# INVESTIGATION INTO YIELD REDUCTION OF SUGARCANE PLANTATION OF THE SAVANNAH SUGAR COMPANY, NUMAN NIGERIA.

**BY**

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**NOVEMBER, 2015**

## DECLARATION

I declare that the work in this thesis entitled "Investigation Into Yield Reduction of Sugarcane Plantation of the Savannah Sugar Company, Numan, Nigeria" has been carried out by me in the Department of Agricultural Engineering under the supervision of Prof. O.J Mudiare and Dr. M. K. Othman. The information derived from the literatures has been duly acknowledged in the text and a list of references provided. No part of this thesis has been previously presented for another degree or diploma at any university.

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|---|---|---|
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## CERTIFICATION

This thesis entitled "**INVESTIGATION INTO YIELD REDUCTION OF SUGARCANE PLANTATION OF THE SAVANNAH SUGAR COMPANY, NUMAN, NIGERIA**" by Pius Awhari DAUDA meets the regulations governing the award of the degree of Master of Science (Agricultural Engineering) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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## DEDICATION

This project is dedicated to Almighty God who inspired me through my academic work, and to my lovely wife; Victoria Dauda Pius for her bountiful love and Parents Mr and Mrs Pius N Awhari for their fatherly advice and encouragement throughout my stay in school.

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## ABSTRACT

This study was undertaken to identify the factors responsible for declining of sugarcane production in Savannah Sugar Company (Dangote Group). Soil samples were collected from the field within the irrigated plots P1, G2 and K2. The pH and EC were determined using the pH meter and EC meter, respectively while Ca,Mg and OM were determined using titration methods. Na and K were determined by flame photometry method. The results of the analysis showed that the range of pH values were from 5.56-7.6, indicating the soil pH from slightly acidic to slightly alkaline. The pH values obtained by Kenting Africa Resource Service Division LTD (1975) from a depth of 0-60cm range from 5.2-7.6 which also showed that the soil was slightly acidic to slightly alkaline. The average mean value of EC was 0.45-0.81 dS/m indicating low concentration of soluble salts. The Exchangeable Sodium Percentage (ESP) of the soil on the average ranged between 0.028-0.029 (2.8-2.9%) which was below the threshold of 15% (Mohsen et.al, 2009).These indicate that the soil is low in salinity and sodicity.

The study reveals that, the reason for the decline in sugarcane production was not soil quality, but rather due to two factors deduced from the checklist administered during the study. The factors are categorized into two; Technical and Managerial Factors. These were importation of environmentally non-compactible seedlings, over ageing of the sugarcane, worn-out and obsolete equipment and inadequate workforce.

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# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background of the Study

Brady and Weil (1999) defined soil quality as the capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Thus, soil quality assessment reflects biological, chemical, physical properties, and engineering processes, and their interactions within each resource unit (Karlen *et al*., 2001).

Sugarcane grown under irrigation in arid and semi-arid region is frequently adversely affected by soil salinity. The crop is moderately sensitive to salinity, with threshold for yield reduction at 1.7 dS/m (Golabi *et. al*, 2009). The Salinity in the root zone of sugarcane decreases sucrose yield, through its effect on both, biomass and juice quality (Lingle and Wiegand, 1996). The salinity of soil or irrigation water reduces sugar stalk yield by reducing both the stalk population and weight. Wiegand *et. al* (1996) found that each dS/m increase in the root zone salinity decreases stalk population by 0.6 stalk/$m^2$ and individual stalk weight by 0.15 kg, resulting in a stalk yield decrease of 13.7 t/ha. It has been estimated that globally, approximately 40% of land under irrigation is salt-affected (Moore, 1984; Shannon, 1984). This problem is prevalent in soils under irrigated sugarcane (*Saccharum* sp.), especially in areas of low rainfall and high evaporative demand (Haynes and Hamilton, 1999).

Decrease in the crop yield potential could be due to biotic and abiotic stresses; among the abiotic stresses, salinity is a major stress that increases day by day due to lack of proper management of soils (Idrees *et. al*, 2004). Salinity in arid and semi-arid areas primarily arises from natural causes of low precipitation to evaporation ratio and the existence of saline parent's rocks. Use of substandard water in agriculture (Syvertsen *et. al*, 1989), accumulation of chemicals from industrial effluents and excessive use of mineral fertilizer are secondary sources. Salinity has a wide range of adverse impact on social and economic set-up of many irrigated arid and semi-arid regions. The economic importance of salinity is strongly realized from a 10 % increase of saline areas all over the world on yearly basis (Ponnamperuma, 1984). Sugarcane (*Saccharum* sp.), is a multipurpose and commercial crop of Pakistan which is cultivated on approximately 1.0 Mha (Anonymous, 1999). It is extensively cultivated in the irrigated salt-affected lands of Pakistan which result in heavy yield losses. Sugarcane has been considered highly salt tolerant together with sugar beet, barley and cotton (Shannon and Noble, 1990); nevertheless, salinity, salinization, sodicity, together with nutrient deficiencies, irrigation water and water quality, high water table and poor drainage, stand out among the limiting factors of sugarcane production. Growing sugarcane on unsuitable soils is possibly the major limiting factor in cane culture worldwide (Rozeff, 1999). Salt-tolerance of sugarcane depends to a large extent on the ionic composition of the soil salinity up to 6 dS/m and still produce greater than 100 kg/ha of cane, when the salt in the soil is Calcium Sulphate ($CaSO_4$) (Zerega and Hernandes,1997). Francois and Maas (1999) reported an increase of 1-3 dS/m of critical salinity values for gypsum containing soils. The soluble fraction of gypsum interferes with measurement of EC due to more

soluble salts. Moreover, crops tend to be more tolerant to salinity in saline gypsiferous soils which are easier to manage.

Sugarcane is an important industrial and economic crop in Nigeria and in many countries of the world. Sugarcane produces numerous valuable by-products such as alcohol (ethanol) used by the pharmaceutical industry, ethanol used as a fuel, chip board manufacturing and press mud used as a rich source of crop production (Kumar *et .al*, 1994; Lingle *et. al*, 2000).

Saline soils are soils having excessive soluble salts that make the soils solution sufficiently concentrated to injure plants and hinder soil productivity. The scanty rains of the region do not penetrate the soil deep enough to leach away the excess salts in the soils (NSW Department of Natural Resource, 2005).

The continued accumulation of salts in soil under irrigation results in greater salt concentration brought in than removed. Generally, irrigation water contains large amounts of salts accumulating in naturally occurring water (Kundili, 1999).

In many researches, it was found that soil salinity reduces net photosynthesis rate , nitrate uptake and resulting in low protein synthesis which causes dwarf plant formation. It also reduces fresh and dry weight as well as the flowers production which leads to low yield ( Levitt,1980 ; Sharma *et.al*,1980 ; Robinson and Marticorena. 1986).

## 1.2 Statement of Problem

Since the establishment of the Savannah Sugar Company plantation in Numan, Adamawa State 38 years ago, there were few of soil quality assessments done within the

period by the Savanna Sugar Company. However, there was no record indicating the result of such assessments except that of the one made by Kenting Africa Resource Service Division LTD (1975) at the time of the plantation establishment. The results of the survey conducted in 1975 in the study area indicated low salinity level of the soil, which ranged from 0.006 to 1.00 dS/m within the root zone depth of 0 to 60cm at the plantation site. However, in recent years it was observed that the yield of sugarcane per hectare declined from 88.64 t/ha in 1980/81 production year to 23 t/ha in 2012/13 per season. This development has been a source of worry to the management of the company and a threat to the expansion of the sugarcane production in Savanna Sugar Company.

## 1.3 Justification of Study

In order to address the problem of declining sugarcane production at the Savannah Sugar cane plantation, there is need to investigate the factors responsible for decrease in production of sugarcane over the period. The outcome of the study will help the management of the company in reversing this ugly trend.

The effort of assessing the soil quality of the sugarcane plantation is aimed at investigating the likelihood of soil contribution to the decline of the sugarcane production. This is because the production is made through irrigation practice, which makes the soil vunerable to fertility deterioration and salt accumulation. Decline in soil fertility and salinity/ sodicity build-up can result in low yield of crops even when other production inputs are adequately used.

Consequently, the research is undertaken with a view to proffering solution to the affore-mentioned problems. The findings of the study would be of benefits to the

management of Savannah Sugar Company for addressing the issues so as to boost the productivity and income of the company.

## 1.4 Aim and Objectives

The general objective of the study is to investigate yield reduction in sugarcane plantation at the Savannah Sugar Company, Numan, Adamawa State. The specific objectives of the project are limited to the following:

1. To determine soil salinity and sodicity levels of the study area.
2. To compare the levels of salinity and sodicity with the recommended or acceptable levels in the study area.
3. To determine other reasons contributing to decline in sugarcane yield per unit area.

# CHAPTER TWO

## 2.0 LITRATURE REVIEW

### 2.1 Introduction

Saline soil is soil containing sufficient soluble salt to adversely affect the growth of most crop plants. The lower limit of saturation extract electrical conductivity $EC_e$ of such a soil , is conventionally set at 0.4 dS per meter. Actually, sensitivity of plants are affected at half this salinity level and highly tolerant ones at about twice the amount (Fourth and Henry, 1984). Also, some plants are more tolerant to soil sodicity than others. Excess exchangeable sodium percentage, high pH, lack of calcium and the resulting poor physical properties are the main causes of reduction in yield due to soil sodicity (Gupta and Gupta, 1997). The yield of crops would be affected over time when salinity build-up in the root zone proceeds upward (Gupta and Gupta, 1997). Maas and Hoffman (1977) and Maas (1985) found that under optimum management conditions the sugarcane yield remains at the potential level until $EC_e$ reaches the threshold level of 1.7 dS/m.

### 2. 2 Ecology of Sugarcane

Sugarcane requires ample supply of water, 1200 - 1500 mm per annum. In freely drained soils, a high precipitation can be tolerated. The duration of the rainy season is important in sugarcane growth. For example, at the Savannah Sugarcane Estate where annual rainfall is 676 mm, sugarcane is also irrigated because of the shortfall in the water requirement. Adequate moisture and temperature are the two most important ecological requirements that are essential for efficient growth and productivity of the sugarcane crop. If excess water is not immediately drained at the sprouting stage, it will

result in rotting of stem cuttings called setts, usually used for the next season's plantings. On the other hand, if rainfall is insufficient during the season, supplementary irrigation becomes necessary to ensure effective development of stems. In this context, water stress occurring in the plant during stem elongation severely reduces cane production. Like many other tropical cereal grasses, optimum temperature for sugarcane is essential for effective germination of the sett, tiller elongation, photosynthate mobilization and ripening. Sugarcane growing areas in Nigeria are warm and conducive for maximum physiological activity throughout the season. According to Purseglove (1974), the optimum temperature for germination of sugarcane is 27-33$^0$C while good tiller production occurs when the temperature is about 30$^0$C. A day temperature of below 18$^0$C lengthens the tillering period and thus, result in uneven maturity of the canes. Stalk elongation is linearly related to temperature with an optimum at 23$^0$C. An air temperature range of 24-30 $^0$C and a soil temperature of around 21$^0$C are optimum for photosynthesis in sugarcane. Sugarcane does not grow when temperatures fall below 15 $^0$C or rise above 38 $^0$C. Insolation in a sugarcane plantation is controlled not only by day length and humidity, but also by cloudiness of the sky. Solar radiation is particularly important in sugarcane because absorption of mineral nutrients from the soil is enhanced by the presence of sun light during the day time and absorption of water from the soil is equally dependent upon solar energy. It is imperative, therefore, that the greater the exposure of sugarcane to sunlight, the greater the yield. These ecological requirements of sugarcane make Nigeria and many other tropical countries best suited for its production. In sugarcane, close spacing increases yield per unit area where the growing season is short. When the growing season is long

enough, proper plant arrangement in rows promotes optimum exposure to solar radiation and hence, greater production .Sugarcane flowers when the photoperiod is conducive. It is optional to harvest sugarcane immediately before or after flowering to extract high quality sugar. If harvesting is long delayed after flowering, sugar quality would be greatly reduced. This happens mainly because the sugar stored in the stem tissues hydrolyse and then transported to the inflorescence to promote development (Banderi *et.al*, 2012) .Sugarcane is a heavy feeder crop. The soils in which it is grown should have optimum properties. In Nigeria, sugarcane is grown mainly on loamy soils with good proportions of sand, silt and clay with good water storage and drainage characteristics. The soils are fairly fertile, thus, supplementary fertilizers are used only when necessary. A pH range of 6-8 is considered optimal for sugarcane production (Banderi *et. al*, 2012).

## 2.3 Sugarcane Production Trends in Nigeria

Dangote Sugar Company is known as Savannah Sugar Company, Numan, Adamawa state which is Nigeria's largest producer of the sweetener with 70 % market share (Sugar Industry Report, 2011). National Sugar Development Council, NSDC, showed that Dangote Group is leading the pack with a fresh investment of $2 billion on projects in six states of Nigeria to produce about 1.5 million tonnes and to expand its agricultural land from the current 4,316.5 hectare (ha) to 21,000 (ha) by 2018 to produce 100,000 tonnes of sugar annually. On its part. Honey-Gold Group is to invest $300 million on two sites in Adamawa state to produce 200,000 tonnes of sugar annually (Financial Vanguard, 2014). Similarly, Crystal Sugar Mills is spending $30 million to expand its operations to produce 60,000 tonnes sugar/annum by 2018 from its recently acquired 1,500 Total Cane Density (TCD) Sugar plant at Hadejia, Jigawa state while Confluence

Sugar Company is investing $240 million in Kogi State to produce 200,000 tonnes sugar/annum on about 37,000 ha of land at Ibaji (Financial Vanguard, 2014). According to National Sugar Development Council (2014), the refinery units of the sugarcane company was the highest employer in the sector with 1,321 staff across its operation and hopes that their total workforce will hit 100,000 mark by 2020. Golden Sugar Company has 695 workforces and hopes to increase it to 3,300; BUA Sugar presently has 75 workers and is targeting 15,000 workforce. Similarly, Confluence Sugar has 115 workers and is targeting 8,000 workforce; Crystal has 35 workers and is targeting 3,500 workforce while PSPAN currently has 400 workers and hopes to increase it to 3,000 by 2020.

Nigeria's demographics and economic growth rates North of 5 % ensures that the demand for the company's products is sustainably growing. The major drawback is that the company does not grow and mill its own sugarcane, rather, it imports raw sugar and refines it for sale as reported by Sugar Industry Report (2011). This exposes it to volatile global sugar prices and forex risks. Nevertheless, the company is working on a project via the Savannah Sugar Company to enable it grow and mill its own sugarcane. Africa only grows about 6.5 % of the world production, while having 11 % of the world's consumption. The largest sugarcane areas of Sub-Saharan Africa (SSA) are in South Africa, Mozambique and Cameroon; whereas, South Africa is the leading producer followed by Sudan, Kenya and Swaziland (Sugar Industry Report, 2011). If one looks at worldwide yields, six SSA countries are among the top eight countries: Peru yields are highest (125.5 t/ha) followed by Colombia, Egypt, Senegal, Malawi, Sudan, Ethiopia, Zambia and Tanzania. However, in the global context, SSA ranks only 21st in

production extent. In SSA, most countries process sugar cane into other products. A few exceptions are in Ghana (92 % of the sugar cane production), Cameroon (30 %), and Democratic Republic of Congo (DRC) and Kenya (about 20 % each) where humans directly consume the crop as food. Overall, Africa remains a net importer of sugar, with the bulk of the imports emanating from Brazil. South Africa is the largest producer on the continent, coming in highest as number 16 on a world scale, reflecting that from a production perspective Africa remains a small player. On an-ex factory cost basis, however, Africa is very competitive, with 5 of the top 10 lowest cost producers being from the continent.

ENL Land Ltd, formerly known as The Savannah Sugar Estates Company Ltd, is ENL's executive arm in the agricultural sector. Following its amalgamation with a sister company Mon Désert Alma Ltd in December 2009; it now manages some 16,000 ha of land situated in the southern and central parts of Mauritius. Most of the land under its supervision is dedicated to sugar cane cultivation. The company currently produces an average of 385,000 tonnes of sugar cane which are sent to Integrated Sugar and Electricity Producing facilities in the South and to the East for the production of sugar. The company has also diversified into other agricultural activities as well as property development due to declining cane and sugar production on the island. These efforts seem to be bearing fruit with property business contributing 16.4% to its turnover. In the same set of results, property and investment (mainly ENL investment) accounted for 30.4% and 65.9% of Profit After Task (PAT), respectively.

Table 2.1 presents the global sugarcane production as at 2011/2012. A total of 165.1 million tonnes of sugarcane production was produced during the 2010/2011 production

season while 172.8 million tonnes was produced in the proceeding year (2011/2012). The developing countries produced 129.3 and 130.8 million tonnes of sugarcane in 2010/2011, while the developed countries contributed 35.8 and 42 million tonnes of sugarcane respectively.

**Table 2.1: World Sugar Production (Million tonnes)**

| Year | 2010/11 | 2011/12 |
|---|---|---|
| Asia | 62.9 | 65.9 |
| Africa | 10.8 | 11.2 |
| Central America | 12 | 12.4 |
| South America | 46.1 | 44 |
| North America | 7.2 | 7.3 |
| Europe | 22 | 27.7 |
| Oceania | 4 | 4.2 |
| Developing countries | 129.3 | 130.8 |
| Developed countries | 35.8 | 42 |
| Total globally | 165.1 | 172.8 |

Source: FAO (2012).

## 2.4 Sugarcane Growth and Development

The crop is usually produced from stem cuttings called setts and each node has all the qualities for growing new plants. The shoots grow from underground nodes, and the axillary buds at these nodes give rise to tillers. The number of tillers may vary from very few to a very large number, such as 144 per stuck arising from one bud (Shamel, 1974).Sett roots supply the germinating bud with water until shoot roots are formed. Root proliferation become abundant when growth conditions are optimum. Root growth ability under sub-optimum conditions for sugarcane growth is among the selection criteria in breeding programmes worldwide. Growth of sugarcane varies depending on

the cropping cycle of one or two years. Whereas numerous stalks may arise from a single sett, over 50% may die before nine months of growth when stable stalks are established. Sugarcane selection for improved clones focus on effective tillering ability and rapid growth rate to maximize exposure to solar radiation. Hawaii selections, for example, are aimed at maximizing high leaf area index (LAI) within six months of growth. LAI declines slowly after the maximum has been achieved. The adaptability of sugarcane to high temperature conditions is mainly associated with expansion rate of the leaf area. In this regard, leaf area expansion rate is more related to temperature than the solar radiation receipt during the first few months of growth. Maximum rates of leaf expansion are observed at 22 ℃ (Bull and Glasziou, 1975). Slow growth in the establishing stage of sugarcane seedlings is one of the limiting factors to utilize this crop in warm temperate zone such as Japan, where the optimum range of temperature for juvenile growth stage was studied by Ehara, *et al.*(1994). Their experiments concluded that 25-30 ℃ was favourable to increase the rate of emergence of leaves, and that 20-25 ℃ was favourable to increase the number of tillers during the juvenile phase. These data well support Evans's (1997) finding because the rate of leaf expansion depends primarily on the rate of leaf emergence and the rate of tillering at this phase. As a specific growth characteristic, it was observed that the relative growth rate (RGR) of sugarcane was much smaller than that of any other crops, such as maize, sorghum and millets, due to a much smaller leaf area ratio (LAR) in spite of a large assimilation rate (NAR) (Ehara, *et al.* 1994).Under cooler conditions, the juvenile growth phase is prolonged but results in higher relative leaf area expansion rates during periods of high radiation exposure in the tropics. Total dry matter (TDM) produced by sugarcane may

average 40 g/ $m^2$ d and may exceed 150 t $ha^{-1}$ $year^{-1}$ under very good growth conditions. In this regard, TDM production can be maximized by extending the growth duration (Bull and Glasziou, 1975). In order to utilize such a high potential for dry matter productivity, the dry matter digestibility (DMD) of sugarcane for cattle feeding was evaluated by *in vitro* cellulose method and it was found that DMD of stems increased with growth up to 77 % while that of leaves remained at 50 to 55 % (Takamura and Nakano, 1986). All these data suggest that sugarcane can be utilized not only for producing sugar but also for feeding cattle.

## 2.5 Managing Yield Decline in Sugarcane Cropping Systems

Yield decline is an issue that has plagued sugarcane production systems worldwide for more than half a century. Initially, yield decline was regarded as an apparent decline in the productive capacity of cane varieties due to genetic shift (Arceneaux and Hebert, 1943; Coleman, 1974). However, much of the recorded decline was subsequently related to ratoon stunting disease (King and Steindl, 1953) because no evidence of genetic shift within varieties was established (Mangelsdorf, 1959; Moore *et al*., 1993).Yield decline has been clearly associated with soil degradation caused by the long-term monoculture of sugar- cane and how that monoculture has been practiced (Arceneaux and Hebert, 1943). Thus, yield decline has been defined as the loss of productive capacity of sugarcane growing soils under long-term monoculture (Garside *et al*., 2002a). Yield decline appears to have been part of the Australian sugar industry for most of its history as declining yields under sugarcane monoculture were recorded as early as 1900 (Maxwell, 1900); while Bell (1935, 1938) attributed these declining yields to fertility decline and root pathogens . However, the impact of yield decline on an

industry wide basis was not fully realized until a productivity plateau occurred from 1970 – 1990 (SRDC, 1995). It was thought that this productivity plateau was largely due to the intensification of the monoculture brought about by the removal of assignment restrictions during the 1970s (Wegener, 1985), which promoted the adoption of a plough-out/re-plant system at the expense of fallowing. Previously, growers had only been able to harvest 75 % of their assigned area in any one year and had, by default, been forced into fallowing 25 % of their land, usually with a legume for green manuring. Concomitant with the increase in plough-out/re-plant was the emergence of the sugarcane root disorder, poor root syndrome (Egan *et al.*, 1984). Studies into the cause of this disorder focused on pathogenic fungi and resulted in the isolation of the root pathogen, *Pachymetrachaunorhiza* as one of the causes. Yield increases of up to 40% were recorded in *Pachymetra* resistant varieties (Magarey,1999). Even greater yield increases (> 100 %) were recorded when long-term sugarcane soil was fumigated with methyl bromide (Croft *et al.*, 1984). However, when *Pachymetra* resistant and susceptible varieties were grown on fumigated and non-fumigated sugarcane soil the resistant variety out yielded the susceptible variety but still showed a 36 % response to fumigation, clearly indicating there was more than *Pachymetra* associated with the disorder (Han, 1998,). Regardless, there was little doubt that soil biological factors were an important component of yield decline. The theoretical potential yield of sugarcane cultivar when grown in environments to which it is adapted is 218.9 t $ha^{-1}yr^{-1}$ (Moore, 2006).

## 2.6 Benefits of Improving Soil and Water Management System

The changed cropping system being promoted is still in its development phase but enough confidence is being shown by many sugarcane growers in Nigeria to adopt at least components of the system while a small number at this stage are embracing the whole system. The system is based upon the basic agronomic principles that organic matter is the key to healthy soil, monocultures are undesirable, compaction should be avoided as much as possible, and excessive tillage destroys organic matter, soil structure, soil biota and is very costly. The benefits that can be envisaged by adopting such a system include:

1) Legume breaks provide a better-balanced biological, control of root pathogens which biologically fix nitrogen, greatly reducing the need for fertilizer nitrogen and improve cane growth and yield.

2) Isolation of cane and crop areas through matching wheel and row spacing can guide the harvester and haul-out tracking and thus reduce the impact of compaction.

3) Minimum/zero tillage, which conserves organic matter, improves soil structure, does not disrupt beneficial soil biota, and reduces surface runoff and erosion.

4) Elimination of the need to till to remove compaction.

5) Reduction of the impact of water logging.

6) Improvement of the timeliness of operations.

7) Savings in fuel and labour costs.

8) Indications that weeds will become less of a problem and herbicide use reduced with continual trash cover.

## 2.7 Criteria of Salt Tolerance

Plant tolerance to salinity is usually appraised as (1) the ability of a plant to survive on saline soils (2) the absolute plant or yield at elevated salinity levels and (3) the relative growth or yield of a crop in saline conditions compared with that obtained in non- saline environment (Lauchli, 1984; Maas, 1986; Qureshi *et al*., 1990; Wahid et al, 1997). Plant survival under higher levels of salinity may be useful to Ecologists. However, this criterion has limited use for Agronomists, although some workers use it for searching more tolerant plants such as wild relatives of crop plants (Schachtman and Munns, l992; Shannon, 1997). Indirectly, this criterion is potentially useful because Plants' breeders can use it as the basis for selecting salt tolerant lines and cultivars.

Economists and farmers are particularly interested in the actual yield obtained from the salt affected soils. The disadvantage of this criterion is that the actual yield is also dependent upon other environmental factors such as soil moisture, soil fertility, insect attack, plant pathogens amongst others. Therefore, one cannot be sure that the differences are due to tolerance to salinity alone (Shannon, 1997). The relative yields of different crops in soil salinized to different degrees( with all other factors being held constant) is a useful criterion for the expression of salt tolerance of crops , which include final germination , percent uptake of $Na^+$ and $Cl^-$ by root and shoot, length of root and shoot growth characters and grain yield ( Ashraf and McNeilly, 1992).

### 2.7.1 Measurement of salt tolerance

Measurement of crop salt tolerance is intriguing as it depends not only upon genetic constitution of the crop but also, environmental factors such as soil water, temperature, humidity, solar radiation intensity, growth stage of the plant, amongst others. Thus, plants may show more tolerance to salinity under one set of conditions than the others. Inspite of environmental factors, some crops are more tolerant to salinity than the others, so the measurement of the relative salt tolerance becomes possible (Maas,1986). Maas and Hoffman (1977) proposed that the salt tolerance of a given dicotyledonous species could be expressed by a linear regression equation:

$$Y= a +b(ECe-A) \quad (2.1)$$

Where:

Y= relative yield

ECe= Soil Salinity

A= Lowest Salinity

a and b are empirical coefficient

Maas and Hoffman (1977) found that equation 2.1 can be given as

$$Y_r=100-b\ (EC_e-A), \quad (2.2)$$

in which a is taken as 100%.

For comparisons of high and low yielding varieties of the same species, data at various growth stages and yield parameters are required to assess the degree of salts injury and the salt tolerance.

## 2.8 Factors Influencing Salt Tolerance

Perhaps the most difficult task in assessing crop salt tolerance is accounting for the many factors that may influence the plants response to salinity.

### 2.8 .1 Plant factors

Salinity affects plants at all stages of development and for some crops, sensitivity varies from one growth stage to the next. Cereal crops seem particularly variable. Several studies showed that sugarcane is moderately tolerant during germination, becomes very sensitive during early growth and then becomes increasingly more sensitive to salinity during production (Ashraf ,1994; Quresh,*et.al,* 1990; Wahid *et al*, 1997).

### 2.8 .2 Soil –water and aeration

Immediately after irrigation, soil water content is maximum and soluble salt concentration is minimal. As water is lost to evaporation and crop transpiration, most of the salts are excluded by the plant and left behind in a reduced volume of the water. The drier the soils become before the next irrigation the higher the average salt concentration for irrigation cycle. Another problem in evaluating salt tolerance is excessive irrigation which can cause poor soil aeration particularly in fine textured soils.

### 2.8 .3 Environmental factors

Climate may significantly influence plant response to salinity. Temperature, humidity and air pollution have markedly influenced salt tolerance. Many crops seem less salt tolerant when grown under hot, dry conditions than under cool humid ones for example cotton, onion, tomato.

### 2.8 .4 Soil factors

Fertility status of the soil can also change the tolerance capability of plants. Crops grown on infertile soils generally have abnormal high apparent salt tolerance as compared with crops grown on fertile soils because yields on non-saline soils are severely limited by inadequate fertility. Other growth limiting factors such as poor

structure or lower permeability to gases and water can reduce the salt tolerance (Keating *et al* ;1986).

## 2.9 Soil Requirement for Sugarcane

Soil is a medium for plant growth. It provides nutrients, water and anchorage to the growing plants. Maintenance of proper physical, chemical and biological conditions of the soil is necessary for realizing higher growth, yield and quality of sugarcane. Sugarcane does not require any specific type of soil as it can be successfully raised on diverse soil types ranging from sandy soils to clay loams and heavy clays. A well-drained, deep, loamy soil with a bulk density of 1.1 to 1.4 g/cm$^3$ and total porosity, with an adequate balance between pores of various sizes, higher than 50 %; ground water table below 1.5 to 2.0 m from soil surface and an available water holding capacity of 15 cm per meter depth of soil or more is considered ideal for sugarcane cultivation. The optimum soil pH is about 6.5 but sugarcane can tolerate considerable degree of soil acidity and alkalinity. Hence, it is found growing in soils with pH in the range of 5 to 8.5. Liming is required if pH is less than 5.0, or gypsum application if pH is more than 9.5. Nematode infestations are likely to occur in very sandy soils. Soil testing before planting is desirable as it helps in determining the optimum quantity of macro and micro nutrient applications. Chemical constraints in the soils, such as acidity and low fertility, are relatively easy to correct or control. Poor physical conditions such as soil compaction due to intense mechanization when limiting, are much more difficult to ameliorate. For this reason, physical properties of soil are given as a factor in sugarcane growth. Based on the experience gained in Brazil, a few criteria to define soils, which

are apt for sugarcane growing, have been given

in Table 2.2.(www.sugarcanecrops.com/soil_requirement) (April, 2013).

**Table 2.2 Criteria for Soils suitable for Growing Sugarcane**

| | Class | | | |
|---|---|---|---|---|
| **Characteristics** | **Good** | **Average** | **Restrict** | **Unfit** |
| Effective depth | Deep | Medium | Shallow | Too shallow |
| Soil texture | Clay | Medium to clayey | Sandy | Too sandy |
| Relief | Flat | Rolling | Too rolling | Hilly |
| Fertility | High | Medium or low | Too low | Too low |
| Drainage | Good | Medium to accentuated or incomplete | Incomplete | Excessive or deficient |
| Restraints to Mechanisation | Absent | Medium | Strong | Too strong |
| Susceptibility to erosion | Low | Medium | High | Too high |

Source: Kofeler and Bonzelli (1987)

## 2.10 Salt Tolerance in Sugarcane

Sugarcane exhibits stunted or no growth under saline condition with its yield falling to 50% or even more of its true potential (Subba Rao and Shaw, 1985). Reports suggest that sugarcane is moderately sensitive to salt, with a saturated-extract electrical conductivity ($EC_e$) threshold for yield reduction at 1.7 dS/m. It is estimated that, globally, about one million hectares under sugarcane production are affected by salinity or sodicity (Akhtar, 2000). Salinity (mg/l) is the better indicator of the salt effect on crops; however, if the sodium absorption ration, SAR, is greater than 15, the site should be carefully monitored. Not only will it take considerable time for salinity levels to

drop, but the field is at a risk of decline in production. Water will not readily infiltrate into such soil, the pH will rise above 8 and toxic amounts of sodium will remain. Reclaiming such soils is costly and requires addition of large amounts of gypsum in addition to mechanical drainage. None of the sites in the initial monitoring studies is currently in need of gypsum, but some sites would benefit from the addition of lime. If a field has an SAR greater than 15 and low pH, application of agricultural lime will ensure that sodium is leached out and sodic conditions avoided. Even where the SAR is less than 15, if soil pH is below 6.0 the addition of lime can help offset the effects of excessive salt and accelerate the leaching process. Monitoring soil salt levels will continue until sugarcane harvest, at which time a yield impact assessment will be made in an attempt to confirm the applicability of the salinity damage threshold for sugarcane. The electrical conductivity (EC) is another important factor determining water quality for irrigation; however there is a great inter- and intra-species variation in response to salinity. SAR is also one of the water quality parameters showing the rate of sodium absorption. As Han *et.al* (1998) stated, a water with high sodium absorption ratio (SAR) can reduce stability of soil structure and ultimately result in low soil permeability and crop yield, due to dispersion and swelling of clay particles

## 2.11 Management of Sugarcane Under Acid Soils

Usually acid soils are found in high rainfall areas and in soils where organic matter content is high. Sugarcane crop grown in such soils may express deficiency symptoms of either calcium, phosphorous, or molybdenum. There could be toxicity of iron, aluminum and manganese. In sugarcane tillering, shoot elongation and growth are

affected due to nutritional problems, thus, causing poor cane yield and juice quality. The general lime requirements are as follows (Eynard et. al, 2005):

1) Sandy soils; 450-675 kg/ha every 2 years
2) Clay loams ;1800-2250 kg/ha every 3-4years
3) Clay soils; 2700-3600 kg/ha every 45years.-
4) Bone meal and rock phosphates are well suited to acid soils to supply phosphorous.

## 2.12 Management of Soil Salinity and Sodicity

The saline and sodic soils are wide spread in sugarcane growing areas of the world. A soil with EC below 2 dS/m, by and large, does not affect growth appreciably. Sugarcane is moderately sensitive to soil salinity. The decrease in crop yield varies with the level of soil salinity (Anderson and Bowen, 1990). The decrease in crop yield is 0 % at an $EC_e$ of 1.7, 10 % at 3.3, 25 % at 6.0, and 50 % at 10.4 dS/m (Anderson and Bowen, 1990). Soil salinity also adversely affects sheath moisture content and nitrogen content. Likewise, SAR of more than 20 causes 50 % yield reduction. Increase in Exchangeable Sodium Percentage from 14.4 to 23.5 has been found to cause reduction in cane (9-26 %) and sugarcane cultivars (Eynard *et. al*, 2005). Sprouting and early growth stages are considerably more resistant to salinity than do the later developmental stages (Wahid *et. al*., 1997a). Rozeff (1995) noted a 50 % reduction in sprouting of sugarcane at 13.3 dS $m^{-1}$ and same reduction of yield at 9.5 dS $m^{-1}$. The salts interfere with sugar production in a two-fold manner; first by affecting growth rate and yield of the cane and secondly by affecting the sucrose content of the stalk. Numerous investigations have touched on

the effects of soil salinity on stripped cane yield, sucrose yield and physiology (Lingle and Weigand, 1997). In sugarcane, the yield components include stripped cane yield, sucrose percentage per stalk, extractable juice per stalk and brix percentage in the cane stalk.

## 2.13 Irrigation Water Quality

Interest in the quality of irrigation water dated back to a comparatively short time. In contrast, the quantity of water available for irrigation is always of primary concern as was recognized by Wilcox and Durum (1967).The proposed standard based on composition of irrigation water quality was recognized by Hilgard (1996) and it is very important to know it before starting any irrigation activities. Bouver and Chaney (1974) observed that land treatment of waste infiltration into ground water or irrigation of agricultural crops may involve the addition of considerable amount of ions and organic residue and alteration of the physio-chemical properties of the soil.

## 2.14 Effect of Salt on Soil Properties.

### 2.14.1. Effects of salinity on soil physical properties

Soil water salinity can affect soil physical properties by causing fine particles to bind together into aggregates. This process is known as flocculation and is beneficial in terms of soil aeration, root penetration, and root growth. Although increasing salinity of soil solution has a positive effect on soil aggregation and stabilization, at high levels salinity can have negative and potentially lethal effects on plants (Bouver and Chaney, 1974).

As a result, salinity cannot be increased to maintain soil structure without considering potential impacts on plant health.

### 2.14.2 Effects of sodicity on soil physical properties

Assessment of the relationship between soil solution salinity and soil physical properties require knowledge of the constituents of the dissolved salts, and especially the sodium concentration. Sodium has the opposite effect on soils than salinity does. While elevated electrolyte concentration may enhance flocculation, sodium saturation may cause dispersion. The relatively large size, single electrical charge and hydration status of adsorbed sodium tends to cause physical separation of soil particles. The physical separation of soil particles results in sufficient distance between individual soil particles such that repulsive forces between like molecules exceed bonding forces and dispersion occurs. Thus, soil dispersion is the primary physical process associated with high sodium concentrations (Miller and Donahue, 1995). A second, somewhat reversible process associated with sodium saturation is platelet and aggregate swelling. The reason other ions such as calcium and magnesium do not have this same effect is because smaller, non-hydrated divalent cations tend to cluster closer to the clay particle (their +2 charge causes a stronger attraction to clay surfaces than sodium, which has a +1 charge). This combination of conditions does not cause the disruption to soil structure that sodium does (Chen and Banin, 1975; Hanson et al., 1999; Shainberg and Shalhevet, 1984). Figure 2.1 helps illustrate this difference in physical arrangement of sodium and calcium molecules on the clay surface. Basically, attractive forces which bind clay particles together are disrupted when too many sodium ions get between the clay particles. When such separation occurs, repulsive forces

begin to dominate, and the soil disperses (Hanson *et al*., 1999).

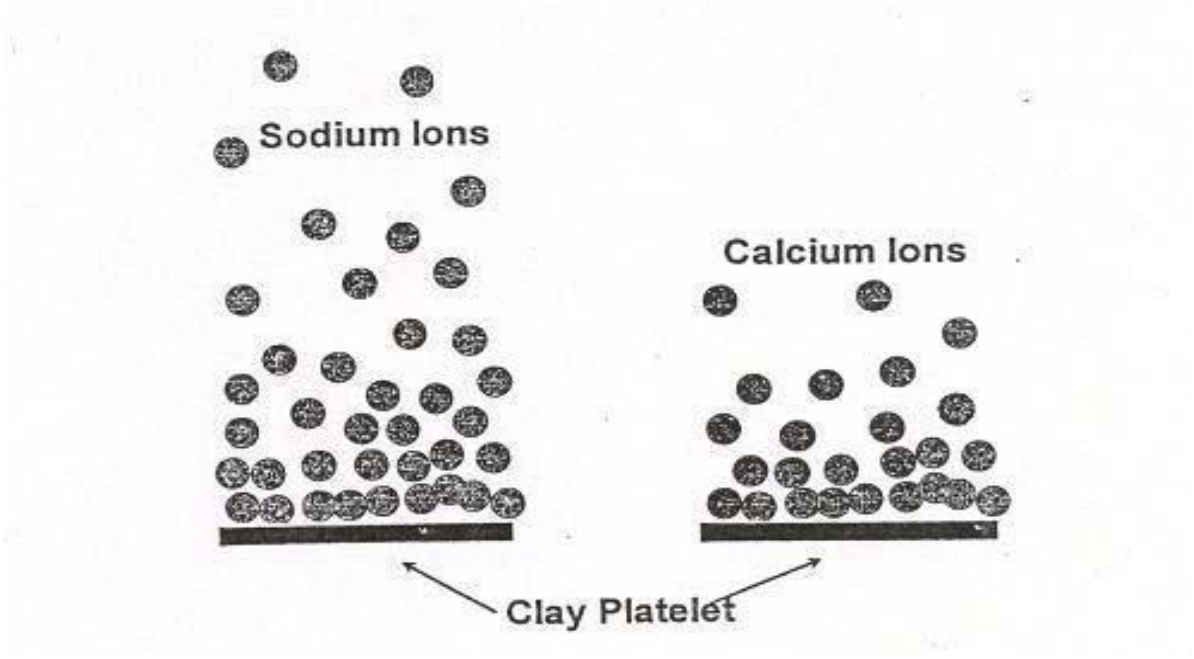



Figure 2.1 Behaviour of sodium and calcium ions attached to a clay platelet. (Source: Hanson et al., 1999.)

## 2.15 Relationship Between (EC and SAR)

The ratio of salinity (EC) to sodicity (SAR) is the indictating factor determining the effects of salts and sodium on soils**.** More than fifty years of research have been conducted to determine this relationship as precisely as possible, and the subject is now well understood to make accurate predictions of how specific soils will behave when exposed to different levels of salts and sodium. The bulk solution salinity will have specific effects on soil physical and chemical properties. Simultaneously, the soil solution sodium concentration and the sodium adsorbed on the soil exchange complex may have a different effect on soil physical and chemical properties**.** Salts (including

sodium) are present in the soil water solution, and therefore move with soil water, generally in a downward direction, as water drains through the soil profile. Sodium, however, attached to the soil particles, will not move downward with soil water (Hanson *et al.*, 1999; Van de Graaff and Patterson, 2001). It should also be noted that the relationships presented herein generally do not take into account the downward migration of salts due to leaching by rainfall, and hence lowering of soil water EC. One of the first studies to investigate the interactive effect of the EC x SAR relationship was conducted by McNeal (1968). He assessed the swelling factor, or the amount a soil is likely to swell, as a consequence of a combination of sodium, adjusted ESP, and salts in solution (EC). The degree to which sodium-induced dispersion interacted with salt-induced flocculation was defined as a swelling factor. Increasing the adjusted ESP or decreasing the salt concentration caused an increase in the swelling factor. This is best illustrated in Figure 2.2. Similar to adjusted SAR, adjusted ESP takes into account the precipitation of calcium and magnesium out of solution. The swelling factor is a measure of the degree to which soil will expand as water is held within the soil matrix. The amount of water retained is directly affected by both ESP and EC (McNeal, 1968).

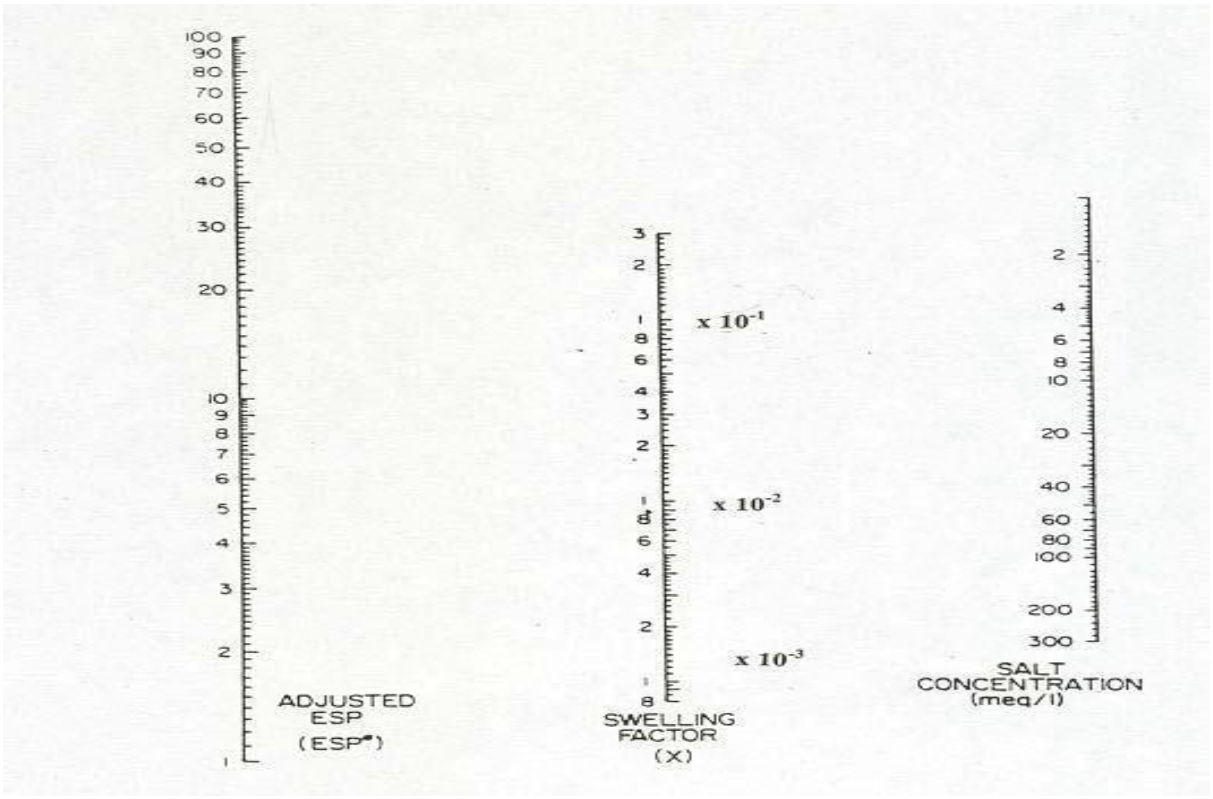



Figure 2.2 Swelling factor as a function of adjusted ESP of soil and salt concentration of soil solution. (Source: McNeal, 1968.)

Using Figure 2.2 it is possible to draw a line from the adjusted ESP on the left column to the appropriate salt concentration on the right column. The line intersects the middle column, the Swelling Factor, indicating the degree to which the soil will swell. For instance, drawing a line between adjusted ESP = 2 and an EC = 40 meq/L yields a swelling factor of 0.3. In this example swelling, and subsequently dispersion, is not a problem. However, a combination of adjusted ESP = 30 and EC = 2 yields a swelling factor of 0.28. In this example, swelling and dispersion are very likely. Fig 2.2 makes it possible to appreciate how the dispersive effects of high ESP can be mitigated with the flocculating effects of high EC**.** For instance, an adjusted ESP = 30 yields a swelling factor of 0.05 when combined with an EC = 60. Conversely, a low adjusted ESP can

still cause swelling if EC is correspondingly low. For instance, an adjusted ESP = 7, less than half of the accepted threshold, and EC of 1 yield a swelling factor of 0.1, which could be a problem (McNeal, 1968).

Another approach in assessing the interactive effect of solution salinity and sodicity on soil physical properties is shown in Figure 2.3, reported by Hanson et al. (1999). This figure was derived from Ayers and Westcot (1976), and subsequently modified by Oster and Schroer (1979). Figure 2.3 presents the potential impact of various combinations of SAR solution and EC of irrigation water on infiltration rates.

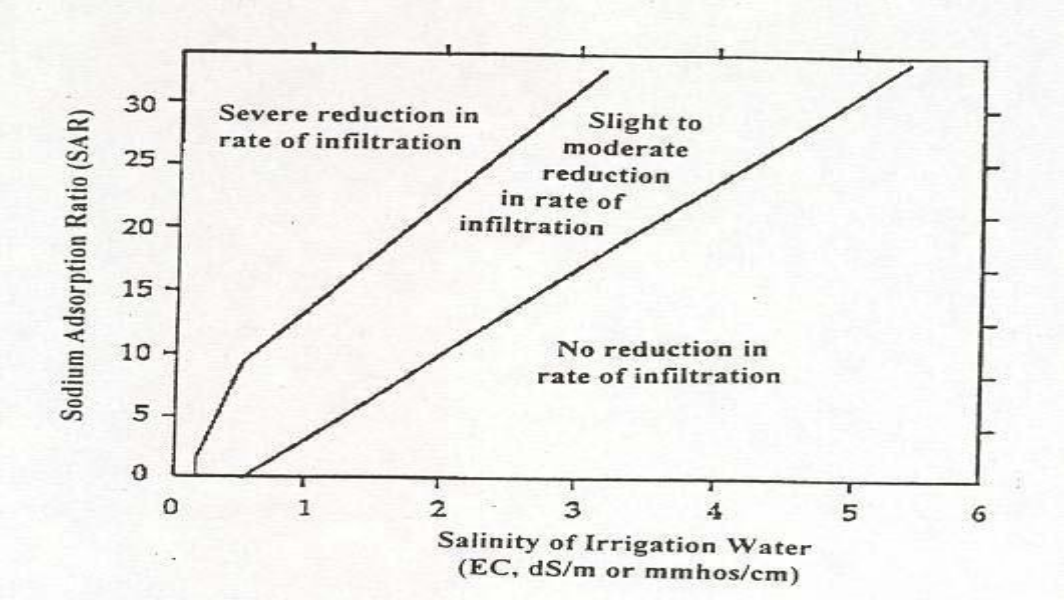



Figure 2.3. Potential for reduction in infiltration rate resulting from various combinations of EC and SAR of applied water. (Source: Hanson *et al*, 1999.)

A severe reduction in infiltration is likely to occur with the condition of relatively low EC and high SAR. For example, at an SAR = 15, a severe reduction in infiltration will

occur at an EC = 1 dS/m. An EC of 2.5 or less results in a slight to moderate reduction in infiltration. With an EC greater than 2.5, there will likely not be a reduction in infiltration**.** Figure 2.3 illustrates the same relationship previously reported: increasing sodium concentration disperses soil and increasing salinity flocculates soil (Hanson *et al*., 1999). Table 2.3 presents a tabular refinement of the data presented in Figure 2.3 (Ayers and Tanji,1981).

**Table 2.3. Guidelines for interpretation of water quality suitability for irrigation (in terms of reduced infiltration)**

| **SAR** | **EC dS/m** | | |
|---|---|---|---|
| | **No problem** | **Slightly to moderate** | **Severe problem** |
| 0 to 3 | <0.20 | 0.2 to 0.9 | >0.9 |
| 3 to 6 | <0.25 | 0.25 to 1.30 | >1.3 |
| 6 to 12 | <0.35 | 0.35 to 2.00 | >2.0 |
| 12 to 20 | <0.90 | 0.9 to 3.10 | >3.1 |
| 20 + | <1.80 | 1.80 to 5.60 | >5.6 |

Source: Ayers and Tanji, 1981)

# CHAPTER THREE

## 3.0 INTRODUCTION

### 3.1 Description, General Characteristics of the Study Area

The study area is the Sugarcane Plantation of Savannah Sugar Company located in Numan Local Government Area (L.G.A) of Adamawa state, Nigeria. It lies between latitude $9^0$10'N- $9^0$39'N longitude $10^0$25'E-$12^0$ 55'E (Figure 3.1). The hectarage for the plantation covers over 27,000 ha. The climate of the area is characterized by two distinct climatic seasons; Wet and Dry seasons, respectively. The wet season starts from April and ends in October while the dry season starts from November to the month of March of the proceeding year. The mean annual rainfall is 676 mm; the wettest months are August and September. The annual mean temperature is $30^0$C with minimum temperature in the period from November to February when the North East trade winds originated in the Sahara desert, reduces the air temperature considerably. The relative humidity ranges between a low value of 20 to 30 % in the months of January to a high value of 80% in the months of August and September.

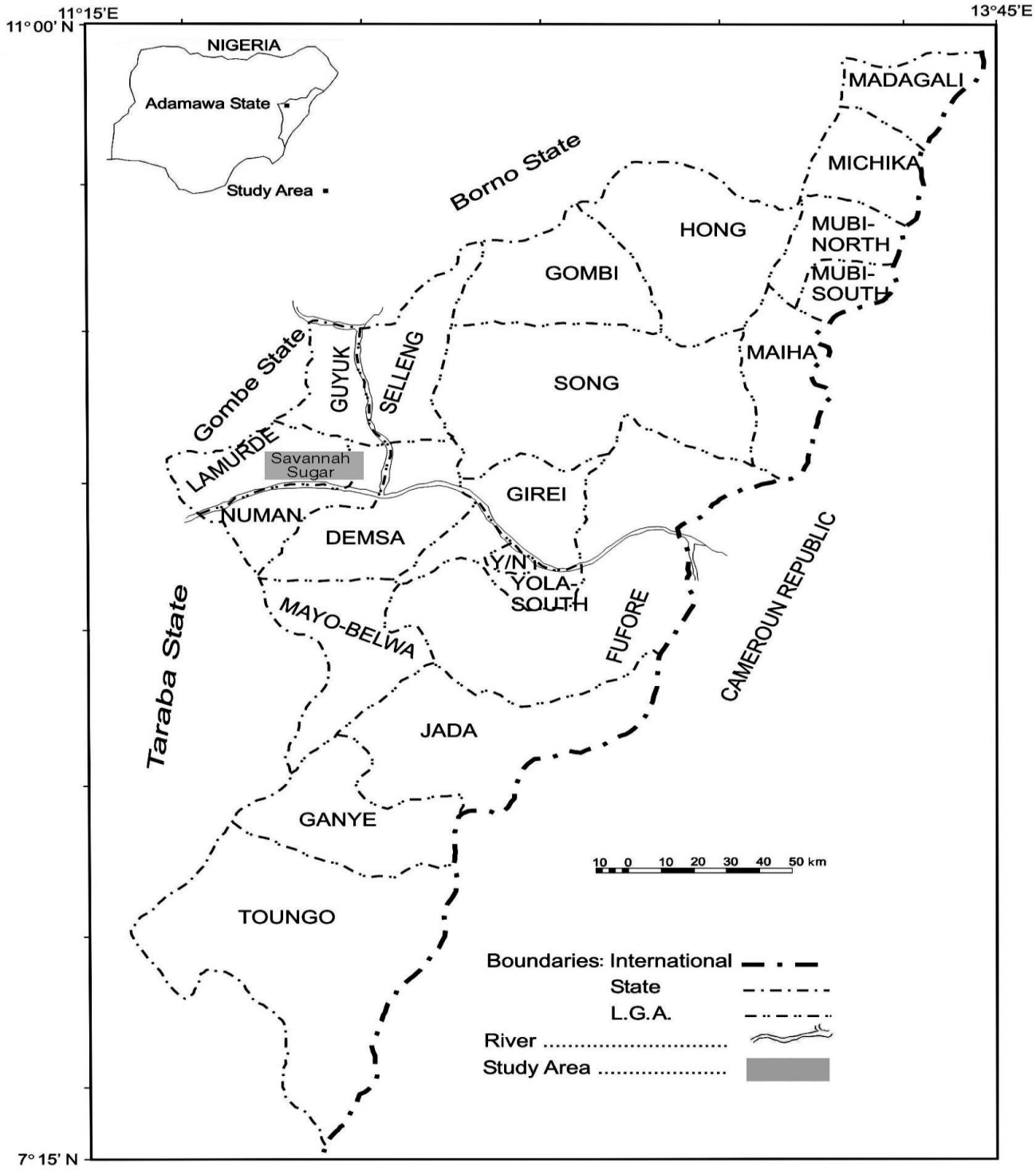



Figure 3.1 Source: Savannah Sugar Company, Numan, Adamawa State.

## 3.2 Field and Laboratory Experimentation

The study consists of field and laboratory experiments. The field experimentation is further divided into two; soil sampling collection for laboratory analysis and questionnaire administration to investigate other factors responsible for yield reduction.

## 3.3 Field Problems Identification

A checklist was used for interaction with the staff of the company to identify the causes for sugarcane yield reduction over the years. The category of staff interviewed were from the top management staff (Agricultural Managers) and some technical staff in Agronomy Department, Soil Science Laboratories and Survey Section of the Sugar company who were in the company right from the 1990s. A copy of the checklist is presented in Appendix 9.

## 3.4 Soil Sample Collection:

Soil samples were randomly collected from the plantation. During the sampling, necessary care was taken to avoid sampling errors including abnormal occurrence in the field. A total of 81 soil samples at 27 selected units were collected. The samples were taken at incremental depths of 20 cm down to a depth of 60cm in each unit. Thus, the samples were taken at 3 different points in field plot P1, G2 and K3, respectively. They were carefully packaged and labelled for the laboratory analysis. Screw auger was used for the samples collection as shown in Plates 3.1 and 3.2. The samples were taken to the Soil Science laboratory at Modibbo Adama University of Technology, Yola, Adamawa State for the analysis.

## 3.5 Soil Chemical Properties:

The soil sample collected was taken to laboratory for salinity testing. The parameters determined were pH, Electric Conductivity (EC), and Cation Exchange Capacity (CEC)



Plate 3.1 : Soil sample collection at Savannah Sugar Company using screw Auger type



Plate 3.2 Soil sample dried and sieved ready for laboratory analysis

### 3.5.1. Determination of pH and electrical conductivity (EC):

The soil pH in water was determined by a pH (water Jenway 3015) meter at soil-water ratio of 1:2, after standardizing the pH meter at a buffer. 10g of soil sample was weighed into a conical flask and 20ml of distilled water was added and stirred for 15 minutes. The mixture is allowed to settle for 30 minutes. The pH probe was inserted into the mixture and reading was taken and recorded. The sample prepared for pH was used in EC determination. EC meter was inserted into the sample and the reading was taken using a procedure detailed by Soil Science laboratory Manual (2008).

### 3.5.2. Determination of exchangeable bases ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$).

The procedure involved the measurement of 10 g of soil samples and then putting it into a container (A). Then, 30 ml of 1.0 M ammonium acetate was added at a pH of 7. The mixture was shaken for about 2 hrs and filtered into container (B). 30 ml of 1.0 M ammonium acetate was added to the first container (A) with residual soil sample and shaken for 30 minutes and filtered into the initial filtrate. The process was repeated for 30 ml and 10 ml ammonium acetate into container (B) to make up 100 ml mark. The exchangeable cations $Ca^{2+}$ and $Mg^{2+}$ were determined by the use of EDTA (ethylenediaminetetraacetic) acid. The titrimetry method was used and blue dye called EBT (Eriochrome Black T) and mureoxide were used as indicator. This blue dye also forms a complex with the calcium and magnesium ions, changing colour from blue to pink in the process. $Na^{+}$ and $K^{+}$ were determined by the flame photometer (Loganathan, 1984).

## 3.6 Organic Matter Content

The procedure involved the measurement of 10 g of soil samples measured after sieving the soil sample in 0.5mm sieve. The sample was placed in a conical flask and 10 ml of 1.0 N $K_2Cr_2O_7$ (Potassium dichromate). 20 ml of concentrated $H_2SO_4$ and 100 ml of distilled water were added. The mixture was allowed to cool. Three drops of diphenylamine indicator was added. The mixture was titrated against 0.5 N $Fe_2SO_4$ and deep green was noted as end point. Walkley-Black method (1934)

$$\% C = \frac{(B-T) \, x \, F \, x \, 0.00399}{W_s} \, x \, 100 \qquad (3.1)$$

Where:

% O.C = Percentage of Organic Carbon

B = Blank or Initial Burette reading

T = Titre Value at end point

F = Normality of $Fe_2SO_4$ (0.5N)

0.00399 = Numerical Factors

$W_s$ = weight of soil sample (g)

The percentage organic matter was then obtained as:

O.M = % O.C x 1.724, (3.1a)

in which O.M is Organic Matter (g/kg)

## 3.7 Determination of Particle Size Distribution

The particle size distribution was determined by a Bouyoucos-hydrometer as described by Jaiswall (2003). A soil sample of 51 g was poured into 500 ml beaker along with 5 percent sodium hexameta phosphate and distilled water. The mixture was stirred and transferred into one liter cylinder. Hydrometer readings ($H_1$ and $H_2$) were taken at temperatures $T_1$, at initial readings and $T_2$ at 2 hours interval as second reading. The percentage of sand, silt and clay were calculated using the following relations. (Soil Science laboratory Manual, 2008).

% Sand $= [100 - H_1 + (T_1 - 20)2$ (3.2a)

% Clay $= (H_2 + 0.2(T_2 - 20) - 2))2$ (3.2b)

% Silt = 100- (%Sand +%Clay) (3.2c)

Where $H_1$ and $H_2$ are Hydrometer readings at Temperature $T_1$ and $T_2$ as initial and second readings respectively.

## 3.8 Determination of CEC, ESP and SAR.

These parameters were determined using the empirical formulae to arrive at actual values.

$CEC = (Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})$ (3.3)

$$ESP = \frac{Na^+}{CEC}\ x\ 100 \quad (3.4)$$

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (3.5)$$

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

The results of the study are presented and discussed under the following headings:

1. Chemical contents of the soil samples.
2. The Cation Exchange Capacity (CEC), ESP, SAR and Organic matter content of the soil.
3. Trend of sugarcane yield
4. Other causes of sugarcane yield reduction.

## 4.1 Chemical Contents of the Soil Sample

The chemical contents of the soil considered include: pH, Electrical Conductivity (EC) and Sodicity of the soil.

### 4.1.1 pH and EC of the soil samples

Table 4.1 presents the average chemical properties of the soil in the Sugarcane plantation. The pH of soil indicates the soils to be slightly acidic on the surface and tends to be slightly alkaline with the increase in depth. This range of pH 6.30 to 7.19 is ideal for growing most sugarcane in Savannah region (Halving *et al*, 2003).

**Table 4.1: Chemical Properties of the Soil at Plots P1, G2 and K2**

| | pH($H_2O$) | | | EC | | | CEC | | | SAR | | | ESP | | | OMC | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Depth (cm)** | **P1** | **G2** | **K2** | **P1** | **G2** | **K2** | **P1** | **G2** | **K2** | **P1** | **G2** | **K2** | **P1** | **G2** | **K2** | **P1** | **G2** | **K2** |
| 0-20 | 6.33 | 6.3 | 6.4 | 0.65 | 0.65 | 0.7 | 39.4 | 43.9 | 50.5 | 0.32 | 0.17 | 0.16 | 3.2 | 1.6 | 1.2 | 1.1 | 1.21 | 1.15 |
| 20-40 | 6.67 | 6.6 | 6.6 | 0.71 | 0.7 | 0.7 | 45.1 | 49.3 | 48.20 | 0.31 | 0.31 | 0.3 | 3.1 | 2.9 | 2.9 | 0.81 | 0.77 | 0.79 |
| 40-60 | 7.17 | 7.2 | 7.1 | 0.74 | 0.74 | 0.7 | 50.4 | 41.8 | 41.8 | 0.28 | 0.44 | 0.41 | 2.8 | 4.1 | 4.0 | 0.62 | 0.47 | 0.55 |

The detailed results showed that the pH values ranged from 5.5 to 7.8 (Appendices 5,6 and 7). These pH values are very close to those obtained in 1975 from depth of 0-60cm given as 6.3 to 7.5. This shows that the pH of the soil ranged from slightly acidic to slightly alkaline at the time of plantation establishment. The results are presented in (Appendices 1 to 4) as made by Kenting Africa Resource Service Division LTD (1975). This range of pH values indicates that the soil in the sugarcane plantation changed slightly from acidic to slightly alkaline as the depth of the soil increases. Thus, the top soil is more acidic than the subsoil. Although, the optimum pH for sugarcane is about 6.5 (Yates, 1978), however, sugarcane can be successfully grown on soils a with a pH value of even 4 as reported by Hartemink (1998a).

Similarly, Table 4.2 presents the result of electrical conductivity (EC) of the soil determined in 2012 in the study reported herein. The EC values ranged from 0.65 to 0.74 dS/m, which is less than the threshold value of 1.7 dS/m for yield reduction in sugarcane production (Golabi *et. al*, 2009). The values of EC in 1975 as obtained from the depth of 0 – 60 cm are presented in (Tables 4.2a, b, c). All the values were below the threshold value of 1.7 dS/m (Muhammad, 1990). Thus, these values indicate no salinity risk to the soil, since no value was found to be close to 4 dS/m, which is the critical limit (Jaiswall, 2003) for indicating a soil to be saline.

**Table 4.2a Table of comparison between EC, SAR and pH in 1976 and 2012 at P1**

| Depth (cm) | pH | | EC | | SAR | |
|---|---|---|---|---|---|---|
| | 1975 | 2012 | 1975 | 2012 | 1975 | 2012 |
| 0-20 | 6.30 | 6.33 | 1.30 | 0.65 | 1.40 | 0.17 |
| 20-40 | 7.10 | 6.67 | 1.40 | 0.71 | 1.80 | 0.31 |
| 40-60 | 6.70 | 7.17 | 0.20 | 0.74 | 1.10 | 0.44 |

**Table 4.2b Table of comparison between EC, SAR and pH in 1976 and 2012 at Plot K2**

| Depth (cm) | pH | | EC | | SAR | |
|---|---|---|---|---|---|---|
| | 1975 | 2012 | 1975 | 2012 | 1975 | 2012 |
| 0-20 | 7.50 | 6.40 | 0.06 | 0.70 | 0.40 | 0.16 |
| 20-40 | 7.40 | 6.60 | 0.10 | 0.70 | 0.17 | 0.30 |
| 40-60 | 7.40 | 7.10 | 0.05 | 0.70 | 0.48 | 0.41 |

**Table 4.2c Table of comparison between EC, SAR and pH in 1976 and 2012 Plot G2**

| Depth (cm) | pH | | EC | | SAR | |
|---|---|---|---|---|---|---|
| | 1975 | 2012 | 1975 | 2012 | 1975 | 2012 |
| 0-20 | 6.30 | 6.40 | 0.004 | 0.65 | 1.04 | 0.17 |
| 20-40 | 7.10 | 6.60 | 0.014 | 0.70 | 1.74 | 0.31 |
| 40-60 | 6.70 | 7.10 | 0.10 | 0.74 | 1.06 | 0.44 |

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### 4.1.2. Soil sodicity contents

The CEC of a soil is primarily influenced by soil texture and organic matter content. CEC is a major controlling agent of stability of soil structure, nutrient availability for plant growth, soil reaction to fertilizer and other ameliorants. Among the mineral components of soil, clay particles generally have the highest cation exchange capacity by silt and sand and with CEC value above 30 (Hausenbuiller,1985).

Data related to exchangeable cation (Appendices 5, 6 and 7), show that the soils have high base status with $Ca^{2+}$ content, followed by $Mg^{2+}$, dominating the exchange complex. Levels of exchangeable $K^{+}$ are in general adequate to support the production of sugarcane successfully.

The values of CEC range from 39.4 to 50.50 cmol/kg of soil as presented in (Table 4.1). The values of CEC can be considered moderate for the sugarcane production. The soil has CEC above 20 cmol/kg, the soil characteristic which indicates a tight soil structure due to high clay content, poor internal drainage (Turf Revolution ,2010) . The CEC can give insight into soil quality and site characteristics. Higher CEC values indicate more clay particles present in the soil (Turf Revolution, 2010).

The Sodium Adsorption Ration (SAR) (Table 4.1) indicate values ranging from 0.16 to 0.44 at incremental depths of 20 cm down to a depth of 60cm for the soil. This indicates that the susceptibility of the soil to alkality hazard is low. Thus, the soil is safe and normal for sugarcane production under irrigation. Todd (1980), James *et.al* (1982) and El-Swaify (2000) found the SAR value between 1-10 in a soil as acceptable for sugarcane production.

ESP values are presented in (Table 4.1) show that the values were between 1.2 and 4.1 %. These values are far below the threshold limit of 15 % that could have a negative influence on the sugarcane production (Cattling, 1999). The ESP is an important parameter of a soil that indicates sodicity of the soil. The sodium hazard to the crop in the plantation is below the critical point that will affect the growth and yield of sugarcane. Soils in all the stations were found to be non- saline and non-sodic soil

## 4.2 Physical Properties of the Soil

During the soil investigation, it was assumed that the soil was homogeneous and therefore the soil at plot G2 was used to determine the physical properties of the soil. The soil was generally clay textured with strong prismatic structure of greyish to dark colour. When wet the soils were sticky and plastic, friable when moist and extremely hard when dry. The mean dry soil bulk density was 1.23 g $cm^{-3}$ in the topsoil (0 to 20 cm), but increased with depth to more than 1.40 g $cm^{-3}$ for the cultivated soils. This change in values of bulk density may be due to agricultural operation over years in the plantation which affected the soil structure. After the clay, the next dominant fractions is silt and are fairly uniformly distributed in the field. The high clay contents have made the soil to have high water holding capacities with concurrent low permeability (Appendix 8) thereby making the soil highly prone to flooding and water logging as well as poor till or workability. The high clay content made these soils very hard and almost intractable when dry, and consequently rendered their cultivation by a hoe or an ox-drawn plough very difficult thereby bringing about compaction problems in the root zone (Lombin and Esu, 1990).

## 4.3 Organic Matter Content (OMC)

Organic matter content (OMC) of the soil in sugarcane plantation field in Savannah Sugar Company was generally low. The OMC values were found to range from 0.47 to 1.21 as presented in Table 4.1. These values were found to be less than the required values of 2 to 3 g/kg of organic matter content in the soils as reported by Muhammad *et.al,* (2000). Loveland and Webb (2003) suggested a threshold value for OMC of 3.4 g/kg in temperate regions. Thus, Low organic matter content in the Savannah soil might be due to intensive cultivation without using farmyard manure and other manure practices to replace the organic matter content used by the crop over the years. The use of chemical fertilizer might have resulted in the low level of organic matter of the soil and created nutritional inbalance in the plantation, since yield in sugarcane is also a factor that depends on organic matter (Muhammad *et.al*, 2000). Organic matter determines the juice quality and quantity by increasing sucrose (Singh and Solomon, 1990). Consequently, the organic matter content might contribute to the yield reduction of the sugarcane since it was found to be less than required values.

## 4.4 Trend of Sugarcane Yield

Figure 4.1 shows the trend of sugarcane production over the years at Savannah Sugar Company. At the commencement of production, when the plantation was established during 1981/82 season the average yield was 88.64 t/ha covering a total land area of 1,596 ha. There was no production during the years 1983/84, 1997/98 seasons and also during the period from 2003 to 2006. The sugarcane yield reduced drastically from 88.64 t/ha in 1981 to 23.00 t/ha in 2012/13 season; and also sugar content of the cane

from 9 to 2 % over the years of agricultural operation ( Table 4.3). FAO (2008) reported that mature stalk of sugarcane is typically composed of 11 to 16 % fibre, 12 to 16 % soluble sugar, 2 to 3 % non sugar and 63 to 73 % of water with an average yield of cane stalk of 60 to 70 % per hectare per year, but the yield of sugarcane could range between 30 to 180 t/ha depending on the knowledge and crop management approach used in the crop cultivation. The rapid decrease in yield between the years of agricultural operation can therefore be mainly explained by the incidence of abnormal nature of the cropping season and poor management practices in the company as deduced from the outcome of the questionnaire exercise (Appendix 9).These indicate that the value of sugarcane production in 1996/97, 2001/02 and 2012/13 coresponding to 25.25, 27.74 and 23.00 t/ha are below the range of FAO (2008) recommended values.

**A typical illustration of yield responses of sugarcane over the years is shown in Figure 4.1**

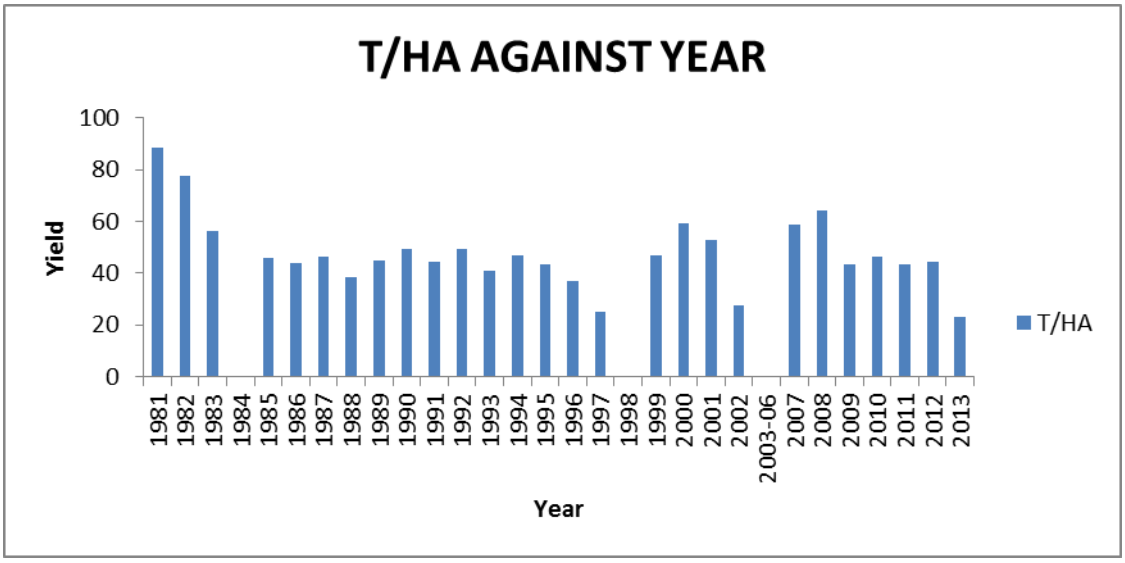



Figure 4.1 Yield responses of sugarcane

## 4.5 Other Causes of Sugarcane Yield Reduction

Interaction with the managerial staff of the Savannah Sugar Company was done through the use of checklist as presented in Appendix 9. This exercise revealed some of the factors responsible for the reduction of sugarcane yields over the years. The factors are categorised into two; Technical and Managerial Factors

### 4.5.1. Technical Factors:

Some of the identified technical factors were as follows:

#### 4.5.1.1 Importation of environmentally non-comparative seedlings:

In 2003, Savannah Sugar Company was sold to Dangote Group of Companies, and thereafter, the company decided to import seedlings from countries such as Sudan,Brazil and India. The imported varieties were B 4149 and SP 71-6180 from Brazil, CO 997 and CO 671 from India, while COC 6806 from Sudan. During the interaction with the personnel, it was difficult to estimate the exact number of tonnage of sugarcane seedlings that were imported to Savannah Sugar Company as at that time. During the interaction with staff, it was however noted that, out of the five varieties imported, four (B 4149, SP 71-6180, CO 997 and COC 671) were able to give high yield with the exception of CO 6806 in the field but the company (Savannah Sugar Company Production Department) prefered SP 71-6180 and CO 6806 because of high sugar content while the others had more weight. These poor performances of CO 6806 might be due to change in soil characteristics and climatic conditions of the Sugarcane plantation which is a savannah zone different from the environment where the seeds were produced. A total of 196,671.81tonnes of cane seedlings were supplied from

outside the company. 18.80 tonnes of seedlings were supplied by Lau project in Taraba State, 125,676 tonnes from Confluence of Lokoja and 70,977 tonnes from Crystal Jigawa State project as presented in Table 4.3 (Savannah Sugar Company , 2013). Consequently, during the interaction it was observed that the trial field plot soils were not tested before the seedlings were transplanted. This type of pre-nursery trial might also have affected the genetics and quality of cane and thereby exposed the seedling to disease and other pests.

**Table 4.3 gives further details about the Seedlings Supplied by other sources in Nigeria**

| Location | Tonnes | STATION |
|---|---|---|
| Taraba State Lau Project | 18.81 | SSCL |
| Confluence Lokoja | 125,676 | OUT-GROWERS |
| Crystal Jigawa State Project | 70,977 | OUT-GROWERS |

Source: Savannah Sugar Company 2013).

#### 4.5.1.2 Over aged cane

One of the primary factors affecting production in Savannah Sugarcane Company is abandonment of plantation for over a long period of time which was attributed to lack of fund to pay workers salary and wages in the field to harvest sugarcane as deduced from the checklist. This scenario of abnormality caused challenges in the Company, thereby allowing the sugarcane to grow beyond the maturity period of one season. For example,

in 2012/13 season a total of 266 ha was not harvested being over aged, as the age was 26.5 months as presented in Table 4.4 out of this, 80 ha was kept for seed cane, while 186 ha left as stool over cane, that is, cane left unharvested ( Savannah Sugar Company 2013)

Over ageing of sugarcane in plantation might have caused the loss of sugar content and increase fibre content of cane. Since according to FAO (2008), sugarcane contains a soluble sugar of 12 to 16 % under proper agricultural manangement.

**Table 4.4 Table of Stood-Over and Annual Sugarcane**

| Sugarcane | Ha | Actual TC | TC/ha | Age (month) |
|---|---|---|---|---|
| Stood-over cane | 266 | 54,576.57 | 19 | 26.5 |
| Annual cane | 1,436.70 | 44,859.82 | 31.2 | 10.25 |

Source: Source: Savannah Sugar Company ( 2013).

#### 4.5.1.3 Worn-out and obsolete equipment

Keeping machine for a long time reduces long run costs but increase risk. In Savannah Sugarcane Company, as at 1990s and 2000 season, most of the tractors owned by the company were old and consumed a lot of diesel and had high maintenance and operation cost for the field operations. This operational cost might have affected the production of sugarcane during the time when Savannah Sugar Company was in operation. These scenarios led to poor irrigation, delay of commencement of crop establishment, excessive breakdown of machineries due to maintenance and general mechanical services. These lengthened the sugarcane dry-off period and subjected it to excessive

drying as indicated by Savannah Sugar Company annual report ( 2013)**.**These scenario was found in field Plot K1, K2, G1, P2:1,P2:2, B1, and B2 (Table 4.5) where most of the field where left unharvested and exceeded the maturity period of one season. When Dangote took over the operation of the company, the company started to import agricultural machinery to bridge the gap of machinery needed for farm operations.

**Table 4.5 Yield Performance in each Plot Sections**

| FIELD | ha Reaped | Age Month | Tonnes actual | Acual TC/ha |
|---|---|---|---|---|
| K1 | 473 | 26.4 | 7,981.54 | 16.8743 |
| K2 | 468 | 23.2 | 12,788.76 | 27.3264 |
| K3 | 802.6 | 19.3 | 12,386.35 | 15.4328 |
| G1 | 352 | 20.3 | 5,876.73 | 16.6953 |
| G2 | 482.4 | 11.8 | 9,502.77 | 19.6989 |
| P1:1 | 164 | 21.9 | 6,490.54 | 39.5765 |
| P1:2 | 439 | 11.2 | 18,068.64 | 41.1586 |
| P2:1 | - | - | - | - |
| P2:2 | 330.5 | 22.5 | 6,697.19 | 20.2638 |
| GK/G5 | - | - | - | - |
| G5 NEW | 216 | 12.1 | 7,139.69 | 33.0541 |
| B1 | 257 | 25.7 | 6,048.78 | 23.5361 |
| B2 | 332 | 25.7 | 6,298.01 | 18.9699 |
| TOTAL | 4316.5 | | 99,279.00 | 272.587 |

Source: Savannah Sugar Company ( 2013).

### 4.5.2 Managerial Factor

Farm management is the science (and art) of optimizing the use of resources in the farm component or farm-households, that is, in systems of order (top management to labourers in the field). In Savannah Sugar Company, there were two major factors identified during the interaction. These are as follows;

#### 4.5.2.1 Inadequate workforce

Labour employment per hectare of sugarcane production, is one of the major constraints of the Savannah Sugar Company. Sugarcane production absorbs a large portion of labour force of the local community and machine (semi-mechanised) so as to achieve high production of cane per hectare. At the peak of activities, it requires skilled and un-skilled labourers. Labourers are hired for works and other activities in the field. During the interaction with the personnel, the average age of labour force involved in the production activities was found to range between 15 to 50 years. Information revealed that the average number of labourers employed for the cultivation of one hectare of sugarcane was about 20 labourers per hectare for all the activities on sugarcane production. This is considered as inadequate a number since an average workforce per hectare in sugarcane plantation is estimated to be 60 (Haruna and Kushwaha, 2003).

#### 4.5.2.2 Non- payment and delay of salaries of workers

Payment of wages and salary to the field labourers and company staff is one of the primary factors affecting the morale of the staff and thus contributing to yield decline in Savannah Sugar Company as deducted from the checklist. However, during the interaction it was an anonymous response by a staff of the company that during the 1998/99, 1999/00, 2001/02, 2007/08 season, most of the staff where under paid or retrenched from the company which involved both skilled and un-skilled workers and some left due to un-paid salaries for several months. During the interaction with the personnel, it was difficult to estimate the exact number of the staff that left the company and the months in which the company owed the staff. This scenario can be seen in Table 4.6 during 1998/99, 1999/00, 2001/02 season from the number of hectares of sugarcane

cultivated. These scenario of abnormality of payment of salary and mis-management caused over ageing of sugarcane in some of the blocks which were not harvested (Table 4.5). These encouraged the nearby communities being owed to engage in stealing of the cane in some sugarcane blocks in the name of non payment of wages or salary to staff by the company as deduced from the checklist. These scenarios led to selling of Savannah Sugar Company to Dangote Group of Companies in 2003 which took total control of the company management and the plantation. As Dangote took over the administrative and management of the company, the company began to recruit skilled and unskilled workers till date.

**Table 4.6: Production and Harvest Statistics for each Agricultural Year**

| YEAR | Hectares Harvested (ha) | Cane Harvested (TC) (tonnes) | Sugarcane Produced (TS) (tonnes) | $\frac{TC}{ha}$ (t/ha) | $\frac{TS}{ha}$ (t/ha) | $\frac{TS}{TC}$ x 100 |
|---|---|---|---|---|---|---|
| 1980/81 | 1,596 | 141,467.00 | 10,004.70 | 88.64 | 6.26861 | 7.07 |
| 1981/82 | 2,181 | 168,935 | 11,957.60 | 77.46 | 5.48 | 7.08 |
| 1982/83 | 2,662 | 149,441 | 11,021.10 | 56.14 | 4.14 | 7.37 |
| 1983/84 | - | - | - | - | - | - |
| 1984/85 | 2,396 | 110,133 | 6,401.00 | 45.97 | 2.67 | 5.81 |
| 1985/86 | 4,500 | 197,494 | 16,410.00 | 43.89 | 3.65 | 8.31 |
| 1986/87 | 5,156 | 240,045 | 21,010.50 | 46.56 | 4.07 | 8.75 |
| 1987/88 | 4,920 | 188,349 | 15,235.60 | 38.28 | 3.10 | 8.09 |
| 1988/89 | 5,012.70 | 224,311 | 20,100.10 | 44.75 | 4.01 | 8.96 |
| 1989/90 | 4,766 | 235,828.30 | 20,117.10 | 49.48 | 4.22 | 8.53 |
| 1990/91 | 4,266.30 | 189,954.10 | 16,365.60 | 44.52 | 3.84 | 8.62 |
| 1991/92 | 4,765.75 | 234,679.70 | 21,597.70 | 49.24 | 4.53 | 9.20 |
| 1992/93 | 5,103 | 209,608.80 | 18,109.50 | 41.08 | 3.55 | 8.64 |
| 1993/94 | 4,674 | 219,790.00 | 18,318.50 | 47.02 | 3.92 | 8.33 |
| 1994/95 | 4,452 | 193,268.40 | 14,440.20 | 43.41 | 3.24 | 7.47 |
| 1995/96 | 4,246.60 | 156,798.40 | 7,753.20 | 36.92 | 1.83 | 4.94 |
| 1996/97 | 3,819 | 96,414.00 | 5,197.80 | 25.25 | 1.36 | 5.39 |
| 1997/98 | - | - | - | - | - | - |
| 1998/99 | 1,672 | 78,432.90 | 3,182.90 | 46.91 | 1.90 | 4.06 |
| 1999/00 | 1,578 | 93,457.30 | 4,410.50 | 59.23 | 2.79 | 4.72 |
| 2000/01 | 3,520 | 138,975.30 | 6,202.50 | 39.48 | 1.76 | 4.46 |
| 2000/02 | 1,097 | 30,434.20 | 789.6 | 27.74 | 0.72 | 2.59 |
| 2003-06 | - | - | - | - | - | - |
| 2006/07 | 2,858 | 167,901.59 | 7,030.50 | 58.75 | 2.46 | 4.19 |
| 2007/08 | 870 | 57,603.21 | 2,375.20 | 66.21 | 2.73 | 4.12 |
| 2008/09 | 4,585 | 199,044.14 | 12,275.00 | 43.41 | 2.68 | 6.17 |
| 2009/10 | 5,320.20 | 247,030.30 | 17,851.00 | 46.43 | 3.36 | 7.23 |
| 2010/11 | 5,866.10 | 244,845.03 | 18,172.55 | 41.74 | 3.10 | 7.42 |
| 2011/12 | 1,334 | 67,124.77 | 3,652.10 | 50.32 | 2.74 | 5.44 |
| 2012/13 | 4,316.20 | 99,278.95 | 5036.5 | 23.00 | 1.17 | 5.07 |

Source: Savannah Sugar Company, (2013).

# CHAPTER FIVE

## 5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Summary

The study was conducted in Savannah Sugar Company (Dangote Company) Numan Local Government Area of Adamawa State from 2012 to 2013. The objective of the study was to investigate the cause of yield reduction in sugarcane plantation over the years of agricultural operation.

Eighty one (81) soil samples at Twenty Seven (27) units were collected at field Plots (P1, G2 and K2) within the plantation. The soil samples were taken to laboratory for analysis. The parameters tested were pH, EC, Ca, Mg, Na and K and Organic Matter content using standard procedures. The SAR, CEC and ESP were determined using the empirical formulae.

The pH contents of the soil was analysed based on the soil depths of 20 cm down to 60 cm at each soil units. The results ranged from 5.5 to 7.8 as presented in Appendices 5, 6 and 7 respectively. EC value ranged from 0.65 to 0.74 dS/m which were less than the threshold value of 1.7 dS/m which causes yield reduction (Golabi *et.al*, 2009). SAR indicate an average value range of 0.16 to 0.44 for the soil and the organic matter content varied from relatively low to medium across the soil horizon.

## 5.2 Conclusion

The following conclusions can be made from the study reported herein:

1) The salinity levels of the soil in the study area were found to range from 0.65 to 0.74 dS/m while the SAR ranged from 0.16 to 0.44. Similarly, the values for ESP were found to range from 1.2 to 4.1 %. Thus, the soils of the study area were found to be non-saline and non-sodic respectively. Therefore, the soils could not be contributory factors to the reduction in the sugarcane production in the area.
2) The study did not find appreciable change of the soil quality when compared with soil conditions of 1975 despite continuous irrigation practices over the years. This might imply that the irrigation water in the area is of good quality.
3) From the interaction, two major issues were found to be contributory factors responsible for the reduction in sugarcane production of the study area; Technical and Managerial issues. They included importation of environmentally non-compatible seedlings, over aged cane, worn-out or obsolete equipment; non-payment and delay of staff salaries and inadequate workforce.

## 5.3 Recommendations

In order to improve the technology for increasing productivity of soil in Savannah Sugar Company, the following remedies should be noted:

1) Adequate management practice and timely provision of farm inputs such as seedling, farmyard manure and less acidifing fertilizer so as to regain the organic matter content of the soil for higher cane yield production should be adopted.

2) A system whereby small farmers could be encouraged to grow sugarcane in the periphery of the factories could spearhead a revolution in Dangote Company.
3) Adequate and routine maintenance of infrastructure and provision of incentive to staff should be adhered to so as to increase productivity of sugarcane in the company.
4) Timely weeding in the sugarcane plantation is necessary in order to increase yield (since weeds have been estimated to cause 12-72% reduction in cane depending on the severity of infestation (FAO, 1992)). If possible the use of some herbicides that contain high acidifing chemicals should be avoided and the use of mechanical/cultural method be encouraged**.**
5) Human and machine efficiency have to be improved upon so as to check or at least minimize operational and processing losses.
6) More study should be used to validate some of the reasons of decline of sugarcane in Savannah Sugar Company (Dangote Group).

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## Web site

www.sugarcanecrops.com/soil_requirement (April, 2013)

## APPENDIX

**Appedix1. Results of Soil Analysis SE Block Surface Horizon Conducted in (1975/76) Season**

| Type | Pit | Depth | Mech Analysis | | | Satn | PH 1:2.5 | | EC | %N | CEC | Exchangeable Cation | | | | BASE | ESP | SAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | no | cm | S | Si | C | % | H2O | KCl | dS/m | | | Ca | Mg | Na | K | Sat% | | |
| 1 | 6N/16 | 30 | 24 | 40 | 36 | 43 | 7.4 | 6.3 | 0.8 | 0.06 | 53 | 17 | 4.3 | 2.8 | 2.2 | 49 | 5 | 0.9 |
| 1 | 9N/18 | 35 | 32 | 40 | 28 | 37 | 6.7 | 5.8 | 0.6 | 0.045 | 42 | 11.1 | 2.1 | 2.7 | 2.2 | 43 | 6.5 | 1 |
| 1 | 5S/2 | 80 | 16 | 28 | 56 | 42 | 6.2 | 5.6 | 1.2 | 0.08 | 36 | 10.9 | 3.3 | 5 | 0.3 | 54 | 13.8 | 1.9 |
| 2 | 7S/4 | 43 | 32 | 32 | 36 | 32 | 6.5 | 5.3 | 1.4 | 0.08 | 27 | 8.7 | 8.5 | 2.7 | 1 | 76 | 10 | 0.9 |
| 3 | 5N/2 | 60 | 24 | 8 | 68 | 56 | 6.7 | 5.7 | 0.2 | 0.034 | 26 | 14.9 | 7 | 3.5 | 2 | 107 | 13.7 | 1.1 |
| 4 | 13N/7 | 33 | 16 | 16 | 68 | 54 | 6.0 | 4.7 | 0.7 | 0.057 | 49 | 10.9 | 1.8 | 2.9 | 2.2 | 36 | 6 | 1.1 |
| 5 | 5N/4 | 68 | 28 | 24 | 48 | 46 | 7.0 | 6.1 | 0.8 | 0.010 | 50 | 15.9 | 3 | 3.8 | 0.4 | 47 | 7.7 | 1.2 |
| 6A | 6N/7 | 50 | 48 | 36 | 16 | 22 | 6.5 | 4.9 | 1.0 | 0.048 | 8 | 3.4 | 5.6 | 3.2 | 0.4 | 156 | 39 | 1.5 |
| 6B | 13N/20 | 15 | 52 | 24 | 20 | 33 | 6.3 | 5.4 | 1.3 | 0.090 | 11 | 4.8 | 4.6 | 3.1 | 1.5 | 123 | 27 | 1.4 |
| 6C | 17N/4 | 41 | 32 | 40 | 28 | 21 | 7.1 | 6.0 | 1.4 | 0.080 | 10 | 4.3 | 3.8 | 3.5 | 0.9 | 125 | 35 | 1.8 |
| 7 | 6N/11 | 43 | 36 | 24 | 40 | 36 | 6.7 | 5.6 | 0.6 | 0.046 | 40 | 12.5 | 3.3 | 2.7 | 1.7 | 51 | 6.5 | 1 |
| 8 | 17N/8 | 55 | 32 | 32 | 36 | 38 | 5.2 | 4.5 | 0.8 | 0.080 | 20 | 5.9 | 6.3 | 2.6 | 1.7 | 81 | 12.9 | 1 |
| corporative data | | | | | | | | | | | | | | | | | | |
| Banks wamp(appro) | | | 15 | 15 | 60 | 70 | 6.5 | 5.5 | 0.1 | _ | 90 | 30 | 40 | 3 | 1 | 80 | 6 | 1 |
| IAR ANALYSIS(APPRO) | | | 25 | 10 | 65 | _ | 9 | − | 0.5? | − | 60 | − | 45 | 2 | 1 | 80 | 5 | 0.5 |

**Appendix2. Results Of Soil Analysis SE Block soil analyses lowest horizon(1975/76)**

| TYPE | PIT | DEPTH | MECH ANALYSIS | | | SATN | PH 1:2.5 | | EC | %N | CEC | EXCHANGEABLE CATION | | | | BASE | ESP | SAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | no | Cm | S | Si | C | % | H2O | KCl | dS/m | | | Ca | Mg | Na | K | Sat% | | |
| 1 | 6N/16 | 100+ | 24 | 44 | 32 | 62 | 8.5 | 7.0 | 0.27 | tr | 57 | 13.4 | 4.1 | 12.2 | 2.6 | 57 | 21.5 | 4.1 |
| 1 | 9N/18 | 110+ | 24 | 52 | 24 | 47 | 8.2 | 6.9 | 0.18 | 0.022 | 55 | 14.6 | 3.5 | 5.8 | 2.5 | 48 | 10.5 | 1.9 |
| 1 | 5S/2 | 80+ | 24 | 28 | 48 | 42 | 7.8 | 6.8 | 0.30 | 0.030 | 35 | 9.0 | 2.7 | 3.5 | 0.3 | 45 | 10.1 | 1.4 |
| 2 | 7S/4 | 110+ | 24 | 36 | 40 | 40 | 8.0 | 6.7 | 0.16 | tr | 30 | 10.5 | 10.3 | 5.2 | 0.3 | 87 | 17 | 1.6 |
| 3 | 5N/2 | 120+ | 16 | 36 | 48 | 71 | 8.4 | 6.8 | 0.17 | 0.018 | 51 | 11.5 | 6.4 | 13.9 | 2 | 67 | 27 | 4.7 |
| 4 | 13N/7 | 90+ | 20 | 16 | 64 | 64 | 7.7 | 6.3 | 1.30 | 0.066 | 58 | 15.4 | 4.4 | 5.5 | 2.8 | 49 | 9.5 | 1.8 |
| 5 | 5N/4 | 68+ | 28 | 16 | 56 | 53 | 8.2 | 6.8 | 0.35 | 0.020 | 46 | 15.9 | 3.3 | 5.9 | 0.5 | 56 | 12.9 | 1.9 |
| 6A | 6N/7 | 130+ | 20 | 44 | 36 | 44 | 8.4 | 7.0 | 0.25 | 0.015 | 45 | 14.9 | 3.3 | 10.9 | 2.6 | 70 | 24 | 3.6 |
| 6B | 13N/20 | 110+ | 28 | 28 | 44 | 43 | 8.1 | 7.3 | 0.31 | 0.030 | 39 | 9.8 | 9.7 | 3.9 | 2.8 | 68 | 10 | 1.3 |
| 6C | 17N/4 | 113+ | 28 | 20 | 52 | 38 | 7.7 | 7.0 | 0.12 | 0.010 | 24 | 9.1 | 10.7 | 4.3 | 1.8 | 108 | 17.8 | 1.4 |
| 7 | 6N/11 | 130+ | 36 | 28 | 36 | 38 | 7.9 | 6.6 | 0.15 | 0.032 | 47 | 11.0 | 4.5 | 6.3 | 2.5 | 52 | 13 | 2.2 |
| 8 | 17N/8 | 100+ | 52 | 12 | 36 | 35 | 8.5 | 7.4 | 0.60 | 0.040 | 22 | 11.9 | 5.7 | 11.5 | 1.0 | 136 | 51.8 | 3.9 |
| corporative data | | | | | | | | | | | | | | | | | | |
| Banks wamp(appro) | | | 15 | 15 | 70 | 80 | 7.5 | 6.5 | 1 | _ | 80 | 25 | 40 | 10 | 1 | 90 | 15 | 2 |
| IAR ANALYSIS(APPRO) | | | 20 | 10 | 70 | – | 8.5 | – | 0.150? | – | 60 | – | 45 | 2 | 1 | 75 | 3 | 0.4 |

**Appendix 3. Results of Soil Analysis Soil analyses and derived functions NW Block (1975/76)**

| Pit no | Depth | pH | EC | CEC | Ca | Mg | Na | K | Sat% | ESP | SAR | SOIL TYPE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WT34N/0-1 | 0-65 | 8.0 | 0.10 | 60.6 | 28.9 | 3.4 | 2.9 | 1.0 | 56 | 4.8 | 0.56 | clay |
| 2 | 65-143 | 8.1 | 0.17 | 71.8 | 26.9 | 3.6 | 6.8 | 1.3 | 54 | 9.5 | 0.57 | clay |
| 3 | 143-177 | 7.0 | 0.44 | 60.6 | 24.4 | 3.5 | 9.4 | 1.3 | 64 | 15.5 | 0.51 | clay |
| WT34N/1-1 | 0-0 | 6.9 | 0.24 | 15.0 | 9.4 | 1.0 | 1.9 | 1.3 | 91 | 12.7 | 1.08 | clay |
| WT34N/2-1 | 0-28 | 6.8 | 0.05 | 9.9 | 2.5 | 0.8 | 2.7 | 0.6 | 67 | 27.7 | 0.45 | clay |
| 2 | 28-50 | 7.4 | 0.05 | 32.2 | 4.4 | 1.3 | 4.3 | 0.8 | 34 | 13.4 | 0.48 | clay |
| 3 | 50-90 | 8.0 | 0.22 | 54.5 | 8.8 | 2.4 | 6.8 | 0.6 | 34 | 12.5 | 0.28 | clay |
| 4 | 90-150 | 8.2 | 0.39 | 59.4 | 16.9 | 3.8 | 8.0 | 1.0 | 50 | 13.5 | 0.41 | clay |
| 5 | 150-180 | 8.0 | 0.50 | 54.5 | 23.1 | 4.1 | 9.4 | 0.8 | 69 | 17.2 | 0.31 | clay |
| WT34N/3-1 | 0-0 | 7.5 | 0.20 | 60.6 | 13.8 | 3.6 | 9.6 | 1.0 | 46 | 15.8 | 0.39 | clay |
| WT34N/4-1 | 0-30 | 7.7 | 0.20 | 50.7 | 14.4 | 4.3 | 7.7 | 0.8 | 54 | 13.8 | 0.33 | clay |
| 2 | 30-110 | 8.5 | 0.56 | 63.1 | 11.9 | 4.4 | 16.6 | 0.8 | 53 | 26.3 | 0.25 | clay |
| 3 | 110-180 | 7.5 | 0.64 | 50.7 | 13.8 | 6.4 | 10.9 | 1.0 | 63 | 21.5 | 0.34 | clay |
| WT34N/5-1 | 0-0 | 7.4 | 0.13 | 38.4 | 6.3 | 1.0 | 2.6 | 0.3 | 27 | 6.8 | 0.22 | clay |
| WT34N/6-1 | 0-20 | 7.5 | 0.06 | 14.9 | 3.1 | 0.5 | 1.8 | tr | 36 | 12.1 | 0.00 | clay |
| 2 | 20-40 | 7.4 | 0.10 | 38.4 | 11.9 | 1.3 | 4.6 | 0.3 | 47 | 12 | 0.17 | clay |
| 3 | 40-130 | 8.5 | 0.29 | 33.4 | 13.8 | 1.9 | 8.0 | 0.8 | 73 | 24 | 0.36 | clay |
| 4 | 130-152 | 8.2 | 0.26 | 32.2 | 6.3 | 2.1 | 11.1 | 0.5 | 62 | 34.5 | 0.19 | clay |
| 5 | 152-172 | 8.7 | 0.60 | 50.7 | 26.9 | 3.8 | 14.9 | 0.8 | 92 | 29.4 | 0.26 | clay |

**Appendix 3. Results of Soil Analysis Soil analyses and derived functions NW Block (Cont) 1975/76**

| Pit no | Depth | pH | EC dS/m | CEC | Ca | Mg | Na | K | Sat% | ESP | SAR | SOIL TYPE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WT20N/0-1 | 0-30 | 7.0 | 0.20 | 39.2 | 31 | 4.8 | 1.9 | 1.9 | 46 | 2.2 | 0.4516 | clay |
| 2 | 30-150 | 8.0 | 0.21 | 41.6 | 26 | 4.8 | 9.0 | 2.2 | 50 | 10.9 | 2.3085 | clay |
| 3 | 150-180 | 7.6 | 1.20 | 36.6 | 19 | 5.0 | 10.3 | 1.9 | 43 | 12.2 | 2.9489 | clay |
| WT20N/1-1 | 0-0 | 7.3 | 0.15 | 46.0 | 39 | 4.3 | 0.5 | 1.8 | 51 | 0.6 | 0.1070 | clay |
| WT20N/2-1 | 0-50 | 7.1 | 0.13 | 45.7 | 37 | 4.8 | 2.2 | 1.8 | 56 | 2.7 | 0.4818 | clay |
| 2 | 50-140 | 8.1 | 0.27 | 50.3 | 31 | 5.8 | 11.7 | 2.2 | 60 | 13.9 | 2.7425 | clay |
| 3 | 140-180 | 7.6 | 1.30 | 57.8 | 31 | 8.0 | 16.3 | 2.2 | 61 | 17.3 | 3.6771 | clay |
| WT20N/3-1 | 0-0 | 7.3 | 0.16 | 41.1 | 31 | 6.0 | 1.9 | 1.9 | 51 | 2.4 | 0.4400 | clay |
| WT20N/4-1 | 0-30 | 7.0 | 1.00 | 48.4 | 44 | 2.8 | tr | 1.8 | 54 | 0.0 | 0.0000 | clay |
| 2 | 30-70 | 7.5 | 0.20 | 56.7 | 51 | 3.6 | tr | 1.8 | 71 | 0.0 | 0.0000 | clay |
| 3 | 70-110 | 7.9 | 0.19 | 43.1 | 39 | 2.0 | 0.3 | 1.4 | 79 | 0.6 | 0.0669 | clay |
| 4 | 110-180 | 8.5 | 0.17 | 43.1 | 38 | 3.6 | tr | 1.4 | 65 | 0.0 | 0.0000 | clay |
| WT20N/5-1 | 0-0 | 7.2 | 0.20 | 29.5 | 23 | 3.2 | tr | 3.2 | 37 | 0.0 | 0.0000 | clay |
| WT20N/6-1 | 0-30 | 7.3 | 0.16 | 44.6 | 37 | 3.8 | 0.5 | 3.4 | 61 | 0.7 | 0.1108 | clay |
| 2 | 30-120 | 7.5 | 0.19 | 34.5 | 26 | 5.0 | 0.7 | 3.2 | 54 | 1.0 | 0.1790 | clay |
| 3 | 120-182 | 8.0 | 0.15 | 48.3 | 37 | 8.8 | 1.0 | 1.6 | 71 | 1.5 | 0.2092 | clay |
| WT20N/7-1 | 0-0 | 7.3 | 0.16 | 38.1 | 31 | 5.1 | tr | 2.4 | 50 | 0.0 | 0.0000 | clay |
| WT20N/8-1 | 0-40 | 7.3 | 0.14 | 33.9 | 29 | 2.1 | tr | 2.4 | 50 | 0.0 | 0.0000 | clay |
| 2 | 40-150 | 7.9 | 0.16 | 32.8 | 26 | 2.4 | 1.9 | 2.9 | 48 | 2.8 | 0.5078 | clay |
| 3 | 150-183 | 8.1 | 0.30 | 36.6 | 29 | 2.3 | 2.7 | 2.2 | 67 | 5.0 | 0.6782 | clay |
| WT20S/1-1 | 0-0 | 7.5 | 0.12 | 26.7 | 21 | 3.9 | tr | 1.9 | 35 | 0.0 | 0.0000 | clay |
| WT20S/2-1 | 0-33 | 7.4 | 0.11 | 25.2 | 19 | 3.2 | tr | 2.6 | 33 | 0.0 | 0.0000 | clay |
| 2 | 33-120 | 7.7 | 0.18 | 27.7 | 17 | 3.2 | 5.4 | 2.2 | 36 | 7.0 | 1.7034 | clay |
| 3 | 120-183 | 8.3 | 0.37 | 29.0 | 14 | 4,0 | 8.7 | 1.9 | 40 | 12.1 | 2.8683 | clay |
| WT20S/3-1 | 0-0 | 7.6 | 0.10 | 25.3 | 19 | 3.9 | tr | 2.6 | 34 | 0.0 | 0.0000 | clay |

## Appendix 3 Results of Soil Analysis Soil analyses and derived functions NW Block (Cont) (1975/76)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WT20S/3-1 | 0-0 | 7.6 | 0.10 | 25.3 | 19 | 3.9 | tr | 2.6 | 34 | 0.0 | 0.0000 | clay |
| WT20S/4-1 | 0-60 | 7.2 | 0.10 | 26.1 | 19 | 4.5 | tr | 2.2 | 35 | 0.0 | 0.0000 | clay |
| 2 | 60-120 | 7.5 | 0.16 | 32.2 | 22 | 5.7 | 2.7 | 1.9 | 42 | 3.5 | 0.7268 | clay |
| 3 | 120-180 | 8.1 | 0.36 | 51.2 | 38 | 5.8 | 5.7 | 1.6 | 69 | 7.7 | 1.2166 | clay |
| WT20S/5-1 | 0-0 | 7.2 | 0.24 | 44.2 | 38 | 3.9 | tr | 2.2 | 65 | 0.0 | 0.0000 | clay |
| WT20S/6-1 | 0-40 | 7.3 | 0.15 | 40.1 | 34 | 3.0 | 0.8 | 1.9 | 64 | 0.7 | 0.1850 | clay |
| 2 | 40-120 | 7.8 | 0.24 | 43.7 | 28 | 3.9 | 10.1 | 1.6 | 65 | 17.6 | 2.5250 | clay |
| 3 | 120-170 | 8.6 | 0.49 | 38.8 | 23 | 4.0 | 10.3 | 1.4 | 63 | 22.4 | 2.7981 | clay |
| WT20S/7-1 | 0-0 | 8.4 | 0.17 | 31.6 | 27 | 3.1 | tr | 1.6 | 49 | 0.0 | 0.0000 | clay |
| WT20S/8-1 | 0-60 | 7.4 | 0.12 | 24.1 | 19 | 2.7 | 0.4 | 1.6 | 40 | 0.5 | 0.1203 | clay |
| 2 | 60-120 | 8.5 | 0.25 | 29.7 | 14 | 3.0 | 10.9 | 1.4 | 48 | 4.0 | 3.6954 | clay |
| 3 | 120-180 | 7.4 | 0.43 | 33.4 | 13 | 3.4 | 15.8 | 1.4 | 47 | 7.5 | 5.5516 | clay |
| WT20S/9-1 | 0-0 | 7.2 | 0.20 | 36.5 | 31 | 2.9 | 0.40 | 2.6 | 50 | 0.7 | 0.0977 | clay |
| WT26S/4-1 | 0-20 | 7.3 | 0.07 | 41.1 | 33 | 4.0 | 2.40 | 1.6 | 64 | 12.5 | 0.5572 | clay |
| 2 | 20-80 | 7.7 | 0.12 | 49.1 | 38 | 4.0 | 5.20 | 1.8 | 76 | 18.6 | 1.1334 | clay |
| 3 | 80-180 | 7 | 0.31 | 41.7 | 36 | 4.1 | 0.40 | 1.6 | 67 | 17.0 | 0.0898 | clay |
| WT28S/8-1 | 0-30 | 7.1 | 0.11 | 44.4 | 33 | 2.8 | 7.10 | 1.4 | 62 | 15.0 | 1.6758 | clay |
| 2 | 30-110 | 8.2 | 0.18 | 39.0 | 26 | 3.0 | 9.00 | 1.4 | 65 | 14.0 | 2.3800 | clay |
| 3 | 110-175 | 7.6 | 0.43 | 26.8 | 23 | 2.9 | tr | 0.8 | 74 | 0.00 | 0.0000 | clay |
| WT32S/4-1 | 0-15 | 7.6 | 0.19 | 39.3 | 33 | 1.7 | 2.60 | 1.9 | 72 | 17.0 | 0.6233 | clay |
| 2 | 15-30 | 7.5 | 0.09 | 5.0 | 1.3 | 0.4 | 2.70 | 0.6 | 44 | 23.4 | 2.9286 | clay |
| 3 | 30-45 | 7.5 | 0.12 | 10.9 | 6.9 | 0.7 | 2.70 | 0.6 | 46 | 11.5 | 1.3851 | clay |
| 4 | 45-73 | 7.7 | 0.11 | 16.5 | 12 | 1.2 | 2.60 | 0.8 | 67 | 10.9 | 1.0159 | clay |
| 5 | 73-106 | 7.7 | 0.08 | 13.3 | 9.4 | 0.7 | 2.60 | 0.6 | 83 | 16.1 | 1.1570 | clay |
| 6 | 106-140 | 7.8 | 0.12 | 28.1 | 21 | 1.8 | 4.60 | 0.8 | 78 | 7.8 | 1.3654 | clay |
| 7 | 140-162 | 7.2 | 0.13 | 20.2 | 14 | 1.0 | 4.60 | 0.8 | 67 | 15.3 | 1.6910 | clay |
| 8 | 162-200 | 7.2 | 0.16 | 38.8 | 30 | 3.5 | 4.60 | 0.8 | 64 | 9.5 | 1.1256 | clay |

**Appendix 3.Results of Soil Analysis Soil analyses and derived functions NW Block (Cont) (1975/76)**

| Pit no | Depth | pH | EC | CEC | Ca | Mg | Na | K | Sat% | ESP | SAR | SOIL TYPE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11N/14-1 | 0-40 | 7.4 | 0.17 | 37.0 | 28.1 | 1.2 | 6.5 | 1.2 | 80 | 0.176 | 1.698 | CLAY |
| 3 | 113-163 | 7.7 | 0.25 | 50.0 | 32.5 | 1.6 | 13.9 | 2.0 | 65 | 0.278 | 3.366 | CLAY |
| 11N/15-1 | 0-0 | 7.5 | 0.16 | 40.8 | 29.7 | 0.8 | 9.2 | 1.1 | 96 | 0.225 | 2.356 | CLAY |
| 11N/30-1 | 0-45 | 7.4 | 0.08 | 34.3 | 28.1 | 0.6 | 4.3 | 1.3 | 91 | 0.125 | 1.135 | CLAY |
| 2 | 45-120 | 7.3 | 0.30 | 38.0 | 28.1 | 0.8 | 7.3 | 1.8 | 96 | 0.192 | 1.920 | CLAY |
| 3 | 120-163 | 7.6 | 0.29 | 40.8 | 29.7 | 1.2 | 8.0 | 1.9 | 93 | 0.196 | 2.035 | CLAY |
| 12N/4-1 | 0-50 | 7.4 | 0.14 | 38.0 | 30.6 | 1.6 | 4.5 | 1.3 | 62 | 0.118 | 1.122 | CLAY |
| 2 | 50-122 | 7.2 | 0.22 | 41.5 | 33.4 | 2.1 | 4.6 | 1.4 | 54 | 0.111 | 1.092 | CLAY |
| 3 | 122-187 | 7.1 | 0.09 | 43.2 | 33.4 | 1.9 | 6.5 | 1.4 | 78 | 0.150 | 1.547 | CLAY |
| 12N/5-1 | 0-0 | 7.4 | 0.22 | 44.3 | 32.5 | 1.6 | 8.6 | 1.6 | 86 | 0.194 | 2.083 | CLAY |
| 12S/4-1 | 0-60 | 7.6 | 0.08 | 28.6 | 23.4 | 1.6 | 2.7 | 0.9 | 60 | 0.094 | 0.764 | CLAY |
| 2 | 60-110 | 7.6 | 0.19 | 40.2 | 29.7 | 2.3 | 6.1 | 2.1 | 74 | 0.152 | 1.525 | CLAY |
| 13N/7-1 | 0-0 | 6.9 | 0.11 | 8.6 | 6.9 | 0.4 | 0.7 | 0.6 | 81 | 0.081 | 0.366 | CLAY |
| 13N/8-1 | 0-24 | 6.2 | 0.10 | 16.7 | 10.9 | 0.8 | 3.7 | 1.3 | 87 | 0.222 | 1.530 | CLAY |
| 2 | 24-78 | 7.2 | 0.20 | 30.2 | 22.5 | 0.8 | 5.7 | 1.2 | 61 | 0.189 | 1.670 | CLAY |
| 14N/6-1 | 0-66 | 6.9 | 0.19 | 42.7 | 33.4 | 2.1 | 5.4 | 1.8 | 70 | 0.126 | 1.282 | CLAY |
| 2 | 66-140 | 7.3 | 0.24 | 43.1 | 31.6 | 1.6 | 7.3 | 2.6 | 54 | 0.169 | 1.792 | CLAY |
| 3 | 140-181 | 7.6 | 0.33 | 44.7 | 33.4 | 1.9 | 7.6 | 1.8 | 76 | 0.170 | 1.809 | CLAY |
| 16N/9-1 | 0-0 | 7.3 | 0.10 | 15.4 | 12.2 | 0.6 | 2.0 | 0.6 | 86 | 0.130 | 0.791 | CLAY |
| 16N/10-1 | 0-15 | 6.9 | 0.12 | 17.9 | 14.4 | 0.6 | 1.9 | 1.0 | 68 | 0.106 | 0.694 | CLAY |
| 2 | 15-40 | 7.2 | 0.08 | 19.9 | 15 | 0.6 | 3.9 | 0.4 | 92 | 0.196 | 1.396 | CLAY |
| 3 | 40-120 | 7.6 | 0.27 | 27.1 | 21.9 | 0.8 | 4.0 | 0.4 | 91 | 0.148 | 1.187 | CLAY |
| 4 | 120-193 | 7.7 | 0.56 | 37.0 | 28.1 | 0.6 | 7.6 | 0.7 | 93 | 0.205 | 2.006 | CLAY |

**Appendix 3.Results of Soil Analysis Soil analyses and derived functions NW Block (Cont) (1975/76)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18N/2-1 | 0-46 | 7.5 | 0.25 | 15.9 | 13.1 | 0.6 | 1.6 | 0.6 | 78 | 0.101 | 0.611 | CLAY |
| 2 | 46-120 | 7.9 | 0.26 | 23.5 | 19.4 | 0.8 | 2.7 | 0.6 | 85 | 0.115 | 0.850 | CLAY |
| 3 | 120-176 | 7.9 | 0.23 | 22.6 | 19.0 | 0.8 | 1.7 | 1.1 | 86 | 0.075 | 0.540 | CLAY |
| 18S/4-1 | 0-30 | 7.6 | 0.09 | 32.8 | 27.2 | 2.3 | 1.6 | 1.7 | 46 | 0.049 | 0.417 | CLAY |
| 2 | 30-110 | 7.9 | 0.46 | 38.4 | 28.1 | 2.1 | 6.4 | 1.8 | 65 | 0.167 | 1.647 | CLAY |
| 3 | 110-181 | 7.7 | 0.23 | 23.7 | 19.4 | 0.8 | 3.0 | 0.5 | 90 | 0.127 | 0.944 | CLAY |
| 18S/8-1 | 0-50 | 7.6 | 0.31 | 42.5 | 33.4 | 1.9 | 5.7 | 1.5 | 84 | 0.134 | 1.357 | CLAY |
| 2 | 50-113 | 7.8 | 0.32 | 45.1 | 32.5 | 1.6 | 9.5 | 1.5 | 82 | 0.211 | 2.301 | CLAY |
| 3 | 113-178 | 7.7 | 0.50 | 47.1 | 33.4 | 1.6 | 10.7 | 1.4 | 84 | 0.227 | 2.558 | CLAY |
| 20S/6-1 | 0-23 | 7.6 | 0.14 | 17.9 | 12.5 | 0.4 | 4.1 | 0.9 | 99 | 0.229 | 1.614 | CLAY |
| 2 | 23-80 | 7.3 | 0.05 | 18.2 | 13.1 | 0.4 | 4.3 | 0.4 | 96 | 0.236 | 1.655 | CLAY |
| 3 | 80-130 | 7.2 | 0.04 | 17.2 | 12.5 | 0.4 | 4.0 | 0.3 | 96 | 0.233 | 1.575 | CLAY |
| 4 | 130-140 | 6.1 | 0.05 | 30.6 | 24.1 | 0.4 | 5.4 | 0.7 | 91 | 0.176 | 1.543 | CLAY |
| 5 | 140-187 | 6.2 | 0.11 | 32.8 | 25.0 | 0.8 | 5.2 | 1.8 | 83 | 0.159 | 1.448 | CLAY |
| 6N/20-2 | 26-120 | 7.0 | 0.31 | 47.3 | 31.9 | 6.0 | 6.8 | 2.6 | 80 | 0.144 | 1.562 | CLAY |
| 3 | 120-163 | 7.4 | 0.31 | 50.9 | 32.5 | 6.2 | 9.2 | 3.0 | 91 | 0.181 | 2.091 | CLAY |
| 9N/21-1 | 0-0 | 7.4 | 0.90 | 39.3 | 28.1 | 4.1 | 4.0 | 3.1 | 93 | 0.102 | 0.997 | CLAY |
| 13N/14-1 | 0-42 | 7.4 | 0.14 | 23.7 | 16.9 | 2.1 | 2.3 | 2.4 | 98 | 0.097 | 0.746 | CLAY |
| 2 | 42-130 | 7.5 | 0.25 | 27.3 | 20.6 | 2.3 | 2.2 | 2.2 | 62 | 0.081 | 0.650 | CLAY |
| 3 | 130-163 | 8.0 | 0.41 | 35.0 | 28.1 | 1.9 | 2.4 | 2.6 | 72 | 0.069 | 0.620 | CLAY |
| 13N/21-1 | 0-0 | 7.3 | 0.08 | 9.5 | 6.9 | 0.6 | 0.8 | 1.2 | 72 | 0.084 | 0.413 | Clay |
| 17N/12-1 | 0-25 | 7.5 | 0.09 | 6.2 | 4.7 | 0.4 | 0.5 | 0.6 | 54 | 0.081 | 0.313 | Clay |
| 2 | 25-50 | 7.4 | 0.28 | 11.5 | 8.8 | 0.8 | 1.0 | 0.9 | 79 | 0.087 | 0.456 | Clay |
| 3 | 50-156 | 7.8 | 0.35 | 28.7 | 13.1 | 13.1 | 1.2 | 1.3 | 87 | 0.042 | 0.332 | Clay |
| 4 | 156-188 | 8.3 | 0.52 | 39.0 | 18.1 | 18.1 | 1.4 | 1.4 | 94 | 0.036 | 0.329 | Clay |
| 18N/5-1 | 0-0 | 7.4 | 0.31 | 21.2 | 9.4 | 9.4 | 1.3 | 1.1 | 94 | 0.061 | 0.424 | Clay |
| 14N/5-1 | 0-0 | 7.4 | 0.13 | 77.8 | 36.3 | 36.3 | 2.8 | 2.4 | 94 | 0.036 | 0.465 | Clay |

**Appendix 4.Results of Soil Analysis Soil analyses and derived functions SE Block (1975/76)**

| Pit no | Depth | pH | EC | CEC | Ca | Mg | Na | K | Sat% | ESP | SAR | SOIL TYPE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5S/3-1 | 0-68 | 7.0 | 0.008 | 23.1 | 15.9 | 3 | 3.8 | 0.4 | 47 | 0.2 | 1.24 | clay |
| 2 | 68-198 | 8.2 | 0.035 | 25.6 | 15.9 | 3.3 | 5.9 | 0.5 | 56 | 0.2 | 1.90 | clay |
| 5S/1-1 | 0-80 | 6.2 | 0.012 | 19.5 | 10.9 | 3.3 | 5.0 | 0.3 | 54 | 0.3 | 1.88 | clay |
| 2 | 80-181 | 7.8 | 0.030 | 15.5 | 9.0 | 2.7 | 3.5 | 0.3 | 45 | 0.2 | 1.45 | clay |
| 17N/8-1 | 0-55 | 5.2 | 0.008 | 16.5 | 5.9 | 6.3 | 2.6 | 1.7 | 82 | 0.2 | 1.05 | clay |
| 2 | 55-100 | 7.0 | 0.008 | 24.6 | 9.1 | 9.7 | 3.5 | 2.3 | 107 | 0.1 | 1.14 | clay |
| 3 | 100-175 | 8.5 | 0.006 | 30.1 | 11.9 | 5.7 | 11.5 | 1.0 | 136 | 0.4 | 3.88 | clay |
| 17N/4-1 | 0-41 | 7.1 | 0.014 | 12.5 | 4.3 | 3.8 | 3.5 | 0.9 | 125 | 0.3 | 1.74 | clay |
| 2 | 41-113 | 9.3 | 0.098 | 25.2 | 12.5 | 5.5 | 6.2 | 1.0 | 81 | 0.2 | 2.07 | clay |
| 3 | 113-181 | 7.7 | 0.012 | 26.1 | 9.1 | 10.9 | 4.3 | 1.8 | 108 | 0.2 | 1.36 | clay |
| 13N/20-1 | 0-15 | 6.3 | 0.013 | 14.0 | 4.8 | 4.6 | 3.1 | 1.5 | 123 | 0.2 | 1.43 | clay |
| 2 | 15-50 | 5.1 | 0.004 | 17.6 | 6.6 | 6.9 | 2.7 | 1.4 | 64 | 0.2 | 1.04 | clay |
| 3 | 50-110 | 7.2 | 0.025 | 20.8 | 7.0 | 8.0 | 3.3 | 2.5 | 92 | 0.2 | 1.20 | clay |
| 4 | 110-157 | 8.1 | 0.031 | 26.2 | 9.8 | 9.7 | 3.9 | 2.8 | 68 | 0.1 | 1.25 | clay |
| 13N/7-1 | 0-33 | 6.0 | 0.007 | 17.8 | 10.9 | 1.8 | 2.9 | 2.2 | 36 | 0.2 | 1.15 | clay |
| 2 | 33-90 | 6.8 | 0.008 | 22.1 | 13.3 | 3.7 | 3.5 | 1.6 | 42 | 0.2 | 1.20 | clay |
| 3 | 90-165 | 7.7 | 0.013 | 28.1 | 15.4 | 4.4 | 5.5 | 2.8 | 48 | 0.2 | 1.75 | clay |
| 9N/18-1 | 0-35 | 6.7 | 0.006 | 18.1 | 11.1 | 2.1 | 2.7 | 2.2 | 43 | 0.1 | 1.05 | clay |
| 2 | 35-110 | 7.9 | 0.013 | 20.2 | 10.4 | 2.1 | 5.1 | 2.6 | 47 | 0.3 | 2.04 | clay |
| 3 | 110-181 | 8.2 | 0.018 | 26.4 | 14.6 | 3.5 | 5.8 | 2.5 | 48 | 0.2 | 1.93 | clay |
| 6N/16-1 | 0-30 | 7.4 | 0.008 | 26.3 | 17.0 | 4.3 | 2.8 | 2.2 | 46 | 0.1 | 0.86 | clay |
| 2 | 30-100 | 8.3 | 0.011 | 29.2 | 11.5 | 3.7 | 11.3 | 2.7 | 53 | 0.4 | 4.10 | clay |
| 3 | 100-163 | 8.5 | 0.027 | 32.3 | 13.4 | 4.1 | 12.2 | 2.6 | 57 | 0.4 | 4.12 | clay |

**Appendix 4. Results of Soil Analysis Soil analyses and derived functions SE Block (cont) (1975/76)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6N/10-1 | 0-43 | 6.7 | 0.060 | 20.6 | 12.5 | 3.7 | 2.7 | 1.7 | 51 | 0.1 | 0.95 | clay |
| 2 | 43-130 | 8.2 | 0.020 | 32.7 | 14.4 | 4.5 | 11.3 | 2.5 | 75 | 0.3 | 3.68 | clay |
| 3 | 130-183 | 7.9 | 0.015 | 24.3 | 11.0 | 4.5 | 6.3 | 2.5 | 52 | 0.3 | 2.26 | clay |
| 6N/7-1 | 0-50 | 6.5 | 0.010 | 12.6 | 3.40 | 5.6 | 3.2 | 0.4 | 156 | 0.3 | 1.51 | clay |
| 2 | 50-130 | 8.3 | 0.270 | 25.5 | 13.4 | 5.1 | 6.0 | 1.0 | 77 | 0.2 | 1.97 | clay |
| 3 | 130-200 | 8.4 | 0.250 | 31.7 | 14.9 | 3.3 | 10.9 | 2.6 | 70 | 0.3 | 3.61 | clay |
| 5N/2-1 | 0-60 | 6.7 | 0.021 | 27.4 | 14.9 | 7.0 | 3.5 | 2.0 | 107 | 0.1 | 1.06 | clay |
| 2 | 60-120 | 7.8 | 0.017 | 36.8 | 14.6 | 7.0 | 12.6 | 2.6 | 70 | 0.3 | 3.83 | clay |
| 3 | 120-190 | 8.4 | 0.017 | 33.8 | 11.5 | 6.4 | 13.9 | 2.0 | 66 | 0.4 | 4.65 | clay |
| 7S/3-1 | 0-43 | 6.5 | 0.014 | 20.7 | 8.50 | 8.5 | 2.7 | 1.0 | 76 | 0.1 | 0.93 | clay |
| 2 | 43-110 | 8.0 | 0.030 | 27.2 | 11.9 | 9.9 | 5.0 | 0.4 | 101 | 0.2 | 1.51 | clay |
| 3 | 110-193 | 8.0 | 0.016 | 26.3 | 10.5 | 10.3 | 5.2 | 0.3 | 87 | 0.2 | 1.61 | clay |
| 2N/2-1 | 0-38 | 7.1 | 0.082 | 31.4 | 22.5 | 2.9 | 4.9 | 1.1 | 84 | 0.2 | 1.37 | clay |
| 2 | 38-80 | 7.2 | 0.200 | 41.6 | 29.7 | 2.7 | 8.0 | 1.2 | 82 | 0.2 | 1.99 | clay |
| 3 | 80-181 | 7.5 | 0.240 | 36.6 | 25.0 | 1.6 | 9.0 | 1.0 | 88 | 0.2 | 2.47 | clay |
| 5N/6-1 | 0-50 | 7.1 | 0.080 | 31.3 | 26.3 | 2.5 | 1.6 | 0.9 | 95 | 0.1 | 0.42 | clay |
| 2 | 50-120 | 7.4 | 0.130 | 33.0 | 25.6 | 1.6 | 4.5 | 1.3 | 80 | 0.1 | 1.22 | clay |
| 3 | 120-193 | 7.8 | 0.240 | 44.2 | 33.4 | 4.1 | 5.0 | 1.7 | 97 | 0.1 | 1.15 | clay |
| 6N/27-1 | 0-0 | 7.6 | 0.200 | 77.8 | 70.0 | 3.7 | 2.4 | 1.7 | 83 | 0.0 | 0.4 | clay |
| 6N/28-1 | 0-60 | 7.4 | 0.150 | 74.4 | 65.0 | 3.9 | 3.9 | 1.6 | 75 | 0.1 | 0.66 | clay |
| 3 | 120-193 | 7.7 | 0.420 | 76.3 | 62.5 | 2.3 | 9.5 | 2.0 | 98 | 0.1 | 1.67 | clay |
| 8N/7-1 | 0-0 | 7.4 | 0.150 | 41.5 | 35.6 | 2.9 | 2.0 | 1.0 | 64 | 0.0 | 0.46 | clay |
| 9N/19-1 | 0-0 | 7.3 | 0.200 | 35.3 | 29.7 | 1.2 | 3.0 | 1.4 | 68 | 0.1 | 0.76 | clay |
| 9N/20-1 | 0-47 | 7.4 | 0.080 | 38.9 | 29.7 | 2.1 | 5.7 | 1.4 | 71 | 0.1 | 1.43 | clay |
| 2 | 47-113 | 7.6 | 0.140 | 36.4 | 26.3 | 2.3 | 6.0 | 1.8 | 99 | 0.2 | 1.59 | clay |
| 3 | 113-171 | 7.8 | 0.320 | 55.0 | 33.4 | 5.0 | 13.9 | 2.7 | 64 | 0.3 | 3.17 | clay |
| 10N/11-1 | 0-0 | 7.4 | 0.090 | 36.6 | 26.3 | 2.5 | 6.5 | 1.3 | 73 | 0.2 | 1.71 | clay |

## Appendix 5 Chemical Properties of the Soil at PLOT P1

| | | | | Exchangeable Bases (cmol/kg) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Horizon** | **Depth(cm)** | **pH($H_2O$)** | **EC dS/m** | **Ca** | **Mg** | **Na** | **K** | **Org-matter (g/kg)** | **SAR** | **CEC (cmol/kg)** | **ESP %** |
| A1 | | | | | | | | | | | |
| | 0-20 | 6.2 | 0.56 | 20.02 | 4.37 | 0.87 | 1.23 | 0.98 | 0.25 | 31.46 | 2.8 |
| | 20-40 | 6.4 | 0.65 | 23.21 | 3.56 | 0.73 | 0.86 | 0.87 | 0.20 | 34.23 | 2.1 |
| | 40-60 | 6.6 | 0.71 | 24.15 | 4.67 | 0.86 | 0.73 | 0.76 | 0.23 | 36.67 | 2.3 |
| A2 | | | | | | | | | | | |
| | 0-20 | 6.1 | 0.67 | 21.23 | 4.87 | 0.56 | 0.76 | 1.95 | 0.16 | 30.45 | 1.8 |
| | 20-40 | 6.7 | 0.69 | 24.45 | 5.87 | 0.76 | 1.87 | 1.23 | 0.20 | 34.56 | 2.2 |
| | 40-60 | 6.8 | 0.71 | 23.54 | 6.98 | 0.98 | 0.90 | 0.89 | 0.25 | 34.56 | 2.8 |
| A3 | | | | | | | | | | | |
| | 0-20 | 6.3 | 0.61 | 21.21 | 7.86 | 0.59 | 0.76 | 1.34 | 0.15 | 32.45 | 1.8 |
| | 20-40 | 6.5 | 0.72 | 23.31 | 7.87 | 0.78 | 1.67 | 0.92 | 0.20 | 37.67 | 2.1 |
| | 40-60 | 7.4 | 0.71 | 37.45 | 6.98 | 0.89 | 1.98 | 0.67 | 0.19 | 49.58 | 1.8 |
| A4 | | | | | | | | | | | |
| | 0-20 | 6.4 | 0.65 | 34.50 | 8.98 | 1.67 | 0.67 | 0.59 | 0.36 | 46.67 | 3.6 |
| | 20-40 | 6.6 | 0.75 | 33.51 | 12.60 | 1.98 | 1.76 | 0.48 | 0.41 | 50.11 | 4.0 |
| | 40-60 | 6.5 | 0.80 | 33.45 | 15.00 | 1.56 | 2.01 | 0.51 | 0.32 | 53.34 | 2.9 |
| A5 | | | | | | | | | | | |
| | 0-20 | 6.6 | 0.65 | 27.78 | 6.87 | 1.76 | 0.89 | 1.45 | 0.42 | 39.56 | 4.4 |
| | 20-40 | 7.4 | 0.69 | 28.67 | 8.98 | 1.56 | 1.43 | 1.11 | 0.36 | 45.56 | 3.4 |
| | 40-60 | 6.5 | 0.73 | 24.67 | 13.90 | 1.67 | 2.98 | 1.01 | 0.38 | 48.56 | 3.4 |
| A6 | | | | | | | | | | | |
| | 0-20 | 6.1 | 0.68 | 21.23 | 12.90 | 1.78 | 0.78 | 0.98 | 0.43 | 41.34 | 4.3 |
| | 20-40 | 7.3 | 0.74 | 24.34 | 8.98 | 1.98 | 0.96 | 0.67 | 0.49 | 45.54 | 4.3 |
| | 40-60 | 7.5 | 0.74 | 30.12 | 7.98 | 1.67 | 1.23 | 0.45 | 0.38 | 46.57 | 3.6 |
| A7 | | | | | | | | | | | |
| | 0-20 | 6.8 | 0.67 | 23.15 | 5.67 | 1.79 | 0.94 | 0.56 | 0.47 | 40.67 | 4.4 |
| | 20-40 | 6.8 | 0.72 | 24.67 | 4.89 | 1.67 | 1.34 | 0.54 | 0.43 | 38.89 | 4.3 |
| | 40-60 | 7.3 | 0.81 | 30.02 | 6.98 | 1.45 | 1.76 | 0.39 | 0.34 | 45.67 | 3.2 |
| A8 | | | | | | | | | | | |
| | 0-20 | 6.3 | 0.69 | 27.56 | 9.91 | 0.97 | 0.98 | 1.25 | 0.22 | 46.67 | 2.1 |
| | 20-40 | 6.3 | 0.71 | 43.34 | 7.98 | 1.34 | 0.67 | 0.94 | 0.26 | 57.67 | 2.3 |
| | 40-60 | 6.4 | 0.69 | 56.76 | 20.90 | 1.43 | 0.78 | 0.45 | 0.23 | 80.56 | 1.8 |
| A9 | | | | | | | | | | | |
| | 0-20 | 6.2 | 0.67 | 22.35 | 5.89 | 1.67 | 0.76 | 0.78 | 0.44 | 45.67 | 3.7 |
| | 20-40 | 6.5 | 0.69 | 34.55 | 12.60 | 1.98 | 1.98 | 0.54 | 0.41 | 61.56 | 3.2 |
| | 40-60 | 7.3 | 0.72 | 35.67 | 8.74 | 1.76 | 1.78 | 0.46 | 0.37 | 57.98 | 3.0 |

## Appendix 6 Chemical Properties of the Soil at PLOT G2

| Horizon | Depth(cm) | pH($H_2O$) | EC dS/m | Exchangeable Bases (Cmol/kg) Ca | Mg | Na | K | Org-matter (g/kg) | SAR | CEC (Cmol/kg) | ESP % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B1 | | | | | | | | | | | |
| | 0-20 | 7.3 | 0.72 | 28.7 | 12.45 | 0.56 | 0.66 | 1.72 | 0.123 | 46.87 | 1.2 |
| | 20-40 | 7.2 | 0.71 | 26.7 | 13.45 | 0.67 | 0.61 | 0.87 | 0.150 | 49.67 | 1.3 |
| | 40-60 | 7.4 | 0.61 | 25.9 | 15.78 | 1.34 | 0.89 | 0.57 | 0.294 | 47.67 | 2.8 |
| B2 | | | | | | | | | | | |
| | 0-20 | 5.5 | 0.67 | 22.9 | 14.67 | 0.78 | 0.78 | 1.55 | 0.180 | 47.78 | 1.6 |
| | 20-40 | 5.6 | 0.79 | 23.9 | 18.98 | 1.98 | 0.43 | 1.23 | 0.428 | 49.56 | 4.0 |
| | 40-60 | 6.8 | 0.71 | 25.7 | 13.13 | 2.01 | 0.34 | 0.59 | 0.456 | 45.76 | 4.4 |
| B3 | | | | | | | | | | | |
| | 0-20 | 5.7 | 0.68 | 6.8 | 4.67 | 0.45 | 0.74 | 1.34 | 0.188 | 22.56 | 2.0 |
| | 20-40 | 6.5 | 0.65 | 8.7 | 7.87 | 0.67 | 0.56 | 0.92 | 0.233 | 25.67 | 2.6 |
| | 40-60 | 7.5 | 0.73 | 7.8 | 3.78 | 0.89 | 0.61 | 0.67 | 0.370 | 21.78 | 4.1 |
| B4 | | | | | | | | | | | |
| | 0-20 | 6.4 | 0.63 | 19.4 | 15.67 | 0.56 | 0.77 | 1.59 | 0.134 | 44.56 | 1.3 |
| | 20-40 | 6.8 | 0.72 | 13.6 | 9.15 | 1.56 | 0.45 | 0.78 | 0.463 | 31.67 | 4.9 |
| | 40-60 | 6.6 | 0.79 | 11.4 | 8.45 | 1.78 | 0.89 | 0.51 | 0.565 | 33.56 | 5.3 |
| B5 | | | | | | | | | | | |
| | 0-20 | 6.4 | 0.61 | 20.56 | 14.45 | 0.98 | 0.63 | 0.45 | 0.234 | 41.54 | 2.4 |
| | 20-40 | 6.7 | 0.71 | 28.67 | 15.75 | 1.23 | 0.47 | 0.31 | 0.261 | 48.78 | 2.5 |
| | 40-60 | 7.2 | 0.73 | 24.67 | 13.89 | 1.45 | 0.54 | 0.21 | 0.330 | 45.57 | 3.2 |
| B6 | | | | | | | | | | | |
| | 0-20 | 6.5 | 0.65 | 21.23 | 12.94 | 0.59 | 1.48 | 0.98 | 0.143 | 43.78 | 1.3 |
| | 20-40 | 7.3 | 0.72 | 23.12 | 18.56 | 1.23 | 0.67 | 0.77 | 0.269 | 56.87 | 2.2 |
| | 40-60 | 7.7 | 0.74 | 11.86 | 7.45 | 1.89 | 0.51 | 0.35 | 0.608 | 41.45 | 4.6 |
| B7 | | | | | | | | | | | |
| | 0-20 | 6.7 | 0.59 | 23.15 | 12.45 | 0.86 | 0.49 | 0.96 | 0.204 | 43.67 | 2.0 |
| | 20-40 | 6.7 | 0.69 | 23.01 | 13.76 | 1.56 | 0.13 | 0.54 | 0.364 | 44.67 | 3.5 |
| | 40-60 | 6.5 | 0.81 | 20.45 | 17.43 | 1.67 | 0.68 | 0.49 | 0.384 | 45.67 | 3.7 |
| B8 | | | | | | | | | | | |
| | 0-20 | 6.3 | 0.68 | 27.56 | 19.92 | 0.67 | 0.94 | 1.35 | 0.138 | 54.67 | 1.2 |
| | 20-40 | 6.9 | 0.70 | 23.12 | 14.78 | 0.98 | 0.67 | 0.74 | 0.225 | 45.67 | 2.1 |
| | 40-60 | 7.6 | 0.81 | 20.11 | 18.11 | 1.98 | 0.85 | 0.45 | 0.453 | 48.67 | 4.1 |
| B9 | | | | | | | | | | | |
| | 0-20 | 5.9 | 0.61 | 22.36 | 17.42 | 0.68 | 0.79 | 0.98 | 0.152 | 50.01 | 1.4 |
| | 20-40 | 6.5 | 0.73 | 23.78 | 12.34 | 1.56 | 0.64 | 0.74 | 0.367 | 45.67 | 3.4 |
| | 40-60 | 7.2 | 0.72 | 20.15 | 15.76 | 1.98 | 0.45 | 0.36 | 0.467 | 45.78 | 4.3 |

## Appendix 7: Chemical Properties of the Soil at PLOT K2

| Horizon | Depth(cm) | pH($H_2O$) | EC dS/m | Exchangeable Bases (Cmol/kg) Ca | Mg | Na | K | Org-matter (g/kg) | SAR | CEC (Cmol/kg) | ESP % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | | | | | | | | | | | |
| | 0-20 | 6.4 | 0.67 | 24.6 | 16.5 | 0.67 | 0.69 | 1.56 | 0.15 | 47.67 | 1.4 |
| | 20-40 | 6.5 | 0.65 | 37.8 | 28.7 | 0.98 | 0.61 | 0.67 | 0.17 | 73.67 | 1.3 |
| | 40-60 | 7.2 | 0.61 | 24.0 | 15.8 | 1.20 | 0.77 | 0.69 | 0.27 | 49.56 | 2.4 |
| C2 | | | | | | | | | | | |
| | 0-20 | 6.2 | 0.71 | 11.5 | 16.8 | 1.02 | 0.96 | 1.56 | 0.27 | 39.67 | 2.6 |
| | 20-40 | 6.6 | 0.65 | 14.7 | 9.67 | 2.10 | 1.32 | 1.11 | 0.60 | 38.78 | 5.4 |
| | 40-60 | 7.3 | 0.65 | 13.7 | 9.56 | 1.89 | 0.77 | 0.78 | 0.55 | 34.67 | 5.5 |
| C3 | | | | | | | | | | | |
| | 0-20 | 6.5 | 0.68 | 25.7 | 20.00 | 0.34 | 1.08 | 0.92 | 0.07 | 56.63 | 0.6 |
| | 20-40 | 6.7 | 0.66 | 14.6 | 3.45 | 0.67 | 1.06 | 0.84 | 0.22 | 32.56 | 2.1 |
| | 40-60 | 7.4 | 0.45 | 13.5 | 8.75 | 0.78 | 0.61 | 0.67 | 0.23 | 31.58 | 2.5 |
| C4 | | | | | | | | | | | |
| | 0-20 | 6.4 | 0.56 | 34.7 | 17.5 | 0.94 | 0.87 | 1.24 | 0.18 | 58.45 | 1.6 |
| | 20-40 | 6.8 | 0.72 | 23.6 | 18.5 | 1.48 | 0.65 | 0.67 | 0.32 | 49.56 | 3.0 |
| | 40-60 | 7.5 | 0.74 | 11.5 | 9.57 | 1.52 | 0.75 | 0.45 | 0.47 | 33.45 | 4.5 |
| C5 | | | | | | | | | | | |
| | 0-20 | 6.8 | 0.65 | 20.6 | 14.8 | 0.45 | 1.32 | 0.65 | 0.11 | 43.55 | 1.0 |
| | 20-40 | 7.2 | 0.71 | 27.9 | 17.5 | 0.98 | 0.78 | 0.55 | 0.21 | 56.73 | 1.7 |
| | 40-60 | 6.9 | 0.76 | 24.7 | 18.5 | 0.87 | 0.54 | 0.35 | 0.19 | 52.56 | 1.7 |
| C6 | | | | | | | | | | | |
| | 0-20 | 6.0 | 0.75 | 22.7 | 17.5 | 0.59 | 0.78 | 0.98 | 0.13 | 45.87 | 1.3 |
| | 20-40 | 6.3 | 0.65 | 24.7 | 19.5 | 1.23 | 1.34 | 0.65 | 0.26 | 56.45 | 2.2 |
| | 40-60 | 6.4 | 0.67 | 12.7 | 9.87 | 1.92 | 0.78 | 0.45 | 0.57 | 34.13 | 5.6 |
| C7 | | | | | | | | | | | |
| | 0-20 | 6.7 | 0.69 | 34.7 | 15.8 | 1.56 | 0.79 | 0.87 | 0.31 | 57.78 | 2.7 |
| | 20-40 | 7.1 | 0.56 | 12.5 | 9.78 | 1.87 | 0.37 | 0.65 | 0.56 | 28.53 | 6.6 |
| | 40-60 | 7.4 | 0.65 | 12.9 | 17.5 | 1.78 | 0.67 | 0.56 | 0.46 | 39.71 | 4.5 |
| C8 | | | | | | | | | | | |
| | 0-20 | 6.3 | 0.65 | 28.7 | 20.5 | 0.37 | 0.94 | 1.25 | 0.07 | 54.78 | 0.7 |
| | 20-40 | 6.3 | 0.56 | 24.8 | 15.5 | 0.67 | 0.78 | 0.97 | 0.15 | 48.67 | 1.4 |
| | 40-60 | 6.4 | 0.68 | 23.1 | 17.8 | 2.45 | 0.78 | 0.56 | 0.54 | 51.11 | 4.8 |
| C9 | | | | | | | | | | | |
| | 0-20 | 6.4 | 0.61 | 23.5 | 19.9 | 0.89 | 0.69 | 1.34 | 0.19 | 49.77 | 1.8 |
| | 20-40 | 6.5 | 0.65 | 25.8 | 13.7 | 1.11 | 1.04 | 0.97 | 0.25 | 48.89 | 2.3 |
| | 40-60 | 7.3 | 0.65 | 24.8 | 18.5 | 2.11 | 0.67 | 0.45 | 0.45 | 49.32 | 4.3 |

## Appendix 8: Physical Properties of Selected Surface Soil Samples PLOT (G2)

| | | Particle Size Distribution | | | | |
|---|---|---|---|---|---|---|
| **Horizon** | **Depth (cm)** | **Sand (%)** | **Silt (%)** | **Clay (%)** | **Textural class** | **Bulk density gcm-3** |
| A1 | | | | | | |
| | 0-20 | 11.34 | 17.45 | 71.21 | Clay | 1.11 |
| | 20-40 | 15.67 | 20.67 | 63.66 | Clay | 1.28 |
| | 40-60 | 13.56 | 24.56 | 61.88 | Clay | 1.32 |
| A2 | | | | | | |
| | 0-20 | 10.55 | 18.21 | 71.24 | Clay | 1.23 |
| | 20-40 | 13.45 | 20.45 | 66.10 | Clay | 1.45 |
| | 40-60 | 14.75 | 23.51 | 61.74 | Clay | 1.65 |
| A3 | | | | | | |
| | 0-20 | 9.67 | 19.67 | 70.66 | Clay | 1.24 |
| | 20-40 | 14.45 | 20.45 | 65.10 | Clay | 1.56 |
| | 40-60 | 19.45 | 17.47 | 63.08 | Clay | 1.71 |
| A4 | | | | | | |
| | 0-20 | 6.54 | 18.38 | 75.08 | Clay | 1.21 |
| | 20-40 | 8.56 | 23.67 | 67.77 | Clay | 1.34 |
| | 40-60 | 15.56 | 24.56 | 59.88 | Clay | 1.45 |
| A5 | | | | | | |
| | 0-20 | 10.43 | 19.56 | 70.01 | Clay | 1.35 |
| | 20-40 | 10.34 | 24.67 | 64.99 | Clay | 1.42 |
| | 40-60 | 14.28 | 21.67 | 64.05 | Clay | 1.56 |
| A6 | | | | | | |
| | 0-20 | 10.34 | 18.98 | 70.68 | Clay | 1.24 |
| | 20-40 | 8.56 | 23.67 | 67.77 | Clay | 1.28 |
| | 40-60 | 13.45 | 25.56 | 60.99 | Clay | 1.32 |
| A7 | | | | | | |
| | 0-20 | 7.78 | 19.67 | 72.55 | Clay | 1.27 |
| | 20-40 | 7.67 | 17.56 | 74.77 | Clay | 1.34 |
| | 40-60 | 9.76 | 18.87 | 71.37 | Clay | 1.61 |
| A8 | | | | | | |
| | 0-20 | 10.45 | 16.45 | 73.10 | Clay | 1.28 |
| | 20-40 | 13.45 | 19.45 | 67.10 | Clay | 1.32 |
| | 40-60 | 15.45 | 32.42 | 52.13 | Clay | 1.45 |
| A9 | | | | | | |
| | 0-20 | 5.67 | 24.48 | 69.85 | Clay | 1.14 |
| | 20-40 | 7.78 | 27.67 | 64.55 | Clay | 1.27 |
| | 40-60 | 14.34 | 32.32 | 53.34 | Clay | 1.45 |

**Appendix 9 Checklist Question and Response**

1. How many types of varieties of sugarcane do you have in Savannah Sugarcane Company?

   **Response**: Five types of sugarcane varieties: Co 997, CoC 671, Co 6806, B 4149 and SP 71-6180

2. Can you compare the varieties in terms of quality/advantages and disadvantages?

   **Response:** Co 6806 have high sugar content over the other varieties but SP 71-6180 has high ratoon compare to the others varieties which only gives weight. Diadvantage/ Co 6806 cannot go high ratoon and attract stem borer.

3. What are the planting season/period for each variety of sugarcane and harvesting?

   **Response:** The planting season of all the varieties of sugarcane start from November to April and Harvesting start October to January but depend on the planting time of the block.

4. Do the company plant the varieties at the same time and harvest at the same time?

   **Response: No.**

5. Where do you get source your seedlings?

   **Response:** Kwara, Lau, Brazil, India and Sudan

6. What is/are the maturity period of each of the varieties?

   **Response:** One Agricultural season.

7. How do you measure the quality of the seedling before planting?

   **Response:** The company don't measure the quality of the seedling imported but they take it to National Research Institute (Badagry) for quarantining the seedling from pest and disease before transplant the seedling to mother nursery for tryer before taken it to field block.

8. Have you observed any changes in the quality of seedlings? if yes, what have you done?

   **Response:** Yes. The company normally discard the non- performant varieties and adopt the varieties that are good for the soil and climatic condition of area.

**Fertilizer**

9. Which or what types of fertilizer do you apply to your sugarcane and in what at stages of growth?

   **Response:** Urea and NPK Fertiliser

10. How many bags of fertilizer do you apply per hectares?

    **Response:** 6 bags of NPK at pre-planting and 5 bags of Urea after (especially when the leaf of sugarcane was observe to be yellow).

11. Do you apply the doses of fertilizer in accordance to agronomic practices as recommended for the type of sugarcane varieties you have planted? if not, what is the gap per hectare?.

    **Response: Yes.**

12. Which method of fertilizer application do you adopt and why?

    **Response:** Broadcasting method. Because sugarcane are very close to each other.

13. Do you test the quality of fertilizer you use? If yes, has quality marched the quality printed on the bag?

    **Response:** No.

**Other Inputs and Issues**

14. Do you apply pesticides/herbicides to the sugarcane and in which stages of growth, how and when?

    **Response**: We do apply herbicides but we don't apply pesticide since the company has never experience pest in the field. The herbicide are normally apply before transplanting and when the weeds are overcoming the sugarcane.

15. Do you think pest or disease contribute to decline in sugarcane production over the years?

    **Response: No**

16. Did the company ever experience infrastructural break down ? when ? has the infrastructural breakdown affected the water supply? and how did you address the situation?

    **Response:** Yes. When Savannah Sugar Company was in operation. There's no fund to address the issue as then.

17. When Savannah Sugarcane was sold to Dangote, is there any transitional document on soil, and general condition of the company?

    **Response:** The only document on soil is that of Kenting Africa Resource Service Division LTD (1975) that was available.

18. Apart from analysis of soil conducted by **KENTE LTD** company done in 1975/76, did you conduct any other soil tests? when? By who? where are the results?

    **Response:** No**.** But when Dangote took over some South African consultant came and took soil sample but upto date they have not bring the result to the company**.**

19. From the table of savannah sugarcane company crop production annual report for 2012/13 what did TS/TC and TS/ha stand for? And what are their relevant to your production?

    **Response:** TS/TC mean amount of sugar in a sugarcane stalk while TS/ha is amount of sugar produce per hectare in the field.

20. From the chart plotted, it shows that there is drastic decline in the yield per hectare over the years, what is/are the reasons for the decrease in your personal opinion to it?

    **Response:** Technical and managerial issues in the company; They included importation of environmentally non-compactible seedlings, over aged cane, worn-out or obsolete equipment; non- payment and delay of staff salaries and inadequate workforce.

21. Recommend ways for improving the yield per hectare in the plantation

    **Response:** Adequate funding and provision of good equipment to carry out agricultural operation.