# The Effects Of Global Warming Towards Sugar Cane Farming In Tongaat Huletts –Tambankulu Estates Swaziland.

**By**

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**DECLARATION**

I Absalom Fana Xulu declare that

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(ii) This dissertation/thesis has not been submitted for any degree or examination at any other university.

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| BMP: | Best Management Practices |
| COMESA: | Common Market for Eastern and Southern Africa |
| EU: | European Union |
| FAO: | Food and Agricultural Organization |
| GAIN: | Global agricultural information network |
| IPCC: | Intergovernmental Panel on Climate Change |
| NDS: | The National Development Strategy, |
| RSE: | Raw Sugar Equivalent |
| RSSC: | Royal Swaziland Sugar Corporation |
| PCSE: | Panels Corrected Standard Errors (s) |
| SACU: | Southern African Customs Union |
| SADC: | Southern African development community |
| SARC: | Southern Africa Regional Resource Centre |
| SSA: | Swaziland Sugar Association |
| TSHA: | Tonnes Sucrose per Hectare |
| TCHA: | Tonnes Cane per Hectare |

## ABSTRACT

This study examined the effects of global warming on sugar cane farming in Tongaat Huletts –Tambankulu Estates in Swaziland, from the period of 2010 to 2015. The researcher adopted the conceptual and theoretical framework related to Global Warming and sugarcane production. Both quantitative and qualitative methods were utilised to capture the effects of global warming on cane production. In particular, the Ricardian production model and thematic analysis were adopted in the study. The study utilised monthly and yearly time series data for the period of 2010 to 2015, collected from Tongaat Huletts Tambankulu Estates, Swaziland.

The findings disclose significant non-linear effects of global warming on sugarcane production in Tongaat Huletts Tambankulu Estates, Swaziland. Observations were that sugarcane production has directly been affected by changes in global warming conditions. Global warming variables such as radiation, temperature and rainfall have negatively affected sugarcane production. The findings showed that for every additional degree in the celsius of temperature, the expected sugarcane production decreases on average, while holding other variables constant. Moreover, for every additional millimetre of rainfall, the expected sugarcane production decreases, and for every additional degree of radiation increase, the expected sugarcane production decreases.

In contrast, the findings revealed that the combination of water use of commercially rain-fed and irrigated sugarcane and increases sun appear, have positive effects on sugarcane production. For every millimetre in combination of water use of commercially rain-fed and irrigated sugarcane, the expected sugarcane production increases. Similar for every additional sun hours, the expected sugarcane production increases.

The findings also revealed that management ought to enhance and improve their knowledge and awareness of global warming and its impact on sugarcane production for better, all including holistic approach to mitigate this threat, especially during critical peak season. The study suggests that strategies adopted to mitigate the threat focus on farming practices that promote sugarcane production regardless of the dangers posed by higher levels of global warming variables (temperature, rainfall, and radiation).

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# CHAPTER ONE
# INTRODUCTION AND BACKGROUND

## 1.1 Introduction

Global warming and climate change have become a major concern for countries all over the world, including African countries. According to "regional climate projections given in the fourth assessment report of the Intergovernmental Panel on Climate Change" (IPCC, 2007), for Africa, "global warming is very likely to be higher than the global annual mean warming throughout the continent and in all seasons". In Southern Africa, for instance, rainfall appears to be decreasing in much of its winter rainfall region (Knox *et al.*, 2012). This assertion points out the importance of climate change as a factor in agricultural productivity, meaning that any extreme changes in climate, like global warming, would negatively affect agricultural production growth and other components of managing agricultural systems.

Many countries in Africa depend on agriculture as the main sector contributing to their economy and livelihoods, for large parts of the population (Waha *et al*., 2016). Africa is home for many smallholder farmers, while fields are heterogeneous and scattered with large varieties of crops. Sugarcane is among these crops, with its production covering more than half a million hectares spread across seven countries in Southern Africa (Waha *et al.*, 2016). Sugarcane is positioned as an important cash crop in the agrarian economy of Africa and Swaziland in particular. In Southern Africa, "sugarcane output produce has increased to 80% over the past 20 years, affecting land and water usage" (Dubb *et al.,* 2016:2). Sugarcane production in Southern Africa is considered as both commercial and developmental. Cane production growth occurs in poorest countries in the southern zone and oriented by commercial investments by South Africa-based companies.

In Swaziland, sugarcane is by far the most prevalent crop in irrigated agriculture areas (Dubb *et al.,* 2016). According to the National adaptation strategy (2010), more than "90% of Swaziland's allocated water is used for growing cane and 96% of all irrigation is in the Lowveld, within adequate rainfall reliable to feed cropping". However, "agriculture in Africa faces challenges such as climate change, population growth and urbanisation, and increased pressure on the land and water resources" (Waha, 2016). These challenges appear crucial to examine the dynamics of global warming and sugarcane production. The studies which relate to “good production of sugarcane in changing conditions of climate have become one among the front lines area of research and is a major concern to scientist's worldwide” (Srivastava and Rai, 2012). Several of these studies have investigated the impact of climate change on agricultural products and what potential farming strategies to adapt and mitigate the consequence (Binbol *et al*., 2006; Knox *et al*., 2012; Inman-Bamber &Smith, 2005; Santos and Sentelhas, 2012; Srivastava, and Rai, 2012; Zhao and Li, 2015; Zullo *et al*., 2008; Tarekegn, 2016). Although a significant amount of research has been done on these determinants, there remain insufficient studies on the effect of global warming on sugarcane farming in Tongaat Huletts Tambankulu Swaziland. It is therefore important that the Tongaat Huletts –Tambankulu in Swaziland comes to terms with this phenomenon under investigation and its diverse effects on sugarcane production to prepare for more optimised strategies to mitigate them and provide opportunities for improvements in productivity.

### 1.2 Context of the study

The study area is in Swaziland, “Swaziland is predominantly rural, landlocked country with a total land area of 17,364 square kilometres” and surrounded by the Republic of South Africa and Mozambique. Swaziland comprises “four distinct ecological regions including Highveld in the north, the west with mountainous scenery and high rainfall, the sloping east, through the intermediate Middleveld to the dry hot and relatively flat Low-veld” (Swaziland, 2016). Tongaat Huletts Tambankulu “Sugar Estate in Swaziland is in the north east of the country and comprises 3838 hectares of fully irrigated farms of which approximately 3740 hectares is harvested annually” (Tongaat Huletts, 2015). Thus, Swaziland ranches Pty (Ltd), trading as Tambankulu Estates, is an agri-business based on two privately owned agricultural estates astride the Black Umbuluki river in north eastern Swaziland.

#### 1.2.1 Location benefits

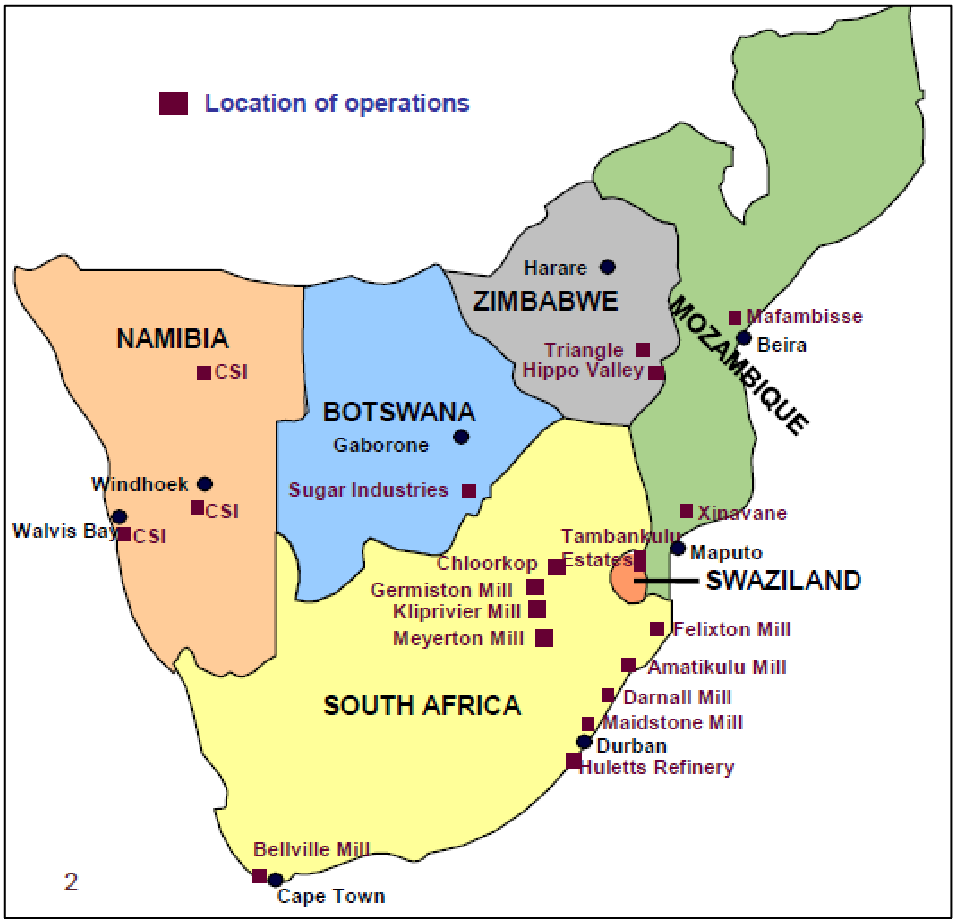
In Swaziland, sugarcane crop is one of the important crops and the main source of sugar production. Swaziland ranked the first grade in the unit area production, according to the absolute growing season. The country is a low-cost producer of sugar hence, it can suitably produce sugar (Dlamini and Masuku, 2013).

In 1955, irrigation works were established along the Umbulizi River and the production of sugarcane began. To date, “3833.67 hectares is under cane, generating 62000 tons of sucrose annually" (Tongaat Huletts, 2015). Furthermore, the estates cover the "good soil and growing conditions in the region and deliver its cane to the nearby Simunye and Mhlume sugar mills". "The estates have the capacity to produce a Raw Sugar Equivalent (RSE) of 60 000 tons per year" (Tongaat Huletts, 2015). More importantly, the estates yield and highly results are comparable to the best in the world.

### 1.2.2 Location Map

Figure 1 is the location map showing the operational locations of Tongaat Huletts in six countries including Botswana, Namibia, Mozambique, South Africa, Zimbabwe and Swaziland. As an agriculture and agro-processing company, Tongaat Huletts' operational focus in these countries has been on sugarcane and maize, with renewable energy prospects.

**Figure 1: Location Operations Map**




**Source: Tongaat Huletts, 2015**

## 1.3 Background of the study

This section presents the background of the study. According to Gornall et al. (2010:2974), the “nature of agriculture and farming practices in any particular locations are strongly influenced by the long-term mean climate trends”. They argue that the location of farmers, availability of infrastructures and practices determine the types of farming and the produce under current climate. “Agriculture is among the economic activities most vulnerable to climatic conditions” (Santos and Sentelhas, 2012; Zhao and Li, 2015:2). Santos and Sentelhas, (2012) indicated that “climate change has a strong impact on crop zoning, harvest and quality”. Vulnerability of agriculture caused by climate change presents direct and indirect effects on crop production in general (Zhao and Li, 2015). These effects include changing climate conditions in temperatures and or in precipitations. Furthermore, changing climate conditions ‘in the severity of pest pressures, availability of pollination services and performance of other environment services affects agricultural productivity’.

“Climate change poses unprecedented challenges to agriculture because of the sensitivity of agricultural productivity; costs of improving growth and environmental conditions” (Zhao and Li, 2015:2). All sugar cane in Swaziland is grown in the Lowveld under irrigation by four categories of growers. These are large “millers and estates accounting for 77 % of production, while large farmers account for 17 % of production, medium size farmers 5 % of production and small farmers account for 1% of production” (Hlophe, 2014 and Gain, 2015). The sugar industry is a key contributor to the Swaziland agriculture industry and the economy. The recent study indicates that “sugar production accounts for almost 60 percent of the total Swaziland agricultural outputs and contributes 10% to the country’s gross domestic product, as well as at least 16% to national employment” (GAIN report, 2016). The report also indicated that “Swaziland is Africa’s fourth largest producer of sugar, after South Africa, Egypt and Sudan, and is ranked 25th largest producer in the world”.

The most significant “challenge facing sugarcane production is the increasing frequency and intensity of extreme weather patterns, especially extreme drought during climate changes” (Zhao and Li, 2015:7). A study conducted by Binbol *et al*., (2006) on “the effect of climate on the growth and yield of sugar cane at Savannah Sugar Company in Numan, Nigeria confirmed” climatic variables or factors as significantly affecting the growth and yield of sugar cane. The results identified two critical factors influencing the sugarcane production, namely “pan evaporation at the boom stage and minimum temperature at germination stage”.

Regarding Swaziland, many studies have investigated the vulnerability of agricultural production and the impact of climate change On crop production and from various perspectives which include: Accordingly, many studies have assessed the impact of climate change on crops production these includes; (a) climate change and its variability on sugarcane production (b) rainfall use in planning (c) obsolete farming techniques and climatic condition variability and (d) spatial patterns and temperature changes in relation to sugarcane production. All these studies have assessed the impact of climate change on both resource availability (for irrigation abstraction) and water demand (for crop production) in Swaziland (Challinor *et al.,* 2005; Downing *et al.*, 1997; Kurukulasuriya and Mendelsohn, 2008; Knox *et al.,* 2010). Their findings point out that current peaks on existing capacity of irrigation schemes could fail to meet the predicted increases in irrigation demands in the future under unconstrained water availability. Despite the unique context of sugarcane production in Swaziland where it is grown with irrigation only, none of the previous studies has investigated the effects of global warming on sugarcane farming in Tongaat Huletts – Tambankulu Estates. It is in this regard, that the researcher is motivated to examine the effect of global warming on sugarcane farming in Tongaat Huletts Tambankulu Swaziland estates.

### 1.4 Problem statement

This dissertation investigates global warming and its effects on sugarcane farming in Tongaat Huletts Tambankulu Swaziland. Many studies indicate that dynamics in global climate change have resulted in natural processes, anthropology dynamics and major environmental concerns that have affected and will constantly affect agriculture (Zhao and Li, 2015; Tadesse, 2010). Climate change has been identified as a leading human and environmental crisis of the 21st century (Tadesse, 2010).

The major crops are maize, wheat, sugarcane, sorghum and the minor ones are groundnuts, sunflowers, dry beans, tobacco, and potatoes Benhin *et al.,* (2006). One of the sustainable livelihood capitals is sugarcane. Sugarcane production faces challenges, among which includes drought and heavy rainfall emanating from global warming. Developing sugarcane varieties as an industrial crop has been considered as one of the most important objectives of Swaziland’s agricultural policy. This policy motivated “Tongaat Huletts Tambankulu

Swaziland estates to develop 3833.67 hectares under cane, producing 62 000 tons of sucrose annually and yields highly comparable to the best in the world" (Tongaat Huletts Tambankulu Estate, 2015). However, for Tambankulu estate to remain the leaders in the production and delivery of high quality canes within the southern African development community (SADC) region, it is crucial to examine the characteristics and dynamics of the effects of global warming on sugarcane farming in this region. The adverse effects of global warming can be reduced by understanding, examining, assessing them with views to implement adoptive practices to maintain and improve the quality of sugarcane farming in Tongaat Huletts Tambankulu Swaziland.

The sugarcane production in Swaziland is affected by global warming as in any other African country. The effects of climate change on sugarcane production, depends on geographic location and the degree of adaptation. Cane yields in most developing countries still tend to increase by improved cultivars and management practices (Hhao and li, 2015). Given that Swaziland is one of Africa's developing countries and producer of sugarcane, this study seeks to examine the effects of global warming on sugarcane farming in Tongaat Huletts Tambankulu Swaziland estates, to propose measures to mitigate the unpredictable phenomenon of global warming currently perceived to be threatening sugarcane production.

## 1.5 Purpose of the Study

The study focuses on the effects of global warming on sugarcane farming in Tongaat Huletts Tambankulu Swaziland. According to Nkulumo, (2016), studies on locating specific climate change are suitable to inform adaptation in dry land systems of Southern Africa. Hence, the purpose is to examine the effects of global warming on sugarcane farming. To achieve this purpose, mixed method exploratory sequential design was used. The author collected views and opinions underlining practices from key informants including executive, senior and middle management, team leaders' general staff, and general farm labourers at Tongaat Huletts Tambankulu Swaziland estates. The study used STATA 13 to test the effects of global warming on sugarcane farming, focusing on data from 2010 to 2015.

## 1.6 Research objectives

### 1.6.1 Primary objective

The overall purpose of this study is to examine the effects of global warming on sugarcane farming, using Tongaat Huletts Tambankulu as a case study. To achieve this, the research specific sub-objectives follow in next section.

### 1.6.2 Secondary objectives

- To determine the effects of water levels supplied by Komati and Umbuluzi rivers, as well as rainfall on sugar cane growing in Tongaat Huletts Tambankulu.
- To determine the effects of increased heat (radiation) levels on sugar cane farming in Tongaat Huletts Tambankulu.
- To determine the relationship between global warming, pesticides and other sugar cane diseases.
- To determine the relationship between a change in seasons on sugarcane production.
- To establish the extent to which Tongaat Huletts Tambankulu employees understand the effects of the global warming on sugar cane production.

## 1.7 Research Question

The research question posed in the study is: what are the effects of global warming on sugar cane farming in Tongaat Huletts–Tambankulu Swaziland? To answer this question, the research formulates questions as follows:

- What are the effects of the water levels supplied by Komati and Umbuluzi Rivers, and rainfall on sugar cane growing in Tongaat Huletts Tambankulu.
- What are the effects of heat (radiation) on sugar cane farming?
- Are there significant relationships between global warming, pesticides and other sugar cane diseases?
- Are there significant relationships between changes in seasons and sugarcane production?
- To what extent do employees in Tongaat Huletts Tambankulu understand the effects of global warming on sugarcane production?

## 1.8 Significance of the Study

Numerous studies have been conducted on the effects of climate change on agricultural productivity using different research methods and techniques (Gornall *et al.*, 2010; Kurukulasuriya and Mendelsohn, 2008 and Zhao and Li, 2015). Ironically, the findings from these studies consider global warming as a key factor of climate change. The examination and analysis of its main effect assist us to understand what causes these changes. Besides it promotes stakeholders' involvement in extreme changes that can be expected and helps to identify both men-made and natural causes of climate change.

In line with the above, this dissertation presents a couple of significances to stakeholders involved in sugarcane farming and management. It also provides a general overview of the effects of global warming in the study area; this will provide specific effects of the phenomenon in the study area. It will also provide various stakeholders associated with Tongaat Huletts Tambankulu Swaziland Estates with knowledge on the dangers posed by climate change on sugarcane farmers and cane production as a whole. The study provides a useful baseline to elucidate detailed effects of global warming on sugarcane production. It will also provide more strategic intervention measures and adaptation of acceptable practices to mitigate the impact of climate change on sugarcane production. In so doing, it will help to identify the relative importance of the effects of different potential causes that can be anticipated. This provides some context for decision making in an area of high uncertainty, to discover its strengths and weaknesses and to plan strategically in balancing the weaknesses and increase the ability of the estates to improve adaptation strategies.

## 1.9 Scope of the study

The study focuses on the effects of global warming on sugarcane production. The baseline of these observations reflects monthly data.

- The study was limited to Swaziland Tongaat Huletts Tambankulu employees for their views and opinions only.
- The study focused on 2010-2015 monthly observations only
- The use of comparative study between Southern Africa sugarcane producers on the effects of global warning on sugarcane in a future study would provide important information relevant in examining the effects.

### 1.10 Structure of the Study

This dissertation is divided into five chapters with each focusing on particular themes of significance. Chapter one presents the introduction and background, which elaborated on the research problem, objectives and questions. This chapter provides an overview of previous studies and presents gaps identified in the available literature. It also presents the geographic location of the study area, followed by the significance of the study. Chapter two presents literature review that comprises conceptual and theoretical framework on the effects of global warming on sugarcane farming. Furthermore, chapter three addresses the methodologies undertaken to achieve the objectives of the study. It presents the data sources, data collection process, including sampling procedure, techniques to collect data and data analysis. Chapter four provides the results of the study. Chapter five gives the analysis and discussion of the results. Finally, chapter six presents conclusion and recommendations.

## CHAPTER TWO
## LITERATURE REVIEW ON GLOBAL WARMING AND SUGARCANE PRODUCTION

### 2.1 Introduction

This chapter focuses on the literature review in relation to the global warming and sugarcane production. In this chapter, the theoretical and conceptual frameworks are provided with related literature. It also provides a brief background on the effects of global warming on sugarcane production from global to local industry levels.

### 2.2 Theoretical review

#### 2.2.1 Location Theory

Location theory originally developed by Alfred Weber (1929) and later extended by Edgar Hoover (1937), Melvin Greenhut (1956), and Walter Isard (1956). "Location theory was developed as an early response to the ignorance of space in traditional economic analyses".

#### 2.2.2 Relevance of the location theory

The main point of the location theory relates to the firm's location specifically and seeks to minimise costs or maximise profits (Svetikas, 2014). Thus, the location theory answers to the questions of how activities are geographically distributed and which factors affect the geographic location of firms. In other words, the location theory addresses questions of what economic activities are located where and why, or who produces what products or services in which location, and why. The location contains three streams (Dawkins, 2003:131). This implies that "Firms will tend to locate near primary input sources when the monetary weight of raw materials is large, relative to the weight of the final product"p132). Firms may also weigh the relative production cost savings from particular locations with the increased transportation costs to minimise the total costs of production and transportation (Dawkins, 2003 and Romanova, 2013).

### 2.2.3 Elements of location theory underpinning the study

#### 2.2.3.1 Sugarcane production

The older and world known production theory plays an important role in any process of producing goods and services. It is called Cob - Douglass production function, which originated in 1928, from Charles Cobb and Paul Douglas. Central to this model is the relationship between two or more factors of production and the amount of output that one can expect (Kumar, 2014; Chilarescu and Nicolas, (2007). In response to returns to scale and the elasticity of substitution, which are the two leading concepts, in relation to sugarcane production, many studies have used this empirical model to assess the impact of change on sugarcane production. Among them include Oduol *et al.*, (2011) who analysed the, "impact of adoption of soil and water conservation techniques on efficiency in Sub-Saharan Africa"; Kumar *et al*., (2014) who investigated the effects of climate on food grain productivity on India and Gupta et al's(2012) analysis on "the impact of climate change on Indian economy".

Therefore, the production of sugarcane may be used to assess the impact of climate variability of the sugarcane productivity. "Sugarcane production model is developed by considering variables such as available sugarcane land, yield rate and various inputs influencing yield rate of sugarcane production". In different ways, the "normal sugarcane production depends on Sugarcane land; normal yield rate; policy interventions; water availability and high yield variety seed; fertilization, crop intensity, de-rocking; and delay" (Mutanga *et al.*, 2016:825). Similarly, in sugarcane production, the "numbers of factors to be considered includes hectare, their length, thickness and density, besides the tonnage, sugar content of the cane and on the cane quality itself" (Mkhize, 2013:25). Significantly, sugarcane production relies on the timing of the harvesting period, which must be suitable to when economic optimum of recoverable sugar per area is reached. Many studies in agricultural production consider the above variables to produce more crops. For example, Ainsworth (2010) examines how to improve crop production in a warming world, while Agricultural Research Technical Information's (1996) analysis provides a guide on sorghum production.

#### 2.2.3.2. The Agricultural Industries

This section provides a description of the agricultural industries in the country, which includes sugar, forestry, citrus, maize, livestock, poultry and cotton in Swaziland. This study focuses on sugarcane industries and describes the industry's specifics, including its production volumes, exports, imports and the contribution of its industries' product to the GDP of Swaziland. The sugarcane industry is one of the major exporting industries, "contributing about 12% to the national GDP of Swaziland, 35% to private sector wage employment and 11% to national wage employment" (Central Bank of Swaziland Report, 2009:6). The "sugar industry produces over 600 000 metric tonnes annually and provides employment to over 3 500 people, besides bringing foreign exchange to the economy through exports" (Dlamini, 2012). Sugarcane is an important industrial crop used for sugar and bio-energy. It is one of the world's major C4 crops mainly cultivated in the tropic and subtropical regions of the world (Zhao and Li, 2015).

The major and dominating companies under this industry are the Royal Swaziland Sugar Corporation (RSSC) and Ubombo Sugar. This industry; is regulated by the "Swaziland Sugar Association (SSA), which also runs the sales and marketing of the product to the global markets" (Dlamini, 2012:9). The sugar industry is a key contributor to the Swaziland agriculture industry and the country's economy. "Sugar production accounts for almost 60 percent of the total Swaziland agricultural output, and contributes at least 10% to the country gross domestic product, as well as 16% to national employment rate" (GAIN report, 2016). As indicated in the previous section Swaziland "is Africa's fourth largest producer of sugar, after South Africa, Egypt and Sudan, and ranked 25th largest producer in the world" (GAIN report, 2016). In Swaziland, the sugarcane crop is one of the important crops and the main source of sugar production. Swaziland ranks the first grade in the unit area production, according to the absolute growing season of twelve months.

#### 2.2.3.3 Sugarcane process

The "basic philosophy is that there are no set recipes, but rather the recognition of on-farm management styles that allow for progress towards the adoption of an improved sugarcane farming system that is based on best practice principles" (Verheye, 2010:2). Sugarcane, "a perennial grass and one of the few plants which stores its carbohydrates reserves as sucrose, is best grown in tropical and subtropical climate" (Verheye, 2010). In the process, "it requires high temperatures, plenty of sunlight, large quantities of water (at least 1500 mm of rain per year unless grown with irrigation) fertile soils and good drainage". It also "requires a long and warm season with adequate rainfall or irrigation, a favourable weather condition for the good growth of sugarcane". Most of "the rain-fed and irrigated commercial sugarcanes are grown between 35°N and S of the equator" (Abera, 2016:14).

According to Vdrheye, (2010) "sugarcane crop cycles vary between 10 and 24 months, but can be extended four times or more by additional ratoon crops". The variation in the timing of sugarcane, as Binbol *et al.* (2006) and Gawander's (2007) studies indicate, presents interesting optimum climates required for cane development in four parameters. This includes rainfall, temperature, sunshine and humidity. Rainfall is an important factor for the good growth ofr sugarcane, as indicated by Gawander (2007). "An average of 1200 mm evenly distributed rainfall in the range of 1100-1500 mm is optimum for higher yield" (Srivastava and Rai, 2012:215). Secondly, the "temperature is equally important as the rainfall levels since its optimum range varies for different phase of the plant, which has a severe effect on the good growth of the plant and recovery of sugar" (Srivastava and Rai, 2012:215). It goes up to "32-38°C and slows down below 25°C, reaches a plateau between 30-34°C, reduced above 35°C and practically stops when the temperature is above 38°C". The duration of "high and low temperature phases influence highly on sucrose accumulation" (Srivastava and Rai, 2012:216).

Thirdly**, "**sunlight increases the leaf area index and rapids during third to fifth month of growth, thus coinciding with the formative phase of the crop to attain its peak values during early growth phase" (Srivastava and Rai, 2012). They specified, "on average, 7-9 hours of bright sunlight is optimum". Fourthly, the humidity and wind have comparatively less control over plant. Humidity and wind affect largely in case of extremes. Binbol *et al.*, (2006) and Gawander (2007) "establish up to 80-85% humidity and warm weather conditions favourable for rapid growth of sugarcane". Srivastava and Rai, (2012) also indicated that "long duration of bright sunshine, warm season with optimum rainfall and high humidity in the growing phase, favour rapid growth of plant and cane length with good yields". In addition, as indicated by Srivastava and Rai, (2012) "a clear sky without precipitation, warm days and dry weather conditions" is recommended for good yields.

The sugarcane process appears to be important in farming practice. The practice requires that farmers know the phases of production, as well as the cane development parameters, rainfall, temperature, sunshine and humidity. The optimum range of variations of these parameters needs to be understood and considered for efficient adaptation and mitigation in sugarcane production process.

#### 2.2.3.4 Factors affecting sugarcane production

This section reviews the factors affecting sugarcane production and these include water, nutrients; temperature; irrigation; diseases and pests (Adhikari *et al.,* 2015; Barnabás et *al.,*2008; Benhin, 2006; Bezuidenhout *et al.,* 2008; Chandiposha, 2013; Cilas *et al.,* 2015; Santos, and Sentelhas, 2012). Generally; the availability of water is considered as the primary heartening factor in sugarcane production process. Water is regarded as the "key factor in quantifying the effect of climate change on sugarcane" (Adhikari *et al.,* 2015). The implication of the lack and/ or reduction of water towards plantation affect its reservoirs levels, as well as the irrigation system (Santos and Sentelhas, 2012). The normal variation conditions under which crops survive well in rainfall revolve around a mean rainfall of 1200 mm/annum. "Water stress leads to the shortening of the crop reproduction stage, reduction in leaf area and the closure of stomata to minimize water loss, reducing crop yields" (Barnabas *et al.,* 2008). However, Swaziland sugarcane is moderately resistant to drought, but server water deficiencies affect growth and yield.

Climate change has a significant impact on sugarcane agriculture and the results clearly demonstrate that irrigation can mitigate this challenge. Irrigation is regarded as key to coping with the climate change and as an alternative to rain water, which plays an important role in frequently cycling water requirements to meet the demands of crops and evaporation (Adhikari *et al.,* 2015, Benhin, 2006 and Chandiposha, 2013). Therefore, an "irrigation deficiency renders the agricultural system vulnerable, where rainfall variability poses problems" (Mupangwa *et al.,* 2006). Despite, "Swaziland's huge potential for agricultural production, limited irrigation-related infrastructure is holding back the sector's growth and crop diversification" (SARC, 2013:3).

In relation to temperature effects, the Climate Emergency Institute reports that "by 2050, Southern Africa's temperatures and rainfall are expected to have risen by 2-4°C and to have fallen by 10-20 percent respectively, compared to the 1961-90 baselines" (SARC, 2013:10). Temperature plays an important role in the life cycle of plants. The "increase in temperature due to climate change is likely to alter the net daily evaporation that is essential in irrigation scheduling …Climate change is likely to pose a challenge in irrigation since the designing does not cater for anticipated increase in net daily evaporation" (Chandiposha, 2013:2815). Temperature changes due to "climate change affects the ripening of sugarcane, elevated temperatures due to climate change are likely to reduce natural ripening and quality of sugarcane" (Chandiposha, 2013:2817). Swaziland is also susceptible to volatile weather conditions as other parts of the world. Therefore, an examination of the effects of seasonal temperature variability on agricultural produce deserves consideration, if one has to expect growth in crops in general and in particular, in sugarcane yield.

Diseases and pests affect sugarcane production. The "change in temperature due to climate change results in diseases, insect attacks on crops and growing weeds in sugarcane production" (Zhao and Li, 2015:3). They stressed that "prolific dry weather exacerbates the symptoms of ratoon stunting disease". This has been supported by a recent study by Cilas *et al.,* (2015) and prior to that, Bezuidenhout *et al.,* (2008), who indicated that temperature infects cooler sugarcane growing in South Africa. "Increased temperature also alters the prevalence of weeds, diseases and insect pests in sugarcane production" (Chandiposha, 2013:2815). Furthermore, "extreme weather events cause more overwintering pests (weeds and insects), more disease pathogens and more input costs" (Zhao and Li, 2015:3). To remedy the factors that affect sugarcane production, Pest control and increase water and nutrient, will lead to "develop disease resistant cultivars which by means of the breeding program and integration of the best management practices *(BMPs*) will efficiently improve the climate change adaptation and sugarcane yield" (Zhao and Li, 2015:3).

The above factors affecting sugarcane production play a crucial role when managing cane production, to reduce the adverse effects of climate change seasonal patterns. Managing the effects of global warming appear to be key to sugarcane production. It follows that the aggravated effects caused by temperature and photoperiod, diseases and pests can be reduced by regular water flow under normal condition, as well as irrigation process. In so doing, there is great expectation for increasing productivity in sugarcane yield. The study by Nkulumo (2016) investigated the effect of climate change, as well as agronomic adaptation in the southern part of Africa and concluded that climate change has important impact on dry-land crop production in the region. The production of certain goods depends on certain quality of land, farm machinery, chemical, climate and many others. Therefore, some locations are good while others do not facilitate the production. The following locations illustrate the case of Brazil. Brazil is ranked as the world number one sugarcane producer. Brazil locates its main production site in the state of Sao Paulo. According Ramiro *et al.,* (2016), "the current, sugarcane plantations in Brazil are located in the central south region and its increases production appears depending on the boost of high level of productivity as well as expansion of area for sugarcane cultivation".

To obtain an optimum location for new or expansion of sugarcane production and ethanol mills, Bargos *et al.*, (2016) findings reveal homogenous areas for sugar and mills locations evenly distributed, while the current mills are densely located in the close cultivated areas. In the same location of Sao Paulo as main production field sugarcane, Tregeagle and Zilberman (2016) analysed the sugarcane production dynamics and found consistent results as yield effects changes from the renewal rate to the predicted effects. In addition, it was noted, temperatures influenced more rather than rainfalls in the sugarcane production. "Tropical natural environment of Brazil sugarcane and its derivative ethanol is the main facilitator of world number one in the production of sugarcane" (Chen and Saghaian, 2015). For this reason, many industries are in the state of Sao Paulo, where this endowment resource exists. In addition, studies by different scholars made use of location and related production model to investigate the impact of climate change and possible environmental adverse on sugarcane yields. For example, Chen and Saghaian, (2015) analysed the relationship among ethanol, sugar and oil prices in Brazil.

The opposite site of the African continent presents also another interesting sugarcane location site. "The production of sugar in India during the last 7 years is rotating around 24.3 to 26.3 Million ton" (Directorate of Sugarcane Development India, 2013). This yield mainly comes from state of Maharashtra which "is the largest producer of sugar, contributing about 34% of sugar in the country" as directorate reported. This location of sugarcane production in India plays an important role as appropriate site to many scholars to find out location productivity reasons, as well as adverse impact to the growing of sugar crop. The location theory in view of this study focuses on the sugarcane activities run by Tongaat Huletts –Tambankulu Swaziland; which embedded specific climate change conditions and land connected to suitable rivers to be studied, in order to inform decision making with adaptation in Swaziland Tongaat Tambankulu estates.

### 2.2.2 Ricardian theory

The Ricardian theory originated from David Ricardo's study on the value of the land and its productivity. This model, known as a cross –sectional method, approaches agricultural production and focuses on the economic impact of climate change on agricultural products (Mendelson *et al*., 1994, Kurukulasuriya and Mendelsohn, 2008).

#### 2.2.2.1 Relevance of the theory for the study

The Ricardian model assumes that "each one of the farmers' desires to maximise income subject to the exogenous conditions of their farm". The emphasis is on the choice of factors of production into the process of farming such as inputs and crop or livestock per unit of land that maximizes income (Mendelsohn *et al.,* 1994; SEO and Mendelsohn, 2007). In other words, the core to this model relies on the return that land as the main factor of production combined with famers practices, yield to the industries. This model considers climate change instabilities, in relation to the land value.

#### 2.2.2.2 Elements of Ricardian theory underpinning the study

Many studies have used this model in attempts to investigate the effects of global warming on sugarcane production. Among them is Nkulumo (2016) who assessed climate change impact and agronomic adaptation in Southern Africa; Kurukulasuriya and Mendelson (2008) who examined the impact of climate change on cropland in Africa; Gbetibouo and Hassan (2005) who estimated the economic impact of climate change on major South African field crops; as well as Nhemachena (2009), who analysed agriculture and the future climate dynamics in Africa. Further assessments of the model were done by Benhin (2008) who assessed South African crop farming and climate change; De Salvo *et al.*, (2014) analysis years of the model. Massetti and Mendelsohn (2011) estimated Ricardian functions with panel data; Mendelsohn *et al.,* (2010) investigated the impact of climate change on Mexican agriculture; Kurukulasuriya, and Mendelsohn, (2007) analysed the Endogenous irrigation. De Salvo *et al.,* (2013) analysed "the impacts of climate change on permanent crops in an alpine region" and, Fezzi and Bateman (2012) examined the "Non-linear effects and aggregation bias". The main significance of this empirical model as highlighted by Kurukulasuriya and Mendelson, (2007, 2008, and 2010) takes in direct and indirect effect of climate change on the productivity and the adaptation measure by farmers to local climate with its different cost. Interestingly, the result from many of these studies indicates the relationship between climate change and land value quadratic, while seasons appear significantly different per location (Mendelsohn *et al.,* 2010). The type of relationship appears to be positive or negative for the sugarcane crops.

The Ricardian production model has been the major methodology in the recent sugarcane production and climate changes literature. However, the Ricardian model appears to be limited, when one associates and considers current data or past data and predict the future, which may not exist. Further, this model considers prices as constant variables, while the global markets may influence its changeability. Above all, this empirical model appears simple and appropriate to examine the effects of global warming on sugarcane production in Tongaat Tambankulu Estates in Swaziland.

#### 2.2.2.3 Global warming

Global warming, which results in climate change, is one of the main challenges threatening the world and the African continent. Climate change is the "long-term changes in average weather conditions, covering all changes in the climate system, including the drivers of change, the changes themselves and their effects". It can also be referred only to "human-induced change in the climate system" (Tadesse, 2010:2). Studies conducted reveal that global warming is increasingly becoming a threat to agricultural production (Adhikari, *et al*., 2015; Li, and Yang, 2014; Srivastava and RaI, 2012; and Zhao and Li, 2015). "Climate change is projected to increase the median temperature by 1.4–5.5°C and median precipitation by −2% to 20% by the end of the 21st century" (Adhikari, *et al.*, 2015). Zhao and Li, (2015) argued that global warming is linked to the increasing volumes of carbon dioxide ($Co_2$) from 0.55 to 0.65 $^o$ C in the last 20 century. These view is supported by Nkulumo, (2016) whose study projected a temperature increase of 1.3-2.7 °C and uncertain rainfall change with range of changes from -15% to 18% in Southern Africa by 2050.

The above variations will have diverse impact on the life of plants. As such, climate change plays an important role in the life of plants. A plant generally stands in the field for 12 to 24 months and experience all possible four seasons (Srivastava and RaI, 2012: 214). The relevance of seasonal and weather phases indicates the role the weather phases play in plant growth. According to Srivastava and RaI, (2012) “crops are grown in the world from latitude 36.7° N to 31.0° S “. A study conducted by Zhao and Li, (2015) and Li, and Yang, (2014) confirms the impact of climate change on agricultural crops. They pointed out that “High temperatures accompanied by drought stress have been two of the major issues influencing agricultural production and economically affects many regions of the world”. Weather and climate related events (for instance growth environment of atmospheric $CO_2$, temperature, precipitation, and other extreme weather) are the key factors for sugarcane production worldwide, especially in many developing countries (Zhao and Li, 2015; Li, and Yang, 2014). Drought for instance, is observed as the most important stressful factor that China sugarcane production experiences, which grows at 80% under rainfall conditions. In the same line of findings, the “effects of drought due to climate change on sugarcane growth and development depends on plant growth stage and the degree of water deficit stress, and duration of the stress” (Zhao and Li, 2015). Chandiposha, (2013) indicated that Zimbabwe observed similar findings with potential “negative impact of climate change on sugarcane production”. This impact mainly occurs under temperature and rainfall, which appears to be damaging in agricultural production in general.

From the above, it is apparent that climate change affects agricultural production. To minimize the unpredictable effects of global warming and understanding of the weather factors and their impact on sugarcane production, appears helpful in manipulating plants to meet human needs.

## 2.3 Empirical review

### 2.3.1 Effects of global warming on Sugarcane production

Numerous studies have investigated the impact of climate change on agricultural products through various methods. Prakash and Muniyandi (2014) investigated sugarcane production in India using 43 years of observations by Autoregressive Integrated Moving Average (ARIMA) model and found it suitable for total crop production to be increased in future. Mustafa *at al.,* (2016) used sugarcane data in India to maximize the quadratic function subjects to sugarcane constraint, their findings demonstrated that the maximum net returns corresponding to the values of cost parameters were achieved during the period of study. Before this result, Mendelsohn *at al.,* (1994) also used the traditional production model which reported that “higher temperatures in all seasons except autumn, reduce average farm values, whereas more precipitation outside autumn increases farm value”. Furthermore, Seo and Mendelsohn (2008) used the Ricardian model for “2300 farms to explore the effects of global warming on land values”. The findings revealed that “farmland values would decrease as temperature increases. The study also predicts that both rain-fed and irrigated farms will lose their incomes by more than 50% by 2100”.

An additional modelling study by Kumar and Sharma (2014) adds value to the research. Their “regression results based on Prais Winsten models with panels’ corrected standard errors (PCSEs) estimations” showed that the “average maximum temperature and average minimum temperature in summer and rainy season are appearing negative with statistically significant impact on sugarcane productivity”. Despite this result, sugarcane crop get benefits with increasing average maximum temperature in rainy and winter seasons. The study further points out that “rising average minimum temperature in winter and summer seasons have positive and statistically significant influence on sugarcane productivity”. Thus, it could be predicted that “sugarcane productivity could be improved with increase in average rainfall in winter seasons”.

The recent study on farmers’ perception in relation to climate change and farming process in the regions of Marlborough and Hawke’s Bay in New Zealand reveal interesting facts (Niles, and Mueller, 2016). The finding indicates that “irrigation is utilized on the majority of cropland; secondly, majority of farmer is perceived to increase in annual rainfall despite instrumental records indicating no significant trends”. They stressed, “Water availability is associated with irrigation growth”. Thirdly, the perception correlated with farmer’s belief in climate change. In “Brazil Sugarcane is extremely dependent on climatic conditions, which can be more or less beneficial to the plant development and biomass production” (Cardozo *et al.,* 2016). Irrigation is largely used to “manage adverse conditions; enabling areas where rain-fed is impracticable into large producing areas”. This confirms the importance of irrigation as efficient use of energy and water impacts on social and environmental aspects. In addition, global warming will likely reduce dry land farm income immensely, more interestingly, the effects will appear severe with precipitation variability and irrigated farms being less sensitive to climate where water is available, “irrigation is a practical adaptation to climate change in Africa” (Cardozo *et al.,* 2016). Brazilian researcher Santos, and Sentelhas, (2012) indicated that “Climate change, independent of the scenarios considered, will impose an increase in potential and actual evapo-transpiration, resulting in higher water deficits in all regions". Consequently, sugarcane farmers will be affected as the yields of rain-fed crops decrease, Mali *et al.,* (2014) conducted a study on coastal weather on sugarcane production in South Gujarat, the result indicated that climatic irregular distribution of rainfall during monsoon and variations in relative humidity, affects crop physiology. This irregularity affects at the peak point of certain varieties of sugarcane. Furthermore, the rainfall negatively correlated with sugar recovery.

### 2.3.2 Effects of global warming on African agricultural crops

Many studies have investigated global warming's effects on the African sugarcane agricultural production. Among them, Deressa, and Hassan, (2009); Eriksen *et al.,* (2008); Christensen *et al.,* (2007); Deressa *et al.,* (2005); Hulme *et al.* (2001). They have all confirmed and expressed the view that global warming is a phenomenon that will continue and accelerate to impact on agricultural production. The indication of global warming through temperature and precipitation variability reveals negative impact on sugarcane production in all sugarcane-growing zones of South Africa (Deressa *et al.,* 2005). Christensen *et al.,* (2007) observations and analysis points out that "in all seasons, the median temperature increase lies between 3°C and 4°C". While Hulme *et al.,* (2001) findings on precision in terms of months noted "African continent warming at a rate of about 0.05°C per decade with slightly larger warming in the June–November seasons than in December–May during the last $20^{th}$ century". Furthermore, Kurukulasuriya and Mendelsohn (2008) confirmed that the current climate affects the net revenues of farms across Africa with expectation of sensitivity on dry land farms in Africa.

In 2006, Kurukulasuriya *et al.,* (2006) questioned if African agriculture could survive climate change. He answered this question using data from a survey of more than 9,000 farmers across 11 African countries. The findings indicated that "Warming has little net aggregate effect as the gains for irrigated crops offset the losses for dry land crops and livestock". Ten years later, the state of climate change affected sugarcane production immensely. Global climate changes have great effects on the environment. Fawaz and Soliman (2016) argue that these effects reflect on high temperatures, changing patterns of rainfall, rising sea levels and the increasing frequency of climate-related disasters, which pose risks to agriculture, water supply and other variables. They further argued that it would affect greatly on economics by the year 2030 through reduction in cultivated area.

Further studies conducted by Knox *et al.,* (2012:19) on the impact of climate change on crop productivity in Africa showed "evidence-based projected yield reduction of up to 40%, across all crop types within the sub-regions". Within the sub-region in South Africa, "the adverse effects of global warming on sugarcane emanates from increasing temperature and precipitation" (Deressa *et al.,* 2005). Climate change significantly affects nonlinearly on net revenue per hectare of sugarcane. Gbetibouo and Hassan (2005) used the Ricardian model to measure the impact of climate change on South Africa's field crops. Their results indicated, "The production of field crops was sensitive to marginal changes in temperature compared to changes in precipitation". They also noted that the "rise in temperature positively affects net revenue whereas; the effect of reduction in rainfall is negative". More importantly; season and location were considered vital to climate change.

As pointed out by scholars, agriculture appears to be the most sensitive and vulnerable sector to global warming (Müller *et al.,* 2011 and Wheeler and Von, 2013). Agriculture is the most vulnerable economic activity at the mercy of climatic conditions. "Climate change will have a strong impact on crop zonings, yields, and quality" (Santos and Sentelhas, 2012), as such, African commodity crops typically depend on irrigation to maintain yields. "Irrigation appears more useful in reducing the effects of changes in rainfall and temperature on sugarcane production" (Knox *et al.,* 2012). From the above, it is apparent that global warming with its concomitant changes in temperature and rainfall patterns lead to climate change and predictable decreasing of crop production in Africa. At the same time, the location of specific climate change patterns determines geographical production under appropriate weather conditions and farmers' practices.

### 2.3.3 Effects of global warming on Swaziland sugarcane production

The sugarcane production in Swaziland contributes highly to the economy of the country via taxation, social services, trade and employment. Dlamini *et al.* (2016) reported that "Swaziland sugarcane industry contributes 18 % to the gross domestic product (GDP) and employs 35% of total wage employment". Moreover, "18% of employment opportunities are created in the country by sugarcane production process". Gain (2015) supported this assertion and re-echoed that Swaziland ranks fourth largest in Africa, in terms of sugarcane production. "Sugarcane production remains the preeminent economic activity accounting for almost 60 % of agricultural outputs, 35% of agricultural wage employment" (Terry and Ogg, 2016).

Literature also confirmed that development in this sector occurs as a transformation from being a source of income and capital accumulation for the small elite, associated with ownership and management of estate production to grassroots beneficiary.

However, the study conducted by Konex *et al.* (2010:19) on climate change and sugarcane suggested that "the future irrigation need of sugarcane in Swaziland would increase by 20 to 22% due to climate change and if improvement of farm management is not executed, it will have adverse effects on production". Biggs *et al.* (2012) predicted "high N loss (10-15%) from sugarcane production".

#### 2.3.3.1 Production of sugarcane in Swaziland

Sugarcane production in Swaziland appears to be heavily concentrated on few large producers. These are the "estates of the two milling companies, the few large growers (including Tibiyo Taka Ngwane, Tambankulu Estates, and Crookes Plantations) account for 77% of the area planted and represented 81% of all cane produced" (Tongaat Hulett, 2015).

***Table 1: Tongaat Huletts Sugar Production***

| Tongaat Huletts sugar production | 2010/11 | 2012/13 | 2013/14 | 2014/15 | 2015/16 Early estimate |
|---|---|---|---|---|---|
| South Africa | 455 000 | 486 000 | 634 000 | 541 000 | <421 000 |
| Zimbabwe | 333 000 | 475 000 | 488 000 | 445 000 | 470 000 - 485 000 |
| Mozambique | 164 000 | 235 000 | 249 000 | 271 000 | 273 000 - 290 000 |
| Swaziland (RSE) | 54 000 | 58 000 | 53 000 | 57 000 | 55 000 - 59 000 |
| Total production | 1 006 000 | 1 254 000 | 1 424 000 | 1 314 000 | < 1 255 000 |

***Source: Updated from Tongaat Huletts 2015***

Currently, Tongaat Huletts (2015:19) projected "sugar production to be lower than 1,255 million tons for the year". This is predominantly due to the recent "severe drought conditions on the north coast of KwaZulu-Natal". Tongaat Huletts "creates value for all stakeholders through an inclusive approach to growth and development". This approach interconnects different activities including maize, sugar operations and land conversion. "Maize operations deals with growing starch and glucose production; sugar operations focus on increasing returns from existing sugar asset base realigning market positions, land conversion and development which accelerates pace of land conversion, increases momentum and substantial step-up in value" (Tongaat Huletts, 2015).

Sugarcane "provides the cheapest from of energy food, with the lowest unit of land area per unit of energy produced" (Verheye, 2010:2). He indicated that "the crop was originally used for chewing, but is now almost exclusively grown to produce sugar as a food sweetener or to produce ethanol for motor fuel". He also stressed that "sugarcane is usually harvested 12 to 24 months after planting". In subsequent years, it re-grows from the stubble, known as a ratoon crop and can be harvested yearly for six consecutive times.

Historically, "Sugar production in southern Africa originated with plantations established in Mauritius in the early European colonial expansion during the eighteenth century" (Lincoln, 2006). The planting and processing technology was subsequently transferred by immigrants from Mauritius in the mid-nineteenth century to Swaziland in 1969. By 1977, sugarcane production in Swaziland had earned the high prices paid by the EU market and overtaken Zambia. On the global scale, "Brazil dominates the market, scaling over 700 million tonnes of cane, double that of India, while South Africa produces around 18 million tonnes and Swaziland, only four to five million tonnes" (Dubb *et al.*, 2016:4).

Sugar dominates "Swaziland's agricultural production by value and is currently a critical export commodity to the EU under preferences, which bestow considerable economic rents upon Swaziland, given the distorted nature of the EU sugar sector" (Sandrey, 2009). According to FAO (2013), the "agricultural sector employs 29 percent of the labour force, and contributes 3.5 percent of total exports". FAO points to the main farming system in Swaziland as subsistence farming and conservation farming. The sector is characterized by both rain-fed and irrigated crop production. Sugarcane is the main crop produced in Swaziland in terms of volume, followed by maize and roots and tubers (FAO). Sugar, both raw and reined, is the main export crop based on value. Between 1999 and 2009, "sugarcane production increased by 16 percent and roots and tubers by 3 percent, while maize production decreased by 51 percent". Similarly, between 2010 and 2015, "Tongaat Huletts increased its sugar production by over 300 000 tons to 1,314 million tons" (Tongaat Huletts, 2015:19). The production has increased from 54 000 tons to 55 000 tons in Swaziland. However, "Tongaat Huletts sugar production for 2015/16 could have been close to 59 000 tons of sugar, under regular growing conditions, perhaps without the adverse impact of climate change impact on the produce” (Tongaat Huletts, 2015).

The cultivation of sugarcane in Swaziland takes place under a “set of conditions that have strictly defined its key parameters, a total annual rainfall in the Lowveld of about 600 mm prohibits any cane growing without irrigation” (Swaziland, 2016). According to Swaziland, national adaptation strategy the concentration of “most of the rain between November and March and the extended period of high juice purities during the rest of the year”, makes “cane harvesting possible over a period of about 30 weeks, from mid-April well into November”. These two conditions practically set the schedule of the main tasks in cane production, planting and harvesting.

### 2.4 Summary and conclusion

This chapter reviewed numerous studies on global warming and its impact on sugarcane production. The consolidated climate change impact on crops across the world revealed the state of the crop sugarcane. The literature reviewed combined results from different studies conducted using several methods and techniques. The findings indicate that the impact of global warming or climate change will negatively increase on crops, including sugarcane production, at the global level. Globally, many studies used econometric models to investigate the impact of climate change and agricultural produces, especially the Ricardian model, which appears to be economically farmers-based and focuses on activities that provide the highest return on any given piece of land. At a global level, projections indicate that there is the potential likelihood for Southern Africa to suffer the negative impact of climate change on agricultural crops, including sugarcane, in the 21$^{st}$ century.

The literature reviewed also indicates that the impact of climate change varies considerably from one geographical location to another and in accordance to their respective crops. In Africa, for instance, it revealed that currently, climate change affects the net revenues of farms across Africa and that sugarcane production would decline globally, including in Southern Africa. In Swaziland, sugarcane production has to date been somewhat increased against the effect of global warming and least as far as production is concerned.

However, adaptation of appropriate and location measures provides the potential to manage the effects of climate change. This will reduce the impact of global warming with an effective management practice in considerable ways. In addition, planning for climate contingencies in anticipated farmer's practices will reduce the adverse effects of global warming. In other words, undertaking adaptive action offers the potential to manage the effects of climate change by altering patterns of agricultural activity to capitalise on emerging opportunities while minimising the costs associated with the negative effects (Zhao and li, 2015).

# CHAPTER THREE
# RESEARCH METHODOLOGY

## 3.1 Introduction

This chapter addresses the research methodology used to investigate the effects of global warming on sugarcane farming in Tongaat Huletts Tambankulu Swaziland estates. Research methodology, as pointed out by Babbie and Mouton (2009:103), refers to "a method, techniques and procedures that are employed in the process of implementing the research design or research plan." As such, Bhattacherjee (2013:5) linked research method to a method referred to a "standardized set of techniques for building scientific knowledge, such as, how to make valid observations, how to interpret results and how to generalize these results." It therefore follows that this study, which examines the effects of global warning on sugarcane in Tongaat Huletts Tambankulu Swaziland estates, adopted the mixed method approach, which is a scientific research approach where the researcher uses the qualitative research method for one phase of a research study and the quantitative research method for another phase of the study. This consists of an investigative approach that seeks answers to the primary research question using steps forward redefined results unexpected.

## 3.2 Type of study
### 3.2.1 Quantitative Research Methodology

Quantitative research methodology "is a research that relies primarily on the collection of quantitative data". "Quantitative research is the numerical representation and manipulation of observations for describing and explaining the phenomena that those observations reflect" (Rubin and Babbie, 2016; Creswell, 2013). Therefore, "quantitative research explains phenomena by collecting numerical data that are analyzed using mathematically based methods". For this study, the database provided was the monthly numerical form, from 2010 to 2015 and the quantitative methodology was applied to test the effects of global warning on sugarcane farming in Tongaat Huletts Tambankulu Estates Swaziland.

### 3.3.2 Qualitative Research Methodology

Qualitative research relied on the collection of qualitative data. This method "seeks to understand a given research problem from the perspectives of the population it involves". The population from which the sample was drawn were employees from Tongaat Huletts

Tambankulu Swaziland. These included the executive, senior and middle management and team leaders, general staff which included the farm labourers, as key informants. The full profiles and details of the key informants will be provided as the study proceeds.

Qualitative methods comprise three most common methods which include participant observation, in-depth interviews and focus groups. To ascertain key information required for this study, the researcher used in-depth interviews to gather the views and opinions of employees in Tongaat Huletts Tambankulu Swaziland. The reason for adopting quantitative and qualitative research methods for the study was to broaden understanding of the effects of Global warming on sugarcane production, particularly on Tongaat Huletts Tambankulu Swaziland estates production since the sequential explanatory approach is better in terms of explaining and interpreting relationships between the effects of global warming and sugarcane production under investigation.

**3.3 Research Design**

A research design is "the arrangement of conditions for the collection and analysis of data in a manner that aims to combine relevance to the research purpose with economy in procedure" (Kumar, 2008). As a work plan, "research design importantly and functionally ensures that the evidence obtained assists to answer the initial question as unambiguously as possible" (Kumar, 2008). To this end, the study used in-depth interviews research as it collects data through asking key informants open ended questions through interviews. To this end, the sequential explanatory strategy of the effects of global warning on sugarcane farming "was characterized by the collection and analysis of quantitative data in a first phase of the research, followed by the collection and analysis of qualitative data in the second phase that built on the results of the initial quantitative results".

The relevant information collected from Tongaat Huletts Tambankulu employees and enterprise accurately described the effects of global warming on sugarcane production. The research design comprises four key components which include sampling design, which deals with the selection of items to be observed in the study; an observational design, which related to the condition under which the observations were created, "statistical design", which deals with the question of how the information and data gathered, were analyzed and "operational design", which deals with techniques by which the procedures satisfied the sampling.

### 3.4 Population of the study

The population for a study comprises the group of people from whom one wants to draw conclusions. In the current study, the population comprised the employees from Tongaat Huletts Tambankulu. As it is impossible to cover all people comprising the group, one has to select a sample from which data would be collected and studied (Babbie and Mouton, 2009). This study considered in 2015, the total number of 360 employees as the population from which the sample was drawn. This consisted of 324 total employees of Tongaat Huletts Tambankulu, including senior and middle management, as well as the general labourers. The next sub sections analyses the sampling technique and sample size of the study.

#### 3.4.1 Sampling technique

The population of the study area is where the sample was drawn. According to Babbie and Mouton (2009:164), "sampling refers to a process of selecting observations." Bhattacherjee, (2013) refers to "sampling as a population of interest for purposes of making observations and statistical inferences about that population". The emphasis was on the observations to select from the total population. According to Kumar (1999), "sampling design comprises random sampling, purpose sampling, convenient sampling and mixed sampling". This dissertation used purposive sampling to achieve its objective. Babbie & Mouton (2009), Bird (2009) and Kumar, (1999) indicate that "information of the population from which the sample is selected is important in accordance with the objectives of the research". The next section elaborates on purposive sampling.

##### 3.4.1.1 Purposive sampling

Bird (2009) defines purposive sampling as "sampling technique that purposively selects participants who are thought to be relevant to the research". In the same line, Kumar (1999) views the main consideration of purposive sampling to be the judgment of the researcher. Accordingly, the research selected key informants to provide the information needed to achieve the objectives of the study under investigation. In this study, population based, which the research relied on, was the Tongaat Hulett Tambankulu Estates. As such, the researcher selected the stakeholders directly involved in the production of sugarcane in Tongaat Huletts Tambankulu Swaziland. This consisted of the Executive, Senior and Middle management

(17), general staff (and team leaders (37) and general farm labourers (270) in Tongaat Huletts Tambankulu Swaziland estates. The next section looks at convenient sampling.

#### 3.4.1.2 Convenience sampling

Besides purposive sampling, this dissertation also adopted convenience sampling, which refers to making a selection of "settings, groups, and/or individuals that are conveniently available and willing to participate in the study" (Onwuegbuzie and Collins, 2007). Bhattacherjee, (2013) asserted that "convenient sampling relates to a technique in which a sample is drawn from that part of the population that is readily available, or convenient". The researcher thus selects key informants available and ready to provide answers to the research questions. The sampling design in this study facilitates the collection of the information needed to achieve the objective of the study.

The emphasis was on the observations selected from the total population. From sampling to purposive sampling, Bird (2009) defines purposive sampling as the sampling technique where participants considered relevant to the research are purposively chosen. Kumar (1999) considers purposive sampling to be based on the judgment of the researcher. The researcher thus selected key informants to provide the information needed to achieve the objectives of the study under investigation.

In this study, the population on which the research relied on was the Tongaat Huletts Tambankulu Estates. As such, this study selected the stakeholders directly involved in the production of sugarcane in Tongaat Huletts Tambankulu Swaziland. This consisted of employees who were employed between the period of 2010 to 2015 as indicated in the above subsection, 324 employees responded to the questionnaire administered to them. These are senior executive, and middle management, general staff, team leaders and general farm labourers in Tongaat Huletts Tambankulu Swaziland estates.

### 3.4.2 Sample size

Sample size is a crucial part of research design. Sample size is important for any empirical study in which the goal is to make inferences about a population from a sample. This study draws its sample from the Tongaat Tambankulu estates employees in Swaziland. This was based on the research questionnaire administered to 324 employees, wherefore this was 90 percent of the available population from their 360 labour strength. Additionally, in the same industry, the researcher collected quantitative data from Cane-Pro system, starting in 2010 – 2015 to test the effects of global warming on sugarcane production. Out of the total labour strength; 360 employees were permanent, the study concentrated on the permanent employees and a sample of 17 was from management, 45 from each of the six agricultural sections and 37 was from general staff in the same company.

Sampling size goes along with sampling criterion. In the current study, participants that formed part of the sample that was selected had to meet the following criteria: It was important:

- To be an employee of Tongaat Tambankulu Estates in Swaziland
- To have work experience in the company for more than five years
- To be willing to participate

The full profile details were obtained for 324 employees that have met the above criteria. In the current study, the effects of a global warming are considered as independent variable and sugarcane production as dependent variable. The purpose of experiment research design in this regard ought to test the validity of hypothesis which, the global warming affects sugarcane production in Tambankulu Estates in Swaziland. In this regard, see appendix for questionnaire administered to all respondents.

### 3.4.3 Variables

The following models, as presented in the theoretical framework helps to identify the variables to be measured in this study. This is the Model (I) Ricardian model:

**Pf= f (Climate variables, land feed, farm inputs (1)**

Model (II)

$$\textbf{LAND F} = \beta 0 + \beta 1Cv + \beta 2C2v + \beta 3Lv + \beta 4L2v + \beta 5\ Wv + Er\ (2)$$

The next section analyses data collection method for the study.

### 3.5 Data collection Method

The data collection was through primary and secondary data sources which include the questionnaire, interviews and observation. For the purpose of this study, the researcher collected information from both primary and secondary data.

#### 3.5.1 Primary sources of data collection

The study used primary sources and was conducted using a questionnaire designed and made available to all respondents through emails. Questionnaires were administered via emails and sent to all the managers and staff that had access to computers and for those without access to systems, a physical written questionnaire was administered to them during working hours to complete them. For those who did have access to emails, the responses were dropped in company locked suggestion box. The research methodology used in the present study included data mining techniques such as clustering, coding, and grouping. The 2010 - 2015 employees' views and opinions were collected; clustered and coded for different identified variables, such as Team leaders, section managers, executive/senior managers, staff, general labourer, and occupational clusters.

The primary data collection "focuses on the planning, collecting, analysing, and reporting emerging themes" (Driscoll, 2011), as first-hand information can be collected using observation, interviews and questionnaires methods (Creswell, 2013 and Kumar, 1999). This type of data comprises variables which are used to collect information to answer specific research question. According to Curtis (2008), "primary data is collected specifically to address the problem in question and is conducted by the decision maker, a marketing firm, and a university or extension researcher: unlike secondary data, primary data cannot be found elsewhere". In terms of advantages, primary data reveals the newness and originality of information collected and disadvantages mainly own data are costly and time consuming, unlikely, secondary data. The data collection process was undertaken in the following steps provided below.

**Qualitative data collection and analysis**

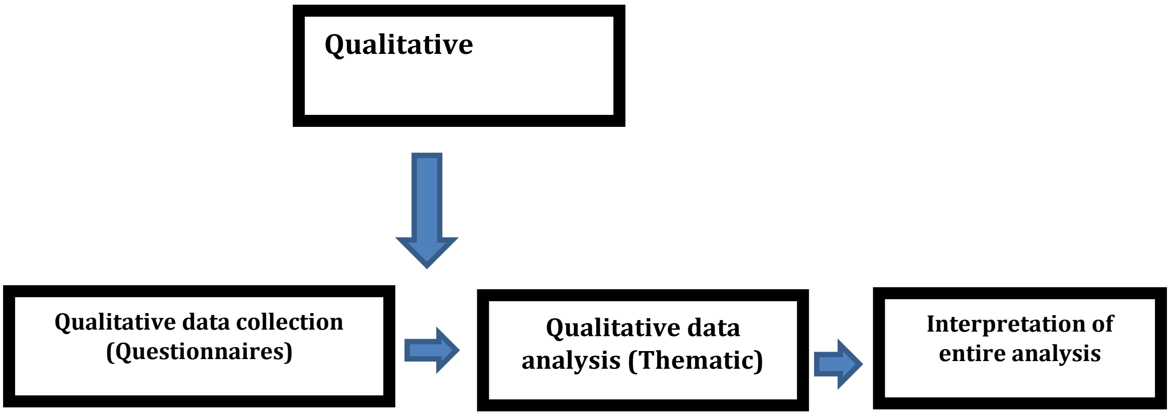



FIGURE 2: Qualitative Data Collection and Analysis Process

### 3.5.2 Secondary sources of data collection

This study used secondary data sources which refers to "an examination of previous studies include information drawn from census data, industry data, journals, magazines, books and periodicals to obtain historical and other extra types of information" (Kumar, 1999). Secondary data presents some advantages and disadvantages, which may or may not validate the impact on the format and the quality of the data. Kumar (1999) indicated that advantages that data are provided will assist in achieving the study under investigation. In addition, they cost less compared to primary data in terms of time and financial means. Therefore, this study used quantitative industry data (Tongaat Huletts Tambankulu estates Swaziland from 2010 to 2015.

Data were extracted from can pro data base, was coded and entered Microsoft Excel (see Appendix 1). The coded data were then transferred to STATA for analysis.

**Quantitative Data Collection and Analysis Process**

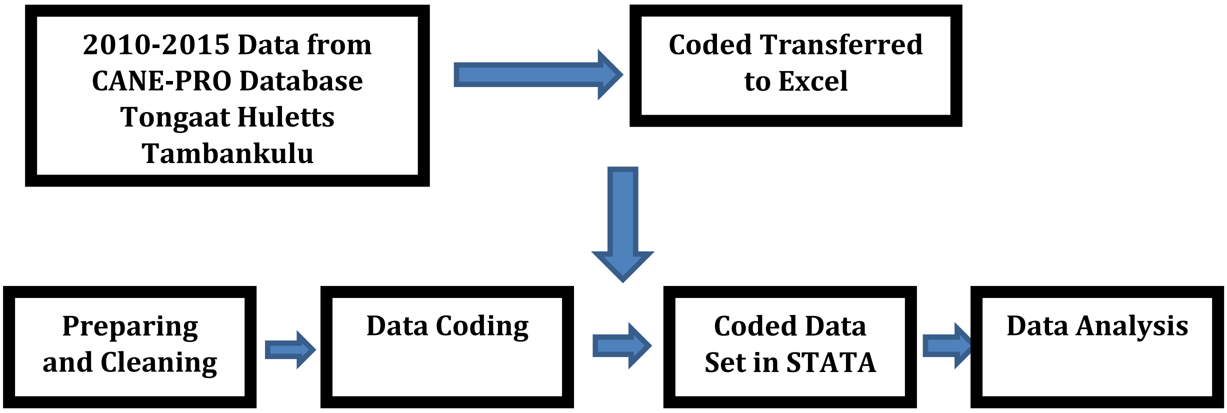



FIGURE 3: Quantitative Data Collection and Analysis Process

### 3.6 Reliability and validity

According to Babbie and Mouton (2009) reliability refers to the extent to which the same research technique can yield the same results. From description standpoint, Bryman (2012) views "validity and reliability as the integrity of the concepts generated in the study". The concern with reliability is that every time a single observer is the source of data, subjectivity prevails. In contrast, "validity refers to the extent an empirical measure adequately reflects the real meaning of the concept under investigation" (Babbie and Mouton, 2009:123). However, it is uncertain to tell with certitude that a particular measure accurately reflects the concept's meaning. Therefore, this dissertation balances the disadvantages "with criterion, construct, and content validity" as portrayed by Babbie and Mouton, (2009:123). Respectively, "criterion validity refers to the external criterion; construct validity, which focuses on logical relationships among variables, and content validity talks to how much a measure covers the range of meanings included within the concept".

### 3.7 Data analysis techniques

Statistical design is concerned with the question of how the information and data gathered are to be analyzed. Firstly, the data analysis process includes facilitating discussion and generating rich data from the interview, complementing them with the observational data collected from the study population. Furthermore, familiarising with the data, which results in major themes emerging and identifying a thematic framework and finally, the indexing data, reframe themes in new content or managing the data.

Accordingly, the researcher made use of one of Leech and Onwuegbusie (2007, 2008) qualitative analysis techniques to analysis the data. This by (a) organising data in small units by codifying them; (b) regrouping them into categories (c) developing them into themes that express the content of each groups as advocated by Leech and Onwuegbusie (2007, 2008). The second step was essentially analysing the data using statistical methods. This can include two ways: The first ways to analysis, the data can be descriptive analysis, which focuses on aggregating and presenting the variable of interest (Bhattachejee, 2012), while the second way refers to inferential analysis which tests the hypothesis. This study used both ways. The econometric Ricardian model, since it has been applied extensively in the analysis of the impact of climate change on agricultural crops (Kurukulasuriya and Mendelsohn, 2008), was considered appropriate for the study under investigation, given that it considers different alternatives.

### 3.8. Ethical considerations

The University of KwaZulu-Natal permits students to undertake research by granted an ethical clearance certificate. With this certificate, ethical considerations carrying on this research was responsible to discuss anonymity and confidentiality with participants as advocate by Alasuutari, Bickman and Brannen 2009 and Punch (2013).The objective was therefore to secure the rights of the key informants and achieve ethical considerations. The key informants were informed of the objectives of this study before being part of any interview and completing the questionnaire.

### 3.9 Summary and conclusion

This chapter has presented the methodology used in this study. The study adopted the quantitative and qualitative methods to implement the research plan. This mixed method approach is relevant to the study and the research design for investigating the impact of global warming on sugarcane production. Firstly, the researcher made use of in depth interviews to collect the data. The questionnaires were administered to stakeholders involved in the population and thematic analysis was employed to analyse primary data from different stakeholders. Secondly; statistic software (STATA 13) was used, to test and analyse the quantitative part of the study. The following chapter analyses the results of the effects of global warming on sugarcane production.

## CHAPTER FOUR: FINDINGS ON THE EFFECTS OF GLOBAL WARMING ON SUGARCANE PRODUCTION

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### 4.1 Introduction

In this chapter, the author provides the findings and the analysis of the data. This is done in two phases which, on one hand, is the qualitative analysis and on the other hand, the quantitative analysis. Semi structured interviews and questionnaires were administered to Tongaat Tambankulu Estates employees. These respondents were the senior and middle management, staff and general labourers.

### 4.2 Understanding of global warming in relation to sugarcane production

#### 4.2.1 Executive and Senior middle management's understanding of global warming

Most of the executive and senior middle management had a good understanding of climate change impact on sugarcane production. Their views and opinions on the global warming effects revealed that less rain leads to less yields. As such, increases pests, diseases and scarcity of irrigation resources. Additionally, climate change causes severe droughts, change in weather patterns that do not favour cane growing and ripening. However, some pointed out that an increase in temperatures can result in high yield, whereas poor emergence result in low plant production, lower sucrose and causes stress as it alters daily net evaporation essential for irrigation scheduling.

#### 4.2.2 General staff, team leaders and general farm labourers' understanding

In responding to the general question on the effects of climate change on sugarcane production, 70% of the general staff, team leaders and general farm labourers respondents reported that the effect would be that of sugarcane production dropping due to the shortage of water and also low yield production due to drought, pests and diseases. The additional 30% of respondents views the climate change effects as resulting in drought due to the decrease in rainfall and thus, increases pests in sugarcane, which affects production. Furthermore, the views and opinions of the respondents touched on rivers and dams. These sources of water for sugarcane production appear to have little water and climate change makes this problem worse, which results in poor irrigation.

The understanding of climate change in seasons on sugarcane production as reported by the majority of respondents revealed a "know how" process. 90% of the respondents reported that sugarcane production positivity gets affected with increasing average maximum temperature in rainy seasons and winter seasons, but when maximum temperature in summer and minimum temperature in rainy seasons, less a negative effect on sugarcane productivity. Put differently, the respondent reported that different seasons give different yields of sugarcane per hectare. This implies that the warm months (summer) are good for sugarcane growth, also with an increase in sucrose percentage and the cooler months (winter) are good for cane ripening. Overall, the effects of climate change on sugarcane as reported by the respondents, indicated that climate change reduces productivity and drops tonnes of sugarcane per hectare. All the respondents could distinguish inputs in sugarcane production process. They could mention global warming inputs such as temperature, rainfall, radiation, sun and inputs cost such as electricity, fertilizer, herbicides and insecticides. The following section discusses the quantitative analyses the data on the effect of global warming on sugarcane production from 2010 to 2015.

## 4.3 Effects of global warming on sugarcane production in Tongaat Tambankulu Estates

### 4.3.1 Theoretical statement of the Ricardian model

The Ricardian model considers a farmer as an income generator. In that case, Tongaat Huletts Tambankulu Estates is an enterprise which generates an income from sugarcane production. Therefore, the Income function or Profit function (Mathematical model theory) is presented as follows:

***Pf= f (climate variables, land feed, farm inputs (1)***

***Where Climate variables include****: rainfall, temperature, radiation, and sun hours*

***Farm inputs cost include****: electricity, insecticides, herbicides, and fertilizers*

When one measures the Ricardian model of land value, crop, yield and product directly, the function interpretations results in two ways (Mendelsohn, 1994; Deressa, 2003; Gbetibouo, and Hassan, 2005; Kabubo-Mariara, 2007). The first one is the direct effects of climate on the yield of different crops and the second interpretation being the "indirect substitution of different inputs and the introduction of different activities/species and other potential".

Gbetibouo and Hassan, (2005:144) put these differently by indicating that "model accounts for the direct impacts of climate on yields of different crops as well as the indirect substitution of different inputs and introduction of different activities and other potential adaptations to different climates".

The relationships between temperature and rainfall are expected to capture the non-linear character of the climate response functions, in the case of $LAND_F$ depending on temperature and rainfall. Therefore, the positive relationship implies that the production or harvest (Return, reap, crop, produce, yield) is U-shaped, but when the relationship is negative, the function $LAND_F$ is hill- shaped (character).

The time series data are collected over a period, such as the data on Area Harvested/To Harvest, Tons CaneTCHA, TSHA, Sucrose %, Total Sun hours, Total Radiation (MJ/m2). Moreover, Max Temperature ($^oC$), Total Cane Ref. Et (mm) (as combination of $O_2$); Total Rainfall (mm), Thrips count and electricity. These data are collected at regular intervals monthly, as well as yearly data from 2010 to 2015(see Appendix 1).

### 4.3.2 Empirical model

The mathematic model of relationship between sugarcane production and climate change variables is assumed exact or determinist, but the results still have to prove this relationship. Therefore, the relationship is presented as follows:

$$\mathbf{LAND_F = \beta_0 + \beta_1 Cv + \beta_2 C^2 v + \beta_3 Lv + \beta_4 L^2 v + \beta_5 Wv + Er \quad (2)}$$

Where Cv and $C^2v$ capture levels and quadratic terms for climate variables such as temperature and Lv and $L^2v$ capture levels and quadratic terms for land feed such as Area Harvested/To Harvest, Wv captures other variables and Er is an error term. According to Deressa, (2003) and Mendelsohn et al., (1994), the quadratic terms in relation to this study reflects non-linear characteristics between harvest/ production of sugarcane and global warming variables.

The author collected the data from Tongaat Huletts Tambankulu CAN-PRO data base and defined land value/return/ harvest/ crop as gross revenue that has already deducted cost of production, which may include the cost of feed, hired labour, transport, packaging, storage etc. In this study, the author considers Area Harvested/To Harvest and Sucrose Percent as land value.

However, the author found it difficult to define monthly data for the area, which has generated the Harvest and Sucrose Percent. This implies that it was difficult to measure the amount of land that Tongaat Tambankulu Estates uses to harvest Sucrose Percent monthly. In contrast, yearly data provide such amount of land that Tongaat Tambankulu Estates used to produce sugarcane.

Climate data were collected from the company itself and are related to total Rainfall (mm), cane Ref. ET (mm/day), max Temperature (oC), and radiation (MJ/m2/day). All monthly data were from 2010 to 2015.

**Table 2: Summary Statistics of Variables**

***Summarize SucroseP TRainf MTemp Radiation TSunh TCaneR Monthly***

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| SucroseP | 49 | 14.11714 | .7160482 | 12.64 | 15.29 |
| TRainf | 72 | 48.42361 | 53.32362 | 0 | 219.9 |
| MTemp | 72 | 28.37778 | 2.242309 | 22.4 | 33.2 |
| Radiation | 72 | 17.15417 | 3.564296 | 11.7 | 24.6 |
| TSunh | 72 | 194.4792 | 30.58026 | 115.8 | 252 |
| TCaneR | 72 | 138.2083 | 39.64648 | 72.4 | 224.5 |
| Monthly | 72 | 6.5 | 3.476278 | 1 | 12 |

**Dependent and independents variables of the study:**
Area Harvested/To Harvest/Sucrose %
Total Rainfall (mm);
Max Temperature (oC);
Total Radiation (MJ/m2);
Total Sunhours
Total Cane Ref. Et (mm) (As combination of "water use of commercial rainfed and irrigated sugar cane")

The author assumes it is difficult to measure the actual amount of land devoted to sugarcane production, more so in mixed cropping areas as indicated by (Seo & Mendelsohn, 2006), In this case, land to harvest or expected to harvest can be allocated to other product than sugarcane.

### 4.3.3 Empirical result

#### 4.3.3.1 Effects of climate on sugarcane production

Equation (2) represented the Ricardian model, according to the author's estimates. The findings consider harvest month variables, but the author excluded December, January, February and March as months of preparation for harvesting. The following table of Regression one: Sugarcane production and Global warming variables shows that results:

**Table 3: Regression One**

| *Variables* | **Coefficients** | **P>\|t\|** | ***Prob > F*** |
|---|---|---|---|
| ***Total Sun hours*** | .0037502 | ***0.250*** | ***0.0000*** |
| ***Combination of "water use of commercial rainfed and irrigated sugar-cane"*** | ***.0243874*** | ***0.000*** | |
| ***Total Rainfall (mm)*** | ***-.0042022*** | ***0.082*** | |
| ***Max Temperature ($^oC$)*** | ***-.0431854*** | ***0.529*** | |
| ***Total Radiation (MJ/m2)*** | ***-.2749954*** | ***0.001*** | |
| ***Constant*** | ***15.83664*** | ***0.000*** | |
| ***Sucrose production***<br>***Dependent Variables*** | | | |
| ***R-squared*** | ***0.5993*** | | |
| ***Adj R-squared*** | ***0.5527*** | | |

The null hypothesis is that $R^2=0$. This means that the model is not good. The alternative is that $R^2$ (Coefficient of determination) is different from Zero. This means that the model has explanatory power.

The ideal for P-Value is that what the researcher wants to see is the probability to be less than 1%, 0.05%, and 0.01%. This corresponded to 95% and 99% significant level respectively. As the result P-value is less than 1%, 0.05% and 0.01%, this shows 0.000 means as it is less than each value 1%,0.05%,0.01% it can be assumed that our variables are statistically significant at all the significant levels. This means that our model is significant at all this level. Because 99% is stronger means that we are 99% confident, in that we can reject the null hypothesis and the null hypothesis $R^2$=0. Therefore, we reject it and we conclude the alternative hypothesis that $R^2$ is different to zero. This means our regression model has explanatory power (independent variables which is the variable of global warming explains dependent (sucrose). It also, shows that our regression model has explanatory power, it is good regression model. If the P-value were above one, we would not work with this regression.

$R^2$=Coefficient of determination. The closest $R^2$ is to (1) one, the best is the model, closest is to (o) zero the west is the model. $R^2$=0.59% after variation in sugarcane production is explained by total Rainfall (mm); Max Temperature (°C); Total Radiation (MJ/$m^2$); Total Sun hours; and combination of "water use of commercial rain-fed and irrigated sugar-cane". The equation displays the following results:

$$\mathbf{LAND_F = \beta_0 + \beta_1 TSunh + \beta_2 TCaneR - \beta_3 TRainf - \beta_4 MTemp - \beta_5\, Radiation + Er\ (2)}$$

$$\mathbf{LAND_F = 15.83664 + 0.0037502\, TSunh + 0\ .0243874\, TCaneR - 0.0042022\, TRainf - 0.0431854\, MTemp - 0.2749954\, Radiation}$$

In this equation, all the estimates of the coefficients of the variables have the correct signs and are statically significant. The results are interpreted as follows:

Sugarcane production is explained by total Rainfall (mm); Max Temperature (°C); Total Radiation (MJ/$m^2$); Total Sun hours; and combination of "water use of commercial rain-fed and irrigated sugar cane". Specifically, sugarcane production is explained or correlated negatively by/to total Rainfall (mm); Max Temperature (°C); and Total Radiation (MJ/$m^2$). In contrast, sugarcane production is corrected positively to Total Sun Hours and combination of "water use of commercial rain-fed and irrigated sugar cane".

Partial regression coefficient $\beta_1$ (**0.0037502**) means that holding all other variables constant (total Rainfall (mm); Max Temperature (°C); Total Radiation (MJ/$m^2$); Total Sun hours increases by one unit of it, production of sugarcane increases by about **0.0037502**.

Partial regression coefficient $\beta_2$ (**0 .0243874**) means that holding all other variables constant (total Rainfall (mm); Max Temperature (°C); Total Radiation (MJ/$m^2$); and Total Sun hours); combination of "water use of commercial rain-fed and irrigated sugar-cane" increases by one unit of it, production of sugarcane increases by about **0 .0243874**. This result is also enriched by the mean water used (In table 3) for sugarcane supply areas is at 138.2083 mm and at 72.4min and 224.5 max respectively during the time analysis.

Partial regression coefficient $\beta_3$ (**0.0042022**) means that holding all other variables constant (Max Temperature ($^oC$); Total Radiation ($MJ/m^2$); Total Sun hours; and combination of water use of commercial rain-fed and irrigated sugar cane); total Rainfall (mm); increases by one unit of it, production of sugarcane decreases by about **0.0042022**. The overall marginal impact of rainfall is negative, implying that increased rainfall will lead to a fall in sugarcane production. In this regard, Tongaat Tambankulu Estates is likely to keep more to mitigate it production in the event of climate change and vice versa.

Partial regression coefficient $\beta_4$ (**0.0431854**) means that holding all other variables (total Rainfall (mm); Total Radiation ($MJ/m^2$); Total Sun hours; and combination of "water use of commercial rain-fed and irrigated sugar-cane"); Max Temperature ($^oC$); increases by one unit of it, production of sugarcane decreases by about **0.0431854**. This also implies that for every any additional increase in degree Celsius of temperature, the expected sugarcane production decreases by **0 .0243874** on average, holding other variables constant.

Finally, Partial regression coefficient β5 (**0.2749954**) means that holding all other variables (total Rainfall (mm); Max Temperature ($^oC$); Total Sun hours; and combination of "water use of commercial rain-fed and irrigated sugar-cane"); Total Radiation ($MJ/m^2$); increases by one unit of it, production of sugarcane decreases by about **0.2749954**. This suggests adaptation options available to the Tongaat Tambankulu Estates Swaziland to mitigate radiation trends throughout the year for better yield of sugarcane.

This means that total Rainfall (mm); Max Temperature ($^oC$); Total Radiation ($MJ/m^2$); Total Sun hours; and combination of "water use of commercial rain-fed and irrigated sugar cane" have significant effect on sugarcane production. The author is optimistic that with this result at 99% level, global warming effects do not equal zero. Therefore, they have significant impact on the production of sugarcane.

The regression results show that the overall models are stable at the level of significance because the $R^2$ shows that the models explain only about 59% of the total variation in harvest (sugarcane/Sucrose) monthly.

#### 4.3.3.2 Rainfall, thrips and chemical on area Harvested

To estimate the model with yearly data, the author considers the following data: Area Harvested/To Harvest Thrips count; Herbicides; and Insecticides. The second regression performs sugarcane production area to harvest, rainfall, thrips, and chemical.

**Table 4: Regression Two**

| ***Variables*** | **Coefficients** | **P>\|t\|** | ***Prob > F*** |
|---|---|---|---|
| ***Total Rainfall (mm)*** | .0076931 | ***0.008*** | ***0.0114*** |
| ***Herbicides*** | ***-5.17e-06*** | ***0.008*** | |
| ***Thrips count*** | ***-.1133904*** | ***0.056*** | |
| ***Constant*** | ***17.53664*** | ***0.005*** | |
| ***Area Harvested (Land)Dependent Variables*** | | | |
| ***R-squared*** | ***0.9999*** | | |
| ***Adj R-squared*** | ***0.9997*** | | |

Again, the null hypothesis is that $R^2=0$. This means that the model is not good and the alternative is that $R^2$ is different from Zero. This means that the model has explanatory power.

The P-Value represented here is 0.01 and it is less than 0.05 this corresponds to 95% of significant. When tested yearly, the results show an indication of $R^2$ different from zero, this implies that there is correlation between the independent and dependent variables. In the study area, Harvested/To Harvest correlated to thrips count, Herbicides and Insecticides on the land for sugarcane.

The model explains about 99% of the total variation in harvest /Area Harvested/To Harvest yearly. The Coefficients are negatively correlated with each other, for every additional unit of Thrips count, Herbicides and Insecticides, the expected decrease by 0.0076931, 5.17e-06 and 0.1133904 on average. This implies that chemical product and thrips affect area Harvested in Tongaat Tambankulu Estates.

#### 4.3.3.3 Water level supplied and rainfall on sugarcane growing

The author considered sugarcane production (sucrose %), rainfall and electricity cost to find out the extent of their relationship.

**Figure 4: Total Rainfall**

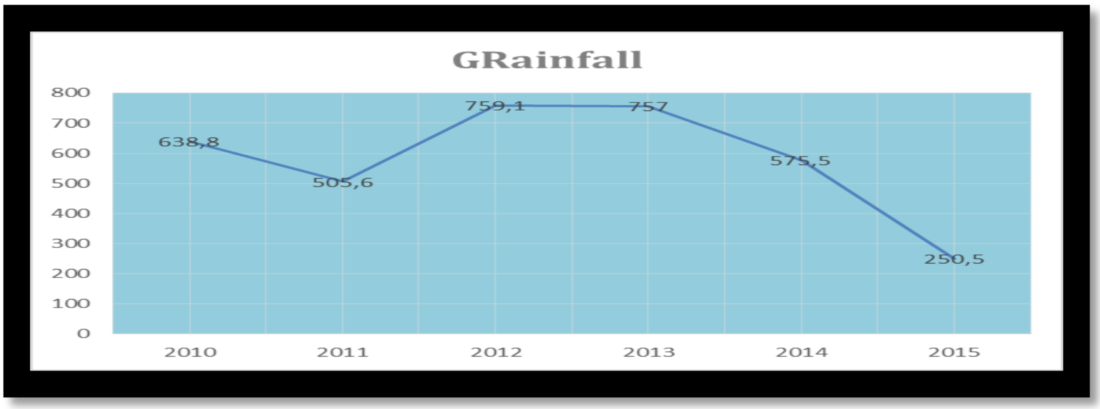
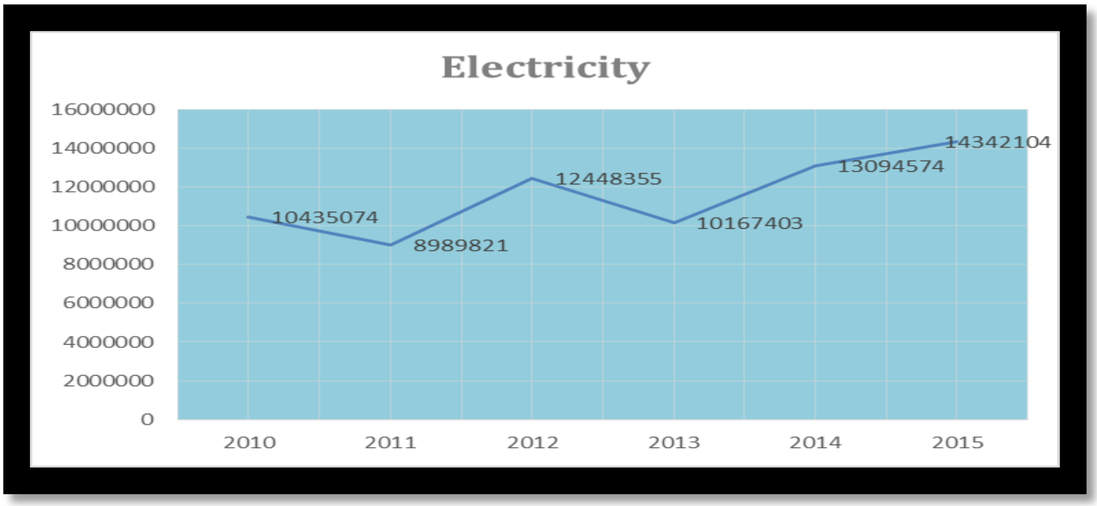



**Figure 5: Electricity**

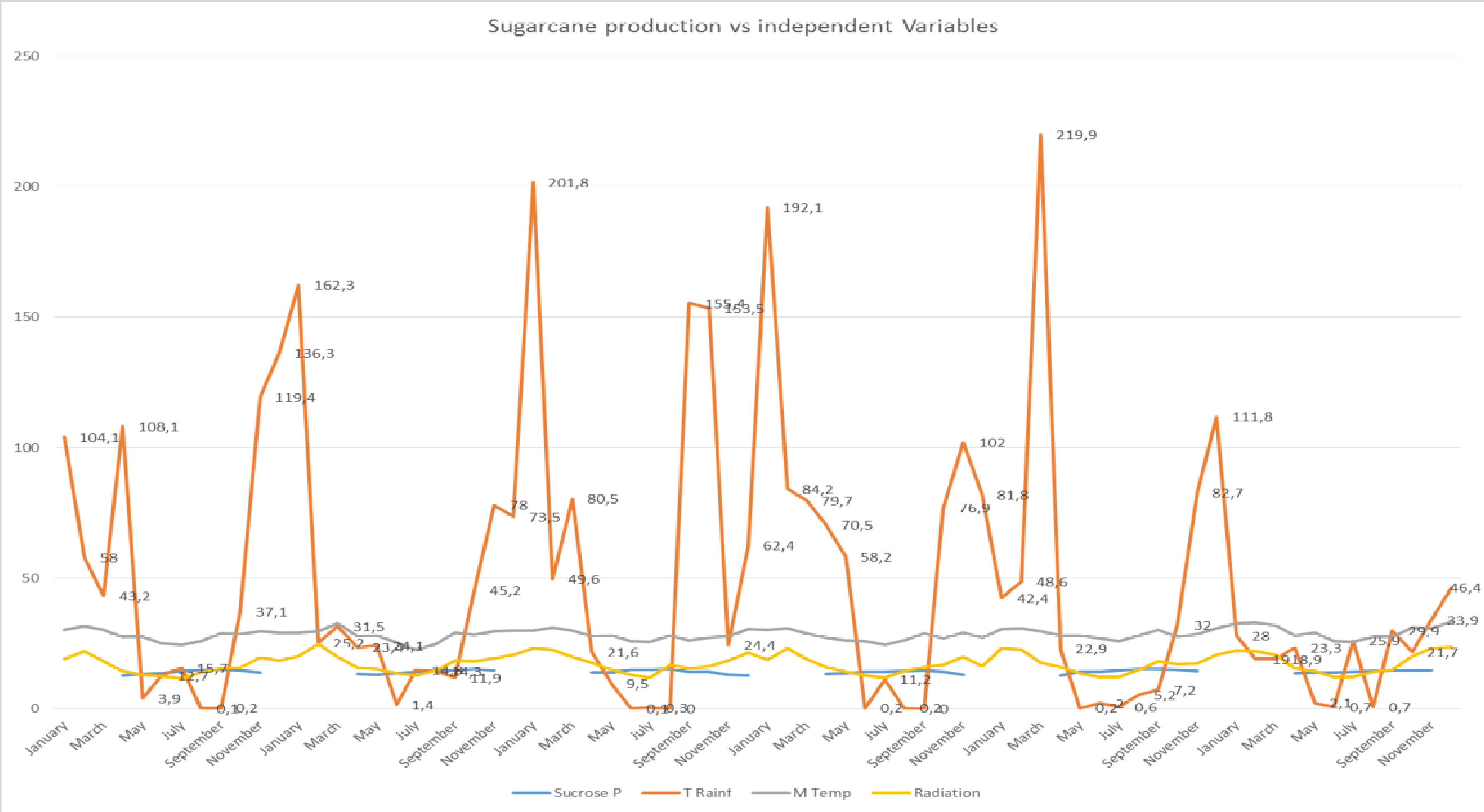


From the two graphs represented above, the relationship indicates that the rainfall levels have declined drastically from 2013 to 2015, while electricity cost has increased during the same period of analysis. This means that electricity cost has increased due to the pumping of water into spray irrigation, this water comes from the two rivers namely Umbuluzi and Komati. This perhaps suggests the need for a new dam to prevent shortage of water when there is decline in rainfall as indicated above.

Monthly analysis presents an interesting result. Graphically, the results show that winter months saw a significant drop in sucrose production, while summer months saw increases in the sucrose production.

Following graph illustrates:

**Figure 6: Sucrose Production vs Global Warming Variables**

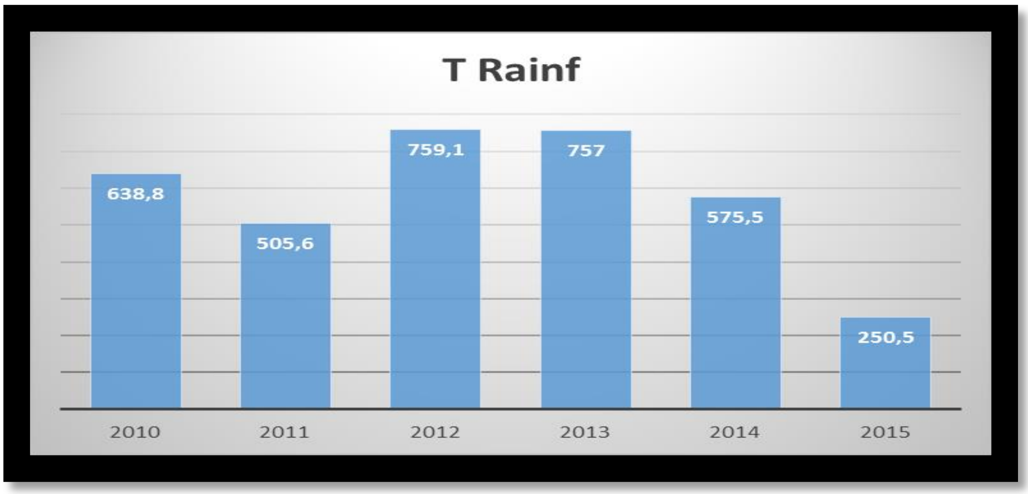


Winter rainfall displays a hill shaped relationship with sucrose production. This implies that increased rainfall in summer is beneficial to the production of sucrose in Swaziland Tongaat Tambankulu estates considering the months of harvest.

The “hill shaped relationship in the graph, suggests that excess winter temperatures are however harmful to the production of sugarcane levels”. The results further show that global warming reveals a non-linear relationship with sugarcane production. Put differently, radiation like, temperature and rainfall, at different levels affected sugarcane production (sucrose) across the production seasons. Critical damage point analysis indicated that increasing winter rainfall levels from November 119,1mm; December 136,3mm and 162, 3 mm in 2010 decreased the sucrose production. Similarly, in 2011, where rainfall increased from 78mm in November, 201,8mm in December, also decreased sucrose production. Additionally, rainfall increased in 2012 at 192,1mm in December; at highest level 219, 9 in March 2013; at 111,8mm in December 2014 and at 46, 4 mm in 2015. This means that rainfall increase from November to March during period of study, which indicates a decrease in production of sucrose. In contrast, rainfall level beyond 0.10mm in August, 1,4mm July; 0.10 mm in July; 0.6mm in June;  and 0.7mm August respectively from 2010 to 2015 shows increases in sucrose production (Figure 6). This negative relationship between increase and decrease in rainfall is due to global warming conditions.

In addition, the critical damage points analysis indicated that increasing radiation degree Celsius up to 24, 23, 22, and 21 $^{o}$C decrease sucrose production, whereas radiation degree Celsius beyond 12, 12, 9 and 12 $^{o}$C increases sucrose production. The following graph shows total rainfall.

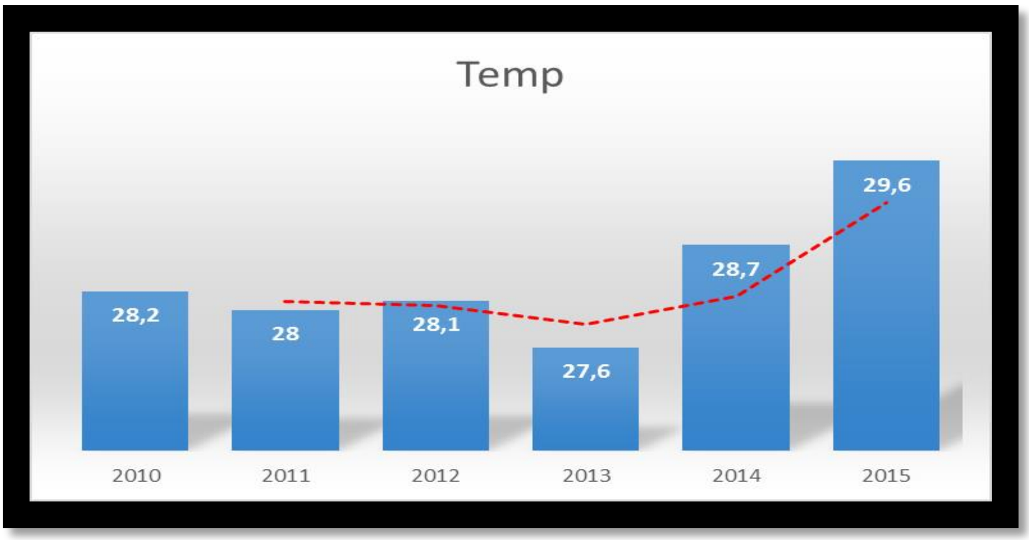
**Figure 7: Total Rainfall**




Source: Author

The reaction of sugarcane production to summer temperatures is U-shaped, but the reply to "winter temperatures is hill-shaped". The results support the usual situation in Swaziland. Though the average summer temperatures in Tongaat Tambankulu estates Swaziland are quite modest at 10, 1 $^{O}$C-26.8 $^{o}$ C minimum and maximum respectively, the temperature can rise to more than 21, 2$^{o}$C- 33.2$^{o}$C, minimum and maximum respectively, which causes negative impacts on sugarcane production. The following graph shows total temperature.

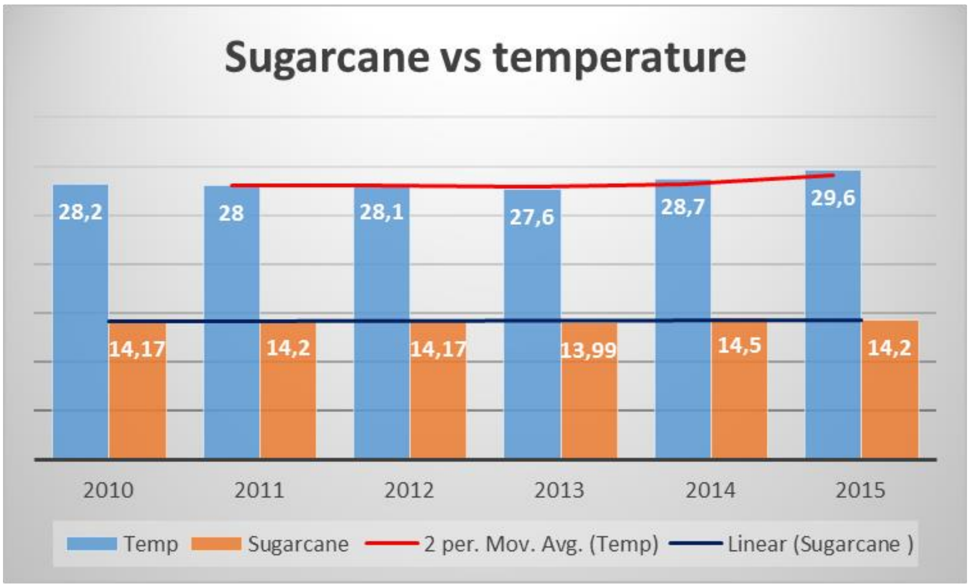
**Figure 8: Total Temperature**




Source: Author

Holding other variables constant, during the years of extreme temperatures and droughts as in recent Southern Africa countries (Including Swaziland), farmers were forced to reduce their production of agricultural product levels or risk losing them altogether. However, Tongaat Tambankulu Estates has made an exception of keeping their level of production constant. The following graph demonstrates these findings.

**Figure 9: Sugarcane vs Temperature**



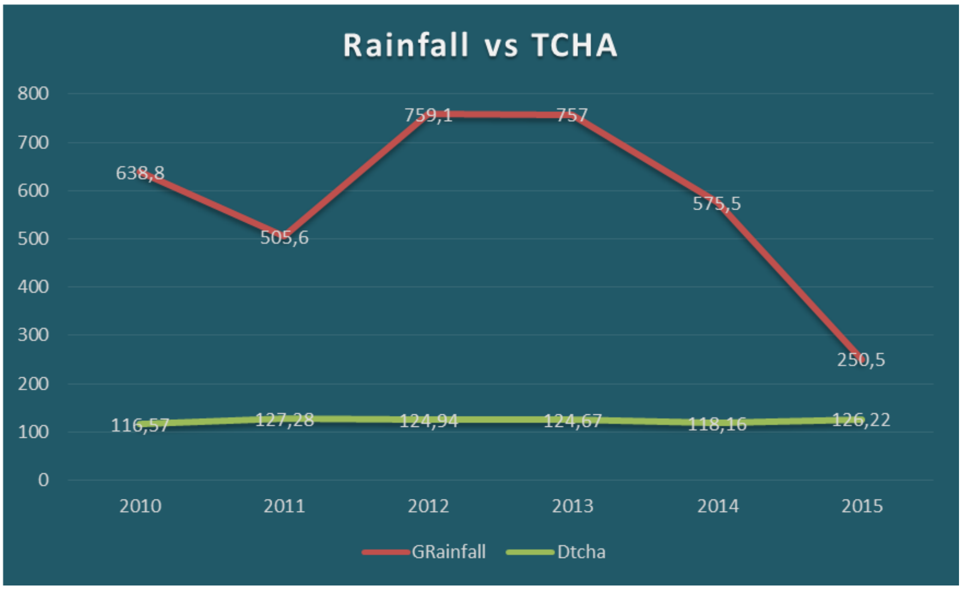

Source: Author

The above results are consistent with previous findings which indicated that African continent agricultural products are more likely to be sensitive to changes in rainfall (Seo and Mendelsohn, 2006; Mendelsohn, and Nordhaus, 2008) endorsed that climate affects the revenues from agricultural products. A similar result was found by Onyekuru and Marchant (2016), who indicated that precipitation "during winter and spring increases net revenue" of agricultural production, while in summer and autumn, it decreases the net revenue. Similar results are also found in the recent work of Kabubo-Mariara, (2008), who revealed that "livestock production in Kenya is highly sensitive to climate change". Likewise, Gebreegziabher *et al.* (2013) reported that warmer temperatures are beneficial to livestock agriculture, while it is harmful to agricultural crop in Ethiopia.

#### 4.3.3.4 Effects of the water levels and rainfall on sugar cane growing

This section analyses the effects of the water levels supplied by Komati and Umbuluzi rivers, as well as rainfall on sugar cane growing in Tongaat Huletts Tambankulu. The following graph presents the level of rainfall and tons of cane per hectare in Tongaat Tambankulu estates in Swaziland. The following graph shows Total Rainfall and tonnes of cane per hectare area.

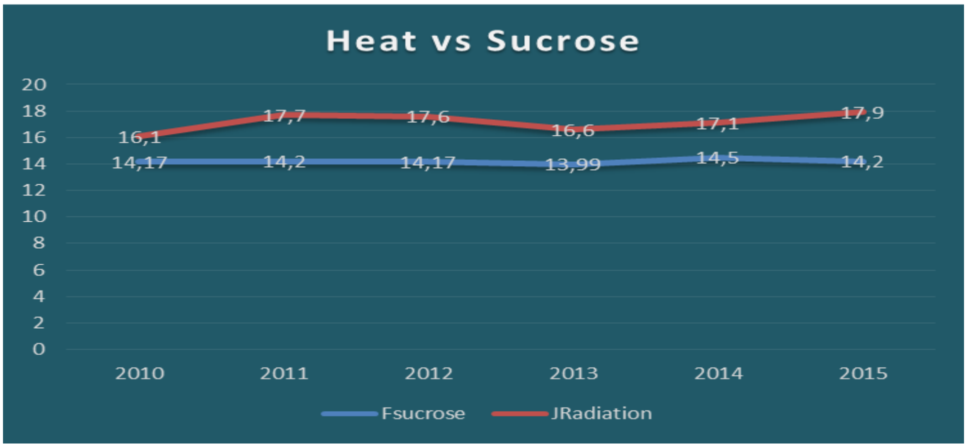
**Figure 10: Total Rainfall vs TCHA**




Source: Author

#### 4.3.3.5 The effects of increase in heat (radiation) on sugar cane farming

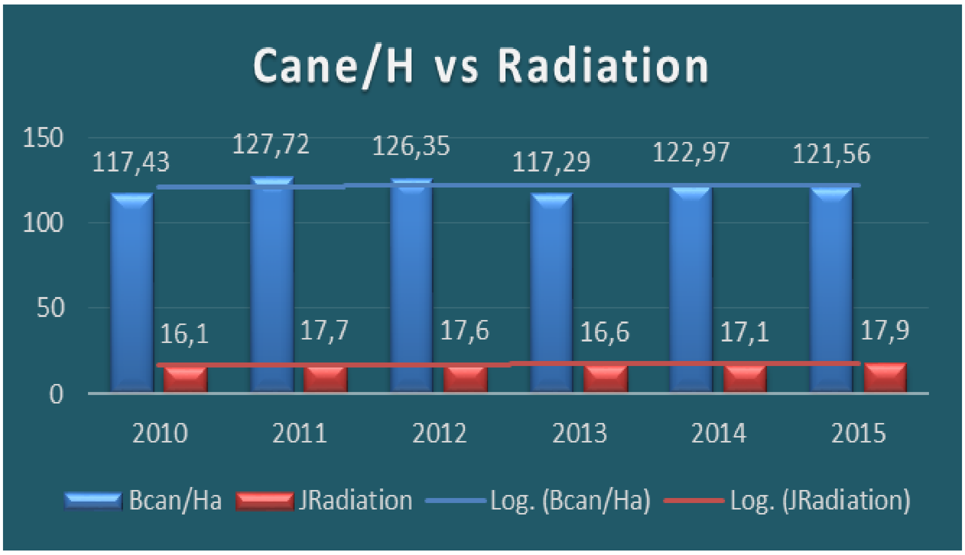
**FIGURE 11: RADIATION ON SUGARCANE**




Source: Author

The above graph demonstrates that radiation has remained constant, while sucrose increased in 2011, 2012, 2014 and 2015, as compared to 2010 and 2013. This implies that radiation is important for the growing of sugarcane. However, more heat will obviously harm the production cane yield in Tongaat Tambankulu estates.

**Figure 12: Cane vs Radiation**



Source: Author

#### 4.3.3.6 Relationship between global warming, pesticides and other sugar cane diseases

There is the need to find the relationship between global warming, chemical and disease (Insects). The expectation is to find the causes of insects and the cost of chemicals in the process of sugarcane production. The author performs third regression on global warming thrips and chemical, as indicated in the table below.

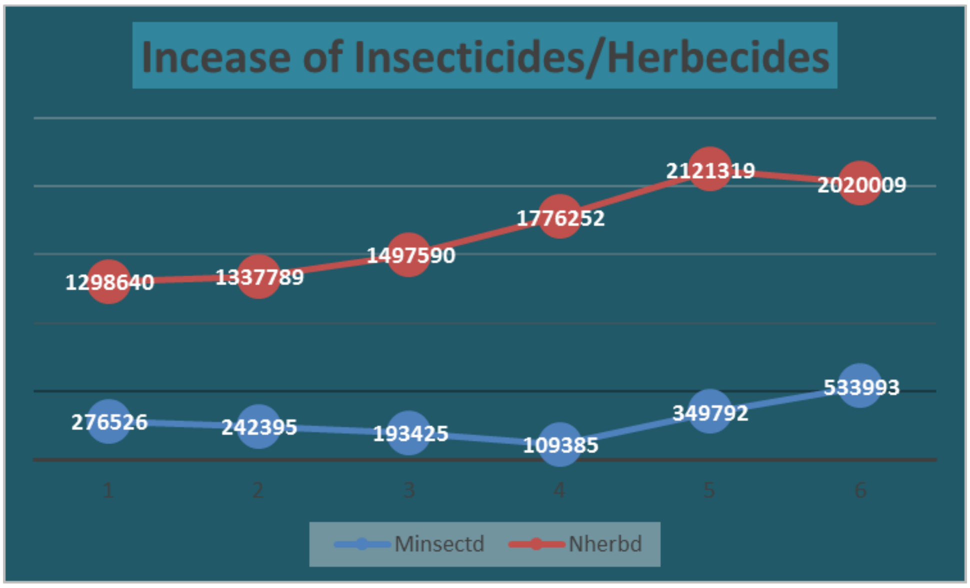
**TABLE 5: REGRESSION THREE**

| ***Variables*** | **Coefficients** | **P>\|t\|** | ***Prob > F*** |
|---|---|---|---|
| ***Thrips count*** | 53.51515 | ***0.136*** | ***0.0394*** |
| ***Insecticides*** | ***-.0018354*** | ***0.030*** | |
| ***Constant*** | ***663.8287*** | ***0.029*** | |
| ***Total Rainfall (mm)Dependent Variables*** | | | |
| ***R-squared*** | ***0.9606*** | | |
| ***Adj R-squared*** | ***0.9212*** | | |

Again, the null hypothesis is that $R^2=0$. This mean that the model is not good and the alternative is that $R^2$ is different from Zero. This means that the model has explanatory power. We reject the null hypothesis that there is no spread of independent variables and we accept the alternative that there is correlation between variables.

The model explains about 96% of the total variation in rainfall yearly. The Coefficients were negatively and positively correlated to each other. For every any additional unit of Thrips count, the expected rainfall increase by 53.51515, while holding other variables constant. In addition, for every additional unit of Insecticides, the expected rainfall decreases by 0.0018354, while holding other variables constant. This implies that Thrips decline when there is rainfall, but when pumping water from the river they increase.

**Figure 13: Insecticides and Herbicides**




Source: Author

The above graph demonstrates that the increase in chemicals, namely insecticides and herbicides, to combat disease or insects from 2010 to 2015, indicates an increase in the cost of inputs of production of sugarcane. The cost of inputs in terms of herbicide chemical increased more, as compare to insecticide chemicals. Additionally, the increase in the cost of chemicals explains the rainfall declines and more irrigation water pumped from the rivers, there is an increase in insecticides. Whereas, when there is rainfall, there is a decline of insecticides.

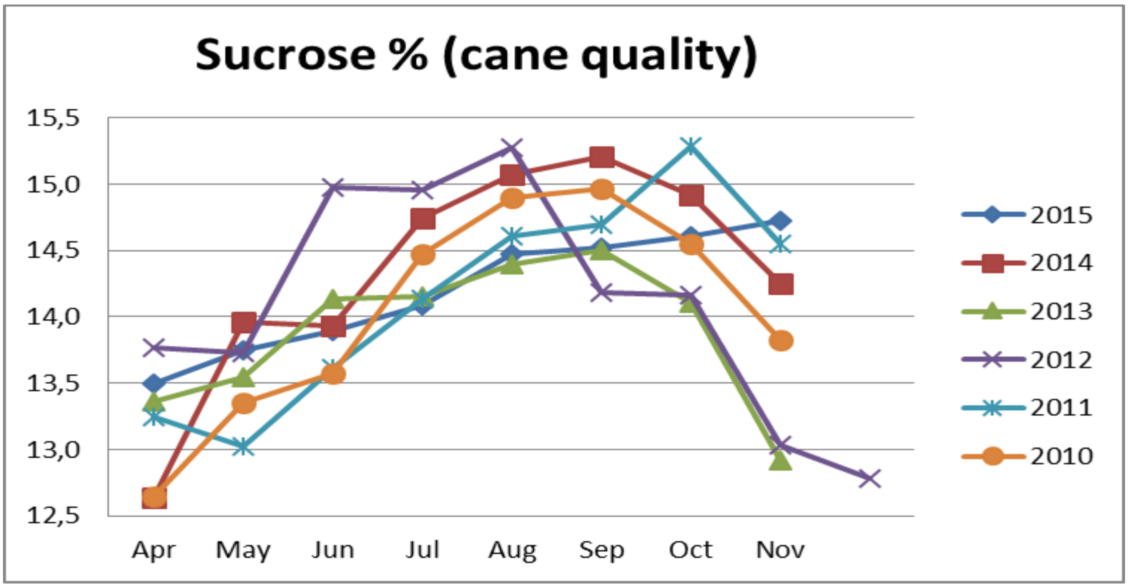
#### 4.3.3.7 Relationship between changes in seasons on sugar cane production

Regarding the equation (2), seasonal variables variation in relation to sugarcane production shows that temperature, rainfall and radiation impact slightly on sugarcane production. Each one of their respective coefficients indicates that at any additional unit, decrease slightly sugarcane production to the number of respective coefficients.

**LAND F =15.83664 +0.0037502 TSunh + 0 .0243874 TCaneR- 0.0042022 TRainf-0.0431854 MTemp-0.2749954 Radiation**

There is a significant relationship between changes in seasons and sucrose percentage. This depicts from the month of February to June; there is drastic decrease in production of sucrose in Tambankulu Estates. From June to July, it shows an indication of production stagnation and August take off up to December. The following graph demonstrates the sucrose percentage during harvesting seasons.

**Figure 14: Seasonal Sucrose Trends**




Source: Author

The above graph indicates total sucrose quality per year during the period of the study.

### 4.4 Summary of the chapter

This chapter was about estimation of empirical model, related to global warming effects on sugarcane production in Tongaat Tambankulu Estates in Swaziland. The findings present interesting results. The relationship between temperature, rainfall, radiation and sugarcane production appears non-linear. This relationship shows that global warming has negative effects on sugarcane production. Mainly temperature, rainfall and radiation, while impacting positively on the total sun and combination of "water use of commercial rain-fed and irrigated sugar-cane". The following chapter discusses and analyses the results. The change in seasonal global warming variables respectively temperature, rainfall, and radiation increase, results in slightly decease of sugarcane production. In contrast, total sun as one of global warming and water used to produce sugarcane, impacts positively on sugarcane production. The above results were enriched with the understanding of the results of global warming effects by stakeholders. Sugarcane production gets affected with increasing average maximum temperature in rainy seasons and winter seasons, but when maximum temperature in summer and minimum temperature in rainy seasons less a negative effect on sugarcane productivity.

# CHAPTER FIVE
# DISCUSSION AND ANALYSES OF THE RESULTS

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## 5.1 Introduction

This chapter discusses and analyses the results from primary and secondary sources of data, regarding global warming variables on sugarcane production in Tongaat Huletts Tambankulu Estates Swaziland. On one hand, the analysis and discussion are based on primary data collected from a sample of 324 Tongaat Tambankulu employees. On the other hand, the analysis and discussion are also based on the secondary data collected from Tongaat Tambankulu Estates data base. This dissertation performed four regressions. The first regression established explanation between sugarcane production and global warming variables. The second regression also established the effects between sugarcane production area to harvest, rainfall, thrips and chemical. In addition, the third regression analysed global warming variables, thrips and chemicals. Finally, the four regression analyses relationship between the changes in seasons on sugar cane production. The primary data collected and analysed are presented in the following section.

## 5.2 Analysis and Understanding of global warming in Tongaat Huletts Tambankulu Swaziland

### 5.2.1 Vulnerability of sugarcane production

Respondents presented two views about the vulnerability of sugarcane production. Firstly, 90% of the respondents recognised direct effects of changing climate conditions namely temperature and precipitation, which make sugarcane production vulnerable. Secondly, the 10% of respondent recognised indirect effects arising from changes in the severity of pest pressures, availability of pollination services and performance of other ecosystem services as causes of sugarcane vulnerability. However, all representatives of the Executive and senior middle management in Tongaat Tambankulu Estates in Swaziland recognized the main cause of sugarcane vulnerability. These causes include increased frequency and intensity of the extreme weather events, such as drought, heat, flooding, typhoon and frost.

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### 5.2.2 Mitigation of sugarcane production Vulnerability

Executive and senior middle management responded on how to "mitigate the effects of global warming". The views presented from Executive and senior middle management showed an understanding of global warming effects. They retorted and considered an adaptive action by altering patterns of sugarcane activity to capitalize on emerging opportunities, while minimizing the costs associated with negative effects.

Adaptation farming systems to climate change and great potential challenges to sugarcane production. Views and opinions were differently presented by Executive and senior middle management, general staff and team leaders and general farm labourers. On one hand, they indicated a better understanding of weather factors and their effects on sugarcane production, followed by the manipulation of plants to meet human needs and formulation of mitigation strategies, followed also by minimization of potential adverse effects on crop production, as adaptation farming systems to climate change. On the other hand, they also reported that low adaptive capacity followed by poor forecasting system and mitigating strategies, as well as high vulnerability to natural hazards, as great potential challenges to sugarcane production. However, half of the respondents suggested multidisciplinary approaches to mitigate the unpredictability of global warning on sugarcane production. These include increasing productivity and profitability; refining best management practices, improving new technology transfer and breeding and molecular biology. This implies that adaptation strategies throughout sugarcane seasonal patterns deserve more consideration to enhance seasonal changes of global warming in Tongaat Huletts Tambankulu Estates.

### 5.2.3 Assessing agriculture crop production systems and climate change

All of the respondents, especially the executive and senior middle management, understood that balancing short-term and long-term goals when assessing agricultural crop production systems and climate change is important. Furthermore, they understood that increased productivity, profitability and sustainability of sugarcane yield, with regards to production system, was also important. Similarly, the general staff, team leaders and general farm labourers who reported on climate change and sugarcane production variation shared similar understanding.

70% of the respondents, especially the general staff, team leaders and general farm labourers, understood that an increase in the average temperature of the earth has detrimental effects on sugarcane production, while, 30% of the respondents reported to have a general understanding of the unpredictable dry weather conditions. Others viewed global warming as a cause of increase in costs of production. The Ricardian regression model estimated presented the results which are subjected to discussion in the following section.

## 5.3 Empirical results

### 5.3.1 Sugarcane production and global warming variables

The first regression established explanation between sugarcane production and global warming variables. The results suggest that global warming variables impact on sugarcane production. Among these variables include temperature, rainfall and radiation, which negatively impact on sugarcane production, while the sun was reported to positively impact on sugarcane production. This implies that an increase in seasonal temperature reduces slightly sugarcane production in Tongaat Tambankulu Estates Swaziland. The temperatures in summer season appear to be decreasing the sugarcane production, while winter season increases sugarcane production. This indicates that for every additional decree Celsius of temperature, the expected sugarcane production decreases by 0.0431854 on average, holding other variables constant. This result is consistent with the work of Onyekuru and Marchant (2016), who assessed "the economic impact of climate change on forest resource use in Nigeria". In addition, Mishra *et al.'s* (2016) study findings revealed that rainfall and temperature have significant influence on agricultural production.

The regression also found that rainfall, which is a global warming variable, negatively impacts on sugarcane production. This implies that for every additional degree of precipitation, the expected sugarcane production decreases by 0.0042022 on average, holding other variables constant. This decrease in sugarcane production established particularly in summer season as the rainfall is at its highest level, while in winter, sugarcane production increases as rainfall decreases.

The regression results further indicated that radiation, which is a global warming variable, has negative effects on sugarcane production. With an increase in radiation (heat), the expected sugarcane production decreases by 0.2749954. This implies that radiation is a threat to sugarcane production.

Furthermore, the results indicate that the combination of water use of commercial rain-fed and irrigated sugar-cane increases production, also the sun appear to have positive effects on sugarcane production. For every millimeter in combination of water use of commercial rain-fed and irrigated sugar cane, the expected sugarcane production increases. As well as for every additional sun hours, the expected sugarcane production increases**.**

However, regardless of increases in temperature, rainfall and radiation, Tongaat Tambankulu Estates in Swaziland slightly decreased its sugarcane production during seasonal changes. Overall, sugarcane production remained constant and the result is more likely to increase in future years. Rainfall, temperature and radiation are more likely to reduce the production, while sun and the combination of water use of commercial rain-fed and irrigated sugar cane are more likely to increase the sugarcane production. These results have been depicted in figure (6).

The above results are consistent with the Ricardian regression model results of Kabubo-Mariara (2008), who indicated that "livestock production in Kenya is highly sensitive to climate change and that there is a non-linear relationship between climate change and livestock productivity". In addition, agricultural products are likely to react differently to climate change. Tedessa (2010) retorted that "climate change is a serious global challenge that demands urgent, cooperative, fair and shared responsibility to act". Prior to this result, Kurukulasuriya and Mendelsohn (2008) asserted that climate change affects the net revenues of farms across Africa. Furthermore, the study of Gebreegziabher *et al.* (2013) also indicated that global warming towards temperature is beneficial to livestock agriculture. Thus, climate has a non-linear effect on agricultural return.

### 5.3.2 Relationship between global warming, pesticides and other sugarcane diseases

The regression performed the relationship between the effects of global warming and sugarcane production harvesting area, rainfall, thrips and chemicals. The results indicate non-linear relationship between the sub-mentioned variables. For every additional unit of thrips on area to harvest, it negatively affects sugarcane production. In addition, herbicides and insecticides increase has a negative effect on the harvesting area for sugarcane production. This implies that when the harvesting area is more affected, insecticides and herbicides reduce productivity of the area from any expected yield. Furthermore, the result also confirms that as in previous regression, rainfall has negative effects on sugarcane harvesting area.

However, the researcher performed third regression between rainfall, thrips, insecticides and herbicides. The model explains about 96% of the total variation in rainfall yearly. The Coefficient are negatively and positively correlated to each other. For every any additional unit of Thrips count, the expected rainfall increases by 53.51515, holding other variables constant. In addition, for every decrease in rainfall, the expected insecticides increase by 0.0018354, while holding other variables constant.

### 5.3.3 Relationship between change in seasons on sugar cane production

There is a significant relationship between changes in seasons and sugarcane production. This is depicted from the month of April to June, there is a drastic decrease in the production of sugarcane in Tambankulu Estates. From June to July, an indication of production stagnation and August take off up to December.

Seasonal variables variation, as indicated in Figure 6, in relation to sugarcane production, shows that temperature, rainfall and radiation, slightly impact on sugarcane production. Sugarcane production decreases in raining season at highest precipitation, while an increase is noted in summer season, during lower levels of temperature, rainfall and radiation. This suggests that an increase in seasonal temperatures, rainfall, and radiation reduces sugarcane production.

Overall, the results for sugarcane production, as indicated in Figure 6, show that the response of sugarcane production to “summer temperatures is U-shaped”, but the response to “winter temperatures is hill-shaped”. This means that hill shape decreases the production of sugarcane, while the U-shape increases the sugarcane production.

## 5.4 Summary of the chapter

This chapter discussed and analysed the results from empirical estimation of global warming variables on sugarcane production in Swaziland Tongaat Tambankulu estates. The analysis was based on primary data collected from a sample of 324 Tongaat Tambankulu employees. The analysis was also based on the secondary data, collected from Tongaat Tambankulu Estates database.

The effect of global warming on the sugarcane production was analysed using the Ricardian approach. The author estimated the marginal impacts and examined the impact of global warming variables including temperature, rainfall, sun, radiation, insecticides, herbicides, thrips, and combination of “water use of commercial rain-fed and irrigated sugar cane” on sugarcane production.

The results revealed that global warming variables have effects on sugarcane production. Particularity, rainfall, temperature and radiation, have negative effects on sugarcane production. For every additional of their increase, the expected sugarcane production decreases. In contrast, commercially rain-fed and irrigated sugarcane on sugarcane production and sun hours increase, lead to an increase in the sugarcane production. In addition, the insecticide and herbicides also impact on sugarcane harvesting areas.

The analysis of primary data collected resulted in the executive and senior middle management, general staff, team leaders and general farm labourers’ better understanding of global warming. Specifically, the results showed relatively high degrees of understanding of global warming, which influenced their practices and mitigation strategies.

## CHAPTER SIX:
## SUMMARY, CONCLUSION AND RECOMMENDATIONS

### 6.1 Summary

The dissertation examined the effects of global warming on sugarcane farming in Tongaat Huletts Tambankulu, in Swaziland. The purpose was to ascertain the effects of global warming on sugarcane farming in Tongaat Huletts Tambankulu, Swaziland. Mixed methods were adopted for an effective examination of the effects of global warming on sugarcane farming. This method was based on the Ricardian model analysis for the period of 2010-2015. Ricardian model was also employed in the quantitative data methods.

Chapter one introduced the background of the study, purpose of the study, problem statement and research objectives. It also presented the geographic location of the study area, followed by the justification of the study. Chapter two presented literature review that comprises the conceptual and theoretical frameworks on the effects of global warming on sugarcane farming. Chapter three presented the literature review on global warming, while Chapter four focused on the methodology of the study. Chapter five presented the findings and discussions. Chapter six finally, provides the summary, conclusions and recommendations of the study.

The objectives of the study were to determine the effects of the water levels supplied by Komati, Umbuluzi rivers and rainfall on sugarcane growing in Tongaat Huletts, Tambankulu. Besides, the study investigated the effects of global warming on sugarcane production, as well as its relation to pesticides, herbicides and other sugarcane diseases. Finally, it also considered the extent of employees’ understanding of global warming in relation to sugarcane production. The objectives of the study were thus met.

The findings of this study, align with the objectives of the study posed in Chapter One, the responses were covered in Chapter Four and Five, section 5.2.1. The results revealed that global warming variables such as temperature, rainfall and radiation have negative impact on sugarcane production, while sun hours and the combination of water use of commercial rain-fed and irrigated sugarcane have positive impact. Total Radiation ($MJ/m^2$) (0.274) causes more negative impact on Tongaat Huletts Tambankulu sugarcane production than

Temperature (0.043 $^{o}$C) as well as rainfall (0.004 mm). This implies that sugarcane production in Tongaat Huletts Tambankulu is highly sensitive to Global warming variables.

Furthermore, the participants responded to the objectives of water levels supplied by Komati, Umbuluzi rivers and rainfall on sugar cane growing. The results revealed that an increase in the combination of water use of commercial rain-fed and irrigated sugarcane leads to an increase in sugarcane production.

The findings, in relation to global warming, pesticides and sugarcane diseases, revealed exhibited non-linear results, as coefficients of thrips count, Herbicides, insecticides and rainfall are negatively correlated to each other. This indicates that for every additional unit of thrips count, Herbicides and Insecticides, the expected harvesting area decreases on average. In addition, as indicated, rainfall reduced sugarcane production. This infers that chemical substances and thrips affect the harvesting area and plants in Tongaat Huletts Tambankulu Estates. Additionally, this infers to the location effects, which can tolerably damage or repair the harvesting area.

Finally, the findings show that employees and management staff understood the effects of global warming. The views and opinions were satisfactory, as the management showed signs of advance knowledge on global warming and sugarcane production. Furthermore, the employees had practical knowledge of farming to anticipate future production of sugarcane.

## 6.2 Conclusion

This dissertation examined the effects of global warming on sugarcane production in Tongaat Huletts Tambankulu Estates Swaziland. Both quantitative and qualitative methods; were adopted to achieve the objectives of the dissertation. This dissertation adopted the Ricardian model to capture the effects of global warming variables of sugarcane production in Tongaat Huletts Tambankulu. Empirical evidences indicated that in general, agricultural products and sugarcane production in particular, are more sensitive to global warming changes.

Findings indicated that sugarcane production has been directly affected by changes in global warming conditions. The global warming variables such as radiation, temperature and rainfall, negatively affect sugarcane production. It further indicates that for every additional increase in degrees Celsius of temperature, the expected sugarcane production decreases on average, holding other variables constant. In addition, for every additional millimetre of rainfall, the expected sugarcane production decreases. Moreover, for every additional degree of radiation, the expected sugarcane production decreases.

In contrast, the combination of water use for commercial rain-fed and irrigated sugarcane increase in sun hours appear to have positive effects on sugarcane production. For every millimetre in the combination of water use of commercial rain-fed and irrigated sugarcane, the expected sugarcane production increases. As well as, for every additional sun hours, the expected sugarcane production increases.

However, the most critical period of production occurs during the change of season. There is a significant relationship between changes in seasons and sugarcane production. This is observed from the month of April to June, where there is a drastic decrease in the production of sugarcane in Tongaat Tambankulu Estates. From June to July, there is an indication of production stagnation, while August experiences production to take off, up to December. Overall, the results for sugarcane production as indicated in Figure 6 show that the response of sugarcane production in “summer temperatures is U-shaped”, but the response to “winter temperatures is hill-shaped”. This means that hill shape depicts decreases production of sugarcane, while the U-shape depicts increases in the sugarcane production.

The model explains about 59% of independents variables on dependent variables, which implies that the model has explanatory power. Total Rainfall (mm); Max Temperature ($^{o}$C); Total Radiation (MJ/m$^{2}$); Total sun hours and combination of water use of commercial rain-fed and irrigated sugarcane explain sugarcane production. These variables are statistically significant at all the significant levels monthly data.

The model explains about 99% of the total variation in harvest /Area Harvested/To Harvest yearly. This indicates that rainfall, thrips count, Herbicides and Insecticides explain sugarcane production. These variables are statistically significant at 0.05% which corresponds to 95% of significance.

The understanding of global warming effects on sugarcane production and their relationship to Tongaat Huletts Tambankulu Estates decisions to adapt and modify their farming practices remains promising in the enterprise. The findings indicated that the employees, management and staff, have a relatively high degree of understanding of global warming effects on sugarcane production.

### 6.3 Limitation of the study

The study area covers only the Tongaat Huletts –Tambankulu Estates in Swaziland,

- This dissertation was constrained by time and financial means
- It was also limited by key respondent availability
- In addition, it was constrained by lack of completeness of data
- The study was limited to sugarcane production only

### 6.4 Recommendations

Sugarcane production is susceptible to global warming through the direct effects of changing temperature, rainfall patterns and radiation conditions. Based on the results made when analyzing the Ricardian model in this study: The recommendations are provided below.

#### 6.4.1 Water levels Supplied and Rainfall

Based on the results from this research, it is suggested that a dam be constructed below Umbuluzi main road bridge catchment area, to mitigate the decline of rainfall caused by the effects of changes in global warming. A small hydro power station can also be constructed within the dam, to help in pumping water back infield and into reservoirs.

#### 6.4.2 Effects on sucrose change of season

The study further recommends that there should be a re-planning of fields harvesting arrangement. This should be done by delaying their harvest on higher sucrose fields and be aligned towards November and December, where sucrose percentage is always likely higher. Delaying the start of harvesting is another possible recommendation, on which more focus could be given on the trend of sucrose peak months, where, if possible, the sugar millers have to buy in on the idea.

### 6.4.3 Sugarcane diseases

It is further recommended that, based on the increase in thrips, wherefore they decrease during rain and increase during irrigation, the water from the rivers (especially Umbuluzi), could be investigated for pollution so that better mitigation measures could be taken.

### 6.4.4 Effects of changes of season on sugarcane

The study recommends that continuous research be done to look at the cane varieties that can sustain themselves in the changes in global warming conditions, that would achieve optimal percentage of sucrose. It is also recommended that Tongaat Tambankulu Estates prioritises and adapts strategies and knowledge in global warming. The purpose of the strategies would be to construct a dam with an objective to mitigate the rainfall risk and the outcome results in the number of liters increasing to respond to the supply and demand requirements. These recommendations are in alignment with previous studies on global warming and sugarcane production.

### 6.4.5 Recommendations for future studies

The study focused on the effects of global warming on sugar cane farming in Tongaat Huletts –Tambankulu Estates, Swaziland, from 2010 to 2015. Future studies could analyze the effects of global warming on sugarcane production in all locations of Tongaat Huletts, which include Namibia, Botswana, Zimbabwe, Mozambique, Swaziland and South Africa to give a clear perspective on the effects. Future studies could further include first all, coastal countries like Namibia, Mozambique, and South Africa first, second landlock countries: Botswana, Zimbabwe and Swaziland.

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# APPENDIX
**Questionnaires**

I. QUESTIONNAIRE FOR DIFFERENT STAKEHOLDERS

The Effects of Global Warming towards Sugar Cane Farming in Tongaat Huletts - Tambankulu.

ANNEXURE A:

Prompts for Executive, Senior and Middle management and Team leaders at Tongaat Huletts Tambankulu

Date:
Interviewee:
Venue:
Organization

1. What are the effects of Climate change on sugarcane production?

______________________________________________________________________

2. Determine the relationship between a change in seasons on sugar cane production

______________________________________________________________________

3. To determine the effects of increase in heat (radiation) on sugar cane farming (Agriculture production (sugarcane production) is vulnerable to climate change through)
   a) Direct effects of changing climate conditions (e.g., changes in temperature and/or precipitation)
   b) Indirect effects arising from changes in the severity of pest pressures, availability of pollination services, and performance of other ecosystem services

4. Climate variability and climate change may result in
   a) changes in sea levels, rainfall pattern,
   b) the frequency of extreme high- and low-temperature events, floods, droughts, and other abiotic stresses
   c) tornados and hurricanes
   d) a.b.c above

5. What are the two major issues influencing agricultural production and economic in Swaziland in Tongaat Huletts –Tambankulu Estate?

______________________________________________________________________

6. How can one manage the effects of climate change?
   a) Adaptive action by altering patterns of agricultural ( sugarcane)activity to capitalize on emerging opportunities while minimizing the costs associated with negative effects
   b) By non-adaptive action related to agriculture( sugarcane) activity to capitalize on emerging opportunities while maximizing the costs associated with negative effects

7. What are the potential negative effects of climate change on sugarcane production in Swaziland Tongaat Huletts –Tambankulu Estate?

a) Temperature and rainfall, on sugarcane production
b) Drought and tropical cyclones
c) Drought and tornados

8. What maybe effects on production of sugarcane in Tongaat Huletts –Tambankulu Estate?
a) increased water deficit stress caused by the warmer climate
b) increases in atmospheric [CO2] and air temperature
c) Adaptive mitigation strategies
d) controlled conditions or based on crop modeling prediction
e) all of the above

9. What is the main cause of sugarcane vulnerability to climate change?

a) increased frequency and intensity of the extreme weather events, such as drought, heat, flooding, typhoon, and frost
b) decreased frequency and intensity of the nonviolent weather events, such as plenty of water or rainfall, coldness, non-flooding, non-typhoon, and non-frost

10. On what depend factor has effects of drought due to climate change on sugarcane growth and development?
a) Depend on plant growth stage,
b) Depend on the degree of water deficit stress, and
c) Depend on the duration of the stress.
d) All the above

11. What is the adaptation farming systems to climate change require for sugarcane production?
a) Taking advantage of the potential benefits on crop production
b) Minimizing potential adverse impacts on crop production.
c) Through a better understanding of the functions of these climate/weather factors and their impacts on sugarcane production
d) Manipulate plants to meet human needs and formulate adaptation or mitigation strategies
e) All the above or none of the above

12. What are the great potential challenges causing great variation in sugarcane yields?
a) Low adaptive capacity,
b) high vulnerability to natural hazards, and
c) poor forecasting system and mitigating strategies
d) None of the above or all of the above

13. What are the environmental economic and social issues to consider when assessing agriculture and crop production systems as well as climate change and its negative impact on cane production?
One has to consider how to:

(1) Balance short-term and long-term goals;
(2) Increase productivity, profitability, and sustainability;
(3) introduce new technologies and transfer them to growers;
(4) meet environmental regulations;
(5) Deal with contradictions between climate change and crop production; and
(6) Balance competition of food and energy in resources

14. What are the most significant challenges for sugarcane production?
a) increases in frequency and intensity of extreme weather events, especially drought during climate change

b) water scarcity

15. What can be done to mitigate the unpredictability of global warning (Climate change) on sugarcane production?
    a) Sugar cane scientists and decision makers need to work closely to mitigate the potential negative effects of climate change on sugarcane and
    b) There is need to improve sugarcane yields by multidisciplinary approaches,
    such as consistently developing new sugarcane cultivars using breeding and molecular biology, refining best management practices, improving new technology transfer, and increasing productivity and profitability

16. What is the economic environmental and social impact of global warming on sugarcane production?
    a) Economically: raise of food prices and declined consumer incomes
    b) Environmentally: decrease the agricultural sugarcane productivity, decrease of sugarcane due to drought, decrease of water, rainfall
    c) Socially: lack of sugarcane or declined the per capita food consumption

17. What is the annual variation in cane productivity due to climate change?

____________________________________________________________

18. What are the effects of climatic and non-climatic factors on sugarcane productivity in different weather seasons such as rainy, winter and summer seasons in Tongaat Huletts –Tambankulu?

____________________________________________________________

19. What is the influence of climatic and non-climatic variables on sugarcane productivity in Tongaat Huletts –Tambankulu Estate Swaziland

____________________________________________________________

20. How sugarcane in Tongaat Huletts –Tambankulu gets affected with annual variation in cane productivity due to climate change?

____________________________________________________________

21. What is your understanding, the extent to which Tongaat Huletts Tambankulu employees understand the global warming in sugar cane production?

## STATA Outputs

## Regression one:

```
      Source |       SS       df       MS              Number of obs =      49
-------------+------------------------------           F(  5,    43) =   12.86
       Model |  14.7481502     5  2.94963005           Prob > F      =  0.0000
    Residual |  9.86264977    43  .229363948           R-squared     =  0.5993
-------------+------------------------------           Adj R-squared =  0.5527
       Total |     24.6108    48     .512725           Root MSE      =  .47892
------------------------------------------------------------------------------
    SucroseP |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       TSunh |   .0037502   .0032193     1.16   0.250    -.0027422    .0102426
      TCaneR |   .0243874   .0035448     6.88   0.000     .0172386    .0315362
      TRainf |  -.0042022   .0023616    -1.78   0.082    -.0089648    .0005604
       MTemp |  -.0431854   .0681017    -0.63   0.529    -.1805255    .0941547
   Radiation |  -.2749954   .0731513    -3.76   0.001    -.4225189   -.1274718
       _cons |   15.83664   1.458468    10.86   0.000     12.89536    18.77792
------------------------------------------------------------------------------
```

## Regression Two

```
      Source |       SS       df       MS              Number of obs =       5
-------------+------------------------------           F(  3,     1) = 4182.36
       Model |  14.7988205     3  4.93294018           Prob > F      =  0.0114
    Residual |  .001179463     1  .001179463           R-squared     =  0.9999
-------------+------------------------------           Adj R-squared =  0.9997
       Total |        14.8     4         3.7           Root MSE      =  .03434

------------------------------------------------------------------------------
        Land |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   GRainfall |  -.0076931   .0000999   -77.04   0.008    -.0089619   -.0064243
      Nherbd |  -5.17e-06   6.30e-08   -81.98   0.008    -5.97e-06   -4.37e-06
     Lthrips |  -.1133904   .0099567   -11.39   0.056    -.2399022    .0131213
       _cons |   17.53664   .1356419   129.29   0.005     15.81315    19.26014
```

## Regression Three

```
      Source |       SS       df       MS              Number of obs =       5
-------------+------------------------------           F(  2,     2) =   24.37
       Model |  170007.513     2  85003.7563           Prob > F      =  0.0394
    Residual |  6977.09939     2   3488.5497           R-squared     =  0.9606
-------------+------------------------------           Adj R-squared =  0.9212
       Total |  176984.612     4   44246.153           Root MSE      =  59.064

------------------------------------------------------------------------------
   GRainfall |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     Lthrips |   53.51515   22.06263     2.43   0.136    -41.41267     148.443
    Minsectd |  -.0018354   .0003246    -5.65   0.030    -.0032322   -.0004386
       _cons |   663.8287   115.7721     5.73   0.029     165.7014    1161.956
------------------------------------------------------------------------------
```

**Tongaat Hulett**
TAMBANKULU ESTATES

02 September 2016

Mr. Absalom Xulu

Graduate School of Business & Leadership

College of Law and Management Studies

Westville Campus

UKZN

Email: absalom.xulu@tongaat.com

Dear Mr Xulu

**RE: PERMISSION TO CONDUCT RESEARCH**

Gatekeeper's permission is hereby granted for you to conduct research at Tambankulu Estates towards your postgraduate studies, provided Ethical clearance has been obtained. We note the title of your project is:

*"The impact and effects of global warming towards sugar cane farming in Tongaat Huletts Tambankulu."*

It is noted that you will be constituting your sample by accessing data of sugar cane growing in Tongaat Huletts Tambankulu Estates.

Please note that the data collected must be treated with due confidentiality and anonymity.

Yours sincerely,

**G. C WHITE**

**GENERAL MANAGER**

UNIVERSITY OF ™
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

**Protocol reference number** : **HSS/1924/016M**

**Project title** : **The effects of Global Warming towards Sugar Cane Production in Tongaat Huletts - Tambankulu**

# ACKNOWLEDGEMENT:
# BREACH OF ETHICAL PROCESSES AT UKZN

**I, the undersigned,**

| | | |
|---|---|---|
| **Student Name (Student Nr)** | : | **Mr Absalom Fana Xulu (213570985)** |
| **School** | : | **Graduate School of Business & Leadership** |
| **Campus** | : | **Westville Campus** |

as the Principal Investigator ("the Applicant") in the above stated project, do hereby acknowledge that:

1. The University of KwaZulu-Natal's (hereinafter "UKZN") Research Ethics Policy (V) does not make provision for Retrospective Ethics Approval;
2. All researchers (both students and staff) at UKZN are obliged to be familiar with this policy;
3. I have been informed that research cannot be done without obtaining full ethical clearance as per the policy and guidelines of the University;
4. **Research for the above project was undertaken by myself without final ethical clearance being obtained**;
5. The University reserves its right to, at any stage and time, withdraw the relevant degree obtained by myself if:
   - 5.1 It becomes known to UKZN that there was an additional ethical breach during any field work or whilst collection data for the above stated project, and / or
   - 5.2 I fail to apply for ethical clearance for any future research projects.
6. In addition to point 5 above, the appropriate disciplinary processes will follow should this occur again.

I further acknowledge that should there be any legal implications/actions emanating from the research in terms of any ethical violations, I will be personally liable and hereby indemnify UKZN against any legal action that may arise from my failure to adhere to the University Research Ethics Policy (V).

Signed at UKZN on the 02nd day of December 2016

Signature of applicant: ____________________

Signed at ________ on the ________ day of ________ 2016

Signature of Chair (HSSREC): ____________________ Date: 5/12/16

**Humanities & Social Sciences Research Ethics Committee**
**Dr Shenuka Singh (Chair)**
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UNIVERSITY OF KWAZULU-NATAL™
INYUVESI YAKWAZULU-NATALI

**(Only complete this section if applicable)**

# ACKNOWLEDGEMENT: BREACH OF ETHICAL PROCESSES AT UKZN

I, the undersigned,

| | | |
|---|---|---|
| **Supervisor name** | : | **Professor Stephen Migiro** |
| **School** | : | **Graduate School of Business & Leadership** |
| **Staff / student number** | : | **Westville Campus** |

acting as supervisor in the above stated project, do hereby acknowledge that:

1. The University of KwaZulu-Natal's (hereinafter "UKZN") Research Ethics Policy (V) does not make provision for Retrospective Ethics Approval;
2. All researchers (both students and staff) at UKZN are obliged to be familiar with this policy;
3. I have been informed that research cannot be done without prospective full ethical clearance as per the policy and guidelines of the University;
4. **I have failed to verify whether the Applicant obtained Final Ethical Clearance in accordance with the UKZN Research Ethics Policy (V) for the above stated Project;**
5. The appropriate disciplinary processes will follow, should this occur again.

I further acknowledge that should there be any legal implications/actions emanating from research in terms of ethical violations, I will be personally liable, jointly and severally with the Applicant and hereby indemnify UKZN against any legal action that may arise from my failure to adhere to the University Research Ethics Policy (V).

Signed at GSBL on the 20th day of Dec 2016

Signature of supervisor (where applicable): ______________________

Signed at ________ on the ________ day of ________ 2016

Signature of Chair (HSSREC): ______________________ Date: 19/12/16

Cc: College Dean of Research: Professor Marita Carnelley
Cc: Academic Leader Research: Dr Muhammad Hoque
Cc: School Administrator: Ms Zarina Bullyraj

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The Effects of Global warming towards

BY XULU ABSALOM

CHAPTER ONE
INTRODUCTION AND BACKGROUND

**1.1 Introduction**

Global warming and climate change have become a major concern for countries all over the world including African countries. According to "regional climate projections given in the fourth assessment report of the Intergovernmental Panel on Climate Change" (IPCC, 2007), for Africa, "global warming is very likely to be higher than the global annual mean warming throughout the continent and in all seasons". In southern Africa, for instance, rainfall appears to be decreasing in much of its winter rainfall region (Knox *et al.*, 2012). These assertion points out the importance climate change plays as a factor in agricultural productivity. Meaning that, any extreme changes in climate like global warming, will negatively affect agricultural production growth, and other components of managing agricultural systems.

Many countries in Africa depend on agriculture as main sector contributing to their economy and provide livelihoods for large parts of the population (Waha *et al.*, 2016). Africa is home for too many smallholder farmers and fields are heterogeneous and scattered with a large variety of crops. Sugarcane is among these crops, with its production covering more than half a million hectares spread across seven countries in Southern Africa (Waha *et al.*, 2016). Sugarcane is positioned as an important cash crop in the agrarian economy of Africa and Swaziland in particular. In Southern Africa, "sugarcane output produce has increased to 80% over the past 20 years, affecting land and water usage" (Dubb *et al.*, 2016). Sugarcane production in Southern Africa is considered as both commercial and developmental. Cane production growth occurs in poorest countries in southern zone and oriented by commercial investments by South Africa-based companies.

In Swaziland, Sugarcane is by far the most prevalent crop in irrigated agriculture areas (Dubb *et al.*, 2016). According to National adaptation strategy (2010), more than "90% of

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