CHAPTER ONE
INTRODUCTION

Sugarcane (*Saccharum officinarum L.*) is a perennial crop belongs to the grass family Poaceae. It is a tropical and sub-tropical plant widely grown around the world between latitudes 37° N, and approximately 30° S (*Sharpe,2005*). Sugarcane can be grown in a wide variety of soil types. Sugarcane Being a C-4 plant, sugarcane possesses high photosynthetic rate coupled with different light response curve, a low CO_2 compensation point, a different response to low oxygen tensions and a unique leaf anatomy which enables sugarcane to produce a huge biomass (*Alexander,1973*). The best climate for growing dry land sugarcane is one with two distinct seasons: one warm and wet, for encouraging germination and vegetative development, followed by a cool, dry season to promote ripening and consequent accumulation of sucrose in the stalks (*Humbert,1968*). Sugarcane comprises many crop categories all of which are recognized as plant cane (*PC*), and many successive ratoons which may reach 10 crops or more in some areas. The crop age may vary from 12 to 24 months.

Sugarcane is a major source of sugar and as a source of basic raw material for various agro–based industries. Sugarcane cultivation is considerably expanding worldwide. The main objective of growing sugarcane is undoubtedly the sugar, but the by-products of the sugar industry constitute vast potential reserves for human and animal consumption as well as providing renewable energy source. Moreover, the cane crop and its by-products provide useful raw materials to over 25 industries (*Solomon, et al.2000*). Currently, more than 130 countries produce either from sugarcane or sugar beet, ten of these produce sugar from both cane and beet crops. Approximately 79 % of the world sugar is produced from sugar cane, while sugar beet represented about 21% of the global sugar production (*Czarnikow,2016)*. Brazil was the largest producer of sugarcane in the world, the next five major producers, in decreasing amounts of production, were India, China, Thailand, Pakistan and Mexico.

All Sudan sugarcane schemes at Guneid, New Halfa, Sennar, Assalaya, Kenana and White Nile lie in the central clay plain. These soils have a number of limitations particularly crop nutrition; they are characterized by high clay content, low organic carbon, low in nitrogen and available phosphorous (*Ibrahim,1998*). Sugarcane is one of the most important crops in the Sudan, and plays a leading role in the local and foreign trade the annual sugar production of the Sudanese factories is estimated at 750,000 metric tons while consumption is estimated to range between 1.2 to 1.3 million metric tons. The gap is expected to be narrowed as the newly established White Nile Company starts achieving full production capacity of 450,000 tons sugar/annum *(Obeid,2013)*.

Sugarcane being a long duration, exhaustive crop removes considerably higher amount of plant nutrients from the soil. Hence it is essential to replenish the depleted soil with plant nutrients at desired levels. (*Jagtab, et al,2006)* reported that, proper fertilization include 4rs strategies; right source, right rate, right time and right place is an important management function in sugarcane production. In most countries, addition of fertilizers mainly nitrogen and phosphorus improves cane and sugar yield. Various types and forms of fertilizers are heavily used worldwide to improve sugarcane yields and to maintain soil fertility.

In Sudan sugarcane fields urea which carries only Nitrogen (N) and Triple Super Phosphate (TSP) as a source of P are the only fertilizers used as a common practice. High losses of N as volatilization of NH_3 and immobilization of P by fixation under Gezira type soil conditions is well documented (*Ali et al,2003*). The cause for lack of response was attributed to fixation of Phosphorus when added as TSP (*Babiker and Abdalla,1990*). (*Ali et al,2006*) suggest that P as monovolent phosphate ($H_2PO_4^-$) and Nitrogen as NH_4 will be effectively available to various crops. Di- ammonium phosphate (DAP) containing 46 % P_2O_5 and 18% N can be a suitable fertilizer satisfying the above condition.

The main objective of the study is to evaluate the effect of source and rate of nitrogen and phosphorous fertilizers on the growth, yield and quality of sugarcane.

CHAPTER TWO
LITERATURE REVIEW

2.1. General:

Sugarcane is a tall perennial plant growing erect even up to 5 or 6 meters and produces multiple stems composed of four principal parts, root system, stalk, leaves and inflorescence (*Moore,1987)*. Moreover, it is a C-4 perennial grass capable of storing large quantities of sucrose in parenchyma cells and is harvested several times before replanting (Rae et *al,2005).*Typically, a cropping cycle comprises one plant crop and 3-4 ratoon crops (*Keating et al,1999). (Gascho and Shih,1982)* reported that, from planting to its maturity sugarcane passes various phases of growth including germination, tillering, vegetative growth, cane formation and maturity.

2.2. Economic importance of sugarcane:

Sugarcane is a major source of sugar and as a source of basic raw material for various agro–based industries. Approximately 79% of the world sugar is produced from sugar cane, while sugar beet represented about 21% of the global sugar production (*Czarnikow,2016).*The crop is of immense economic importance for the prosperity of people, it provides income to the grower and employment for numerous farm and industrial workers throughout the year. Sugar crops offers production alternatives to food, such as livestock feed, fiber and energy, particularly bio fuels and/or co-generation of electricity. The main by-products of sugarcane industry are bagasse, molasses and filter cake. Besides, there are products of less importance, viz., cane trash and tops, wax and boiler ash. In most countries, some of the sucrose is fermented to produce ethanol (*Schubert,2006)*. In Cuba, it has been estimated that up to 31 products are produced from sugarcane; these include refined sugar, raw sugar, molasses, alcohol, rum, yeast, bagasse, syrups, dextran, crude wax, glucose, etc., (*Allen et al,1997)*.

2.3. Sugarcane climate:

Sugar cane is basically a crop of tropical climates, with yields affected significantly by temperature, relative humidity and solar radiation (*Humbert, 1968)*. Optimum temperature for germination of stem cuttings is 32° to 38°c and slows down below 25°.Temperatures above 38° reduce the rate of photosynthesis and increase respiration. For ripening, however, relatively low temperatures in the range of 12°-14° are desirable (Julien *et al,1989)*. Sugar recovery is highest when the weather is dry with low humidity; bright sunshine hours, cooler nights. Soil moisture is another critical factor in germination, relative humidity ranging between 55–85% at grand growth period favors stalk development (*SC,2012)*. According to (*Oliverio et al,2004)*, sugarcane plant is one of the most efficient converters of sunlight into chemical energy stored in sugars, fiber and straw. The optimal solar radiation requirement is 18–36 MJ/m^2, stalk growth increases when daylight is in the range of 10–14 hours. The ripening and harvesting season of six to nine months should be cool, with mean day temperatures between 10 and 20 °C, but frost free, dry and with high incident radiation (Fageria*, et al,2010*).

2.4. Sugarcane soil:

Sugarcane can be grown on various types of soils. It however, thrives best on well drained soils. Ideally sugarcane soils are deep, well drained, and well-structured sandy loam to clay loam with an adequate amount of organic matter (*Humbert,1968)*. The sugarcane grows and develops better on soils with a neutral reaction pH 6.5 to 7. Macronutrients tend to be less available in soils with low pH. (*Humbert,1968),* in his discussion of soil as a factor in sugarcane growth, gives much emphasis to soil physical properties which depend on a range of factors including parent materials, climate, drainage, age of soils, and the organic matter content in surface soil. In Sudan, all the sugarcane estates lie within the central clay plain. The soils of this plain are vertisols with moderate chemical fertility, i.e. high contents of smectitic clays, high pH values, low N and organic matter in general. Total N ranges from 0.03% to 0.04% (Idris*,2001)*.

2.5. Sugarcane cultural practices:

Regarding the cultural practices of sugarcane in Sudan, it can be said that sugarcane is usually planted in June and October. The crop of the June planting is harvested at an older age compared to that of October planting (16 to

18 months versus 14 months). Higher productivity of the cane and sugar depends on the interactive effects of genetic potential of the cultivars and proper crop husbandry practices including application of fertilizer at appropriate rate and time (*Gaffer et al,2010)*.

2.5.1. Land preparation:

Land preparation is one of the major costs in establishing a crop of sugarcane. Proper land preparation is very essential for good establishment and vigorous growth of the crop. In Sudan, land preparation for sugar cane planting includes successive operations with off-set disc harrow to provide ridge and furrow system for placement and covering of cane setts in the furrow. Tillage, used to control weeds, to incorporate fertilizers and to shape beds. As sugarcane crop stands in field for more than a year, stubbles uprooted by disc plough, then harrow is worked three to four times to break clods to make the land smooth, leveled and then furrowed. Furrows at required distance depending upon the spacing are then opened across the major slope; much of the world's sugarcane has been planted at 1.5 m spacing (*Mahalingam,1999).*

2.5.2. Sugarcane planting:

Sugarcane is generally propagated by cuttings of the stalk containing one or more buds. Cuttings are usually taken Cuttings are taken from carefully selected canes from the upper third of the stalk in plant cane 8–12 months old, three budded sets are reported to be the best for optimum germination (*Yadav,1990)*. Establishing an optimum plant population in any crop is vital for achieving maximum production. (*Cock,2003)* reported that, sugarcane requires 30000 to 40000 setts per hectar in order to maintain a desired millable stalk population target of 130,000/ha. Setts are usually 30-45 cm in length and are planted in long furrows 15-30 cm deep. After planting buds develop into primary and secondary stalks and form a dense homogenous tuft known as a stool, cuttings are carefully sorted in order to eliminate those that are misshapen or have a ready sprout then soaked for 20–30 minutes in a bath water at 52^0 C to which a fungicide has been added by way of disease control. Cuttings are taken from carefully selected canes (*Verma,2004)*.

2.5.3. Irrigation:

(*Iftkhar et al,2010)*, reported that water is essential at every stage of plant growth from seed germination to plant maturation. Efficient use of irrigation water is of vital importance, depending on climate, crop stage and soil moisture content. Water requirements of sugarcane range from 1500 to 2500 mm evenly distributed over the growing season (Doorknobs *and Kassam,1986)*. Studies of (Cavazza*, and Gammino,1996)* indicated that irrigation of seven to ten days in New Guinea produced the highest cane and sugar yields, although there were differences in yield from season to season. World-wide sugarcane is irrigated using three conventional irrigation methods viz: furrow, overhead and drip. Furrow irrigation system characterized with low cost, easy to operate during day time, measured quantity of water can be given at desired frequency and irrigation efficiency was 80 to 90% (*Soopramanien,1998)*. In Sudan, (*Abdel wahab,2005)* concluded that irrigation at 75% depletion decreases cane yield and yield components, whereas the best cane yield and yield components are attained under irrigation at 50% soil moisture depletion followed by 25% depletion.

2.5.4. Fertilization:

Continuous sugarcane production without balanced nutrient management depletes the soil nutrients and in the long run cause the loss of productivity of the soil. Fertilizer rates should be determined based on yield response and economic profitability (*IPNI,2012)*.The use of N and P fertilizers play a key role in development of cane and sugar yields, but imbalanced fertilizer use seems to be one of the factors responsible for the constantly low cane yield (*Milford, et al,2000)*. The common practice is to apply phosphorus to the plant crop at or soon after planting, while nitrogen, usually added after planting as full or split doses, (*Thorburn et al,2005)*. Broadcasting is the common application method generally used for large field areas; nutrient uptake varies considerably depending on the climate, cultivar and available nutrient status even at comparable yields (*Hunsigi,1993)*. (*Humbert,1968)* reported that nutrient uptake by sugarcane plant is most active during the first 6 months of crop age which is known as the boom stage of growth.

2.5.5. Harvesting and quality:

Cane should be harvested only when it is mature; general yellowish color of whole plant and brix% reading between 21% and 24%. It is a complex process that involves careful cutting and handling procedures to maintain high sugar content and cane quality and cane maturity is usually determined by monitoring sugar yield parameters. However, most researchers focus their evaluation on Pol % cane and its value ranged from 10.5-17.9 (Meade *and Chen,1977*). Dry off period 25 to 30 days prior to harvesting was required. Harvesting methods include the most primitive and the most modernized. Sugarcane is harvested either green or burnt. Burnt cane harvesting was introduced in Australia during the 1940's in response to labour shortages (*Christiansen,2000)*. Manual harvesting of sugarcane is done manually with the help of human labours, the field is first set on fire, and then fire burns dry leaves, and kills any lurking venomous snakes, without harming the stalks and roots. Proper harvesting should ensure ground level harvest so that the bottom sugar rich internodes are harvested which add to yield and sugar, de-topping at appropriate level so that the top immature internodes are eliminated and proper cleaning of the cane. In green cane harvesting, sugarcane is harvested without burning, and a thick leafy residue commonly called trash remains on the soil surface, (*Sandhu et al,2013)*. Now adays in many countries mechanical sugarcane harvester is used for sugarcane harvesting, it is fully automated. During harvest, the cane harvester drives along each row and cuts the cane stalk off at the bottom of the plant, the long stalk is then cut into many shorter lengths called 'billets' Moreover, it requires very less time for cutting sugarcane around large area. Many foreign company involved sugarcane manufacturing like john deer, new Holland (E. *Meyer,1999)*. Once sugarcane has been harvested, it must be transported to a sugar mill as soon as possible. The longer it takes, the more sugarcane juice stored in the stalks will evaporate - so it is important that it arrives within 16 hours of being cut, to minimize deterioration.

2.6. Nitrogen (N):

Nitrogen (N), is the most limiting nutrient required for food productivity worldwide and is an essential component of amino acids, nucleic acids, chlorophyll and other pigments and it also takes part in all enzymatic processes, important for high yields, it fuels crop growth and development, leading to strong tillering, (*Gillbert et al,2006)*. Moreover, it is absorbed by the plant roots in the form of ammonium (NH_4^+) and nitrate (NO_3^-) ions. N deficiency Symptoms appear first on older leaves due to the mobility of this element in the plant. The excess N delays maturation by stimulating new growth, including suckering (*Salter and Bonnett,2000)*.

(*Mengel and Kirkby,2000)* reported that, nitrogen recommendations are based on soil analysis and land systems.*(Franco, et al,2010)* reported that current sugarcane nitrogen (N) rate recommendations are based of crop age and soil type, the highest uptake of N occurs during the initial development stages, typically within 90 days of fertilization, before full development of the canopy. (*Srivastava et al,1992)* reported that, all mineral sources of N are considered to be equally effective and in most sugarcane industries the N source is selected on the basis of price per unit of N and convenience of application. In some situations, apparent advantages of products such as ammonium sulfate may be due to a correction of S deficiency (*Malavolta,1994)*. Both excess and lower Nitrogen supply have deleterious effects on cane and sugar yields such that N deficiency reduces cane yield which it excess levels delay maturity and reduces sugar accumulation (*Kakde,1985)*.

Generally, only about one third of the nitrogen applied as fertilizer to a crop of sugarcane is removed by the crop in the year of application. The rest of the nitrogen goes into the soil reserves or is lost by leaching of especially nitrate, de nitrification of nitrate through reduction to volatile nitrous and nitric oxide gases under water logging, and volatilization of ammonium to ammonia gas, other major losses of N from the production system are through the removal of harvested cane (*Keating et al,1993)*. (*Freney et al,2004)* reported that losses of N by volatilization ranged from 17-39 % for surface applied urea, compared to less than 1.8% for sulfate of ammonia.

2.6.1. Ammonium sulfate (AS):

Ammonium Sulphate (AS) {$(NH_4)_2SO_4$} 21% N, and 24% S is a chemical compound that is primarily used as a nitrogen fertilizer with other minor uses. It occurs in crystals with particle size that is variable, colored white to beige produced by two methods by-product and synthetic *(IPNI,2012)*. AS fertilizer was one of the first and most widely used nitrogen fertilizers for crop production. All of the nitrogen that is supplied by the ammonium sulfate fertilizer is in the positively-charged ammonic form (NH_4^+).The ammonium present in DAP is an excellent N source and will be gradually converted to nitrate by soil bacteria, resulting in a subsequent drop in pH. Moreover, both nitrogen and sulphur are immediately available to crops. AS has the least tendency to absorb atmospheric water, this characteristic favors longer storage and compared to urea, it is more resistant to ammonia volatilization (*Thorup,1984)*. Efforts in substitution of AS fertilizer as a source of nitrogen nutrient has been studied by several researchers using urea (*Muchovej and newman,2004)* Reported that, application of Ammonium sulphate, as fertilizer in sugarcane cultivation has been proven to be able to increase the sugarcane yields up to the optimum dose of 500–800 kg/ha. AS has a greater acidifying effect of soils than some other fertilizers. In general, N losses tend to be considerably lower from ammonium sulphate than that from urea therefore, other sources of fertilizes with less loss of N are being considered.

2.6.2. Urea:

Urea is the most common nitrogenous fertilizer widely used in the agricultural industry as an animal feed additive and fertilizer and relatively easiness to handle costs over other dry N forms. A dry material in granular or prilled form, it is estimated that more than half of all fertilizer used globally is in the form of urea (*Gillbert et al,2006)*. Urea is known as carb amide, is an organic compound of carbon, nitrogen, oxygen and hydrogen, with the formula $\{CO\ (NH_2)_2\}$. Urea with its relatively higher nitrogen content (46%), easy handling, safe storage and transportation is the main N–source used for sugarcane and other crops in Sudan, (*Mukhtar,2008)*. However, urea–N is subjected to high losses through hydrolysis and during transformation to nitrate.(*Havlin et al,1999)* reported that in calcareous and high pH soils if the applied urea is not covered, the ammonia gas will be lost by volatilization, even when quickly watered to wash urea into the soil, ammonia gas will volatilize during the drying process, this elucidates the importance of covering the applied urea.

2.6.3. Sugarcane response to Nitrogen (N):

In most soils, N fertilizers are added for better development and nourishment of crops to get high yields, but not more than 30% of the applied N is recovered by the sugarcane crop, (*Dharmawardene and Keerthipala,2005).*The difference between sources of nitrogen, are expected to have consequences on growth, yield and quality parameter that could affect sugar processing (*Mokadem,1998)*.The world recommended rates of Nitrogen fertilizer for sugarcane production vary between 45 and 300 kg N ha^{-1} yr^{-1} (*Srivastava and Suarez,1992)*. The current recommended Nitrogen rate for Florida sugarcane is 90 kg $ha^{-1}yr^{-1}$, but the rate was derived from research for sugarcane syrup production (*Kidder et al, 2002)*. In South Africa, the optimum Nitrogen rate for plant crop 50 to 150 kg N ha^{-1} yr^{-1} did not respond to any of the rates tested (*Inman-Bamber,1984)*. In most areas of Australia, current recommended rates for N fertilizer are 120 to 150 kg N ha^{-1} for the plant cane crop following a fallow period and 160 to 200 kg N ha^{-1} for successive plant cane crop and ratoon crops (*Husingi,1993)*.

(*Franco, et al,2010)* reported that N increases the quantity of green tops, yield component, and yield of cane and sugar. However, nitrogen application at rates exceeding sugarcane plant utilization has adverse effect on cane quality. (*Saravanan, et al*,2006) found that cane yield was increased with increasing N application rate. *(Verma,1999)* treated sugarcane with 0, 150, 225 and 300 kg N/ha and observed that cane yield was highest with 300 kg N/ha.

In Sudan, (*Ibrahim,1979)* reported that the response of plant cane to N fertilization was not remarkable, although the soils where experiments were conducted were very low in soil N. *(Yousef et al,2000*), have shown that nitrogen has significant influence on cane growth, yield, quality and recoverable sugar. (*Ali, 2003*) recommended the application of 357 kg urea ha^{-1} for the plant cane of cultivars Co 997 and Co 6806, under fallow land conditions of Kenana cane scheme. (*Osman,2007)* reported that cane yields recorded under 69, 92 and 115 kg urea/Fed were higher than the control although no significant differences were found between treatments from zero. Recently, (Elhag*, et al,2007)* recommended applying 69 kg N/fed (3N) instead of the current rate of 92 kg N/fed (4N).

2.7. Phosphorus (P):

Phosphorous, is essential to the formation of a vigorous and healthy root system, stimulates tillering, and influences favorable better growth and there by better yield and juice quality (*Bokhtail and Sakauri,2003).*Phosphorus main functions are: energy transportation and storage and maintenance of cell wall integrity. Phosphorus deficiency in soils severely restricts crop yields Tropical and subtropical soils are predominantly acidic and often extremely deficient in phosphorus (*IPNI,2012)*. Phosphorus is typically present in soils in combination with other elements. Moreover, it forms complex minerals inorganic and organic compound s with only a small amount present in the soil solution. Even in the fertilized soil, the available P was low, this phenomenon might be due to P-fixation in this soil which has an alkaline reaction a deficiency of P will slow overall plant growth, delay crop maturity and decreased cane and sugar yield .

Because P is mobile in the plant, deficiency usually occurs first in older tissues, distinct symptoms are not always obvious, the main effect of deficiency is retarded growth, older leaves may turn yellow and eventually die back from tips and along margins and phosphorus deficiencies in the sugarcane plant show poor ratooning ability with thin stalks and short inter nodes (*Husingi,1993)*. Plants take up phosphorus almost entirely as the phosphate anion (HPO_4^{-2}) or (H_2PO_4-).The relative amount of each ionic species in the soil solution depends on soil pH. Acid soils favor the ($H_2PO_4^-$) species, and alkaline soils favor presence of HPO_4^{-2}. Plants are able to absorb both species effectively (*IPNI,2012).* In most soils, phosphorus moves little because of the low amount dissolved in the soil solution. About 10 to 20% of applied P is utilized, much less than that of other nutrients likes N and K (*Oseni,1978*).

Crops need much more phosphorus than what is dissolved in the soil solution. Most phosphorus fertilizers on the market today have a water-soluble phosphorus content of 75 % or less. (*Bakker, et al,1999)* reported that, comparisons of sources of Phosphorous have not indicated consistent differences in performance with wheat. Generally, the higher the water solubility, the more effective the phosphorus source. Using the right phosphorus source improves management of tropical soil fertilization, highly soluble sources are more efficient in the short term but not for longer periods Hussain*, et al (2001).* Selection of a phosphorus fertilizer source can be confusing, as many products exist on the market, with each having unique characteristics that are touted by the manufacturer. The world phosphate fertilizer demand is expected to increase from a total of 41.7 million tons in 2011 to 45.0 million tons in 2015 at a growth rate of 1.9 % per year. Of the overall increase in demand for 3.3 million tons (P_2O_5), 55 % would be in Asia, 29 % in America, 8 % in Europe, 4 % each in Africa and Oceania (*FAO, 2012).*

2.7.1. Triple superphosphate (TSP):

{Ca (H_2PO_4)$_2$}, 46 % (P_2O_5) and 13 % Ca. TSP fertilizer is produced by treating Rock Phosphorus with phosphoric acid, was one of the first high analysis P fertilizers that became widely used in the 20th century. Triple Phosphorous Phosphate (TSP) 46% (P_2O_5) produced in about 10 countries. The largest producers and exporters are Chinese, Tunisian, Morocco, Bulgarian and Egyptian companies. The main consuming countries are Brazil, Bangladesh, Iran the USA and North West Europe (*FAO,2012*). As a low cost source of phosphorus, TSP is the main substitute for Single Superphosphate in cropping blends. The product is used mainly in blends with DAP and MOP. TSP is water soluble, so it becomes rapidly available for plant uptake. It is a source of phosphorus in situations where no nitrogen is required. It is an excellent P source, but its use has declined as other

P fertilizers have become more popular (*IPNI, 2012)*.The popularity of TSP has declined because the total nutrient content ($N+P_2O_5$) is lower than ammonium phosphate fertilizers such as Di-ammonium phosphate, which by comparison contains 18% N and 52% (P_2O_5). Costs of producing TSP can be higher than Di-ammonium phosphates, making the economics for TSP less favorable in some situations (*IPNI,2012)*.

2.7.2. Di- ammonium phosphate (DAP):

Di- ammonium phosphate (DAP) $\{(NH_4)_2HPO_4\}$, DAP 18% N and 46% (P_2O_5) is the most worldwide fertilizer. It is produced in around 20 countries and consumed in every developed agricultural market (*FAO, 2012*). It is made from two common constituents in the fertilizer industry–Nitrogen (N) and Phosphorus (P). Moreover, it is relatively high in nutrient content and its excellent physical properties make it a popular choice in farming and other industries. DAP are water soluble and highly soluble and thus dissolves quickly in soil to release plant-available phosphate and ammonium. The ammonium present in DAP is an excellent N source and will be gradually converted to nitrate by soil bacteria, resulting in a subsequent drop in pH. DAP releases free ammonium and nitrogen in the ammonium form resists leaching and is a slower release form of nitrogen. DAP fertilizer is an excellent source of Phosphorus (P) and Nitrogen (N) for plant nutrition. It is highly soluble and thus quickly dissolves in to the soil to release

Phosphorus and Nitrogen to plants. DAP can be applied to all soil types and field crops, grassland and in gardens and orchards. For the best effect, DAP should be applied prior to sowing mixed with soil at the depth of 20 cm under the ground. Nitrogen content in DAP supports the photosynthesis process and improves roots growth and development. Changes in the supply or price of any of these inputs will impact DAP prices and availability. The low cost of nitrogen in DAP makes it a cost effective source of nitrogen if Phosphorus is also required **(***IPNI,2012).*

Moreover, it is an excellent source of Phosphorus and nitrogen for plant nutrition. DAP is highly water soluble than TSP and thus dissolves quickly in soil to release plant-available phosphate and ammonium. DAP, has excellent handling and storage properties. A notable property of DAP is the alkaline pH that develops around the dissolving granule. Generally, the higher water solubility, the more effective the phosphorus source.

2.7.3. Sugarcane response to Phosphorus:

Phosphorus is applied only once every 5 to 6 years when plantations are renovated or when new fields are established. Application of P fertilizer promotes root growth, stimulates tillering, influences millable cane growth, and thereby sugarcane yield per ha (Pannu *et al,1985)*. Besides yield, adequate P nutrition is conducive for higher sugar accumulation in cane tissues. Although phosphorus does not exist as (P_2O_5) in fertilizer materials, phosphorus recommendations are made for rates of (P_2O_5). Application of Phosphorous fertilizer especially on p deficient soils promotes root growth, stimulates tillering, and influences favorably for better growth and their better sugarcane yield and juice quality (*Malie, et al,1982)*. Adequate Phosphorus concentrations increase sugar cane productivity and also improve quality of the juice and sugar (*Santos et al,2010)*. Phosphorus deficiency on sugarcane may result in reduced cane tonnage, but excessive phosphorus increases cane tonnage with a simultaneous decrease in sugar concentration (*Glaz et al,2000).* Higher P application increased both cane yield and stalk height. The varietals differences were reported for the requirement of P fertilizer in sugarcane (*Sreewarome et al,2005).* It has been estimated that a sugarcane crop of 100 tons /ha would remove about 50–53 kg of (P_2O_5) from soil (*Yaduvanshi and Yadav,1990)*.The over use of Phosphorus fertilizer does not increase crop productivity substantially as only a certain percentage of applied fertilizer can be consumed by the crops, depending on the soil type, Phosphorus fixing rates and other factors (*Keating,1993). (Kumar and Verma,1999)* observed that application of 50 kg (P_2O_5/ha) and above increased cane yield significantly over the control.

In Sudan, Fertilization of cane fields was geared towards using nitrogen fertilizers and phosphorous to small extent, very meager research work was assigned for the response of cane to added phosphorus and potassium fertilizers

(*El-tilib, et al,2004)*. (*Mohammed,1993)* reported that a significant response of cultivar Co527 to P when added in combination with 4N at Guneid Cane Research Station Farm at the rate of 54.7 kg (P_2O_5/ha) but there was no significant response beyond this rate. (*ELTahir,1991)* reported there was no significant effect of (P_2O_5) on the two varieties Co 6806 and Co 527 when treated with P fertilizer at the rate of 54.7 kg (P_2O_5/ha) in Sennar. (*Elnasikh,2001)* testing 64.5 and 59.3 kg (P_2O_5 ha) did not observe any significant effect on Co 6806 and Co 527 yields at Sennar. (*Abouna,2007)* reported that since there was no significant difference in cane performance between the tested phosphate rate of 54.7 kg (P_2O_5/ha) and that of the normal P rate of 109.4 kg (P_2O_5/ha) the study recommends the 54.7 (P_2O_5 /ha) for the plant cane for the Sudanese Sugar Company Estates Farms.

CHAPTER THREE
MATERIALS AND METHODS

3.1. Experimental site:

The experiments were carried out within Guneid Sugarcane Research Farm (latitude 14° 52′, N and longitude 33° 19′ E) during seasons 2015/2016 and 2016/2017 as plant cane crop. The main objective of the study is to evaluate the effect of different sources, rates of nitrogen and phosphorus fertilizers on the yield and quality of sugarcane. The climate is tropical aridic. (*Idris,1990)* described these soils as clayey (52–55 %), smectitic alluvium with suitability subclass S_2v, bulk density 1.7 g cm^{-3}, % N 0.03, % O.C 0.4, available P (mg/ kg soil) 0.9–3, exchangeable K (cmol/ kg soil) 0.6 and CEC 58–61.

3.2. Materials:

3.2.1. Variety tested:

The variety tested in the study was Co 6806.

3.2.2. Fertilizers applied:

Triple super phosphate (TSP) with urea and Di-Ammonium phosphate (DAP) with Ammonium sulphate (AS) in different optimum rates.

3.3. Methods:

3.3.1. Experimental design: The experiment was laid out according to a Randomized Complete Block Design (RCBD) having four replications; 28

subplots and the size of the plot was 6 ridges x 10-meter-long x 1.5-meter row width =93 m^2.

3.3.2. Treatments:

T1:238 kg TSP/ha + 129 Kg N/ha as urea (3 N) as control*

T2:100 kg DAP/ha (46 kgP_2O_5+18 kg N) +111 kg N/ha as AS(3N).

T3:100 kg DAP/ha (46 kgP_2O_5+18 kg N) +154 kg N/ha as AS(4N).

T4:150 kg DAP/ha (69 kgP_2O_5+27 kg N) +102 kg N/ha as AS(3N).

T5:150 kg DAP/ha (69 kgP_2O_5+27 kg N) +145 kg N/ha as AS (4N).

T6:200 kg DAP/ha (92 kgP_2O_5+36 kg N) + 93 kg N/ha as AS (3N).

T7:200 kg DAP/ha (92 kgP_2O_5+36 kgN) +136 kg N/ha as AS(4N).

* *The recommended sugarcane fertilizing practice in (SSCF).*

3.4. Cultural practices:

Agronomic cultural practices used in the study, according to the standard manual adopted in the Sudanese Sugar Company Farms (SSCF).

3.4.1. land preparation:

land preparation for sugarcane which was carried for all experiments included deep ploughing, harrowing, leveling and furrowing at distance of 1.5 m.

3.4.2. planting materials:

A field experiment was planted with cane variety Co 6806 at July for two seasons (2015/2016 and 2016/2017). Good cane setts 14 cm in length which contain 3 to 4 buds selected from 8-10 months age. To control cane from smut disease and ratoon stunting diseases (RSD) cane setts treated with hot water at 52° C for 2 hours. The cane seed rate range from 3.4 to 4 tons per feddan. The planting method was single over lab.

3.4.3. Irrigation:

Furrow irrigation system was applied in all the Sudanese Sugar Company Farms. Irrigation interval was within the recommended range of 10-12 days according to the environmental conditions during the season of the crop.

3.4.4. Fertilizing:

broadcasting was the common application method generally used for large field areas. Phosphorus fertilizers usually applied with land preparation or at cane planting and nitrogenous fertilizers applied two months after planting.

3.4.5. Weed control:

Due to non- availability of labours for hand weeding, chemical weed control is now coming popular. Chemical herbicides useful to control weed; (Ametryino + Atrazinco) 1.6 Liter per feddan applied before the 2^{nd} irrigation. Hilling up process done after 3-4 months for getting better suppression of late tillers, pruning of non-functional roots, weed control and avoid lodging. After hilling up, cane planted in furrow will come in ridges.

3.4.6. Harvesting:

Cane should be harvested only when it is mature. Dry off period range from 25 to 30 days before harvest required to increase sugar concentration and facilitate mechanical harvesting process. Manual harvesting plant cane harvested at the age of 14-16 months was done with sharp cane cutting and very closed to the ground.

3.5. Data collected:

3.5.1. Plant height and plant diameter:

plant height and plant diameter (cm) were determined by the average height and diameter of the samples were measured from 10 millable stalks for every experiment unit.

3.5.2. Plant population:

plant population of two inner rows were counted of each subplot was counted to calculate the number of stalks per hectare according to formula:

$$\text{No. of stalks/ ha} = \frac{\text{millable stalks of 10 m x 2 rows x10,000 m}^2}{\text{plot area (m}^2\text{)}}$$

3.5.3. Cane yield:

At harvest, for the two experiments the two inner rows were manually cut by cane knives, topped, cleaned from dead leaves and trash, weighed and the cane yield was calculated according to the equation:

$$\text{Cane yield (ton/ ha)} = \frac{\text{millable stalks wt. of 10m (kg) x (2 rows) x10000 m}^2}{\text{1000 x plot area (m}^2\text{)}}$$

3.5.4. Cane quality:

At harvest, for each experimental unit, 10 stalks from the inner two rows were randomly taken and their weight was added to the corresponding final yield of that experimental unit. From these 10 stalks quality of the cane was determined according to *ICUMSA,(1994)*. 10 stalks from every experiment unit crushed in the mill to produce cane juice, then some juice put in digital Refractometer to measure Brix% juice. 50 ml from juice treated with 3 gram lead acetate and filtered and put into 200 ml tube in Saccharimeter device to measure pol reading. From standard table find out pol% juice. The following measurements were taken:

Total soluble solids (Brix% cane) = Brix% juice x {100 – (Fiber% cane +3}.

Sucrose content (Pol% cane) = Pol% juice x (100 - Fiber% cane + 5).

Estimated recoverable Sugar (ERS%) = Pol% juice x 0.75-3.

Sugar yield (TS/ha) = ERS (%) x yield of cane (TC /ha).

To determine Fiber % cane 100 gram cane sample from every experiment unit area taken and put in Jeffco device for 10 mintues to clan sugar in the sample, the fresh sample put in the oven over night and then fiber% cane was calculated according to the equation:

$$\text{Fiber\% cane} = \frac{\text{Dry weight sample x 100}}{\text{Fresh weight sample}}$$

3.6. Statistical analysis:

Data collected was analyzed statistically through SAS statistical software volume,1997. ANOVA and the least significant difference (LSD) test were employed to compare the significance between treatment means.

CHAPTER FOUR

RESULTS

4.1. Effect of source and rate of N and P fertilizers on growth and cane yield:

Table (1): Effect on plant height (cm) and plant diameter (cm)

Treatments	plant height (cm)		plant diameter (cm)	
	1st season	2nd season	1st season	2nd season
T1	261.6b	243.4b	2.4a	2.2b
T2	293.4a	260.9ab	2.4a	2.3ab
T 3	305.9ab	274.8a	2.2b	2.3ab
T4	286.8ab	249.8b	2.3ab	2.3ab
T5	288.6ab	251.1b	2.3ab	2.4a
T6	295.9ab	262.8ab	2.3ab	2.2b
T7	299.2ab	263.0ab	2.3ab	2.3ab
Mean	*290.2*	*258.0*	*2.3*	*2.3*
CV%	*9.0*	*5.4*	*4.3*	*3.9*
LSD ($P \leq 0.05$)	*38.9*	*20.7*	*0.15*	*0.13*

4.1.1: Effect on plant height (cm) and plant diameter (cm):

Data presented in Table (1) showed that a significant differences between treatments at ($p \leq 0.05$) level for plant height and plant diameter (cm). The highest and the lowest plant height 305.9- 274.8 and 244.1-246.8 (cm) values were recorded with the application of T3 and T1 (control) in the two seasons respectively. The highest and lowest Plant diameter values 2.4–2.4 and 2.2-2.2 (cm) were recorded with the application of T1, T2 and T5 and T3, T6 respectively.

Table (2): Effect on plant population (thousand/ha) and cane yield(ton/ha)

Treatments	plant population (thousand/ha)		cane yield (ton/ha)	
	1st season	2nd season	1st season	2nd season
T1	140.8a	140.9a	131.9b	139.1c
T2	148.5a	152.0a	160.9a	164.1a
T 3	145.3a	145.3a	141.5ab	153.2ab
T4	149.8a	151.2a	153.6ab	149.4ab
T5	144.3a	153.6a	152.6ab	149.5ab
T6	151.5a	143.6a	143.2ab	146.3bc
T7	146.5a	137.6a	147.6ab	152.3ab
Mean	*146.7*	*147.0*	*146.5*	*150.6*
CV%	*6.6*	*7.6*	*12.7*	*4.3*
LSD ($P \leq 0.05$)	*17.3*	*16.5*	*26.4*	*9.7*

4.1.2. Effect on plant Population (thousand/ha) and cane yield (ton/ha)

Data presented in Table (2) showed that, there were some differences between treatments for plant population (thousand/ha) but not significant the highest and the lowest plant population values 148.5–152.0 and 140.8–140.9 was recorded with the application of T2 and the control T1 in the two seasons respectively. According to cane yield (ton/ha) the results presented in Table (2) showed that there were a significant differences between treatments at ($p \leq 0.05$) level for cane yield (ton/ha). The highest and lowest cane yield 160.9-164.1 and 131.9-139.1(tons/ha) were recorded with the application of T2 and the control T1 in the two seasons respectively. All treatments in the study contain DAP and AS fertilizers; T3, T4, T5, T6 and T7 recorded cane yield (ton/ha) higher than the control T1.

4.2: Effect of source and rate of N and P fertilizers on cane Quality:

Table (3): Effect on POL% cane and ERS% cane

Treatments	POL % cane		ERS % cane	
	1st season	2nd season	1st season	2nd season
T1	13.7[abc]	12.7[ab]	11.2[ab]	9.7[ab]
T2	14.2[ab]	12.7[ab]	10.6[ab]	9.7[ab]
T 3	14.5[a]	12.6[ab]	11.1[a]	9.6[ab]
T4	13.0[c]	13.0[ab]	9.4[c]	9.8[ab]
T5	13.8[abc]	13.2[a]	10.3[abc]	10.2[a]
T6	13.5[bc]	12.4[b]	10.1[bc]	9.4[b]
T7	14.1 [ab]	12.5[b]	10.5[ab]	9.5[b]
Mean	*14.0*	*12.7*	*10.5*	*9.7*
CV%	*4.4*	*3.4*	*6.0*	*4.1*
LSD (P≤0.05)	*0.9*	*0.6*	*0.8*	*0.6*

4.2.1: Effect fertilizers on Pol% cane and ERS% cane:

Data presented in Table (3) showed that there were a least significant differences (LSD) between treatments for Pol % cane and ERS% cane in the two seasons of the study. The highest Pol% cane values 14.5% and 13.2 % were recorded with the application of T1 and T5 while the lowest Pol % cane values 13.0 and 12.4 (%) were recorded with the application of T4 and T6 in the two seasons of the study respectively. The highest ERS% cane values 11.2%, 11.1%, and 10.2 %, were recorded with the application of T1, T3 and T5 and the minimum ERS % cane value 9.4% were recorded with the application of T4 and T6 in the two seasons of the study respectively.

Table (4): Effect on fiber % cane and sugar yield (ton/ha)

Treatments	Fiber % cane		Sugar yield (ton/ha)	
	1st season	2nd season	1st season	2nd season
T1	15.1[a]	15.6[a]	13.5[b]	13.5[b]
T2	15.3[a]	16.5[a]	17.3[a]	15.9[a]
T 3	15.2[a]	16.2[a]	14.9[ab]	14.7[ab]
T4	15.5[a]	15.3[a]	14.6[ab]	14.3[ab]
T5	15.3[a]	16.7[a]	15.8[ab]	15.2[ab]
T6	16.1[a]	16.4[a]	14.5[ab]	13.7[b]
T7	15.0[a]	15.6[a]	15.3[ab]	14.4[ab]
Mean	*15.3*	*16.0*	*15.3*	*14.5*
CV%	*5.29*	*10.9*	*13.3*	*5.7*
LSD (P≤0.05)	*1.2*	*2.6*	*2.9*	*1.2*

4.2.2: Effect fertilizers on Fiber % cane and sugar yield (ton/ha):

Data presented in table (4) showed that there was some differences between treatments for fiber% cane but not significant for two seasons of the study. the highest fiber % cane values 16.1% and 16.7% were recorded with the application of T6, T5 and the minimum fiber % cane values 15.1% and 15.3% were recorded with the application of T1 and T4 in the two seasons of the study, respectively. According to sugar yield results presented in Table (4) showed that there was a least significant differences between treatments for two seasons of the study. The highest sugar yield values 17.3-15.9 (tons/ha), was recorded with the application of T2 followed by the other treatments more than T1 (control) which gave the minimum sugar yield values 13.5-13.5 (ton/ha) in the two seasons of the study respectively.

CHAPTER FIVE

DISCUSSION

5.1:Effect of source and rate of Nitrogen and Phosphorus fertilizers on growth and cane yield:

Among the yield influencing characters, sugarcane plant height is a major attribute of growth and yield. From results presented in table (1) for plant height and plant diameter. These results similar to that of (*Ayub et al., 1999*) who reported that plant height and plant diameter increased with the application of proper rates of NPK. Also the results agree to that of (*Abbasi, 2005*) who observed that greater cane length under chemical sources of fertilizers in sugarcane. From results obtained, there were a significant differences between treatments but in irregular trend because plant diameter had considerable association with plant height and both were influenced by the source and rate in a parallel way. According to plant population and cane yield parameters presented in table (2), these results agree to that of (*Abbasi, 2005*) who observed that sources fertilizers with optimum rates has better performance for sugarcane tillering and final plant population and cane yield. The results obtained for cane yield (ton/ha) in the study may be achieved due to high losses of N by volatilization of urea, which agree to (*Fereny,2004*), who reported that N losses ranged from 17-39 % for surface applied urea, compared to less than 1.8 % for sulfate of ammonia, and might be due to P-fixation in this soil which has an alkaline reaction a deficiency of P will slow overall plant growth, delay crop maturity and decreased cane and sugar yield Cane yield result values achieved in the study agree to (*Milford, et al,2000)* who reported that he use of balance N and P fertilizers play a key role in growth and cane yield. Also these results similar to that of (*Chaudhry and Chatta,2000*) whom noticed that maximum stripped cane yield of 71.1 ton/ha was reported when phosphorous was applied at the rate of 100 kg (P_2O_5/ha) and 200 kg N/ha. In Sudan, the finding results from this study, similar to that of (*Abouna,2007*),who recommended to apply the economical P optimum rate 54.7 (P_2O_5 /ha) for the plant cane.

5.2. Effect of source and rate of N and P fertilizers on cane quality:

For juice quality parameters results values presented in table (3) and table (4), It was observed that for Pol% cane and ERS% cane there were quite changed as was in the case of other growth and cane yield contributing characters. These results agree to (*Yousef* et al*., 2000*) who reported that N and P fertilizers had significant influence on cane growth, yield, quality and recoverable sugar. The results achieved for cane quality parameters also agree to that of (*Jagtab, et al,2006)* who reported that, In most countries, addition of fertilizers mainly nitrogen and phosphorus improves stalk length, stalk diameter, cane and sugar yield. The results recorded above agree to that of (*Santos et al,2010*)*,* who reported that adequate phosphorus concentrations increase sugar cane productivity and also improve quality of the juice and sugar.

According to fiber % cane, the result values recorded presented in table (4) was not significantly affected by treatments of the study considered normal for sugarcane variety Co 6806 which range from 15 to 17% fiber% cane. Sugar yield (ton/ha) which represent the important quality parameter followed a similar trend as the cane yield recorded significant differences between treatments in the study. The results achieved for sugar yield agree to that of (*Mokadem,1998)*, who reported that the difference between sources of N and P are expected to have consequences on growth, yield and quality parameter that could affect sugar yield. Also the results values agree to that of (*Bokhtiar, et al,2008*) who reported that in general the effect of phosphate and nitrogen fertilization on cane quality yield parameters are less affected, this can be explained by the influence of other yield factors, making the evaluation of fertilizers effects on those parameters difficult therefore it might be related to genetic material.

CHAPTER SIX
CONCLUSION AND RECOMMENDATION

6.1. Conclusion:

- Based on the findings of the study, Cane and sugar yields significantly increased by application of T2: (100 kg/ha Di-ammonium phosphate (46kg P_2O_5+18 kg N)+111 kg N/ha as Ammonium Sulphate (3N) which constantly gave highest average cane yield 162.5 (ton/ha), highest average sugar yield 16.6 (ton/ha) compared to T1(control): (238 kg/ha Triple super phosphate +129 kg N/ha as urea (control) 3N which constantly gave lowest average cane yield 135.5 (ton/ha).
- All treatments in the study which contain di-ammonium phosphate (DAP) in combination with ammonium sulphate (AS) fertilizers recorded higher cane and sugar yield (ton/ha) than T1 (control).
- There were no significant differences between (DAP) rates; 100, 150 and 200 (kg/ha) treatments in cane and sugar yield (ton/ha) in the two seasons of the study.

6.2. Recommendation:

According to the results achieved, 100 kg Di- ammonium Phosphate (46 kg P_2O_5+18 kg N)/ha applied at planting and 111 kg N/ha Ammonium sulphate applied at two months after planting sugarcane could be recommended for an optimum sugarcane yield.

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APPENDICES

Appendix 1. Main soil properties of the experimental site:

Soil characteristic		
Nature of parent material origin	Clayey smectitic alluvium	
Current land Suitability subclass	S2 v	
Clay	%	52 – 55
Silt: clay	Ratio	0.55
Moisture (PW)	%	15
Saturation (SP)	%	90
Hydrolic conductivity	Cm hr^{-1}	0.6 – 0.7
Water holding capacity	Cm	7 – 8
Bulk Density	G cm^{-3}	1.6 – 1.7
pH	Paste	8.10
Organic Matter	%	0.3 – 0.4
Nitrogen	%	0.03-0.04
C/N	Ratio	10.75
Available P	ppm	0.9 – 3.0
Mobile K	Meq/100 g.g.	2.14
Exchangeable K	Meq/100 g.g.	0.6 – 0.9
Exchangeable Na	Meq/100 g.g.	10.73
CEC	Cmol (+) kg^{-1}.s	58
Ece	mSm^{-1}	2 – 3
ESP		18.5

Sources: (*Blockhuis, W.A 1993*); and (*Idris, M.A.1990*) .

Appendix 2. Climatic conditions (2015-2016):

Year 2015:

Months	LIGHT w/m²	WIND S. m/s	WIND D. deg.	RAIN F. mm	RH %	Temp
January	163.0	1.0	54.0	0.0	60.0	29.8
February	177.0	1.0	98.0	0.0	52.0	34.4
March	186.0	1.0	74.0	0.0	45.0	38.2
April	164.0	1.0	112.0	0.0	48.0	40.8
May	213.0	1.0	158.0	11.28	54.0	32.7
June	252.0	1.0	161.0	16.48	57.0	32.6
July	268.0	2.0	188.0	85.1	87.0	30.9
August	248.0	2.0	181.0	106.5	92.0	28.5
September	246.0	1.0	190.0	83.9	95.0	28.9
October	258.0	1.0	185.0	15.8	90.0	29.1
November	270.0	1.0	144.0	0.0	83.0	25.5
December	251.0	1.0	108.0	0.0	84.0	21.5

Year 2016:

Months	LIGHT w/m²	WIND S. m/s	WIND D. deg.	RAIN F. mm	RH %	Temp
January	250.0	1.3	36.0	0.0	50.0	22.7
February	282.0	1.5	35.0	0.0	49.0	26.5
March	313.0	1.6	36.0	0.0	36.0	27.1
April	336.0	1.1	43.0	0.0	31.0	30.6
May	305.0	1.2	120.0	32.7	45.0	33.3
June	284.0	2.0	201.0	109.7	67.0	32.0
July	309.6	1.3	174.0	73.6	78.3	32.5
August	243.4	1.6	154.6	73.9	96.7	27.8
September	313.4	1.5	167.5	3.9	94.2	29.7
October	288.6	1.3	168.6	0.0	91.5	29.0
November	267.1	1.3	162.5	0.0	87.6	28.9
December	256.7	1.3	158.4	0.0	86.2	27.9

Source: Guneid Sugarcane Research Center Farm (GSRCF)

Appendix 3. Analysis of Variance:

Appendix 3.1. Analysis of Variance of the first season (2015/2016):

Analysis of Variance for plant height (cm):

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	3737.9085	1245.9695		
Treat	6	4806.4942	801.0823	1.17	0.3653
Error	18	12333.6314	685.2017		
Total	27	20878.0342			

Analysis of Variance for plant thickness (cm):

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	0.18607	0.1860		
Treat	6	0.0923	0.0153	1.53	0.2251
Error	18	0.1811	0.0100		
Total	27	0.4595			

Analysis of Variance for for Pol % cane

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	7.1625	2.3875		
Treat	6	5.9653	0.9942	3.02	0.0321
Error	18	5.9341	0.32967		
Total	27	19.0620			

Analysis of Variance for for ERS % cane

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	5.5426	1.8475		
Treat	6	6.6851	1.1141	3.48	0.0184
Error	18	5.7669	0.3203		
Total	27	17.9948			

Analysis of Variance for Fiber % cane

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	6.3571	2.11905		
Treat	6	3.4386	0.57310	0.87	0.5363
Error	18	11.8729	0.65960		
Total	27	21.6686			

Analysis of Variance for Plant population (thousand/ha):

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	1603259769.8214	534419923.2738		
Treat	6	312486339.2142	52081056.53570	0.38	0.8805
Error	18	2449777057.9285	136098725.4404		
Total	27	4365523166.9642			

Analysis of Variance for cane yield (tons/ha)

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	2129.8949	709.9649		
Treat	6	2128.1080	354.6846	1.12	0.3885
Error	18	5687.8752	315.9930		
Total	27	9945.8782			

Analysis of Variance for sugar yield (tons/ha)

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	32.4665	10.8221		
Treat	6	24.2726	4.0454	1.05	0.4275
Error	18	69.4266	3.8570		
Total	27	126.1658			

Appendix 3.2. Analysis of Variance of the second season (2016/2017)

Analysis of Variance for plant height (cm):

Source of Variance	D.F	SS	MS	F. cal	Pr > F
Reps	3	610.1701	203.3900		
Treat	6	2656.0417	442.6736	2.28	0.0822
Error	18	3498.6870	194.3715		
Total	27	6764.8989			

Analysis of Variance for plant thickness (cm)

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	0.0851	0.0283		
Treat	6	0.1150	0.0191	2.38	0.0715
Error	18	0.1447	0.0080		
Total	27	0.3449			

Analysis of Variance for Pol % cane

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	0.3200	0.1066		
Treat	6	2.0648	0.3441	1.87	0.1410
Error	18	3.3064	0.1836		
Total	27	5.6914			

Analysis of Variance for ERS % cane

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	0.6485	0.2161		
Treat	6	1.6493	0.2748	1.79	0.1576
Error	18	2.7620	0.1534		
Total	27	5.0598			

Analysis of Variance for Fiber % cane

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	50.4272	16.8089		
Treat	6	6.4414	1.07352	0.35	0.8995
Error	18	54.8963	3.0498		
Total	27	111.764			

Analysis of Variance for Plant population (thousand/ha)

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	615319266.392	205106422.130		
Treat	6	888965961.357	148160993.559	1.20	0.3492
Error	18	2216711946.357	123150663.686		
Total	27	3720997174.107			

Analysis of Variance for cane yield (tons/ha)

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	491.7464	163.9154		
Treat	6	1376.7215	229.4535	5.41	0.0024
Error	18	763.0002	42.3889		
Total	27	2631.4682			

Analysis of Variance for sugar yield (tons/ha)

Source of Variance	D.F	SS	MS	F. Cal	Pr > F
Reps	3	7.1515	2.3838		
Treat	6	17.2427	2.8737	4.14	0.0088
Error	18	12.5068	0.6948		
Total	27	36.9012			