----------------------------|-------------|------------------|---------------|---------------|
| 1987 | 515.1            | 25.0                       | 83.0        | 7.5              | 215.2         | 582.3         |
| 1988 | 572.4            | 25.3                       | 83.0        | 7.0              | 23.0          | 570.1         |
| 1989 | 595.5            | 24.5                       | 81.0        | 6.4              | 222.6         | 543.2         |
| 1990 | 1142.2           | 24.3                       | 81.0        | 6.8              | 207.3         | 554.1         |
| 1991 | 322.5            | 23.1                       | 79.0        | 7.3              | 271.2         | 573.7         |
| 1992 | 351.6            | 24.8                       | 76.0        | 6.6              | 200.2         | 585.2         |
| 1993 | 271.9            | 24.6                       | 77.0        | 7.0              | 189.1         | 584.8         |
| 1994 | 385.9            | 24.6                       | 76.0        | 6.4              | 187.0         | 549.0         |
| 1995 | 671.8            | 24.8                       | 78.0        | 6.9              | 187.0         | 581.0         |
| 1996 | 579              | 25.1                       | 82.0        | 6.0              | 197.7         | 558.0         |

Source: TPC meteorological station.



Appendix 2: Location of the fields sampled and soil profiles

### Appendix 3.1. Soil profile description and analytical data for South area

#### Profile No. TPC.SP

Region : Kilimanjaro  
District : Moshi (R)  
Location: TPC estate about 5 km south of factory area

Described by: M.Baitalwake, M. Maro and A. Kiwale  
Parent material: Recent alluvium of volcanic and pyroclastic origin  
Landform: Alluvial plain at footslopes of mountain  
Slope: 1.5%

Topography: Very gently sloping  
Drainage: Well drained  
Erosion: Slight water erosion  
Vegetation/ land use: Cultivated with sugarcane  
Flooding/ponding: Few during heavy rains  
Ground water level: 150 cm  
Presence of salt or alkali: Class 3, soils strongly affected by salts or alkali

Soil: Deep, well drained, uniform, very dark grey to dark greyish brown top soil to very dark greyish brown subsoil, clay to loam sand

#### Soil profile characteristics:

Ap: 0-18 cm: Dark brown (10YR 3/5) dry, Very dark grey (10YR 3/1) moist; sand clay loam; soft dry, friable moist, slightly sticky and plastic wet; moderate medium granular; few fine and very fine pores; few very fine and fine roots; clear wavy boundary  
BA: 18-50 cm: Very dark grey brown (2.5YR 3/2) moist; clay; friable moist; slightly sticky and slightly plastic wet; moderate coarse angular blocky wedge-shaped; few fine, medium and coarse pores; very few fine roots, abrupt wavy boundary.  
Ab: 50-70 cm: Very dark grey brown (10YR 3/2) moist; clay; friable moist; slightly sticky and angular blocky; few fine and very fine pores; very few and fine roots; gradual wavy boundary.  
Bu1: 70-95 cm: Dark grey brown (2.5YR 4/2) moist; loamy sandy; extremely firm moist; slightly sticky and slightly plastic wet; very strong very coarse sub angular blocky; very few fine and very fine pores; very few fine roots; diffuse smooth boundary.  
Bu2: 95-180 cm: Dark grey brown (2.5YR 4/2) wet; sandy; friable moist; non sticky wet; moderate medium sub angular blocky; very few fine and very fine pores; no roots; diffus: smooth boundary.

#### ANALYTICAL DATA FOR PROFILE TPC.SP

| Horizon               | Ap    | BA    | Ab    | Bu1   | Bu2    |
|-----------------------|-------|-------|-------|-------|--------|
| Depth (cm)            | 0-18  | 18-50 | 50-70 | 70-95 | 95-180 |
| Clay (%)              | 31.4  | 33.7  | 25.7  | 17.7  | 27.7   |
| Silt (%)              | 55.04 | 63.62 | 55.62 | 31.62 | 25.62  |
| Sand (%)              | 13.6  | 2.7   | 18.7  | 50.7  | 46.7   |
| Textural class        | SiCL  | SiCL  | SiL   | L     | SCL    |
| Bulk density (g/cc)   | 1.01  | nd    | 1.14  | nd    | 1.31   |
| pH (H <sub>2</sub> O) | 8.4   | 8.7   | 8.2   | 8.5   | 8.5    |
| Organic C (%)         | 2.1   | 1.5   | 0.99  | 0.37  | 0.15   |
| Total N (%)           | 0.13  | 0.11  | 0.08  | 0.04  | 0.03   |
| Available P (mg/kg)   | 47.06 | 27.96 | 8.3   | 6.62  | 2.12   |
| CEC (cmol(+)/kg)      | 28.7  | 27.7  | 15.5  | 32.8  | 25.5   |
| Exch. Ca (cmol(+)/kg) | 2.3   | 2.8   | 4.2   | 1.2   | 6.3    |
| Exch. Mg (cmol(+)/kg) | 1.0   | 1.4   | 0.6   | 0.4   | 0.5    |
| Exch. K (cmol(+)/kg)  | 0.7   | 0.4   | 0.5   | 1.2   | 5.4    |
| Exch. Na (cmol(+)/kg) | 3.5   | 5.5   | 7.7   | 8.7   | 5.7    |
| Base saturation (%)   | 26.1  | 36.5  | 83.9  | 35.1  | 70.2   |
| Ec (dS/m)             | 0.2   | 0.22  | 0.16  | 0.1   | 0.16   |

Soil classification: Humic Cambisols, Sodic phase, (FAO, 1988), Typic Ustults (USDA, 1990).

### Appendix 3.3. Soil profile description and analytical data for North area

#### Profile No. TPC.NP

Region: Kilimanjaro  
 District: Moshi (R)  
 Location: TPC estate North area, field no. N65  
 Described by: M. Bantwaka, J. Mrema and A. Kivale.  
 Parent material: Recent alluvium of volcanic and pyroclastic origin  
 Landform: Alluvial plain at footslopes of mountain  
 Slope: 1%  
 Topography: Gently sloping  
 Drainage: Well drained  
 Erosion: Slight water erosion  
 Vegetation/land use: Cultivated with sugarcane  
 Flooding/ponding: No evidence

Soil  
 Soil profile characteristics:  
 Ap: 0-20 cm  
 BA: 20-130 cm  
 Deep, well drained, very hard friable, sandy clay loam and clay soils  
 Very dark brown (7.5YR 2.5/1) dry, black (2.5YR 2.5/1) moist; sand clay loamy; very hard dry; friable moist; slightly sticky and slightly plastic wet strong medium angular blocks; few fine and very fine pores; very few fine roots; gradual smooth boundary.  
 Very dark brown (7.5YR 2.5/1) dry; black (2.5YR 2.5/1) moist; sandy clay loam; slightly hard dry; friable moist; slightly sticky and slightly plastic moderate medium sub angular blocks; few fine pores; common fine and medium roots; diffuse smooth boundary.

Sand layer 30-180 cm

Course textured gravelly layer with rounded pebbles.

#### ANALYTICAL DATA FOR PROFILE FOR TPC.NP

| Horizon               | Ap   | BA     | Bu      |
|-----------------------|------|--------|---------|
| Depth (cm)            | 0-20 | 20-130 | 130-180 |
| Clay (%)              | 27.7 | 29.7   | 7.7     |
| Silt (%)              | 37.7 | 39.62  | 29.62   |
| Sand (%)              | 34.7 | 30.7   | 62.7    |
| Textural class        | CL   | CL     | SL      |
| Bulk density (g/cc)   | 1.34 | 1.29   | 1.7     |
| pH (H <sub>2</sub> O) | 8.8  | 8.7    | 8.3     |
| Organic C (%)         | 1.42 | 1.08   | 0.34    |
| Total N (%)           | 0.08 | 0.09   | 0.10    |
| Available P (mg/kg)   | 42.8 | 53.5   | 10.84   |
| CEC (cmol(+)/kg)      | 6.7  | 24.1   | 16.2    |
| Exch. Ca (cmol(+)/kg) | 0.3  | 10.0   | 6.9     |
| Exch. Mg (cmol(+)/kg) | 0.1  | 0.6    | 0.9     |
| Exch. K (cmol(+)/kg)  | 0.7  | 0.7    | 0.6     |
| Exch. Na (cmol(+)/kg) | 3.2  | 2.9    | 3.2     |
| Base saturation       | 64.2 | 58.9   | 71.6    |
| Ec (dS/m)             | 0.17 | 0.2    | 0.17    |

Soil classification: Eutric Gleysols, Sodic phase (FAO, 1988). Typic Urochrepts (USDA, 1990).

### Appendix 3.2. Soil profile description and analytical data for West area

#### Profile No. TPC.WP

Region: Kilimanjaro  
 District: Moshi (R)  
 Location: TPC estate West area, field no Q2  
 Described by: M. Baitlwake, J. Kpama and A. Kiwale.  
 Parent material: Recent alluvium of volcanic and pyroclastic origin  
 Landform: Alluvial plain at footslopes of mountain  
 Slope: 1.5%  
 Topography: Very gently sloping  
 Drainage: Well drained  
 Erosion: No evidence  
 Vegetation/land use: Cultivated with sugarcane  
 Flooding/ponding: Few during heavy rains  
 Soil: Moderately deep, well drained, very hard friable, sandy clay loam and clay soils

#### Soil profile characteristics:

Very dark grey 7.5YR 3/1 moist, sandy clay loam, friable moist slightly sticky and slightly plastic wet, moderate fine prismatic, few fine and very fine pores; common fine roots; gradual smooth boundary.

Ap: 0-20 cm

BA: 20-40 cm

Black (7.5YR 2.5/1) moist, clay loam, friable moist, slightly sticky and slightly plastic wet, moderate fine prismatic, few fine and very fine pores, few fine and very fine roots; abrupt wavy boundary.

B: 40-75 cm

Very dark grey brown (10YR 3/2) moist; sandy loam friable moist, slightly sticky and slightly plastic wet; moderate medium sub angular

#### ANALYTICAL DATA FOR PROFILE FOR TPC.WP

| Horizon                | Ap    | BA    | B     |
|------------------------|-------|-------|-------|
| Depth (cm)             | 0-30  | 30-40 | 40-75 |
| Clay (%)               | 17.7  | 41.7  | 21.7  |
| Silt (%)               | 37.62 | 39.62 | 29.62 |
| Sand (%)               | 9.5   | 33.62 | 39.62 |
| Textural class         | SCL   | C     | L     |
| Bulk density (g/cc)    | 1.55  | n.d   | 1.59  |
| pH (H <sub>2</sub> O)  | 8.6   | 6.7   | 7.3   |
| Organic C (%)          | 0.15  | 0.87  | 0.54  |
| Total N (%)            | 0.01  | 0.06  | 0.07  |
| Available P (mg/kg)    | 8.58  | 46.6  | 48.48 |
| CEC (cmol(+) /kg)      | 24.1  | 16.9  | 16.0  |
| Exch. Ca (cmol(+) /kg) | 8.1   | 0.9   | 0.7   |
| Exch. Mg (cmol(+) /kg) | 0.6   | 0.3   | 0.2   |
| Exch. K (cmol(+) /kg)  | 0.4   | 0.3   | 0.2   |
| Exch. Na (cmol(+) /kg) | 2.9   | 0.8   | 0.9   |
| Base saturation        | 49.8  | 13.6  | 12.5  |
| Ec (dS/m)              | 0.04  | 0.04  | 0.04  |

Soil classification: Calcic Fluvisols, Sodic phase (FAO, 1988),  
 Fluventic Ustodrepts (USDA, 1990).

### Appendix 4.1 Distribution of micronutrients in South area

| Field   | Depth | Fe    | Zn   | Mn    | Cu   |
|---------|-------|-------|------|-------|------|
| (mg/l)  |       |       |      |       |      |
| 12      | 0-30  | 28.16 | 1.32 | 20.0  | 1.32 |
|         | 30-60 | 19.50 | 0.90 | 12.3  | 1.02 |
|         | 60-90 | 21.02 | 0.80 | 8.96  | 1.56 |
| 10K     | 0-30  | 10.34 | 0.42 | 7.04  | 0.50 |
|         | 30-60 | 10.92 | 0.52 | 4.18  | 0.80 |
|         | 60-90 | 16.26 | 0.46 | 7.6   | 0.44 |
| 19A     | 0-30  | 10.5  | 1.18 | 18.6  | 0.98 |
|         | 30-60 | 4.06  | 0.08 | 10.22 | 0.58 |
|         | 60-90 | 3.92  | 0.14 | 5.14  | 0.08 |
| 3C      | 0-30  | 36.7  | 1.24 | 38.0  | 1.76 |
|         | 30-60 | 14.04 | 0.26 | 15.22 | 0.60 |
|         | 60-90 | 13.88 | 1.24 | 8.00  | 1.06 |
| 4D      | 0-30  | 55.42 | 2.38 | 19.8  | 3.62 |
|         | 30-60 | 46.7  | 1.68 | 22.0  | 3.06 |
|         | 60-90 | 36.6  | 2.46 | 13.24 | 1.72 |
| 4F      | 0-30  | 10.66 | 0.52 | 11.04 | 1.10 |
|         | 30-60 | 8.22  | 0.28 | 4.2   | 0.72 |
|         | 60-90 | 9.64  | 0.86 | 9.84  | 0.14 |
| 6       | 0-30  | 49.42 | 1.52 | 7.22  | 2.46 |
|         | 30-60 | 26.20 | 0.72 | 7.96  | 0.44 |
|         | 60-90 | 29.28 | 0.48 | 2.34  | 0.78 |
| 21D     | 0-30  | 10.86 | 1.14 | 26.6  | 0.42 |
|         | 30-60 | 7.18  | 0.46 | 11.02 | 0.78 |
|         | 60-90 | 6.28  | 0.28 | 8.38  | 0.82 |
| G5      | 0-30  | 54.38 | 2.02 | 9.00  | 1.1  |
|         | 30-60 | 46.90 | 1.52 | 7.60  | 2.22 |
|         | 60-90 | 26.70 | 0.92 | 8.76  | 1.58 |
| 15B     | 0-30  | 84.40 | 2.02 | 21.4  | 0.84 |
|         | 30-60 | 54.12 | 1.24 | 10.8  | 1.58 |
|         | 60-90 | 52.58 | 1.24 | 15.74 | 1.38 |
| Donga A | 0-30  | 5.74  | 0.56 | 12.46 | 0.40 |
|         | 30-60 | 9.40  | 0.32 | 5.30  | 0.42 |
|         | 60-90 | 15.38 | 0.38 | 6.32  | 0.90 |

### Appendix 4.2 Distribution of micronutrients in West area

| Field  | Depth | Fe    | Zn   | Mn    | Cu   |
|--------|-------|-------|------|-------|------|
| (mg/l) |       |       |      |       |      |
| Q3     | 0-30  | 14.04 | 0.74 | 13.50 | 0.44 |
|        | 30-60 | 13.08 | 1.76 | 14.76 | 0.82 |
|        | 60-90 | 25.50 | 2.74 | 3.76  | 0.72 |
| R3     | 0-30  | 14.30 | 0.51 | 2.00  | 0.20 |
|        | 30-60 | 13.74 | 0.68 | 2.02  | 0.36 |
|        | 60-90 | 34.08 | 1.46 | 6.0   | 0.68 |
| L4     | 0-30  | 12.50 | 0.56 | 7.50  | 0.31 |
|        | 30-60 | 36.1  | 0.72 | 10.76 | 0.44 |
|        | 60-90 | 13.5  | 0.76 | 12.05 | 0.22 |
| R3     | 0-30  | 9.64  | 1.14 | 3.10  | 0.38 |
|        | 30-60 | 22.28 | 0.46 | 3.76  | 0.80 |
|        | 60-90 | 17.74 | 0.36 | 2.42  | 0.64 |
| M6     | 0-30  | 71.68 | 3.48 | 45.6  | 0.34 |
|        | 30-60 | 55.02 | 1.82 | 13.0  | 1.56 |
|        | 60-90 | 35.01 | 2.20 | 10.20 | 0.80 |
| KI     | 0-30  | 20.53 | 0.85 | 14.05 | 0.56 |
|        | 30-60 | 38.72 | 0.98 | 23.0  | 1.06 |
|        | 60-90 | 17.60 | 1.20 | 16.00 | 0.65 |
| K8     | 0-30  | 22.30 | 0.58 | 5.50  | 0.90 |
|        | 30-60 | 39.36 | 1.28 | 7.04  | 1.72 |
|        | 60-90 | 38.90 | 2.26 | 6.00  | 2.06 |
| M2     | 0-30  | 41.74 | 1.76 | 8.76  | 1.30 |
|        | 30-60 | 52.20 | 0.33 | 9.00  | 1.78 |
|        | 60-90 | 65.94 | 1.18 | 10.52 | 1.38 |
| b02    | 0-30  | 16.71 | 0.66 | 7.03  | 0.11 |
|        | 30-60 | 17.40 | 0.72 | 9.06  | 0.20 |
|        | 60-90 | 26.52 | 0.86 | 5.86  | 0.36 |
| d28    | 0-30  | 12.42 | 0.78 | 56.00 | 0.56 |
|        | 30-60 | 12.84 | 0.24 | 14.78 | 0.40 |
|        | 60-90 | 13.94 | 0.20 | 12.46 | 0.76 |

### Appendix 4.3 Distribution of micronutrients in North area

| Field  | Depth | Fe    | Zn   | Mn    | Cu   |
|--------|-------|-------|------|-------|------|
| (mg/l) |       |       |      |       |      |
| N31    | 0-30  | 49.98 | 2.00 | 10.38 | 0.92 |
|        | 30-60 | 31.24 | 0.56 | 7.96  | 1.10 |
|        | 60-90 | 39.1  | 1.48 | 7.92  | 1.20 |
| N42    | 0-30  | 24.44 | 0.52 | 23.6  | 1.02 |
|        | 30-60 | 36.12 | 0.28 | 21.4  | 0.80 |
|        | 60-90 | 37.18 | 0.38 | 46.0  | 0.38 |
| N71    | 0-30  | 45.46 | 2.02 | 7.38  | 2.90 |
|        | 30-60 | 73.9  | 0.94 | 14.26 | 2.10 |
|        | 60-90 | 51.46 | 0.76 | 5.44  | 0.46 |
| N66    | 0-30  | 32.68 | 1.04 | 30.80 | 0.30 |
|        | 30-60 | 52.26 | 0.84 | 19.00 | 0.46 |
|        | 60-90 | 25.44 | 0.18 | 11.02 | 1.26 |
| N22    | 0-30  | 80.94 | 2.96 | 52.20 | 0.50 |
|        | 30-60 | 51.06 | 0.76 | 20.2  | 0.62 |
|        | 60-90 | 48.24 | 1.00 | 42.00 | 0.66 |
| N60    | 0-30  | 65.96 | 3.18 | 71.2  | 0.68 |
|        | 30-60 | 26.50 | 0.20 | 19.8  | 0.72 |
|        | 60-90 | 17.96 | 0.22 | 4.00  | 0.26 |
| N93    | 0-30  | 37.38 | 2.38 | 18.52 | 0.52 |
|        | 30-60 | 47.14 | 0.76 | 27.8  | 0.46 |
|        | 60-90 | 24.88 | 0.14 | 8.46  | 0.30 |
| N51    | 0-30  | 35.80 | 0.21 | 15.02 | 0.32 |
|        | 30-60 | 45.02 | 1.04 | 23.01 | 1.08 |
|        | 60-90 | 49.52 | 0.76 | 22.8  | 0.66 |
| N80    | 0-30  | 58.92 | 2.00 | 35.6  | 2.96 |
|        | 30-60 | 45.00 | 1.63 | 38.2  | 1.20 |
|        | 60-90 | 36.30 | 0.89 | 13.70 | 0.36 |
| N100   | 0-30  | 53.93 | 4.22 | 65.2  | 1.06 |
|        | 30-60 | 160.0 | 1.32 | 52.6  | 0.46 |
|        | 60-90 | 55.30 | 0.82 | 40.12 | 0.41 |