APPROPRIATE HARVESTING STAGE OF SWEET-STEM SORGHUM (*Sorghum bicolor* (L) Moench*)* CULTIVAR FOR OPTIMUM BIO-ETHANOL PRODUCTION IN NAMIBIA

A THESIS SUBMITTED IN FULFILMENT OF REQUIREMENTS FOR THE DEGREE

OF

MASTER OF SCIENCE IN AGRICULTURE IN THE DEPARTMENT OF CROP SCIENCE

OF

FACULTY OF AGRICULTURE AND NATURAL RESOURCES

UNIVERSITY OF NAMIBIA

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NOVEMBER 2017

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APPROVAL PAGE

This research has been examined and is approved as meeting the required standards for the fulfilment of the requirements of the degree of Master of Science in Crop Science.

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DECLARATION

I, Sylvester Okon Asuquo, hereby declare that this thesis titled 'Appropriate harvesting stage of sweet stem sorghum *(Sorghum bicolor (*L*)* Moench) cultivar for optimum bio-ethanol production in Namibia' has been written by me and that it is the record of my own research work. This work or part thereof has not been submitted for a degree in any other institution of higher learning.

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DEDICATION

This work is dedicated to the loving and ever green memory of late Professor Luke Kanyomeka, former Deputy Dean, Faculty of Agriculture and Natural Resources, University of Namibia: Ogongo Campus, who was my initial supervisor but passed on to Eternal Glory before the completion of this study. May his soul rest in peace. Amen. I am also dedicating this work to my late parents: Mr Lawrence Asuquo Edet and Mrs Theresa Umo Asuquo Edet for the sacrifices they made to lay the foundation for all my educational achievements; My loving wife: Mrs Ekanem Sylvester Asuquo; my Brother: Francis Asuquo Edet; my sons: Nta and Francis; my daughters: Umo, Ekpa, Attai, Grace, Kristofina-Helena, and Lawrencia-Eunike for the joy and motivation to work harder I received from them.

ACKNOWLEDGEMENTS

First, I give thanks to our Almighty God who has granted me this opportunity to be admitted for this programme and the strength He gave to enable me complete this study. I acknowledge the constructive criticisms and useful inputs of my main supervisor, Professor Percy M. Chimwamurombe and Co - supervisor, Professor Levi Shadeya-M. Akundabweni, in all aspects of this research work. They willingly shared their in-depth knowledge of the topic with me as well as formatting the document according to requirements of University of Namibia (UNAM). I would not have been able to accomplish this task without their invaluable dexterity, encouragement, assistance, understanding, politeness and diplomacy.

The following persons and institutions are also acknowledged for their supports and assistance:

Late Professor Luke Kanyomeka: my pioneer supervisor who laid the foundation for this research, Dr. Cousins Gwanama: former Head of Department of Crop Science, UNAM: Ogongo Campus who built on it after the demise of Professor Kanyomeka; Dr. James Abah of UNAM: Katima Mulilo Campus; Dr. Adedamola Shobo of UNAM: Hifikepunye Pohamba Campus; Elder Anietie Idio of the University of Uyo, Nigeria; Dr. David Inyang of the University of Calabar, Nigeria and Dr. Ebong Akpabio, an Independent Health and Development Consultant in Namibia for the useful suggestions they offered whenever I encountered problems with this research. Mr. Kudakwashe Hove of UNAM: Ogongo Campus is also appreciated for his assistance in the analysis of data generated for this study.

Professor Fisseha Itanna: the current Head of Department of Crop Science, Ogongo Campus; Professor Mohammed Bello of UNAM: Neudam Campus, who is also the Faculty of Agriculture and Natural Resources Postgraduate Studies Head of Department.

Dr.Sacky M. Iipinge, the Assistant Pro- Vice Chancellor of UNAM: Hifikepunye Pohamba Campus; Dr. Shiwana Naukushu, the Head of Department of Mathematics, Science and Sport

Education and Mr. Moses Hidengwa, the Head of Department of Curriculum, Instruction and Assessment Studies: Faculty of Education, UNAM are appreciated for their awesome motivations and moral support. Without them the success of this work could have been a mirage.

The efforts of Dr. Helena Miranda: UNAM Deputy Director, Academic Affairs and Research is highly appreciated for spending long hours editing the language to make sure it is grammatically correct. Messrs Sacky Namusheshe and Jeffrey Naukaku are acknowledged for assisting me in field activities, juice extractions and taking of pictures. The author also greatly acknowledged the benevolence of Crop Science Department UNAM: Ogongo Campus laboratory and Chemistry laboratory of UNAM: Hifikepunye Pohamba Campus staff members for providing ideal analytical environment for the successful brix sugar percentages determinations during the study. My good friends Messrs Abed Nangombe, Severeni Ashili, Erastus Namakumbu, Obert Sanyambe, Gibson Munene and Walter Hangula are also appreciated for their suggestions that have greatly enhanced this thesis.

To all authors whose works I have consulted and all people who have contributed in various ways to make this thesis possible I say a big thank you. Last but not the least, my greatest debt of gratitude goes to my family, especially my wife Ekanem and children for their love, support, inspiration and patience. I do not have enough words to thank you except to pray that Almighty God should show His Mercy unto you all. Amen.

ABSTRACT

There has been growing global concern over dwindling fossil fuel supply. This development has led to increased interest in exploration of alternative energy sources, especially bio-fuel. Sweet sorghum (*Sorghum bicolor*), sugar cane *(Saccharum officinarum*), corn (*Zea mays)*, wheat (*Triticum aestivum*), rape seed (*Brassica napus*), barley (*Hordeum vulgare*), sugar beet (*Beta vulgaris*), cassava (*Manihot esculenta*), oil palm (*Elaies guineensis*), sweet potato (*Ipomoea batatas*) and many more have been recognized as feedstock crops for bio-fuel production. Like most bio-fuel crops, sweet stem sorghum has the potential to reduce carbon emissions. In addition, this crop shows stronger tolerance than other crops under hot and dry climatic conditions. Its bagasse can be exploited as a by-product including burning, material for electricity generation, paper or fibre board manufacturing, silage for animal feed or juice for ethanol production.

While there is abundant availability of sweet stem sorghum in Namibia, its potential as feedstock crop for bio-fuel has not been fully explored.

One of the major problems associated with sorghum as a feedstock crop for bio-fuel is the issue of knowing the right harvesting stage for optimum brix sugar yield. In Namibia, great potentials exist for the development of the energy sector through adoption of bio-fuel production. Therefore, this study aimed at ascertaining appropriate harvesting stage of sweet-stem sorghum (*Sorghum bicolor* (L) Moench) cultivar for optimum brix sugar yield for bio-ethanol production in Namibia.

Two trials (February to June 2014) and (October 2014 to February 2015) were conducted in the demonstration plot of the University of Namibia (UNAM), Hifikepunye Pohamba Campus. A total of six harvesting stages (booting stage, and one after every week for five weeks) were used to determine the following response variables: plant height, stem diameter, stem biomass, percentage juice extract, and percentage brix sugar. Data obtained were analyzed using SPSS statistical software and inferences were made at p = 0.05.

Mean plant height at 50 % booting was 74.9 cm in trial I and 73.7 cm in trial II with respective coefficients of variation of 20.3 and 21.0. The t-test analysis for plant height was not significant (f = 22.5, p = 0.05). Mean stem weight was 71g in trial 1 (dry season) and 65g in trial 2 (raining season). Mean brix value of the extracted juice was 9.8 % in trial I and 11.8 % in trial II, with coefficients of variation of 5.0 % and 14.5 % respectively. The brix value increases significantly until it peaked at 5 weeks after booting. The study confirms that sweet stem sorghum IS 2331 cultivar could be grown in both dry and wet seasons in the study area. They could be harvested for optimum brix sugar yield for bio-ethanol production at five weeks after booting. Therefore, the study recommends that the Namibian government should raise awareness among crop farmers of the potential of growing sweet stem sorghum in both dry and wet seasons. Future studies should determine the brix sugar yield beyond 5 weeks after booting until possible grain harvest stage.

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ACRONYMS

ANOVA	Analysis of Variance
BS	Base saturation
CV	Coefficient of variation
df	Degrees of freedom
ECEC	Effective cation exchange capacity
F	Variance ratio (F-value) in analysis of variance
GHG	Green House Gases
HBS	Harvesting at initial booting stage
LSD	Least significant difference
MASL	Metres above sea level
MS	Mean square
NPK	Nitrogen, Phosphorus and Potassium
RCBD	Randomised complete block design
SS	Sum of squares
TEB	Total exchangeable bases
UNAM	University of Namibia
WAE	Weeks after emergence
WB	Weeks after booting

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Technological development and the subsequent increase in standards of living have placed great pressure on global energy demands. Conventional energy sources which are mainly fossil fuels (petroleum oil, gas, coal and wood) are fast being depleted and soon will be exhausted as they are non-renewable (Kitani *et al*, 1999). Therefore, a substitute should be found. Bioenergy as an alternative to fossil fuel, and also as a CO_2 neutral source of energy has seen a rapid growth in recent years. Pradipta *et al*., (2011) are of the opinion that the development of modern bio-energy sector through adoption of bio-fuel for energy production is an important step in supplying ecologically friendly energy and reducing carbon dioxide emission. This applies particularly to Europe and the USA; the farmer as an energy producer – '*Landwirt als Energiewirt*' - is the new slogan in the German – speaking agricultural press (Wilcke, 2007). But bioenergy also has a great potential for developing countries. It helps them achieve independence from expensive oil imports. Wilcke (2007) further observed that USA used almost all of the maize destined for exports to produce ethanol in 2006. Indeed, this is more than food for thought.

Frisby and Schuminacher (2002) recalled that the two serious world economic depressions in the recent past have been traced to shortage of petroleum products. The first was in 1974, when oil-rich Middle East countries placed embargo on crude oil supply to developed nations. The second was in 1991, during the Persian Gulf War. They further noted that in both cases, operations of many industries and establishments were grounded. Hence, after these crises, many developed nations embarked on serious alternative and renewable energy programs.

A lot has been achieved in solar energy development, wind and hydro power. However, solar energy conversion has low efficiency. Another problem is that solar energy, wind and hydro power, are not of direct-use energy types (cannot be stored and transported), unlike petroleum fuel which can be stored and transported for use when and where needed. Consequently, more efforts were placed on the development and utilization of bio-fuel (Frisby and Schuminacher, 2002). There are many crops available for producing energy.

Hence Xuan *et al.,* (2015) reported that ethanol can be produced from various crops such as sweet sorghum (*S. bicolor*), sugar cane (*Saccharum officinarum*), sugar beet (*Beta vulgaris*), maize *(Zea mays*) and wheat (*Triticum aestivum*), rape seed (*Brassi canapus*), barley (*Hordeum vulgare*), cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), oil palm (*Elaies guineesis*).

These researchers are of opinion that even though there are many raw material sources that can be used to produce alcohol, sweet sorghum is one of the best alternatives for the following reasons: high biomass yield, high content of fermentable sugar in the stalks, wide adaptability, resistance to diseases, pests, drought, saline- alkaline conditions and water logging. They further claimed that 6106 liters /ha of alcohol could be produced from sweet sorghum which is much higher than for other crops such as yam 1700 liters / ha , sugarcane 4700 liters / ha and maize 1883 liters /ha.

Namibia faces the challenge of energy supply similar to other countries in the sub-continent. Namibia gets its energy supply mainly from imported petroleum products, coal and hydropower generation. Rising oil prices, national security concerns, and depressed farm incomes have many and varied deleterious effects on Namibia’s development. In general terms, over dependency on imported fossil fuels retards the growth of the economy, accentuates import bills, and dislocates incomes from Namibian farmers to oil workers in already affluent countries. The country is however, a major supplier of uranium to developed countries but it lacks the capacity to use uranium for energy generation locally.

In Namibia, great potentials exist for the development of the energy sector through the adoption of bio–fuel production since this will offer independence from expensive oil imports. Meeser (2008) noted that any grain crop (maize, sorghum, wheat and other similar grains) is suitable for Namibian soil and climatic conditions. In the views of Stehn (2009) there is abundant availability of sorghum and it is used as a staple grain food crop in Namibia. Stehn (2009) further noted that sorghum grains are rich in starch while the stems of some cultivars are rich in simple sugars.

Nghithila (2003) reported that in foreseeing the improvements renewable energy will make in the Namibian energy sector, government included bio-fuel production in its intervention program in the energy sector. As a step towards actualization of that objective, the Omahenene Research station and the University of Namibia were mandated to advise government on the use of grain crop to implement the bio-fuel production proposal. The collaborative work between the two institutions evaluated eight sorghum cultivars for adaptability to the Namibian environment, determined maximum grain yields and sugar content in the stem extract of the cultivars. The work confirmed high affinity of sweet stem sorghum to the Namibian environment, and a high brix sugar yield by the sweet stem sorghum variety, among others. However, the work did not give information on total sorghum stem sugar yields per hectare (Dr. Gwanama, personal communication). In order to have maximum quantities of bio-ethanol per hectare, high sugar yielding sorghum cultivars are required.

Literature is however replete with evidence of the fact that silage and sweet stem varieties of sorghum are harvested at the end of the milky or the beginning of the waxy ripeness, when the stems contain the largest amounts of sugar (Bencini, 1991; Ustimenko – Bakumovsky, 1983; Anthony, 1982). Sugar content in sorghum is known (Ustimenko – Bakumovsky, 1983; Anthony, 1982) to vary in accumulation, beginning soon after anthesis and reaching a peak within the grain-filling period, followed by a gradual reduction before grain maturity and harvest.

Within this wide window of over a month, neither the exact peak sugar content period nor brix sugar yield per hectare of sweet stem sorghum has been documented in Namibia. This study therefore aimed at determining the appropriate harvesting stage of sweet stem sorghum for maximum sugar yield per hectare for bio-ethanol production in Namibia. Specifically, the study aimed at: identifying the growth stage at which sugar yield per hectare is highest in sweet stem sorghum cultivar *IS 2331* in Namibia to harvest for sugar extract needed for bio-fuel production; establishing the exact peak sugar accumulation period per hectare in the stem of sweet stem sorghum cultivar *IS 2331* in Namibia, and determining the variations in stem sugar yield per hectare within the growing season of sweet stem sorghum cultivar *IS 2331* in Namibia.

It is expected that the results of this work will provide the necessary empirical evidence to stimulate further research that may assist the Namibian government to make positive policy recommendations for production of bio-ethanol for local use and even for export.

Much of the land of Namibia is semi-arid to arid and sweet stem sorghum, which is drought tolerant, is one of the few crops that have acceptable yields in this country. Therefore, large hectares of sweet-stem sorghum can be raised for commercial production of bio-ethanol. Hence creating employment and supporting the Namibian Government in the realization of its Vision 2030, a blue print towards fulfilling the needs for national self-esteem and self-actualization (GRN, 2004).

1.2 Statement of the Problem

Namibia is one of the non–oil producing nations. It has been overburdened by high cost of imported petroleum products and high carbon emissions resulting from utilization of imported fossil fuels (Nghithila, 2003). In order to alleviate the energy crisis, affected nations such as Brazil, Zimbabwe and Mauritius are producing and utilizing bio–fuel (Demibras, 2005). Bio–fuel is produced from hydrolysis of starch or sugar and many of the affected countries are making use of different cereal crops which are known for high sugar yielding ability for bio-fuel production (Clashausen, 2007).

Namibia is rich in sweet stem sorghum (Meeser, 2008; Stehn, 2009), one of the cereal crops whose stem is rich in simple sugars and its grain rich in starch. This has led Namibia to desire to join its counterparts in the western and other parts of the world to produce and utilize bio–fuel as a cost reduction strategy and for self–dependency in energy generation. In order to actualize this objective, initial corroborative work between the Omahenene Research Station and the University of Namibia on the mandate of the Government of the Republic of Namibia evaluated eight sorghum cultivars for adaptation to the Namibian environment. It also determined grain yield and sugar content in the stem extract but no information was given on total sorghum stem sugar yields per hectare.

The determination of total sorghum stem sugar yields per hectare is necessary because high brix sugar content does not necessarily translate into a high hectare sugar yield which maximum bio- ethanol production will be totally dependent upon. Furthermore, large expanse of semi–arid to arid land which supports growth of sweet–stem sorghum exists, from which only the stem of the cultivar can be used to produce bio-ethanol, while the grain continues to be reserved for human consumption.

It should be noted that almost all studies on sweet stem sorghum crop being carried out in Namibia are for the purpose of utilizing it as a food crop. Unfortunately, no studies have been carried out to optimize production of sorghum for energy production purposes. This is an indication that a sustainable farming practice that will ensure continuous supply of quality sweet stem sorghum for the production of bio–ethanol will also have to be evolved.

Inspired by the relationship between high sugar yield per hectare and maximum quantity of bio – ethanol that will be produced, this study investigated the critical period during which sugar content is highest, in essence determining best time to harvest the sweet–stem sorghum to get maximum sugar yield in the stems per hectare for production of bio–ethanol in Namibia.

1.3 Research Questions

The main research question that this research was set out to answer was "What is the best time to harvest sweet stem sorghum cultivar to get maximum sugar yields per hectare in Namibia?"

The research also sought to answer other auxiliary questions such as:

(1) What have been the variations in stem sugar yields per hectare within the growing season of sweet stem sorghum cultivar in Namibia?

(2) What is the exact peak sugar accumulation period per hectare in the stem of sweet stem sorghum cultivar in the study area?

(3) What is the growth stage at which stem sugar yield per hectare is maximum in sweet stem sorghum cultivar in Namibia?

1.4 Objectives of the study

1.4.1 General Objective

The general objective of this study was to determine the appropriate harvesting stage of sweet stem sorghum for maximum sugar yield per hectare for bio-ethanol production in Namibia.

1.4.2 Specific Objectives

The specific objectives of this study were to:

1. Identify the growth stage at which sugar yield is highest in sweet stem sorghum cultivar *IS 2331* in Namibia to harvest for sugar extraction needed for bio-fuel production.
2. Establish the peak period in which sugar accumulation in the stem of sweet stem sorghum cultivar *IS 2331* is highest.
3. Determine the variations in stem sugar yield between the growing seasons of sweet stem sorghum cultivar *IS 2331* in Namibia.

1.5 Hypotheses

The following null hypotheses were tested in the study:

Ho1. There is no significant difference in stem sugar concentrations in sweet stem sorghum cultivar *IS 2331* at any time of harvest during the reproductive stage.

Ho2. There is no significant difference in the stem sugar yield of sweet stem sorghum cultivar *IS 2331* between the harvesting season.

1.6 Significance of the Study

The findings from this study provide baseline data on best time to harvest sweet stem sorghum to get maximum stem sugar yield per hectare in Ongwediva, Oshana Region, Namibia, for the Namibian agricultural and energy sector players. The findings will stimulate further research on the subject at other areas of Namibia to generate sufficient data on per hectare sugar yield of sweet stem sorghum. It could stimulate interest and research on the conversion / utilization of sweet stem sorghum for bio-ethanol production in Namibia. Replicating the findings from this research would assist energy sector players including bio-fuel technologists, producers and industries, researchers, marketers of bio-fuel products, crop farmers, fertilizer blending industries, agricultural development agencies, government agricultural extension services delivery and rural development agencies and non–governmental and faith based extension organizations as well as environmental development experts and agencies and other interested persons to invest on energy generation, distribution and utilization cycle in Namibia.

The finding will also be useful to the agricultural sector players who include policymakers, bio-fuel technologists, researchers and crop farmers in either the consolidation or improvement of the sector's formulated development policy framework on sweet stem sorghum production or in promulgating new ones. Namibia's grain crops sub-sector development policy framework is currently based on a number of options, prominent among which is the production of sweet stem sorghum for grains used as staple food in the country. There is also the promotion of the use of the husks or dry stalk as forage or hay for the animals to boost meat and milk production. Finding of this study will therefore be useful for consideration of a possible diversification to optimize the use of sweet stem sorghum by using the stem sugar for bio-ethanol production in the country.

The result will add phenological knowledge of sweet stem sorghum to the existing body of knowledge on sweet stem sorghum production in Namibia and this will facilitate further research in related fields for diversification of the economy. The finding will be useful to researchers as a guide to their exploitation of sugar resource–based crops for bioenergy production as sugar hydrolysis have been confirmed to have bio–ethanol yielding function and this can provide an alternative to fossil fuel products.

Given the high oil and gas prices, bio-fuel offers sorghum farmers relative high added values for their crops. Findings from this research will serve as empirical evidence to propel increase in domestic production of sweet stem sorghum by farmers in Namibia.

Agricultural development programmes can use the findings of this study in implementation of their mandate to serve as a two way link between government, research, manufacturers and the farming community. They will also publish and distribute extension guides, leaflets, posters and bulletins to publicise this initiative to farmers. The empirical information provided by this work could provide a good message to be incorporated for dissemination through those media.

With increasing concern about global climate change, energy production from biomass is experiencing a renaissance. Replicating the findings of this research will help Namibia go into bio energy production which provides a clean source of energy.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Origin and Distribution of Sweet Stem Sorghum

The sweet stem sorghum has been regarded as a multi-purpose crop, yielding food in the form of grains, fuel in the form of ethanol from its stem juice, and animal feed in the form of fodder from its leaves and grain (Nimbkar & Rajvanshi, 2003). Some authors simply called sweet stem sorghum as "sweet sorghum" and regard it as a viable energy crop for alcohol fuel production (Irvine, 1979; Yu, *et al.*, 2012). In this study, sweet stem sorghum is regarded as a multi-purpose energy crop that can be cultivated for simultaneous production of bio-fuel and grain foods.

Given its tremendous amount of morphological variability, there seem to be a disagreement over the origin of sorghum (in general). There is a wide consensus among agronomists and other agriculturists (Murty and Renard, 2001; Reddy, 2012; Kelly, 2013) that the most possible area of initial sweet sorghum domestication was the savanna, between Western Ethiopia and Eastern Chad. According to these researchers, the most likely progenitor of cultivated sweet sorghum was the widely distributed complex of wild and weedy races of sorghum bicolor sp: *verticiliflorum* that extends across the African savanna. Murty and Renard (2001) further maintained that there are some archaeological evidences which suggest that early domestication of sweet stem sorghum might have occurred 5000 years ago or even earlier.

Vavilov (2013) placed the origin of sweet sorghum in the northeast Africa, while Dogget (1970) placed its origin in the Indo – Malaysian area. Eastin (1983) noted that there was evidence of sorghum in Abyssinia (Ethiopia) and Assyria (Turkey, Syria, Iran) by 700BC and in India and Europe by First AD. De Wet *et al.*, (1970) suggested a diverse origin of domesticated sorghum, with *S. verticilliflorum* as the possible progenitor.

According to Irvine (1979) and Ustimenko-Bakumovsky (1983), sweet stem sorghum originated in Equatorial Africa.

Reddy (2012) traced the origins of *S. Almum, S. gambicum, S. notabile, S. membranaceum* and *S.durra* to Australia. These varieties of sweet sorghum are excellent for their sweet stem and fodder. Murty and Renard (2001) noted that soon after the initial domestication, sorghum spread to west and east Africa. It is wide spread throughout the inter-tropical zone and its cultivation now extends well into the temperate regions. Sweet stem sorghum is said to have further spread from Ethiopia to the Near East and then to India and China by way of the ancient silk routes probably around the beginning of the Christian era. Thereafter, it was introduced into USA from Africa in 1857 (Irvine, 1979; Murty and Renard, 2001; Reddy, 2012).

The species of the subseries *Guineensia* Sn. are annual; they are spread in the South–West of Africa (*S. margaritiferum* St., *S. guineense* St., *S. mellitum* Sn.) and in the South–East of Africa (*S. conspicuum* Sn.). They have different vegetation periods which last from 3 to 7 months. Most widely cultivated is *S. guineense* St. which is a tall (3 meters) high branching plant (with as many as 40 runners). The grain is of high palatability (Irvine, 1979; Anthony, 1982).

The subseries Bicoloria Sn. (*S. dochna* Sn., *S. bicolor* M., *S. technicum* Sn., *S. elegans* Sn.) is represented by annual, filmy forms grown for its sweet stems, fodder and for making brooms and brushes (Anaso, 1985).

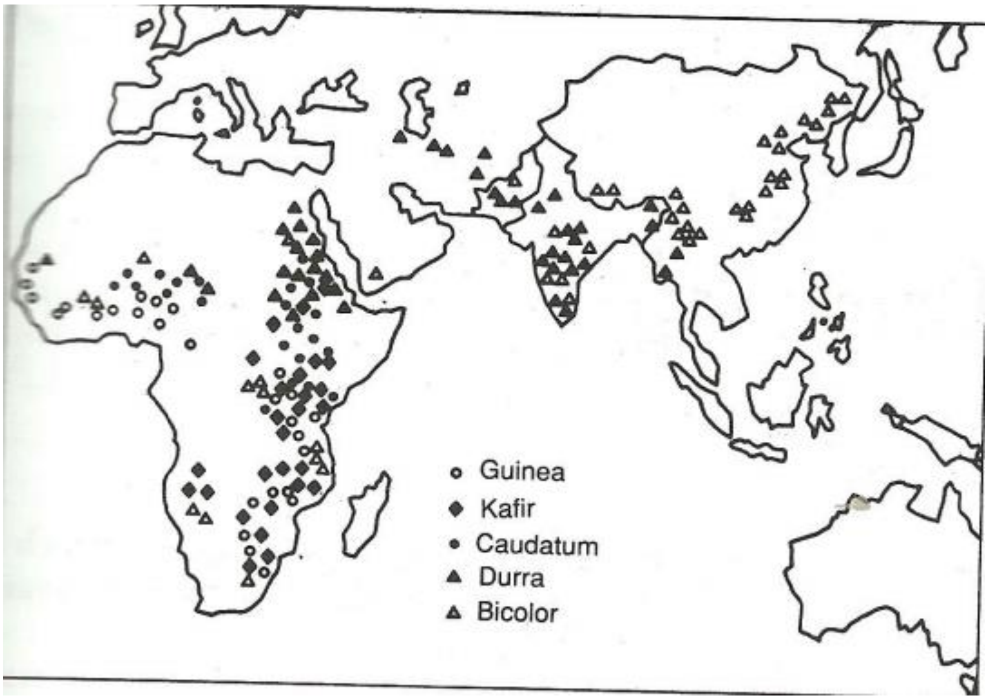
From the subseries Caffra comprising *S. caffrorum* B., *S. nigricans* Sn., and *S. caudatum* St., *S. caffrorum* B. is the most frequently sown (South Africa). The caffras are common in southern central (Bantu) Africa; the Caudatums in Central Sudan and the nigricans in West Africa (Harlan and De Wet, 1972). The caffras are highly resistant to droughts and their uses are extremely diverse (as grain, as fodder, for sweet stem, etc). Some of its populations (Kafir) are very important for heterosis selection and they vegetate between 4 and 6 months. *S. nigricans* Sn. vegetates 3.5 – 4.5 months; and it is mainly raised in Equatorial Africa for the production of sugar substances. *S. caudatum* St. is grown in Central Africa both as a fodder and a food grain plant. The population *feterita* of this species is widely employed in selecting fodder varieties of high yielding quality (Aba *et al*., 2004).

The subseries Durra includes *S. durra* Sn. and *S. cernuum, S. cernuum* is chiefly spread in the subtropical zone on all the continents of the world. These plants are tall or short stature, have a compact tassel, the vegetation period lasts 3 – 6 months, the grain is bare, and the tassel is erect or curved (Murty and Renard, 2001).

Sweet stem sorghums are grown in small amounts in West Africa but in USA they are grown in larger quantities for their sweet stems and for fodder (Irvine, 1979).

Chantereau and Nicou (2006) reported that the main crop areas under sweet stem sorghums are concentrated in the countries of a hot dry climate. In recent years, the world crop area (43 million hectares) and average yield of sorghum (1,100 – 1,200 kilograms per hectare) have not changed much. It is most widespread in Africa (30% of world crop area) and Asia (42%), but the yields on these continents are not high (600 – 700 kilograms per hectare).

The largest growers of sweet stem sorghum in Africa are Nigeria (6 million hectares), Sudan (2.5 million hectares). India is the world's largest producer with (16 million hectares). Although sorghum is not as widely sown in America (11 million hectares), the yields on this continent are higher (2,500 kilograms per hectare in South America and 3,200 kilograms in North America). Generally, sweet stem sorghum fields are concentrated in the USA (6 million hectares), Argentina (2.6 million hectares) and Mexico (1.2 million hectares) (Irvine, 1971; Idem and Showemimo, 2004).

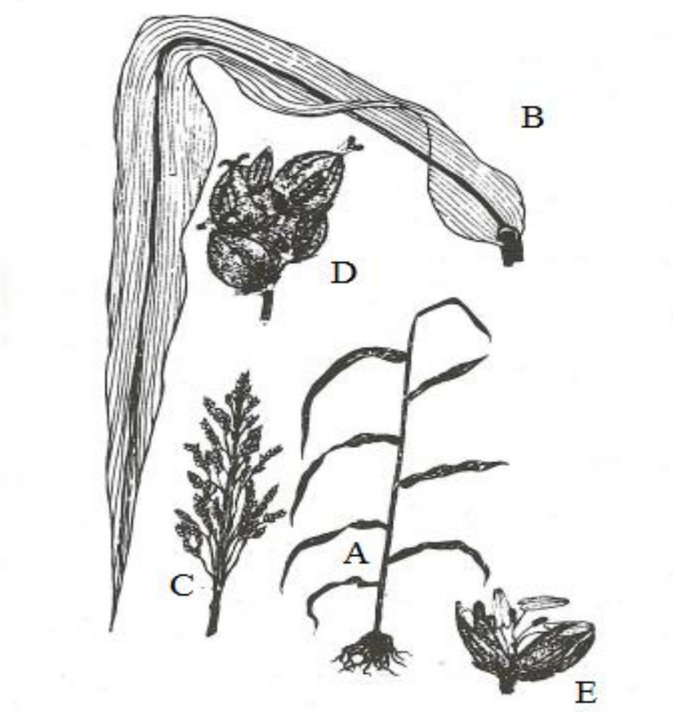


Adapted from Chantereau and (2006)

Figure 1. Distribution of the five main cultivated varieties of sorghum.

(a)

(b)



A   Young plant (main stem)

B   Leaf

C   Panicle

D   Terminal portion of the panicle

E   Flower

Adapted from Chantereau and Nicou (2006)

Figure 2. (a) Morphology of sweet stem sorghum

(b) Plant parts.

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2.2 Botanical Characteristics of Sweet Stem Sorghum

Sweet sorghum has many desirable characteristics such as wide adaptability, tolerance to abiotic stresses like drought, salinity and alkalinity as well as the capacity to grow quickly and also to accumulate sugar in stalks. The main essence of sweet stem sorghum is not for its seeds, but for its stalk, which contains high sugar content, hence the name sweet stem sorghum (Almodares *et al.*, 2008). It belongs to a group of sorghum (*Sorghum bicolor* (L.) Moench.) (Owen, 2009). All these desirable agronomic and biochemical characteristics of sweet sorghum make it an alternative feedstock for fuel-grade ethanol production. However, sweet sorghum might not be tolerant to excessive and prolonged flooding; they may be damaged by water logging as experience of 2010 in Namibia revealed (Dr. Gwanama, personal communication).

According to Rutto *et al*., (2013), sweet stem sorghum when compared to other types of sorghum, produces less grain but has a large amount of easily fermentable sugars in the stem. It produces 23% more fermentable carbohydrates and requires 37% less nitrogen fertilizer and 17% less irrigation water than maize. It has a short cycle growth of about four months making it suitable for double cropping and dual purpose cropping for both stem sugar and grain starch. It is widely adaptable to different environments.

Irvine (1979) noted that some sweet sorghum varieties tiller profusely and produce two crops in one season, the second crop consisting mainly of tiller shoots; and that the grains of these varieties are not usually eaten but the stems are very sweet and are chewed like sugar cane.

Murty and Renard (2001) gave a more precise description of sweet stem sorghum plant: sweet sorghums have a single, erect and solid stem supported by a strong adventitious root system developing from the lowest nodes. The adventitious roots have numerous fine rootlets that can extract soil moisture to a depth of 1.5m and make sorghum adapted to dry regions. Stems of sorghum can be pithy or juicy: the juice can be sweet or insipid.

Sweet sorghum is a C_4 plant and has an efficient growth rate (> 18 to 22 g/m^2 per day), exceeded only by Napier grass *(Pennisetum purpureum schumach)*.

The culm or stem is 0.5 -5.0 cm in diameter and 0.5 – 5.0 m in height; it exhibits a series of nodes and internodes. The leaves are 30 – 135 cm long and 1.5 – 13 cm wide; their number varies from 7 to 30. Sweet Sorghum is known to be a short-day plant i.e. long nights (dark period) are required for floral initiation and each cultivar needs a specific critical period of darkness for floral bud formation.

The uppermost internode bears the inflorescence, which is the panicle. The morphological characteristics of sweet sorghum panicles differ widely among cultivars. The peduncle may be erect or pendent. The panicle may be compact or loosely packed, conical or oval to semi-lax and lax depending on the length of the central axis (rachis) and its branches and the number of spikelets per branch. The spikelets normally occur in pair: a spikelet with pedicel containing a male or sterile flower and a sessile spikelet with a hermaphroditic flower exhibiting three functional stamens and a pistil. The number of sessile spikelets per panicle varies from a few hundred to a few thousand. The glumes of the spikelet vary in colour from black, brown, sienna to cream. The length of the glumes and their persistence also varies among cultivars.

Sweet Sorghum is pollinated by wind and is classified as a predominantly self-pollinated crop. The extent of cross-pollination varies from 2 to 10%. Depending on the cultivar, flowering of an inflorescent can take from 4 to 9 days.

Sweet Sorghum grains attain maximum weight in 25 to 50 days after blooming. They are highly variable in colour, size and shape. Grain colour is generally due to pericarp colour, which may be white, cream, lemon yellow, red or brown. The shape of the grains is spherical, oval, ellipsoidal, pear-shaped or plano-convex. Thousand-grain weight varies from 7.5 to 75.0 g. Cultivars belonging to the durra race generally exhibit heavy grains while some guinea types produce the smallest grains.

The seed consists of three parts: pericarp, endosperm and embryo. The pericarp is either thick or thin and affects the luster of the grain. The endosperm is white or yellow. The peripheral endosperm is hard and vitreous while the central part is floury and soft. In some sorghum grains there is a highly pigmented layer (called testator subcoat) just beneath the pericarp. The testa contains polyphenolic compounds called tannins. They make the grain testa bitter and the flour grey or pink in color.

A cyanogenic glycoside called dhurrin occurs in most sweet sorghum varieties; it is toxic because it produces HCN when hydrolyzed. However, it is localized in young shoots and tillers and is absent after flowering. Most sweet sorghum cultivars in Africa mature in 100 to 210 days with a harvest index < 0.25 (ratio grain/straw). Seed dormancy is not common in sweet sorghum and when occurring, rarely exceeds a few weeks.

2.3 Phenological Phases of Sweet Stem Sorghum

According to Hornby (2008), phenology is defined as the study of the pattern of events in nature, especially in the weather and in the behavior of plants and animals.

Phenological phase is simply biomass production and partitioning pattern in crops (Trouslot, 1982; Njoku *et al.*, 1984; Orkwor and Ekanayake, 1998).

These researchers went further to observe that sweet stem sorghum exhibits sigmoidal growth pattern common to most annual plants. A period of slow growth during establishment, followed by a phase of rapid exponential growth as the stem reaches maximum height and finally, growth rates decline. Specifically, Ustimenko-Bakumovsky (1983) distinguished ontogenesis of sweet sorghum for the following phases: germination, the formation of the 3rd leaf, tillering, tasseling, blossoming and ripeness (milky, waxy, complete ripeness).

In many varieties and hybrids of sweet sorghum, the seeds after harvesting remain dormant for 1 – 3 months. Unripe caryopses of sweet sorghum have a lengthy dormancy period and it takes them very long to germinate. The duration of germination phase is typically between 3 and 9 days but can be protracted if conditions are unfavorable. Dormancy ends when grains germinate and the growing shoot(s) emerged (Ustimenko-Bakumovsky, 1983).

In the temperate zone, sweet sorghum gives sprouts on the 6th – 7th day and in the tropics – on the 3rd – 4th day after sowing. At this phase the plant is not fully capable of photosynthesizing and has no well-developed leaves so the growing stem is partially dependent on the mobilization of stored food reserved in the grain (Orkwor and Ekanayake, 1998).

Sweet stem sorghum begins tillering about 1.5 – 3 weeks after sowing which lasts from one to two months. On the average, as many as 4 – 5 runners develop on each plant. In some varieties of sweet stem sorghum, the vegetative period lasts up to seven months and they develop as many as forty runners within this period. During this time the growth of sorghum is retarded, and its rows become heavily weeded.

Depending on the cultivation techniques, the sweet sorghum begins tasseling in 6 – 12 weeks after tillering and tasseling lasts from 2 to 6 weeks (Idem and Showemimo, 2004). It commences blossoming on the 3rd – 4th day after tasseling. The first to blossom are the bisexual flowers of the upper part of the panicle, and 4 – 5 days later the male flowers follow them. Sweet stem sorghum is a cross – pollinating plant (Ustimenko-Bakumovsky, 1983).

2.4 Production Requirements of Sweet Stem Sorghum

With regards to temperature, the minimum temperature for good growth of most varieties of sweet sorghum is 16 - 18 ^{o}C; for germination it is 11 - 12 ^{o}C.

If the temperature is raised to 14 ^{o}C, germination increases by 22 - 30% and if raised to 21 ^{o}C it increases by 55 - 60% (Irvine, 1979; Aba *et al*., 2004).

Sweet stem sorghum is very sensitive to early frosts, which may affect the length of the vegetation period. Only very few of its varieties withstand short-time frosts of -0, -1 ^{o}C in early age (the first 3 weeks of life) (Ustimenko-Bakumovsky, 1983). The optimum temperature for normal growth of sweet stem sorghum is 33 – 34 ^{o}C (Orkwor and Ekanayake, 1998; Ustimenko-Bakumovsky, 1983; Aba *et al*., 2004).

In terms of moisture requirement, sweet stem sorghum is one of the most drought-resistant plants; it is called "the camel" of the world's crops. This name of the plant may be attributed to its great capacity to form grain yields at low moisture availability and at high temperatures. And, indeed, grain sorghum is frequently grown in those regions of the world where rainfall is scarce or its distribution is uneven throughout the entire cropping season.

To produce one kilogram of dry matter, sweet stem sorghum consumes 291 litres of water, while under the same conditions maize uses 336 litres. Average sweet stem sorghum yields in areas with annual rainfalls of about 325 millimeters may be increased if the rainfall is distributed in the following way: 25 millimeters from sowing until sprouting, 250 millimeters during the growth stage, and up to 50 millimeters during the grain formation stage . At the same time, when raised in arid regions, sweet stem sorghum highly responds to irrigation.

The drought-resistance of sweet stem sorghum is largely due to its specific root system. The primary roots in this crop and in maize practically spread equally wide in area. But a sweet sorghum plant has twice as many secondary roots as a maize plant of the same age (Ustimenko-Bakumovsky, 1983).

Reddy (2012) has found out that 100 centimetres of moistened soil layer during sorghum sowing produced satisfactory yields of these crops. If the soil was moistened to 100-150 centimetres, the yields were good; more than 150 centimetres-they were high. If the soil is deeply wetted (up to 2 metres) during the sowing of sweet stem sorghum and there is no additional rainfall during vegetation, the sweet stem sorghum will give the same yields as during regular irrigation.

Furthermore, Reddy (2012) confirms that sweet stem sorghum consumes water more economically than other plants. If before blossoming, sweet stem sorghum plants face severe droughts, they remain in a latent state for a long time. The generative organs do not die, but as soon as the situation changes for the better, they regain vigour and continue their development. The leaves during droughts begin twisting along the central vein, thus reducing considerably the surface of transpiration. The sweet stem sorghum plant spreads its roots horizontally to 1 meter and vertically down to 1.8 metres, so that they utilize water from the 90-centimetre soil layer. The highest horizontal absorptive capacity of roots was observed at a distance about 38 centimetres away from the plant (the sowing scheme was 100x12.5centimetres).

Idem and Showemo (2004) and Ajayi, *et al.*, (1998) noted that sweet stem sorghum is a short –day plant (the optimum day lasts 10 hours). However, the photoperiodic reaction of sorghum depends on the genetic type. The species (subspecies or groups or varieties) growing far from the equator does not respond as much to shorter photoperiod as those growing in the equatorial latitudes (Idem and Showemimo, 2004).

In reaction to photoperiod, sweet sorghum is classified into three groups: (1) photosensitive group or species (varieties, population): examples include *mailo, hegari, kalo, durra, fete,* and *rita*, (2) neutral forms: example black kafir, white kafir, and (3) intermediate group with forms of low photoperiodic response.

In all regions of cultivation, sweet stem sorghum has no special soil requirements. It responds best to fertile, well-drained structural soils, of medium-texture and neutral composition. But it develops well on soils unfit for other cultures, i.e. on salinized and alkaline soils with a pH of 8-9 (Ustimenko-Bakumovsky, (1983).

Its requirement of basic macro elements (Nitrogen, Phosphorus and Potassium (NPK)) depends on the purpose of its cultivation and on moisture availability. Of all other elements, nitrogen is consumed most. To form 1000 kilograms of grain, sorghum uptakes about 14 - 18 kilograms of nitrogen , 6 - 8 kilograms of K_2O, and 3 - 3.5 kilograms of P_2O_5. (Ajayi *et al.*, 1998; Ado *et al.*, 1999; Murty and Renard, 2001; Kelly, 2013). Its largest uptake of nitrogen is marked during the stage of intensive growth, that is, 20 - 35 days after sprouting. Nitrogen is actively consumed until the onset of blossoming. High absorption of nitrogen during the second half of sorghum vegetation often extends its grain maturation stage.

The roots of sweet stem sorghum plants begin to consume large amounts of P_2O_5 from the very first day of their life. At tasseling they absorb about 50% of the total phosphorus in the soil. As to potassium uptake, it is more even and uniform throughout the entire vegetation period of sorghum (Idem and Showemimo, 2004; Ajayi *et al*., 1998).

The fate of the whole grain yield of sorghum depends on timely plant care. It begins with the first appearance of sprouts, and ends only when the rows touch. In dry regions of the subtropics and in warm areas of the temperate zone, where the soil dries rapidly, it is advisable to compact it after sowing. This helps water to rise into the upper soil horizons, and accelerates sprouting by 2 - 4 days.

When the sprout emerges, the rows are harrowed, so as to eradicate many weeds and rid the soil surface of cake resulting from rains. Pre-sowing harrowing is very useful during weed germination (4 - 5 days before sorghum sprouting). In the first month of vegetation, sorghum plants grow slowly, and are easily suppressed by weeds. At this time, wide-rowed fields sown with one species of sweet stem sorghum are weeded and cultivated. The first loosening of the soil is effected to a depth of 7 - 10 centimeters in about 7 - 10 days after harrowing; the second, which is shallower, takes place at the stage of the 4^{th}-5^{th} leaf and coincides with thinning, which is carried out before tillering. In the humid tropics, in about a month after sprouting, the sorghum plants are most frequently weeded by hand, two or three times (the first time, in 10 - 15 days after sprouting) (Aba *et al*., 2004; *Ajayi et al*.,1998).

To control weeds on sorghum fields, herbicides are employed: propazine (3 kilograms per hectare) before sowing, and 2, 4-D (1.5-2 kilograms per hectare) during thinning. When sown on ridges or hills, sorghum is weeded two to three times and also cultivated and hilled (Aba *et al*., 2004; Ajayi *et al*., 1998).

In the hot climate regions, sorghum is often sown in mixtures with maize, lucerne, and other cultures. A mixed sowing may be quite beneficial, provided its components, rates and time are properly chosen. In warm regions of the temperate zone and in the dry subtropics under irrigation, mixed sowings are mainly practiced to raise sorghum for fodder; ratio between maize and sorghum in mixed sowings is 2:1 (2 rows of maize and 1 rows of sorghum). When using such mixtures in arid regions (400 millimetres of rainfall), there should be 30,000 plants per hectare, in more humid areas (600 millimetres of rainfall) - 50,000 plants per hectare. Good yields of silage sorghum are raised with two rows of sweet stem sorghum and one row of soybean (80,000 sweet stem sorghum pants and 60,000 soybean plants per hectare). In the dry Soviet subtropics, mixed sowing of sorghum with soybean and Lucerne are quite popular (Ustimenko-Bakumovsky, 1983).

When grown in some arid region of the subtropics and during the dry season in the tropics, sorghum is irrigated. Its response to additional irrigation is much higher than in all other grain crops. In areas with annual rainfall below 450 millimeters (Central Asia, the northern regions of India, the south of the USA and Mexico, North Africa,), Sorghum is irrigated 3 – 4 times during vegetation, at a rate of 600 - 800 cubic metres of water per hectare. Irrigation is effected from tillering until blossoming. In some cases (for example, with water deficit), sorghum fields are irrigated only once, to enhance seed germination and the onset of growth after which the plants depend on precipitations which do or do not fall (Yemen, Sudan, Ethiopia, Iran) (Aba *et al*., 2004; Ajayi *et al*., 1998).

Sweet stem sorghum responds well to organic and mineral fertilizers. In the arid steppes of the Stavropol Territory (the former USSR), 20 tons of manure applied per hectare during the main soil tillage increased the yields of sweet stem sorghum grain by 25 – 30 %. Higher yield increments were obtained (up to 35 - 45%) when mineral fertilizers were applied together with manure. Fertilizing of sweet stem sorghum fields is very effective when grown for silage or in arid regions, under irrigation (Ustimenko-Bakumovsky, 1983).

The rate of fertilizers applied to sorghum plants depends on the reserve of soil nutrients, their removal by sorghum plants, and moisture availability. To form 2,000 kilograms of grain per hectare and the respective yield of green mass, short-stature varieties of grain sorghum utilize about 40 - 54 kilograms of nitrogen, 15 - 18 kilograms of phosphorus, and 30 - 32 kilograms of potassium.

Sweet stem orghum responds best to nitrogen fertilizers (Idem & Showemimo, 2004) but their efficiency directly depends on the soil moisture content. The application of mineral fertilizers in arid regions, without irrigation, is not effective and often leads to adverse effects. Under these conditions, the best fertilization of sorghum fields is to sow them with green-manuring crops as intermediate cultures (Cowpeas, pea vine, beans) (Irvine, 1979).

The time of application of mineral fertilizers on irrigated sorghum fields (at least 450 - 550 millimeter of rainfall) coincides with that of the main and pre-sowing tillage. This provides for normal growth of sorghum plants in the first half of vegetation, when there is sufficient soil moisture content for the intensively developing root system of the plants. When cultivated under irrigation sorghum prefers the application of split fertilizer: 30 - 40% of nitrogen, 50-60% of phosphorus and 40 - 60% of potash fertilizers during the main tillage 30 - 60 days before sowing. The remaining quantities should be applied prior to sowing or as top-dressings in the first month of vegetation, provided the field is irrigated (Irvine, 1979; Ustimenko-Bakumovsky, 1983).

The rates of fertilizers application markedly varies In India, unirrigated sorghum fields are fertilized with 20 kilograms of nitrogen and 10 - 20 kilograms of P_2O_5 per hectare; while irrigated sorghum fields receive 40 kilograms of nitrogen and 20 kilograms of $P_2O_{5.}$ In the USA, the rate of fertilization for sorghum fields is 45 - 90 kilograms of nitrogen and in West Africa 40 - 50 kilograms of nitrogen and 90 kilograms of P_2O_5 per hectare (Irvine, 1979).

2.5 Harvesting time of Sweet Stem Sorghum

Literature is replete with evidence of the fact that silage and sweet stem varieties of sorghum are harvested at the end of the milky or the beginning of the waxy ripeness, when the stems contain the largest amounts of sugar (Bencini, 1991). Sugar content in sorghum is known to vary in accumulation, beginning soon after anthesis and reaching a peak within the grain-filling period, followed by a gradual reduction before grain maturity and harvest.

Within this wide window of over a month, the exact peak sugar accumulation period and brix sugar yield per hectare of sweet stem sorghum in a given location may be determined.

Irvine (1979) noted that generally, harvesting is usually done in October and November or December and January according to the variety.

When the grains are ripe the stems are cut a few centimeters below the heads, or in some areas, at ground level. According to Orkwor and Ekanayake, (1998); and Aba *et al*., (2004), short–statured varieties of grain sorghum are harvested at the stage of complete ripeness by grain combines; tall stem varieties are gathered by hand, the upper part of the plant stem is cut together with the tassel.

In some African countries (Nigeria, Tanzania, Senegal, Sudan), the local varieties of sorghum are strong branching tassels. Hence, the reason for which the grains in different tassels ripen unevenly. In these cases, ripe tassels are harvested as they mature, and the grain harvest occurs in several stages (Irvine, 1979). Silage and sweet varieties of sorghum are harvested at the end of the milky or the beginning of waxy ripeness, when the stems contain the largest amounts of sugar (Irvine, 1979).

Sweet stem sorghum plants used as green fodder or hay are harvested several times during vegetation: the first time after leaf tube formation, but always before the onset of tasselling; the second time and subsequently, as the plants grow. Mowing at later stages (blossoming, the beginning of grain maturation) is not desirable because during these periods the sorghum plant accumulates hydrocyanic acid which is toxic for animals.

Mixed crops of sweet stem sorghum (with cowpeas, soybeans, beans, lucerne) for silage are harvested at the stage when the legumes blossom or form fruits because the fodder mixture will be rich in protein and easy to be used as silage (Irvine, 1979).

2.6 Economic Importance of Sweet Stem Sorghum

Sweet sorghum is a crop of multiple uses. Its grains are widely used for food and starch, its culms as fodder for farm animals, and its fresh sweet stem as raw material for treacle and alcohol production (Aba *et al.,* 2004; Ado *et al.,* 1999; Nkama, 1993; Vogel and Graham, 1979). In the countries of Asia, Africa and America, Sweet Stem Sorghum is grown for making special drinks (malt). In Namibia, particularly among the Oshiwambos, the indigenous people of Ongwediva, the locus of this study, sweet sorghum is used in brewing traditional beer called oshikundu, omalodu iilya and otombo. The grains are also cooked and eaten by humans and pigs as omahola.

In other countries it is raised for the production of brooms and brushes (Italy, Spain, the USA, and countries of the former USSR) (Ustimenko-Bakumovsky, 1983).

Murty and Renard (2001) maintained that sweet stem sorghum is not only a stable cereal for millions of farmers in the world, but that it has also good feed and forage values.

The most important use of sweet stem sorghum is for food (Wilsie, 1962; Reddy, 2012; Kelly, 2013). In Africa and Asia, sorghum grains are processed by hand to make a variety of traditional foods. Milling of the grains is done by placing cleaned moist grain in a mortar and pounding it to remove the pericarp. The decorticated grains are further pounded to make flour, semolina or grits, depending upon the product desired. Traditional stone mills are also used to make flour, which is sieved to obtain the required particle size. Traditional foods prepared from sorghum are many and are known by numerous names in various languages and dialects. They are broadly classified into eight classes: unfermented breads *(chapati, roti)*, fermented breads *(kisra, injera)*, stiff or solid porridges *(ugali, tuwo, sankati, to)*, thin or light porridges *(ogi, ugi, akamu)*, steam – cooked products *(couscous)*, boiled products *(annam)*, snack foods, alcoholic and non – alcoholic beverages *(sorghum beer, dolo, pito, amgba, burukutu, busa, mahewu)*. Traditional methods of processing sweet sorghum are very laborious and increasingly difficult to perform in urban areas. Industrial milling is adopted in many cases in countries where sweet sorghum is used for feed.

Sweet sorghum can replace up to 30% of wheat flour in bread and other complete flour–based products (Murty and Renard, 2001). Several milling projects producing composite flour were initiated in countries such as Senegal, Sudan, Nigeria, Botswana and Kenya, but were generally not viable for various socio–economic reasons. The availability of subsidized cereals such as wheat, rice and maize was an important reason for the failure of such projects. Medium–scale milling technologies were successfully tried in Botswana and small–scale technologies are under experimentation.

The use of malted sweet sorghum in the preparation of diverse drinks is widespread particularly in the sub-humid and humid zones of Africa, where brown grain cultivars are commonly cultivated for this purpose (Aba *et al.*, 2004). The grain is steeped and germinated for four or five days. The dried seedlings (malt) are ground, after winnowing off the rootlets, and used in beer production with starch from sorghum, maize, cassava or banana. Sweet sorghum beer is an important source of nutrients because it contains vitamins, minerals, proteins and carbohydrates. Industrial production of opaque beer of sorghum has been common in Southern Africa for a long time. Sweet stem sorghum grains or malt is now being used in the production of clear beer in Nigeria and Mexico. Right now, non–alcoholic drinks and popular malt drinks are everywhere in all countries.

Sweet sorghum cultivars that have sweet juicy stems are used for chewing (Aba *et al.,* 2004; Udo and Ndon, 2016). They can also be used for the production of alcohol and granular sugar, although the manufacture of sugar is currently not competitive economically. Special purpose sorghums for popping and parching grains are also known. Wax sweet sorghums were used in the USA for the manufacture of starch.

Sweet stem sorghum is used as forage in many parts of the world (Orkwor and Ekanayake, 1998; Udo and Ndon, 2016). Stalks and foliage are fed to cattle only after the crop reaches 50 days of growth to prevent HCN poisoning. Columbus grass (*S. almum*), Johnson grass (*S. halepense*), Sudan grass (*S. bicolor*) and more recently, hybrids of sorghum with Sudan grass are used in the developed world as pasture grasses and for forage, hay and silage. In the developing countries, especially India, certain cultivars have a dual purpose, i.e. grain and forage. In Africa, the use of sweet sorghum as forage is limited but is gaining importance. However, crop residues of sorghum are grazed by livestock. The feed value of tannin–free sweet sorghum compares well with that of maize and its protein content is higher. Sweet sorghum heads contain approximately 70% grain and are well suited for use in high–energy feeding of cattle.

The use of sorghum straw for the production of fibre boards has been noted (Orkwor and Ekanayake, 1998). Dry stalks are commonly used as fuel for cooking and for fencing or roofing huts also.

The chemical composition of the grain and vegetative organs greatly varies: 1.5 – 3% ash content in the grain and 8 – 12% in the stem and leaves; 8 – 10 and 10 – 17% of protein; 70 – 75 and 45 – 50% of carbohydrates, respectively. The green mass contains a cyanic compound, *glucosidedurrin*. The content of cyanic compounds is greatly reduced in mature plants (Nkama, 1993; Vogel & Graham, 1979).

Sorghum plants used as green fodder or hay are harvested several times during vegetation: the first time after leaf tube formation, but always before the onset of tasseling; the second time and subsequently, as the plants grow. Mowing at later stages (blossoming, the beginning of grain maturation) is not desirable because during these periods sorghum plants accumulate hydrocyanic acid which is toxic for animals.

Mixed crops of sorghum (with cowpeas, soybeans, beans, lucerne) for silage are harvested at the stage when the legumes blossom or form fruits because the fodder mixture will be rich in protein and easy to silage (Orkwor and Ekanayake, 1998; Ustimenko-Bakumovsky, 1983; Aba et al., 2004; Udo and Ndon, 2016).

Sweet sorghum is extremely resistant to salts, and can even desalt the soil it grows on. Therefore, it is widely used on irrigated cotton fields. When forming its yield, sorghum removes many nutrients from the soil (particularly, great quantities of nitrogen), and reduces its effective fertility. That is why after sorghum, the plots are usually sown with crops that are not sensitive to soil fertility, such as cassava, groundnuts, or grasses. Plots under sorghum are less fertile than those under maize, but more fertile than those under African millet. Early-ripening varieties of sorghum grow better on light-textured soils of low water capacity; late-ripening-on heavy-textured clay soils (Udo and Ndon, 2016).

Sweet sorghum can be used for ethanol production which is a good source of bio-fuel (Semelsberger *et al*., 2006). Bio-fuels are liquid or gaseous fuels made from plant matter and residues, such as agricultural crops, municipal wastes and agricultural and forestry by-products. Liquid bio-fuels can be used as an alternative fuel for transport, as can other alternatives such as liquid natural gas (LNG), compressed natural gas (CNG), liquefied petroleum gas (LPG) and hydrogen (Semelsberger *et al*., 2006; Balat & Balat, 2009).

Bio fuel is fuel or energy produced from biomass. Biomass use is a tradition dating back to thousands of years. Biomass is the sum of all living matter - from bacteria and fungi in soils to plants and animals on land, to algae in the oceans; and it also includes organic wastes (example: dung, slurry and straw) (Huber *et al.,* 2006). For thousands of years, people have been using biomass as a commodity (for construction, textiles, and many more) and as a source of food for themselves and for their animals (Karakezi, 2004). There is a similar long tradition of using energy derived from biomass. From the first flame held alight as a torch through to modern-day steam engines, wood gas generators and cooker, bio-energy or bio-fuels offer a broad range of applications. In industrialized countries, fossil fuel or energy sources – first coal, then petroleum and natural gas – rapidly overtook bio-fuel or bio-energy use, whereas in developing countries the traditional bio-energy uses (cooking, baking) are still widespread even today (Karakezi, 2004).

Biomass therefore provides an opportunity to produce fuel or energy from domestic sources. The last few years, however have seen a worldwide resurgence of interest in bio-fuels or bio-energy (Renewable Energy Policy Network for the 21st Century – REN_{21} – 2006).

Bio-fuel is available as gas and as liquid fuel. It can be used for heat and power generation or as fuel in the transportation sector. Today, the most important liquid bio-fuels are bio-ethanol and bio-diesel. Both are suitable for use in conventional engines.

Liquid bio-fuel plants are subdivided into first and second generations (Clashausen, 2007). First generation bio-fuel plants include pure plant oils, bio-diesels and bio-ethanol which can be produced using traditional technology. Synthetic fuel (examples: "biomass-to-liquid" – BtL) and ethanol from cellulose belong to the second generation fuels, in which all of the biomass (entire plant and/or residues) is converted into liquid bio-fuel using sophisticated technologies (Clashausen, 2007).

2.7 Why Bio–Fuel?

Frisby and Schumacher (2002) noted that the world energy crisis has necessitated new and innovative ways to supply power in the realization of diminishing fossil fuels. Hence various forms of alternative energy sources have been developed. These include solar energy, geothermal energy, wave energy and bio-fuels. Bio-fuels are unique from other renewable energy types because they can be stored and transported to other places of need. Besides, bio-fuels are considered not to add to the stock of total carbon dioxide in the atmosphere because they release what the plant took in during photosynthesis.

In the USA following the increasing demand, depletion of fossil resources leading to persistent increase in prices of fossil fuels, coupled with uncertainty of future supply, and the heavy dependence on imported petroleum oil, there was the need to find an alternative source to fossil fuel energy. This attracted the attention of researchers to find ready market for the excess genetically modified (GM) maize produced, following the refusal of the European Union (EU) to import GM maize from USA (Obasi, 2009).

As a consequence, the production of ethanol from maize presented an alternative use to GM maize. The successes recorded in producing agro fuels (ethanol) from maize eventually presented an alternative to fossil fuels, and opened a way for exploitation of other alternative sources for generating power (Obasi, 2009). Since then, many innovative co-generation energy projects have been initiated, some involving the use of agricultural crops for agro-fuels. Ethanol is predominantly produced through fermentation of carbohydrates extracted from sugar rich plants. Corn is the traditional feedstock for ethanol production due to its high starch content and its being well- developed for growth and processing.

Obasi (2009) classified agricultural crops used for bio-fuels into three categories:

(i) Crops containing sugars (e.g. sugar beets, sugarcane, sweet stem sorghum and ripe fruits).

(ii) Crops containing mainly starch (e.g. grains, potatoes, Jerusalem artichokes).

(iii) Crops containing mainly cellulose (e.g. Stover, grasses and wood).

It has been found that sweet-stem sorghum is a crop close to sugarcane in respect to its sucrose accumulation and juicy nature of the stem which can also be processed into granulated sugar which is used in many products that we eat every day and is an excellent source of energy. When sugar is extracted from the stem, much of the waste product, called *bagasse,* is used to make other products such as paper, fibre board and card board (Aves *et al*, 2000).

In Mauritius and Guyana, *bagasse* is used to replace coal in electricity production (Spore, 2007). Almost all sugar factories in Zambia, Zimbabwe and Uganda produce their own electricity from bagasse. The use of agricultural crops including sweet sorghum for bio-fuels production which are economically viable makes bio–fuel better alternative to fossil fuels.
Bio–fuel can contribute to the mitigation of greenhouse gas emissions, provide a clean and sustainable energy source, and increase the agricultural income for rural poor in developing countries (Balat and Balat, 2009).

2.8 Bio-Fuel Potentials

A recent joint study by the US Department of Agriculture and Energy found that bio-fuels could substitute for more than one third of US transport fuel use within the next 25 years. The bio-fuel potential in Europe is estimated to be in the range of 20 to 25 percent, even assuming that strict sustainability criteria are used for land use and crop choice and that bio-energy use in non - transport sectors grows in parallel. Many small developing countries with favorable growing climates could likely meet all of their liquid fuel needs with bio-fuels (Walter, 2007).

Goldemberg (2000) indicated that bio-fuels could significantly increase energy security. One condition for realizing sustainable development is the establishment of a global sustainable energy supply. The current energy supply system is responsible for several problems: exhaustion of fossil energy sources, unacceptable security risk of local, regional and global environmental problems, including the emission of greenhouse gases affecting the earth's climate system. There are also cases of several people with very limited or no access to modern energy carriers (Goldemberg, 2000).

Jefferson (2000) opined that solving these problems requires a new energy paradigm shift that considers the impacts of energy use at local and global scale, develops a wider portfolio of energy resources and cleaner technologies, widens access and increases efficiency, and concerns with both our present needs and the future generations' welfare.

The opportunity to diversify and participate in new markets of bio-fuel can result in social and rural development, because bio-fuel industries increase employment, generate income, provide energy security, infrastructure and training, and develop human resources and skills capacity (Wilson, 2007). Thus, replacing fossil fuels with bio-fuels has the potential to generate a number of benefits mainly because in contrast to the exhaustible resources of fossil fuels, bio-fuels are produced from renewable feedstock and hence, their production is sustainable.

In Zimbabwe, the production and blending of ozone friendly bio-fuels with petrol has recently brought about a reduction in the price of petrol pump price (The Southern Times, 5-8 December 2011 p13). Studies have found that the major criticism of bio-fuel potentials is that it takes away food products and burn as fuel, in the process worsening the world food crisis. In other cases involving the use of non-food crops (e.g. the use of *Jatropha*), the major criticism is that the land is diverted from food production to energy crop production, thus still fueling the food crisis (Frisby and Schumacher, 2002; Orkwor and Ekanayake, 1998; Ustimenko-Bakumovsky, 1983; Aba *et al.,* 2004; Obasi 2009; Spore, 2007; Aves *et al.,* 2000).

Obasi (2009) had listed bio - fuel feed stocks to include many crops that would otherwise be used for human consumption directly, or indirectly as animal feed.

Swanson *et al., (*2003) argued that diverting these crops to bio-fuels may lead to more land area devoted to agriculture, increased use of polluting inputs (different agrochemicals), and higher food prices. Even where cellulosic feed stocks are used, these can also compete for resources (land, water, fertilizer) that could otherwise be devoted to food production. As a result, some researchers such as (Fargione *et al*., 2008; Rosegrant *et al*., 2008, Fischer *et al*., 2009; Searchinger *et al*., 2008; Melillo *et al*., 2009)have suggested that bio-fuel production may give rise to several undesirable developments.

It has been reported that changes in land use patterns may increase green-house gas emissions by releasing terrestrial carbon stocks to the atmosphere (Searchinger *et al*., 2008). Bio-fuel feed stocks grown on land cleared from tropical forests, such as soybeans in the Amazon and oil palm in South East Asia, generate particularly high green-house gas emissions (Fargione *et al*., 2008). The use of cellulosic feed stocks can also spur higher crop prices that encourage the expansion of agriculture into undeveloped land, leading to green-house gas emissions and biodiversity losses (Melillo *et al*., 2009).

Regarding non green-house gas environmental impacts, research suggests that the production of bio-fuel feed stocks, particularly food crops like corn and soy, could increase water pollution from nutrients, pesticides, and sediment (National Research Council [NRC], 2011). Fertilizer usage in the course of bio-fuel feedstock production could release nitrous oxide, a potent green-house gas. Furthermore, increases in irrigation and ethanol refining could deplete aquifers, while air quality could decline in some regions if the impact of bio-fuels on tail pipe emissions plus the additional emissions generated at bio-refineries increases net conventional air pollution (NRC, 2011).

Economic models have shown that bio-fuel use can result in higher crop prices, though the range of estimates in the literature is wide. For example, a 2013 study gave projections for the effect of bio-fuels on corn prices in 2015 ranging from 5 to 53 percent increase (Zhang *et al.* 2013). The National Research Council's (2011) report on the RFS included several studies finding a 20 to 40 percent increase in corn prices from bio-fuels during 2007 to 2009. However, the *National Centre for Entrepreneurship in Education* (NCEE) working paper found a 2 to 3 percent increase in long-run corn prices for each billion gallon increase in corn ethanol production on average across 19 studies (Condon *et al.*, 2013). Higher crop prices lead to higher food prices, though impacts on retail food in the US are expected to be small (NRC 2011). The higher crop prices may lead to higher rates of malnutrition in developing countries (Rosegrant *et al*., 2008, Fischer *et al*., 2009).

Bio-ethanol is an oxygenated fuel that contains 35% oxygen, which reduces particulate and nitrogen oxides (NO_2) emissions from combustion (Balat and Balat, 2009). Adding bio-ethanol to gasoline increases the oxygen content of the fuel, improving the combustion of gasoline and reducing the exhaust emissions normally attributed to imperfect combustion in motor vehicles. Bio-ethanol can be used in various methods as a transportation fuel. It can be directly used as a transportation fuel or it can be blended with gasoline. Bio-ethanol can be mixed with gasoline it is substituting for and can be burned in traditional combustion engines with virtually no modifications needed. Bio-ethanol is most commonly blended with gasoline in concentrations of 10% bio-ethanol to 90% gasoline, known as E10 and nicknamed ‘‘gasohol”. In Brazil, bio-ethanol fuel is used pure or blended with gasoline in a mixture called gasohol (24% bio-ethanol and 76% gasoline) (Oliveria *et al.*, 2005). Bio-ethanol can be used as a 5% blend with petrol under the EU quality standard. This blend requires no engine modification and is covered by vehicle warranties. With engine modification, bio-ethanol can be used at higher levels, for example, E85 (85% bio-ethanol) (Demirbas, 2008).

Bio-ethanol and bio-ethanol/gasoline blends have a long history as alternative transportation fuels. It has been used in Germany and France as early as 1894 by the then incipient industry of internal combustion (IC) engines (Demirbas, and Karslioglu, 2007). Brazil has utilized bio-ethanol as a transportation fuel since 1925. The use of bio-ethanol for fuel was widespread in Europe and the United States until the early 1900s. Because it became more expensive to produce than petroleum-based fuel, especially after World War II, bio-ethanol's potential was largely ignored until the oil crisis of the 1970s (Balat, 2009). Since the 1980s, there has been an increased interest in the use of bio-ethanol as an alternative transportation fuel. Countries including Brazil and the United States have long promoted domestic bio-ethanol production.

In addition to the energy rationale, bio-ethanol/gasoline blends in the United States were promoted as an environmentally driven practice, initially as an octane enhancer to replace lead. Bio-ethanol also has value as oxygenate in clean-burning gasoline to reduce vehicle exhaust emissions (Demirbas, 2005). Bio-ethanol has a higher octane number, broader flammability limits, higher flame speeds and higher heats of vaporization. These properties allow for a higher compression ratio and shorter burn time, which lead to theoretical efficiency advantages over gasoline in an internal combustion engine (Balat, 2007). Octane number is a measure of the gasoline quality for prevention of early ignition, which leads to cylinder knocking. The fuels with higher octane numbers are preferred in spark-ignition internal combustion engines.

In Namibia, report shows that the Namibian government did not allow large scale *Jatropha* plantations to be established in Kavango and Caprivi Regions until an environmental impact assessment was done. According to Cabinet recommendations, the industry has a negative impact on food security, land tenure, and loss of access to communal land; has climate change implications and low financial viability (New Era, 6 Dec 2011, p6). In these circumstances, sweet-stem sorghum presents a unique solution as it simultaneously answers both the fuel and the food needs of the world.

The incessant increases in the prices of petroleum products in recent years in Namibia as reported in the Namibian Sun of March 12, 2012 p12, resulting from instability in oil producing regions and rising global oil prices should be a wakeup call for investment in bio-fuel. If this trend in high fuel prices continues unabated, there will be serious repercussions on the transport sector and the entire economy (The Namibian Newspaper, March 15, 2012).

In Namibia, energy is generated locally from hydro, coal and diesel-burning power stations. Local supply is inadequate. The demand is met by importing electricity from the South African power pool. Imports accounted for 42.5 % of total electricity used in 1999 (Nghithila, 2003). In the rural areas, energy needs are met with diesel and petrol generators, paraffin, candles and fuel wood. Solar energy is not a large part of the energy used but has great potential especially for domestic purposes such as cooking and heating (Nghithila, 2003).

While attempt is being made here to discuss the major disadvantages that should be considered when considering bio-fuels development, it is not aimed to discourage their uses, but rather to encourage responsible use of this technology, which is likely to become our predominant source of energy as we transit over to cleaner alternatives in the more distant future.

According to Fritsche (2007), despite being an unattractive proposition in economic terms in the 21st century, bio-energy and bio-fuel are viewed as potential products which, in the light of oil and gas prices, offer the farmer relatively good added value, and, at first glance, price trends are not dependent on the feed and food markets. Tax concessions are granted for bio-fuel and additional feed-in tariffs for electricity from biomass are incorporated into the

Renewable Energy Act (REC) in some countries. Some EU countries support bio-energy and bio-fuel with a multitude of instruments.

As crude oil prices rose, there was increased concern about supply security, as most oil supplying countries were viewed as “unstable” (the Middle East, West Africa). Moreover, Russian natural gas has also been rated as potentially insecure since the end of 2005. Bio-energy, in contrast, offers the clear advantage of originating from domestic production, and hence does not create vulnerability to extortion nor risk price instability. Moreover, biomass stores energy relatively well which is an important condition for electricity production and is thus suitable for continuous base-load power generation. For oil-producing developing countries (for instance, Brazil and Mexico), making use of their domestic biomass potentials instead of using their own oil production would mean they could export oil and oil products without having to overcome customs barriers such as those applying to ethanol (Kaltner et al. 2005; Neuhaus 2006). For developing countries without their own oil resources, biomass is an important option to mitigate the price and supply risks associated with fossil fuel oil (Gehua, *et al.*, 2006; Janssen, 2005; TERI, 2005).

In the supply security argument, the country of origin of imports is a very important factor. Potential bio-energy exporters, like Brazil, Mozambique, Romania, Ukraine and South Africa are potential “new” suppliers with relatively stable political framework conditions, and consequently imports from these countries are expected to enhance supply security. A corresponding rise in world bio-energy trade might also check the upward trend in oil prices. Bio-energy can lay claim to yet further advantages: both in industrialized and in developing countries, it is highly relevant to rural development in general and to jobs in structurally weak regions in particular. Bio-energy brings clear benefits here (Gehua, *et al.*, 2006; Janssen 2005; TERI 2005).

Moreover, in developing countries especially, it can help to reduce air pollutants – mainly SO_2, which originate from "dirty" energy sources such as fuel oil or coal. While the production of bio-fuel results in greenhouse gases (GHG) emissions at several stages of the process, EPA's (2010) analysis of the Renewable Fuel Standard (RFS) projected that several types of bio - fuels could yield lower lifecycle GHG emissions than gasoline over a 30 year time horizon. Academic studies using other economic models have also found that bio - fuel can lead to reductions in lifecycle of GHG emissions relative to conventional fuels (Hertel *et al.* 2010; Huang *et al*.,2013). Second and third generation bio-fuel have significant potential to reduce GHG emissions relative to conventional fuel because feed stocks can be produced using marginal land. Moreover, in the case of waste biomass, no additional agricultural production is required, and indirect market-mediated GHG emissions can be minimal if the wastes have no other productive uses.

Bio-fuels can be produced domestically, which could lead to lower fossil fuel imports (Huang *et al*., 2013). If bio-fuel production and use reduces our consumption of imported fossil fuel, we may become less vulnerable to the adverse impacts of supply disruptions (United States Environmental Protection Agency [US EPA], 2010). Reducing our demand for petroleum could also reduce its price, generating economic benefits for local consumers, but also potentially increasing petroleum consumption abroad (Huang *et al*., 2013). Bio-fuel may reduce some pollutant emissions. Ethanol, in particular, can ensure complete combustion and reducing carbon monoxide emissions (US EPA, 2010). It is however, important to note that in order for bio-fuel production and consumption to reduce GHG or conventional pollutant emissions; lessen petroleum imports, or alleviate pressure on exhaustible resources, the bio-fuel production and use must be made to coincide with reductions in the production and use of fossil fuels for the same purposes. These benefits would be mitigated if bio-fuel emissions and resource demands augment, rather than displace, those of fossil fuel.

Interest in the use of bio-fuels worldwide has grown strongly in recent years due to the limited oil reserves, concerns about climate change from greenhouse gas emissions and the desire to promote domestic rural economies (Balat, 2009). With increasing gap between the energy requirement of the industrialized world and inability to replenish such needs from the limited sources of energy like fossil fuel, an ever increasing level of greenhouse pollution from the combustion of fossil fuels in turn aggravate the perils of global warming and energy crisis (Mohan *et al.,* 2008).

Motor vehicles account for a significant portion of urban air pollution in most of the developing world. In support of this assertion, Goldemberg (2000) confirms that motor vehicles account for more than 70% of global carbon monoxide (CO) emissions and 19% of global carbon dioxide (CO_2) emissions. There are 700 million light duty vehicles, automobiles, light trucks, SUVs and minivans, on roadways around the world (Balat and Balat, 2009). These numbers are projected to increase to 1.3 billion by 2030, and to over 2 billion vehicles by 2050, with most of the increase coming in developing countries (Hansen, 2004). This growth will affect the stability of ecosystems and global climate as well as global oil reserves (Goldemberg, 2000; Hansen, 2004 and Balat, 2009)

The world's total proven oil, natural gas and coal reserves are respectively, 168.6 billion tons, 177.4 trillion cubic meters, and 847.5 billion tons by the end of 2007, according to the recently released the 2008 BP Statistical Review of World Energy (British Petroleum Company, 2008). With current consumption trends, the reserves-to-production (R/P) ratio of world proven reserves of oil is lower than that of world proven reserves of natural gas and coal - 41.6 years versus 60.3 and 133 years (British Petroleum Company, 2008) respectively. In 2007, the world oil production was 3.90 billion tons, a decrease of 0.2% from the previous year (British Petroleum Company, 2008). According to the International Energy Agency statistics (IEA) (2008), the transportation sector accounts for about 60% of the world's total oil consumption.

Bio-fuel is attracting growing interest around the world, with some governments announcing commitments to bio-fuel programs as a way to both reduce greenhouse gas emissions and dependence on petroleum-based fuels. In an issue paper: "gain or pain? Bio-fuel and invasive species", UNEP (2010) reported that international initiatives to enhance the sustainability of bio-fuel sector have been established with a target on the national level through partnerships between governments and intergovernmental agencies, such as the Global Bio-energy Partnership.

The United States, Brazil and several EU member states have the largest programs promoting bio-fuel in the world. Observation has shown that the recent commitment by the United States government to increase bio-energy threefold in ten years has added impetus to the search for viable bio-fuels (Demirbas, 2006; Demirbas and Balat, 2006; Chen *et al*., 2008; Demirbas, 2008; Demirbas and Dincer, 2008; Balat, 2007). In South America, Brazil adopted policies that mandate at least 22% bio-ethanol on motor fuels and encourage the use of vehicles that use hydrous bio-ethanol [(96 bio-ethanol + 4 water)/100] to replace gasoline (Stevens *et al*., 2004).

In the United States, the desire to promote the production and use of bio-fuel, particularly bio-ethanol produced from maize, started in the early 1980s, largely to revitalize the farming sector at a time of oversupply of agricultural produce (Jull *et al*., 2007).

Bio-ethanol can be used in fuel mixtures such as E85 (a blended fuel of 85% bio-ethanol and 15% gasoline) in vehicles specially designed for its use, although E85 represents only approximately 1% of US bio-ethanol consumption (Yacobucci and Schnepf, 2007). To promote the development of E85 blended fuel and other alternative transportation fuels, the

US Congress has enacted various legislative requirements and incentives. At the national level, the Energy Policy Act of 2005 (EP Act 2005) is one of the most significant steps (Hoekman 2009). The legislation set a target of 28.4 billion liters consumption of bio-ethanol by 2012 (Renewable Fuels Standard [RFS]), it represents around 5% (in volume) of gasoline consumption projected for the year 2012 (Jank *et al*., 2007).

In Brazil, there has been a long history of bio-fuel production dating back to 1975 when the National Alcohol Fuel Program (ProAlcool) was initiated. The program aimed to increase production of bio-ethanol as a substitute for expensive and extremely scarce gasoline. With substantial governmental interventions to increase alcohol demand and supply, Brazil created assets and developed institutional and technological capabilities for using renewable energy on a large-scale. By 1984, a majority of new cars sold in Brazil required hydrous bio-ethanol [(96 bio-ethanol + 4 water)/100] as fuel (Kline *et al*., 2007). In 1993, the government passed a law in which all gasoline marketed in Brazil would be blended with 20 – 25% of bio-ethanol (Kline *et al*., 2007).

Widespread availability of flex-fuel vehicles (promoted through tax incentives) combined with rising oil prices have led to rapid growth in bio-ethanol and sugar cane production since 2000 (Kline *et al*., 2007). Today, more than 80% of Brazil's current automobile production has flexible-fuel capability, up from 30% in 2004. With bio-ethanol widely available at almost all of Brazil's 32,000 gas stations, Brazilian consumers currently choose primarily between anhydrous bio-ethanol/gasoline and a 25% bio-ethanol/gasoline blend on the basis of relative prices (Coyle, 2007).

In the European Commission's view, mandating the use of bio-fuels will improve energy supply security, reduce green-house gas emissions, and boost rural incomes and employment (Balat, 2007; Demirbas, 2008; Balat, 2008; Bozbas, 2008; Jansen, 2003).

The European Commission White Paper (European Commission, 2001) calls for dependence on oil in the transport sector to be reduced by using alternative fuel such as bio-fuel. In addition, due to the increasing mobility of people and goods, the transport sector accounts for more than 30% of final energy consumption in the EU and is expanding. Therefore, an increasing use of bio-fuels for transport is emerging as an important policy strategy to substitute petroleum-based fuels (Malça and Freire 2006).

The EU bio-fuels directive (2003/30/EC) set a target of an indicative 5.75% total bio-fuel share of all consumed gasoline and diesel fuel for transport placed on the market by 2010. This indicative target has been adopted by most Member States in their national bio-fuel objectives (Wiesenthal *et al*., 2009). For example, France established an ambitious bio-fuels plan, with goals of 7% by 2010, and 10% by 2015. Belgium set a 5.75% target for 2010. The European Commission's Green Paper on ''A European Strategy for Sustainable, Competitive and Secure Energy" (European Commission, 2006) and its 2007 strategic energy review, ''An Energy Policy for Europe" document released in January 2007 (European Commission, 2007) have both emphasized the need to take effective actions to address climate change (including actions to mitigate greenhouse gas emissions), promote jobs and growth and enhance security of energy supply in the internal market. On 23 January 2008, the European Commission (European Commission, 2008) proposed a binding minimum target of 10% for the share of bio-fuel in transport in the context of the ''EU directive on the promotion of the use of energy from renewable sources" that envisages a 20% share of all renewable energy sources in total energy consumption by 2020.

In 2007, the EU agreed amendment of the Fuel Quality Directive to allow adequate levels of blending. In these proposed rules the commission set a minimum value of 35% of greenhouse gas savings (Pfuderer and Del Castillo, 2008; Thamsiriroj and Murphy, 2009) which bio-fuels must achieve in order to count towards the bio-fuels target.

The bio-ethanol sectors in many EU member states have responded to policy initiatives and have started growing rapidly. The EU bio-ethanol production increased by 71% in 2007, reaching 2.9 billion liters while consumption reached 2.44 billion liters in 2007, an increase of 58% with net imports of bio-ethanol increasing to 0.16 billion gallons in the same year (Tokgoz, 2008). The potential demand for bio-ethanol as a transportation fuel in the EU countries, calculated on the basis of Directive 2003/30/EC, is estimated at about 12.6 billion liters in 2010 (Zarzyycki and Polska, 2007).

Table 2.1. Major bio-fuel producing countries in the world.

Country	**Bio-ethanol (billion liters)**	**Bio-diesel (billion liters)**
Brazil	15	---
United States	13	0.1
China	2	---
Germany	0.02	1.1
France	0.1	0.4
Italy	---	0.35
Canada	0.2	---
Thailand	0.2	---
Spain	0.2	---
Denmark	---	0.08
Czech Republic	---	0.07
Australia	0.07	---
World Total	31	2.2

Source: Renewable (2005)

In China, policy instruments for the promotion of bio-fuels include research, subsidies, tax, price limits, quotations, limits and changes established by law (Wang *et al*., 2006). Starting from 2001 two major fuel bio-ethanol programs have been implemented in China with the objective to promote renewable energy sources, enhance national energy security and improve domestic environment (Gnansounou *et al.,* 2005). There are many other countries which are setting up new initiatives for the production and use of bio-fuels for transportation.

An estimate in 2008 suggested that the following regions could grow bio-fuel on abandoned agricultural land (See Table 2.2).

Table 2.2. Potential bio-fuel production by regions of the world.

Region	Bio-fuel Production (millions of tones/year)
Africa	88 – 245
Asia	139 – 293
Australia/Indonesia	95 – 321
Europe	144 – 364
North America	211 – 697
South America	154 - 480

Source: Bio-fuel UK (2010)

Last but not the least, advanced bio-energy and bio-fuel technologies offer export opportunities globally. This is certainly one of the reasons why the EU and the USA are investing heavily in the next generation of bio-fuels and bio-refineries as new high-tech applications for biomass (EC/DOE 2005).

2.9 Potentials of Sweet Stem Sorghum for Bio-Fuel Production

Bio-fuel feed stocks can come from a variety of agricultural crops. Thus, when these crops are grown in a sustainable manner, using good management practices, there are long term benefits to farmers, farming communities and the land (Obasi 2009; Spore, 2007; Aves *et al*, 2000).

As already pointed out in the introduction, many researchers have appraised the use of crops for bio-fuel production.

In their contributions, Drapcho *et al.*, (2008) also identified high energy crops such as sweet stem sorghum, corn, wheat, barley, sugar cane, sugar beet, cassava, sweet potato as being suitable for biofuel production. According to them, like most biofuel crops, sweet sorghum has the potential to reduce carbon emissions.

Furthermore, Almodares *et al*., (2008), specifically pointed out that sweet stem sorghum has a high concentration of directly fermentable sugar which normally varies between 12 - 21 %. They therefore, concluded that based on the above characteristics, it seems that sweet sorghum is the most suitable plant for biofuel than other crops under hot and dry climatic conditions.

Although, the multiple and diverse environmental impacts of bio-energy development do not differ substantively from those of other forms of agriculture, the question remains of how they can best be assessed and reflected in field activities (Food and Agricultural Organization [FAO], 2008). Existing environmental impact-assessment techniques and strategic environmental assessments offer a good starting point for analysing the bio-physical factors. There also exists a wealth of technical knowledge drawn from agricultural development during the past 60 years. New contributions from the bio-energy context include the analytical frameworks for bio-energy and food security and the bio-energy impact analysis (FAO, 2008); work on the aggregate environmental impacts, including soil acidification, excessive fertilizer use, biodiversity loss, air pollution and pesticide toxicity (Zah *et al.,* 2007); and work on social and environmental sustainability criteria, including limits on deforestation, competition with food production, adverse impacts on biodiversity, soil erosion and nutrient leaching (Faaij, 2007).

The environmental concerns about bio-fuel feedstock production are the same as for agricultural production in general, and existing techniques to assess the environmental impact offer a good starting point for analysing the bio-fuel systems. New complementary methodologies are being developed to assess bio-energy specific issues, for instance FAO's analytical framework for bio-energy and food security.

The adoption of “good practices” in soil, water and crop protection, energy and water management, nutrient and agrochemical management, biodiversity and landscape conservation, harvesting, processing and distribution can contribute significantly to making bio-energy sustainable (Green Facts, 2015). For instance, good agricultural practices, such as conservation agriculture, and good forestry practices can reduce the adverse environmental impacts of bio-fuel feedstock crops production.

Good practices aim to apply available knowledge to address the sustainability dimensions of on-farm bio-fuel feed stocks production, harvesting and processing. This aim applies to natural-resource management issues such as land, soil, water and biodiversity as well as to the life-cycle analysis used to estimate greenhouse gas emissions and determine whether a specific bio-fuel is more climate-change friendly than a fossil fuel. In practical terms, soil, water and crop protection; energy and water management; nutrient and agrochemical management; biodiversity and landscape conservation; harvesting, processing and distribution all count among the areas where good practices are needed to address sustainable bio energy development (Green Facts, 2015).

The development of sustainability criteria or standards as already under way in a number of flora, such as the Global Bio-energy Partnership and the Roundtable on Sustainable Bio-fuels, are established with the active collaboration of developing country partners and this go hand in hand with training and support for implementation.

Given that most environmental impacts of bio-fuels are indistinguishable from those of increased agricultural production in general, it could be argued that equal standards should be applied across the board. Furthermore, restricting land-use change could foreclose opportunities for developing countries to benefit from increased demand for agricultural commodities. There are also strong arguments that agricultural producers and policy-makers should learn from earlier mistakes and avoid the negative environmental impacts that have accompanied agricultural land conversion and intensification (Green Facts, 2015).

Another reason behind the renaissance of bio-energy is the mitigation of global climate change. The European emissions trading scheme and the Clean Development Mechanism (CDM) have created instruments for pricing CO_2. At average bio-energy prices, a CO_2 price of 20 EUR/tone represents additional potential revenue of 20 to 30 percent of the pure energy value.

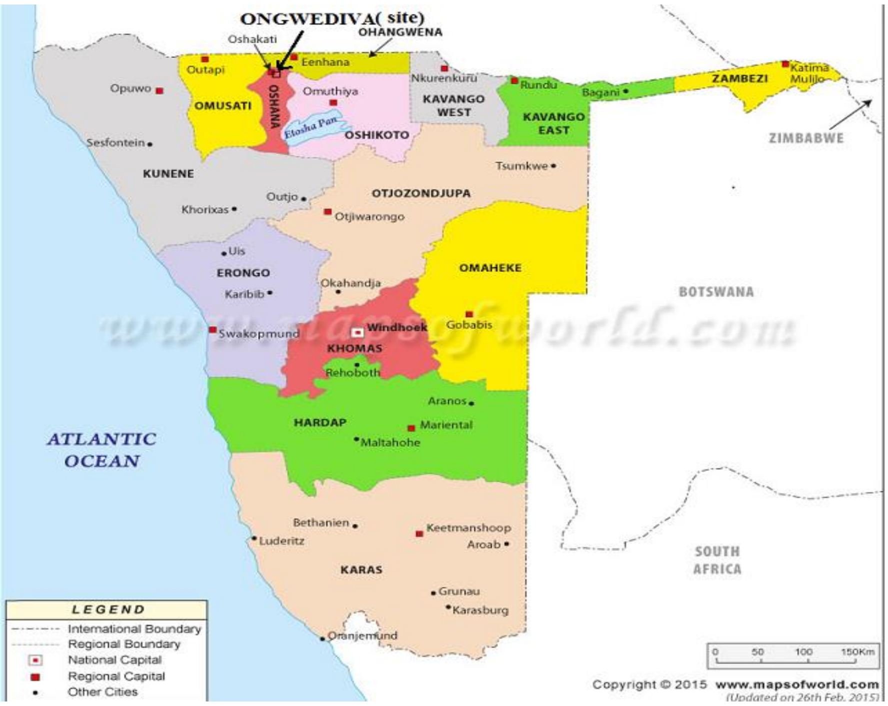
Bio-energy is CO_2 neutral if it originates from sustainable production or from biogenic waste. For other greenhouse gases (CH_4, N_2O), much depends on the type of biomass, how and where it is produced, what type of energy products or fuels it is processed into, and by what method. Moreover, the energy used, e.g. for process heating in ethanol manufacture, can give rise to additional greenhouse gas emissions. Likewise, the production of agro-chemicals (fertilizers, pesticides) and the processes of sowing, cultivation and harvesting all contribute to some extent.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Site and Setting

The study was conducted at Ongwediva in northern Namibia (See Figure 3).



Adapted from www.maps ofworld.com

Figure 3. Map of Namibia showing study location.

Hifikepunye Pohamba Campus of the University of Namibia is in Ongwediva, Oshana Region. Ongwediva is located between latitudes 5.17 °N and 5.27 °N and longitudes 7.27 °E and 7.58 °E. The climate of the area is tropical and is characterized by summer, winter, spring and autumn (Nghithila, 2003; Meeser, 2008). Reports have also indicated that rainfall patterns of the study area are unpredictable with annual mean rainfall of 250mm/annum while the mean temperature varies between 35 °C and 45 °C respectively (Nghithila, 2003; Messer, 2008).

The relative humidity of the area ranges from 30 – 50% while the mean monthly sunshine hours during the summer months is 13 - 14 hours and that of the winter ranges between 10 – 12 hours. The site is mainly made up of alluvial soil which was determined through visual appraisals and observations, rich in mineral particles as well as adequate organic matters.

3.2 Experimental Design and Field Layout

The study employed a quantitative and experimental research design with an analytical and comparative nature to determine the appropriate harvesting time for sweet stem sorghum grown under two seasonal conditions. The experiment was laid out in a randomized complete block design (RCBD) with three replications (see Figure 4).

Randomized complete block design makes assumption that the experimental units can be divided into a number of homogenous sub-population of blocks and treatment are then randomly assigned to the experimental units such that each treatment occurs equally in each block.

A total of six treatments were carried out as follows: (i) T_1 - harvest at booting stage (ii) T_2 - harvest one week (7 days) after booting , (iii) T_3 - harvest two weeks (14 days) after booting , (iv) T_4 - harvest three weeks (21 days) after booting, (v)T_5 - harvest four weeks (28 days) after booting and (vi) T_6 - harvest five weeks (35 days) after booting .

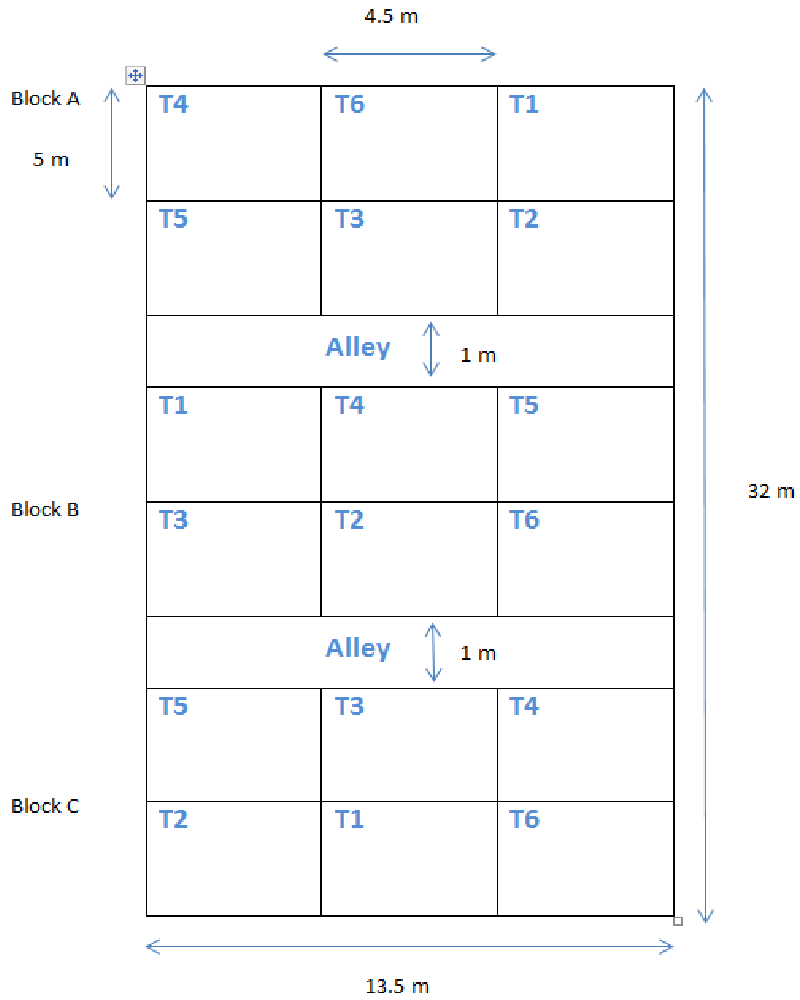


Figure 4: Plot layout showing the randomization of field plots

The whole experiment was done in the dry season under irrigation and repeated in the rainy season to stabilize variances from a larger sample and infer on the seasonal variability of parameters. Two trials were conducted: the first took place between February and June 2014 while the second was done between October 2014 and February, 2015.

3.3 Land Preparation

The experimental site was manually cleared using machete, raked and debris burnt on the site. The dominant vegetation on the site were bunchgrasses, old man saltbush, spineless prickly pear, Mexican agave, various *Acacia* species especially camel–thorn, Prosopis (mesquite), makataan (a type of watermelon), and tsamma.

The pre-sowing soil tillage was done and ploughed in up to a depth of 30cm, harrowing thereafter was at a depth of 14-18cm.

The tilled site was pegged using sticks and lines according to the field plan (see Figure 4 above). The plot measured $4.5\ m \times 5.0\ m$, was replicated three times (blocks) and totaled 18 plots.One meter alley was kept between blocks and there were no borders between plots within a block. One meter buffer zone was put around the whole experimental plot (See Figure 4). Seedbeds were then constructed.

3.4 Planting and Cultural Management

IS 2331, was used for all the treatments. The seeds were obtained from International Crop Research Institute for Semi-Aid Tropics (ICRISAT). ICRISAT works on crops for regions with rainfall less than 800mm.

This breeder's line with sweet stem was chosen because it had shown in previous experiments at UNAM to have the best yield combination of grain, sugar and stover, making it the best candidate for commercialisation where human food, bio-fuel and animal fodder were all of importance. The seeds were then sun dried before sowing. Seeds for first trial were planted on 2 February, 2014 at a depth of about 10cm while planting for the second trial was done on 2^{nd} October, 2014 maintaining the same planting depth.

Within the rows the crop was initially being over-sown, but thinned out two weeks after emergence to 20 cm intra-row spacing. This spacing of 75 cm inter and 20 cm intra row gave plant population of 66 000 plants/ha.

A basal compound fertilizer N P K; 2:3:2 (37) + Fe 0.5 % obtained from AGRA Windhoek, was applied at a rate of 150 kg/ha two weeks after emergence (WAE) and urea was applied at a rate of 175 kg/ha 6 WAE. These rates were within the range for standard fertiliser application for sweet sorghum in Namibia. Farmyard manure was applied at a rate of 2 tons/ha to improve nutrient and water holding capacities.

Manual weeding was done using native hoe at one month after planting (MAP). Subsequent weeding was done at 6 and 10 weeks after planting (See Figure 8 and Figure 9). The importance of weeding as one of the agronomic activities associated with sorghum production cannot be ignored. Weeding was done to ensure the weeds do not compete with the planted sweet stem sorghum for minerals, moisture, air, light and space and to reduce the presence of pests that may attack the crops. Weeding also prevented the blockage of water drains, thus ensuring optimum growth of the planted sweet stem sorghum.

There were no serious infestations of pests or diseases during field preparation and planting period. Therefore no agricultural chemicals apart from chemical fertilizers were used and these were environmentally friendly. The few insect pests such as grasshoppers and termites that were found during the planting period were controlled culturally by weeding and hand-picking. Weeding eliminated the hiding places of insect pests. Grasshoppers and termites usually destroy crops through biting and chewing of the plants.

3.5 Data Collection

Data on growth and yield parameters were collected from each plot on the following dates:

First trial from 1st April -12th May, 2014.

Second trial from 2nd December 2014 – 20th February, 2015.

The growth and the yield parameters were collected at weekly intervals from each plot. These included the different treatments through randomization process. The harvested sorghum stems were prepared for measurements and subsequent processing for analysis.

3.5.1 Establishment Percentage

The seeds took 5-7 days to germinate in each of the trials and the germination rate was 95% for each of the trials. The numbers of sprouted stands of sorghum for each plot were counted for the purpose of determining percentage stand establishment.

Sweet stem sorghum, like most cereals, develops tillers and runners during the growth phase. The number of tillers and runners for each stand of the sorghum plant was randomly assessed from each plot. Times of tillering and runners development were noted for all the treatments.

A tiller is a shoot that grows at the ground level from the main stem at an angle between a leaf and the main shoot.

Tillering is usually visible 4 weeks after germination and can lead to realization of a heavier yield especially when adequate moisture is available.

Runners are long lateral shoots of the sorghum plant, ending in a tuft of leaves which will take root.

However, the tillers and runners for each of the sorghum plant stand were pruned manually to prevent them from competing with the main shoot.

3.5.2 Stem Height Determination Data Collection

Data for stem height was collected by measuring the height of the stem using meter rule. The stems were cut 10 cm above ground at different booting stages and at the last node. The leaves were removed from the base to flag leaf node of the plant before measuring as shown below in figure 5.

Figure 5: Measuring the stem's height (cm)

3.5.3: Stem Diameter Determination Data Collection

The circumference of the sweet stem sorghum (mm, taken from 20 cm above base), was measured using veneer caliper as shown in figure 6. With the help of an assistant each sweet sorghum stem was placed in a vertical position with the assistant holding the stem. The researcher then used a veneer caliper and measured the circumference of the stem at 20cm above the ground level. The measurement was then recorded on a data sheet.

Figure 6: Using Vernier caliper to determine the circumference of the stem of sweet sorghum.

3.5.4 Stem Weight and Sugar Yield Determination / Extraction Techniques Data Collection

Ten randomly selected stems (Figure 7) in each plot were harvested for sugar content determination at different stages of growth, starting at booting stage.

Figure 7: Stems harvested by randomization during the second trial.

The stems were measured, weighed and then cut into pieces, finely ground, using a hand-driven sugar-cane extractor to squeeze the stalks through a roller mill (figure 8).

Figure 8: Juice extraction process

Juice and sugar recovery increased with reduced roll gap, but tighter crushing led to more frequent blockages in the mill.

Juice collected was filtered by filter papers into small reagent jars (figure 9a) and the sugar content (Brix %) was determined by using hand-held field / laboratory refractometer (figure 9b-d). Data collected were recorded on plot mean basis.

A

B

C

D

Figure 9: Laboratory activities during the testing for brix value

The framework of the process is illustrated below:

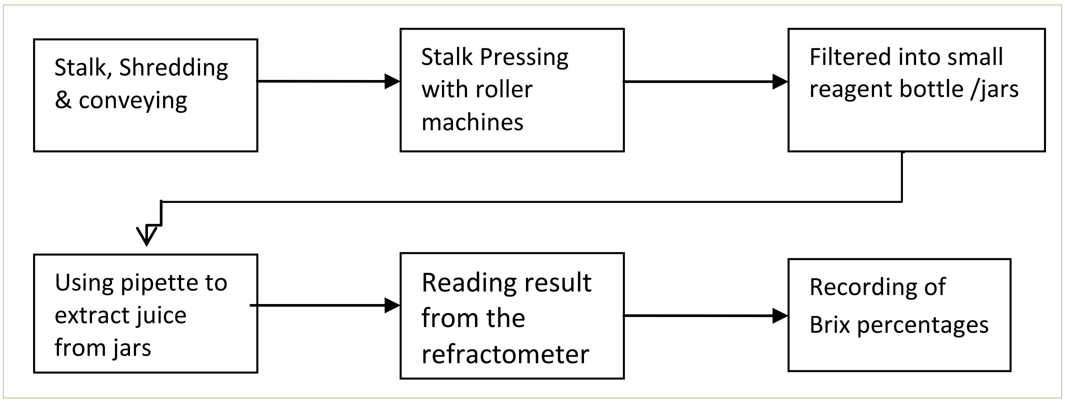


Figure 10: Major processes involved in juice extraction from sweet stem sorghum for optimum brix sugar yield determination for bio-ethanol production.

3.6 Response variables measurement

Response variables which were measured were (i) plant height at booting stage (m, taken from base to flag leaf node), (ii) thickness of stem at booting stage (cm, taken from 20 cm above base), (iii) mean stems weight (kg), (iv) percentage juice extracts (volume juice/mass stem weight), (v) percent Brix sugar content in the juice, (vi) percentage sugar in the stem (as derived variable $= Brix\ X\ Mean\ stem\ weight/100$), (vii) stem biomass yield per hectare (as derived variable $= mean\ stem\ weight\ \times plant\ population$) and

(viii) Sugar yield in tons per hectare

variable= $percentage\ stem\ sugar \times stem\ biomass\ per\ hectare$).

3.7 Data analysis

The data collected from the field and that generated from the measurements carried out were subjected to analysis using SPSS statistical package. All inferences were made at 5% level of significance (p = 0.05).

The following analyses were carried out:

(a) **Analysis of Variance (ANOVA):**

Data generated from the two trials were subjected to analysis of variance procedures as outlined by Gomez and Gomez (1984) to test for the existence of significant differences among treatments.

The pooled analysis of variance for the two seasons was based on the following mixed effects model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\Gamma)_{ik} + \varepsilon_{ijk}$$

Where:

Y_{ijk} is the plot mean for the ith harvest stage taken from the jth replication (block) in the kth season,

μ is the overall mean,

α_i is the effect if the ith harvest stage,

β_j is the effect of the jth block (blocks in season 1 and 2 being non-repetitive),

Γ_k is the effect of the kth season,

$(\alpha\Gamma)_{ik}$is the interaction of harvest stage and season,

ε_{ijk} is the random error.

Harvest stage was treated as a fixed effect, while the replication and season were random effects. Interactions for replication by treatment and replication by season were ignored and therefore included in the error term.

(ii) Mean separation by Least Significant Difference (LSD):

Means that showed significant differences were separated using the least significant difference (LSD) at 5% level of probability.

(iii) Sugar content: was analyzed by plotting the sugar content against the harvest time to see the sugar distribution in time and make inferences on the harvest window for maximum sugar yield.

(iv) Correlation analysis: was carried out with all the variables to determine which ones were most associated with sugar yield.

The researcher did not consider the use of Path Coefficient analysis in this research as the data generated were from experimental data and Path Coefficient analysis is often employed to test whether a particular set of non-experimental data fits well with a particular causal model (Wuensch, 2015).

(v) Linear modeling:

A regression analysis was performed to fit a linear model for predicting sugar yields under field conditions.

CHAPTER FOUR

RESEARCH RESULTS

4.1 Introduction

This chapter presents the results of the study based on the analysis of the data obtained from the field over the two periods. The significance of the findings are discussed and further compared to what other researchers on the subject have reported in the literature. The findings are then related to the aim and objectives of the research and the contribution of the research to knowledge.

4.2 Stand Establishment Percentage

The result of the experiment showed that the seeds took 5 - 7 days to sprout in each of the trials and stands establishment rate was 100% for each of the trials. The numbers of sprouted stands of sorghum for each plot were counted and the percentage stands establishment calculated based on the total number of stands planted per plot. Two seeds were planted per hole and about 95% germination was achieved. However, the feeble and unhealthy seedlings were thinned two weeks after germination, leaving one seedling to be established per stand. There were a total of 120 established stands of sorghum plants in each of the eighteen plots, giving a total of 2160 sorghum plant stands (Figure 11 - 12).

(a)

(b)

Figure 11: Sweet stem sorghum stands during first trial

Figure 12a: Sweet stem sorghum stands during second trial

Figure 12b: Sweet stem sorghum stands stressed by heavy rainfall, hailstorm, lodging and flooding during the second trial

Thinning sorghum is a very necessary agronomic practice as sorghum seeds are planted in holes. A crop such as sorghum with a high plant density requires thinning since the field may be adversely affected by drought if the prevailing climactic condition is dry. When thinning is postponed due to unfavorable climatic condition, and the failure rate is high, it is often more effective to re-sow eight days after the original seeds had germinated (Chantereau and Nicou, 1994).

4.3 Data Collected

The first trial was planted in the dry months of the year and grown under irrigation from February to June 2014 while the repeat trial was rain-fed in summer from October, 2014 to February 2015. Data collection for growth and sugar yield parameters of the first trial of the experiment (dry season cropping season) took place between April 1, 2014 and May 12, 2014 (6 weeks). Similarly, data collection for growth and sugar yield parameters of the second trial of the experiment (rainy season cropping season) was done between December 2, 2014 and January 15, 2015 (6 weeks). The data for growth and yield parameters were analyzed and results are shown in table 4.1 below.

Table 4.1: Parametric Analysis of Variance (ANOVA) for comparing effects of trial and period after booting of sweet stem sorghum on various parameters

Source of Variation	Parameter	P-Value
Trial	Brix sugar (%)	**0.047****
Period after booting	Brix sugar (%)	0.145n.s
Trial	Juice extract (ml)	0.55n.s
Period after booting	Juice extract (ml)	0.968n.s
Trial	Stem weight	**0.002*****
Period after booting	Stem weight	0.285n.s
Trial	Plant Height	**0.006*****
Period after booting	Plant Height	0.306n.s
Trial	Stem Biomass	**0.002*****
Period after booting	Stem Biomass	0.284n.s
Trial	Stem diameter	**0.024****
Period after booting	Stem diameter	0.619N.s

*** Significance at 1%; ** significance at 5%, * significance at 10% and n.s not significant

A two-way Fisher's parametric Analysis of variance was performed to compare various phenological phases of sorghum on different parameters tested. There was statistical significant difference in Brix sugar at 5% level across trial (Seasons) p-value=0.047. Stem weight, stem biomass and plant height were highly significant across trials with respective p-values 0.002; 0.002 and 0.006. All the parameters tested namely Brix sugar; juice extract; stem weight; plant height; stem biomass and stem diameter were not statistical significantly different across all the phenological stages of growth.

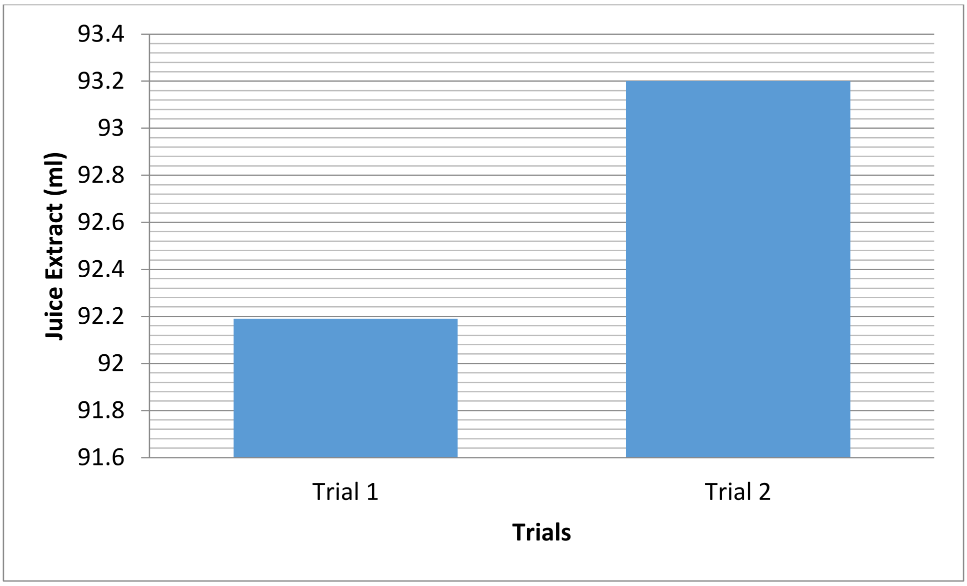


Figure 13: Average Juice extracted across the seasons

The results (Figure 13) above showed that a higher Juice extract was recorded during rainy season (Trial 2) with an average of approximately 93.2 ml. Dry season (Trial 1) gave a lower volume of approximately 92.19 ml.

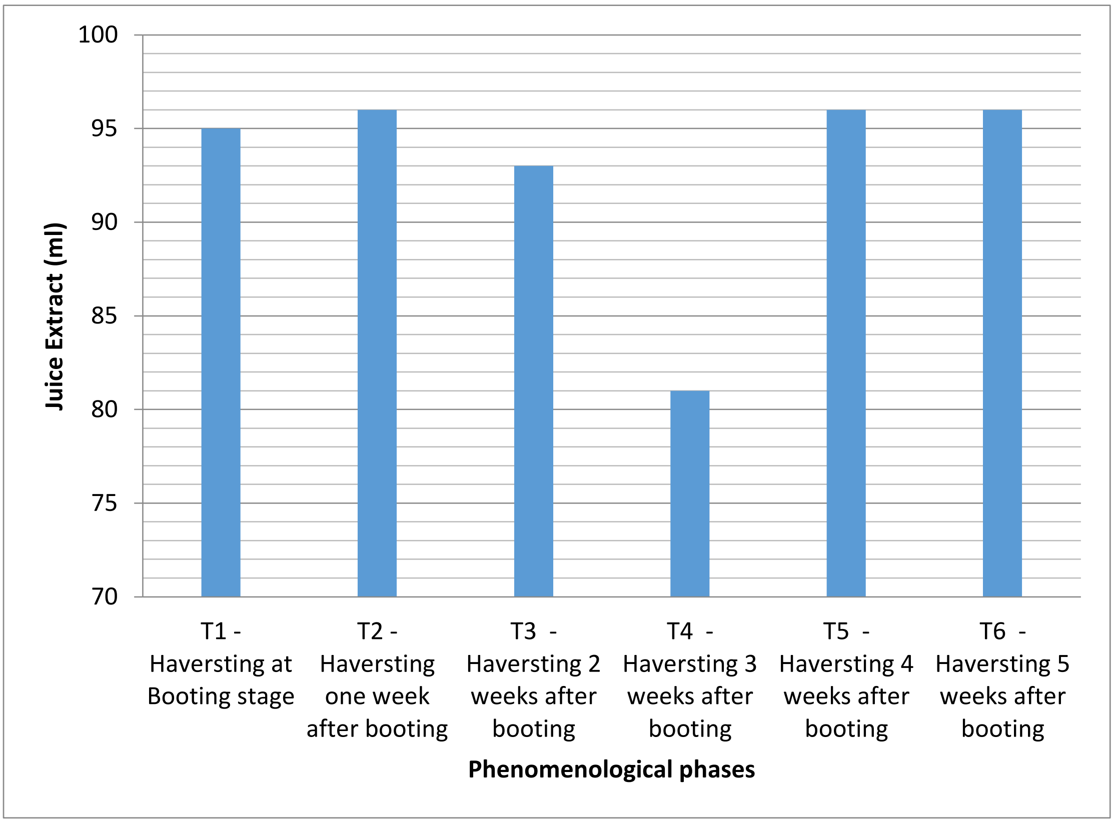


Figure 14: Comparison of volume of juice extracted across the different phonological phases of growth

Figure 14 shows the comparison of the volume of juice extracted across the different phenological phases of growth. The volume of juice extracted remained steadily high between 1WB and 3WB, above 90 ml. There was a sudden drop for the 4WB to below 85 ml and a sudden rise to slightly above 95ml for 5WB and BS.

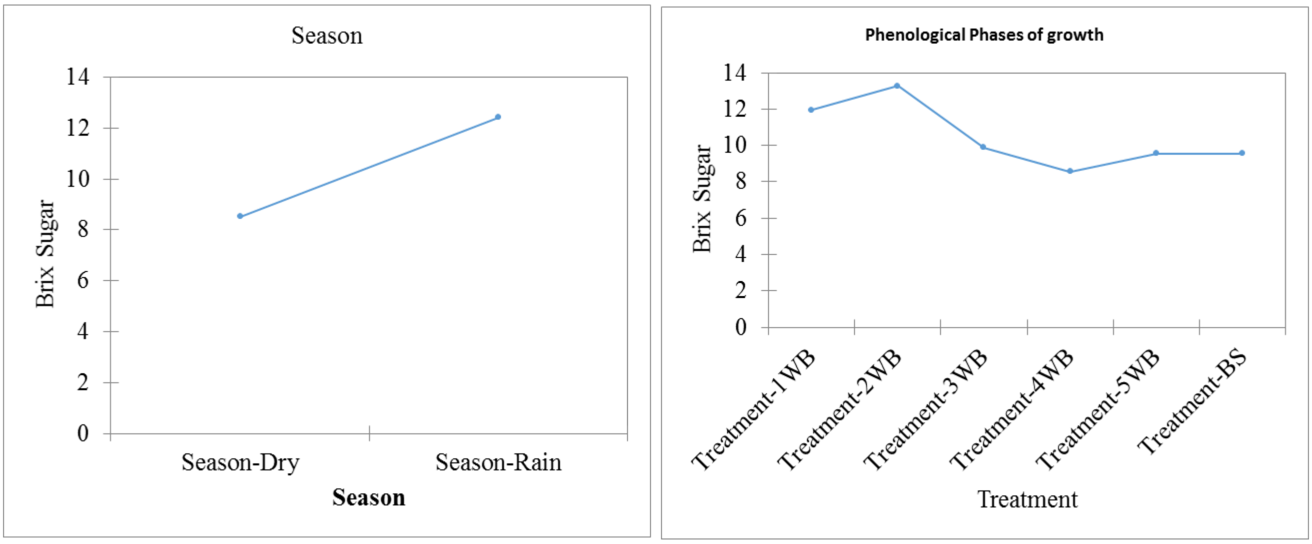


Figure 15: Comparison of Brix (%) sugar across seasons and across phenological phases of growth

Figure 15 shows the comparison of percentage Brix sugar across seasons and across phonological phases of growth. Higher percent brix sugar was recorded during the rainy season. 1WB and 2WB are favored for high percent brix sugar content but decline thereafter and reaching lowest at 4WB.

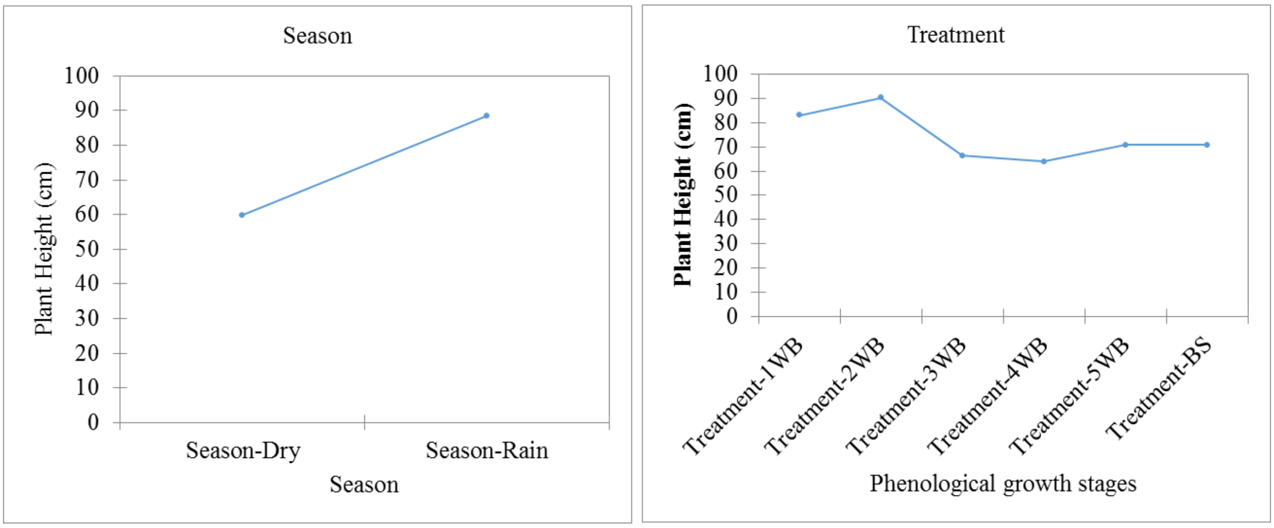


Figure 1 6: Comparison of plant height in cm across seasons and across phenological phases of growth

The results of the comparison of plant height (cm) across seasons and across phenological phases of growth (Figure 16) revealed that higher plant height was recorded during the rainy season, with the sweet stem sorghum reaching approximately 90 cm compared to almost 60 cm recorded during the dry season. 1WB and 2WB have higher plant height compared to any of the phenological phase of growth.

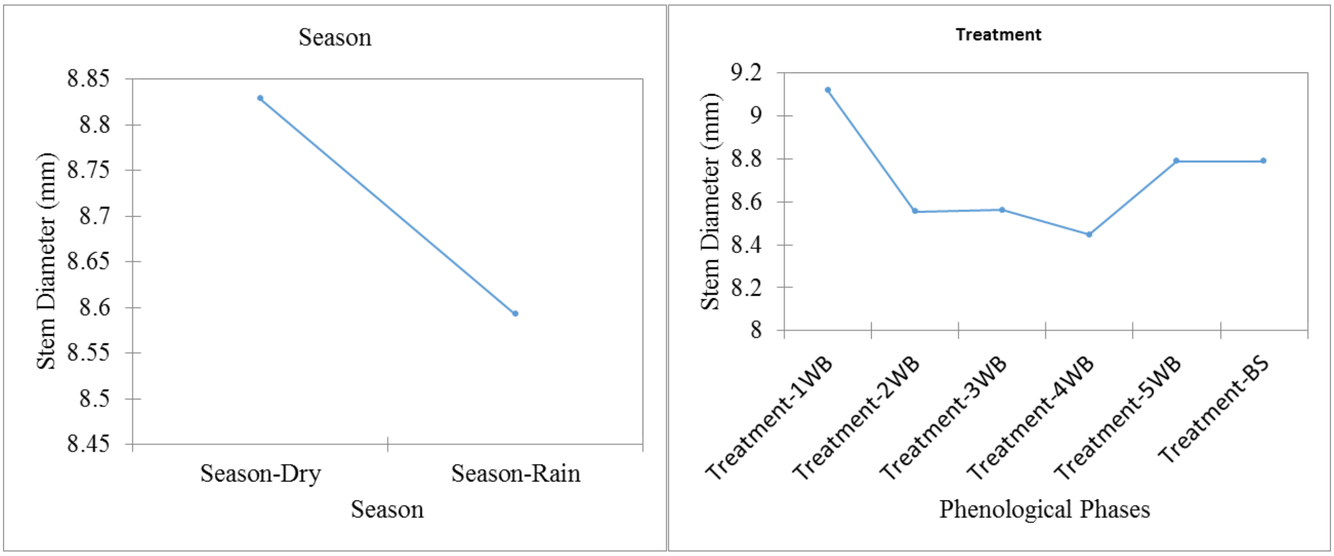


Figure 17: Comparison of plant stem diameter (mm) across seasons and across phenological phases of growth

As shown in Figure 17, the results of the comparison of plant stem diameter (mm) across seasons and across phenological phases of growth revealed that the greatest diameter was recorded during the dry season (above 8.8 mm) compared to 8.6 mm recorded in the rainy season. 1WB also gave the highest diameter compared to all phenological phases with the lowest being 4WB where approximately 8.5 mm was observed on average.

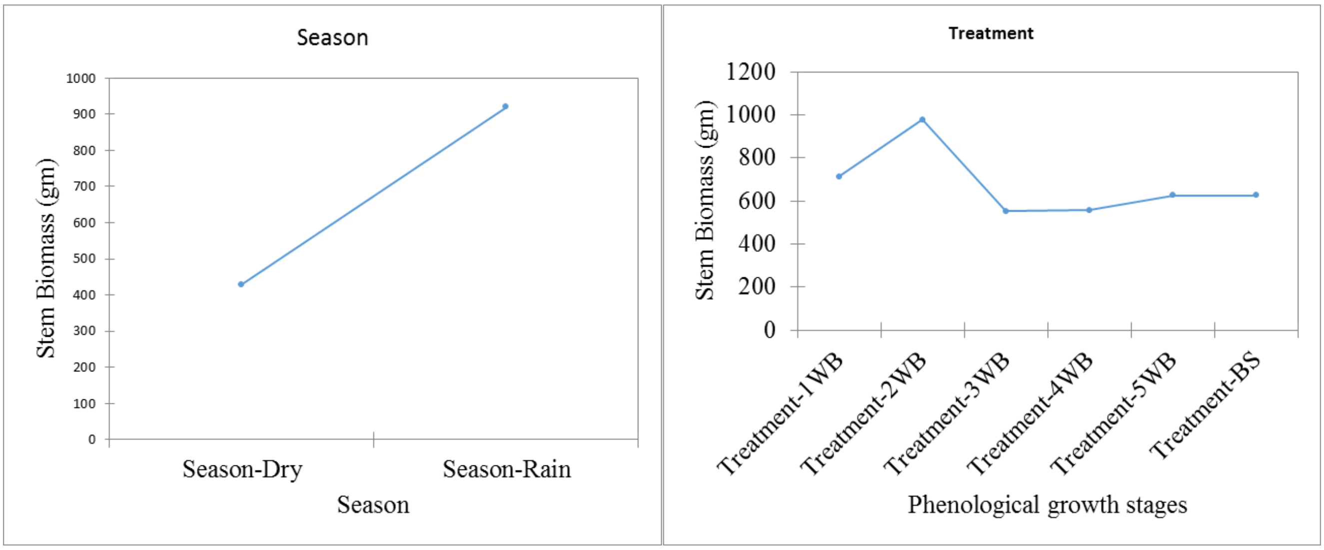


Figure 18 : Comparison of stem biomass (gm) across seasons and across phonological phases of growth

The results in Figure 18 above show the comparison of stem biomass (gm) across seasons and across phenological phases of growth of the sweet stem sorghum. Higher mean biomass was recorded during the rainy season and 2WB.

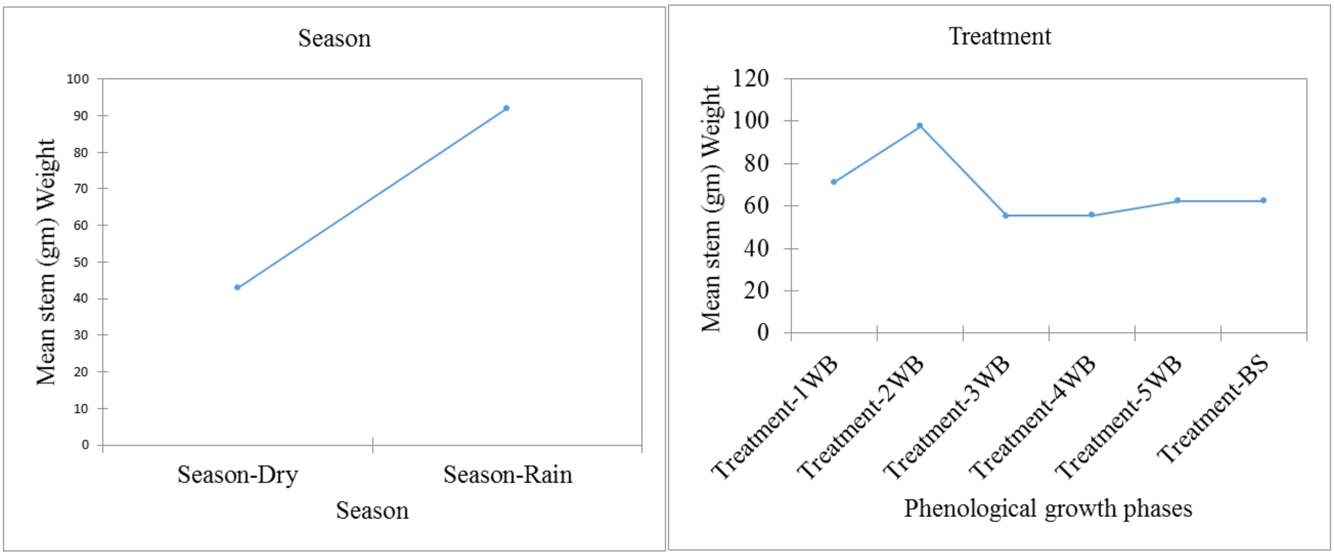


Figure 1 9: Comparison of mean stem weight (gm) across seasons and across phonological phases of growth.

The results in Figure 19 above show the comparison of mean stem weight (gm) across seasons and across pheonological phases of growth of the sweet stem sorghum. Higher mean stem weight was recorded during the rainy season and 2WB.

4.4 Correlations between Sampling Date and Brix Sugar Yield

The tables (Tables 4.2- 4.5) and the graphic representations below show the relationship between sugar yield and sampling date.

Table 4.2. Percentage brix sugar yield recorded weekly from 58 to 93 days after germination during trial 1

No of Days (X)	% Brix Sugar Yield (Y)
58	23
65	33
72	39
79	41
86	43
93	45

Table 4.3 : Correlation analysis between the days and percent brix sugar yield in trial 1

		Number of Days	Brix Sugar Yield
Number of Days	Pearson Correlation	1	.932
	Sig. (1-trial)		.007**
	N	6	6
Brix Sugar	Pearson Correlation	.932	1
	Sig. (1-trial)	.007**	
	N	6	6

Table 4.4 Percentage brix sugar yield recorded weekly from 66 to 101 days after germination during trial 2

No of Days (X)	Brix Sugar Yield (Y)
66	21
73	27
80	29
87	30
94	40
101	48

Table 4.5. Correlation analysis between the days and percent brix sugar yield in trial 2

		Number of Days	Brix Sugar Yield
Number of Days	Pearson Correlation	1	.957
	Sig. (2-trial)		.003**
	N	6	6
Brix Sugar	Pearson Correlation	.957	1
	Sig. (2-trial)	.003**	
	N	6	6

** Correlation is significant at the 0.01 level (2-trial).

The results of the correlation analysis serve in informing that if sampling date is correlated to Brix sugar yield, then the variation in the yield of sugar can reasonably be expected by either earlier or later harvesting of the sweet stem sorghum plant. The correlation analysis between the two variables (Brix sugar yield and sampling date) in Trial 1 indicated a strong correlation (r = 0.932)**.** Similarly, the correlation analysis between the two variables (Brix sugar yield and sampling date) in Trial 2 also indicated a strong correlation (r = 0.957). The analysis did not use the exact same number of days after germination for Trial 1 and Trial 2 for brix sugar variation analysis as the main focus was to show if there was variation during the growth phase in the brix sugar in each trial. The choice of the initial days after germination for sampling of the brix sugar differed in the two trials based on assumed differences in sugar content because of seasonal variation.

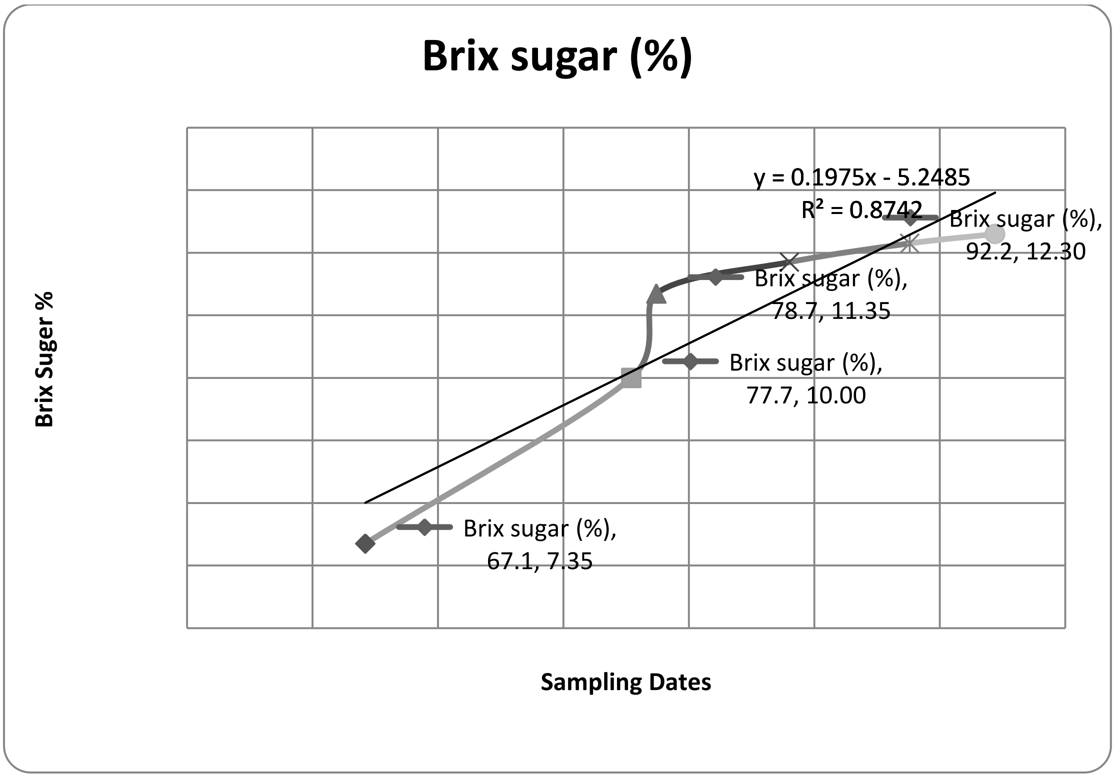


Figure 20: Relationship between sampling dates and percent brix sugar yield in trial 1

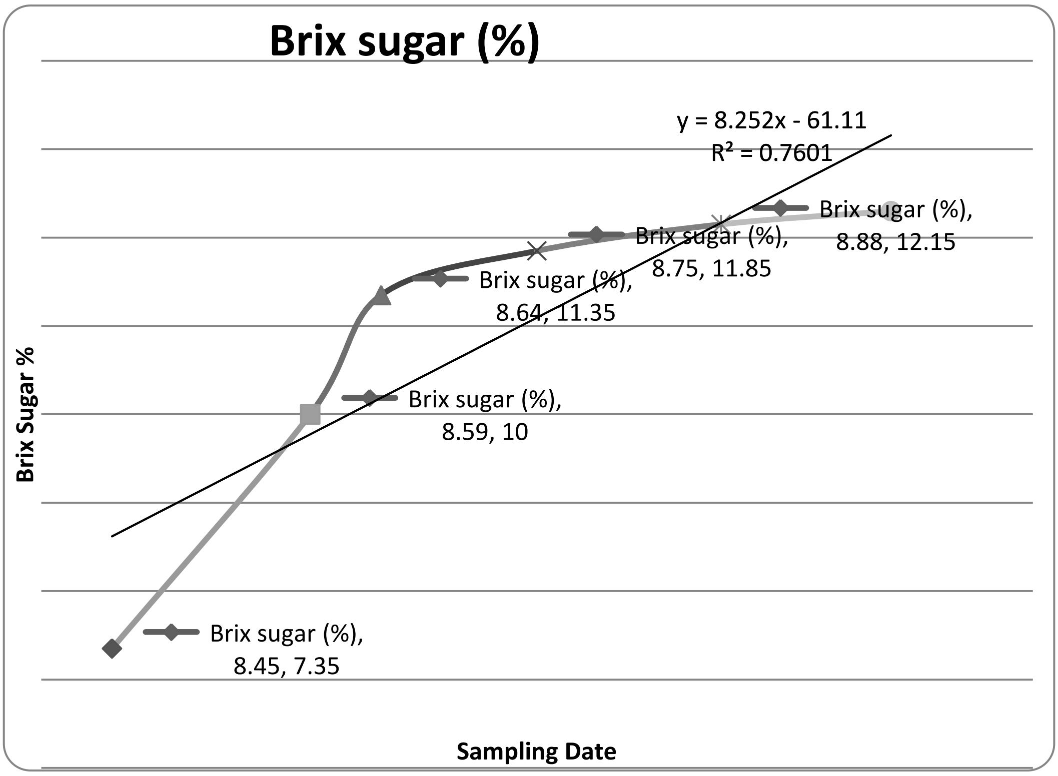


Figure 21. Relationship between Sampling Date and percent Brix Sugar Yield in Trial 2

The results in Figures 13 and 14 showed that seasons did not produce different effect with respect to the percent brix sugar yield. However the different booting stages gave statistically significant different percent brix sugar yields at 5%, p-value=0.028. Pair-wise comparison using Fisher's protected Least Significance Difference was performed for the different harvesting stages in order to find out which treatment means or growth stage had highest percent brix sugar yield.

***** See Appendixes 1 and 2 for raw data.**

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter presents the discussion of the main findings of this research and compares it to what other researchers have reported on similar studies in the literature that the researcher reviewed. The purpose of the research was to determine the appropriate harvesting stage of sweet stem sorghum for maximum sugar yield for bio-ethanol production in Namibia. The objectives of the research were to determine the growth stage at which sugar yield is highest and to determine the exact peak sugar accumulation in the stem of sweet stem sorghum cultivar in Namibia as well as determine if there are variations in the sugar yield during the growing season.

5.2 Growth parameters of the sweet stem sorghum during the irrigated and rain-fed cultivations

The research has revealed that the maximum height attained by sweet stem sorghum IS2331cultivar under dry, irrigated period in this study (Trial 1) was 95cm, reached 3 weeks after booting while under rain-fed conditions (Trial 2) the maximum height reached was 89.33cm, 5 weeks after booting. There were some variations in the heights of the sweet stem sorghum for both trials during the growth stage but the mean height was 78.26cm and 73.71cm for Trial 1 and Trial 2 respectively. The results of this study revealed that there was no significant difference ($p = 0.05$) in the mean plant height of the sweet-stem sorghum IS 2331 cultivar used in both trials I and 2 established in the dry (February to June 2014) and rainy (October 2014 to February 2015) seasons respectively.

The stem diameter of the plants also showed little variation between trial 1 and trial 2 during the growth phase with maximum stem diameter of 9.16cm reached during trial 1 and 9.03cm during trial 2. Furthermore, the percentage juice extract did not vary significantly between seasons. During trial 1, the maximum brix sugar concentration achieved was 13.7%, 3 weeks after booting and during trial 2; the maximum brix sugar concentration was 12.3% which was achieved 5 weeks after booting. No significant differences at the 5% level of significance were therefore found for the stem diameter and sugar concentration in sweet stem sorghum under trial 1 and trial 2. This suggests that the sweet-stem sorghum IS 2331 cultivar could be cultivated under both seasons in Namibia.

The mean stem weight obtained was however, higher in trial under dry season condition. There was significant variation in the stem weight during the growth phase during trial 1 (irrigated) and maximum weight of 802.04 gram was recorded 3 weeks after booting and the mean weight under trial 1 was 651.72 grams. During trial 2 (rain-fed), the maximum weight achieved was 767.5 grams, 5 weeks after booting and the mean weight was 648.2 grams. This suggests that much water supply may not be required for high stem weight development of sweet-stem sorghum IS 2331 cultivar and the plant could grow well under dry season conditions or sparingly water supply conditions.

The mean brix percentage of the extracted juice was 11.8 % in trial I and 9.8 % in trial 2, with coefficients of variation of 5.0 % and 14.5 % respectively. The brix percentage increased significantly until it peaked at 4 and 5 weeks after booting. This suggests that this sweet sorghum cultivar could be harvested for bio-ethanol production at about five weeks after booting. The fact that the brix percentage (sugar yield) increases after the booting and remains nearly constant at weeks 4 and 5 of reproductive phase gives a wide window in which to harvest sweet-stem sugar IS 2331 for bio-ethanol production.

The fact that the stem brix percentage increases after booting and peaked at weeks 4 and 5 in this study led to not accepting the null hypothesis that there is no significant difference in stem sugar concentrations of sweet stem sorghum IS 2331 cultivar at any time of harvest during the reproductive stage. Furthermore, the 5th week after booting showed the stage of physiological maturity of the sweet stem sorghum but the grains still contain high moisture and could not be harvested for long storage. This again led to not accepting the null hypothesis that there is no significant difference between maximum stem sugar concentrations and grain maturity. The study revealed that the brix percentage concentration increases after booting and peaks at 3 weeks after booting when planted during the dry season but rises steadily and peaks at 4 - 5 weeks after booting when planted under rainy conditions.

The study has also revealed that sweet stem sorghum IS2331 cultivar is adversely affected by very cold conditions and flooding as experienced during the hailstorm and heavy convectional rainfall that occurred during the growth of the plants on 23rd January 2014 during trial 2, resulting in lodging, stress and partial lodging during the second trial. The experience is similar to the finding reported by Fedenko, Erickson and Singh (2015).

The results suggest that plant heights and stem diameters for trial 1 were indicative of the tolerance of sorghum to cool weather and low water supply. The mean night temperatures during the trial were in the range of 8 – 15 ˚C. Sorghum is adapted to high temperatures of 20 - 35 ˚C (Ustimenko-Bakumovsky, 1983). The result was not significant, however, in that it showed that under the weather conditions of Namibia’s north-central regions, sorghum can be grown in winter since it is not severely cold.

Plant heights and stem diameters for trial 2 were lower than trial 1 (see Table 4.4). Sorghum heights vary from 60 cm to 300 cm, depending on the variety (Ustimenko-Bakumovsky, 1983). The variety which was used for the trial, IS2331, was previously reported to have mean stem height of 155 cm at booting (Gwanama, 2011) at Ogongo—a site which is located 60 km north west of the current trial site. One reason that could be attributed for the poor performance during the current research was the adverse climatic condition during the growing season including the hailstorm, flooding and lodging experienced during trial 2.

The sugar yield per hectare reached a maximum of 116.33mls 3 weeks after booting during trial 1 and the mean sugar yield during trial 1 was 94.35mls. During trial 2, the maximum sugar yield per hectare was 126.67mls, also achieved 3 weeks after booting and the mean sugar yield per hectare was 93.17mls. The combined analysis revealed that except for the harvest at booting, the sugar yield per hectare was not significantly different for the rest of the harvest dates. The trait was stable with non-significant mean squares for season, although the trends were season-specific, as shown by significant mean squares for harvest date by season interaction (Table 4.7). The fact that sugar yield increases fairly quickly after booting, and remains nearly constant for most of the remaining reproductive phase gives a very wide window in which to harvest sweet-stem sugar for bio-ethanol production. However studies by (Ustimenko-Bakumovsky, 1983; and Aba *et al.*, 2004) showed that sugar yield is greatest towards the end of the reproductive phase, after which it begins to fall. The results of this study are in sharp contrast to that finding. One reason for the difference is that previous studies were confined to using the Brix concentration as an indicator of the sugar yield. This study has looked at the sugar yield itself by calculating it from the primary variables of Brix concentration, stem biomass and volume of the juice extract.

It is to be expected that the sorghum crop uses most of its photosynthetic assimilates in the vegetative stage for growth. However, in a variety selected for sugar concentration, the accumulation of sugars in the stems begins in the late vegetative stage and continues into the early reproductive phase. Thereafter, the sugar partitioning shifts in favour of grain formation (Hay and Walker, 1989). By the time grain filling has progressed to near completion, most of the leaves have begun drying up and are effectively assimilate sinks, rather than assimilate sources. During grain filling, as well as when most leaves become sinks, some of the simple sugars in the stems could be trans-located to the grain head, thereby reducing stem sugar content (Hay and Walker, 1989). In sugarcane (*Saccharum officinarium*) the sugar content declines after tasselling. To prevent the decline and prolong the harvest window, either plant hormones are sprayed on the crop to prevent tasselling or the crop is mechanically de-tasselled (Idem and Showemimo, 2004).

Perhaps inclusion in this of harvest dates beyond five weeks after booting could have shown declining sugar content. Nonetheless, in situations where the sorghum crop is grown solely for bioethanol production, late harvests would be unadvisable. The finding in this study that the sugar content is still stable until five weeks after booting (when physiological maturity has been reached) is significant in that it underscores that the IS2331 cultivar can be used to produce bioethanol and grain simultaneously. However, at five weeks after booting, the grain still has very high moisture content (harvest maturity not met) (Idem and Showemimo, 2004). Harvesting grain at that time may require further drying.

The trend for a reduction in the juice extract was only in the general sense as the direction and cause of the changes between harvesting intervals were not determined by this work. However, it could be suggested that the variance could be as a result of the moisture status of the soil before harvesting of the stems because drought or precipitation in the days before harvesting could reduce or increase sorghum stem juice, respectively (Idem and Showemimo, 2004). If this suggestion hold true, the amount of juice extract seems not to be a precise measure for field use in determining the time for stems harvesting. Furthermore, it can be generalised that in the very early stages of the reproduction phase, stems are juicer, albeit with low Brix sugar concentrations.

Harvesting date by season interaction for this trait was significant as this study has revealed, and the variation in the juice extract was season-specific: Season I, being an irrigated season, had more constant soil moisture, resulting in non-significant juice variation, while Season 2 was weather dependent.

Where a rain-fed crop is involved, the same result could be obtained by adjusting planting date so that stem harvest coincides with the recession of the rainy season. This scenario may be similar, but not completely the same as when sorghum is raised as a grain crop.

In the latter case, complete cessation of the rainy season would be desired so that grain moisture content falls below 16 % which is required for harvest maturity (Ustimenko-Bakumovsky, 1983; Obigbesan *et al.*, 1977 and Aba *et al.*, 2004). Harvest maturity is when a crop is dry enough to be stored after harvesting without the need for further drying. In the case of sweet-stem sorghum, only moderately low soil moisture would be desirable. If the harvest is well after the rain, the amount of extractable juice would be insignificant. If permanent wilting point is reached, most of the water in the plant is bound water which is held tenaciously by the plant matrix and not amenable for extraction (Idem and Showemimo, 2004).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Summary of major findings of the research

The main objective of this study was to determine the appropriate harvesting stage of sweet stem sorghum for maximum sugar yield per hectare for bio-ethanol production in Namibia. The research also aimed to determine the exact peak sugar accumulation period per hectare in the stem of sweet stem sorghum cultivar IS 2331 in Namibia as well as find out the variations in stem sugar yield per hectare within the growing season and identify constraints in the cultivation process. The research employed two trial periods for growing sweet stem sorghum.

The results of this study revealed that there was no significant difference ($p = 0.05$) in the mean plant height of the sweet-stem sorghum IS 2331 cultivar in the two trial periods/conditions – dry, irrigated condition and rain-fed condition. Furthermore, the percentage juice extract did not vary much between seasons. This suggests that the sweet-stem sorghum IS 2331 cultivar could be cultivated under both seasons in Namibia. The study revealed that the brix value reached a desirable level at 5 weeks after booting. This suggests that the sweet stem sorghum could be harvested for bio-ethanol and seeds production at about five weeks after booting. Also adverse weather and environmental conditions have detrimental effect on the growth and maturity as well as the sugar content of sweet stem sorghum cultivar in Namibia. However with good agronomic practices, the potential for large scale growth, harvesting and processing of sweet stem sorghum for bio - ethanol production is a possibility in Namibia.

6.2 Conclusion

The main finding of the research has highlighted that sweet stem sorghum can be planted in both the dry and rainy seasons in Namibia. There was no remarkable difference in the maximum sugar yield between the two trial periods. However, maximum sugar content varies during the growth phases and the research has indicated that the best harvesting time for maximum sugar content for bio-fuel is 2 weeks after booting. However, if this crop is to be harvested for bio-fuel and seeds productions, then the ideal stage of harvesting should be 5 weeks after booting. Though, more research would need to be done in order to determine the future direction and growth of the industry, including the possibility of harvesting sweet stem sorghum beyond 5 weeks after booting.

6.3 Recommendations based on study findings

The findings from the study has highlighted the need for more large scale studies using similar and other varieties of sweet stem sorghum to corroborate the findings from the present study. Also there is need to replicate the study in other locations, weather and soil conditions.

References

Aba, D. A.; Idem, N. A; Marley, P. S. and Maigida D.N. (2004): Sorghum. In: Idem N.U.A. and Showemimo, P. A. (Eds): Cereal crops of Nigeria: Principles of Production and Utilization pp 38-78.

Ado, S. G. Abubakar, I. U.; and Mani, H. (1999): Prospects of Extra-early Maize varieties in the Nigerian Savanna zones. In: Valencia *et al (*1999): Proceedings of National Maize Workshop. July 22-24, 1999.

Ajayi, O., Owonuti, J. J; Uyovbisere, E. O. and Zarafi, A. B. (1998): Climatic, Edaphic and Biological factors limiting pearl millet in Nigeria. Pp 9-13 In: Pearl millet in Nigerian Agriculture; Production, Utilization and research priorities. Proceedings of the pre-season of the nationally coordination and planning meeting of nationally coordinated research programme on pearl millet.

Almodares A, Taheri R, Safavi V. (2008): Sorghum, Botany, Agronomy and Biotechnology, JahadDaneshgahi of University of Isfafa ,Isfafa.

Alvira, P; Tomás-Pejó, E; Ballesteros, M. and Negro, M. J. (2010): Pre-treatment technologies for an efficient bio-ethanol production process based on enzymatic hydrolysis: A. Review. Bio-Resource Technology, 101, 4851–4861.

Amon, D. I. (1972): Influence of hydrogen ion concentration on the Growth of Higher Plants under Controlled Conditions. Plant Physiology, Vol.4. 17: 54 .

Amon, B. O. E. and Adetunji, S. A. (1970): Research Report No 55. Research Division, Ministry of Agriculture and Natural Resources, Ibadan, Nigeria.

Anthony, W. J. (1982): Proceeding of Sorghum and Millet. FAO, Rome.

Aves, J; Benkelman, W; Liebenberg, W and Mouton, D. (2000): *Agriculture in Context, Grade 9*. Longman Namibia (Pty) Ltd.

Awala, S. (2010): Evaluation of eight varieties of sorghum (personal communication)

Balat, M. (2007a): An overview of biofuels and policies in the European Union countries. Energy Sources, Part B, Vol. 2: 67–71.

Balat, M. (2007b): Global bio-fuel processing and production trends. Energy Exploit, Vol., 25: 195–201.

Balat, M. (2008): Global trends on the processing of bio-fuels. International Journal of Green Energy, Vol. 5: 22–38.

Balat, M. (2009): New biofuel production technologies. Energy EducSciTechnol. Vol. 22: 147–161.

Bencini, M. C. (1991): Post-harvest and processing technologies of African staple foods: A Technical Compendium. FAO Rome.

Bloodworth, M. E; Burleson, C. A. and Cowley, I. N. R. (1958): Root Distribution of Some Irrigated Crops using Undisrupted Soil Cores. Agro J 50: 317 – 320.

Bozbas, K. (2008): Biodiesel as an alternative motor fuel: production and policies in the European Union.

Bresler, E; McNeal, B.L. and Carter, D. L. (1982): Saline and Sodic Soils. Springer Verlag. Berlin.

British Petroleum Company [BPC] (2008). BPC Statistical Review of World Energy 2008 London: BP PLC.

Bryan, W.L. (1990). “Solid-state fermentation of sugars in sweet stem sorghum,” Enzyme and Microbial Technology, 12 (6) 437–442.

Cadenas, A. and Cabezudo, S. (1998). Biofuels as sustainable technologies: perspectives for less developed countries. Technology Forecast. Social Change, 58: 83–103.

Chantereau J., and Nicou, R. (1994). Sorghum. The Tropical Agriculturalist. Macmillan Publishers: London.

Chen, C.S., Lai, Y.W. and Tien, C.J. (2008): Partitioning of aromatic and oxygenated constituents into water from regular and ethanol-blended gasoline. Environ PollutionVol.156: 90–96.

Clashausen, C. (2007). Biofuels- what are the technical options? In: Wilcke, Angelika (ed.); Agriculture and Rural Development, 2007 (2): 25-27.

Condon, N., Klemick, H. and Wolverton, A. (2013): Impacts of Ethanol Policy on Corn Prices: A Review and Meta-Analysis of Recent Evidence. NCEE Working Paper 2013-05.

Coyle, W (2007): The Future of Biofuels: A Global Perspective. Amber Waves 5: 24–9.

Biomass and Bioenergy, Volume 8, Issue 6, Pages 401-409

Demibras, A. and Dincer, K. (2008): Sustainable Green Diesel: A Futuristic View. Energy Sources Part A 30:1233–41.

Demibras, A. and Karslioglu, S (2007): Biodiesel Production Facilities from Vegetable Oils and Animal Fats. Energy Sources Part A, 29: 133–341.

Demibras, A. (2005): Bioethanol from Cellulosic Materials: A Renewable Motor Fuel from Biomass. Energy Sources Part A. 27: 327–37.

Demibras, A. (2006): Global Biofuel Strategies. Energy EducSciTechnol 17: 33–63.

Demibras, A (2008a): Biodiesel: A Realistic Fuel Alternative for Diesel Engines. Chemistry and Material Science. London: Springer.

Demibras, A. (2008b): Biofuels Sources, Biofuel Policy, Biofuel Economy and Global Biofuel Projections. Energy Convers Manage, 49: 2106–16.

Demibras, A. (2008c): The Importance of Bioethanol and Biodiesel from Biomass. Energy Sources Part B, 3: 177–85.

Demibras, M.F. and Balat, M. (2006): Recent advances on the production and utilization trends of bio-fuels: a global perspective. Energy Convers Manage 47: 2371–81.

De Wet, J. M. J; Harlan, J. R. and Price, E. G. (1970): Origin of Variability in Spontania Complex of *Sorghum Bicolor*. AMJ Bot 53: 85 – 109.

Doggett, H. (1970): Sorghum. Longman, London.

Downes, R. W. (1972): Physiological Aspects of Sorghum Adaptation. In: Sorghum in Seventies. Oxford and IBH, London.

Dhaliwal, S.S; Oberoi, H.S; Sandhu, S. K; Nanda, D; Kumar, D. and Uppal, S. K. (2011): Enhanced Ethanol Production from Sugarcane Juice by Galactose Adaptation of a Newly Isolated Thermo Tolerant Strain of Pichia Kudriavzevii, Bioresource Technology, 102 (10): 5968–5975.

Dodić, S; Popov, S; Dodić, J; Ranković, J; Zavargo, ZandJevtić-Mučibabić R (2009): Bioethanol Production from Thick Juice as Intermediate of Sugar Beet Processing, Biomass and Bioenergy, 33 (5): 822–827.

Eastin, J. D (1983): Sorghum In: Potential Productivity of Field Crops Under Different Environments. International Rice Research Institute, Los Bonos, Philippines.

Energy Assessment, United Nations Development Programme, New York NY USA, 415-452.

Ensinas, A.V., Modesto, M., Nebra, S. A. and Serra, L. (2009). Reduction of irreversibility generation in sugar and ethanol production from sugarcane, *Energy*, 34 (5): 680–688.

European Commission [EC] (2001): European Transport Policy for 2010: Time To Decide. White Paper: Brussels.

European Commission [EC] (2003): Directive 2003/30/EC of the European Parliament and of the Council. Official Journal of the European Union, Brussels.

European Commission [EC] (2006): Green Paper ‘‘A European Strategy for Sustainable, Competitive and Secure Energy”: Brussels.

European Commission [EC] (2007): Strategic Energy Review – An Energy Policy for Europe: Brussels.

European Commission [EC] (2008): Proposal for a directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources: Brussels.

Explorable.com, (2009): Randomization. https://www.explorable.com/randomization, Accessed: December 9, 2015.

Food and Agricultural Organization FAO (1983): Processing and Storage of Food Grains by Rural Families FAO Agricultural Services Bulletin 53. FAO, Rome.

Fargione, J. (2008). Land Clearing and the Biofuel Carbon Debt. Science 319: 1235–1238.

Fedenko, J., Erickson, J. and Singh, M. (2015). Root Lodging Affects Biomass Yield and Carbohydrate Composition in Sweet Sorghum. Journal of Industrial Crops and Products 74 (2015) 933-938.

Fischer, G., Hizsnyik, E., Prieler, S., Shah, M.and vanVelthuizen, H. (2009). Biofuel and Food Security. OPEC Fund for International Development.

Fischer, K. S. and Wilson, G. L. (1971): Studies of Grain Production in Sorghum. Agro J 19; 532 – 538.

Frisby, J. C. and Schumacher C. G. (2002): Biodiesel Fuel. Retrieved from:
http://muextension.missouri.edu/xplor/agguides/agengin/go01990.htm.

Fritsch, Uwe R (2007): What is Driving Bioenergy's Exceptional Upswing? Agricultural and Rural Development 2/ 2007: 22 – 25.

Food and Agriculture Organization of the United Nations [FAO], (2008). The State of Food and Agriculture, Part I: Biofuels: Prospects, Risks and Opportunities.

Gehua, O; Zubaidha, P. K. and Ayyangar, N. R (2006): Tetrahedron Lett. 33, 4605.

Gnansounou, E; Bedniaguine, DandDauriat, A (2005): Promoting Bio-Ethanol Production Through Clean Development Mechanism: Findings and Lessons Learnt From ASIATIC Project. In: Proceedings of 7th IAEE European Energy Conference, Bergen.

Goldemberg J. (2008). Environmental and ecological dimensions of biofuels. In: Proceedings of the conference on the ecological dimensions of biofuels, Washington, DC, March 10; 2008.

Goldemberg, J. (2000). World Energy Assessment, preface, United Nations Development

Gomez, R. A. and Gomez, A. A. (1984): Statistical Procedures for Agricultural Research, New York, USA. John Will and Sons, P. 680.

Government of the Republic of Namibia (GRN, 2004): Namibia Vision 2030:

Policy Framework for Long-term National Development Summary Document, Windhoek, Namibia.Office of the President.Pp.7-11.

GreenFacts (2015).Liquid Biofuel for Transport Prospects, risks and opportunities,

http://www.greenfacts.org/en/biofuels/figtableboxes/figure-22.htm. Accessed: *November 8, 2015.*

Gwanama, C. (2011): Evaluation of sweet sorghum cultivars as multipurpose Crops. Year IIProject Technical Report Creative Entrepreneurs Solutions, Ondangwa, Namibia.

Gyalai-Korpos, M., Fülöp, T., Sipos B., and Réczey, K. (2012).Processing Sweet Sorghum: Handbook of research on educational communications and technology, 2nd Ed., (pp. 10211043).

Hansen G. (2004). Driving technology in the motor vehicle industry. In: Proceedings of the IPCC expert meeting on industrial technology development, transfer and diffusion, Tokyo, September 21–23, 2004.

Harmsen, P.F.H., Huijgen, W.J.J., BermúdezLópez, L.Mand Bakker, R.R.C (2010). Literature review of physical and chemical pre - treatment processes for lignocellulosic biomass, ftp://ftp.ecn.nl/pub/www/library/report/2010/e10013.pdf Accessed: November 16, 2015.

Hay, R. K.M. and Walker, A.J, (1989). An introduction to the physiology of crop yield. Longman/JohnWiley.

Hertel, T., Golub, A. Jones, A., O'Hare, M., Plevin, R. and Kammen, D.(2010). "Effects of US Maize Ethanol on Global Land Use and Greenhouse Gas Emissions: Estimating Market-mediated Responses." Bio - Science 60: 223–231.

Hoekman, S.K. (2009): Biofuels in the US – challenges and opportunities. Renew Energy, 34: 14–22.

Hossain, A.B.M.S. and Fazliny, A.R. (2010). Creation of alternative energy by bio-ethanol production from pineapple waste and the usage of its properties for engine, African Journal of Microbiology Research, 4 (9): 813–819. http://www.greenfacts.org/en/biofuels/l-2/1-definition.htm. Accessed: December 9, 2015

http://www.ide-jetro.jp/English/Publish/Download/Dp/pdf/109.pdf**,** Accessed: December 9, 2015.

http://www.nrel.gov/biomass/glossary.html#E, Accessed: December 9, 2015.

Huang, H., Khanna, M., Onal, H. and Chen, X. (2013). Stacking low carbon policies on the renewable fuels standard: Economic and greenhouse gas implications. Energy Policy 56 (May 2013): 5-15.

Huber, G.W., Iborra, S. and Corma, A. (2006). Synthesis of transportation fuels from biomass: chemistry, catalysts, and engineering, Chem. Rev., 106, 4044−4098.

Idem, N. U. A. and Showemimo, P. A. (eds) (2014): Cereal crops of Nigeria principles of production and utilization pp. 38-78.

International Energy Agency [IEA]. (2008). Key World Energy Statistics 2008.Paris, OECD/IEA.

Irvine, F (1979): West African Crops. FAO Rome Doggett, H. (1979): Sorghum London.

ICAR (2009): Handbook of Agriculture. Indian Council of Agricultural Research, New Delhi.

ICAR (1980): Jowar. Indian Council of Agricultural Research, New Delhi.

Walter, Arnnold (2007): Is Brazilian Bio-fuels experience a model for other developing countries? In: Wilcke, Angelika (ed): Agriculture and Rural Development.(20).40-41.

Jank, M.J., Kutas, G., Amaral, L.F. andNassar, A.M. (2007). EU and US policies on biofuels: potential impacts on developing countries. GMF study, The German Marshall Fund, Washington, DC.

Jansen, J.C. (2003). Policy support for renewable energy in the European Union. Energy Research Centre of the Netherlands, ECN Publication, ECN-C-03-113; October 2003.

Jefferson, M. (2000). Energy policies for sustainable development, in: Goldemberg J, World

Jull, C., Redondo, P.C., Mosoti, V. andVapnek, J. (2007). Recent trends in the law and policy of bioenergy production, promotion and use. Legislative Study 95, Food and Agriculture Organization of the United Nations, FAO, Rome.

Kaltner, E; Yamaguchi, M; and Mukaiyama, T (2005): Supply Security: Biomass as a Home Grown Energy Source. Chem. Abstr. 101: 636.

Kaigama, B. K; Teare, I. D; Stone, L. R and Powers, W (1997): Root and Top Growth of Irrigated and Non – Irrigated Grain Sorghum. Crop Sci 17: 535 – 539.

Karakezi, J (2004): Bio Energy's Exceptional Upswing. Agriculture and Rural Development 2: 22 – 25.

Kelly, A. Fenwick (2013): Seed Production of Agricultural Crops. Scientific Publishers, India pp 65 – 95.

Kitani, O.; Jungbluth T.; Peart, M. andRamdani. A. (1999).*CIGR Handbook of Agricultural Engineering*, vol. 5: Energy and Biomass Engineering. ASAE. St. Joseph.

Kline, K.L., Oladosu, G.A., Wolfe, A.K., Perlack, R.D., Dale, V.H. and McMahon M. (2007): Biofuel feedstock assessment for selected countries. Oak Ridge National Laboratory Report,ORNL/TM-2007/224, Oak Ridge, Tennessee.

Lall, S. B and Sankhare, R. S. W (1970): Salt Tolerance in Jowar. Botanique 1: 23 – 28.

Lingegowda, B. K; Inamdar, S. S and Krishnamurthy, K (1971): Effect of Date of Planting on Yield of Sorghum. Indian J Agro 16: 155 – 156.

Li Guiying, GuWeibin , Alastair Hicks and Keith R. Chapman (FAO n.d.) : A training manual for sweet sorghum.

Lockman, R. B (1972): Mineral Composition of Grain Sorghum Plant Samples. Comm Soil Sci Pl Anal 3: 271 – 303.

Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Malça, J and Freire, F (2006): Renewability and life-cycle energy efficiency of bioethanol and bio-ethyl tertiary butyl ether (bioETBE): assessing the implications of allocation. Energy 31: 3362–80.

Meeser, Lechna (2008). Rangeland management .Joint Presidency committee (NAU and the NNFU), Windhoek, Namiba.56 pp.

Melillo, J., Reilly, J., Kickligher, D., Gurgel, A., Cronin, T., Paltsev, S., Felzer, B., Wang, X., Sokolov, A. and Schlosser, C.A. (2009). "Indirect Emissions from Biofuels: How Important?" Science 326 (5958): 1397-1399.

Mohan, S.V., Babu, V.L. andSarma, P.N. (2008): Effect of various pre-treatment methods on anaerobic mixed microflora to enhance bio-hydrogen production utilizing dairy wastewater as substrate. Bioresource Technol. 99: 59–67.

Mosnier, A. Havlik, P., Valin, H., Baker, J., Murray, B., Feng, S., Obersteiner, M., McCarl, B., Rose, S. and Schneider, U. (2013). The Net Global Effects of Alternative U.S. Biofuel Mandates: Fossil Fuel Displacement, Indirect Land Use Change, and the Role of Agricultural Productivity Growth. Energy Policy 57 (June 2013): 602-614.

Murty, D. S and Renard, C (2001): Sorghum In: Romain, H Raemaekers (ed): Crop Production in Tropical Africa. Directorate General for International Cooperation (DGIC), KarmelieTeustraat, 15 – Rue des PetitsCarmes 15, B – 1000. Brussels. Belgium. Pp 78 – 95.

Namibian Sun (2012).*Petrol prices reach record high*. Namibian Sun Newspaper.12March, 2012: p.12.

National Renewable Energy Laboratory [NREL] (2014):Glossary of biomass terms,

National Research Council [NRC] (2011): Committee on Economic and Environmental Impacts of Increasing Biofuels Production. Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy. Washington, DC: The National Academies Press.

New Era (2011).*Jatropha Mass Production Put On Hold*. Ministry of Information and Communications Technology, Windhoek, Namibia. Monday, June 6, 2011: p6.

Neuhaus, J (2006): Supply Security: Imports from Secure Countries. Spore 130: 24 – 25.

Nghithila, T. (2003).*Namibia and Climate Change*. Ministry of Environment, Windhoek.

Njoku, E. Nwoke P. I. O; Okonkwo, S. N. C. andOyolu, C. (1984): Pattern of growth and development in Dioscorearotundatapoir. Tropical Agriculture, 61: P 17-19.

Nkama, I (1993): Studies on Improving the Nutritional Quality of Masa – A Traditional Nigeria Fermented Cereal – Based Food. A Report. United Nations University, CF TRI, Mysore. India.

Nimbkar, N. and Rajvanshi, A. (2003). Sweet sorghum ideal for Biofuel – NARI.

Nield, R. F and Seely, M. N (1977): Growing Degree – day predictions for corn and sorghum development and some applications to crop production in Nebraska. RS Bull 280, AgricExp Stan.

Obasi, P. C. (2009). *The Trade – offs between Agro – Fuels Production and Food Prices*. Proceedings of the International Conference on Global Food Crises.Federal University of Technology, Owerri, Nigeria. April 19 – 24 p 270.

Obigbesan, G. O. Agbwla, A. A. and Fayemi, A. A. A. (1977): Effect of Potassium on tuber yield and nutrient uptake of yams. In: Proceedings of 4^{th} symposium of international, society for tropical crops CIAT, Cali, Columba, 1-7 August 1976.

Oliveria, M.E.D., Vaughan, B.E., Rykiel Jr, E.J. (2005). Ethanol as fuel: energy, carbon dioxide balances, and ecological footprint. Bioscience 55: 593–602.

Orkwor, G. C. and Ekan2ayake, I. J. (1998): Growth and development In: Orkwor, G. C; Asiedu, R and Ekanayake, I. J (eds): Food Yams Advances in Research. IITA/NRCRI (International Institute for Tropical Agriculture/ Natural Root Crops Research Institute and Cereal Research Institute), Ibadan, Nigeria. Pp 32 – 62.

Owen, G. H. (2009). *O- Level Agriculture*. Longman Group Limited, Essex, England.Oxford University Press, (2015). Bio-ethanol. http://www.oxforddictionaries.com/definition/learner/bioethanol,

Pai, A and Hukkeri, S. B (1979): Irrigation Requirements of Crops In: Manual on Irrigation Water Management. Dept of Agriculture, Krishi Bhavan, New Delhi.

Prihar, S. S and Sandhu, B. S (1987): Irrigation of Field Crops: Principles and Practices. Indian Council of Agricultural Research, New Delhi.

Ponniah, B. W. X and Appathurai, R (1953): Proper Time of Sowing Irrigated Millets in Kovilpathi. Madras Agric J 40: 532 – 536.

Pfuderer, S. anddel Castillo, M. (2008). The impact of biofuels on commodity prices. The Department for Environment, Food and Rural Affairs, DEFRA, London; April 2008.

Pradipta, H., Pieterinen, S., Pelkonen, P., Chang, C., Prokop, P. and Usak, M. (2011). Knowledge, perceptions and attitudes as predictors of youth's intentions to use bioenergy – a cross-national perspective.Journal of Applied Energy, vol 88, pp 1233-1240.

McGraw-Hill Dictionary of Scientific & Technical Terms, 6E. (2003): Refractometry.http://encyclopedia2.thefreedictionary.com/Refractometry, Accesseded: December 10, 2015

Renew Sustain Energy Rev. 12: 542–52.

Reddy, S. R (2012): Agronomy of Field Crops. Kalyani Publishers. Ludhiana. India. Pp 209 – 243.

Reddy, B. V. S., Ramesh, S., Reddy, P. S., Ramaiah, B., Salimath, M., Kachapur, R. (2005) *Sweet sorghum - a potential alternate raw material for bio-ethanol and bio-energy.* International Sorghum and Millets Newsletter, 46. pp. 79-86.

Rao, K. N (1971): Weather and Crop Yields. Pre Pub Sci Rep 137. Indian Meteorological Dept, New Delhi

Rosegrant, M.W, Zhu, T., Msangi, S. and Sulser, T. (2008).Global Scenarios for Biofuels.Impacts and Implications. Review of Agricultural Economics, 30(3), 495-505.

Ross, S. M. and Morrison. G. R. (2004). Experimental research methods, In D. J. Jonassen (Ed).

Rutto, K., Yixiang X., Brandt M., Ren S. and Kering M. (2013).Juice, Ethanol, and Grain Yield Potentials of Five Sweet Sorghum (*Sorghum bicolor* [L.] Moench Cultivars. Journal of Biosystems, 2013(3), p113-118.

Saintclair, P. M (1997): Root Growth of Cultivated Sorghum. Nat Can 104: 537 – 541.

Searchinger, T. 2008. Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 319: 1238-1240.Renewables 2005: Global Status Report. Notes and References Companion Document. Renewable Energy Policy Network for the 21st Century. http://www.ren21.net, Accessed: November, 7 2015.

Semelsberger, T.A.; Borup, R.L.; and Green, H.L. (2006).Ethanol *Production from Sweet Sorghum Syrup for Utilization as Automotive Fuel in India* [online].Available at http:// www.scribd .com / doc. Accessed 10th August 2011.

Sipos, B., Réczey, J., Somorai, Z., Kádár, Z., Dienes, D. andRéczey, K. (2009). Sweet sorghum as feedstock for ethanol production: enzymatic hydrolysis of steam pretreated bagasse, Applied Biochemistry and Biotechnology,153, 151–162, DOI 10.1007/s12010-008-8423-9.

Slade, R.B. (2009). Prospects for cellulosic ethanol supply-chains in Europe: a techno-economic and environmental assessment, in Centre for Process Systems Engineering and Centre for Environmental Policy, University of London, P170.

Spore 130 (2007): Carbon Market: A Golden Opportunity? CTA, Wageningen, The Netherlands.

Singh, Mahendra; Krantz, B. A and Baird, G. B (1972): Agronomic Production techniques. In: Sorghum in Seventies. Oxford and IBH, London.

Stehn, Helmut (2008): Rangeland Management. Joint Presidency Committee (NAU and the NNFU), Windhoek, Namibia. 56pp.

Stevens,D.J., Wörgetter, M. & Saddler, J. (2004). Biofuels for transportation: an examination of policy and technical issues. IEA Bioenergy Task 39, Liquid Biofuels Final Report 2001–2003, Paris.

Suresh, K.P. (2011). An overview of randomization techniques: An unbiased assessment of outcome in clinical research, J Hum Reprod Sci. 4(1): 8–11. Doi: 10.4103/0974-1208.82352.

Takavarasha, T., Uppal, J. and Hongo (2005).Feasibility study for the production and use of biofuel in the SADC region.

TERI (2005): Transterification. Energy and Climatic Division, Institute of Applied Ecology. Pp 22 – 28.

Thamsiriroj, T. and Murphy, J. D. (2009). Is it better to import palm oil from Thailand to produce biodiesel in Ireland than to produce biodiesel from indigenous Irish rape seed? Appl Energy, 86: 595–604.

The Southern Times (2011). *Zim Benefits From Going Green*. The Southern Times. Namzim Property Limited, Windhoek, Namibia. 02-08 December, 2011: p.13.

The Namibian Newspaper (2012): Petrol Prices Reach Record High. March 15

Tokgoz, S.(2008). The impact of energy markets on the EU agricultural sector. In: Proceedings of the 12th congress of the European Association of Agricultural Economists – EAAE 2008, Ghent, Belgium, August 26–29; 2008.

Trouslot, M. F. (1982): Croissance of tube Afisationrisation chez quatre cultivars du complex Discoreacayenesis, D. rotundata. In: Yam ignames, 118 – 146(eds: J. Mie Age and N. Lyonga). Oxford University Press.

Ueki, Y. (2007). Industrial development and the innovation system of the ethanol sector in Brazil, a discussion paper No. 9,

United Nation Environmental Protection [UNEP] (2010): Gain or pain? Biofuels and invasive species.http://www.issue%20paper3-biofuels-and-invasive-species.pdf*(Accessed: November 7, 2015).*

United States Environmental Protection Agency [US EPA]. (2010). Renewable Fuel Standard Program (RFS2). Regulatory Impact Analysis. Available at http://www.epa.gov/otaq/renewablefuels/420r10006.pdf (PDF) *(Accessed: November 8, 2015).*

University of New Hampshire (undated).Randomized Complete Block Designs [online].Accessed 2nd January, 2017. Available at: www.unh.edu/halelab/BIOL933/lectures/lect_9_reading.pdf.

Ustirnenko-Bakumousky, G. V. (1983): Plant Growing in the tropics and sub-tropics. MIR publishers Moscow, P72 – 82.

Vanderlip, R. L (1992): How a Sorghum Plant Develops. Cooperative Extension Service, Kansas State.Uni Madison. USA.

Vanderlip, R. L and Reeves, H. E (1972): Growth Stages of Sorghum. Agro J 64: 13 – 16.

Venkateswarlu, J and Singh, S. N (1982): Crop Management to Mitigate Soil Moisture Stress. In: Fifteen Years of Agricultural Research under CRIDA, Hyderabad, India.

Vovilov, V. M (2013): Sorghum Adaptation In: Sorghum in the 21st Century. Am J. bot 107. 85 – 109.

Vogel, S and Graham, M (1979): Sorghum and Millet. Food Production and Uses. International Development Research Centre Publication, IDRC. 123e.

Wang, G., Lixin, Z., Yanli, Z., Yujie, F., Huba, E. M., Dongsheng, L., Shizhong, L., Dehua, Landmang, H.P. (2006). Liquid bio-fuels for transportation: Chinese potential and implications for sustainable agriculture and energy in the 21st century. Assessment Study, Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing.

Wiesenthal, T., Leduc, G., Christidis, P., Schade, B., Pelkmans, L. and Govaerts L. (2009). Biofuel support policies in Europe: lessons learnt for the long way ahead. Renew

Sustain Energy Rev.13: 789–800.

Wilson, M. (2007): Building on bio-fuel production opportunities, http://www.scidev.net/global/biotechnology/opinion/building-on-biofuel-production-**o**pportunities.html **(***Accessed***:** *November 7, 2015).*

Wilcke, Angelika (2007): The Importance of Bioenergy for Developing Countries. In: Wilcke, Angelika (ed): Agriculture and Rural Development. 2007(2): 25 – 27.

Wilsie, Carrol P (1962): Crop Adaptation and Distribution. W. H. Freeman and Co. San Francisco and London.

World Map (undated): Political Map of Namibia. Accessed on line on 20th November, 2015 at www.worldofmap.com.

Wuensch K. (2015). An introduction to Path Analysis [online].Accessed from http//core.ecu.edu/psyc/wuenschk/MV/SEM/Path.pdf.

Yacobucci, B.D. and Schnepf, R. (2007): Ethanol and bio-fuels: agriculture, infrastructure, and market constraints related to expanded production. CRS Report, Washington, DC: Congressional Research Service, RL33928, March 16; 2007.

Yu, J., Zhang, T., Zhong, J., Zhang, X. and Tan, T. (2012). Biotechnol Adv. 30(4):811-6. Doi: 10.1016/j.biotechadv.2012.01.014.

Zabed, H., Faruq, G., Sahu, J.N. Azirun, M.S., Hashim, R. and Boyc, A.N. (2014).Bio-ethanol production from fermentable sugar juice. The Scientific World Journal, http://dx.doi.org/10.1155/2014/957102 pp1-11**.**

Zarzyycki, A. and Polska, W. (2007). Bioethanol production from sugar beet: European and polish perspective. The first TOSSIE workshop on technology improvement opportunities in the Europea sugar industry, Ferrara, Italy, January 25–26; 2007.

Zhang, W., Yu, E., Rozelle, S., Yang, J. and Msangi, S. (2013). The impact of biofuel growth on agriculture: Why is the range of estimates so wide? Food Policy 38: 227–239.

APPENDIX 1

FIRST TRIAL: RAW DATA COLLECTION

	FROM 1^{ST} APRIL TO 12^{TH} MAY,2014											
Treatment	**Replication**	**Brix Sugar**	**Plant Height (cm)**	**Stem Diameter (mm)**	**Stem Biomass (gm)**	**Mean stem (gm) Weight**	**% Juice Extract (ml)**	**% Juice Extract (ml)**	**Brix %**	**Plot**	**Block**	**Treat**
Booting Stage	A	7	43.9	8.57	311.32	31.132	70	11.3%	7	3	A	1
1WAB	A	14	62.2	9.88	443.01	44.301	70	11.3%	14	6	A	2
1WAB	A	5	86.2	9.64	857.83	85.783	155	25.1%	5	5	A	3
Booting Stage	A	7	60.4	8.73	237.19	23.719	140	22.7%	7	1	A	4
1 WAB	A	14	77.3	9.5	546.21	54.621	60	9.7%	14	4	A	5
Booting Stage	A	9	45.5	8.84	238.28	23.828	122	19.8%	9	2	A	6
2WAB	B	12	69.3	9.62	491.06	49.106	60	10.4%	12	7	B	1
3WAB	B	12	83	8.8	849.55	84.955	110	19.0%	12	11	B	2
3WAB	B	13	86.3	8.32	850	85	90	15.5%	13	10	B	3
2WAB	B	12	79.1	8.11	1109.46	110.946	139	24.0%	12	8	B	4
2WAB	B	15	82.73	9.01	967.45	96.745	100	17.3%	15	9	B	5
3WAB	B	16	79.5	8.15	635.36	63.536	80	13.8%	16	12	B	6
5WAB	C	12	93.6	9.2	1151.3	115.13	90	17.9%	12	17	C	1
5WAB	C	7	88.6	8.58	1088.96	108.896	80	15.9%	7	16	C	2
4WAB	C	12	65.1	7.43	698.32	69.832	102	20.3%	12	14	C	3
4WAB	C	13	94.6	8.53	716.73	71.673	70	13.9%	13	15	C	4
4WAB	C	15	64.4	7.71	698.44	69.844	70	13.9%	15	13	C	5
5WAB	C	13	86.8	8.35	878	87.8	90	17.9%	13	18	C	6

Appendix 2

SECOND TRIAL: RAW DATA COLLECTION

FROM 20TH DEC 2014 TO 2nd FEBRUARY 2015

Treatment	Replication	Brix Sugar	Plant Height (cm)	Stem Diameter (mm)	Stem Biomass (gm)	Mean stem (gm) Weight	Juice Extract (ml)	% Juice Extract (ml)	Brix %	Plot	Block	Treat
Booting Stage	A	7	44.2	8.3	288.9	28.9	68	12.2 %	7	3	A	1
Booting Stage	A	6	59.9	9.5	451.8	45.2	65	11.7 %	6	6	A	2
Booting Stage	A	8	88.1	10.1	821.8	82.2	103	18.5 %	8	5	A	3
1 WB	A	7	63.0	8.7	222.0	22.2	133	23.9 %	7	1	A	4
1WB	A	10	74.9	9.2	523.6	52.4	82	14.7 %	10	4	A	5
1WB	A	10	49.2	8.5	211.6	21.2	105	18.9 %	10	2	A	6
2WB	B	12	57.2	8.4	501.5	50.1	82	14.8 %	12	7	B	1
2WB	B	11	84.8	8.0	726.4	72.6	120	21.7 %	11	11	B	2
2WB	B	6	82.8	8.9	597.9	59.8	67	12.1 %	6	10	B	3
3WB	B	9	77.5	8.8	896.8	89.7	150	27.1 %	9	8	B	4
3WB	B	9	81.9	8.7	960.1	96.0	85	15.3 %	9	9	B	5
3WB	B	12	75.9	7.9	597.7	59.8	50	9.0 %	12	12	B	6
4WB	C	9	94,1	9.2	1206.3	120.6	84	14.8 %	9	17	C	1
4WB	C	7	87.9	9.0	1097.3	109.7	71	12.5 %	7	16	C	2
4WB	C	7	63.3	8.1	396.7	39.7	98	17.3 %	7	14	C	3
5WB	C	10	97.4	8.9	745.2	74.5	97	17.1 %	10	15	C	4
5WB	C	16	61.6	8.2	818.7	81.9	99	17.5 %	16	13	C	5
5WB	C	11	82.9	8.8	539.8	54.0	118	20.8 %	11	18	C	6

Appendix 3

Measuring stem weight (kg).