EVALUATION OF KILOMBERO ESTATE SOILS WITH RESPECT TO THEIR POTENTIAL AND CONSTRAINTS TO SUGARCANE PRODUCTION

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ABSTRACT

A study was carried out in Kilombero Sugar Estate in order to determine the soil constraints which limit sugarcane production. This was done through soil characterization and evaluation of fertility status of the soils. Soil characterization was based on morphological, physical, chemical and mineralogical properties.

In addition, soil and sugarcane leaf samples were sampled from 16 cane fields under second ratoon crop and analysed for N, P, K. Ca, Mg, Fe, Zn, Mn and Cu. Nutrient uptake by sugarcane was also carried out from field fertilizer trials.

A soil morphology study revealed that the cultivated soils in section 1 to 3 are young (AC) profiles, very deep alluvial deposits. The virgin soils showed relatively more advanced profile development (ABC profile) when compared to the cultivated soils.

Generally, soils were of mixed clay mineralogy with kaolinite, illite, smectite and goethite in varying proportions.

Total nitrogen in all soils was low (0.08 to 0.15%) and therefore a limiting factor for sugarcane production Poor soil aeration, poor drainage and flooding effects limit sugarcane production in sections 2 and 3.

Exchangeable K in soils ranged from 0.52 to 2.68 cmol(+)/kg (very high). Exchangeable Mg ranged from medium to high (1.53 to 6.22 cmol(+)/kg) while exchangeable Ca was low to medium (2.99 to 7.02 cmol(+)/kg). Available P was very low to medium (2.18 to 18.2 mg/kg).

DTPA extractable micronutrients are in good supply Mean values in topsoils are: Zn, 1.13 mg/kg; Mn, 28.9 mg/kg; and Fe, 131.0 mg/kg.

The cultivated soils of sections 1, 2, and 3 were classified as Eutric Fluvisol (KLP3), Mollic Fluvisol (KLP1) and Mollic Gleysol (KLP2) respectively according to FAO-UNESCO system of classification. The virgin soil (KLP4) was classified as Eutric Cambisol. According to USDA Soil Taxonomy, the soils were classified as follows: Section 1, Typic Ustifluvent; section 2, Typic Haplaquoll; section 3, Fluventic Haplaquoll; and the virgin soil as Typic Tropaquept.

Field fertilizer trials indicated that different levels of NPK applied in the soil did not affect nutrient uptake by sugarcane to significant level. These results were expected as there were appreciable amounts of native P and K in these soils, and synergism effect among the nitrogen, phosphorus and potassium.

Irrigation and underground water was found to be of good quality.

DECLARATION

I, ANDREW MATHEW YOHANE KUNDA, 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. L. Kunda and my mother Mrs. E. Kunda, through whose love and tireless efforts I got my education.

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ABBREVIATIONS

B.D = Bulk density
BS = Base saturation
C = Clayey
CEC = Cation exchange capacity
DTPA =Diethylene triamine Pentaacatic acid
EC = Electical conductivity
ESP = Exchangeable sodium percent
FAO = Food and Agriculture Organization of the Unated Nations
FC = Field capacity
KLP = Kilombero profile
KSC = Kilombero Sugar Company
KSL = Kagera Sugar Limited
LS = Loamy sand
LTA = Long term average
MSE = Mtibwa Sugar Limited
na = Not available
nd = Not determined
NORAD = Norwegian Agency for Development Cooperation
O.C = Organic carbon
P.D = Particle density
ppm = Parts per million
PWP = Permanent wilting point

R.H = Relative humidity

RSC = Residual sodium carbonate

SAR = Sodium adsorption ratio

SC = Sandy clay

SCL = Sandy clay loam

SL = Sandy loam

TAZARA = Tanzania- Zambia Railway Authority

TEB = Total exchangeable bases

TPC = Tanganyika Planting Company

TDS = Total disolved solids

USDA = Unated States Department of Agriculture

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CHAPTER 1

INTRODUCTION

Sugar is a well known and important commodity used with food and beverage at household level for various purposes at industrial level. In Tanzania, the most important source of sugar is sugarcane (*Saccharum officinarum*). The sugar industry in Tanzania plays an important role in the economy of the country. Despite domestic shortfall, Tanzania exports 10 000 metric tons of sugar annually to European Economic Community (EEC). Molasses, an important byproduct of sugar industry is widely used as raw material for other industries. It is 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. Kilombero Sugar Company alone employs more than 3 500 people on permanent terms.

The dominant sugarcane production system in the country is that of plantation which combines cultivation with sugar processing. Tanzania sugar industry consist of five sugar factories and estates owned by four companies. Kilombero Sugar Company Limited (KSC) and Mtibwa Sugar Estate (MSE) are in Morogoro region, while Kagera Sugar

Limited (KSL) and Tanganyika Planting Company (TPC) are in Kagera and Kilimanjaro regions respectively.

The combined installed capacity of the five sugar factories in the country is 228 000 metric tons of processed sugar per year while the actual production is about 110 000 tons per year. The national annual demand in 1993 was 400 000 metric tons (Ministry of Agriculture, 1993). Therefore, the locally produced sugar represents only about 25% of the estimated annual demand. As a result, Tanzania imports sugar to bridge the gap between domestic production and demand while the potentials for increasing sugar production exist (Senkoro, 1988).

KSC operates two estates each with its own factory namely Msolwa and Ruembe. A total of 6 000 hectares are under sugarcane production and the factories have an initial installed capacity of 85 metric tons of sugar per season (about six months). The main portion of Msolwa estate (3 000 hectares) has been under sugarcane production relatively longer (since 1961) than Ruembe estate (since 1975). The whole estate is under sprinkler irrigation with almost all field operations either partially or fully mechanized.

History on fertilizer application shows that only nitrogen fertilizers have been used in this estate while sugarcane production indicates a declining trend. The highest production of 144 tons of cane per hectare was attained in the first year of production (1962) while the lowest was 51 tons of sugarcane per hectare in 1980 (Appendix 1). The production in 1991/92 season was 50.2% lower than that of 1962. The decreasing trend in sugarcane yields in Tanzania during 1980s deviated from the almost world wide increase in yield levels as a result of more intensive cultivation and overall improvement in agronomic practices (Netherlands Development cooperation, 1992).

In view of the above facts it is likely that a number of factors such as managerial, financial and agronomic are responsible in cane yield decline over the years. World Bank (1984) and Netherlands Economic Institute (1988) observed that low soil fertility and shortcomings in fertilizer application in sugarcane estates in Tanzania were among the factors which contributed to poor sugarcane yields. They further pointed out that few soil analyses have been done to identify nutrient deficiencies in soil and serve as basis for effective fertilizer application policy. It was therefore deemed necessary to evaluate these soils with the following specific objectives:

1. To fully characterize soils of Msolwa Estate including their morphological, physical-chemical properties and mineralogical composition.
2. To evaluate soil fertility status of Msolwa Estate of Kilombero Sugar Company.

3. To assess quality of irrigation, and underground waters in Msolwa Estate

CHAPTER II

2.0 LITERATURE REVIEW

2.1 Importance of soil characterization

The entire agricultural system of a nation depends on the productivity of the soil (Collins, 1977). A small farmer is in particular affected by the deterioration of the soil resources because the quality of his life depends on the productivity of his land. It is important, therefore, to characterize soil resources for sustainable and profitable use.

Soil characteristics are some of the land qualities needed in carrying out assessment of suitability of land for the selected crop or crops (Samki, 1989). These characteristics include both physical and chemical properties of soils, mineralogical characteristics and soil-water relationships (Landon, 1984).

Soil physical characteristics include effective soil depth, soil structure and porosity, and soil tilth.

The depth of soil that can be effectively exploited by plant roots is an important criterion in selecting land for irrigation (FAO, 1979). A soil depth of 90 cm is often chosen as a minimum for highest level of production under average management (FAO, 1979).

Soil structure refers to the nature and degree of aggregation of soil particles (ILLACO, 1981). It exerts a dominant influence on soil air, moisture regime, hydraulic conductivity and consequently the root growth and soil productivity (Yang, 1978). An abundance of large air-filled pores is associated with stable aggregates and productive soils. Other guidelines to aeration are given by soil bulk density, infiltration and permeability rates.

Texture is one of the most basic soil characteristics for consideration in soil appraisal. It influences water infiltration, moisture and nutrient retention, and susceptibility to erosion (London, 1984) . It is generally accepted that fine textured soils are more fertile than coarse textured soils due to influence of high clay content which is related to nutrient supply, soil water and plant nutrient retention (De Datta, 1981).

Soil reaction (pH) provides a general indication of soil salinity and acidity. It can be used to appraise correctable soil deficiencies related to economic correlation such as lime and gypsum requirements.

In evaluating soils, interest in cation exchange capacity values is two-fold that means as a measure of potential productivity in terms of capacity of the soil to retain and supply plant nutrients and as a clue to the nature of clay minerals present. It is also known that the nature of exchangeable cations determine the productivity of soils. Soils of inherently high productivity for most crops usually have an exchange complex dominated by Ca^{2+}

and Mg^{2+} and contain only minor amounts of K^+ and Na^+ (FAO, 1979). Soils with high proportion of hydrogen and aluminium ions in their exchange sites tend to be unproductive. Excessive high amount of exchangeable Na has deleterious effects on soil physical characteristics, plant growth and development. Minerals present in the sand and silt fraction of the soil are primarily indicative of the soil parent material and of the degree of weathering (Fanning *et al.*, 1989). The type and amount of clay minerals present in the soil determine many of the physical and chemical properties (Borchrdt, 1989) and thus exert a most important influence on its suitability for irrigation.

Full documentation of all soil characteristic is important because it is useful to other disciplines and may be used to consider alternative development possibilities (FAO, 1979). According to Dent and Young (1980), and Sombroek and Van de Weg (1980), soil characterization can be used for: (i) transferring of research findings from one area to another (ii) farm planning (ii) rural and land classification (iv) town planning (v) guiding prospective investors in agriculture and especially commercial large scale cropping (vi) forestry and forestry management (vii) town master plan and settlements arrangements (viii) engineering purposes.

2.2 Soil fertility evaluation

Soil fertility is the major component of soil productivity. It is defined as the status of the soil with respect to the amount and availability to the plants of the nutrient elements necessary for optimal growth of a specified crop (Ponnamperuma, 1975). In order to provide sound advice on fertilizer program, a proper soil fertility evaluation is important. Soil fertility evaluation is the process by which nutritional problems are diagnosed and fertilizer recommendations are made where necessary (Sanchez, 1976). This process can be achieved by soil testing, plant analysis, simple fertilizer trials and a combination of these. Each method has both advantages and disadvantages.

Soil testing is an important and indispensable tool for assessing fertility status of soils (Sahrawat, 1983). However, the shortcomings of this technique is its inadequacy to account for crop specific nutrient requirement, nutrient transport within rhizosphere and interaction between nutrients (Bringer, 1985).

Analysis of plant material is another approach used in soil fertility evaluation. This technique is based on the concept that the greater the nutrient content in the plant the higher is its availability in the soil. It has become widely accepted as a means of improving the effectiveness of fertilizer use (Wood, 1987). A leaf sample is an excellent indicator of the nutrient status of the plant and therefore provides a useful check on uptake of applied fertilizer. The major limitation of this technique which limits its use is that the results of leaf analysis are often too late to provide the adequate basis for fertilizing the current crop, correcting deficiency, or toxicity without a considerable yield loss (Sanchez, 1976; Sahrawat, 1983; Wood, 1987). Further more, the concentration of the nutrients in the plant is greatly affected by other factors such as kind of plant organ used, environmental conditions and levels of other nutrients in the soil (Mengel and Kirkby, 1987).

Field fertilizer trials is another technique used in soil fertility evaluation. The result so obtained can be translated directly to the farmers' field conditions. However, it has been pointed out by Milsted and Peck (1973) that fertilizer field trials are relatively expensive to conduct and that the research results from these trials are not easily transferred from one field to another. Regardless of the shortfalls of these techniques, they are still useful for soil fertility evaluation when the results are correctly interpreted.

2.3 Effect of some chemical and physical soil characteristics on sugarcane growth and development

2.3.1 Chemical properties

2.3.1.1 Soil pH

Sugarcane grows on slightly acidic to slightly alkaline soils (Husz, 1974). Mmikonga (1981) observed a pH range (topsoil) of 4.9 to 6.6 in one section of the study area. Soil pH values near 7.5 or 8 are usually associated with saline soil which contains excessive soluble salts. Sergio (1978) observed a highly significant inverse correlation between exchangeable sodium percent (ESP) and cane yields of sugarcane grown in alkaline soils (pH range of 7.5 to 10). ESP of up to 10 did not cause harmful effect on sugarcane. An ESP level of 15 can be considered as a critical level over which sugarcane yield is highly restricted.

Alkaline soil have been reported to have adverse effect on production and quality of sugarcane. Lakshminkantham (1983) observed low sucrose content and difficulties in processing sugarcane grown in alkaline soils. An electrical conductivity value of 4 mmhos was found to be the threshold level above which the growth of sugarcane is drastically reduced (Shoji and Sound, 1965). On the other hand acid soils (pH 5.6) caused reduced sugarcane elongation while in alkali soils (pH 8) poor cane growth and tillering was observed (Lakshmikantham, 1983). When ratoon and plantcane was compared, Leon et al. (1966) found that ratoon crops are only half as tolerance as plantcane but difference in salt tolerance between varieties diminishes during the second ratoon crop.

2.3.1.2 Soil organic matter

Trash is an important source of organic matter in sugarcane soils. When incorporated in the soil it improves soil structure and enhance the utilization of top dressed fertilizers by sugarcane (Lakshmikantham, 1983). The author reported an average gain of 3.63 metric tons of sugar/ha when 251 metric tons/ha of bagasse was applied in the soil. Buried sunhep at age of two months improved cane yield of succeeding sugarcane by 43%. (Lakmishkantham, 1983).

Yates (1977) observed that an organic carbon percentage of 1.2 to 2.3% is the appropriate range for sugarcane growth and development. In the study area, Mkelenda (1985) found that organic matter content was below this sufficient range (0.84 to 0.55%). The author emphasized the need to incorporate organic material in the soils in order to maintain the above range.

2.3.1.3 Macronutrients

Nitrogen

Total N in the soils of study area was found to be inadequate for cane production (Mmikonga, 1981; Mkelenda, 1985). Mmikonga (1981) reported a range of 0.12 to 0.22% versus threshold value of 0.3% reported by Demeterio (1960) as cited by Mkelenda (1985).

Sugarcane requires up to 300 kg N/ha for normal growth (Srivastava *et al.*, 1986). Ratoon crop uses more N per ton of cane than plant crop when adjustment is made for age (Chui and Samwel, 1977). Higher doses of N above that required for optimum growth exert an adverse effect on juice quality (Mkelenda, 1985; Strivastava, 1986). Increased N from 100 to 150kg/ha decreased markedly the sucrose content of the first three ratoons of sugarcane variety NCO 376 (Inman-Bamber, 1984). The author observed a quality decrease of 7% in variety N52/219 as compared to that of 18% in NCO 376 when 200 kgN/ha was applied. On the other hand number of tillers and stalk length increased with increasing N rates.

The critical concentration of N in sugarcane leaf has been set by several authors (Mkelenda, 1985; Wood, 1987). Mkelenda (1985) working with sugarcane variety NCO 376 in Kilombero Sugar Estate, observed a threshold value of 1.8% while Schroeder *et al.* (1993) observed a critical concentration of 1.6 to 1.9% N in South Africa depending on cane age and month of sampling. Wood (1987) found a concentration of between 1.7 to 1.9% N for plant cane and 1.6 to 1.8% N as critical levels applicable in South Africa depending on soil type, crop age and month of sampling. Therefore, N critical concentration in sugarcane should be considered locally depending on local environmental conditions, age of crop at sampling and whether it is a plant cane or ratoon crop.

Phosphorus

Phosphorus has been called "the key to the life'' (Thompsons and Troeh, 1985) because it is involved in most life processes. Adequate amounts of P in the soil help reduce a fall in juice pol caused by higher doses of nitrogen (Srivastava *et al.*, 1986). Application of 50kg of phosphate\ha per season for seven consecutive years significantly improved yield of ratoon crop when compared to control treatment (Jafri, 1984). Lakshmikantham (1983) observed reduced stalk length and diameter and poor tillering of sugarcane growing in P deficient soil.

For the response of sugarcane to P fertilizer, Ayres and Humbert (1957) observed a critical level of 6 ppm P for acidic and neutral soils. On the other hand, Yang and Chen (1991) working with clayey alluvial soils observed a 52% yield increase corresponding to 33 tons of cane per hectare by applying 83 kg P/ha. A critical level of 0.17 to 0.19% P in sugarcane leaves of a ratoon crop has been reported by Wood (1987), Meyer *et al.* (1989) and Schroeder *et al.* (1993) in South African sugarcane growing regions. In Msolwa Sugar Estate of Kilombero Sugar Company, Mkelenda (1985) found that uptake of P by sugarcane depended on levels of N in the soil. When 200 kg P/ha was applied sugarcane leaf P content was found to range from 0.16 to 0.21%.

Potassium

Potassium is required by sugarcane in amounts greater than any other nutrient (Husz, 1974; Lakshmikantham, 1983). Potassium deficiency in sugarcane results in accumulation of free amino acids in the plant, depressed growth and slender stalks (Lakshimikantham, 1983), low sucrose content and rendment (Humbert, 1968). According to Wood (1987), 112 ppm of exchangeable K in the soil has been used as a critical concentration for growth and development of sugarcane in South Africa. The author observed a significant response of K levels for sugarcane grown in light textured soils and lower critial level as compared to heavy textured soils. In heavy textured soils the critical concentration was variable and was not well correlated with pretreatment of K levels in the soil. However, a significant response was found to be associated with soil K levels ranging from 112 to 549 ppm. An interim threshold value of 150 ppm of exchangeable K has been introduced for soils with clay content of more than 30%. Wood and Meyer (1986) suggested a threshold value of 225 ppm K for soils with high proportions of K fixing clay minerals.

The critical concentration of K in sugarcane leaf has been reported by different workers (Wood, 1987; Ng Kee Kwong, 1990; Schroeder *et al.*, 1993). It was found to be affected by age of the cane and rainfall regime (Ng Kee Kwong, 1990). The authors observed a threshold value of 1.45% K in sugarcane leaves aged six months following a total rainfall of 262 mm over 30 days preceding leaf sampling. This was in contrast to 1.32% K for sugarcane of the same age and variety sampled when 114 mm of rainfall had been received over 30 days prior to leaf sampling. Wood (1987) observed a critical concentration of 1.05% K for 3rd leaf sample taken from a vigorous growing cane of three months old ratoon crop.

2.3.1.6 Micronutrients

Micronutrient deficiency or toxicity in sugarcane has received little publicity in Tanzania and other sugarcane growing countries. It appears that this problem is infrequent. In Tanzania most soils are deficient in Cu, Zn, B and Mo but the deficiencies of Mn and Fe are not very common (Sillanpaa, 1982). The availability of these nutrients to plants are mainly affected by soil reaction and moisture regime (Neue, 1989). Pathak *et al.* (1976) reported increased availability of Fe under waterlogged conditions. Deficiency of Zn in the same soils was reported by Agarwal *et al.*(1970) and Neue (1989).

One of the micronutrients necessary for growth of sugarcane is Zn. It functions in the plant as a component of plant tissue and enzyme factors (Juang *et al.*, 1977). When plants are deficient in Zn the synthesis of amino acids is inhibited (Schutte and Schendel, 1958). Wood (1987) reported that the deficiency of micronutrients in sugarcane growing soils in South Africa is infrequent with exception of Zn which has been a continuing problem. Juang (1972) observed a significant relationship between sugarcane yields and soil Zn contents. The authors found that the maximum yields for both cane and sugar occur when soil Zn was between 12 to 18 ppm. Lakshmikantham (1983) reported that in Guyana the Zn content of most visible dew lap leaf lamina of sugarcane variety Co997 at the age of 90 days increased from 16.6 to 18.7 ppm as the levels of N increase from 0 to 224 kg N/ha. A threshold value of 13 ppm Zn in 3rd leaf of cane at the age of 3-4 months is used in South Africa (Wood, 1987).

Iron is present in sugarcane only in small quantities but is essential to plant growth and formation of chlorophyll (Husz, 1974). Iron deficiency in sugarcane causes leaf chlorosis (Fogliata and Bustos, 1980) and diminished growth. It is usually associated with very high contents of manganese (Husz, 1974; Fogliata and Bustos, 1980; Lakshmikantham, 1983). The Fe:Mn ratio of 15:1 is recommended for normal growth (Husz, 1974). When this ratio is 1:1 or less, Fe deficiency or Mn toxicity develops. Evans (1959) observed that Fe toxicity can be reduced by application of lime and better drainage. Lakshmikantham (1983) observed that Fe concentrations in sugarcane leaves ranged between 206 to 270 ppm for sugarcane variety Co419 and 212 to 282 ppm for variety Co997 without specifying the age of the crop at sampling.

Manganese in plants is important for protein metabolism. Its uptake by plants is highly affected by soil pH. Like for many other micronutrients, high soil pH induces manganese deficiency in plants. Toxicity results from unfavourable Fe:Mn ratio. In sugarcane a threshold concentration of 15 ppm Mn was found by Schroeder *et al.* (1993) based on 3rd leaf samples and large number of fertilizer trials conducted over 40 years in South Africa.

Copper is needed by plants for oxidation and reduction processes. It is indispensable for protein metabolism and formation of certain enzymes (Husz 1974). High soil pH induces Cu deficiency. In sugarcane it is characterized by poor development of stool, leaf chlorosis and failure of leaf spindle to unroll. The critical concentration of 3 to 4 ppm Cu in topmost visible dewlap leaf at the age of 3 to 4 months was observed by Evans (1959), Wood (1987) and Schroeder *et al.* (1993).

2.3.2 Soil physical properties

2.3.2.1 Soil texture

Sugarcane crop is grown under varied soil conditions. However, soils with high amount of expanding clays are difficult to work with. They cause crop logging due to deep cracks which develop during dry season (Lakshmikantham, 1983). Careful drainage of water and application of green manure will improve the texture of these soils. Moreover, fine textured soils have impact on nutritional status of a sugarcane crop. For example, Wood (1987) observed a low critical concentration of K in sugarcane grown in light textured soils as compared to heavy textured soils. Well drained loamy soils have been found to be ideal for sugarcane crop (Husz, 1974; Lakshmikantham, 1983).

2.3.2.2 Soil structure

Sugarcane crop prefers permeable soils for the growth of its roots, the bulk of which occupy the upper 40 to 50 cm layer of the soil (Fernandes *et al.*, 1978).

Sugarcane estates are characterized by mechanization of field operations due to labour shortage and high labour cost (Yang, 1978). The use of heavy agricultural machinery in arable land can, however, lead to serious problems due to soil compaction (Yang, 1978; Mathan and Natesan, 1990). Traffic induced compaction decreases the water infiltration rate, increases soil bulk density and decrease vertical root growth (Kayombo *et al.*, 1991). Yang (1978) observed that soil bulk density and penetration resistance increased with increasing number of traffic passes. Significant decrease in ratoon cane growth and yield resulted from compaction up to 40 cm depth which in turn increased linearly as bulk density increased from 1.55 to 1.75 g/cm^3. The effect of heavy machinery was more pronounced in soils with high moisture content and a massive structure.

Mechanization in sugar industry is indispensable but the deleterious effect of soil compaction is unfavourable. However, the excessive soil compaction caused by heavy machinery could be reduced if the following recommendations suggested by Yang (1978) on soil management are observed.

1. Mechanical harvesting should not be done under conditions which are conducive to soil compaction, such as high soil moisture content. If it is absolutely essential, loading truck with wide tires and a lower inflation

pressure should be used.

2. In medium to fine textured soils, irrigation should be cut off one month before harvesting.

3. Amelioration of fine textured soils with sand and organic matter to decrease their compactibility. However, this exercise is difficult to practice in large areas.

4. Lowering of water table to a desired depth by a proper drainage system in order to have a dry surface soil.

2.3.2.3 Soil moisture regime

Water is nearly a universal solvent helping plants to absorb nutrients. It is the key to growth, development and maturity of the sugarcane crop and the conversion of reducing sugar to recoverable sucrose (Humbert, 1972). Water stress in sugarcane is known to impair photosynthesis significantly. It can also result in high fibre:juice ratios, low sugar recovery and poor yield of cane per hectare (Lakshmikantham, 1983). Excess or deficiency of moisture have adverse effect on plant growth and availability of nutrient elements in plant (Samwel, 1971). The author observed that moisture deficiency in the soil caused reduction in sugarcane growth. Interaction between soil moisture conditions, levels of nitrogen in the soil and yields of cane crop has been observed by Verma (1962) and Fogliata and Gargiulo (1978). Yang and Chen (1980) found that soil moisture regime affects sugarcane bud germination. The optimal soil moisture for germination was at the range of field capacity (0.3 bars). Under water saturated conditions, no germination was observed for 25 days germination period. According to Husz (1974) a soil water potential of 0.2 to 2.5 bars for arid climates and 0.2 to 1.8 bars for humid conditions should be maintained to ensure continuous cane growth.

2.4 Effect of clay mineralogy on soil fertility

Clay fraction is the most reactive inorganic constituent of the soil. The difference in chemical and physical properties of soils can be associated with the variation in mineralogical composition of these soils (Chatterjee and Dalal, 1976). Consequently the basic properties of soil relevant to their use can not be properly understood without a knowledge of mineralogical makeup (Ghabru and Ghosh, 1985). The amount and type of clay minerals in the soil dictate some physical and chemical characteristics which are directly related to soil fertility such as cation exchange capacity, water and plant nutrient retention, erodibility and workability.

2.4.1 Micas

Micas is a group of minerals which are non hydrated phyllosilicates with 2:1 layer structure. One fourth of tetrahedral sites is occupied by Al^{3+} and the rest is occupied by silicon (Si^{4+}). Excess negative charge is balanced by monovalent cation, commonly K^+ which occupies the interlayer sites (Schulze, 1989). Mica species are differentiated depending on substitution of Mg^{2+} and Al^{3+} for Fe^{3+} or Fe^{2+} in the octahedral site and Na^+ and Ca^{2+} for K^+ in the interlayer sites. Micas with interlayer K^+ are the most important and abundant in most soils (Fanning *et al.*, 1989). Generally they are primary minerals abundant in many rocks such as shales, schists, granites, gneisses and sedentary rocks (Thompson and Troeh, 1985). Jackson (1964) as cited by Fanning *et al.* (1989) observed that micas are more prevalent in clay minerals of younger, less weathered soils such as Entisols, Inceptisols, Mollisols and Alfisols but less prevalent in highly weathered soils such as Oxisols and Ultisols.

The cation exchange capacity (CEC) of mica is small compared to expanding minerals such as vermiculite and smectites. For example, the CEC of illites range from 20 to 40 cmol(+)/kg. Although K released from micas is an important source of K to growing plants, the nature of K supplying power of soils depends on the kind, amount and particle size of mica present and upon factors that affect the release of K such as wetting and drying. However, Tributh *et al.* (1987) pointed out that fixation of K by illite is more complex when compared with other phylosilicates. They can both fix and release K depending on their degree of weathering. Also it has been established that dioctahedral mica such as muscovite are more resistant to weathering than trioctahedral micas such as biotite and that they release K at a much lower rate (Jackson, 1953).

2.4.2 Vermiculites

Vermiculites are made up of 2:1 layer structure. Unlike micas, they have lower layer charge (0.9 to 0.6) and contain exchangeable cations usually Ca and Mg between the layers. They have high CEC and affinity for weakly hydrated cations such as K^+, NH_4^+ and Cs^+ (Fanning *et al.*, 1989).

Vermiculites are found in soils of all climatic regions and soil orders where either mica or chlorite is present in soil material (Ross *et al.*, 1982). It has been reported by Smith (1962) that they are formed from feldspar in basic igneous rocks and basic igneous, mica-free rocks (Barshard and Kishk, 1969). Trioctahedral vermiculites are prevalent in sand, silt and clay fractions of soil. Dioctahedral vermiculite is seldom observed in soil fraction larger than medium silt (Ross *et al.*, 1982).

Vermiculites have strong influence on CEC of the soil. They are among minerals with large CEC (Douglas, 1989). Also vermiculite are known to fix or exhibit selective adsorption of K^+ and NH_4^+ (Page *et al.*, 1967). Potassium fixation and release by phyllosilicate clay minerals in soils influence the availability of K to plants (Buabid *et al.*, 1991). Beidelites and vermiculite are known to have greater K fixation capacities than smectites (Ross and Cline, 1984).

2.4.3 Smectites

This group of minerals is composed of minerals with 2:1 structure like mica and vermiculite but with the lowest charge per formula weight (0.6 to 0.25) (Schulze, 1989). The inter layer contains exchangeable cations, Ca^{2+}, Mg^{2+}, and Na^+.

Among the naturally occurring smectites, only montimorillonite and beidellite are of major importance in soil environment (Borchardt, 1989). They are distributed world wide (Buol *et al.*, 1980). Vertisols are dominated by smectites which commonly occur in gently sloping soils of alluvial plains (Borchardt, 1989).

Smectites have expanding lattice minerals that permit both water and cations to enter between their layers (Thompson and Troeh, 1985). The major portion of the fertility of moderately weathered soils can be traced to the presence of smectites. This is due to its ability to hold fertilizer cation such as K^+ and NH_4^+, macronutrients such as Ca^{2+} and Mg^{2+}, and micronutrients such as Cu^{2+} and

Zn^{2+} against the effect of leaching by rainfall or irrigation water. With exception of soil organic matter, smectites have the highest CEC. It ranges from 47 to 162 cmol(+)/kg with an average of 100 cmol(+)/kg. Smectites also exhibit some of the K fixing properties (Laird *et al.*, 1991). However it is generally accepted that K fixation in soils containing smectite is due to presence of vermiculite or weathered mica (Laird *et al.*, 1991). Smectites in large amount in the soil are associated with poor hydraulic conductivity and poor root development. Cropping of soil containing smectite causes Mg and Fe to be released from octahedral sheet (Christenson and Doll, 1973) which are available to growing plants.

CHAPTER III

3.0 MATERIALS AND METHODS

3.1 General characteristics of Kilombero Sugar Estate

3.1.1 Location and extent

Kilombero Sugar Estate is located in Msolwa and Ruembe river valleys in Kilombero district, Morogoro region (Fig. 1). It extends between latitudes 7^0 30′ and 7^0 50′ South and longitudes 36^0 and 37^0 10′East. The estate is bounded by Mikumi National Park, The low plateau Selous Game Reserve to the south and East, and the Gologolo and Migomberani mountains to the West (Fig. 2).

The study area covers Kilombero 1 (Msolwa estate) which lies between the Great Ruaha river to the North and East, Migomberani and Gologolo Mountains to the West and Sanje river in the South.

3.1.2 Geology and soils

Msolwa and Ruembe river valleys are part of the East African Rift Valley system (Mmikonga, 1981). The North-South fault separates the hilly and mountainous terrain of central Tanzania along the Western margin of Kilombero Estate (Whittingham, 1963). The raised block to the west consists of Gologolo and Migomberani Mountains. These mountains are composed of igneous rocks of Usagaran system of the basement complex (Fig. 3). The rocks are composed of two major stratigraphic groups:

i. Migmatic gneisses with biotite and, or hornblende together with Usagaran undifferentiated.

ii. Granulite with migmatic gneiss.

In the valley floor, colluvial and alluvial sediments of Neogene age overly the Usagaran rocks. According to reconnaissance survey of Kilombero valley carried out by Whittingham (1963) and IILACO (1967) differentiated the sediments into two broad groups:

i. Light sand earth, cemented sand and gravel.

ii. Alluvial sand and silt.

The major portion of Msolwa estate is covered by the later group. The alluvial sediments appear to have been deposited from Msolwa river and its tributaries while colluvial materials are supposed to have originated from Gologolo mountains (Mmikonga, 1981). The author identified four soils orders in a section of this Estate which was under fallow. They were Entisols, Inceptisols, Mollisols and Ultisols.

3.1.3 Geomorphology and hydrology

Rivers from the elevated land which flow to the East and South are the major land forming agents in the valleys of Lower Ruembe and Msolwa. In these valleys the gradient

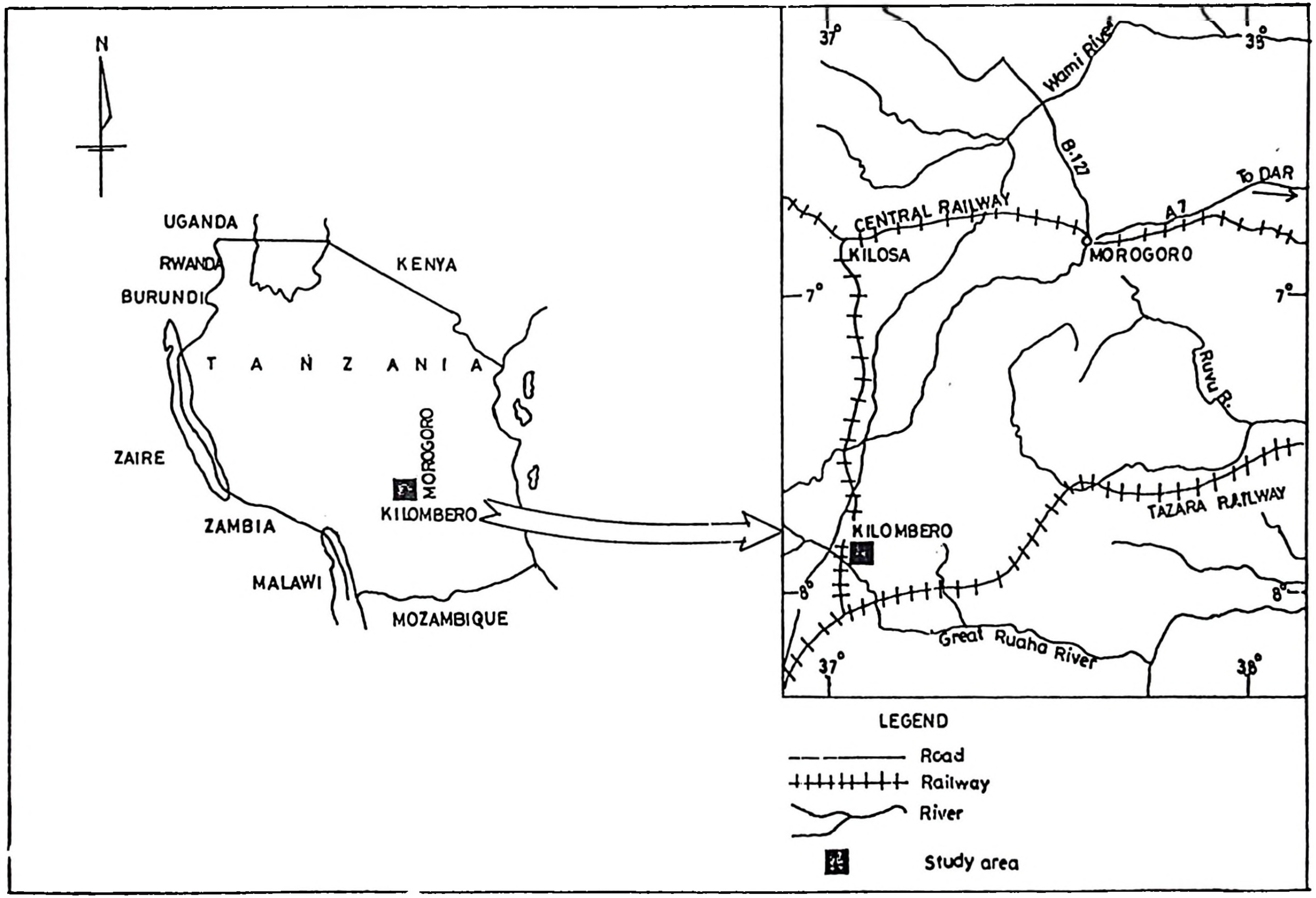

Figure 1- Map showing the location of the study area

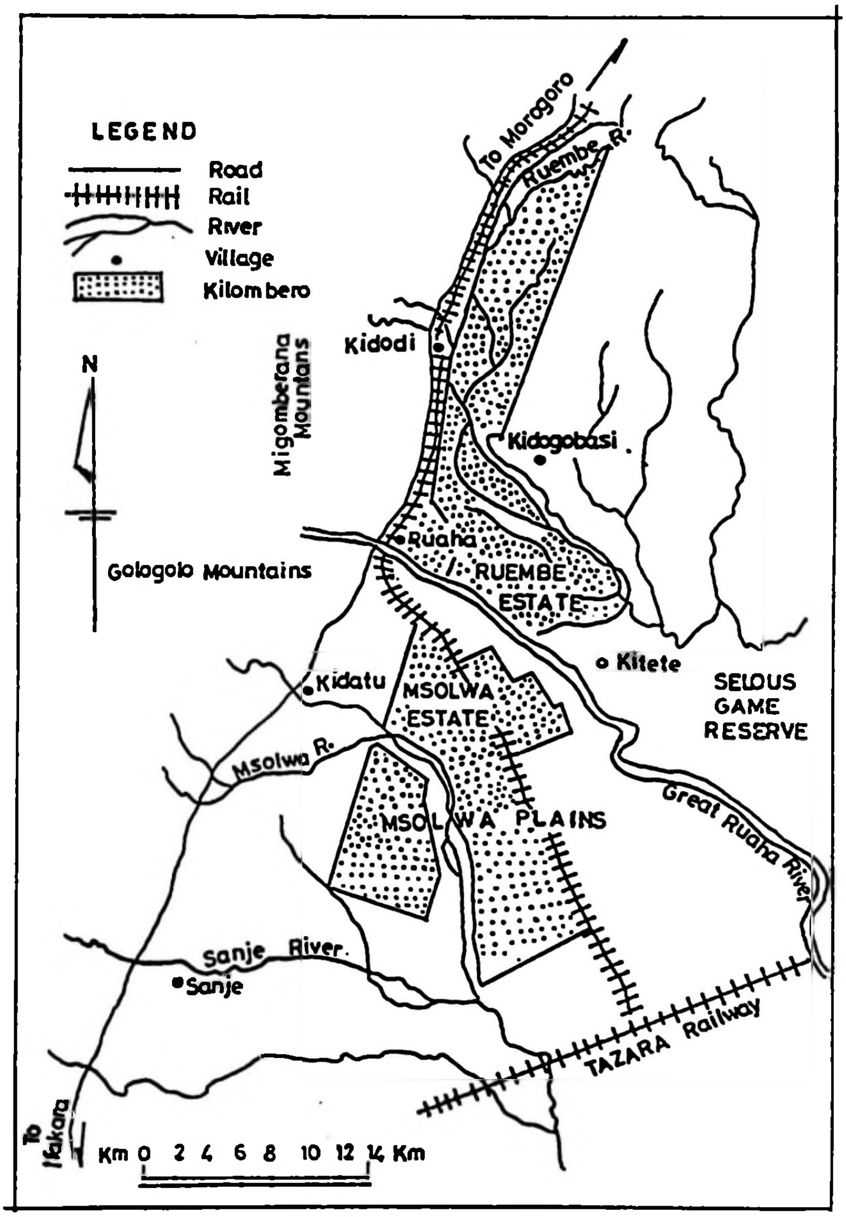

Figure 2. Existing sugar estate: Msolwa Estate along the Msolwa plains and Ruembe Estate along the lower Ruembe river valleys.

of the river beds becomes small, allowing for an overflow of the river. The flush flood inundate a large area. Near the river beds are some erosion gullies which penetrate inland over a distance usually not exceeding few hundred feet (ILACO, 1967).

The Great Ruaha is the largest river in the area. It flows through a narrow gorge in the Gologolo mountains carrying with it a high sediments load during the rainy season. This is deposited at the bottom of the scarp in Ruembe and Msolwa valleys. Due to seasonal nature of the flow combined with frequent flooding, there are numerous course changes over a short time interval leaving a slightly undulating landscape, sand banks, old channels and levees. Further from the river the finer fractions of the river sediments have been deposited. The Ruembe river flows from North to South and it is also subjected to flush flooding. It has deposited a large amount of alluvium in the area East of Kidodi. The other smaller rivers in the area show similar features but in small scale.

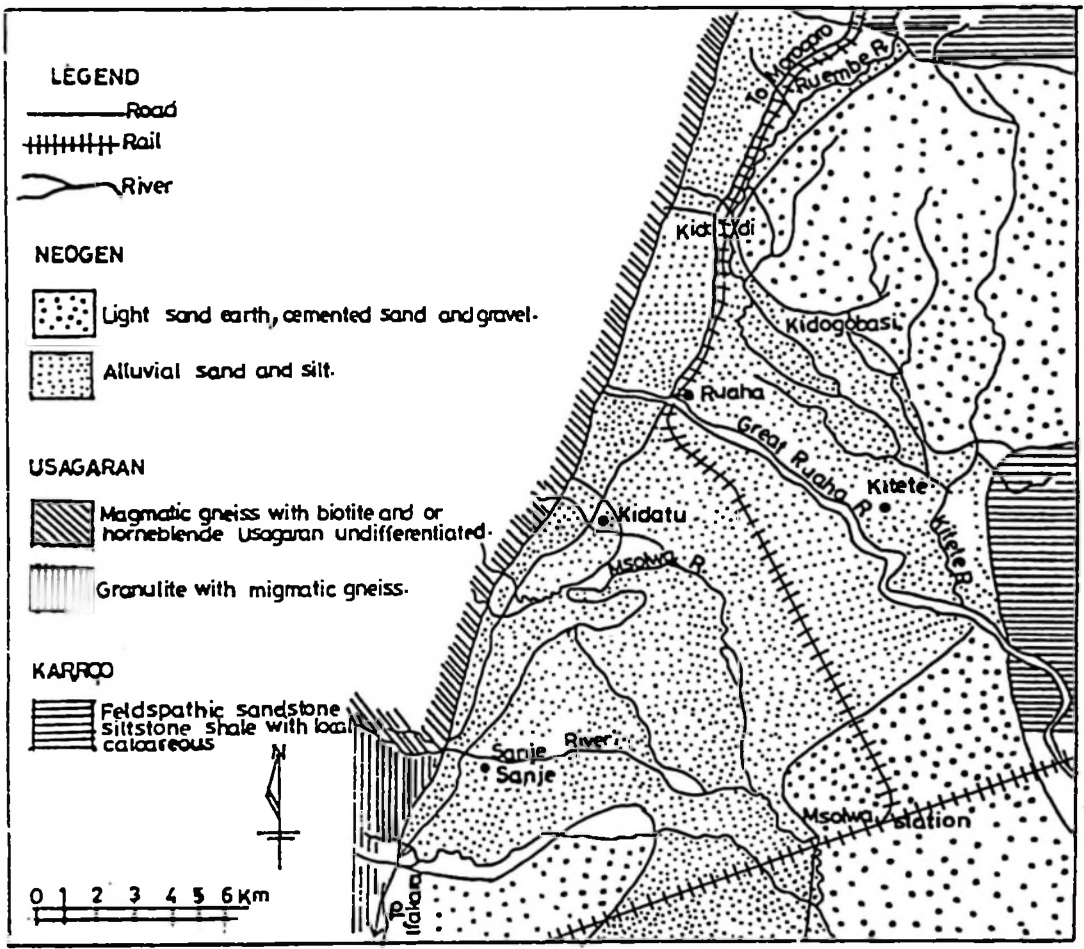

Figure 3. Geology of Msolwa and Lower Ruembe valley

3.1.4 Climatic conditions

Generally the climate of Kilombero Sugar Estate is tropical rainy with annual rainfall of 800 to 1700 mm and showing a well defined wet and dry season. The rainfall distribution shows a peak in March and April and a dry spell from June to September. The short rains usually start in November and end in January. During the wet period, the main portion of Msolwa Estate experiences flooding and waterlogging. The soil moisture regime is therefore aquic.

The mean monthly temperature is about 24.5°C. The mean minimum and maximum temperatures are 18.9°C and 30.2°C respectively. Minimum and maximum relative humidity are 52.9% and 93% respectively. The main climatic data for Msolwa Estate are in appendix 3.

3.2 Site selection and characterization

3.2.1 Site selection

Msolwa Estate was selected from two estates owned by Kilombero Sugar Company for this study. The selection was based on the fact that it has been under sugarcane production for a relatively longer time than the Ruembe Estate. Msolwa Estate is subdivided into three main sections based on different soil types (appendix 4). Selection of soil profile positions was done based on existing soil information (ILLACO, 1967; Mmikonga, 1981) (coupled with reconnaissance auger field observations in various parts of Msolwa Sugar Estate).

Section 1:

This starts immediately from the foothills of Gologolo mountains to the North and Great Ruaha river to the West. It is characterized by light textured soils, mostly sandy clay loams. This section is comprised of seventy fields each of about 20 hectares under sugarcane.

Section 2:

It is occupied by light to heavy textured soils, almost encompassed by Msolwa river to the North and Nyarubungo river to the South. There are 40 fields (each of about 20 hectares) under sugarcane in this area.

Section 3:

This is located between Msolwa river on the Eastern side and TAZARA railway to the West. It is characterized by seasonal flooding and heavy textured soils. This section has 54 fields (each of about 20 hectares) under sugarcane.

3.2.2 Soil profile description and sampling

One representative soil profile from each section and one control profile from a virgin land (Appendix 4) were dug to a depth of at least 200 cm. Soil samples were collected from each horizon for physical and chemical analysis (Table 1). Undisturbed soil samples were also collected at 0-5 cm, 50-55 cm, and 100-105 cm depth for determination of bulk density and water retention characteristics. The morphological characteristics of each profile were described in detail using guidelines for Soil Profile Description (FAO, 1990). Soil colour was determined using Munsel Soil Colour Chart (Munsel Colour Company, 1975). Exact locations of each site in terms of international coordinates were determined using Sony Global Positioning System Receiver. Basing on both field and laboratory data, the soils were classified to the family level according to USDA Soil Taxonomy System (Soil Survey Staff, 1990) and to 2^{nd} level of FAO-Unesco soil classification system (FAO, 1988).

3.2.3 Soil sampling for fertility evaluation

Sixteen commercial cane fields, each of about 20 hectares under second ratoon crop were randomly selected in the Msolwa Sugar Estate of Kilombero Sugar Company. Basing on the area, seven, five, and four fields from section 1, 2 and 3 respectively were sampled. Each field was equally subdivided into three sampling units. From each field, 32 auger samples, 8 from each sampling unit were taken at each depth of 0-30, 30-70 and 70-100 cm. These samples were composited into one for each respective depth. All samples were air dried, ground to pass through a 2 mm sieve then analyzed for chemical properties.

3.3 Laboratory Soil Analysis

The methods used to analyse for physico-chemical characteristics of the soils are presented in table 1.

3.4 Mineralogical analyses

One subsoil sample was taken from each profile for mineralogical study. The clay mineralogical study was done on soil clay fraction. The following procedure was used: All samples were treated with equal amount (30ml) of 30% hydrogen peroxide overnight to destroy soil organic matter. The excess of H_2O_2 was evaporated on a water bath at 70°C. The samples were then dispersed by using 1N sodium hydroxide. These samples were then shaken overnight on an end over end shaker. Sand fractions were removed by wet sieving. Clay and silt fractions were transferred to a glass cylinder and their volumes made up to 1000 ml. At appropriate time and depth intervals, clay fraction was separated from silt by successive decantation and flocculation by 0.5N HCl. The process of decantation to separate clay from silt continued until enough clay was obtained for analysis. The clay samples were then saturated with Mg^{2+} and K^{+}. Magnesium and potassium saturated samples were mounted on glass slides from a water suspension at room temperature and allowed to dry. Mg saturated samples were later glycerol-solvated while K saturated samples were heat-treated for one hour at 300°C and 550°C. The clay mineralogy of soil was determined using X-ray diffractometer model Shimadzu XD-D1 by interpreting the x-ray diffractograms using the standard guidelines and books (Thorez, 1975; Brindley and Brown, 1980; and Dixon and Weed, 1989).

3.5 Sampling of plant material and water

3.5.1 Sampling of sugarcane leaves

Twenty cane leaves were sampled from each sampling unit of the same field where soil sampling was done giving a total of 60 leaves per field. The 3rd leaf (partially unrolled leaf taken as 1st leaf) was sampled at the age of 3-4 months. The second sampling was done after 2-3 weeks. All sampling were confined to the time period between 6.30 and 8.00 a.m. (Societe de Technologie Agricole et Sucriere de Maurice, 1975). Each leaf was folded into two to get the exact middle of the same. A section of 5cm was cut from each side and the midrib carefully removed. The samples were composited to obtain one sample per field. Then the obtained samples were suspended by a piece of

Table 1. Methods used for characterization of soils

Parameter	Method of analysis	Reference
a) Particle size analysis	Hydrometer method	Juo (1979)
b) Bulk density	Metallic core procedure	Blake and Hartage (1986)
c) Soil moisture retention at various suction	Pressure Plate apparatus	National Soil Service (1987)
d) Soil pH	Potentialmetrically using glass electrode pH-meter in 1:2.5 soil/water suspension and 0.01M $CaCl_2$	Mclean (1982)
e) Total Nitrogen	Semi-micro Kjedahl procedure	Bremner and Mulvaney (1982)
f) Available Phosphorus	Bray and Kurtz 1	Olsen and Sommer (1982)
g) Exchange-able bases	In neutral ammonium acetate extract, then determined by atomic absorption spetrophoptometer	National Soil Service (1987)
h) Cation exchange capacity	specrophotometer By Percolation with 1M NH_4OAC.	National Soil Service (1987)

wire in a well ventilated oven at a temperature of 70-90^{0}C for two hours. Dried leaves were chopped into pieces of approximately 1.0 cm long, ground in a mill to pass through a 1.0 mm mesh ready for analysis. The soil fertility assessment was based on the obtained soil and plant material analytical data.

3.5.2 Sampling irrigation and underground waters

Irrigation water was sampled at the main intake to Msolwa Estate. Two samples were collected in a day, in the morning (8.30 a.m) and the other sample in the evening (6.30 p.m). Other sets of samples were collected one month later. Also one sample of underground water was collected from profile no. KLP3, (in field no. 34 of section 1) at a depth of 150 cm from the surface in mid January 1995. All samples were analyzed for K, Ca, Mg, Na, Fe, Mn, Zn, Cu and total soluble salts to determine water quality for irrigation and some nutrients contribution to the soil.

3.6 Field Fertilizer Trials.

One field trial was conducted in two sites (field no.12 of section 1 and field no. M17 of section 2) to determine nutrient uptake (N, P, K, Ca, and Mg) under different NPK levels in the soil. The second ratoon of sugarcane variety NCO 376 was used as a test crop. Triple supper phosphate (TSP), Potassium sulphate (K_2SO_4) and urea

Table 2. NPK treatment combinations applied to soils of sections 1 and 2

Treatment	N kg/ha	P kg/ha	K kg/ha
T1	0	0	0
T2	30	20	60
T3	60	40	120
T4	90	60	180
T5	120	80	240

were used as the source of P, K and N respectively. A complete randomized block design was employed in five replicates. Treatments are summarized in table 2.

The second field trial was conducted in field no. M4 located in section 2 to study the effect of K, P, and different combinations of P and K in the soil on the nutrient uptake by sugarcane plant leaves. A completely randomized block design was employed. Treatments are shown in table 3.

Leaf samples were collected from each plot three months after fertilizer application for determination of nutrient uptake. All fertilizers in form of urea, triple supper phosphate and potassium sulphate were applied at the same time when crop was one month old and covered by soil to prevent loss of nitrogen through volatilization.

3.7 Laboratory analysis of plant material and water

The analytical methods used to analyse plant materials and water are summarized in table 4.

Table 3. Treatment combinations P.K. and PK applied to soils of section 2 with recommended rates of N.

Treatment	N(kg/ha)	P(kg/ha)	K(kg/ha)
A	0	0	0
B	80	0	0
C	80	20	0
D	80	20	60
E	80	40	0
F	80	40	60
G	80	40	120

Table 4. Methods used to analyse plant and water samples

i) Leaf samples:

Parameter	**Method of analysis**	**Reference**
a) Percentage N	Digestion, distillation and titration against Boric acid	National Soil Service(1991)
b) Percentage P	H_2O_2-Selenium-Salicylic acid method.	National Soil Service (1991)
c) Percentage (K, Ca, Mg)	H_2SO_4-selenium-salicylic acid digestion then determined by atomic absorption spectrophotometer	National Soil Service (1991)
ii) Water Samples:		
a) Soluble cations (Ca^{2+}, Mg^{2+}, Na^+, K^+)	By atomic absorption spectrophotometer	Rhoades (1982)
b) Total soluble salts	Electrical conductivity method	Rhoades, (1982)
c) pH	Potentialmetrically by pH-meter	Mclean, (1982)
d) Sodium adsorption ratio	By calculation using the formula: $SAR = \frac{(Na^+)}{((Ca^{2+}+Mg^{2+})/2)^{1/2}}$	Bohn *et al*. (1985)
e) Micronutrients	By atomic absorption spectrophotometer	Rhoades (1982)

3.8 Statistical Analysis

Simple correlation coefficients were calculated to test the following sets of data:

a) Exchangeable K, Ca, Mg and Na levels in the soils versus sugarcane leaf contents.

b) DTPA- extractable Fe, Mn, Zn and Cu levels in the soils versus concentration in cane leaf.

The analysis of variance as outlined by Snedecor and Cochran (1989) was used to assess treatment effects in field experiments based on the model:

$Y_{ij} = U + T_i + B_j + E_{ij}$

Where: Y_{ij}=leaf N,P,K,Ca content due to treatment T_i and block B_j.

U= general mean.

T_i=true effect due to ith treatment.

B_j=true effect due to jth block.

E_{ij}=residual error.

CHAPTER IV

4.0 RESULTS AND DISCUSSION

4.1 Soil characterization

4.1.1 Soil Morphological properties

Detailed information on the sites and representative soil profile descriptions together with the chemical and some physical properties of Msolwa Estate soils are presented in appendix 2. The morphological characteristics of soils from all three sections indicate that they are very deep occupying alluvial plain with a slope of less than 1% and without surface stoniness or rock outcrops. The cultivated soils are young, stratified soils (AC profiles). The presence of some illitic mica and high activity clay is an indication that these soils are not highly weathered. Occurrence of Fe and Mn nodules (KLP1 and KLP2) and high activity clay suggests an intermediate stage of ferralization process and an evidence of senile stage of development of alluvial soils (Buol *et al*. 1980). Fluctuation of water table (KLP1 and KLP2) and occurrence of oxidation-reduction mottles is an evidence of gleization process. The topsoil texture is sandy loam to clayey and the structure is subangular blocky. The colours of surface soils are mostly dark grey when dry and black when moist.

4.1.2 Soil physical Properties

A summary of the physical properties of soils used from representative soil profiles are in table 5 and appendix 2. Physical and chemical properties for the auger samples from sugarcane commercial fields are in appendices 5, 6 and 7.

Soil texture

Composite auger soil samples from section 1 showed that about 86% of topsoils (0-30 cm) are sandy clay loam with minimal textural change within a depth of 100 cm (appendix 5). Generally the percentage of sand is lowest in the surface with mean value of 60%. The Ah horizon of the representative profile (KLP3) is sandy loam with fine and medium size sand constituting the major part of the sand fractions.

Although sugarcane grows in a wide range of soils, loamy and clay loamy soils provide the best rooting medium for this crop and it requires little management to minimize possible reduction in yields due to poor soil conditions (Yates, 1977; ILACO, 1981). Soils of this section appear to have favourable soil texture for sugarcane.

Soils of section 2 which were represented by profile KLP1 had sandy clay loam texture in Ah horizon (0-35). The general trend showed that the total sand contents increased with depth while clay contents decreased with depth. Auger composite samples (appendix 6) showed that this section is predominantly sandy clay in texture with appreciable amounts of clay up to 100 cm depth.

Section three was represented by profile KLP2. Both profile and composite auger samples (appendix 7) showed that these soils are clayey with clay contents ranging between 38 and 64% in topsoils with slight increase with depth.

The clay content of soils of section 1 were within the acceptable range of 7 to 27% suggested to be very good for most agricultural use (Landon, 1984). Soils of section 2 and 3 were above this range. Such soils are associated with poor aeration, drainage and restricted plant root growth. In mechanized agriculture they are easily compacted. Therefore they require extra management effort to minimize yield losses (Yates, 1977) such as improved drainage and deep ploughing.

Bulk density

The bulk density of the topsoils ranged from 1.24 in the virgin soils to 1.47 g/cc in soils of section 3. In all profiles bulk density increased with depth (Table 5).

Soils of section 3 showed a sharp increase in bulk density up to 1.70 g/cm^3 below a depth of 30 cm from the surface. This trend may be caused by decrease in soil organic matter with depth. Also it may be reflecting the effect of heavy agricultural machinery on these soils. Yang (1978) observed that the effect of heavy agricultural machinery was more pronounced in soils with high water holding capacity and massive structure, a situation applicable to some of soils of section 2 and 3. Bulk density values of topsoils were less than critical values of 1.46 and 1.63 g/cm^3 for silty and clayey soils respectively (Taylor *et al*., 1966; Landon, 1984).

For sugarcane growth, bulk density values of less than 1.4 g/cm^3 are recommended (Trouse and Humbert, 1961). Bulk density values between 1.4 and 1.6 g/cm^3 are critical for sugarcane growth (Juang, 1972). Higher bulk density values in section 3 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. Cultivation and other mechanical operations should be carried out under ideal soil moisture regime to avoid further soil compaction.

Table 5. Some soil physical characteristics of the representative soil profiles

Sample and Depth (cm)	% Soil separets			Text. Class	Silt/ Clay	B.D. g/cc	P.D g/cc	Porosity %
	sand	silt	clay					
Section 1								
Ah 0-60	70	18	9	SL	2.00	1.46	2.65	44.9
C1 60-110	86	5	9	SL	0.55	1.52	2.71	43.9
C2g 110-130	55	18	22	SCL	0.82	1.57	2.89	45.7
C3g 130-145	25	28	47	C	0.58	nd	nd	nd
C4g 145-207	63	12	25	SCL	0.48	nd	nd	nd
Section 2								
Ap 0-35	61	14	25	SCL	0.56	1.43	2.54	43.7
Cg 130-70	69	8	23	SCL	0.35	1.50	2.61	42.5
Cg2 70-100	67	8	25	SCL	0.32	nd	nd	nd
Cg3 100-134	75	8	17	SL	0.47	1.52	2.89	47.4
Cg4 134-161	70	9	21	SL	0.43	nd	nd	nd
2Cr 161-214	89	2	9	Ls	0.22	nd	nd	nd
Section 3								
Ap 0-35	44	15	41	C	0.36	1.47	2.44	39.7
Cg1 35-82	30	16	54	C	0.29	1.56	2.65	41.1
Cg2 82-150	39	10	51	C	0.20	1.70	2.68	36.6
Cg3 150-200	47	12	41	SC	0.29	nd	nd	nd
Virgin								
Ah 0-40	62	12	26	SCL	0.46	1.24	2.55	51.4
Bw 40-75	61	10	29	SCL	0.34	1.44	2.67	46.1
C1 75-120	57	26	17	SL	1.53	1.48	2.71	45.4
C2g 120-165	33	2	65	C	0.03	nd	nd	nd
Ahb 165-190	23	33	54	C	0.61	nd	nd	nd
Bbg 190-212	23	32	45	C	0.71	nd	nd	nd

nd = not determined, SL= Sandy loam, SCL= Sandy Clay Loam, LS= Loamy sand, SC= Sandy Clay C= Clayey

Porosity

The total porosity for topsoils and subsoils ranged from 39.7 to 51.4 and 36.9 to 47.4% respectively. For topsoils, a range of 30 to 70% is generally accepted for most crops (Harrold, 1975). The author observed that less than 40% in sandy and 50% in clayey soils are likely to restrict root growth. On this basis restricted sugarcane root growth is likely to occur in sections 2 and 3. The relatively high values of porosity and low values of bulk density in the virgin soils compared to cultivated ones reflects the influence of soil organic matter on these parameters and possibly the effect of agricultural machinery on cultivated soils. Virgin soils had relatively higher contents of organic matter in topsoil (4.48%) than cultivated ones (an average of 2.70%). Organic matter is very important factor in the formation of good soil structure. It functions as granulator for the mineral particles creating a loose condition which results to porous soils (Brady, 1974). On the other hand, heavy agricultural machinery can cause soil compaction (Trouse and Humbert, 1961; Yang 1978). Soil compaction increase soil bulk density (Yang, 1978).

Soil moisture retention characteristics

Figure 4 shows the moisture retention characteristics of three depths of the studied soils. At any given water potential, the volume fraction of water in the surface layer (0-5cm) was lower than intermediate (50-55 cm) and subsoil (100-105 cm) layers.

Soils from section 3 contained a higher water content at field capacity (FC) (-10kPa matric potential) than those of section 1 and 2. These findings are in agreement with the observations by Hillel (1982) that soils dominated by fine particles can hold more water than those dominated by course particles.

Soil water content at permanent wilting point (PWP) (-1500kPa matric potential) ranged from 13.6 to 32.7 and 12.5 to 31.1% in topsoils and subsoils respectively. The highest values are in section 3. High clay contents could be a possible reason because not all water retained by the soil fine particles can be drained easily at 1500 KPa matric potential (Baver *et al.*, 1983). Despite relatively high water contents at FC and PWP in section 3, the available water was the lowest. These findings are in agreement with those of Oswal (1983) that fine particles can hold much water which is not necessarily available to higher plants. Available water was generally low ranging between 6.1 and 16% in topsoils and from 3.7 to 23.1% in subsoils.

From the gradients of soil moisture characteristic curves, soils of section 2 showed a tendency to lose more water with small change in matric potential as compared to other sections. This trend suggests a different moisture release pattern of these soils.

On the basis of these findings, it is apparent that soils of each section should have different irrigation schedules which must take into consideration the observed differences in water holding characteristics.

Relatively higher clay contents in soils of section 2 and 3 contribute significantly to poor drainage conditions in these ares, thus suggesting that a well planned and extensive drainage system should be designed to improve drainage.

Waterlogging is believed to be one of the chief causes of soil salinity (Gupta and Gupta, 1987). Poor drainage observed in section 2 and 3 can cause development of soil salinity. Precautions should be taken by practising proper land drainage and flood control measures. This can be achieved by improving the gradient and capacity of existing drainage canals.

4.1.3 Soil Chemical properties

Results of some chemical analysis of composite auger soil samples from sugarcane fields for fertility evaluation are given in table 6 and appendices 5, 6 and 7.

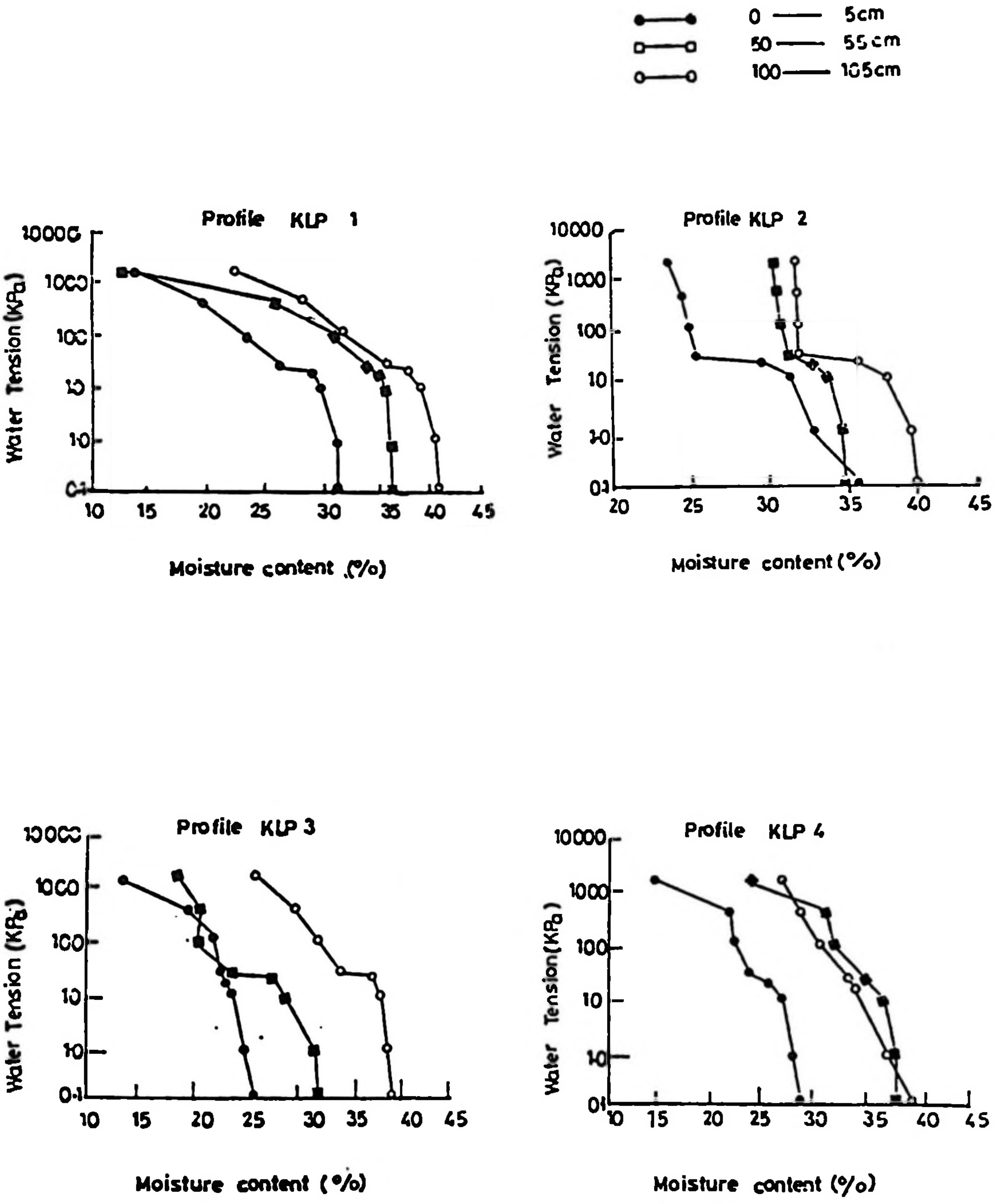

Figure 4. Soil moisture retention characteristics

4.1.3.1 Soil reaction

All soils had pH values greater than 5.5. The pH values of topsoil varied from slightly acidic to very slightly acidic across the estate and increased with soil depth. Section 1 had relatively high soil pH (mean: 6.7 and 7 for topsoil and subsoil respectively) as compared to section 2 and 3 (mean 6.2 for topsoil). The relatively low pH values in topsoils may be due to acidification resulting from continuous application of ammonium based fertilizers which have acidifying effects. However, the pH values were found to be within the acceptable range for sugarcane production (5 to 8.5) (Husz, 1974).

4.1.3.2 Total nitrogen and organic carbon

Soil nitrogen in topsoil was rather low. It ranged from 0.08 to 0.15% across the estate with a mean of 0.1% and standard deviation of 0.04%. Generally, total N contents in soils decreased with depth. Mean values are relatively high in section 3 with little variation with depth when compared with other sections, a trend which was also observed for soil organic carbon.

Nitrogen is a very important nutrient for sugarcane (ILACO, 1981) which is known to be a heavy feeder of this nutrient. Demeterio (1960) as cited by Mkelenda (1985) found that critical N concentration in soils for

Table 6. Mean values of some chemical properties of composite soil samples of Msolwa Estate

	Section 1			Section 2			Section 3		
Depth (cm)	0-30	30-70	70-100	0-30	30-70	70-100	0-30	30-70	70-100
Soil pH (1:2.5)									
H_2O	6.7	6.9	7.0	6.2	6.4	6.8	6.3	6.4	6.5
KCl	5.1	5.3	5.4	4.8	5.1	5.4	4.8	4.9	5.0
O.C (%)	1.45	0.49	0.19	2.16	0.69	0.49	1.60	0.54	0.43
Total N (%)	0.08	0.05	0.03	0.13	0.06	0.05	0.12	0.08	0.05
Bray-1 P (ppm)	12.7	8.6	6.0	14.5	6.8	3.6	6.7	1.3	0.9
CEC (cmol(+)/kg)	16.2	12.2	10.2	16.6	17.6	15.1	20.0	19.0	15.8
Exchangeable Bases (cmol(+)/kg)									
Ca	7.8	4.6	3.2	6.6	5.7	4.7	6.2	6.0	4.8
Mg	2.0	1.7	1.7	2.1	2.52	2.48	4.0	4.5	2.6
K	1.3	1.4	1.6	1.72	1.76	1.34	1.60	1.30	1.50
Na	0.6	0.6	0.5	0.54	0.88	0.71	0.60	0.80	0.90
B.S (%)	73.7	67.6	69.0	62.0	61.7	61.7	62.0	65.4	65.7

sugarcane in Philippines was 0.3%. Therefore, for optimum production of sugarcane in this estate N should be relatively high in section 3 with little variation with depth when compared with other sections, a trend which was also observed for soil organic carbon.

Nitrogen is a very important nutrient for sugarcane (ILACO, 1981) which is known to be a heavy feeder of this nutrient. Demeterio (1960) as cited by Mkelenda (1985) found that critical N concentration in soils for sugarcane in Philippines was 0.3%. Therefore, for optimum production of sugarcane in this estate N should be supplied in form of fertilizers.

Organic carbon content of topsoils ranged from 0.7% to 2.6%. The mean values in topsoils was in the order of section 1 (1.45%) < section 2 (2.16%) < Section 3 (1.6%) < virgin soil (2.6) In some of representative soil profiles, organic carbon contents was found to decrease irregularly with depth, a characteristic behaviour of alluvial soils (FAO, 1988). The relatively high organic carbon in soils of section 2 and 3 may be due to low rate of mineralization caused by frequent flooding and general poor soil aeration in heavy textured soils. According to Yates (1977) the organic carbon content of 1.22 to 2.3% in the topsoil is appropriate for sugarcane crop. Therefore, organic matter is not a limiting factor for cane production in this estate.

The carbon/nitrogen (C/N) ratio for the topsoils ranged from 8.4 (low) to 19.0 (high) with a mean of 15.0 and standard deviation of 3.2. Section 1 had relatively high mean C/N ratio (15.0) > section 3 (13.4) > section 2 (13.0). According to the rating by ILACO (1981) the C/N ratios of the studied soils are medium. The medium values suggest a good quality soil organic matter with good potential for nitrogen mineralization. Despite good quality and medium contents of soil organic matter, total N is rated as low due to high demand for this nutrient by sugarcane which can not be supplied from the soil organic matter alone.

4.1.3.3 Available soil phosphorus

According to ratings by EUROCONSULT (1989), Bray-1 extractable P in the topsoil ranged from very low to medium (2.10 to 18.2 mg/kg) with a mean of about 10.2 mg/kg and standard deviation of 4.4 mg/kg. The mean values in the topsoils are low in section 3 (6.7 mg/kg); medium in sections 1 and 2 (12.6 and 14.5 mg/kg respectively). The change in P contents from top to 100 cm depth was very sharp in soils of section 3 with mean P content of 0.9 mg/kg as compared to that of 6 and 3.6 mg/kg at the same depth for section 1 and 2 respectively. These results may be due higher Ca and Mg contents in the subsoils of section 3 as compared to sections 1 and 2. The higher Ca and Mg contents can fix P through formation of insoluble compounds. The trend of available P within the profile and from one section to another was similar to that of organic carbon, thus suggesting that soil organic matter supplies the main portion of available P in these soils. According to Yates (1977) and Ayres and Humbert (1957), a critical level of P for sugarcane response to fertilizer is 6.0 mg/kg Bray-1 P. These results indicate that sugarcane grown in section 3 may require mild application of P fertilizers in the soil.

4.1.3.4 Exchangeable K, Ca, Mg and Na

These soils had very high contents of exchangeable K ranging from 0.52 to 2.68 cmol(+)/kg in topsoils with a mean of about 1.51 cmol(+)/kg and standard deviation of 0.56 cmol(+)/kg. Mean exchangeable K in both topsoils and subsoils were very high (>1.2 cmol(+)/kg) in all three sections). Since the exchangeable K in these soils is above the optimal range of 0.2 to 0.64 cmol(+)/kg (Sanchez, 1976; Yates, 1977), sugarcane response to K fertilization is therefore unlikely.

Exchangeable Mg values in the studied soils was generally high ranging from 1.53 (medium) to 6.22 cmol(+)/kg (high) in the topsoils with a mean of about 2.69 cmol(+)/kg (medium) and standard deviation of 1.47 cmol(+)/kg. The mean values in topsoils were high in section 3, (4.0 cmol(+)/kg); medium in section 1 and 2 (about 2.0 cmol(+)/kg). For subsoil samples mean values of exchangeable Mg were in the order of section 3 (3.5 cmol (+)/kg) > section 2 (2.3 cmol(+)/kg) > section 1 (1.7 cmol(+)/kg).

Levels of exchangeable calcium in the topsoils ranged from 2.99 (low) to 9.98 cmol(+)/kg (medium) with a mean of about 7.0 cmol(+)/kg (medium) and standard deviation of 1.72 cmol(+)/kg. There was a general trend that exchangeable Ca decreased with depth, section 1 had the highest concentrations of exchangeable Ca in the topsoil. It has been generalized that sugarcane growing in soils with exchangeable Ca concentration of more than 3.5 cmol(+)/kg can not respond to Ca fertilization (Yates, 1977).

The exchangeable Na in topsoils of the study area ranged between 0.35 (medium) to 0.86 cmol(+)/kg (high) with a mean of 0.6 cmol(+)/kg (medium). The exchangeable sodium percent (ESP) appears to be low (mean 5.1). The levels of these parameters indicate that salinity, and/ or sodium toxicity are not likely to be a limiting factor for sugarcane production in the study area. Sugarcane is known to tolerate ESP values of up to 15% (ILACO, 1981) without significant yield losses. However, precaution should be taken to avoid possibility of building up of the salts from the subsoils to topsoils due to raised ground water table. Improving drainage can prevent accumulation of salt from irrigation or underground water.

4.1.3.5 Cation exchange capacity (CEC)

The CEC of the topsoil ranged from 11.6 to 25.6 cmol(+)/kg with a mean of about 17.6 cmol(+)/kg and standard deviation of 3.85 cmol(+)/kg. The comparatively high CEC of section three (mean 20 cmol(+)/kg in topsoil) is contributed by relatively high amounts of clay and organic matter. This observation is further supported by a significant ($P=0.01$) correlation coefficient (0.76) between CEC and clay. The CEC of clay was generally high. In topsoil it ranged from 46 (section 3) to 78 cmol(+)/kg (section 1) while for the subsoil the range was between 35 and 88 cmol(+)/kg. Although 1:1 clay mineral (kaolinite) are dominant in these soils (Table 10), the CEC of clay reflects the influence of smectites which have CEC between 80 and 150 cmol(+)/kg as compared to that of kaolinite (3-15 cmol(+)/kg) (Buol *et al.*, 1980).

4.1.3.6 Micronutrient contents of the studied soils

Table 7 shows the levels of some DTPA extractable micronutrients in the studied soils. Generally their levels were lower in subsoils as compared to topsoils (Fig. 5 and 6). This is probably due to continuous deposition with fresh sediments. The difference in micronutrient contents between topsoil and subsoil may affect micronutrient uptake by the crop especially during the late stages of growth (Sillanpaa, 1982). At this stage, the root system is highly developed and the they depend on nutrients supply from the subsoil.

The level of DTPA-extractable Zn (topsoil) ranged from 0.62 to 1. 64 mg/kg with a mean value of 1.15 mg/kg. In subsoils, the Zn level decreased to mean value of 0.32 with a range between 0.14 and 1.13 mg/kg. Section 3 recorded lowest Zn levels in topsoils with mean value of 0.94 as compared to section 1 and 2 which had a mean values of 1.14 and 1.44 mg/kg respectively. The proposed deficiency level for Zn in the soil is 0.4-0.6 mg/kg. Values greater than 10-20 mg/kg are regarded as excessive (Sillanpaa, 1982). In all soils Zn levels were above the critical level and hence adequate for sugarcane production.

The levels of Fe and Mn in topsoils ranged from 55.3 to 205.7 (mean 131.0) and 7.4 to 69.0 (mean 28.9) mg/kg respectively. Among the three sections, section 2 had highest Fe levels (mean 187.6 mg/kg) but lowest Mn level (mean 14.0 mg/kg). Proposed deficiency level of DTPA-Mn in the soil vary from 2 to 5 mg/kg. Values greater than 140 to 200 mg/kg are regarded as excessive (Sillanpaa, 1982). Therefore the crop will not suffer from excess or deficiency of Mn. Levels of Fe in these soils

Table 7. Micronutrient contents of the studied soils

Field/N	Depth (cm)	Micronutrients contents (mg/kg)			
		Zn	Cu	Fe	Mn
		Section 1			
1	0-30	1.16	1.60	130.14	23.57
	30-70	0.15	1.13	39.15	17.19
8	0-30	1.09	1.13	97.76	7.41
	30-70	0.20	0.76	38.61	27.64
12	0-30	1.22	2.27	129.60	27.11
	30-70	0.18	1.40	37.26	12.85
27	0-30	1.64	2.16	135.54	18.96
	30-70	0.19	1.53	36.99	11.96
51	0-30	0.84	2.07	148.50	26.40
	30-70	0.27	1.57	60.75	12.85
71	0-30	1.28	1.53	109.08	23.04
	30-70	0.14	0.80	31.32	7.41
132	0-30	0.77	1.96	55.35	18.96
	30-70	0.23	2.40	72.09	18.43
		Section 2			
M10	0-30	1.20	2.26	163.62	11.16
	30-70	0.34	1.07	25.38	17.54
M17	0-30	1.45	2.76	174.96	17.72
	30-70	0.42	1.06	28.35	6.11
M20	0-30	1.58	2.60	170.10	13.83
	30-70	0.53	1.43	44.55	11.16
M38	0-30	1.56	3.00	205.74	12.76
	30-70	0.31	1.00	46.71	3.08
		Section 3			
65	0-30	0.54	3.40	109.08	36.86
	30-70	0.20	2.70	36.18	13.33
101	0-30	1.54	3.37	154.98	36.33
	30-70	0.17	1.60	22.41	20.38
105	0-30	0.77	3.03	134.46	69.10
	30-70	0.21	1.33	25.11	14.18
120	0-30	0.62	0.66	100.98	56.52
	30-70	0.50	0.83	26.73	34.91
124	0-30	1.25	1.73	77.49	63.52
	30-70	1.13	1.43	30.24	15.9

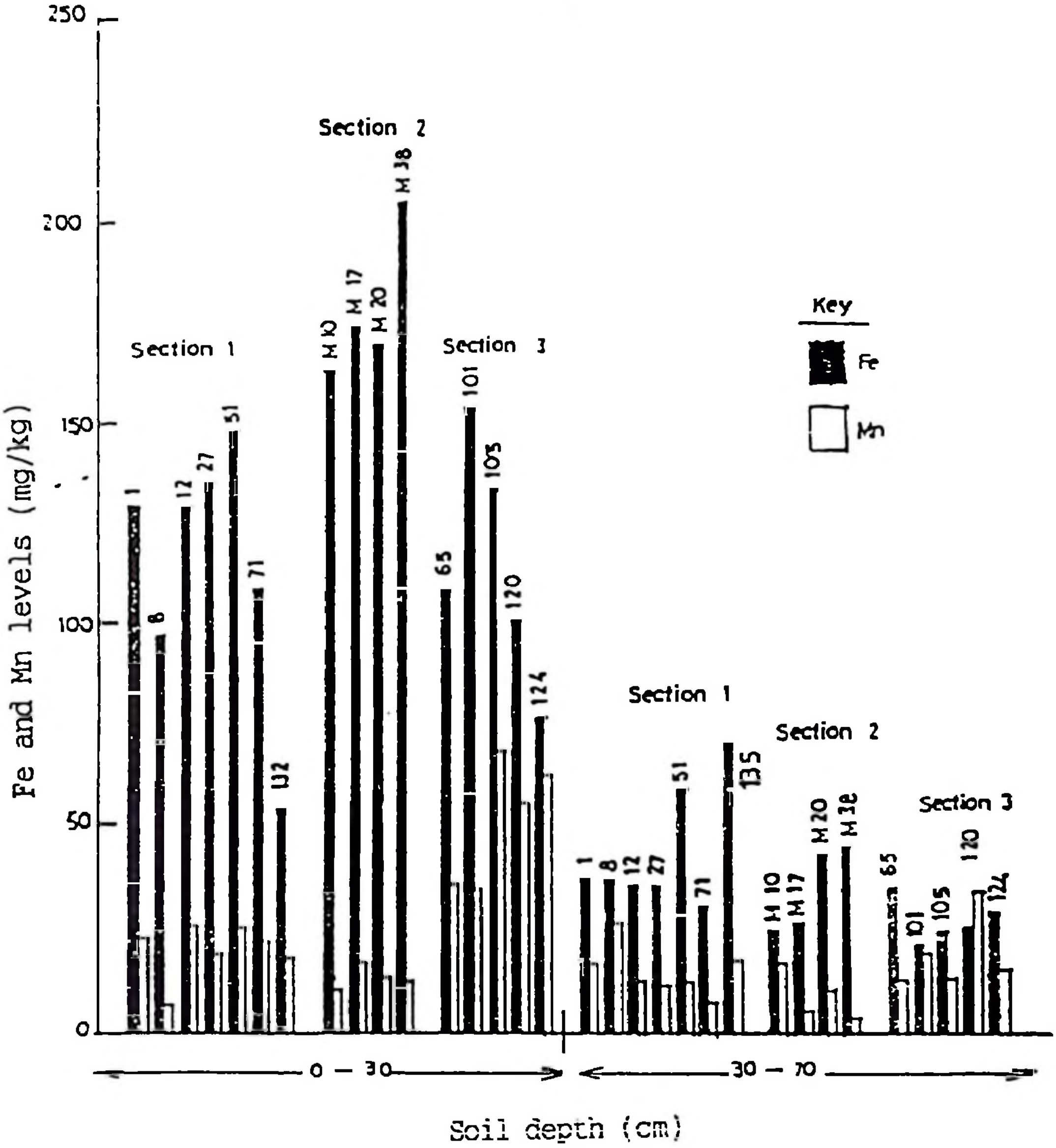

Figure 5. Variation of Fe and Mn with soil depth

NB: 1-124 are field numbers

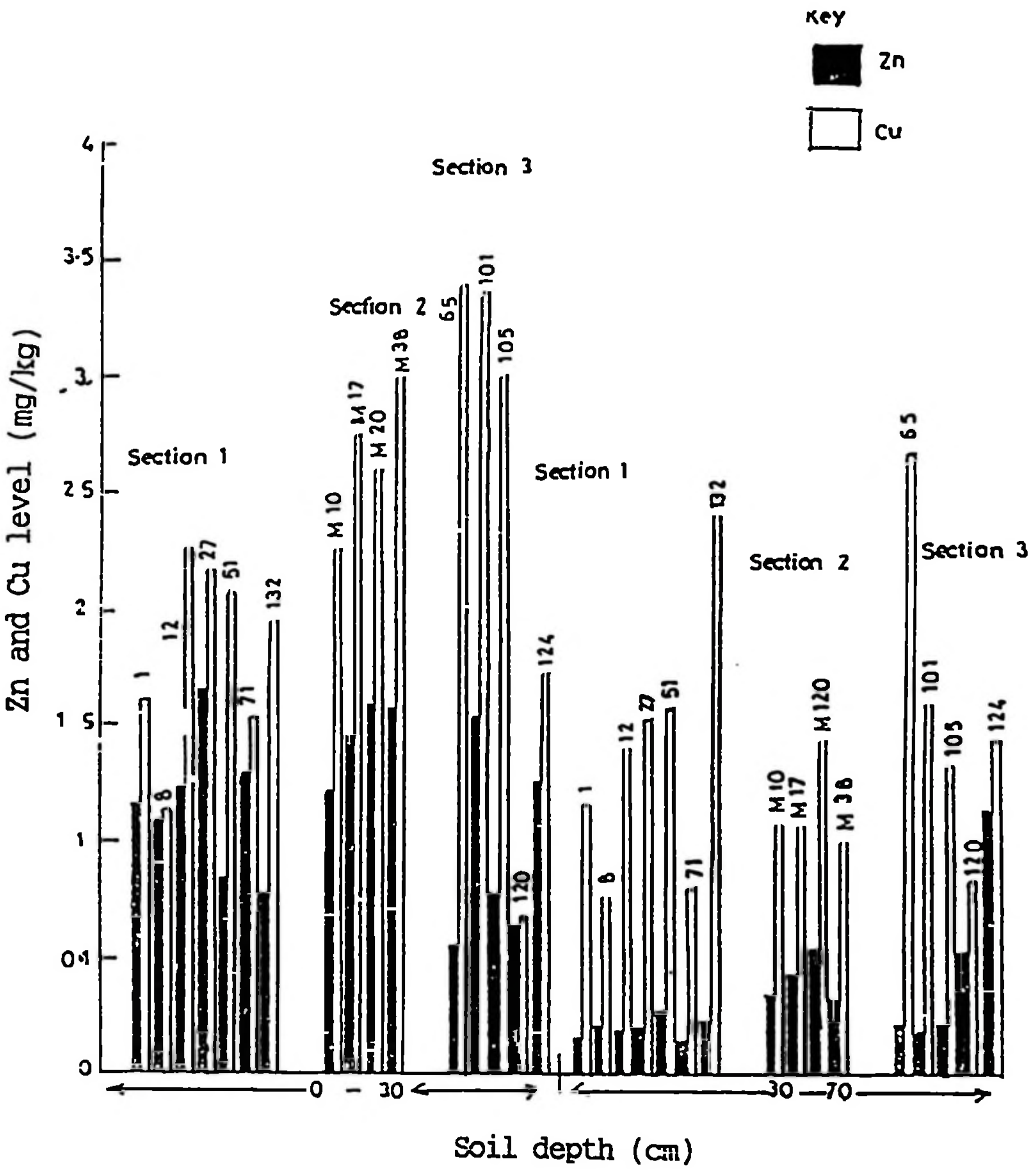

Figure 6. Variation of Zn and Cu with soil depth

NB: 1-124 are field numbers

appear to be high which may fix P by forming insoluble compounds hence limiting its availability to sugarcane. The mean values of Copper levels in the soils ranged from 0.66 mg/kg (very low) to 3.4 mg/kg (very high) in topsoils and 0.76 mg/kg (very low) to 2.6 mg/kg (very high) in subsoils. Generally, it appears that these levels are adequate for cane production.

High levels of Fe and Mn found in these soils especially in section 3 are most likely due to high contents of the same in the parent material and flooding effects. The Migomberani and Gologolo Mountains from which Msolwa estate receives sediments, are composed of igneous rocks. Igneous rocks are known to be rich in Fe (Thompson and Troeh, 1985). This fact is further confirmed by the presence of goethite (FeOOH) in the clay mineralogy (Table 10) and Fe and Mn nodules in profile KLP1 and KLP2 (Appendix 2).

Muji and Bandyopandhyah (1992) observed that soil submergence caused decrease in contents of DTPA extractable Cu while DTPA extractable Fe and Mn were found to increase in a range of 201 to 2022.3 % and 2.1 to 101.0 % respectively. This increase in Fe and Mn is due to reduction of Fe^{3+}, Mn^{3+} to Fe^{2+} and Mn^{2+} respectively which are more soluble. However, the levels of Fe and Mn did not correlate with soil pH data. It is generally accepted that high levels of micronutrients are associated with acidic soils (Neue, 1989; Tisdale *et al.*, 1990).

In order to prevent these micronutrients from accumulating to toxic levels, an improved drainage system and deep tillage to provide better soil aeration are essential.

4.1.3 Soil fertility status

Table 8 presents ratings of some soil chemical properties. Composite topsoil (0-30cm) samples from sugarcane commercial fields were used to assess soil fertility status for the Msolwa Estate according to EUROCONSULT (1989). With the exception of total N which is in low supply all other tested parameters are within the acceptable range for sugarcane production.

4.1.4 Nutrient balance for selected elements

The availability of nutrients for plant uptake depends on both absolute levels and balances in the soils (Ngailo and Kips, 1991). It was therefore deemed necessary to consider the nutrient ratios for Ca/Mg, Mg/K, K/Total exchangeable bases (TEB) and Fe/Mn (Table 9). The Ca/Mg ratio ranged from 0.9 to 4.7 with a mean value of 3.0. The mean values were: Section 1 (3.8) > section 2 (3.4) > section 3 (1.8). The Ca/Mg ratio of 2 to 4 are the most favourable (Ngailo and Kips, 1991). When this ratio is greater or equal to 5:1, Mg becomes increasingly unavailable and P availability may be reduced (Landon, 1984). Soils of section 1 and 2 are within the acceptable limits. With exception of field no. 120 other fields in section 3 are above the lowest acceptable limit of 1, below which Ca deficiency symptoms are likely to be observed on the plants.

With exception of field no. M10 and M20 of section 2, Mg/K ratios are within the desired range of 1 to 4. A Mg/K ratio of less than one may adversely affect Mg uptake.

In all soils K/TEB ratios were above 2% which has been reported to be the minimum requirement to avoid K deficiency. (Ngailo and Kips, 1991).

The ratios of Fe/Mn ranged from 1.2 to 16.1 (mean 6.8). Section 3 had the lowest mean values of 2.4 < section 1 (6.2) < section 2 (13.2). The Fe/Mn ratio of 15:1 is recommended for normal growth (Husz 1974). When this ratio is 1:1 or less, Fe deficiency or Mn toxicity develops. Therefore Fe deficiency or Mn toxicity is no likely to be the limiting factor for cane production in this estate.

4.1.5 Soil clay mineralogy

The x-ray diffractograms of the studied soils are presented in appendix 8. The estimation of the relative mineralogical composition of the clay fractions is based

Table 8. Rating of fertility status of Msolwa Estate soils (0- 30cm)

Parameter	Range	Mean	Rating
pH (H_2O)	6.0-7.2	6.4	Slightly acidic
N (%)	0.08-0.15	0.1	low
O.C (%)	0.7-2.5	1.68	Medium
C/N ratio	8.4-19	15.0	medium
P (mg/kg)	2.10-18.2	10.2	medium
K (cmol(+)/kg)	0.52-2.68	1.51	Very high
Ca(cmol(+)/kg)	2.99-9.98	7.02	Medium
Mg (cmol(+)/kg	1.53-6.22	2.69	medium-High
Na (cmol(+)/kg	0.35-0.86	0.60	medium
ESP	2.40-9.0	5.1	low
CEC (cmol(+)/kg	11.6-25.6	17.6	medium
DTPA-Fe (mg/kg)	55-205	131.0	na
DTPA Mn (mg/kg)	7.4-69.0	28.9	na
DTPA Zn (mg/kg)	0.62-1.64	1.15	na
DTPA Cu (mg/kg)	0.66-3.4	2.1	na

na = not available

Table 9. Ratios of some nutrients in the topsoils (0-30) of Msolwa Estate

Field/no.	Ca/Mg	Mg/K	K/TEB	Fe/Mn
		Section 1		
1	4.7	1.8	0.08	5.5
8	3.7	1.4	0.12	13.2
12	4.1	1.2	0.13	4.8
27	4.2	1.5	0.11	7.1
51	3.2	1.5	0.13	5.6
71	4.2	2.8	0.06	2.9
132	2.3	1.5	0.15	4.2
		Section 2		
M10	2.6	0.9	0.20	14.7
M17	4.7	1.2	0.12	9.9
M20	3.9	0.8	0.19	12.3
M38	2.3	3.3	0.08	16.1
		Section 3		
65	0.9	3.2	0.11	3.0
101	1.7	2.6	0.12	4.3
105	1.6	2.5	0.13	1.9
120	3.2	2.0	0.10	1.8
124	1.6	1.4	0.20	1.9

on these diffractograms and the results are presented in table 10.

The x-ray diffraction pattern of the clay minerals did not differ much from one section to another. This may suggest the same origin and similar mineralogical composition of these soils. Magnesium - saturated, air dried samples showed x-ray diffraction peaks at 14.7Å, 3.6Å, 7.2Å, 5Å 10Å and 4.18Å. The peak formed at around 14.72Å shifted to 19.2Å upon glycol solvation and to around 13Å upon K saturation (air dry) but reduced to 10Å when heated at 300°C and 550°C. This behaviour indicates the presence of smectite minerals (Msanya *et al.*, 1995; Supriyo *et al.*, 1992).

The basal spacing of 7.2Å and 3.6Å observed in all treatments but which disappeared after heat treatment at 550°C are indicative of kaolinite (Dixon and Weed, 1989). The peaks around 10Å and 5Å which are unaltered by heat treatments are indicative of illites. A basal spacing of 4.18Å observed in magnesium- saturated, air dried samples which disappeared after heat treatments represent goethite.

Semi-quantitative evaluation by peaks summation method shows that soils of section 2 (KLP1) are kaolinitic while the rest are of mixed clay mineralogy, whereby KLP2 and KLP4 have kaolinite, smectite, illite and goethite in varying proportions. Unlike KLP2 and KLP4, KLP3 has no goethite.

Kaolinites and goethites are the components of highly weathered soils (Allen and Hajek 1989). Classification of Kilombero Estate soils (Table 12) reveals that they are relatively young. It is therefore apparent that these minerals are not formed *insitu* but rather been transported from Gologolo and Migomberani mountains. Allen and Hajek (1989) observed that the kaolinite content of Inceptisols and Entisols developed in sedimentary materials depends mostly on provenance of parent sediments.

Illite constitute between 18.3 to 35.6% of the clay minerals in these soils. Like kaolinite, illites have low CEC (20 to 40 cmol(+)/kg) when compared to expanding 2:1 minerals. Potassium released from illitic mica is an important source of K to the growing plants (Fanning *et al.*, 1989). But they can both fix and release K depending on their degree of weathering (Tributh *et al.*, 1987).

Smectites constitute between 15.8 and 22.9% of the clay minerals in the studied soils. Unlike kaolinite and illite, they are expanding minerals which exhibit high cation adsorption capacity (mean CEC of 100 cmol(+)/kg). Their ability to hold fertilizer cations, macronutrients and micronutrients against leaching effect accounts for the fertility of these soils. According to Christenson and Doll (1973) cropping of soil containing smectite effect release of Mg and Fe from their octahedral sheet which are

Table 10. Clay mineralogical composition of subsoil clay samples of the studied soils

Profile	Diagnostic x-ray diffraction peaks	Mineral species and approximate amounts
KLP1	10.2Å, 5.0Å, 3.3Å	Illite (18.27%)
	14.72Å	Smectite (15.8%)
	7.2Å, 3.6Å	Kaolinite 59.1%)
	4.18Å	Goethite (6.8%)
KLP2	10.2Å, 5.0Å, 3.3Å	Illite (31.0%)
	15.2Å	Smectite (16.6%)
	7.2Å, 3.6Å	Kaolinite (49.0%)
	4.18Å	Goethite (3.4%)
KLP3	10.2Å, 5.0Å, 3.3Å	Illite 35.6%)
	14.72Å	Smectite (19.0%)
	7.2Å, 3.6Å	Kaolinite (45.4)
KLP4	10Å, 5Å, 3.3Å	Illite (30.8%)
	15.2Å	Smectites (22.9%)
	7.2Å, 3.6Å	Kaolinites (43.4%)
	4.18Å	Goethite (2.9%)

made available to growing plants. This behaviour may account for high levels of Mg and Fe in the studied soils. On the other hand, smectites have negative effect on physical conditions of soils. High contents are associated with poor hydraulic conductivity, restricted root development and poor workability (Borchrdt, 1989).

4.2 Soil classification

Table 11 gives a summary of the salient morphological and diagnostic features of the studied soils. Table 12 presents the classification of the soils. Profiles in cultivated soils (KLP1, KLP2 and KLP3) had mollic epipedon overlying a C1 horizon. The Mollic epipedon has base saturation of at least 50% which is an indication of fertile soils. The virgin soils (KLP4) had a cambic B horizon underlying an ochric A horizon. The presence of cambic B horizon in the virgin soils suggests a relatively more advanced stage of profile development when compared to the cultivated soils. Other common diagnostic features include aquic soil moisture regime which implies water saturation in some soil horizons and a reducing regime; isohyperthermic soil temperature regime (mean annual soil temperature is 22^0C or higher) and a mixed clay mineralogy.

Table 11. Summary of salient morphological and diagnostic features of the Msolwa Estate soils

Pedon	Diagnostic horizons	Other diagnostic features	Particle size class	Calcareous and reaction class	Soil depth	Mineralogy class
KLP1/section 2	*Mollic A (Molllic epipedon)	Isohyperthermic STR, *gleyic properties (aquic SMR), *fluvic properties: O.C> 0.2% up to 145cm from the surface	Fine loamy	Nonacid noncalcareous	Very deep	Kaolinitic
KLP2/section 3	*Mollic A (Mollic epipedon)	Isohyperthermic STR, *gleyic properties (aquic SMR)	Fine	nonacid non-calcareous.	Very deep	Mixed (Kaolinite, Smectite, Illite, Goethite)
KLP3/section 1	*Ochric A (Ochric epipedon)	Isohyperthermic STR, ustic SMR, *fluvic properties: O.C decreasing irregularly with depth	Coarse loamy	nonacidic non-calcreous	Very deep	mixed (Kaolinite, Smectite, Illite, Goethite
KLP4/virgin	*Orchric A (Orchric epipedon) *Cammbic B (Cambic horizon)	Isohyperthemic STR, *gleyic properties (aquic SMR), thick A horizon (40cm), BS of 75% and dry colour of 7.5YR5/4	fine silty	Nonacid non-calcareous	Very deep	mixed (Kaolinite, Smectite, Illite, Goethite)

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[1] * Terminology used in FAO-Unesco classification, those without * are used mostly in USDA system

Table 12. Classification of the studied soils

Pedon	FAO-UNESCO Classification		USDA Soil Taxonomy				
	Level-1	Level-2	Order	Suborder	Greatgroup	Subgroup	Family
KLP1	Fluvisol	Mollic Fluvisol (FLm)	Mollisol	Aquoll	Haplaquoll	Typic Haplaquoll	Fine silty, kaolinitic, isohyperthemic, very deep, flat, Typic Haplaquoll
KLP2	Gleysol	Mollic Gleysol (GLm)	Mollisol	Aquoll	Haplaquoll	Fluventic Haplaquoll	Fine, mixed, isohyperthemic, very deep, flat, Fluvaquentic Haplaquoll
KLP3	Fluvisol	Eutric Fluvisols (FLe)	Entisol	Fluvent	Ustifluvent	Typic Ustifluvent	Coarse loamy, mixed, isohyperthermic, very deep, flat, Typic Ustifluvent
KLP4	Cambisol	Eutric Cambisols (CMe)	Inseptisol	Aquept	Tropaquept	Typic Tropaquept	Fine silty, mixed, isohyperthermic, very deep, flat, Typic Tropaquept

Profile KLP3 differed from the rest in soil moisture regime (Ustic). Sugarcane requires well drained and aerated soils (Yang, 1978). The observed aquic soil moisture and reducing regime in sections two and three is likely to cause poor sugarcane yields in these sections. The existing poor drainage system and poor flood control measures are among the causes of unfavourable soil moisture regime. The situation can be improved by increasing capacity and gradient of existing drainage canals.

4.3 Nutrients uptake by sugarcane from unfertilized commercial fields

The data on nutrients uptake by sugarcane are presented in table 13 and 14. With exception of K and Ca all other plant nutrients showed a weak positive correlation between levels in the soils and concentration in the plant tissues (Table 16) with mean values above critical concentrations. According to Meyer *et al.* (1989), N, P and Mg contents were satisfactory while Zn was high. Sugarcane leaf K concentrations (mean 0.6 %) was far below the critical concentration of 1.05 % (Wood, 1987) and negatively correlated (r= -0.446) with exchangeable K levels in the soils. Meyer *et al.* (1971) in a nutrient survey in South African Sugar industry has also reported a poor agreement between leaf K values and corresponding soil exchangeable levels. Forty five percent of the cane leaf sample from alluvial soils showed this anomality. These results may be due high levels of Ca and Mg in the soils which showed a weak negative correlation (Table 16) with leaf K values (r= -0.60 and -0.54 respectively). Another reason for this anomality may be due to moisture stress before sampling. Most of the leaf sampling was done during the dry spell (mid January to February). Although this estate is under sprinkler irrigation, the irrigation intervals are long (14 days) and irregular. As a result sugarcane experiences moisture stress in dry seasons. For example, Schroender *et al.* (1993) observed that data for leaf N, P and K values collected during the moisture stress showed low to very low concentrations. In comparison, leaf samples taken in April from the same crop after good rains (160 mm) had fallen in March indicated a substantial improvement in the leaf nutrient status. Also, these results express doubts that the level of soil exchangeable K as a single value forms a sound basis for predicting fertilizer requirements and whether the critical concentration of 1.05% is applicable for Kilombero soils.

4.4 Field Fertilizer trials

4.4.1 Effect of NPK application on nutrients concentration in sugarcane leaves

The percentage N, P, K, Ca and Mg concentrations in sugarcane grown in section 1 (Field no 12) and 2 (field no. M17) were not affected by NPK levels in the soil to significant level (Table 17). These results may be due to satisfactory native levels of P and K in the soils (Appendix 9) and synergism effect between N, P and K. However these treatments may have influence on yield components of sugar cane such as cane yields and sucrose contents. Other parameters like juice quality and fibre contents may also be affected. A longer period of research is needed to study the effect of NPK levels on these parameters.

4.4.2 Effect of K, P and different combinations of P and K levels on nutrient concentrations in sugar cane.

Different levels of N, P, and P&K combinations in the soils had a non significant influence on concentrations of these nutrients in sugarcane (Table 18). Application of 80 kg N/ha increased leaf N by 0.18% and Ca by 0.01% Increasing P level from 20 to 40 kg/ha with fixed level of N slightly increased leaf P by 0.01%. However the same levels of P and N applied together with 60 kg K/ha

Table 13. Uptake of macronutrients by sugarcane from commercial unfertilized fields

	Nutrients contents (%) in sugarcane leaf					
F/no.	N	P	K	Ca	Mg	Na
1	1.78	0.25	0.65	0.23	0.14	0.03
8	1.73	0.18	0.60	0.23	0.16	0.05
12	1.57	0.15	0.60	0.15	0.09	0.03
27	1.16	0.16	0.55	0.23	0.09	0.03
51	1.89	0.21	0.65	0.23	0.12	0.05
71	1.95	0.10	0.60	0.23	0.12	0.03
132	2.19	0.31	0.78	0.20	0.15	0.03
M10	1.85	0.3	0.45	0.25	0.17	0.03
M17	1.68	0.16	0.45	0.25	0.23	0.03
M20	1.96	0.20	0.53	0.25	0.24	0.03
M38	1.91	0.20	0.40	0.25	0.26	0.03
65	1.85	0.23	0.60	0.20	0.17	0.04
101	1.78	0.21	0.4	0.20	0.42	0.03
105	1.79	0.21	0.55	0.20	0.16	0.03
120	1.94	0.19	0.55	0.25	0.19	0.04
124	1.88	0.29	0.33	0.25	0.27	0.03

Table 14. Micronutrient uptake by sugarcane from commercial unfertilized fields

	Nutrient contents mg/kg in sugarcane leaf			
F/No.	Fe	Mn	Zn	Cu
1	1128	69.0	20.0	8.6
8	1024	40.5	19.0	8.5
12	1136	39.0	22.0	Trace
27	1040	42.0	25.0	2.1
51	1072	45.0	20.0	11.0
71	920	45.0	20.6	12.8
132	1072	45.0	25.3	10.7
M10	1088	63.0	22.3	8.5
M17	1136	39.0	32.3	4.3
M20	960	52.5	21.3	10.9
M38	960	102.0	20.0	9.9
65	1024	57.0	19.6	8.8
101	944	45.0	20.0	12.9
105	1008	57.0	18.3	12.8
120	976	127.5	21.0	7.6
124	880	73.5	14.2	12.8

Table 15. Range, mean, critical levels and status of some nutrients in sugarcane leaf from commercial fields

Nutrient	Range	Mean	Critical level	Status
N (%)	1.16-2.19	1.81	1.7-1.9	Satisfactory
P (%)	0.1-3.0	0.21	0.17-0.19	Satisfactory
K (%)	0.33-0.78	0.60	1.05	Low
Ca (%)	0.15-0.25	0.23	na	na
Mg (%)	0.09-0.42	0.19	na	Satisfactory
Fe(mg/kg)	880-1136	1023	na	na
Mn(mg/kg)	31-127	58.9	15	na
Zn(mg/kg)	37.3-80.0	46.8	13	High
Cu(mg/kg)	Trace-14	10.1	3-4	na

na: not available

increased leaf N and P by 0.15% and 0.02% respectively. Increasing levels of PK combinations slightly increased leaf P but depressed leaf K.

Poor uptake of P and K from applied fertilizer in these soils irrespective of the levels applied in the soils may be due to the appreciable native levels of same in the soils (Appendix 9 field no M4).

4.5 Irrigation and underground water quality

Table 19 presents the composition of irrigation water from Great Ruaha river and underground water sample collected from the Msolwa estate. The important characteristics of irrigation water which have been used to determine its quality are water reaction (pH), electrical conductivity (EC), Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC) specific ion effect (FAO, 1985; Gupta and Gupta, 1987) and total dissolved salts (TDS). The irrigation water pH ranged from 6.4 to 6.8. Underground water recorded higher pH value of 6.9 as compared to the mean value of 6.6 for irrigation water. This range of pH values rules out the presence of significant amounts of carbonates, bicarbonates and soluble salts.

Electrical conductivity of irrigation water was low ranging between 0.20 to 0.26 ms/cm and the mean of 0.22 ms/cm while that of underground water was slightly higher

Table 16. The correlation coefficients of some plant nutrient levels in the soil to leaf nutrient contents

Levels in the soils	Leaf nutrient contents								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
N	0.17								
P		0.14							
K			-0.45						
Ca			-0.60	-0.32					
Mg			-o.54		0.34				
Fe						0.14			
Mn						-0.23	0.36		
Zn								0.26	
Cu									0.18

Table 17. Effect of different NPK levels in soils on sugarcane leaf nutrient contents

NPK Combination (kg/ha	Leaf nutrient contents (%)				
	N	P	K	Ca	Mg
Section 1 (F/No. 12)					
$N_0P_0K_0$	1.80	0.16	0.56	0.27	0.17
$N_{30}P_{20}K_{60}$	1.77	0.17	0.58	0.22	0.16
$N_{60}P_{40}K_{120}$	1.80	0.18	0.61	0.21	0.18
$N_{90}P_{60}K_{180}$	1.90	0.18	0.65	0.24	0.19
$N_{120}P_{20}K_{240}$	1.91	0.18	0.65	0.24	0.19
Section 2 (F/No. M17)					
$N_0P_0K_0$	1.70	0.13	0.60	0.19	0.14
$N_{30}P_{20}K_{60}$	1.79	0.13	0.59	0.18	0.12
$N_{60}P_{40}K_{120}$	2.03	0.13	0.59	0.18	0.13
$N_{90}P_{60}K_{180}$	1.94	0.14	0.61	0.19	0.14
$N_{120}P_{80}K_{240}$	1.80	0.15	0.63	0.19	0.15

Table 18. Effect of N. P. K and different PK combinations on nutrients uptake by sugarcane in field M4

Nutrient Applied (kg/ha)	Leaf nutrient contents (%)				
	N	P	K	Ca	Mg
$N_0P_0K_0$	1.55	0.22	0.57	0.27	0.09
$N_{80}P_0K_0$	1.75	0.23	0.55	0.28	0.10
$N_{80}P_{20}K_0$	1.71	0.23	0.55	0.29	0.10
$N_{80}P_{40}K_0$	1.66	0.22	0.57	0.30	0.11
$N_{80}P_{20}K_{60}$	1.81	0.24	0.57	0.29	0.10
$N_{80}P_{40}K_{60}$	1.81	0.24	0.57	0.29	0.11
$N_{80}P_{40}K_{60}$	1.70	0.25	0.53	0.31	0.10

(0.25 ms/cm). The potential of these EC values to cause soil salinity and sodicity problems is low. According to Richard (1954) water with EC values of 0.1 to 0.25 ms/cm are regarded as having low potential to cause soil salinity or sodicity. Sodium adsorption ratio (SAR) for both irrigation and underground water was very low (mean 0.65 for irrigation water). These values are less than critical limit of 3.0 above which irrigation water can cause soil salinity (FAO, 1985).

With the exception of Fe, other micronutrient concentrations like Mn, Zn and Cu were only in trace quantities (less than 0.01 mg/l). Iron concentrations in irrigation water were relatively high and ranged from 3.8 to 18.9 mg/l (0.14 to 0.69 meq/l). It appears that the irrigation water has contributed to high levels of Fe in both soils and sugarcane leaf. However, all values were below the maximum concentrations for use up to 20 years on fine textured soils of pH 6.0 to 8.5 (FAO, 1979). Calcium, magnesium and sodium concentrations were within the usual range (Table 20) (FAO, 1985). Potassium levels in irrigation water was above the usual range (0-2mg/l).

Table 19. Chemical composition of irrigation and underground water

	Irrigation water		Underground water
	January'1995	February'1995	January'1995
K meq/l	0.20	0.16	0.15
Ca ,,	2.42	2.57	2.97
Mg ,,	0.37	0.42	0.59
Na ,,	0.6	1.0	0.7
Fe ,,	0.68	0.22	0.41
TDS ,,	2.0	2.5	2.5
SAR	0.55	0.82	0.52
EC (ms/cm)	0.20	0.25	0.25
pH	6.7	6.5	6.9

Table 20. Parameters used in evaluating irrigation and underground water quality

Parameter	Range	Usual range
Salt contents		
EC (ms/cm)	0.24-0.26	0-3.0
TDS (mg/l)	129-167.7	0-2000
SAR	0.49-0.82	> 3.0
Cations		
Calcium (meq/l)	2.55-2.59	0-20
Magnesium (meq/l)	0.39-0.44	0-5.0
Potassium (mg/l)	5.7-7.9	0-2.0
Iron (mg/l)	3.8-18.9	< 20

CHAPTER V

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions can be drawn from this study:

1) Soils of all three sections are deficient in total nitrogen while available P is low in soils of section 2.

2) All soils have medium to high exchangeable Mg, medium in calcium and very high in exchangeable K.

3) Soils of section 1-3 contain fairly high amounts of available Fe and Mn. Soil physical environments in sections 2 and 3 favour their accumulation.

4) Soil physical conditions in sections 2 and 3 are limiting sugarcane production due to poor drainage and heavy textured soils.

5) In terms of soil mineralogical composition, Mollic Fluvisol (KLP1) had illite (18.27%), smectite (15.8%), kaolinite (59.1%) and goethite (6.8%). Mollic Gleysol (KLP2) and Eutric cambisols (KLP4) had the same mineralogical composition as Mollic Fluvisol but relatively higher contents of illite (about 30.0%). Eutric Fluvisols (KLP3) had illite (35.6%) smectite (19.0%) and kaolinite (45.4).

6) With exception of Potassium contents, all parameters used to evaluate irrigation and underground water was

found to be within the usual range. Therefore irrigation and underground water is of good quality.

5.2 Recommendations

1) According to the observations from this study, seepage of the drainage canals contribute significantly to water- logging conditions in section 2 and 3. Low speed of water and overflooding are among the reasons. Since lining of the canals is expensive, this situation can be improved by increasing the capacity and gradient of these canals.

2) Filtermud, which are produced in hundreds of tons from Ruembe factory in each production seasons, should be incorporated in soils of section two and three to improve their structure.

For future research work the following topics are suggested:

1) Detailed study of different forms of K in these soils and establishment of the critical concentration in sugarcane under the local environments.

2) Improvement of heavy textured soils using byproducts of sugar factory (e.g filtermud and decomposed bagasse) for sugarcane production.

REFERENCES

Agarwal, S.C., N.K. Sharma., S. Ahmed and V.K. Sharma (1970). Wide spread occurrence of zinc deficiency in Eastern region of Uttar Pradesh. *Journal of the Indian Society of Soil Science*, 18 (4): 415-427.

Allen, B.L. and B.F. Hajek (1989). Mineral occurrence in soil environment. In: *Minerals in soil environments. (edited by J.B. Dixon and S.B. Weed)*. Soil Science Society of America Madison, Wisconsin, pp. 199-246

Ayres, A. and R.P. Humbert (1957). Phosphorus and potassium. *Hawaiian Sugar Planters' Association.* special release, 155: 1-4.

Barshard, I. and F.M. Kishk (1969). Chemical composition of soil vermiculite clay as related to their genesis. *Mineral and Petrol,* 24: 136-155.

Baver, L.D., W.H. Gardener and W.R. Gardener (1983). *Soil physics* 4th ed. John Wiley and Sons, pp. 498.

Blake, G.R. (1986). Particle density and bulk density. In: *Method of soil analysis part two (edited by C.A. Black)* Madison Wisconsin, USA. America Society of Agronomy. Inc. Publishers, pg. 371-390.

Blake, G.R. and K.H. Hartge (1986). Bulk density. In: *Methods of Soil Analysis. Part 1 Physical and Mineralogical Methods (edited by Klute, A.)*. Second edition. Number 9 (Part 1) in series. Agronomy. American Society of Agronomy, Inc. Soil Science Society of America, Inc. Madison, Wisconsin, pg. 364 - 376.

Bohn, H.L., B.L. McNeal and G.A. O'connor (1985). *Soil chemistry, second edition*. New York USA. Wiley Interscience Publication, pp. 341.

Borchrdt, G. (1989). Smectites. In: *Minerals in soil environments (edited by J.B. Dixon and S.B. Weed)*. Soil Science Society of America, Madison, Wisconsin, pp. 275-727.

Boyer, J. (1972). Soil potassium. In: *Soils of humid tropics (edited by M. Drodoff)*. US National Academy of Science, Washington DC, pp. 49-61.

Brady, N.C. (1974). *Nature and properties of soils, 9th edition*. Mcmillan Publishing Company, New York, pp. 750

Bremner, J.M. and C.S. Mulvaney (1982). Total Nitrogen In: *Methods of Soil analysis. Part 2. (edited by A.L. Page, R.M. Miller and D.R. Keeney)*. American

Society of Agronomy Madison, Wisconsin, pp. 149-157.

Brindley, G.W. and G. Brown (Editors) (1980). *Crystastal structure of clay minerals and their X-ray identification*. Mineralogical Society, London.

Bringer, H. (1985). Adequacy of soil testing for predicting fertilizer requirements. *Plant and Soil*, 35: 401-414.

Buabid R., M. Badraoni and P.R. Bloom (1991). Potassium fixation and charge characteristic of the soil clay. *Soil Science Society of America Journal*, 55 (5): 1493-1498.

Buol, S.W., F.D. Hole and R.J. McCracken (1980). *Soil genesis and classification (second edition)*. Iowa State University Press Ames Iowa, pp. 404.

Chatterjee, R.K. and R.C. Dalal (1976). Mineralogy of clay fraction of some soil profiles from Bihar and West Bengal. *Journal of Indian Society of Soil Science*, 24 (3): 253-262.

Christenson, D.R. and E.C. Doll (1973). Release of Mg from soil clay and silt fractions during cropping. *Soil*

Science, 116: 59-63.

Chui, F. and G. Samwel (1977). Evaluation of N fertilizer efficiency for plant and ratoon crop in irrigated sugarcane. *International Society of Sugarcane Technologists,* 2: 1259-1264.

Collins, J.B. (1977). Soil resource inventory for the small farmer. In: *soil resource inventories.* Cornell University, New York. pp. 205-261.

De Datta, S.K. (1981). *Principles and practices of rice production.* International Rice Research Institute, Los Bonos, Philippines, pp. 618.

Dent, D. and A. Young (1980). *Soil survey and land evaluation.* E. and F.N. Spon. London, pp. 278.

Douglas, L.A. (1989). Vermiculite. In: *Minerals in soil environments (Edited by J.B. Dixon and S.B. Weed).* Soil Science Society of America. Madson Wisconsin pg. 635-688.

Dixon, J.B. and S.B. Weed (editors) (1989). *Minerals in soil environment, 2^{nd} edition.* Soil Science Society of America. Madison, Wisconsin.

Evans, H. (1959). Elements other than N P and K in the mineral nutrition of sugarcane. *International Society of Sugar and Cane Technologists, 10: 473-508*

EUROCONSULT (1989). *Agricultural compendium for rural development in the tropical and subtropics*. Elsevier, Amsterdam, Oxford, New York Tokyo, pp. 740.

Fanning, D.S., V.Z. Keramidas and M.A. El-Desoky (1989). Mica. In: *Minerals in soil environments (edited by J.B. Dixon and S.B. Weed)*. Soil Science Society of America. Madson, Wisconsin, pp. 552-624.

FAO (1979). *Soil survey investigation for irrigation*. FAO soil bulletin no.42. FAO. Rome, pp. 188.

FAO (1985). *Guidelines: land evaluation for irrigated agriculture*. FAO Soil Bulletin no. 55. FAO, Rome, 299 pp.

FAO (1988). *FAO-Unesco Soil Map of the World, revised legend*. World Resource Report 60, FAO, Rome, Reprinted as technical paper 20, ISRIC, Wageningen, 1989.

FAO (1990). *Guidelines for soil description, 3rd edition (revised)*. Soil Resource Management and Conservation

Services Land and Water Development Division, FAO, Rome, pp. 70.

Fernandes, J.D., V. Composilavan, L.F. Neto and K. Reichardat (1978). *Proceedings of Soil preparation for Sugarcane. In: International Society of Sugarcane Technologist* (edited by Reis, E and J. Dick), 2: 1113-1121.

Fogliata, F.A. and V.N. Bustos (1980). Sugarcane ferric chlorosis in excessive calcareous soils. In: *Proceedings of International Society of Sugar cane Technologists*. (edited by M.A. Lopez and C.M. Marazo), 1: 262-281.

Fogliata, F.A. and C.A. Gargiulo (1978). Sugarcane production as a function of rainfall and nitrogen application. In: *Proceedings of International Society of Sugarcane Technologists* (edited by F.S. Reis and J. Dick), 2: 1417-1424.

Ghabru, S.K. and S.K. Ghosh (1985). Soil mineralogy and clay mineral genesis in Alfisol from Dhauladhar Range of middle Siwaliks. *Journal of Indian Society of Soil Science,* 33: 98-109.

Gupta, S.K. and I.C. Gupta (1987). *Management of saline soils and water*. Oxford and IHB Publishing Co. PVT LTD. New Delhi, pp. 73-120.

Harrold, M.L. (1975). Field experience on light soils. *Soil physical conditions and crop production*. MAFF Technical Bulletin no. 29, HMSO, London, pg. 22-51.

Hillel, D. (1982). *Introduction to soil physics*. Academic Press Inc. pp. 200-207.

Humbert, R.P. (1968). *The growth of sugarcane*. Elsevier Publishing Company. Amsterdam, pp. 720.

Humbert, R.P. (1972). Water-a key to sugarcane production. A paper presented in 14th Congress of *International society of Sugar and Cane technologists*, pp. 727-732.

Husz, G.S. (1974) *Sugarcane Cultivation and fertilization*. Ruhr-Stickstoff A.G Bochum, pp. 49-68.

ILLACO (1967) Report in the Regional development of the Msolwa and lower Ruembe Valleys, North Kilombero Valley, Tanzania, Volume one part two.

ILACO, B.V. (1981). *Agricultural compendium for rural* *development in the tropics*. International Land Development Consultants. Arhen, The Netherlands. Elservier, Amsterdam. pp. 739.

Inman-Bamber, N.G. (1984). The effect of nitrogen fertilizer on sugarcane varietal differences in 3rd leaf nutrient contents. *Annual congress of South African Sugar Technologists' Association*, 58: 149-153.

Jackson, M.L. (1953). Chemical weathering of minerals in soils. In: *Advances in Agronomy* (edited by A.G. Norman), 5: 221-309.

Jackson, M.L. (1964). Chemical composition of soils. In: *Chemistry of the soils (edited by F.E. Bear)*. Reinhold Publishing Corporation. New York. pp. 71-141.

Jafri, S.M.H. (1984). Effect of residual phosphate and potash on multiple ratoons of sugarcane. *Proceedings of 48th Annual Convention of Sugar technologists' Association of India* pp. 201-209

Juang, T., M. Kao and C. Chang (1977). The effect of Zn application on yield and nutrient uptake of sugarcane. *Proceedings of International Society of Sugarcane Technologists* (edited by F.S. Reis and J. Dick), 2: 907-917.

Juang, T.G. (1972). The effect of groundwater table and soil compaction on nutrient uptake and growth of sugarcane. *Taiwan Sugar*. (From soil and fertilizer 40: Abstract no. 5824.).

Juo, A.S.R. (Editor) (1979). *Selected methods for soil and plant analysis*. Manual series No 1 2nd edition. International Institute of Tropical Agriculture. Ibadan, pp. 70.

Kayombo, B., R. Lal., G.C. Mrema and H.E. Jensen (1991). Characterizing compaction effect on soil properties and crop growth in south Nigeria. *Soil and Tillage Research*, 21: (3-4) 315-354.

Kimaro, D.N., B.M. Msanya and J.P. Magoggo (1995). Pedological investigation of sites for slash and burn experiment in Lupilo village and soil erosion studies in Tukuzi village, Mbinga District, Tanzania. Miombo Woodland Research Project, Natural Resources Study Team Technical Report no.2. National Soil Service, Mlingano, Tanga and Department of Soil Science, Sokoine University of Agriculture, Morogoro, pp. 17.

Laird, D.A., P. Barak., E.A. Nater and R.H. Dowdy (1991). Chemistry of smectitic and illitic phase in interstratified soil smectite. *Soil Science Society of America Journal*, 55: (5) 1495-1500.

Lakshmikantham, M. (1983). *Technology in sugarcane growing second edition*. Oxford and IBH Publishing Co. New Delhi, pp. 259.

Landon, J.R. (1984). *Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and sub tropics*. longman New York, pp. 450.

Leon, B., L.E. Francois and R.E. Clark (1966). Salt tolerance of NCO varieties of sugarcane I: Sprouting growth and yield. *Agronomy Journal* 58: (2) 489-493

Mathan, K.K. and R. Natesan (1990). Effect of soil compaction on strength and productivity of swelling clay. *Journal of Indian Society of Soil Science*, 38: 385-388.

Mclean, E.O. (1982). Soil pH and lime requirement. In *methods of Soil analysis, Part 2 (edited by A.L. Page, R.H. Miller and D.R. Keeney)*. American Society of Agronomy. Madison, Wisconsin pp. 199-224.

Milsted, S.W. and T.R. Peck (1973). The principle of soil testing. In: *Soil testing and plant analysis (edited by L.M. Walsh and J.A. Beaton)*. Soil Science Society of America. Madison, Wisconsin, Pg. 13-21.

Mengel, K. and Kirkby, E.A. (1987). *Principle of plant nutrition*. Potash Institute, Berne, Switzaland, pp. 687.

Meyer, J.H., R.A. Wood and P. de Preez (1971). A nutrient survey of sugarcane in the South African industry with special reference to trace elements. *Proceedings of South African Sugar Technologists Association*, 45: 196-204

Meyer, J.H., R.A. Wood and R.L. Harding (1989). Fertility trend in South African sugar industry. Proceedings of *South African Sugar Technologists' Association-* June 1989, pp.159-163.

Ministry of Agriculture (1993). *Industrial review of Sugar Annual Report*. The United Republic of Tanzania, pp.

Mkelenda, A.S. (1985). Effect rate and time of nitrogen application on growth, leaf nutrient content and yield of sugarcane at Kilombero Sugar estate. MSc. thesis. University of Dar Es Salaam.

Mmikonga, A.A. (1981). Soil and land evaluation of the section of the Kilombero valley. MSc.Thesis. University of Dar Es Salaam. pp. 59-63.

Msanya, B.M., D.N. Kimaro and A.J. Shayo-Ngowi (1995). Soils of Kitulanghalo Forest Reserve Area, Morogoro District, Tanzania. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro. pp. 74.

Muji, B. and Bandyopadhyah (1992). The effect of submergence on Fe, Mn, and Cu in some coastal rice soils of West Bengal. *Journal of Indian Society of Soil Science,* 40: 390-392.

Munsell Colour Company (1975). *Munsell soil colour charts.* Munsell Colour Inc. Baltimore.

National Soil Service (1987). *Laboratory procedures for routine plant analysis.* MALD-Agricultural Research

Institute Mlingano, Tanga Tanzania. pp. 238.

National Soil Service (1991). *Laboratory procedure for routine plant analysis*. MALD-Agricultural Research Institute Mlingano, Tanga Tanzania, pp. 238.

Netherlands Development Cooperation (1992). *Sector aid and structural adjustment*. The case study of sugar in Tanzania. The Haque. pp. 183.

Netherlands Economic Institute (1988). *Feasibility study of a development plan for Sugar Industry in Tanzania*. Rotterdam. pp. 193.

Neue, H.U. (1989). Rice growing soils: Constraints, Utilization and research needs. In: *classification and management of rice growing soils*. FFTC Book series No. 39, pp. 347-354.

Ngailo, J.A. and Ph.A. Kips (1991). Soils of Mikindani Estate (Mtwara Region) and their suitability for cashew, mango, lime, hybrid sisal and teak cultivation. Agricultural Research Institute, Mlingano Tanga, Tanzania.

Ng Kee Kwong, K.F., L. Ross and C. Caralot (1980). Liming soils under sugarcane in Mauritius. *Proceedings of International Society of Sugarcane Technologists* (edited by M.R. Lopez and C.M. Madrazo), 1: 244- 254.

Ng Kee Kwong, K.F. (1990). Foliar diagnosis of sugarcane - Variation of leaf potassium values with age of cane and rainfall regime. *Proceedings of the South African Sugar Technologists' Association*. June, 1990 pp. 22-25.

Olsen, S.R. and L.E. Sommer (1982). Phosphorus. In: *Methods of soil analysis part two. Agronomy monography no. 9. (Edited by Page, A.L; R.H. Miller and D.R. Keeney)*. American Society of Agronomy. Madison, Wisconsin, pp. 403-430.

Oswal, M.C. (1983). *A textbook of soil physics 2nd edition*. Vikas Publishing House. PVT Ltd. pp. 34-55.

Page, A.L., W.D. Burge., T.J. Ganje and M.J. Garber (1967). Potassium and ammonium fixation in vermiculate soils. *Soil Science society of America Proceedings*, 31: 337-341.

Pathak, A.N., S. Krishna and K.N. Tiwari (1976). Correlation between P, Fe and Mn availability in waterlogged soils at different fertility levels.

Journal of Indian Society of Soil Science, 20: (4) 385-389.

Ponnamperuma, F.N. (1975). Chemical kinetics of wetland rice soils relative to soil fertility. In: *Wetland soils: Characterization, classification and utilization*. International Rice Research Institute, Los Bonos, Philippines, pp. 109-122.

Rhodes, D.J. (1982). Cation exchange capacity. *In Methods of Soil Analysis part two (edited by A.L. Page; R.H. Miller and D.R. Keeney)*. American Society of Agronomy, Wisconsin, pp. 149-158.

Richard, L.A. (editor) (1954). *Diagnosis and improvement of saline and alkali soils*. United States Salinity Laboratory Staff, pp. 69-81.

Ross, G.J., C. Wang, A.I. Ozhan and H.W. Rees (1982). Weathering of chlorite and mica in new Brnshick Podzol developed on the tile derived from chlorite-mica-schist. *Geodema*, 27: 244-267.

Ross, G.J. and R.A. Cline (1984). Potassium exchange characteristics in relation to mineralogical properties and potassium uptake by grapes of selected soils in Niagara Peninsular of Southern Ontario Canada. *Journal of Soil Science*, 64: 87-98.

Sahrawat, K.L. (1983). Nitrogen availability index for submerged soil. *Advance in Agronomy*, 36: 415- 447.

Samki, K.J. (1989). Soil formation, classification and land evaluation of soils developed over gneiss, limestone and marine sediments in the Mlingano, Tanga Region. Ph.D Thesis. Sokoine University of Agriculture, pg. 37-161

Samwel G. (1971). Influence of water deficiency and excess on growth and leaf element content of sugar cane. *International society of sugar cane Technologists Proceedings* 1: 653-656

Sanchez, P.A. (1976). *Properties and management of soils in the tropics*. John Wiley and Sons., Inc. New York and Toronto, pp. 618.

Schroeder, R.A., A. Wood and J.H. Meyer (1993). Foliar analysis in the South African Sugar Industry for diagnostic and nutrient trend purposes. *Plant Nutrition from genetic engineering to field practice (edited by N.J. Barrow)*. Kluwer Academic Publishers

Lancaster, pp. 299-302.

Schulze, D.G. (1989). An introduction to soil mineralogy. In: *Minerals in soil environment. (edited by J.B. Dixon and S.B. Weed)*. Soil Science Society of America. Madison, Wisconsin, pp. 552-624.

Schutte, K.H. and H.E. Schendel (1958). Influence of trace element upon plant protein. *Nature*, 182 pp. 958

Senkoro, E.M.Z. (1988). Economic analysis of Tanzania's Sugar Industry. The case study of Kilombero Sugar Company. MSc. thesis University of Nairobi, pp. 1-6.

Sergio, V.V. (1978). Effect of excess sodium on sugarcane yield. *Proceedings of International Society of Sugar cane Technologists Association* (Edited by F.S. Reis and J. Dick), 2: 861-866.

Shoji, K and K.A. Sound (1965). Drainage and salinity investigation at the Hafttappch Sugarcane Project. *Proceedings of 12th. Congres of International Society of Sugar and Cane Technologists*, pg. 90-95.

Sillanpaa, M. (1982). *Micronutrient and nutrient status of soils:* A global study. FAO, Rome, pp. 444.

Societe de Technologie Agricole et Sucriere de Maurice (1975). *Manual of sugarcane agronomy*. The Standard Printing Establishment, pp. 73.

Soil Survey Staff (1990). *Key to Soil Taxonomy. Agency of International development, United States Department of Agriculture. Soil Management Support Services Technical monograph no. 19.* Virginia Polytechnic Institute and State University, pp. 422.

Sombroek, W.G. and R.F. Van de Weg (1980). *Some considerations in quality and readability of soil maps and their legends*. International Soil Museum Annual report 1980. Wageningen.

Smith, W.W. (1962). weathering of some Scottish basic igneous rocks with reference to soil formation. *Journal of Soil Science* 13: 202-215

Snedecor, G.W. and W.G Cochran (1989). *Statistical methods. 8th edition,* Iowa State University Press/Ames,pp. 505.

Srivastava, S.P., A.C. Shukla, and A.K. Tewari (1986). Influence of nitrogen and phosphorus on yield and juice quality of sugarcane grown on different Soils.

Journal of the Indian Society of Soil Science, 35: 349-352.

Srivastava, S.P., S.N. Pandey., A.K. Gupter and R.K. Srivastava (1986).Influence of N and P fertilization on sugarcane yield and juice quality in sandy loam clay. *Bharatiya Sugar*, 11:(5) 41-46.

Supriyo, H., N. Matsue and N. Yoshinago (1992). Chemistry and mineralogy of some 217 soils from Indonesia. *Soil Science and Plant Nutrition*, 38: (2) 217-225.

Thompsons L.M. and F.R. Troeh (1985). *Soil and soil fertility, fourth edition*. New York. Tata McGran-Hill Publishing Company Limited, pp. 516.

Tisdale, S.L., W.L. Nelson and J.D. Beaton (1990). *Soil fertility and fertilizers (4th edition)*. Macmillan Publishing Company. New York, pp. 754.

Thorez, J. (1975). *Phyllosilicates and clay minerals. A laboratory handbook for their x-ray diffraction analysis*. Edition Lilotte, Belgique.

Tributh H., H. Van Boguslawski, A. Van Lieres., D. Steffens, and K. Mengel (1987). Effect of K removal by crops on transformation of illitic clay minerals. *Soil Science*, 143: 404-409.

Trouse, A.C. and R.P. Humbert (1961). Some effects of soil compaction on the developments of sugarcane roots. *Soil Science*, 91: 208- 217.

Taylor, H.M., G.R. Robernson and J.J. Parker (1966). Soil strength and root penetration relations for medium to course textured soil materials. *Soil Science*. 102: 18-22.

Verma, H.P. (1962). Irrigation investigations conducted on sugarcane in India: A critical review. *Indian Journal of Sugar Research and development*, 6: (2) 76-78.

Whittingham, J.K. (1963). The geology environment of the Kilombero valley. The record of geological survey of Tanganyika, volume X- 1963.

Wood, R.A. (1987). The bases of fertilizer recommendations for the South African sugar industry. *Sugarcane*, no. 2, pp. 10-14.

Wood, R.A and J.H. Meyer (1986). Factors affecting potassium nutrition of sugarcane in South Africa. *Proceeding of South African Sugar Technologists Association*, 60: 198-204.

World Bank (1984). *Project compilation report, Tanzania, Kilombero Sugar Project Loan*, Washington, pp. 234.

Yang, S.J. and J.M. Chen (1991). A review of fertilizer trials carried out by the first sugar corporation between 1977 to 1987. *Taiwan-Sugar Taipei*: Taiwan Sugar corporation. pp. 19-24.

Yang, S.J. (1978). Soil physical properties and the growth of ratoon cane as influenced by mechanical harvesting. *Proceedings of International Society of Sugarcane Technologist* (Edited by F.S. Reis and J. Dick), 2: 835- 847.

Yang, S.J. and J. Chen (1980). Germination response of Sugarcane cultivars to soil moisture and temperature. *Proceedings of International society of Sugarcane Technologists (Edited by M.B. Lopez and C.M. Madrazo)*, 1: 30-36.

Yates, R.A. (1977). The environment for sugarcane. In: *FAO World Soil Report No*. 47. FAO, Rome. pp. 58-72.

APPENDICES

Appendix 1. Kilombero Sugar Company Production Statistics

	Msolwa		Ruembe		Total	
Year	TCH	Sugar(tons)	TCH	Sugar(tons)	TCH	Sugar(tons)
1962	144	11109			144	11109
1963	104	12894			104	12894
1964	93	19602			93	19601
1965	106	25234			106	25234
1966	91	26538			91	26538
1967	99	31300			99	31300
1968	85	29075			85	29075
1969	101	36118			101	36118
1970	124	39193			124	39193
1971	102	37543			102	37543
1972	112	35625			112	35625
1973	117	38973			117	38973
1974	93	35378			93	35378
1975	83	34318			83	34318
1976*	81	35238	77	11549	79	46787
1977	79	20821	70	23111	75	43932
1978	70	33145	77	23940	74	66085
1979	67	25328	69	26620	68	51948
1980	51	19504	63	28566	57	48070
1981	59	20093	73	30000	66	50093
1982	67	14712	74	25394	70	40106
1983	83	24040	89	31100	86	55140
1984	71	21210	66	25018	68	46228
1985	67	20892	61	24615	64	45507
1986	63	18676	66	22510	64	41186
1987	70	20948	72	24270	72	45218
1988	67	20737	63	21832	65	42569
1989	57	15710	62	23494	59	39204
1990	62	18376	70	24361	75	53674
1991	73	22501	78	31173	75	53674
1992	77	23529	77	24380	77	57909
1993	79	19554	79	24615	79	44169

* Ruembe Factory started sugar production.

Appendix 2 Soil profile and routine analytical data

Profile 1

Profile number : KLP1. Block no: F/no.M6 Agro-ecol. zone: E4
Region: Morogoro. District: Kilombero. Map sheet no.: 217/2
Coordinates: 36° 58' 46 6" E/ 7° 43' 40.1" S
Location: Trans-Msolwa.F/no.M6. 7.5 km from Agronomy Department office. Elevation:300 m asl.
Parent material: unconsolidated material. Landform: alluvial/flood plain: flat or almost flat.
Slope: 0.5 %: straight. Surface characteristics: Cracks: 0.5 wide. 5 cm deep. Erosion: moderate. Deposition: 2 cm. Natural drainage class: imperfectly drained
Described by B.M. Msanya and A. Kunda on 21/01/95

Soil: Deep. poorly drained. very hard.friable when moist. slightly sticky. slightly plastic when wet. subangular blocky to massive structure. brown. sandy clay loam textured alluvial soil.

Ap 0 - 35 cm: Dark grey (7.5YR4/1) dry. black (7.5YR2.5/1) moist: sandy clay loam: very hard dry. friable moist. slightly sticky and slightly plastic wet: moderate coarse and medium subangular blocks: many fine and common medium pores: few medium and fine roots: abrupt smooth boundary to

Cg1 35 - 70 cm: Brown (7.5YR4/2) dry. dark brown (7.5YR3/2) moist: sandy clay loam: many fine distinct clear 5YR4/4 mottles: very hard dry. friable moist. slightly sticky and plastic wet: structureless massive: many fine and few medium pores: few medium and fine roots: many mica flakes: abrupt smooth boundary to

Cg2 70 - 100 cm: Brown (7.5YR4/2) dry. black (7.5YR4/2) moist: sandy clay: few fine distinct clear 5YR4/4 mottles: very hard dry. friable moist. slightly sticky and plastic wet: structureless massive: many fine and common medium pores: few medium spherical hard Fe & Mn nodules: few fine and medium roots: gradual smooth boundary to

Cg3 100 - 134 cm: Brown (7.5YR4/4) dry. black (7.5YR5/4) moist: sandy clay loam: common fine distinct clear 5YR3/3 mottles: hard dry. friable moist. slightly sticky and slightly plastic wet: structureless massive: many fine and few medium pores: few medium irregular hard Fe & Mn nodules: few medium and fine roots: gradual smooth boundary to

Cg4 134 - 161 cm: Brown (7.5YR5/4) dry. brown (7.5YR5/4) moist: sandy clay loam: common fine distinct clear 5YR3/3 mottles: very hard dry. friable moist. slightly sticky and slightly plastic wet: structureless massive: many fine and few medium pores: few medium irregular hard Fe & Mn nodules: few medium and fine roots: many mica flakes: clear smooth boundary to

2Cr 161 - 214 cm: Pale grey (7.5YR6/2) dry. brown (7.5YR5/3) moist: loamy sand: loose dry. very friable moist. non-sticky and non-plastic wet: structureless massive: many fine and common medium pores: many mica flakes

SOIL CLASSIFICATION: FAO Legend: Mollic Fluvisol (FLM)

USDA Soil Taxonomy. 1990: Typic Haplaquoll

Appendix 2 continued

ANALYTICAL DATA FOR PROFILE KLP1

Horizon		Ap	Cg1	Cg2	Cg3	Cg4	2Cr
Depth (cm)		0 - 35	35 - 70	70 - 100	100 - 134	134 - 161	161 - 214
Clay	%	25	23	25	17	21	9
Silt	%	14	8	8	8	9	2
Very fine sand	%	11	13	13	12	6	3
Fine sand	%	25	27	17	18	17	11
Medium sand	%	22	23	30	34	36	42
Coarse sand	%	2	3	4	7	9	14
Very coarse sand	%	1	1	2	2	2	14
Total sand	%	60	67	66	73	65	84
Texture class		SCL	SCL	SCL	SL	SL	LS
pH H2O	1:2.5	6.1	6.2	7.0	7.0	7.1	7.1
pH KCl	1:2.5	4.6	4.7	5.2	5.3	5.1	5.2
EC mS/cm	1:2.5	nd	nd	nd	nd	nd	nd
Organic C	%	1.5	0.5	0.3	0.3	0.2	0.1
Total N	%	0.13	0.09	0.06	0.03	0.02	0.01
C/N		12	6	5	10	10	10
Available P mg/kg		23	12	9	9	9	10
CEC NH_4OAc(cmol(+)/kg)		13.0	12.0	14.0	15.0	14.0	5.0
Exch. Ca (cmol(+)/kg)		5.5	6.5	6.4	5.2	6.0	2.4
Exch. Mg (cmol(+)/kg)		2.0	2.1	3.0	2.0	3.0	1.0
Exch. K (cmol(+)/kg)		1.38	0.33	0.51	1.53	1.78	0.60
Exch. Na (cmol(+)/kg)		0.09	0.15	0.22	0.33	0.22	0.08
Exch. H (cmol(+)/kg)		nd	nd	nd	nd	nd	nd
TEB (cmol(+)/kg)		9.0	9.1	10.1	9.1	11.0	4.1
Base saturation	%	69	76	72	60	79	82
CECclay (cmol(+)/Kg)		52	52	56	88	70	56

nd. not determined

Appendix 2 continued

Profile 2

Profile number : KLP2. Block no: F/no.97. Agro-ecol. zone: E4.
Region: Morogoro: District : Kilombero. Map sheet no. : 217/4.
Coordinates : 37° 0' 43.2" E/ 7° 45' 19.1" S. Location : S/Mbende, F/no.97, 8.5km from Agronomy Department office. Elevation : 300 m asl. Parent material: unconsolidated mixed material. Landform: alluvial/flood plain; flat or almost flat. Slope: 5 %; straight. Surface characteristics : Erosion: moderate. Deposition: 4 cm. Natural drainage class : very poorly drained.
Described by B.M. Msanya and A. Kunda on 21/01/95.

Soil: Deep, poorly drained, very hard firm.sticky and plastic when wet, massive, very few fine pores, grey, clay soils.

Ap	0 - 35 cm:	Very dark grey (5YR3/1) dry, black (2.5YR2.5/1) moist; clay; very hard dry, firm moist, sticky and plastic wet; weak coarse subangular blocks; few very fine and medium pores; medium and few fine roots; abrupt irregular boundary to
Cg1	35 - 82 cm:	Dark grey (10YR4/1) dry, very dark grey (10YR3/1) moist; clay; few fine faint diffuse5YR3/3 mottles; very hard dry, friable moist, sticky and plastic wet; structureless massive; few very fine and medium pores; fine roots; clear smooth boundary to
Cg2	82 - 150 cm:	Dark yellowish brown (10YR4/4) dry, dark grey (10YR4/1) moist; clay; common fine distinct clear7.5YR3/3 mottles; very hard dry, friable moist, sticky and plastic wet; structureless massive; few fine and medium pores; gradual wavy boundary to
Cg3	150 - 200 cm:	Grey (10YR5/1) dry, grey (10YR6/1) moist; clay; common coarse distinct sharp5YR3/3 mottles; very hard dry, friable moist, sticky and plastic wet; structureless massive; medium and few fine pores; few medium irregular soft Fe & Mn nodules

SOIL CLASSIFICATION: FAO Legend, 1989: Mollic Gleysol (GLM)

USDA Soil Taxonomy, 1990: Fluventic Haplaqoll

Appendix 2 continued

ANALYTICAL DATA FOR PROFILE KLP2

Horizon		Ap	Cg1	Cg2	Cg3
Depth (cm)		0 - 35	35 - 82	82 - 150	150 - 200
Clay	%	41	54	51	41
Silt	%	14	16	10	12
Very fine sand	%	11	6	6	7
Fine sand	%	15	10	11	12
Medium sand	%	14	8	19	22
Coarse sand	%	4	1	0	6
Very coarse sand	%	1	0	1	1
Total sand	%	45	25	37	48
Texture class		C	C	C	SC
pH H_2O	1:2.5	6.7	6.6	7.2	6.4
pH KCl	1:2.5	5.0	5.0	5.5	5.5
EC mS/cm	1:2.5	nd	nd	nd	nd
Organic C	%	1.7	1.2	0.4	0.2
Total N	%	0.13	0.09	0.04	0.03
C/N		13	13	10	7
Available P	mg/kg	8	1	1	2
CEC NH_4OAc	(cmol(+)/kg)	19.0	23.0	18.0	16.0
Exch. Ca	(cmol(+)/kg)	9.2	10.2	9.6	9.6
Exch. Mg	(cmol(+)/kg)	3.7	4.8	3.8	3.5
Exch. K	(cmol(+)/kg)	1.26	1.09	1.02	0.23
Exch. Na	(cmol(+)/kg)	0.62	0.90	1.15	1.37
Exch. H	(cmol(+)/kg)	nd	nd	nd	nd
TEB	(cmol(+)/kg)	14.8	17.0	15.6	14.7
Base saturation	%	78	74	86	92
CECclay	(cmol(+)/kg)	46	43	35	39
ESP	%			6	9

nd= not determined

Appendix 2 continued

Profile 3.

Profile number : KLP3. Block no:34. Agro-ecol. zone: E4.
Region: Morogoro. District: Kilombero. Map sheet no. : 217/2
Coordinates : 36° 59' 12.1" E/ 7° 42' 20.9" S. Location : Ruaha area, F/no.34, 6 km from Agronomy Department Office. Elevation : 300 m asl. Parent material: unconsolidated mixed material. Landform: alluvial/flood plain; flat or almost flat. Slope: 0.5 %; straight. Surface characteristics : Erosion: moderate. Deposition: 2 cm. Natural drainage class : well drained.
Described by B.M. Msanya and A. Kunda on 23/01/95.

Soil: Deep, well drained, slightly hard to very hard, friable slightly sticky , slightly plastic when wet, massive coherent,few medium pores, brown sandy clay loam.

Ap	0 - 60 cm:	Dark grey (10YR6/4) dry, very dark grey (10YR3/1) moist; sandy loam; slightly hard dry, friable moist, non-sticky and non-plastic wet; weak medium subangular blocks; many fine and medium pores; common fine roots; abrupt smooth boundary to
C1	60 - 110 cm:	Yellowish brown (10YR6/4) dry, dark yellowish brown (10YR4/4) moist; sand; slightly hard dry, very friable moist, non-sticky and non-plastic wet; structureless massive; many medium pores; medium roots; clear smooth boundary to
C2	110 - 130 cm:	Yellowish brown (10YR5/4) dry, dark yellowish brown (10YR3/6) moist; sandy clay loam; common medium distinct diffuse5YR4/4 mottles; hard dry, firm moist, slightly sticky and slightly plastic wet; structureless massive; and many fine pores; medium roots; clear smooth boundary to
C3	130 - 145 cm:	Yellowish brown (10YR3/4) dry, brown (10YR4/3) moist; sandy clay loam; many coarse distinct diffuse 5YR3/3 mottles; very hard dry, firm moist, slightly sticky and slightly plastic wet; structureless massive; many fine pores; many fine roots; clear smooth boundary to
C4	145 - 207 cm:	Dark yellowish brown (10YR3/5) dry, dark yellowish brown (10YR3/4) moist; sandy clay loam; many medium prominent diffuse mottles; very hard dry, friable moist, slightly sticky and slightly plastic wet; structureless massive; many fine and common medium pores; medium roots

SOIL CLASSIFICATION: FAO Legend 1989: Eutric Fluvisol
USDA Soil Taxonomy, 1990: Typic Ustifluvent

Appendix 2 continued

ANALYTICAL DATA FOR PROFILE KLP3

Horizon		Ap	C1	C2g	C3g	C4g
Depth (cm)		0 - 60	60 - 110	110 - 130	130 - 145	145 - 207
Clay	%	9	8	22	47	25
Silt	%	18	6	18	28	12
Very fine sand	%	14	15	18	10	11
Fine sand	%	15	30	21	7	6
Medium sand	%	40	40	16	8	44
Coarse sand	%	1	1	0	0	0
Very coarse sand	%	0	0	0	0	1
Total sand	%	70	86	55	25	62
Texture class		SL	LS	SCL	C	SCL
pH H2O	1:2.5	6.5	7.0	6.9	6.8	6.6
pH KCl	1:2.5	4.8	5.4	5.1	5.3	5.5
EC mS/cm	1:2.5	nd	nd	nd	nd	nd
Organic C	%	1.5	0.2	0.2	0.4	0.2
Total N	%	0.11	0.02	0.04	0.05	0.03
C/N		14	10	5	8	7
Available P	mg/kg	22	23	23	1	2
CEC NH4OAc	(cmol(+)/kg)	7.0	5.0	14.0	20.0	13.0
Exch. Ca	(cmol(+)/kg)	3.2	2.1	6.6	10.4	6.2
Exch. Mg	(cmol(+)/kg)	0.7	1.5	2.6	5.0	2.7
Exch. K	(cmol(+)/kg)	0.30	0.35	0.28	0.77	0.55
Exch. Na	(cmol(+)/kg)	0.31	0.07	0.30	0.45	0.43
Exch. H	(cmol(+)/kg)	nd	nd	nd	nd	nd
TEB	(cmol(+)/kg)	4.5	4.0	9.8	16.6	9.9
Base saturation	%	64	80	70	83	76
CECclay	(cmol(+)/kg)	78	63	64	43	52
ESP	%	4				

nd: not determined

Appendix 2 continued

Profile 4

Profile number : KLP4. Block no: 22. Agro-ecol. zone: E4.
Region: Morogoro. District: Kilombero. Map sheet no. : 218/1.
Coordinates : 37° 0" 38.2' E/ 7° 42" 40.0' S. Location: Ruaha, F/no.22, 7km from Agronomy Department office. Elevation: 300 m asl. Parent material: unconsolidated mixed material. Landform: alluvial/flood plain; flat or almost flat. Slope: 1 %; straight. Surface characteristics : Erosion: none or slight. Deposition: none. Natural drainage class : moderately well drained.
Described by B.M. Msanya and A. Kunda on 23/01/95.

Soil: Very deep, moderetely well drained, very hard friable when moist non plastic non sticky when wet, subangalar to massive, fine pores brown sandy clay loam soil over a burred A horizon below a depth of 165cm having clay texture.

Ah	0 - 40 cm:	Brown (7.5YR4/1) dry, black (7.5YR2.5/1) moist; silty loam; very hard dry, friable moist, non-sticky and non-plastic wet; weak medium subangular blocks; common medium and few fine pores; few coarse and medium roots; 0; abrupt wavy boundary to
Bw	40 - 75 cm:	Brown (7.5YR5/4) dry, brown (7.5YR4/4) moist; silty loam; very hard dry, friable moist, non-sticky and non-plastic wet; weak coarse subangular blocks; common medium and few fine pores; fine and few coarse roots; y; abrupt smooth boundary to
C1	75 - 120 cm:	Brown (7.5YR5/4) dry, dark brown (7.5YR5/6) moist; sandy loam; hard dry, friable moist, non-sticky and non-plastic wet; structureless massive; common very fine pores; medium and few coarse roots; y; abrupt smooth boundary to
C2g	120 - 165 cm:	Brown (7.5YR4/3) dry, dark brown (7.5YR3/3) moist; clay; common fine faint clear 5YR4/4 mottles; extremely hard dry, very friable moist, slightly sticky and slightly plastic wet; structureless massive; medium and common fine pores; fine roots; abrupt smooth boundary to
Ahb	165 - 190 cm:	Dark grey (7.5YR4/1) dry, black (7.5YR2.5/1) moist; clay; very hard dry, friable moist, slightly sticky and slightly plastic wet; structureless massive; common medium pores; fine roots; abrupt smooth boundary to
Bbg	190 - 212 cm:	Brown (7.5YR4/2) dry, brown (7.5YR4/3) moist; clay; few fine faint diffuse 5YR3/3 mottles; very hard dry, friable moist, slightly sticky and slightly plastic wet; structureless massive; common very fine pores; few fine roots

SOIL CLASSIFICATION: FAO Legend, 1989: Eutric Cambisol

USDA Soil Taxonomy, 1990: Typic Tropaquept

Appendix 2 continued

ANALYTICAL DATA FOR PROFILE KLP4

Horizon	Ah	Bw	C1	C2g	Ahb	Bbg
Depth (cm)	0 - 40	40 - 75	75 - 120	120 - 165	165 - 190	190 - 212
Clay %	26	29	17	65	54	45
Silt %	12	10	26	2	23	32
Very fine sand %	16	17	19	7	15	12
Fine sand %	28	24	33	14	7	6
Medium sand %	14	11	0	10	1	3
Coarse sand %	4	5	0	0	0	0
Very coarse sand %	0	0	0	0	0	0
Total sand %	62	57	52	31	20	21
Texture class	SCL	SCL	SL	C	C	C
pH H2O 1:2.5	6.4	6.4	7.3	7.4	7.4	7.5
pH KCl 1:2.5	5.5	5.4	5.5	6.0	5.8	6.0
EC mS/cm 1:2.5	nd	nd	nd	nd	nd	nd
Organic C %	2.6	1.1	0.2	0.5	0.8	0.4
Total N %	0.18	0.09	0.03	0.05	0.07	0.05
C/N	14	12	7	10	11	8
Available P mg/kg	23	4	2	9	7	2
CEC NH4OAc (cmol(+)/kg)	20.0	23.0	14.0	40.0	39.0	30.0
Exch. Ca (cmol(+)/kg)	10.0	9.6	5.4	20.0	18.5	13.8
Exch. Mg (cmol(+)/kg)	2.7	3.8	1.9	6.6	8.9	7.2
Exch. K (cmol(+)/kg)	3.04	3.37	3.67	3.09	2.80	1.61
Exch. Na (cmol(+)/kg)	0.40	0.21	0.96	6.10	6.78	5.40
Exch. H (cmol(+)/kg)	nd	nd	nd	nd	nd	nd
TEB (cmol(+)/kg)	16.1	17.0	11.9	35.8	37.0	28.0
Base saturation %	81	74	85	89	95	93
CECclay (cmol(+)/kg)	77	79	82	62	72	67

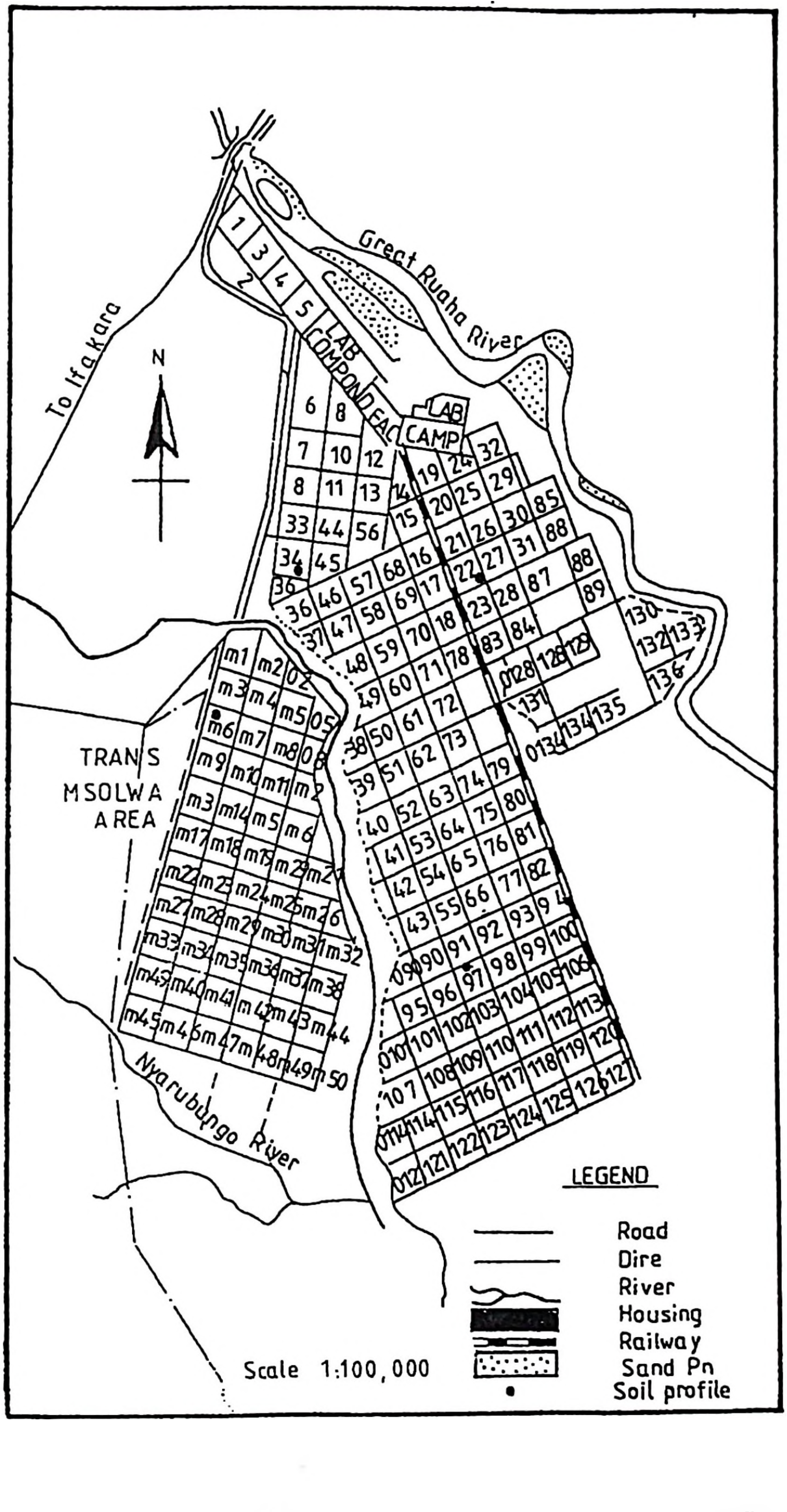
nd: not determined

Appendix 3

Mean monthly climatic data for 1994 and long term average (LTA) for 1961-1994

Parameter	Jan.	Feb.	March	Apr.	May	Jun.
Max. Temp. °C	36.6	31.0	32.2	30.	29.9	8.4
LTA	31.4	32.3	30.7	29.9	27.9	26.2
Min. Temp. °C	na	na	na	na	23.2	20.9
LTA	21.9	21.9	22.0	22.4	20.4	17.2
MAX. R.H (%)	91.4	95.9	95.8	94.2	94.9	94.0
LTA	94.4	93.9	95.0	95.5	95.0	97.0
Min. R.H (%)	57.5	67.4	64.0	67.9	68.9	56.2
LTA	51.9	52.9	54.5	57.1	55.1	53.2
S/shine (hrs)	6.6	4.3	6.3	4.6	3.0	6.2
LTA	6.2	6.4	6.1	5.2	6.3	6.2
Rainfall (mm)	147.7	281.8	283.7	214.1	117.0	6.5
LTA	173.7	281.8	283.7	214.1	131.0	31.4
Evaporation (mm)	193.0	103.6	140.7	105.1	106.0	121.5
LTA	168.8	156.2	155.2	113.8	124.5	121.1
	July	Aug.	Sept.	Oct.	Nov.	Des.
Max. Temp. °C	28.4	29.4	31.7	31.6	33.1	30.6
LTA	26.2	28.8	28.0	33.3	35.3	34.4
Min. Temp. 0C	19.0	19.1	19.7	22.0	22.1	24.5
LTA	16.5	17.5	18.2	20.1	21.6	22.1
Max. R.H (%)	96.0	91.4	90.3	91.7	92.1	92.4
LTA	96.0	91.4	90.3	91.7	92.1	92.4
Min. R.H (%)	54.3	56.1	51.1	55.2	49.0	56.4
LTA	50.3	48.8	45.1	46.8	47.5	50.4
S/shine (hrs)	5.0	4.8	4.8	5.4	6.7	6.3
LTA	5.9	5.8	6.1	6.7	7.4	7.0
Rainfall (mm)	32.2	10.6	0.00	130.5	69.6	52.2
LTA	nd	9.8	17.6	43.3	123.7	168.2
Evaporation(mm)	132.9	130.6	69.5	160.2	181.6	186.3
LTA	129.6	139.8	162.3	191.1	196.7	196.3

na = not available



Appendix 4 . Kilombero 1 (Msolwa) sugar estate : Location of soil profiles

Appendix 5. Some Physico-chemical properties of soils of section 1.

F/	Depth	Soil Separets (%)			Text.	OC	N	Bray 1-P	pH	
No.	(cm.)	Sand	Silt	Clay	Class	(%)	(%)		H20	KCl
1	0-30	72.6	10	17.4	SL	1.43	0.11	9.8	6.8	5.0
	30-70	71.4	10.0	18.6	SL	0.16	0.04	10.5	7.0	5.5
	70-100	76.6	8.0	17.4	SL	0.2	0.03	7.0	6.9	5.2
8	0-30	64.4	10.6	25.1	SCL	1.51	0.09	10.5	6.7	5.0
	30-70	60.4	10.5	29.1	SCL	0.40	0.03	9.8	6.8	5.1
	70-100	84.4	2.5	13.1	LS	0.21	0.02	4.2	6.9	5.4
12	0-30	63.6	13.0	23.4	SCL	1.47	0.02	10.5	6.9	5.2
	30-70	71.6	8.0	20.4	SCL	0.37	0.04	5.6	7.0	7.3
	70-100	65.4	17.0	17.6	SL	0.19	0.03	6.0	7.2	5.6
27	0-30	56.0	23.0	26.4	SCL	2.10	0.11	13.2	6.4	5.1
	30-70	60.9	14.0	25.4	SCL	1.00	0.06	4.2	6.5	4.9
	70-100	79.6	6.0	14.4	SL	0.4	0.03	4.2	6.5	5.2
51	0-30	59.4	12.8	28.6	SCL	1.25	0.08	12.6	6.8	5.1
	30-70	63.4	13.0	23.6	SCL	0.48	0.06	10.5	6.9	5.4
	70-100	69.4	8.0	22.6	SCL	0.22	0.02	6.3	7.1	5.5
71	0-30	59.6	20.0	20.4	SCL	1.63	0.11	18.2	6.5	5.1
	30-70	79.6	8.0	12.4	LS	0.33	0.05	7.7	6.9	5.2
	70-100	73.4	10.0	16.6	SL	0.26	0.04	6.3	6.9	5.2
132	0-30	48.6	27.0	24.4	SCL	0.76	0.09	14.0	7.0	5.5
	30-70	57.6	28.0	24.4	SCL	0.69	0.07	11.9	6.9	5.4
	70-100	55.6	26.0	18.4	SL	0.44	0.04	8.4	7.2	5.7

Appendix 5 continued
Exchangeables bases, CEC and BS of the soils of section one.

F/No.	Depth (cm)	Exchangeable Bases Ca	 Mg	K	Na	CEC	%BS
		-------------(cmol(+)/kg	------------------				
1	0-30	9.12	1.93	1.07	0.52	16.8	75.2
	30-70	5.79	1.48	1.46	0.43	13.0	73.8
	70-100	3.89	1.68	1.07	0.74	10.4	71.0
8	0-30	7.08	1.92	1.38	0.70	14.6	75.0
	30-70	3.49	1.18	0.54	0.52	9.0	63.0
	70-100	2.19	1.00	2.27	0.35	8.8	66.0
12	0-30	8.28	2.0	1.65	0.74	16.4	77.2
	30-70	5.78	2.17	2.91	0.43	16.0	70.0
	70-100	1.89	2.17	2.45	0.35	11.0	62.4
27	0-30	9.98	2.37	1.56	0.35	19.9	72.0
	30-70	5.12	2.22	1.38	0.43	13.6	76.8
	70-100	3.19	1.43	1.38	0.70	9.2	72.8
51	0-30	8.28	2.57	1.76	0.70	18	73.9
	30-70	5.54	2.65	1.33	0.78	14.2	72.5
	70-100	5.20	2.30	1.46	0.76	13.2	73.6
71	0-30	7.18	1.68	0.61	0.52	14.0	71.4
	30-70	3.19	0.89	0.84	0.74	8.8	64.3
	70-100	3.21	1.09	1.13	0.52	8.2	72.5
132	0-30	5.08	2.17	1.42	0.86	13.4	71.1
	30-70	3.18	1.61	1.12	1.02	11.2	61.8
	70-100	3.15	2.16	1.42	0.35	10.9	64.9

Appendix 6. Some physico-chemical properties of soils of section 2

Field	Depth	Soil Separetes (%)			Text.	Bray-P	O.C	Total	pH (1/5)	
No.	(cm)	Sand	silt	Clay	Class	(mg/kg)	(%)	N(%)	H_2O	KCl
M10	0-30	53.6	14.0	32.4	SCL	18.0	2.5	0.15	6.2	5.0
	30-70	51.6	12.0	36.4	SC	7.0	0.68	0.06	6.3	5.0
	70-100	49.6	10.0	40.4	SC	4.9	0.56	0.05	7.0	5.5
M17	0-30	48.6	16.0	35.4	SC	7.0	2.2	0.12	6.2	4.8
	30-70	45.4	16.0	38.6	SC	0.7	0.6	0.05	6.4	5.1
	70-100	49.6	17.0	42.6	C	0.4	0.46	0.05	6.4	5.1
M20	0-30	49.6	16.0	34.4	SCL	15.4	1.74	0.12	6.2	4.6
	30-70	43.6	14.0	42.4	C	9.8	0.84	0.08	6.6	5.2
	70-100	43.6	12.0	44.4	C	4.2	0.52	0.06	6.8	5.4
M38	0-30	49.6	15.0	35.4	SCL	17.8	2.2	0.12	6.3	4.8
	30-70	52.4	13.0	34.6	SCL	9.8	0.64	0.06	6.4	5.0
	70-100	50.6	12.0	37.4	SL	4.9	0.42	0.05	6.9	5.4

Appendix 6 continued

Exchangeable bases CEC and base suturation of soils of section two

Field No.	Depth (cm)	Exch. Bases cmol(+)/kg Ca	Mg	K	Na	C.E.C	BS (%)
M10	0-30	6.69	2.52	2.68	0.35	16.9	72.4
	30-70	6.52	3.03	2.05	0.83	18.2	68.0
	70-100	5.49	3.03	1.23	0.52	16.3	63.3
M17	0-30	7.18	1.53	1.30	0.39	17.0	61.1
	30-70	5.59	2.09	2.30	0.56	18.0	58.5
	70-100	4.79	2.40	0.63	0.52	13.8	63.5
M20	0-30	6.09	1.56	2.07	0.70	16.4	60.0
	30-70	6.59	2.20	1.79	1.56	20.2	60.0
	70-100	6.13	1.86	1.82	1.43	18.2	62.7
M38	0-30	6.29	2.76	0.84	0.74	16.8	63.3
	30-70	4.19	2.76	0.90	0.56	14.0	60.1
	70-100	2.40	2.81	1.69	0.39	12.0	60.7

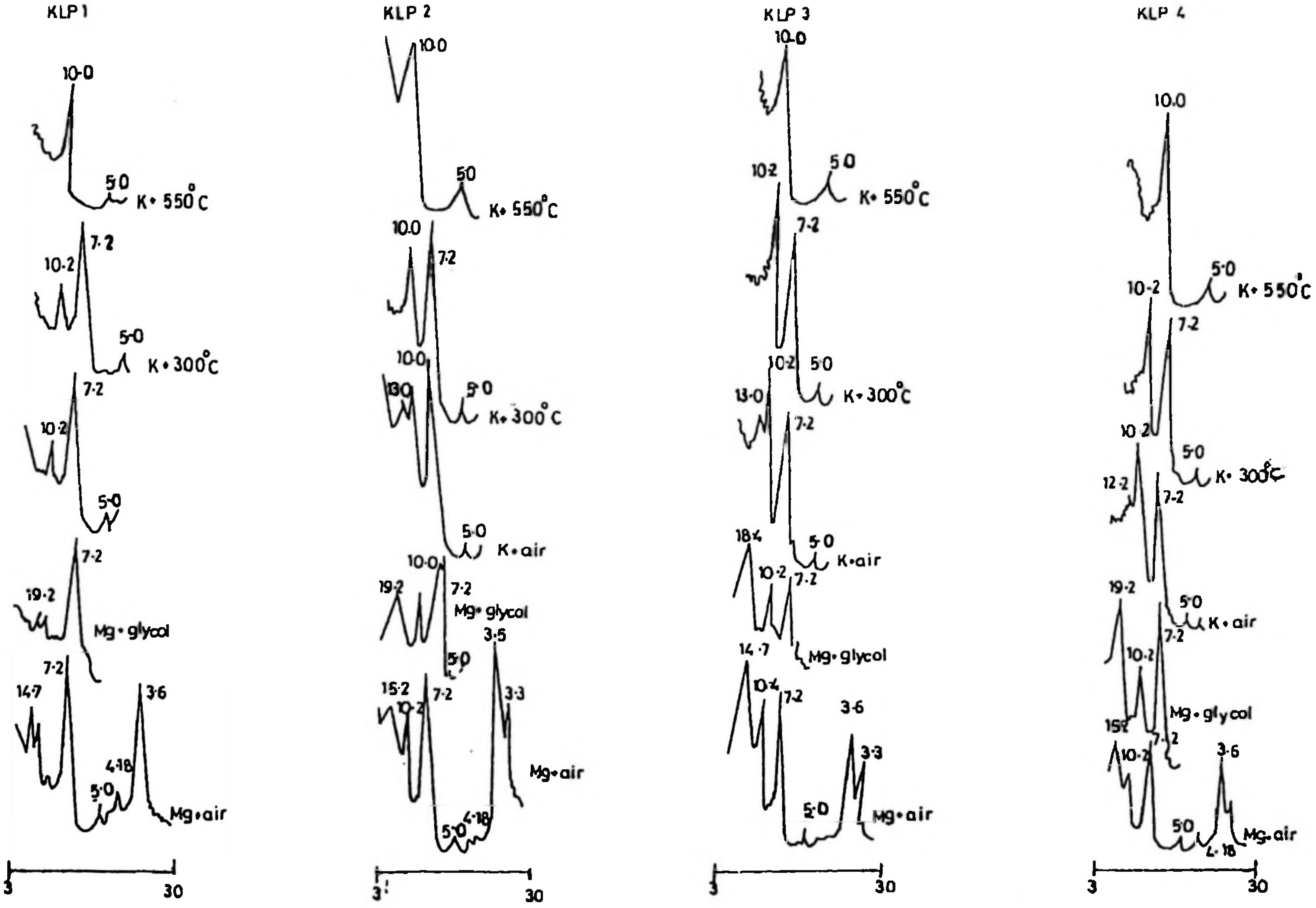
Appendix 7. Physico-chemical properties of soil of section 3

Field No.	Depth (cm)	Soil separetes (%)			Text. Class	Bray-I P(mg/kg)	O.C (%)	Total N(%)	pH(1/2.5)	
		Sand	Silt	Clay					H20	Kcl
65	0-30	33.6	16.0	50.4	C	2.10	1.55	0.11	6.2	4.8
	30-70	25.4	8.0	64.6	C	0.4	0.54	0.09	6.6	5.1
	70-100	39.4	8.0	52.6	C	0.4	0.34	0.05	7.0	5.5
101	0-30	45.4	16.0	38.6	C	12.6	1.74	0.12	6.9	5.2
	30-70	36.5	14.0	49.4	C	0.70	0.72	0.07	6.5	5.1
	70-100	54.6	8.0	37.4	SC	0.4	0.56	0.04	7.0	5.6
105	0-30	37.6	14.0	48.4	C	7.0	1.78	0.13	6.1	4.7
	30-70	27.6	12.0	60.4	C	0.4	0.52	0.08	6.3	4.8
	70-100	32.6	7.0	60.4	C	0.4	0.5	0.07	6.5	5.0
120	0-30	49.9	10.0	40.6	SC	4.9	1.47	0.13	6.0	4.6
	30-70	69.4	4.0	26.6	SCL	4.2	0.32	0.07	6.2	4.9
	70-100	55.4	4.0	40.6	SC	2.8	0.27	0.04	6.0	4.5
124	0-30	66.6	5.0	28.4	SCL	7.0	1.52	0.09	6.3	4.8
	30-70	46.6	9.0	50.4	C	0.7	0.16	0.07	6.0	4.3
	70-100	41.6	8.0	50.4	C	0.4	0.46	0.07	6.0	4.3

Appendix 7 continued

Exchngeable bases, CEC and BS of soils of section 3

Field No.	Depth (cm)	Exchangeable Bases (cmol(+)/kg) Ca	 Mg	 K	 Na	C.E.C.	BS. (%)
65	0-30	5.79	6.22	1.97	0.78	25.6	60.9
	30-70	6.36	8.86	1.97	1.48	27.0	69.1
	70-100	7.2	5.68	1.61	1.48	25.0	63.3
101	0-30	9.28	5.57	2.15	0.70	22.8	77.7
	30-70	9.58	4.65	0.72	1.04	21.6	77.6
	70-100	5.89	3.96	1.79	1.26	18.8	71.7
105	0-30	7.68	4.77	1.92	0.78	24.0	63.1
	30-70	7.68	6.91	1.25	0.43	23.6	68.9
	70-100	5.79	3.95	1.34	0.74	16.0	73.4
120	0-30	5.39	1.68	0.84	0.52	16.0	52.6
	30-70	2.69	0.45	1.07	0.7	8.0	61.3
	70-100	2.49	0.60	0.76	0.35	6.5	64.6
124	0-30	2.99	1.87	1.30	0.39	11.6	56.4
	30-70	3.59	1.71	1.68	0.56	15.0	50.2
	70-100	2.89	1.53	2.07	0.61	12.8	55.4



Appendix 8: X-ray diffractograms of clay fractions from subsurface horizons of studied soils
Peaks in Angstrom units (Å)

Appendix. 9. Some physical and chemical properties of the soils from experimental plots

Depth (cm)	% Particle size distribution			%O.C	Bray-1 P mg/kg	% N	pH (H$_2$O)	exchangeable bases(cmol(+)/kg					CEC cmol(+)/kg
	Sand	Silt	Clay					Ca	Mg	K	Na		
section 1 (Field no. 12)													
0-30	60.6	10	29.4	1.60	8.0	0.08	6.1	6.5	2.3	1.9	0.4		14.0
30-70	78.6	2.0	9.4	0.32	4.9	0.03	6.2	3.6	0.59	0.5	0.56		8.0
Section 2 (Field no. M17)													
0-30	53.4	14.0	32.6	1.86	10.6	0.12	6.2	8.4	2.5	1.6	0.4	0.3	17.8
30-70	44.6	7.0	39.4	0.72	4.9	0.09	6.4	6.7	2.2	1.4	0.5	0.3	16.2
Section 2 (Field no. M4)													
0-30	50.0	14.6	35.4	1.64	12.3	0.12	6.0	8.2	2.0	1.7	0.40		19.0
30-70	44.0	18.4	36.4	0.81	6.3	0.07	6.3	6.9	1.8	1.1	0.32		15.8