SUDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF GRADUATE STUDIES

EFFECT OF SULFUR FERTILIZER ON SUGARCANE (*SACCHARUM OFFICIANARUM SPP.)* IN THE HEAVY CLAY SOILS (VERTISOLS) OF (KENANA/ SUDAN)

تأثير سماد الكبريت على قصب السكر في الأراضي الطينية الثقيلة (كنانة/ السودان)

BY:

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بسم الله الرحمن الرحيم

قال تعالى:

(وَفِي الْأَرْضِ قِطَعٌ مُتَجَاوِرَاتٌ وَجَنَّاتٌ مِنْ أَعْنَابٍ وَزَرْعٌ وَنَخِيلٌ صِنْوَانٌ وَغَيْرُ صِنْوَانٍ يُسْقَىٰ بِمَاءٍ وَاحِدٍ وَنُفَضِّلُ بَعْضَهَا عَلَىٰ بَعْضٍ فِي الْأُكُلِ إِنَّ فِي ذَٰلِكَ لَآيَاتٍ لِقَوْمٍ يَعْقِلُونَ)

الرعد 4

Dedication

DEDICATION

To My Parents, Wife, Brothers, Sisters and Colleagues, With my Respect and Love.

Acknowledgement

Above all I render my full thanks to the merciful **Allah** who offer me all things to accomplish this work

I hope to express my deep gratitude and many thanks to my supervisor **Prof. Dr.Yassin Mohammed Ibrahim Dagash** for his helpful guidance, encouragement and criticism during the work of this study.

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ABSTRACT

The study was initiated mainly to investigate the response of sugarcane (*Saccharumofficianarumspp.)* cultivars (TUC75-3 and R 579) to different levels of sulfur in the form of ammonium sulfate fertilizer inthe heavy clay soils "vertisols" (Kenana sugar scheme, Sudan).

Two identical field experiments were conducted at Research and Development farm, at Kenana Sugar Scheme, during 2012/13 and 2013/14 seasons in which five levels of sulfur were tested, namely 0.00, 12.00, 24.00, 36.00, and 48 kg S/fed.

The experiments was designed by randomized complete block design (RCBD) with four replications and 10ten plots each, area of plot was (4 rows × 1.50 m width × 10 m length) and 5m inspection road.

sulfur had no significant effects on sugarcane yield and yield components, in both seasons but there was an increase in cane and sugar but it didn't reach significant level(probably due to high soil exchangeable sulfur or due to high amount of Sulfur fixed by the high clay content).

Cane quality (including, Brix % cane, Pol % Cane, Fiber % cane, ERSc. %cane, Purity % cane and Moisture % cane) were also affected by sulfur application in both seasons, but not significantly.

From these results, it's clear that sulfur had a positive effect on sugarcane performance on the heavy clay soil under Kenana conditions but the effect didnot reached the significant level for both varieties under investigation (TUC75-3 and R 579) possibly due to other factor, such as soil sulfur content.

الخلاصة

- أجريت هذه الدراسة لتقييم استجابة صنفان من قصب السكر(TUC75-3و579 R) لمستويات مختلفة من سماد الكبريت في شكل كبريتات الأمونيوم في التربية الطينية الثقيلة.
- صممت هذه التجربة بتصميم القطاعات العشوائية الكاملة بأربعة مكررات و10 عشر قطع في كل مكرر، مساحة القطعة الواحدة 4 سرابات× 1.50 م× 10 أمتار
- أجريت تجربان متطابقتان في مزرعة البحوث والتطوير بشركة سكر كنانة خلال مواسم 13/2012 و 14/2013 وتم فيهما اختبار خمسة مستويات من الكبريت وهي: 0.00، 12.00، 24.00، 36.00 و 48.00 كيلوجرام كبريت/ فدان.
- صممت التجربة بتصميم القطاعات العشوائية الكاملة من اربعة قطاعات و10 عشرة قطع في كل قطاع، مساحة القطعة الواحدة (4 سرابات × 1.50 متر عرض × 10 متر طول) و 5متر شوارع لتفتيش التجربة.
- لم يكن هناك تأثير معنوي لإضافة الكبريت على الإنتاجية (طن قصب/ فدان) ومكونات الإنتاجية وإنتاج السكر (طن سكر/ فدان) في الموسمين ولكن كانت هنالك زيادة غير معنوية في الإنتاجية.
- لم تؤثر إضافة الكبريت إيجاباً في مكونات عصير القصب كذلك، وأيضاً كانت هنالك زيادة ولكنها غير معنوية.
- من هذه النتائج، فإنه من االواضح أن إضافة الكبريت لها أثر إيجابي على قصب السكر في التربة الطينية الثقيلة في أراضي كنانة ولكن هذا التاثير لم يكن تأثيراً معنوياً في الأصناف تحت الدراسة خلال موسمين متتابعين، ربما يرجع ذلك لعدم استجابة الأصناف تحت الدراسة للمعاملة بالكبريت بصورة كبيرة أو لعوامل أخرى مثل إرتفاع نسبة الكبريت المتبادل في التربة.

CHAPTER ONE

Introduction

Sugarcane (*Saccharumofficianarumspp.)* belongs to the grass family (Poaceae), an economically important family that includes cereal crops such as maize, wheat, rice, sorghum and many forage crops (Jannoo *et al.*, 2007).Sugarcane is one of the most importanteconomiccropsin the world.According to the report of theFood and Agriculture Organizationof the United Nations.(FAO, 2010)estimates it was cultivated on about 23.8 million hectares, in more than 90 countries, with a worldwide harvest of 1.69 billion tons.

Sugarcane (trispecies, *Saccharumofficianarumspp.*, *poaceae*) is a large, perennial, tropical or subtropical grass widely grown in a zone within 30º of equator. It is usually vegetatively propagated from axiliary buds on stem (or stalk) cuttings. The first, "plant" crop is generally harvested from 12 to 24 months after planting; thereafter, "ratoon" crops may be harvested at shorter and equal time periods. Ratoon crops may be grown from one to several cycles. The large, mature stalks contain juice of 9 to 18% sucrose content(Ming *et al.*, 2006). The juice is extracted by crushing the stalks with high-pressure rollers in a mill. Sucrose is crystallized from the juice after water is removed by boiling to produce a brown-colored raw sugar. White sugar is produced by re-crystallization from raw sugar in a refiner(Ming *et al.*, 2006). The main sugarcane growing countries include: India, Brazil, Cuba, Australia and Mexico(Ali, 1986). The world annual sugar production is about 173.21 million tons, of which 60% is cane sugar,(Kingsman, 2011). In the Sudan, sugarcane was first grown on commercial scale at the Guneid scheme in 1963(Ali, 1986), and subsequently a number of sugar factories came into operation at New Halfa (1965/66), North-west Sennar (1976/77), Assallaya (1979/80) and

Kenana (1980/81). Severalfactoriesunder constructions, such as the White Nile Sugar, Alredaies, Sabinaand Mashkour, (Appendix1).

Kenana sugar factory produced more than 350.000 tons of refined sugar during the 2011/2012 season(KSC, 2012). The other Sudanese sugar combined factories produced more than 300.000 tons(SSC, 2012). The White Nile sugar factory is expected to produce 450.000 tons sugar at the full capacity. This total production constitutes 96% of the total domestic consumption.

The Sudanese sugar industry started in the early 1960s. Currently, the production capacity, design capacity of the existing five sugar factories, is 755,000 tons(Luken *et al.*, 2006). The soaring world sugar prices in the late 1950s motivated the Government of Sudan to plan establishment of a sugar industry to ease pressure on its foreign exchange reserves and create jobs and employment within a new industrial environment(Ali, 1986). El Guneid Sugar Factory was commissioned in 1962 and the New Halfa Sugar Factory in 1964, each with a sugar production capacity of 60,000 tons per annum. The two projects were established to meet the then domestic demand levels estimated at 120,000 tons per annum. In the early seventies the Sudanese Government designed a new plan to meet the growing demand for sugar. Three major sugar plantations were successfully constructed, namely HajarAssalaya, North West Sennar and Kenana(Ali, 1986).Kenana Sugar Company (KSC) was established as a private (integrated) company while Sudan's remaining four sugar plantations were administered by the Sudanese Sugar Company (SSC), a publicly owned enterprise(Taylor, 2004). The soil at Kenana scheme is heavy clay soil "vertisols" (Ali, 1986),the most important fertilizers used in Kenana Sugar Co. Ltd. are nitrogenous fertilizers "urea" and phosphorus Fertilizers "triple super phosphate". Neither cane nor sugar production were significantly affected by increasing nitrogen dose above 69kg N/fed. in the plant cane cycle(El-Hag *et al.*, 2006). The general fertilizers recommendations

have been transformed into a set of a site/soil- specific approach that recommendations are promoted with an integrated or (whole-of system) approach to nutrient management(AW *et al.,* 2005). Usually, the plant exhibits a visual symptom indicating deficiency in a specific nutrient, which normally can be corrected or prevented by supplying that nutrient. Visual nutrient deficiency symptoms can be caused by many other plant stress factors, therefore; caution should be exercised when diagnosing deficiency symptoms(Tisdale *et al.*, 1985). Use of fertilizers plays an important role in increasing cane and sugar yields. Proper fertilizer and variety experiments should be conducted to determine optimum fertilization methods for plant cane and subsequent ratoons for different varieties grown at different locations.

Sugarcane exhibits luxury consumption and removes a considerable quantity of S from the soil. A hundred tons crop of cane contains about 47.6 kg $SO_4^{=}$(Ali, 1986; Humbert, 1968).

Sulfur is becoming more of a limiting nutrient in crop production than in the past. The reasons for this increasing need include: higher crop yields which require more sulfur; increased use of high analysis fertilizers containing little or no sulfur; reduced amounts of atmospheric sulfur fallout in rainfall; and reduced soil sulfur reserves from organic matter losses due to mineralization and erosion. Sulfur plays an important role in the plant metabolism, and required for amino acids, proteins systems and photosynthesis and it is one of the most important nutrients for all plants and animals, it is considered as the fourth major nutrient after nitrogen, phosphorous and potassium for agricultural crop production. Sulfur is a structural constituent of organic compounds, some of which are uniquely synthesized by plants, providing human and animals with essential amino acids (methionine and cysteine). It is involved in chlorophyll formation, activation of enzymes and is a part of vitamins biotin and thiamine (B_1)(Hegde andBabu,

2007; Samaraweera, 2009). Sulfur deficiencies are often confused with nitrogen deficiencies. Symptoms of Sulfur deficiency appear as: stunted plant growth, general yellowing of leaves. In less severe S deficiency situations, visual symptoms may not be apparent, but both yield and quality of crops will be affected. Sulfur concentrations in crop plants should range between 0.2 and 0.5 percent. The sulfur status of crops is best diagnosed by plant analysis(Tandon, 1991).

Under Kenana conditions, after several years of cane cropping, the question of applying sulfur to the fields was raised. A number of experiments and demonstration plots were established for studying the response of sugarcane to applied sulfur(Ali and Hamid, 2012). The results of these experiments showed a high response of sugarcane to S in form of ammonium sulfate (AS) and phosphorus in the form of (DAP) Di-ammonium phosphate. A recommendation was formulated to apply both S and P combined with N in cane commercial fields atthe rate of 24kg S/fed., 23kg P and 76 kg N/fed.

In view of the inadequate information available about the response of sugarcane to S fertilization in the Sudan (Kenana), a need to investigate the response in more detail seemed justifiable. The present study was conducted to address the following:

- Determination of optimum levels of applied S for sugarcane grown in fields of Kenana schemewith different initial soil S levels.
- Construction of S response curves as a guide for proper S fertilization at Kenana.

CHAPTER TWO

LITERATURE REVIEW

2.1 Sulfur and agriculture:

Agriculture worldwide faces many challenges in same regions.Productionmust be expanded to provide food for growing populations, while in others, current production levels have to be maintained while striving for the right balance between intensive agriculture and environmental concerns(Ceccotti, 1996; Hegde and Babu, 2007; Samaraweera, 2009).

Sulfur is necessary for all living cells, but humans and animals only get it from plants. In plants, sulfur in essential for nitrogen fixation bacteria in legumes, and necessary for the formation of chlorophyll.Plants use sulfur in the processes of producing proteins, amino acids, enzymes, and vitamins. Sulfur also improve the plants resistance to disease, aids in growth, and in seed formation(Ceccotti, 1996; Hegde and Babu, 2007; Samaraweera, 2009). The primary nutrients N, P and K are those that plant need in large quantities. The secondary macronutrients are calcium, magnesium and sulfur. In reality, plants need sulfur in about the same quantity as phosphorus, but sulfur is still considered a secondary nutrient. (There is a third group of nutritional minerals, which the soil needs only in trace amounts, hence the name "trace minerals")(Pitchay *et al.*, 2005).Sufficient of the secondary nutrients(calcium, magnesium and sulfur) were often found in soils, avoiding the need to add them in fertilizers. Calcium and magnesium are almost always added as a byproduct of the process of liming to raise the pH. That's because many alkaline (lime) compounds contain calcium and magnesium compounds(Pitchay *et al.*, 2005). If an application to raise soil pH is done by applying gypsum, the sulfur

in soil is also raised. Increasedsoil levels of sulfur have the effect of lowering pH, although that is not the best way to lower pH(Pitchay *et al.*, 2005).

Industrial usage of sulfur is largely in the form of sulfuric acid used for phosphate extraction(Pitchay *et al.*, 2005). Sulfur in the soil is normallyinorgarganic form, and microbes change it to sulfide compounds which is oxidized to $(SO_4)^{-2}$that enter the soil solution and can be taken up by plant roots for growth(Specht Koch and Resinicky, 1957). The bacterial process of changing sulfur to compound forms plant can use renders it a slow-release fertilizer, which is oxidized for use over the growing season. An "instant" absorbable compound is Epsom salts (magnesium sulfates), adding both sulfur and magnesium(Specht, Koch and Resinicky, 1957). Soilssulfur come from three sources: airborne gases (SO_2),the weathering of minerals in soils, and microbial activity. *S*ulfur conversion by microbes happens in soil containing large amounts of decomposing organic materials like green manures, animal wastes (including urine), insects, worms, and dead microbes(Pitchay *et al.*, 2005). Grass clippings contain organic sulfur and should also be added back to the soil(Pitchay *et al.*, 2005). In some circumstances like sandy soils, the sulfur in soil solution can leach into water systems. In water-logged soils, sulfur can be converted by microbial activity into a gas, and escape into the atmosphere. Soil sulfur can also react/bond with iron and become insoluble(Hodges, 2010).

2.2 Distribution of sulfur in plants:

Plants need sulfur for many aspects of growth, and absorb it either as the sulphate ion through the roots, or as gaseous sulfur dioxide from the air(Bowen, 1965). Analytical data about sulfur in plants have been reported by(Beeson Lyon and Barrentine, 1944; Spector, 1956),Conifer leaves contain only about 0·1% of the element, grasses contain 0·05-0·2%, while most other Angiosperm leaves contain

0·2-0·4%. Exceptionally large amounts of sulfur are found in species of Cruciferae and the genus *Allium* (0·5-1·5%), halophytes such as Salicornia and Suaeda 2-3%, and Cuscutaeuropaea 1%(Bowen, 1965).

The biochemistry of sulfur compounds in plants tissue has been reported by(Kjaer, 1963),He points out that all species of Cruciferae, together with members of the related families Resedaceae and Capparidaceae, contain thioglucosides (mustard oils), which are responsible for the pungent taste of such well-known condiment plants as radish, horseradish, cress, watercress and the mustards. Species of the genus Allium contain no thioglucosides, but instead have a wide range of unusual sulfur compounds, including the lachrymator propenyl-sulphenic acid. Other genera which have been shown to contain unusual sulfur derivatives include Equisetum, Athyrium, Pteridium, Petroselinum, Lactuca, Petasites and Asparagus. Much remains to be discovered in this field, but it is clear that the Cruciferae and the genus Allium need more sulfur than other plants and are adapted to high concentrations of the element(Bowen, 1965).

Sulfur dioxide is known to be absorbed almost entirely by the leaves, but very few studies of chronic exposure of plants have been made(Bleasdale, 1962; Bowen, 1965).

2.3 Function:

The range of biological compounds that contain sulfur is vast. S is found in vitamins viz, biotin and thiamine; cofactors S-adenosyl-L-methionine, coenzyme A, molybdenum cofactor (MoCo), and lipoic acid; the chloroplast lipid sufloquinovosyldiacylglycerol; and many secondary compounds(Leustek, 2002; Leustek and Saito, 1999). It also serves important structural, regulatory and catalytic functions in the context of proteins, and as a major cellular redox buffer in the form of the tripeptide glutathione and certain enzymes such as thioredoxin,

glutaredoxin and protein disulfide isomerase. A feature of many sulfur-containing compounds is that the S moiety is often directly involved in the catalytic or chemical reactiveness of the compound. A good example is the way in which cysteine residues in proteins sometimes form covalent disulfide bonds. Disulfides can, in turn, be reduced to the thiol form by glutathione or redox proteins like thioredoxin(Leustek and Saito, 1999; Saito, 2000). For some enzymes, disulfide bond formation serves to regulate activity. Many enzymes of carbon dioxide fixation are regulated in this way as a means to coordinate their activity with the light reactions of photosynthesis. The regulatory molecule, in this case is thioredoxin, which reduces target enzymes using electrons from ferredoxin(Leustek and Saito, 1999; Matsubayashi *et al.*, 2002; Saito *et al.*, 2005).

2.4 Soil and sulfur fertilizer:

2.4.1 Soil sulfur:

Sulfur is 13th most abundant element in the earth's crust, averaging between 0.06 and 0.10%. The main S-bearing minerals in rocks and soils are gypsum ($CaSO_4.2H_2O$), epsomite ($MgSO_4.7H2O$), mirabilite ($Na_2SO_4.10H_2O$), pyrite (FeS_2), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), and cobaltite (CoAS). Other important sulfides, including pyrrhotite ($Fe_{11}S_{12}$), galena (PbS), arsenopyrite ($FeS_2.FeAs_2$), and pentlandite $(Fe,Ni)_9S_8$, are also known(Tisdale *et al.*, 1985). Sulfur is present in soils in the form of both organic and inorganic compounds. Their proportion depends on the type of soils and the depth of the generic horizon studied. Even elemental sulfur is found in soil; it may be the product of transformation of sulfur-containing compounds or inherited from the parent material(Orlov, 1992).

The sulfur of the upper horizons of nonsaline soil ranges from 0.01- 0.02% to 0.2-0.4%. The lowest concentration and reserves of sulfur are typical of low-humus sandy and sandy loam soils. The maximum content and reserves are typical of peat and peat beds. In the upper humus horizons organic compounds account for 70 to 80% of sulfur reserves. The proportion of mineral sulfur compounds increases with a decrease in humus reserves, increase in mineralization of subsoil and ground water, and accumulation of carbonates and gypsum in soils(Orlov, 1992).

Although sulfur is described as a secondary plant nutrient, largely because it is not deficient as often as are nitrogen, phosphorus, and potassium, it is as important as any of the major nutrients. In fact, many crops contain approximately equal amounts of sulfur and phosphorus(Schulte, 1981).

Sulfur in agricultural soils occurs in organic and inorganic forms, with organic S accounting for > 95% of the total S. Analysis of a wide range of soils shows that from 25 to 75% of the organic S in soils is highly-reducible, from 7 to 30% is C-bonded, and from 11 to 22% is unidentified S(Tabatabai, 1984).

2.4.2 **Soil Organic Sulfur:**

Up to 95% of the total soil S is present as organic S compounds and is associated with a heterogeneous mixture of plant residues, animals and soil microorganisms(Jamal Moon and Abdin, 2010). The profile of organic S concentration generally follows the pattern of organic matter concentration in soils with depth(Jamal*et al.*, 2010; ME, 1980). Soil organic S is divided into two main groups: the first group contains S atom in the oxidized state and the other group contains S atom in the reduced state. According to(Jamal *et al.*, 2010)and (Stevenson and Cole, 1999)between 1 and 3% of the soil organic S can be accounted by microbiological biomass, while more recent investigations suggested that the soil microbiological biomass S generally accounts for 1.5 -5% of total soil

organic S(Banerjee *et al.*,1993; Wu *et al.*, 1995).Proteins and amino acids are the major forms of S in microbial cells(Banerjee *et al.*, 1996). Based on dry weight, the S concentration of most soil microorganisms ranges between 1 and 10µg/g, the C: S ratio between 57:1 and 85:1 and the N: S ratio is about 10:1. However, there is evidence that the C: S ratio in the biomass is not fixed, but may vary quite rapidly, depending on the supply of S(Jamal *et al.*, 2010). When S becomes a limiting factor, either because of low S concentrations in the substrate or where plant uptake is competing, the C: S ratio of the biomass may reach values between 80 and 100(Banerjee *et al.*,, 1993). The microbiological biomass is relatively labile and thought to be the most active pool for S turnover in soil(Stevenson and Cole, 1999). Generally, the application of organic matter to soil increases the microbiological biomass including microbial S. Further microbial S seems to increase with temperature and to decrease at low soil moisture content(Ghani *et al.*,, 1990; Gupta *et al.*, 1989).

2.4.3 **Soil Inorganic Sulfur:**

Inorganic S is usually much less abundant in most of the agricultural soils than is organically bound S(Bohn *et al.*, 1986). Sulphate is the most common form of inorganic S and can be divided into $(SO_4)^{-2}$ in soil, adsorbed $(SO_4)^{-2}$ and mineral S(Barber, 1995). Sulfur may precipitate in form of $(SO_4)^{-2}$of calcium, magnesium or sodium. In tidal marshlands large amounts of sulfide metals like pyrite (FeS2) accumulate. After draining these areas, the S compounds are oxidized to $(SO_4)^{\mathbf{-2}}$ accompanied by a decrease in pH. If adsorbed $(SO_4)^{-2}$ in soil is not readily available to plants, any treatment causing a decrease in retention and a corresponding increase of $(SO_4)^{-2}$ in soil solution should increase $(SO_4)^{-2}$ availability to plants.(Elkins and Ensminger, 1971)found that the release of adsorbed $(SO_4)^{-2}$ was in relation to the addition of successive increments of

$Ca(OH)_2$, which is assumed to be the result of increased pH. Therefore, little $(SO_4)^{-2}$ adsorption is to be expected in surface soils which are adequately limed(Evans, 1986) and consequently the joint application of limestone and gypsum results in an increased availability of $(SO_4)^{-2}$(Serrano RE, 1999). The higher concentration of $(SO_4)^{-2}$ in the soil solution of the uppermost soil layer may also be caused by the application of S containing fertilizers and other S inputs(Eriksen J., 1996). Further, it may be assumed that surface soil material adsorbs less $(SO_4)^{-2}$ than does subsoil material, because organic matter and phosphate accumulations are thought to be major factors, which block $(SO_4)^{-2}$ adsorption sites.(Barton D, 1999)found that deeper profile layers showed less capacity for $(SO_4)^{-2}$ adsorption.(Couto W, 1979)detected that the adsorption of $(SO_4)^{-2}$ increased with the depth in the soil profile. According to their results, this difference between the horizons is assumed to be caused by the higher organic matter content in the topsoil.(Johnson and Todd DE., 1983)found that $(SO_4)^{-2}$adsorption is negatively correlated with the soil organic matter content as the adsorption sites of Fe and Al hydroxides can be blocked by anionic groups of organic matter. Further, organic anions in soils, which are derived from decomposition of organic materials, may affect $(SO_4)^{-2}$ adsorption by occupying adsorption sites(Martinez *et al.*, 1998). by their preferential adsorption based on the number of oxygen containing functional groups(Inskeep, 1989).

2.5 Sulfur fertilizer:

Sulfur is one of the major essential plant nutrients, and it contributes to an increase in crop yields by providing direct nutritional value and improving the use efficiency of other essential plant nutrients, particularly nitrogen and phosphorus. As agricultural productivity has increased, the demand for all nutrients has increased. While nitrogen fertilization, in particular, andlesser degree, phosphorus

and potassium fertilization needs have been addressed, sulfur has emerged as fourth major nutrient for the fertilizer industry(Randazzo, 2009). There are many fertilizer materials containing significant quantities of S which can generally be divided into two groups:

2.5.1 **FERTILIZERS CONTAINING SULFATE:**

The fertilizers containing sulfates provide most of the fertilizer S applied to the soil. These materials have the advantages of supplying S primarily as a component of multi-nutrient fertilizers in a form of $(SO_4)^{-2}$ that is immediately available for plant uptake. The most significant and popular sources are ammonium sulfates (AS), single super phosphate (SSP), potassium sulfates, potassium and magnesium sulfates and gypsum(FAN, 2007; Randazzo, 2009).

2.5.1.1 Ammonium Sulfates ($(NH_4)_2SO_4$):

Ammonium sulfate (21-0-0-24S) is one of oldest of N and S-containing fertilizers and still remains popular in the world. Improvements in the ammonium sulfate formulation processes allow for increasing shares of larger-sized granular material, which is easy to handle and suitable for bulk blending. This has greatly increased application options and spreading performance. Now ammonium sulfates are deliberately being added to increase S content of compound fertilizers(FAN, 2007; Randazzo, 2009).

2.5.1.2 Ammonium Sulfate Nitrate:

Ammonium sulfate nitrate was produced by neutralizing nitric and sulfuric acids with NH_3. With analyses of (30-0-0-5S) and (27-0-0-11S).of the two grades, the former which contains about 21% $(NH_4)SO_4$ and 79% NH_4NO_3 was the more popular. The major grade is (26-0-0-14S). It has been very successful for direct application to forage, and small grains(FAN, 2007; Randazzo, 2009).

2.5.1.3 Urea-Ammonium Sulfate:

Granular urea-ammonium sulfate has been made by coating ammonium sulfate fines with urea in a granulator and by air prilling. Grades range from 40-0-0-14S to 31-0-0-13S. Urea-ammonium sulfate granules tend to be more resistant to physical breakdown and less hygroscopic than urea prills. Its physical properties can be further improved by the addition of gypsum, which forms a complex with urea. The N/S ratio may be varied from 3:1 to 7:1, resulting in considerable flexibility in the correction of N and/or S deficiencies in most soils. The acid-forming reaction of $(NH_4)SO4$ in soil can reduce urease activity and NH_3 volatilization by reducing pH rising from urea hydrolysis(FAN, 2007; Randazzo, 2009).

2.5.1.4 Ammonium Phosphate-Sulfate:

Ammonium phosphate sulfate (ASP) is a complex of ammonium sulfate and ammonium phosphate. The most common grades of ammonium phosphate-sulfate are 20-20-0-13 to15S and 16-20-0-15S. It is composed of about 40% monoammonium phosphate and 60% ammonium sulfate. Other products of this type include 13-39-0-20S, 19-9-0-7S. The latter contains some urea. They are produced by several processes, including reaction of a mixture of phosphoric acid and sulfuric acid with ammonia, and introducing ammonium sulfate solutions and H_2SO_4 into H_3PO_4 plant circuit. Direct application of 16-20-0-15S to forage crops, particularly legumes, is practiced in many countries. It is also popular for in-row applications on small grains and rapeseed/canola. This product frequently used for formulating bulk blends.

In 1993, china developed a new technology of producing S-based, NPK compound fertilizers using phosphate rock, sulfuric acid, ammonia, urea and potassium chloride as raw materials. This new technology combines all three technical processes for producing ammonium phosphate, potassium and NPK (S) together, which, is greatly simplifying the production process, and reducing production cost.

The major product contains 14.5%N. 16%P_2O_5, 14.5%K_2O and 11%S(FAN, 2007; Randazzo, 2009).

2.5.1.5 Single Superphosphate (SSP):

Single superphosphate (SSP) was once the most important P source in the world and still is a major P fertilizer in many countries due to its P and S contents. It is composed of 50% by weight each of monocalcium phosphate and gypsum or its lower hydrate. SSP contains 12 to 22% P_2O_5 and 10 to 14% S and is an excellent source of S. the occurrence of S deficiencies has been delayed in many areas of world because of the involuntary addition of S when large amounts of SSP were used to supply P in the past. Its S (10 to 14%) and Ca (18 to 21%) content can be important in soils low in these nutrients and good for crops with high S and Ca demand, such as oil and legume crops(FAN, 2007; Randazzo, 2009).

2.5.1.6 Potassium Sulfates K_2SO_4:

Potassium sulfate is the major potash fertilizer containing S. it is a white material containing 50 to 53% K_2O and 17 to 18% S. Potassium sulfate is produced by different processes, depending on the original raw material. Most K_2SO_4 is recovered directly from potash salts or brines. About 40% of world K_2SO_4 capacity is based on the reaction between potassium chloride and H_2SO_4. Potassium sulfate is widely used as specialty fertilizer for valuable cash crops such as potatoes and tobacco, which are sensitive to chloride, and also it has the advantage of supplying S(FAN, 2007; Randazzo, 2009).

2.5.1.7 Potassium Magnesium Sulfate:

Potassium magnesium sulfate is a double salt and contains 18% K (22% K_2O), 11% Mg and 22% S. It has the advantage of supplying both Mg and S and is frequently included in mixed fertilizers for soils deficient in these two elements. It is particularly useful when low levels of chloride are desired, as is often the case

for crops such as tobacco, potatoes, peach, some legumes and turf grass. It is suitable for direct application, bulk bleeding and inclusion in suspensions(FAN, 2007; Randazzo, 2009).

2.5.1.8 Magnesium Sulfate and Micronutrients Sulfates:

Magnesium sulfate containing 13% S and 9.8% Mg has been used as a source of Mg and S in clear liquid fertilizers and foliar sprays. Micronutrient sulfate salts are also carriers of S the group consisting of Cu, Fe, Mn and Zn, concentration of S varies between 13 and 21%(FAN, 2007; Randazzo, 2009).

2.5.2 FERTILIZERS CONTAINING ELEMENTAL S:

Elemental S based fertilizers are the most concentrated S carrier. Modern technologies increased their use in direct applications or as additives to NPK fertilizers. Elemental S is a yellow, inert, water-insoluble crystalline solid. When S is finely ground and mixed with soil, it is oxidized to SO_4 by soil microorganisms. This oxidation process determines the effectiveness of S in supplying S to plants, and depends on several factors, including particle size, rate, method of application, S-oxidizing characteristics of the soil and environmental conditions. S oxidation rate increases as particle size is reduced(FAN, 2007; Randazzo, 2009).

2.5.2.1 Granular Sulfur-Bentonite:

A variety of S-bentonite fertilizers have been produced to improve the effectiveness of granular elemental S products by incorporating 5 to 10% by weight in swelling clay such as bentonite. Particles of S-bentonite are sized for blending with solid N, P and K fertilizers. When it's applied to soil, this bentonite component imbibes soil moisture, causing fertilizer granules to disintegrate into finely divided S, which is more rapidly converted to $(SO_4)^{-2}$This material has gained wide acceptance as a source of plant nutrient S for high analysis, bulk blend

formulations because it provides elemental S in an acceptable physical form that can be converted easily into $(SO_4)^{-2}$forms in soil.

Because of uncertain effectiveness of these S sources for plants during the first growing season after application, it should be incorporated into soil prior to planting. When it is applied just before seeding and on severely S deficient soils, some $(SO_4)^{-2}$should also be provided. The repeated use of elemental S containing fertilizers tends to gradually enlarge the population of S-oxidizing microorganisms, resulting in a corresponding increase in the rate of $(SO_4)^{-2}$formation(FAN, 2007; Randazzo, 2009).

2.5.3 **LIQUID SULFUR FERTILIZERS:**

Ammonium thiosulfate (ATS) solution is a popular source of S for use in liquid fertilizers because of its solubility and compatibility with various ions. Fertilizer-grade ATS is in 60% aqueous solution with 12-0-0-26S analysis. It is compatible in any proportion with neutral to slightly acidic phosphate-containing solutions or suspension, as well as with aqueous NH_3 and N solutions. A wide variety of N-S, N-P-S and N-P-K-S formulations are possible utilizing this material. Thiosulfates $(S_2O_4)^{-2}$ are noncorrosive and nonhazardous to handle; they also are well adapted to or suitable for direct applications or blending, offering versatility to farmers and fertilizer retailers(Randazzo, 2009).

2.6 ROLE OF SULFUR:

Historically, gypsum has been used to improve sodic soils. The calcium replaces the sodium, which leached; thus, improving conditions in the root zone. Sulfuric acid and sulfur, proper, are now being examined as having a role in improving Na affected soils. Sulfuric acid and elemental sulfur make the relatively insoluble calcium carbonate commonly, found in sodic soils, available for replacement of

sodium. Sulfuric acid and sulfur lower soil pH, improve water penetration, and increased the availability of phosphorus and many other nutrients(Kanwar and Mudahar, 1986).

Sulfuric acid brings about these effects most rapidly. Because sulfur must first be oxidized to sulphate by soil microorganisms, its reaction with the soil is slower than that of gypsum and sulfuric acid, but its residual effect, particularly on nutrient availability, is generally longer lasting. Also, elemental sulfur is more concentrated than gypsum and sulfuric acid, lowering transport costs. Plus, elemental sulfur is easier to handle in field conditions than sulfuric acid. Elemental sulfur is in ample supply in many parts of the world, especially North America, the former Soviet Union, and the Middle East, which stands to make it a suitable soil amendment(Randazzo, 2009).

2.7 SULFUR UPTAKE BY SUGARCANE:

Sulfur is an essential element for growth and physiological functioning of plants. However, its content strongly varies between plant species and it ranges from 0.1 to 6% of the plants' dry weight(DeKok *et al.*, 2002). Sulfates taken up by the roots are the major sulfur source for growth, though it has to be reduced to sulfide before it is further metabolized. Root plastids contain all sulfate reduction enzymes, but the reduction of sulfate to sulfide and its subsequent incorporation into cysteine predominantly takes place in the shoot, in the chloroplasts. cysteine is the precursor or reduced sulfur donor of most other organic sulfur compounds in plants. The predominant proportion of the organic sulfur is present in the protein fraction (up to 70% of total sulfur), as cysteine and methionine (two amino acids) residues. Cysteine and methionine are highly significant in the structure, conformation and function of proteins. Plants contain a large variety of other organic sulfur compounds, asthiols (glutathione), sulfolipids and secondary sulfur

compounds (alliinns, glucosinolates, phytochelatins), which play an important role in physiology and protection against environmental stress and pests(DeKok *et al.*, 2002). Sulfur compounds are also of great importance for food quality and for the production of phyto-pharmaceutics. Sulfur deficiency will result in the loss of plant production, fitness and resistance to environmental stress and pests(Schnug and Beringer, 1998)

Sulfate is taken up by the roots with high affinity and the maximal sulfate uptake rate is generally already reached at pedospheric sulfate levels of 0.1 mm and lower(Hawkesford, 2003; Hawkesford *et al.*, 2003; Hawkesford, 2000). The uptake of sulfate by the roots and its transport to the shoot is strictly controlled and it appears to be one of the primary regulatory sites of sulfur assimilation. Sulfate is actively taken up across the plasma membrane of the root cells, subsequently loaded into the xylem vessels and transported to the shoot by the transpiration stream. The uptake and transport of sulfate is energy dependent (driven by a proton gradient generated by ATPases) through a proton/sulfate co-transport(Clarkson, Hawkesford and Davidian, 1993). In the shoot the sulfate is unloaded and transported to the chloroplasts where it is reduced. The remaining sulfate in plant tissue is predominantly present in the vacuole, since the concentration of sulfate in the cytoplasm is kept rather constant. Distinct sulfate transporter proteins mediate the uptake, transport and sub-cellular distribution of sulfate. According to their cellular and sub-cellular gene expression, and possible functioning the sulfate transporters gene family has been classified in up to 5 different groups(Buchner *et al.*, 2004; Davidian and Kopriva, 2010; Hawkesford *et al.*, 2003; Hawkesford, 2000). Some groups are expressed exclusively in the roots or shoots or expressed both in the roots and shoots. Group 1 is high affinity sulfate transporters', which are involved in the uptake of sulfate by the roots. Group 2 are vascular transporters and are 'low affinity sulfate transporters'. Group 3 is the so-called 'leaf group',

however, still little is known about the characteristics of this group. Group 4 transporters are involved in the efflux of sulfate from the vascuoles, whereas the function of Group 5 sulfate transporters is not known yet(Buchner *et al.*, 2004). Regulation and expression of the majority of sulfate transporters are controlled by the sulfur nutritional status of the plants. Upon sulfate deprivation, the rapid decrease in root sulfate is regularly accompanied by a strongly enhanced expression of most sulfate transporter genes (up to 100-fold), accompanied by a substantially enhanced sulfate uptake capacity(Buchner *et al.*, 2004; Hawkesford, 2003; Hawkesford *et al.*, 2003; Hawkesford, 2000); it is not yet resolved, whether sulfate itself or metabolic products of the sulfur assimilation (O-acetylserine, cysteine, glutathione); act as signals in the regulation of sulfate uptake by the root and its transport to the shoot, and in the expression of the sulfate transporters involved(Abrol and Ahmad, 2003; Buchner *et al.*, 2004).

Even though root plastids contain all sulfate reduction enzymes, sulfate reduction takes predominantly placepredominantlyin the leaf chloroplasts. The reduction of sulfate to sulfide occurs in three steps. Sulfate needs to be activated to adenosine 5'-phosphosulfate (APS) prior to its reduction to sulfite. The activation of sulfate is catalyzed by ATP sulfurylase, its affinity for sulfate is rather low (K_m approximately 1 mm) and the *in situ* sulfate concentration in the chloroplast is most likely one of the limiting/regulatory steps in sulfur reduction(Stulen and De Kok, 1993). Subsequently APS is reduced to sulfite, catalyzed by APS reductase with likely glutathione as reductant(Kopriva and Koprivova, 2003; Leustek and Saito, 1999). The latter reaction is assumed to be one of the primary regulation points in the sulfate reduction, since the activity of APS reductase is the lowest of the enzymes of the sulfate reduction pathway and it has a fast turnover rate (Brunold *et al.*, 2003). Sulfite is with high affinity reduced by sulfite reductase with ferredoxin as a reductant and the formed sulfide is incorporated into cysteine,

catalyzed by *O*-acetylserine(thiol)lyase, with *O*-acetylserine as substrate. The synthesis of *O*-acetylserine is catalyzed by serine acetyltransferase and together with *O*-acetylserine (thiol)lyase it is associated as enzyme complex named cysteine synthase(Dahl *et al.*, 2008; Droux *et al.*, 1992). The formation of cysteine is the pre-dominant direct coupling step between sulfur and nitrogen assimilation in plants(Brunold *et al.*, 2003). The remaining sulfate in plant tissue is transferred into the vacuole. The remobilization and redistribution of the vacuolar sulfate reserves appears to be rather slow and sulfur-deficient plants may still contain detectable levels of sulfate(Buchner *et al.*, 2004; Cram, 1990). Sulfur is constituent of protein of protoplasm and of essential amino acids like cystine, cysteine and methionine. Amino acid cystine which forms protein thiamine, biotine and hormones need sulfur nutrition.(Golden, 1983; Thangavelu and Chiranjivi Rao, 2006); found S and CI concentrations in plant parts were large; the effect on yield was small, though positive, where S and Cl were applied, also found When the rate of fertilizer N was increased, the concentration of N generally increased and the concentration of P, K, S and C1 generally decreased in sugar yield. Although increases in yield have been found due to fertilizer P and S. Among the nutrients, N, P, K and S, interaction effects on yield and plant composition were generally small(Golden, 1983). When S is deficient in soil, full yield potential of the crop cannot be realized regardless of other nutrients even under good crop husbandry practices(Rasheed, Ali and Mahmood, 2004).

2.8 TISSUE ANALYSIS

Tissue analysis has been widely practiced in sugarcane for planting and evaluation of fertilization programs. Different methods have been used in different cane growing areas. Such methods include crop logging, leaf analysis and stalk analysis (Samuels, 1960). The crop logging technique has been developed is more suited

for irrigated cane with 18 to 24 months cycle (Clements, 1980). The top visible dewlap (TVD) leaf method is well suited for 12 months cane in both irrigated and rainfall areas. (Clements, 1980; Singh and Agrawal, 2007), found that the diagnosis and recommendation integrated system (DRIS) approach was more accurate in the assessment of nutrient needs by sugarcane than soil and tissue analysis.

The determination of nutritional need of crops is an important aspect of nutrient management for farmers. Information and advice on their use must be made available prior to bud differentiation, expression of the potential yield and before the crop load is known. Crop plants are often fertilized by the grower on the basis of soil fertility, experience of successful growers, salesmanship and speculation or even hearsay. Considerations of economy, energy and pollution hazards make it imperative that manures and fertilizers be used efficiently to ensure high crop yield and to either sustain the available nutrient status at the maintenance level or raise it to the sufficiency level for specific crops. Reliable information is required to decide the quality and type of manures and fertilizers, and this can best be achieved by use of one or more diagnostic methods in combination with available research results. Diagnostic tools are designed to avoid nutrient stress or excess and if properly used no decrease in production or quality should occur. Among several diagnostic methods, analysis of growing plants seems to be the most efficient method in arriving at the need-based manuring schedule for various crops. Knowledge of nutrient concentration in growing plants can serve as a tool for correcting any deficiencies if carried out early enough to safeguard yield. It can also be used to evaluate the efficacy of a recent application. Analysis of harvested plant parts or mature tissues is like a post mortem. The information it provides can help to plan nutrient application only in subsequent years on that field (Bhargava and Raghupati, 1999).

2.9 SULFUR DEFICIENCY SYMPTOMS:

Sulfur deficiency in crops has only recently become widespread(Scherer, 2001). Previously, sufficient **S** to meet crop requirements was obtained from the frequent incidental additions of **S** to soils when **N** and **P** fertilizers, such as ammonium sulphate and single superphosphate, were applied. Industrial pollution as a result of coal combustion also contributed substantial amounts of **S** for plant needs by aerial deposition.(Gosnell and Long, 1969; Jamal Moon and Abdin, 2010).Over the last two decades, however, there has been a fundamental shift in the **S** balance toward deficit in agricultural systems for several reasons. High analysis **N** and **P** fertilizers have gradually replaced traditional ones that contain **S**(Jamal Moon and Abdin, 2010)**.** In addition, yields of agricultural crops have increased markedly, and in some cases more than doubled, during the last 20 years ago, resulting in increased removal of nutrients, including **S** from soils(Scherer, 2001). In intensive crop rotations including oil crops, **S** uptake can be very high, especially when the crop residue is removed from the field along with the product(Jamal, Moon and Abdin, 2010). **S** deficiency which was noticed many years ago only in localized areas has engulfed much larger area in its fold(Takkar, 1987). Ninety districts in pritish had been identified to have **S**-deficiency problem of varying degree and intensity. In 1991, the number of **S**-deficient districts increased to about 120(Tandon, 1991). When a soil is deficient in **S** and the deficiency is not rectified, then full potential of a crop variety cannot be realized, regardless of top husbandry practices(WH, 1971).

2.10 RESPONSE OF SUGARCANE TO SULFUR:

The sulfate-sulfur (SO^4-S) content of plants has been used as an indicator of their S nutrient status(Beaton Burns and Platou, 1968). The basic principle is based on the observation that, although plants take up **S** as the sulfate $(SO_4)^{-2}$ anion from the soil(Kowalenko, 1998). The dominant form of **S** in the plant is reduced **S** such as **S**-containing amino acids and related organic compounds(Dijkshoorn, Lampe and Van Burg, 1960; Lakkineni and Abrol, 1994; Mengel and Kirkby, 1987). Sulfate is assumed to be transitory in the plant since it is reduced quickly for incorporation into plant components, and will accumulate only when it is in excess to plant requirement(Kowalenko, 1998). Sulfate is assumed to be transitory in the plant since it is reduced quickly for incorporation into plant components, and will accumulate only when it is in excess to plant requirement(Kowalenko, 1998). Results showed that sulfur application could increase crop yield by 6.9%, 6.8% 9.4%, 11.8% and 8.1% on average, respectively, for corn, wheat, rice, soybean, and oilseed rape. The effect of ammonium sulfate or potassium sulfate on crop yield was better than gypsum or elemental sulfur, Sulfur application increased S uptake by both grain and straw. For cereal crops sulfur content and total uptake of straw was more than that of grain(Li, Lin and Zhou, 2005). There were some differences in crop responses to various sulfur sources. At the same application rate ammonium sulfate or potassium sulfate increased crop yield more than gypsum or elemental sulfur. For elemental sulfur application rate of 25 kg S/fed. was better than lower rate, further increase S rate could not increase crop yield(Li, Lin and Zhou, 2005).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Theexperimentalsite

An experiment was conducted at two locations on the Research and Development Department farm of Kenana Sugar Company Ltd.During seasons 2012/3 and 2013/14. Kenana, Sudan, is located between White Nile and the Blue Nile, at the intersection of longitude 33˚ E, latitude 13˚ N and is 410m above the sea level. Kenana is located about 330km south of the capital Khartoum, and 30km South East of Rabak Town(Elzaki, 2003). The climate is tropical with a rainy summer season of four months, June to September, with a peak in August. Annual rainfall is 360 mm and fluctuates greatly between years. The seasonal weather data during this study are shown in appendix 2. The soil is brown heavy clay and classified as true vertisols(Ali, 1986). The 60 cm of the soil profile is cracking clay with 40 to 60% clay content(Ali, 1986). The dominant clay mineral is montmorillonite. The soil pH rangefrom7.50 to 8.50.Above 90% of the upper horizon has an electrical conductivity is less than 3 mmhos/cm. The extractable sodium (ppm) is within a range of 510 and 770 ppm.

3.2 The experiments:

Two identical experiments were carried out during the 2012/13 and 2013/14 seasons, all sulfur experiments designated as the first season and second season.
All the experiments were conducted on exhausted soil (appendex 3).

3.3 Land preparation:

Land preparation was adopted according to the standard practice followed at Kenana estate. This consists of deep ploughing at 60 cm (uproot), a second deep

ploughing at 30 cm, harrowing, leveling and ridging at 1.50 m between ridges. The effective area of each experiment was 1.02 fed., divided into four blocks with 10 plots each. The plots were arranged in a randomized complete block design (RCBD) with four replications, inspection roads were made between blocks, each 5 m in width.

3.4 Fertilizers and application:

Sulfur was applied in the form of ammonium sulfate $(NH_4)_2SO_4$(N 21% and Sulfur 24%)at the rate of 0.00, 12.00, 24.00, 36.00 and 48.00 kg S/ fed., All plots received nitrogen in the form of urea mixed with ammonium sulfate to complete the rate of 69.00 kg N/fed., and also all plots received phosphorus in the form of tri- super phosphate (T. S. P) at the rate of 23 kg P/fed., All fertilizers were mixed thoroughly and applied uniformly in the ridges in continues bands as one dose at planting date.

3.5 Varieties:

The varieties used in the experiments were R579 and TUC75-3, which are characterized by fast growing, no-lodging, high cane and sugar yields, profuse tillering in the ratoon. R 579 is shy- flowering and all are fairly resistant to the smut disease.

3.6 Planting methods and date:

The crop was planted with stem cutting (setts), obtained from 9 months old seed cane, each set, with three buds. The sets were planted by hand in an end to end arrangement and covered with a thin layer of soil. The crop in the first season was planted on the 5th of February 2012 and the second season on the 4th of January 2013.

3.7 Irrigation:

Irrigation was carried out immediately after planting date and subsequently every 10 days throughout the growing season.

3.8 Weeding and herbicides:

The crop received 6 hand weedings until full canopy was reached and in the second season it was treated by 2.4.D twice to control striga infestation.

3.9 Pests and diseases:

Neitherpest infestation nor smut incidence were recorded during the growing seasons.

3.10 On barring:

At the age of three months mechanical on barring (split-ridging) was done in both seasons.

3.11 Harvesting:

The crop was harvested during March 2013 and February 2014 at 13 months age.

3.12 DATA COLLECTION

3.12.1 Soil Sampling

Prior to planting, soil samples were taken from five plots (four from each corner and another from the center) at depths of 0 to 30 cm by an auger and similar samples were carried out after harvesting from all plots. Each soil sample was dried under room temperature, ground and passed through a 2 mm screen mesh and 5 grams were taken for S determination. Analysis was done in the Kenana soil laboratory according to(Bashour and Sayegh, 2007; Tripathi *et al.*, 2005) procedures.

3.12.2 **Leaf Sampling:**

Leaf sampling was taken at six months age. Each leaf sample consisted of leaves number 3, 4, 5 and 6 which were separated from six cane stalks of the inner rows from each plot.In the lab. The leaf blades were separated from leaf sheaths, the midribs removed and the leaf blades were chopped and dried in the type of oven at 70°c for 24 hours. The dried samples were ground separately by grinder mill and kept in labeled plastic bags. Analyses were done mainly for determining S and other main macro nutrients N, P and K according to(Bhargava and Raghupathi, 1993)procedure appendix .

3.12.3 **Growth measurements:**

Growth parameters were measured at 7, 8, 13 and 9, 10 and 13 months of age in the first and second seasons respectively.

3.12.3.1 **Plant Density (1000 stalk/ feddan).**

Millable cane stalks in the 2-inner rows of each plot were counted. Plant density per feddan was calculated as follows:

$$\frac{\text{Number of Stalks in } (\text{15-m-inner row} \times 2 \text{ rows}) 4200}{\text{plot area } (30\text{m}^2) \text{ in m}^2}$$

3.12.3.2 **Stalk Height(cm).**

Ten stalks were taken randomly from 2-inner rows in each plot for stalk height measurements. Stalk height was measured from the soil surface to the top-visible-dewlap leaf (TVD) by a measuring tape and the heights were recorded in centimeters.

3.12.3.3 Stalk diameter (cm).

Stalk diameter was measured by a caliper at 30 cm above the soil surface and the stalk diameters were recorded in centimeters.

3.12.3.4 Final Yield:

The crop was harvested in March 2013 and February 2014 in the first and second season respectively at 13 months age. All millable cane in 2-inner rows of each plot were cut manually and arranged in bundles for weighting. The weight of harvested millable stalks was recorded using portable spring balance. Weight of cane in tons per feddan (TC/fed.) was calculated as follows:

$$\frac{\text{Weight of millable Stalks in } \left(\text{15-inner-row in kg} \times \text{2 rows}\right) 4200}{1000 \times \text{plot area } (30\text{m}^2) \text{ in m}^2}$$

3.12.3.5 Estimated Tons Sugar Perfeddan:

The estimated tons sugar per feddan (TS/fed.), was obtained by the following equation:

$$\text{TS/ha} = \frac{\text{TC/ fed.} \times \text{estimated recoverable Sugar (E. R. Sc)}}{100}$$

3.12.4 Chemical analysis:

Chemical analysis was done after harvesting date. Each maturity sample consisted of 10 cane stalks collected out of the harvested area (the tow inner rows) randomly. In the laboratory the cane stalks were cut into small pieces. A sample of 1 kg was taken from the chopped cane and passed through the Jeffco machine for juice extraction, the remaining cane after juice extraction, called bagasse, was used for

determining moisture% cane and fiber% cane, while the extracted juice was used for determining pol% cane (P% c), Brix% cane (B% c) and purity.

Determinations of the previous maturity parameters were done according to laboratory manual for Queensland sugar mills at the agronomy sugar lab. atkenana. A polarimeter and a refractometer were used for determinations of P% C and B% C respectively.

3.12.5 **Statistical analysis**

Analysis of variance was used for all data (except soil and tissue analysis data) statistix8 and SAS statistical programs were used to obtain the results.

CHAPTER FOUR

RESULTS

4.1.1 **Plant height**

Analysis of varianceshowed that the effect of applied Sulfur on stalk height was not significant for all sulfur levels at the two seasons (appendices 6, 7), however, it was found that the treatment 36 kg/fedd.caused a slight reduction in stalk height at all varieties and both seasons except variety TUC75-3 second season. Plant height measurements in this study are shown in (table 1). Generally, plant height was increased, as cane age progressed, clearly greater cane heights were obtained at harvest (13 Months age).

Table 1: Effect of Sulfur on Stalk height (cm.

Dose/ kg S/ fed	Season 1			Season 2		
	TUC75-3	R 579	**Mean**	TUC75-3	R 579	**Mean**
0.00	272.25	323.00	**297.63**	231.27	282.25	**256.76**
12.00	257.75	317.25	**287.50**	243.00	276.20	**259.60**
24.00	279.25	306.25	**292.75**	245.10	279.05	**262.08**
36.00	261.80	303.75	**282.78**	249.20	262.60	**255.90**
48.00	268.10	319.60	**293.85**	254.05	288.50	**271.28**
Mean	267.83	313.97	**290.90**	244.52	277.72	**261.12**
LSD_{05}		27.25			24.14	
C. V		7.49			7.39	

4.1.2 **Internodes No.**

Analysis of variance of internodes number showed that the effect of applied sulfur on internodes number was no significant different between all treatments but

appear significant in varieties and an interaction at second season (appendices 8, 9).Internodes properties (no, length, thickness and shape) are varietal characters, yet the rate of elongation and length of the internodes and plant height provide information about the general conditions of the crop vigour. In (table 2) application of sulfur did not affect internodes number in any particular trend.

Table 2: Effect of Sulfur on internodes number.

Dose/ kg S/ fed	Season 1			Season 2		
	TUC75-3	R 579	**Mean**	TUC75-3	R 579	**Mean**
0.00	22.00	24.20	**23.10**	21.27	23.50	**22.39**
12.00	21.45	23.75	**22.60**	23.85	23.65	**23.75**
24.00	23.60	23.35	**23.48**	22.00	24.70	**23.35**
36.00	21.45	23.60	**22.53**	20.85	24.80	**22.83**
48.00	22.70	25.55	**24.13**	22.15	25.40	**23.78**
Mean	22.24	24.09	**23.17**	22.02	24.41	**23.22**
LSD_{05}		2.13			1.88	
C. V		7.36			6.44	

4.1.3 **Stalk diameter (cm)**

Analysis of variance (appendices 10, 11) showed no significant between all treatments. Stalk diameter measurements for two seasons are shown in (table 3). It was clear from this data the stalk diameter was not affected by sulfur application at two seasons.

Table 3: Effect of Sulfur on stalk diameter (cm).

Dose/ kg S/ fed	Season 1			Season 2		
	TUC75-3	R 579	**Mean**	TUC75-3	R 579	**Mean**
0.00	2.57	2.96	**2.77**	2.92	3.00	**2.96**
12.00	2.81	2.85	**2.83**	2.99	3.28	**3.14**
24.00	2.75	2.87	**2.81**	2.88	3.16	**3.02**
36.00	2.85	2.99	**2.92**	2.81	3.11	**2.96**
48.00	2.87	2.89	**2.88**	2.86	3.16	**3.01**
Mean	2.77	2.91	**2.84**	2.89	3.14	**3.02**
LSD_{05}		0.20			0.18	
C. V		5.88			4.55	

4.1.4 **Plant density**

Analysis of variance (appendices 12, 13), showed that there were no significant different among treatments with respect to plant density for all counts, hence the plant population did not respond to sulfur application in both seasons.

Plant population counts for different sulfur levels and two seasons are shown in (table 4). Generally the number of plants/feddan obtained in the first season was higher than that obtained in the second season, best dose in the first season is 24 kg S/ fed.The best in the second season control 0.00kg S/ fed. Is the best than all, this may due to infestation of striga in this season.

Table 4: Effect of Sulfur on plant population density (1000 stalk/ feddan).

Dose/ kg S/ fed	Season 1			Season 2		
	TUC75-3	R 579	**Mean**	TUC75-3	R 579	**Mean**
0.00	40.18	39.31	**39.75**	44.03	36.16	**40.10**
12.00	43.54	42.28	**42.91**	42.07	35.14	**38.61**
24.00	37.21	41.86	**39.54**	40.36	35.53	**37.95**
36.00	39.97	37.70	**38.84**	44.28	34.16	**39.22**
48.00	40.32	36.19	**38.26**	42.74	37.03	**39.15**
Mean	40.24	39.47	**39.86**	42.70	35.60	**39.15**
LSD_{05}		5.83			5.18	
C. V		11.73			10.57	

4.1.5 **Cane Yield:**

Analysis of variance (appendices 14, 15), showed that there was no significant differencebetween treatments the two varieties for both seasons. Finally, moreover sulfur did not increase cane yield significantly in both seasons, although it increased it slightly.

The final cane yield in first and second seasons are shown in (table5).Generally, the higher cane yield was obtained from the first season than in the second season to both two varieties. Also, higher cane yields were recorded under treatments 36, 48 and 12 kg S/fed.respectively; while lower yields were obtained under treatments 24 and 0.00 kg S/fed. Respectively.Inthe variety TUC75-3.A similar response was obtained for variety TUC75-3 in both seasons. Variety(R 579) gave the best yields in both seasons than the variety (TUC 75-3).Higheryields were obtained in variety (R 579) under treatments, 48, 24, and 12 kg S/fed respectively, while lower yields were obtaining under treatments 0.00 and 36 kg S/fed, respectively in both seasons.

Table 5: Effect of Sulfur on cane yield, ton cane/feddan (TCF), two seasons.

Dose. Kg S/Fed.	First Season Varieties		**Means**	Second Season Varieties		**Means**
	TUC75-3	R 579		TUC75-3	R 579	
0.00	54.79	62.00	58.40	42.43	50.05	46.24
12.00	59.75	70.21	64.98	52.70	56.03	54.37
24.00	57.19	71.26	64.23	48.74	56.87	52.81
36.00	63.84	63.96	63.90	48.00	49.52	48.76
48.00	62.00	71.64	66.82	51.89	57.84	54.87
Mean	59.51	67.81	63.66	48.75	54.06	51.41
C. V %		5.81			14.51	
LSD_{05}		4.68			9.33	

4.1.6 **Sugar Yields**

Analysis of variance (appendices 16, 17) showed that there was no significant difference in sugar yieldbetween treatments in both seasons.

The final sugar yields of the first and second seasons are shown in (table 6).

Higher sugar yield was obtained in the first than in the second season. Also, higher sugar yield was recorded under treatments 48, 12, 0.00 kg S/fed.while lower yield was recorded under 24 and 36 kg S/fed.respectively in the first season.Thehigher Sugar yields was recorded under treatments 48, 24 and 12 kg S/fed.while the lower sugar yields were recorded under treatments 36 and 0.00 kg S/fed.respectively in the second season in combined varieties at both seasons.

In this study, each increment of applied sulfur caused an increase in sugar yield (not significant) in variety TUC75-3 in other variety (R 579) the dose 36 is the worst of all added doses.

Table 6: Effect of Sulfur on Sugar Yield ton sugar/ feddan (TSF), two seasons.

Dose kg S/ fed	First season			Second season		
	Varieties		Means	Varieties		Means
	TUC75-3	R 579		TUC75-3	R 579	
0.00	7.97	10.76	9.36	6.54	7.43	6.99
12.00	8.38	10.44	9.41*	7.00	8.44	7.72
24.00	8.57	10.11	9.34	6.97	9.12	8.05
36.00	9.44	9.22	9.33	7.03	7.21	7.12
48.00	9.19	10.64	9.91*	7.42	9.27	8.34
Mean	8.71	10.23	9.47	6.99	8.29	7.64
C. V%		7.07			16.36	
LSD_{05}		0.98			1.58	

4.1.7 **Brix% Cane (B% C):**

Analysis of variance (appendices 18, 19) showed that there were no significant differences in B% C among treatments at all two seasons.

Results of Brix% cane are shown in (table 7). Generally lower (B% C) was obtained from variety TUC75-3 in both seasons also (B%C) in the second season was better than than the first season.

From this results, it was clear that B % C was not affected by sulfur application.

Table 7: Effect of Sulfur on Brix% Cane. Two seasons

	First season			Second season		
Dosekg S/ fed	Varieties		Means	Varieties		Means
	TUC75-3	R 579		TUC75-3	R 579	
0.00	17.06	R 579	17.85	18.80	18.19	18.50
12.00	17.23	18.64	17.55	16.54	18.51	17.53
24.00	18.09	17.87	17.68	18.05	19.16	18.61
36.00	18.09	17.28	17.70	18.19	17.91	18.05
48.00	17.85	17.32	17.96	17.55	19.33	18.44
Mean	17.66	17. 84	17.75	17.83	18.62	18.22
C. V%		6.41			5.17	
LSDº5		1.40			1.18	

4.1.8 **Pol% Cane (P% C):**

Analysis of variance (appendices 20, 21) showed that there were no significant differences in P% C among treatments.

Results of Pol% Cane were shown in (table 8). The results showed a high P% C in the variety R 579 than the variety TUC75-3. Generally low P% C was obtained in the first season than in the second season, and the variety R 579 is better than the variety TUC75-3.

From these results, it was clear that P% C was not improved by sulfur application, except in few cases.

Table 8: Effect of Sulfur on Pol% Cane

First season				Second season		
Dose kg S/ fed	Varieties		Means	Varieties		Means
	TUC75-3	R 579		TUC75-3	R 579	
0.00	16.08	17.23	16.56	17.26	16.64	16.95
12.00	15.82	15.95	16.13	15.05	16.73	15.89
24.00	16.72	16.61	16.50	16.39	17.67	17.03
36.00	16.59	16.66	16.19	16.53	16.34	16.44
48.00	16.56	16.34	16.36	16.04	17.81	16.92
Mean	16.35	16.59	16.43	16.26	17.04	16.65
C. V%		5.34			5.59	
LSD		1.08			1.18	

4.1.9 **Fiber% Cane:**

Analysis of variance (appendices 22, 23) showed no significant differences were obtained among all treatments for fiber% cane for all sulfur levels.

Fiber% cane data is shown in (table 9). Generally, higher values of fiber% cane were obtained in the first season than in the second season.

4.1.10 **ERSc% Cane**

Analysis of variance (appendices 24, 25) did not shown any significant differences among treatments at all sulfur levels.

Extracting reducing sucrose (ERSc.) data are shown in (table10). Generally higher values of ERSc were obtained in second season, and the variety R 579 was better than the variety TUC75-3 in the two seasons.

Table 9: Effect of Sulfur fiber% Cane

First season				Second season		
Dosekg S/ fed	Varieties		Means	Varieties		Means
	TUC75-3	R 579		TUC75-3	R 579	
0.00	16.30	13.02	13.83	14.47	12.70	13.58
12.00	15.67	14.73	14.68	14.44	13.49	13.96
24.00	16.02	13.87	14.03	14.47	12.63	13.55
36.00	14.97	14.66	14.75	13.89	12.83	13.36
48.00	15.21	15.37	14.82	14.60	12.87	13.73
Mean	15.63	14.54	14.83	14.37	12.90	13.64
C. V%		7.06			6.53	
LSD°5		1.28			1.13	

4.1.11 **Purity% Cane**

Analysisof variance of purity% cane was shown in (appendices 26, 27) did not show any significant differences among all sulfur treatments for both seasons. Purity% cane is shown in (table 11). Generally higher values of purity% cane were obtained in first season than the second season.Also the variety TUC75-3 gave high value of purity% cane was obtained in first season than in the second season, while the reverse was there in the second season.

Table 10: Effect of Sulfur on ERSc% Cane

First season				Second season		
Dosekg S/ fed	Varieties		Means	Varieties		Means
	TUC75-3	R 579		TUC75-3	R 579	
0.00	14.48	15.53	14.87	15.36	14.92	15.14
12.00	14.00	14.22	14.47	13.25	14.90	14.07
24.00	14.92	14.85	14.79	14.51	15.95	15.23
36.00	14.76	15.00	14.43	14.68	14.61	14.64
48.00	14.80	14.57	14.61	14.27	16.08	15.18
Mean	14.59	14.83	14.69	14.41	15.29	14.85
C. V%		5.17			6.68	
LSDº5		0.98			1.25	

4.1.12 **Moisture% Cane (M% C):**

Analysis of variance (appendices 26, 27) showed significant different among treatments at the second season only, but at the interaction there were no significant differences.

Moisture% cane for all sulfur levels are shown in (table 12). Moisture percentages obtained at the second season was higher than the first season.

Table 11: Effect of Sulfur on Purity% Cane

Dosekg S/ fed	First season			Second season		
	Varieties		Means	Varieties		Means
	TUC75-3	R 579		TUC75-3	R 579	
0.00	94.52	92.51	92.67	91.40	91.45	91.43
12.00	91.86	92.30	93.32	90.22	90.30	90.26
24.00	92.93	91.98	92.55	90.77	92.25	91.51
36.00	91.86	93.51	92.26	90.84	91.20	91.02
48.00	88.94	92.61	92.59	91.42	92.11	91.77
Mean	92.02	90.46	92.29	90.93	91.46	91.20
C. V%		3.08			2.10	
LSDº5		3.50			2.10	

4.1.13 **Tissue analysis:**

Tissue analysis was done only once at the age of six months. Nutrients determined were N, P, K and S. (appendix 31). The analysis of variance table 18 showed no significant difference in N, P, K and S percentages among all Sulfur levels.

It was obvious that N, P, K and S in cane tissues were not affected significantly by S application. However, there was an inverse non-significant relationship between the applied S and N% of cane tissues. In treatment (0.00 kg S/fed), the average N% was 2.00 and 1.54, while in (48 kg S/fed.), it was 1.93 and 1.65 at the first and second season respectively. S application didn't effect on S% of plant tissues significantly and S concentration remained unchanged for the different treatments which show the lack of response to the soil applied Sulfur.

Table 12: Effect of Sulfur on Moisture% Cane

Dosekg S/ fed	First season			Second season		
	Varieties		Means	Varieties		Means
	TUC75-3	R 579		TUC75-3	R 579	
0.00	66.70	68.35	68.30	67.75	69.35	68.55
12.00	67.10	68.00	68.00	69.40	69.20	69.30
24.00	65.95	68.05	68.14	67.45	68.25	67.85
36.00	66.95	67.53	67.70	67.85	69.50	68.68
48.00	66.95	66.98	67.48	68.30	68.40	68.35
Mean	66.73	67.50	67.44	68.15	68.94	68.55
C. V%		1.46			1.43	
LSDº5		1.10			1.23	

CHAPTER FIVE

DISCUSSION

The general recommendation according to these findings, soil analysis and regarding to the application of sulfur fertilizer in this investigation is that the status of sulfur in clay soils in Kenana sugar scheme is adequate and there is no need to supplement it by artificial S fertilization, However, theadditionof sulfurgenerallya positive effecton theabsorption of someother nutrients by plants, such as phosphorus, which makes it availablearebest than addedin the formofindividual fertilizers. As the lack of information regarding the sulfur fertilizer requirements of the sugarcane in the Sudan has warranted to experimental work covered in this study, the following is the discussion of the findings.

5.1 GROWTH MEASUREMENTS:

Plant height is a major parameter of growth. Although length, thickness and shape of the internodes are varietal characteristics, yet the rate of elongation and length of the internodes and hence plant height provide information about the general growth of the crop. Stalk height and plant density in addition to other varietal characters did not respond significantly to sulfur application as shown by the results. This is in line with results that obtained by(Hamid and Dagash, 2014), were found that the stalk height, internodes number and stem thickness of sugarcane did not show any response to S application. The lack of response might be due to high levels of soil exchangeable Sulfur (9- 27 ppm S). In the first and second season plant densities found at 7, 13 and 10, 13 months age, were lower than those obtained at 6 and 9 months respectively in both seasons. This might be due to the fact that some tillers died as the result of competition between plants for

light, water and/or nutrients at old age. The high density recorded at harvest in the first season was caused by the inclusion of newly formed tillers and suckers. Also variety TUC75-3 showed better than the variety R 579 in both seasons.

5.2 CANE YIELD (TCF):

The results showed that sulfur application did not increase the cane yield significantly; however, there was slight increase, however results found by (Singh *at al.*, 2007) showed that application of sulfur up to 80 kg S/ ha to the cane crop increased the cane yield significantly. The cane yield increased from 4.36 to 8.34 tons/ fed and 0.72 to 8.72 ton/ fed due to applying sulfur on sugarcane varieties TUC75-3 and R 579 respectively over the control. Again highest sulfur level of 36 kg S/fed was found to reduce cane yield insignificantly in comparison to other levels except the control in both varieties. On other hand, the combined effect of applied sulfur on varieties showed that there was an increase in cane yield, but it not reached the significant level. But between varieties there was clear increase may that cause to varieties characteristics.

5.3 SUGAR YIELD (TSF):

Sulfurapplication did not increase sugar yield significantly, however, there was a slight increase. It could also be noted that there was a clear but insignificant response to sulfur up to 24 kg S/ fed, and then a drop in response. Dose 36 kg S/ fed gave a lower sugar yield in both varieties. Variety R 579 gave a higher response than variety TUC75-3, and it gave the highest of sugar yield. Similar results were obtained by (Singh, Srivastava and Singh, 2007)who found that application of sulfur up to 80 kg S/ ha increased the average sugar yield to 8.47 ton sugar/ha in comparison to the control which gave 6.58 ton sugar/ha.

5.4 Cane quality

5.4.1 **Brix% Cane:**

The Brix% Cane did not respond significantly to the application of sulfur on sugarcane in first and second season may be attributed due to the high soil exchangeable sulfur at Kenana.

5.4.2 **Pol% Cane**

Pol% cane (sucrose) did not respond significantly to S application.Thisresult was contrary to that obtained by (Naga, *et al.*, 2011) whofound that the cane juice quality and jaggery were positively and significantly influenced by the application of sulfur irrespective of sources of sulfur.The lack of response to sulfur on this study may be attributed mainly to high soil exchangeable sulfur at Kenana.

5.4.3 **Fiber% Cane**

Fiber% cane didn’t respond significantly to S application in both seasons may be due to the high soil exchangeable Sulfur.

5.4.4 **Purity% Cane**

The purity% cane did not respond significantly to S application in both seasons possibly due to high exchangeable sulfur.

5.4.5 **Moisture% Cane**

Moisture percentages obtained of both experiments were similar. The analysis of variance showed no significant differences in M% C in both seasons that may attributed to high exchangeable sulfur at Kenana soil.

Conclusion

1. This study was initiated to evaluate the influence of different sulfur levels on sugarcane cultivars (TUC75-3 and R 579) yield, yield components and quality. The applied sulfur was found to have no significant effect on growth parameters, juice quality cane and sugar yields as was illustrated by the results of tow experiments and both seasons. The lack of response to applied sulfur was mainly might due to the soil exchangeable sulfur and/or lack response of the varieties under test.
2. The results of soil analysis from the experimental site showed a significant trend of sulfur buildup in the upper soil layer (0- 30cm depth) following cane cropping.
3. The N, P and K in cane tissues were not affected significantly by the addition of sulfur.

DEFINITIONS AND ABBREVIATIONS:

According to(King, 1970) and (Chen and Chou, 1993), several general terms which have recently come to prominence and important definitions associated with the milling train have been added.

Bulk Density: The bulk densityof prepared cane is used as a measure of the degree of cane preparation and is defined as the weight of prepared cane sample, divided by its bulk volume under standard test conditions.

Brix: The Brix of a solution is the concentration (in g solute per 100 g solution) of a solution of pure sucrose in water, having the same density as the solution at the same temperature.

Cane: The raw material delivered to the mill, including clean cane, trash and any other extraneous matter.

Extraction (pol): The percentage of pol extracted from the incoming material by a train of mill either individually or cumulatively.

Fibre: Technically, fibre is the dry, water-insoluble matter in the cane. For commercial purpose a standard method of determination of fibre percent cane is specified.

Molasses: The mother liquid separated from a massecuite. It is distinguished by the same term as the massecuite from which it was extracted.

KSC: Kenana Sugar Company Ltd.

Pol: The pol of a solution is the concentration (in g solute per 100 g solution) of a solution of pure sucrose in water having the same optical rotation at the same temperature. For solutions containing only pure sucrose in water, pol is a measure of concentration of sucrose present; for solution containing sucrose and other optically active substances, pol is the algebraic sum of the rotations of the constituents present.

Purity: Purity is the percentage of sucrose in the total solid in sample.

SSC: Sudanese sugar company Ltd.

Sucrose: The pure chemical compound with the formula $C_{12}H_{22}O_{11}$**.** This is commonly referred to in the industry as pure cane sugar.

Sugar: The crystals of sucrose, together with any adhering molasses, as recovered from the massecuites. The various grades are commonly identified in terms of grade of massecuites processed, or in terms of the avenue of disposal of the sugar-hence, A sugar, C sugar, Shipment sugar.

TVD:top visible dewlap

Turbidity: A measure of material in suspension in a sugar solution as determined by a spectrophotometer.

ICUMSA: International Commission of Uniform Methods of Sugar Analysis.

TCF: Ton Cane per Feddan.

TSF: Ton Sugar per Feddan.

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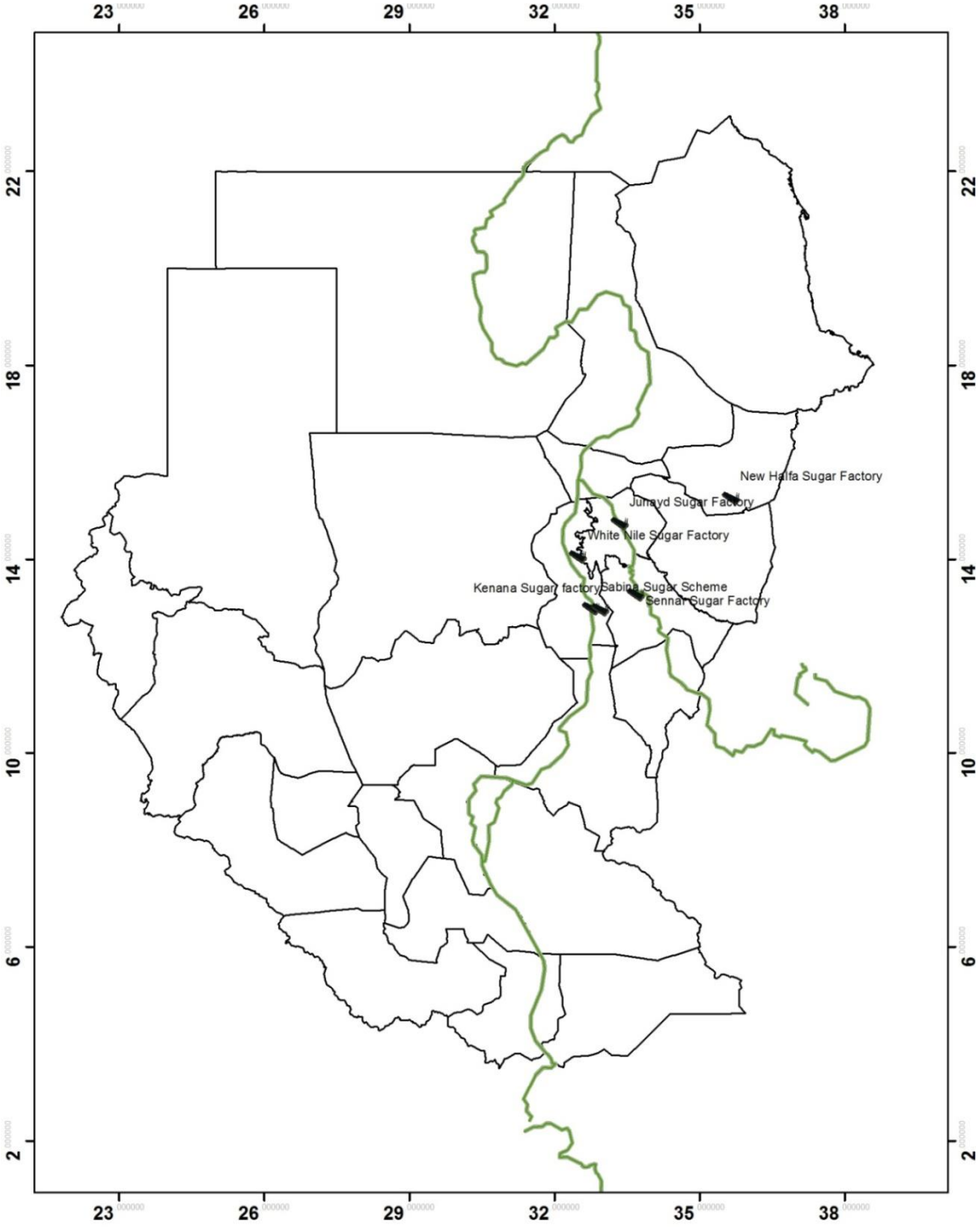
Appendices

Appendix 1: sugar factories in Sudan



Appendix 2: weather data

2012					
Month	Temperature Cº			Relative humidity%	Rainfall mm
	Max.	Min.	Mean		
January	37.10	14.30	25.70	32.70	0.00
February	36.40	19.00	27.70	32.60	0.00
March	36.80	19.50	28.15	25.70	0.00
April	39.70	22.10	30.90	21.10	0.00
May	39.50	23.30	31.40	44.90	32.00
June	34.70	22.70	28.70	68.90	25.00
July	29.80	21.10	25.45	81.30	127.00
August	30.20	20.90	25.55	85.10	142.00
September	32.10	21.50	26.80	78.70	18.00
October	36.60	21.00	28.80	69.90	27.00
November	35.50	18.80	27.15	41.50	0.00
December	33.00	16.20	24.60	40.20	0.00
2013					
January	33.10	16.30	24.70	39.70	0.00
February	35.70	18.20	26.95	31.80	0.00
March	38.70	19.20	28.95	24.00	0.00
April	39.80	20.90	30.35	20.60	0.00
May	40.00	23.30	31.65	37.70	8.00
June	37.60	21.80	29.70	22.50	12.50
July	34.10	21.40	27.75	68.90	42.50
August	30.70	19.90	25.30	85.60	302.00
September	32.70	20.40	26.55	77.70	73.00

October	35.10	19.90	27.50	63.00	0.00
November	35.40	18.20	26.80	39.30	0.00
December	32.00	15.50	23.75	45.70	0.00
2014					
January	32.80	13.10	23.00	38.50	0.00
February	34.00	15.10	24.60	33.00	0.00
March	37.80	20.10	29.00	40.20	0.00

Appendix 3: Pre-application- Soil analysis

S. No	Depth	pH	EC mSsms	N%	P ppm	K Exc.	S ppm
1	0-30	7.33	0.47	0.10	4.60	290.00	17.13
2	30-60	8.27	0.40	0.07	9.71	170.00	16.71
3	0-30	7.93	0.40	0.08	4.27	310.00	27.15
4	30-60	7.91	0.43	0.09	3.29	290.00	10.03
5	0-30	7.91	0.48	0.08	3.12	310.00	9.19
6	30-60	8.09	0.45	0.10	2.13	250.00	14.20
7	0-30	7.84	0.55	0.07	1.48	310.00	12.95
8	30-60	8.04	0.30	0.08	0.65	210.00	11.28
9	0-30	7.65	0.67	0.10	2.30	350.00	12.12
10	30-60	7.90	0.21	0.10	0.65	310.00	11.70

Appendix 4: soil analysis procedure

Reagents

1. Monocalcium phosphate extracting solution (500 mg P/liter), dissolve 2.035 g of Ca $(H_2PO_4)_2.H_2O$ in liter water.
2. Gum acacia- acetic acid solution: dissolve 5 g of chemically pure gum acacia powder in 500 ml of hot water and filter in hot condition through No. 42 filter paper. Cool and dilute to 1 liter with dilute acetic acid.
3. Barium chloride: pass AR-grade $BaCl_2$ salt through 1-mm sieve and store for use.
4. Standard stalk solution (2000 mg S/liter): Dissolve 10.89 g of oven dried AR-grade potassium sulfate in 1 liter of water.
5. Standard working solution (10 mg S/liter): measure exactly 2.50 ml of stalk solution and dilute to 500 ml.
6. Barium sulfate seed suspension: Dissolve 18 g of AR-grade $BaCl_2$ in 44 ml of hot water and add 0.5 ml of standard stalk solution. Heat the content to boiling and then cool quickly. Add 4 ml of gum acacia- acetic acid solution to it. Prepare a fresh seed suspension for estimation every day.
7. Dilute nitric acid (about 25 percent): dilute 250 ml of AR-grade concentrated HNO_3 to 1 litre.
8. Acetic-phosphoric acid: Mix 900 ml of AR-grade glacial acetic acid with 300 ml of H_3PO_4 (AR-grade).

Procedure

1. 20 g of soil sample in a 250-ml conical flask was weighed. 100 ml of the monocalcium phosphate extracting solution (500 mg P/litre) was added and shake for 1 hour. Thenfiltered through No. 42 filter paper.
2. 10 ml of the clear filtrate and Placed in a 25-ml volumetric flask was put.
3. 2.50 ml of 25 percent HNO_3 and 2 ml of acetic-phosphoric acid were added,

anddiluted to about 22 ml stopper the flask and shaked well (if it's required).

4. The$BaSO_4$ seed suspension was shaking and then add 0.5 ml was added and 0.2 g of $BaCl_2$ crystals. Was added and inverted after 10 minutes and after 5 minutes 5 times.
5. The mixture was allowed to stand for 15 minutes and then 1 ml of gum acacia-acetic acid solution was added.
6. To make the volume up to 25 ml, it was inverted 3 times and then set aside for 90 minutes.
7. Then it was inverted 10 times and the turbidity intensity was measured at 440 nm (blue filter).
8. A blank was run side by side.

Preparation of the Standard Curve:-

2.5, 5.0, 7.5, 10.0, 12.5 and 15.0 ml of the working standard solution (10 mg S/litre) was put into a series of 25-ml volumetric flasks in order to obtain 25, 50, 75, 100, 125 and 150 µg of S.

Proceeded to develop turbidity as described above for sample aliquots.

Theturbidity intensity was read and the curve was prepared by plotting reading against S concentrations (in micrograms in final volume of 25 ml).

Calculation:-

$$Available\ Sulfur\ \left(SO4-S\right)\ in\ soil\ \left(mg/kg\right)\ =\frac{W\times100}{10\times20}=\frac{w}{2}$$

Where:

W stands for the quantity o f S (in milligram) as obtained on the X-Axis against an absorbance reading (Y-axis) on the standard curve.

20 is the weight of the soil sample (in grams).

100 is the volume of the extractant (in millitre).

10 is the volume of the extractant (millitre). In which, turbidity is developed

Appendix 5: Determination of Sulfur in Plants procedure.

Determination of Sulfur:

The decide digestion is used for determination of **S** with many other nutrients. It is carried out using 9:4 mixture of HNO_3:$HClO_4$. If the sample is high in fats/oils, pre-digesting using 25 ml HNO_3/g sample is recommended to avoid explosion. Detailed procedure is as follows.

One g ground plant material is placed in 100 ml volumetric flask. To this, 10 ml of acid mixture is added and the content of the flask is mixed by swirling. The flask is placed on low heat hot plate in a digestion chamber. Then, the flask is heated at higher temperature until the production of red NO_2 fumes ceases. The contents are further evaporated until the volume is reduced to about 3 to 5 ml but not to dryness. The completion of digestions is confirmed when the liquid become colorless. After cooling the flask, add 20 ml of deionized or glass distilled water. Volume is made up with deionized water and the solution is filtered through whatman No. 1 filter paper. Aliquots of this solution are used for determination of S.

Total plant sulfur can be determined by a number of techniques with comparable results. A common procedure follows wet ashing of plant tissue sample and sulphate content in the digest is then determined by barium sulphate turbidity method. During ashing/wet digestion of the sample, all the plant sulfur is converted to sulphate form, which when treated with $BaCl_2$ is precipitated as while $BaSO_4$. This provides turbidity to the solution which is proportional to the amount of sulphate present. Measurement of this turbidity provides the means for quantitative determination of sulfur (Bhargava and Raghupathi, 1993; Bhargava and Raghupati, 1999).

Estimation of sulfur in plant:

Sulfur concentration was calculated is as follows:

$$S(\%) = \frac{R}{4} \times \frac{100}{Sample} \times \frac{100}{1000000}$$

Where 1 ppm S = 4 reading in KlettSummersoncolormeter

Appendix6: Analysis of Variance for plant height (cm) 1ST season

Source	DF	SS	MS
Rep.	3	5661.00	1887.00
Var.	1	21289.00	21289.00*
Error a	3	2355.70	785.20
Dose	4	1079.40	269.90NS
Interaction	4	1224.70	306.20NS
Error b	24	11406.00	475.20
Total	39		
Mean		290.90	
C. V%		7.49	

* Statistically significant at P = 0.05

Ns: statistically insignificant at p = 0.05

Appendix 7: Analysis of Variance for plant height (cm) 2nd season

Source	DF	SS	MS
Rep.	3	1350.00	450.00
Var.	1	11020.10	11020.10**
Error a	3	873.60	291.20
Dose	4	1220.90	305.20NS
Interaction	4	1420.80	355.20NS
Error b	24	8948.40	372.90
Total	39	21833.80	
Mean		261.12	
C. V%		7.39	

** Statistically significant at p = 0.01

Ns: statistically insignificant at p = 0.05

Appendix 8: Analysis of Variance for internodes number 1st season

Source	DF	SS	MS
Rep.	3	32.50	10.83
Var.	1	34.23	34.23*
Error a	3	15.99	5.33
Dose	4	14.01	3.50**NS**
Interaction	4	11.65	2.91**NS**
Error b	24	69.70	2.90
Total	39	178.07	
Mean		23.17	
C. V%		7.36	

* Statistically significant at P = 0.05

Ns: statistically insignificant at p = 0.05

Appendix 9: Analysis of Variance for internodes number 2nd season

Source	DF	SS	MS
Rep.	3	85.20	28.40
Var.	1	56.95	56.95*
Error a	3	6.20	2.07
Dose	4	11.69	2.92NS
Interaction	4	20.00	5.00*
Error b	24	53.71	2.24
Total	39	233.75	
Mean		23.22	
C. V%		6.44	

* Statistically significant at P = 0.05

Ns: statistically insignificant at p = 0.05

Appendix 10: Analysis of Variance for stalk diameter (cm) 1st season.

Source	DF	SS	MS
Rep.	3	1.12	0.37
Var.	1	0.20	0.20NS
Error a	3	0.20	0.07
Dose	4	0.12	0.03NS
Interaction	4	0.18	0.05NS
Error b	24	0.67	0.03
Total	39	2.49	
Mean		2.84	
C. V%		5.88	

NS: statistically insignificant at p = 0.05

Appendix 11: Analysis of Variance for stalk diameter (cm) 2nd season.

Source	DF	SS	MS
Rep.	3	0.36	0.12
Var.	1	0.65	0.65*
Error a	3	0.14	0.05
Dose	4	0.16	0.04NS
Interaction	4	0.08	0.02NS
Error b	24	0.45	0.02
Total	39	1.82	
Mean		3.02	
C. V%		4.55	

NS: statistically insignificant at p = 0.05

Appendix 12: Analysis of Variance for density (1000 stalk/ feddan) 1st season

Source	DF	SS	MS
Rep.	3	78.72	26.24
Var.	1	6.04	6.04**NS**
Error a	3	190.87	63.62
Dose	4	104.87	26.11**NS**
Interaction	4	86.47	21.62**NS**
Error b	24	523.75	21.82
Total	39	990.29	
Mean		39.85	
C. V%		11.72	

NS: statistically insignificant at p = 0.05

Appendix 13: Analysis of Variance for density (1000 stalk/feddan) 2nd season

Source	DF	SS	MS
Rep.	3	136.15	45.39
Var.	1	502.82	502.82**
Error a	3	15.15	5.05
Dose	4	25.52	6.38ns
Interaction	4	33.64	8.41ns
Error b	24	410.60	17.11
Total	39	1123.89	
Mean		39.15	
C. V%		7.53	

** Statistically significant at P = 0.01

NS: statistically insignificant at p = 0.05

Appendix 14: Analysis of Variance for yield, ton cane/ feddan (TCF) 1st season

Source	DF	SS	MS
Rep.	3	40.39	13.46
Var.	1	948.87	948.87*****
Error a	3	373.86	124.62
Dose	4	97.52	24.38**NS**
Interaction	4	267.84	66.96******
Error b	24	335.74	13.99
Total	39	2064.21	
Mean		64.39	
C. V%		5.81%	

** Statistically significant at p = 0.01

* Statistically significant at P = 0.05

Ns: statistically insignificant at p = 0.05

Appendix 15: Analysis of Variance for yield, ton cane/ feddan (TCF) 2nd season

Source	DF	SS	MS
Rep.	3	75.37	25.13
Var.	1	282.60	282.60*****
Error a	3	67.90	22.63
Dose	4	450.83	112.71**NS**
Interaction	4	64.34	16.09**NS**
Error b	24	1335.01	55.63
Total	39	2276.06	
Mean		51.41	
C. V%		14.51	

* Statistically significant at P = 0.05

Ns: statistically insignificant at p = 0.05

Appendix 16: Analysis ofVariance for yield, ton sugar/feddan (TSF) 1st season

Source	DF	SS	MS
Rep.	3	3.53	1.18
Var.	1	23.27	23.27NS
Error a	3	17.70	5.90
Dose	4	1.99	0.50NS
Interaction	4	9.88	2.47**
Error b	24	10.77	0.45
Total	39	67.15	
Mean		9.47	
C. V%		7.07%	

* Statistically significant at P = 0.05

NS: statistically insignificant at p = 0.05

Appendix 17: Analysis of Variance for yield, ton sugar/ feddan (TSF)2nd season

Source	DF	SS	MS
Rep.	3	0.97	0.32
Var.	1	28.93	28.93**
Error a	3	2.22	0.74
Dose	4	22.15	5.54*
Interaction	4	11.38	2.84NS
Error b	24	40.87	1.70
Total	39	106.	
Mean		7.60	
C. V%		11.33%	

** Statistically significant at P = 0.01

* Statistically significant at P = 0.05

Ns: statistically insignificant at p = 0.05

Appendix 18: Analysis of Variance for brix% cane, 1st season

Source	DF	SS	MS
Rep.	3	7.48	2.49
Var.	1	0.31	0.31**NS**
Error a	3	15.48	5.16
Dose	4	0.82	0.20**NS**
Interaction	4	8.10	2.03**NS**
Error b	24	31.05	1.29
Total	39	63.23	
Mean		17.75	
C. V%		6.41%	

NS: statistically insignificant at p = 0.05

Appendix 19: Analysis of Variance for brix% cane, 2nd season

Source	DF	SS	MS
Rep.	3	7.28	2.43
Var.	1	6.30	6.30*
Error a	3	1.95	0.65
Dose	4	6.28	1.57NS
Interaction	4	11.20	2.80NS
Error b	24	21.27	0.89
Total	39	54.30	
Mean		18.22	
C. V%		5.17%	

* Statistically significant at P = 0.05

NS: statistically insignificant at p = 0.05

Appendix 20: Analysis of Variance for pol % cane, 1st season

Source	DF	SS	MS
Rep.	3	6.72	2.24
Var.	1	5.83	2.83*
Error a	3	2.49	0.83
Dose	4	1.30	0.32NS
Interaction	4	2.79	0.70NS
Error b	24	20.66	0.86
Total	39	39.79	
Mean		16.43	
C. V%		5.65	

* Statistically significant at P = 0.05

NS: statistically insignificant at p = 0.05

Appendix 21: Analysis of Variance for pol% cane, 2nd season

Source	DF	SS	MS
Rep.	3	10.91	3.64
Var.	1	6.08	6.08*
Error a	3	1.66	0.55
Dose	4	7.50	1.88ns
Interaction	4	9.84	2.46*
Error b	24	21.70	0.90
Total	39	57.69	
Mean		16.65	
C. V%		5.71	

* Statistically significant at P = 0.05

NS: statistically insignificant at p = 0.05

Appendix 22: Analysis of Variance for fiber% cane, 1st season

Source	DF	SS	MS
Rep.	3	11.39	3.80
Var.	1	25.76	25.76*
Error a	3	13.44	4.48
Dose	4	3.31	0.83ns
Interaction	4	9.56	2.39ns
Error b	24	26.27	1.09
Total	39	89.72	
Mean		14.83	
C. V%		7.06%	

* Statistically significant at P = 0.05

NS: statistically insignificant at p = 0.05

Appendix 23: Analysis of Variance for fiber% cane, 2nd season

Source	DF	SS	MS
Rep.	3	2.41	0.80
Var.	1	21.67	21.67*
Error a	3	3.63	1.21
Dose	4	1.64	0.41ns
Interaction	4	1.48	0.37ns
Error b	24	17.77	0.74
Total	39	48.59	
Mean		13.64	
C. V%		6.31	

* Statistically significant at P = 0.05

NS: statistically insignificant at p = 0.05

Appendix 24: Analysis of Variance for ERSc.% cane, 1st season

Source	DF	SS	MS
Rep.	3	7.36	2.45
Var.	1	0.39	0.39ns
Error a	3	6.41	2.14
Dose	4	1.62	0.41ns
Interaction	4	4.49	1.12ns
Error b	24	15.16	0.63
Total	39	35.45	
Mean		14.69	
C. V%		5.41%	

NS: statistically insignificant at p = 0.05

Appendix 25: Analysis of Variance for ERSc.% cane, 2nd season

Source	DF	SS	MS
Rep.	3	13.03	4.34
Var.	1	7.70	7.70*
Error a	3	2.17	0.72
Dose	4	7.84	1.96ns
Interaction	4	8.88	2.22ns
Error b	24	24.42	1.02
Total	39	64.04	
Mean		14.85	
C. V%		6.79	

* Statistically significant at P = 0.05

NS: statistically insignificant at p = 0.05

Appendix 26: Analysis of Variance for Purity% cane, 1st season

Source	DF	SS	MS
Rep.	3	19.98	6.66
Var.	1	2.85	2.85NS
Error a	3	24.74	8.25
Dose	4	40.26	10.07NS
Interaction	4	30.02	7.51NS
Error b	24	193.78	8.07
Total	39	311.64	
Mean		92.29	
C. V%		3.08	

NS: statistically insignificant at p = 0.05

Appendix 27: Analysis of Variance for purity% cane, 2nd season

Source	DF	SS	MS
Rep.	3	17.76	5.92
Var.	1	2.81	2.81NS
Error a	3	7.99	2.66
Dose	4	11.02	2.76NS
Interaction	4	2.18	0.70NS
Error b	24	91.45	3.81
Total	39	133.84	
Mean		91.20	
C. V%		2.14	

NS: statistically insignificant at p = 0.05

Appendix 28: Analysis of Variance for Moisture% cane 1st season

Source	DF	SS	MS
Rep.	3	3.13	1.04
Var.	1	19.88	19.88**
Error a	3	1.73	0.58
Dose	4	2.37	0.59NS
Interaction	4	1.47	0.37NS
Error b	24	23.41	0.98
Total	39	51.99	
Mean		67.44	
C. V%		1.46	

** Statistically significant at P = 0.01

NS: statistically insignificant at p = 0.05

Appendix 29: Analysis of Variance for Moisture% cane 2nd season

Source	DF	SS	MS
Rep.	3	2.84	0.95
Var.	1	6.24	6.24*
Error a	3	2.85	0.95
Dose	4	8.86	2.22*
Interaction	4	5.70	1.43NS
Error b	24	22.94	0.96
Total	39	49.44	
Mean		68.55	
C. V%		1.43%	

* Statistically significant at P = 0.05

NS: statistically insignificant at p = 0.05

Appendix 30: N, P, K, S concentration in cane tissue

variety	N %	P %	K %	S %	N %	P %	K %	S %
TUC75-3	1.995	0.360	0.358	0.002	1.540	0.200	1.400	0.143
TUC75-3	1.925	0.370	0.380	0.002	1.708	0.228	1.370	0.163
TUC75-3	2.065	0.370	0.345	0.002	1.680	0.215	1.410	0.188
TUC75-3	1.925	0.370	0.335	0.002	1.778	0.233	1.440	0.195
TUC75-3	1.925	0.360	0.335	0.003	1.653	0.203	1.320	0.188
R 579	1.645	0.370	0.363	0.002	1.515	0.215	1.650	0.115
R 579	1.750	0.380	0.375	0.003	1.585	0.208	1.750	0.155
R 579	1.750	0.390	0.348	0.003	1.528	0.205	1.540	0.208
R 579	1.715	0.410	0.360	0.003	1.428	0.200	1.590	0.150
R 579	1.820	0.380	0.370	0.003	1.555	0.178	1.570	0.200
Mean	1.850	0.380	0.370	0.000	1.600	0.210	1.500	0.170
C. V%	7.550	10.410	8.150	32.110	7.930	12.670	7.060	35.270
LSD_{05}	0.180	0.050	0.030	9.800	0.150	0.030	0.130	0.080