Measuring the impact of climate change on South African agriculture: The case of sugarcane growing regions

by

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Abstract

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This study utilized the Ricardian approach that captures farmer adaptations to varying environmental factors to analyze the impact of climate change on South African Sugarcane production. Two production systems, irrigated and dryland were taken for the study. A total of 11 districts, two from the irrigated and nine from the dryland-farming zone were selected for the study. Data for the period 1976/77 to 1997/98 were pooled over districts and net revenue per hectare was regressed on climatic and control variables. The results indicated that climate has a non-linear and significant impact on net revenue per hectare.

Based on the Inter Governmental Panel on Climate Change (IPCC) benchmark warming scenario of increasing temperature by 2°C and precipitation by 7%, which is associated with the doubling of CO_2*, it was found that climate change reduces net revenue per hectare in the South African sugarcane production. Moreover, the result of increasing temperature by 2.75°C(associated with the doubling of* CO_2 *under South Africa) across all seasons, by keeping other factors constant, indicated that both the irrigated and dryland farming zones were equally damaged by this scenario. Increasing precipitation levels by 7% across all seasons, keeping other factors constant benefited the irrigated farming whereas it damaged the dryland farming.*

Additionally, the partial impacts of increasing a given season's temperature by 2.75°C or rainfall by 7% indicated that the seasonal effects of temperature and rainfall are differently distributed across seasons and production zones. Finally, the likely impacts of climate change on South African sugarcane production were analyzed based on the critical damage point analysis. The results indicated that sugarcane production in South Africa is more sensitive to future increases in temperature than precipitation as a consequence of climate change.

While the consensus is that arid and semi-arid regions are more vulnerable to warming, management options, such as irrigation, are thought to provide an adaptation mechanism. This however was not the case for sugar farming in South Africa, as irrigation did not reduce the harmful impacts of climate change significantly.

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I am very grateful to my family and friends (specially Mampity, Fufa, Yeshi and Bultosa) for their encouragements and assistance under all circumstances.

> *" I will bless the Lord at all times: his praises*
> *shall continually be in my mouth. "*
>
> *Psalm 34:1*

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Chapter 1: Introduction

1.1 Background and Motivation

Agriculture in South Africa has a central role to play in building a strong economy and in the process, reducing inequalities by increasing incomes and employment opportunities for the poor (Hanekom, 1998). The sector contributes directly and indirectly to the total economy. It accounts for 5.2 % of the GDP, employs 13 % of the economically active population and generates about two billion US dollars from exports annually (AAS, 2001). The sector indirectly contributes to the growth of the economy through income and employment multipliers (Van Zyl, 1988; McDonald *et al.*, 1997; Townsend, 1997; Hassan, *et al.*, 2001)

It is generally recognized that climate change has an impact on agriculture (IPCC, 1990). Many efforts have been made to estimate the economic impact of climate change on agriculture (Adams, 1989; Rosenzweig, 1989; Mendelson *et al.*, 1994; Kaiser *et al.*, 1993). However, most of these studies focused on the United States and other developed countries.

Due to the global nature of climate change, concerns of the impact of climate change on agriculture in developing countries have been increasing (IPCC, 1996). As a consequence some attempts have been made to estimate the impact of climate change on agriculture in developing countries (Winter *et al.*, 1996; Dinar *et al.*, 1998; Kumar and Parikh, 1998; Mendelson et *al.*, 2000).

Sugarcane production is an important activity in the South African agriculture (Hassan *et al.*, 2001). Based on the actual sales and selling prices in 2000/2001, it is estimated that the South African Sugar industry contributed R 1.9 billion to the country's foreign exchange earnings. Employment within the sugar industry is approximately 85000 jobs, direct and indirect employment is estimated at 350000 people & there are approximately one million people dependent on the sugar industry (SASA, 2001). Given these contributions, any factor affecting the industry has an impact on its contribution to the total GDP of agriculture and hence to the overall economy.

Like other agricultural sectors, sugarcane farming is expected to be significantly influenced by climate Change. Studies have been conducted to analyze the impact of climate change on maize production (Schulze *et al.*, 1993; Du Toit, 2001), the farming sector of the Western cape (Erasmus *et al.*, 2000) and sugarcane farming (Kiker, 2002 and Kiker *et al.*, 2002) in South Africa. All of these studies adopted the production function approach, which does not include farmers' adaptations. So far there has not been any study to address the economic impact of climate change on sugarcane farming and farm level adaptations that sugar farmers make to mitigate the potential impact of climate change. Accordingly, little is known about the impact of climate change on sugar farming. This presents a serious limitation on policy formulation and decision making in terms of adaptation and mitigation strategies. This study makes an attempt to analyze and measure the economic impact of climate change on sugarcane farming in South Africa contributing to bridging the mentioned gap in literature.

1.2 Objectives of the Study

The main objective of this study is to measure the economic impact of climate change on South African agriculture using sugar-producing regions as a case study. Under this overall objective the following specific objectives are set for this study.

a) Develop and apply an empirical model to assess the impact of climate change on sugar farming in South Africa.

b) Use the developed model to assess and compare the seasonal and regional distribution of the impacts of climate change on agriculture across the sugarcane producing regions.

c) Inform policy and decision-making in the sugar industry on appropriate adaptation and mitigation strategies.

d) Identify gaps for further research.

1.3 Approach and Methods

To achieve the above listed objectives the study will adopt the Ricardian approach to examining farmers' performance across climatic zones and measuring the contribution of environmental variables such as climate factors to farm income. The Ricardian approach uses a regression of land values or net revenue on a set of environmental inputs to measure the marginal contribution of such inputs to farm income.

Farmers are likely to respond to changing climate and other environmental factors by varying among other things, the crop mix, planting and harvesting dates, irrigation scheduling and application of fertilisers and pesticides. By doing so, farmers mitigate the potential negative effects of climate change. The mitigation and adaptations farmers make to reduce the negative effects of climate change involve economic costs, which materialise in the form of reductions in net revenues or farm asset values. The Ricardian approach measures these economic costs (reductions in net revenue or farm value), which are caused by environmental variables.

1.4 Organisation of the Study

The study is organized in six chapters. Chapter two provides an overview of the South African agriculture, its contribution to the national economy and the position of sugarcane farming. Chapter three reviews relevant literature and models of measuring the climate sensitivity of agriculture in general and in South Africa. The approaches and methods applied in the analysis are presented in chapter four. Chapter five presents and discusses the results of the analysis. Conclusions and implications for policy formulation and mitigation strategies are distilled and gaps for future research are identified in chapter six.

Chapter 2: Agriculture, Sugar Farming and the South African Economy

2.1 Introduction

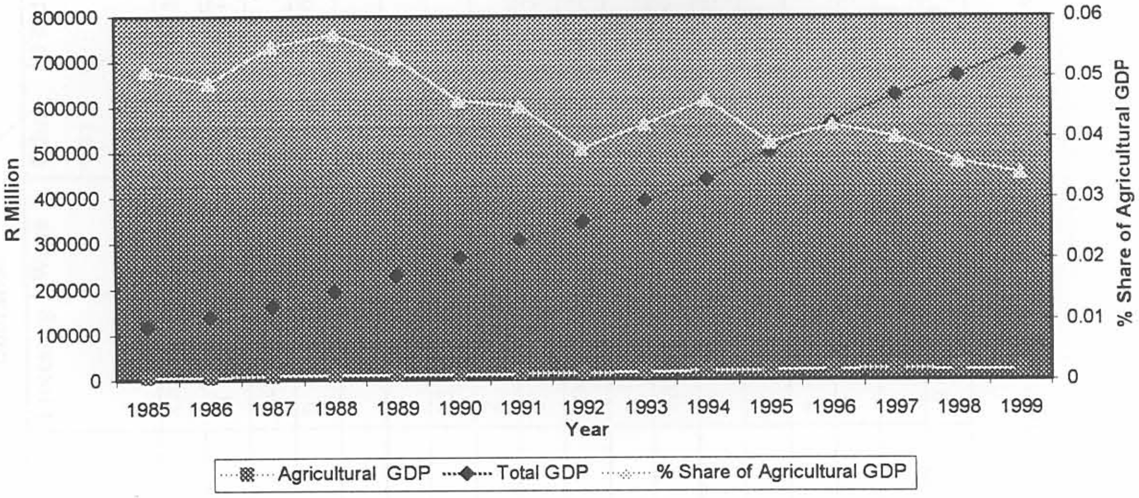
Agriculture is one of the most important sectors contributing to the development of the South African economy. It is an important source of employment, foreign exchange and food supply. Agriculture also contributes to the rest of the economy through economic multipliers effects. Agriculture is sensitive to climate change because, activities in this sector are dependent on climate factors such as rainfall and temperature. The degree of the sensitivity of agriculture is therefore influenced by geographic location. This chapter describes the contribution of the agricultural sector and sugar farming to the economy of South Africa, the sensitivity of agriculture to climate variables and the agro ecological features of South Africa.

2.2 Contribution of Agriculture to the Economic Well-being in South Africa

2.2.1 Contributions to GDP

Agriculture's contribution to GDP at factor cost increased from R 6,091 million in 1985 to R 24,555 million in 1999 (AAS, 2001). But agriculture's share of GDP decreased from 5.1 % to 3.4 % over the same period (Figure 2.1). This was due to the fact that the output of non-agricultural sectors grew faster than that of the agricultural sector. The low growth rate of the agricultural sector relative to that of the overall economy is part of the transformation of the economy over the past century from one dependent on primary sectors (agriculture and mining) to a broadly diversified manufacturing and services economy (Meyer, 1998).

Figure 2. 1: Share of agriculture in the gross domestic product of South Africa (1985-1999)



Source: AAS (2001)

2.2.2 Food supply and Food Security

Providing adequate supply of food at reasonable prices is a major contribution of agriculture. In general South Africa is considered self-sufficient in food. According to table 2.1, South Africa is self-sufficient in most foods. Large surpluses are particularly generated in some sectors such as sweeteners, fruit and vegetables. On the other hand, the largest shortages in domestic supply components to local demand are observed in vegetable oils, spices and animal fats.

Food prices have significantly increased over the 1985 to 1998 period (Figure 2.2). Prices of the major food items such as field and horticultural crops, vegetables and animal products have shown an upward trend. While increasing food price is an incentive for producers, it has a negative impact on the household food security level especially for low-income groups. The negative impact of increasing prices can be minimized by different policy interventions. Government interventions such as support to micro enterprises, human capital formations and investment in infrastructure, which enhance rural development, can be targeted to increase the income levels of the poor (Sadoulet and De Janvry, 1995).

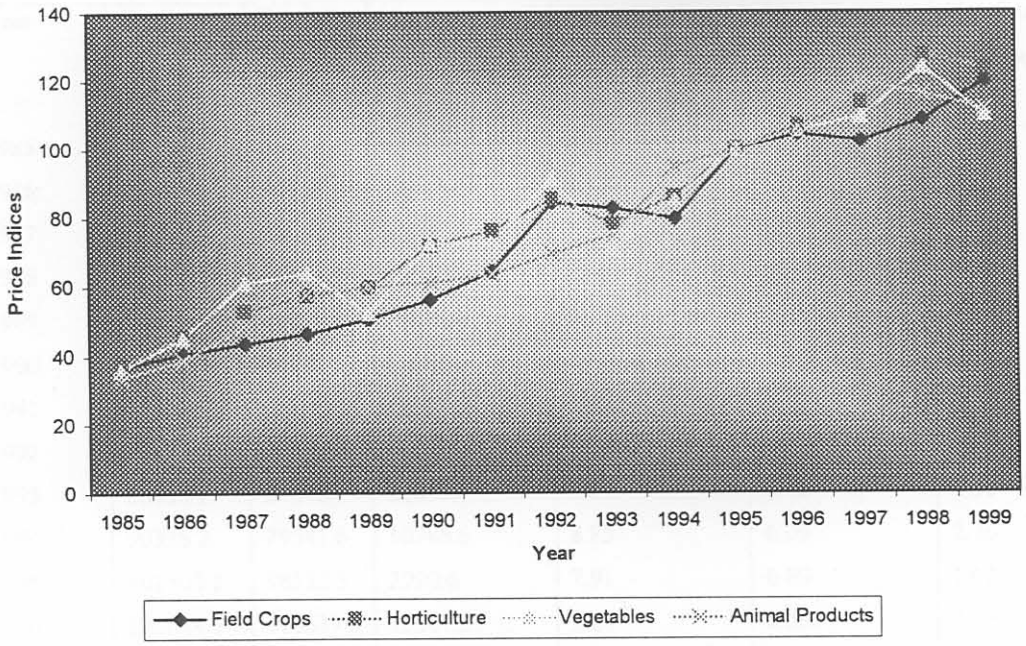
Table 2. 1:South African food balance sheet, for the year 2000, (1000 Metric tone)

Products	Supply					Utilization						Degree of Self sufficiency1)
	Production (Domestic supply)	Imports	Stock Changes	Exports	Total Supply	Feed	Seed	Processing	Waste	Other uses	Food	
Cereals	13333	1854	-693	970	13524	4368	129	470	415	250	7922	0.99
Starchy Roots	1606	106	0	68	1644	208	64	-8	79	89	1212	0.98
Sugar Crops	24061	0	0	0	24061	0	-	22858	1203	-	-	1.00
Sweeteners	2670	35	371	1519	1557	-	-	0	-	5	1556	1.71
Pulses	112	62	0	7	168	17	9	-	5	-	138	0.67
Tree Nuts	9	9	0	5	13	-	-	-	-	-	13	0.69
Oil Crops	907	200	257	48	1315	6	18	1236	16	0	41	0.69
Vegetable Oils	472	430	63	66	899	-	-	2	0	352	544	0.53
Vegetables	2070	26	0	19	1417	70	-	0	138	-	1212	1.46
Fruit	4759	33	5	1901	2896	-	-	1043	176	5	1672	1.64
Spices	10	13	0	7	16	-	-	-	-	-	16	0.63
Alcoholic Beverages	3277	35	0	472	2841	-	-	205	-	56	2850	1.15
Meat	1559	170	0	23	1705	1	-	-	-	6	1701	0.91
Offals	175	22	0	0	197	0	-	-	-	44	152	0.89
Animal Fats	57	46	0	9	95	8	-	-	-	-	50	0.60
Milk excluding butter	2667	213	0	141	2739	104	-	-	22	-	2613	0.97
Eggs	318	0	0	3	315	-	29	-	32	-	254	1.01
Fish, Sea food	592	94	0	177	510	239	-	-8	-	-	279	1.16

Source: FAO, (2002)

1) Degree of self - sufficiency equals the ratio of domestic supply (Production) to total supply. A ratio less than one indicate low self-sufficiency and vice versa.

Figure 2. 2: Price trends of agricultural products (1985-1999)



Source: AAS (2001)

2.2.3 Agriculture as a Source of Foreign Exchange

South Africa has a positive and growing trade balance. The growth of the surplus in trade balance is mainly due to the faster growth in exports than imports (Table 2.2). Agriculture is one of the sectors contributing to the growth of the balance of payment. This contribution of agriculture to trade balance is growing as the result of the integration of the sector into the international market with the current market liberalization policies, which enabled agricultural exports to grow faster than imports.

Table 2. 2: The contribution of agriculture to the external trade balance in South Africa (1985-99)

Year	Total exports (Rm)	Total imports (Rm)	Net export (Rm)	Agricultural exports as % of total exports	Agricultural imports as % of total imports	% of trade balance due to agriculture[1)]
1985	36410.4	22731.9	13678.5	6.54	5.71	0.83
1986	41327.8	26863.6	14464.2	7.32	5.48	1.84
1987	42762.5	28672.6	14089.9	7.47	5.27	2.2
1988	49360	39483.9	9876.1	7.62	5.27	2.35
1989	58728.4	44741.8	13986.6	9.72	4.65	5.07
1990	60770	44141.5	16628.5	8.70	4.99	3.71
1991	61146.5	44195.2	16951.3	8.91	5.52	3.39
1992	69196.8	52594.4	16602.4	7.82	8.54	-0.72
1993	80938.1	59078.7	21859.4	6.77	6.42	0.35
1994	90328.2	79541.6	10786.6	8.85	6.09	2.76
1995	101503.1	98512.5	2990.6	7.91	6.89	1.02
1996	126044.7	115537.5	10507.2	9.24	6.66	2.58
1997	143814.3	129907.9	13906.4	8.52	6.62	1.9
1998	156184.2	146805.1	9379.1	8.58	6.37	2.21
1999	163180.8	147091.8	16089	8.81	6.07	2.74

Source: AAS (2001)

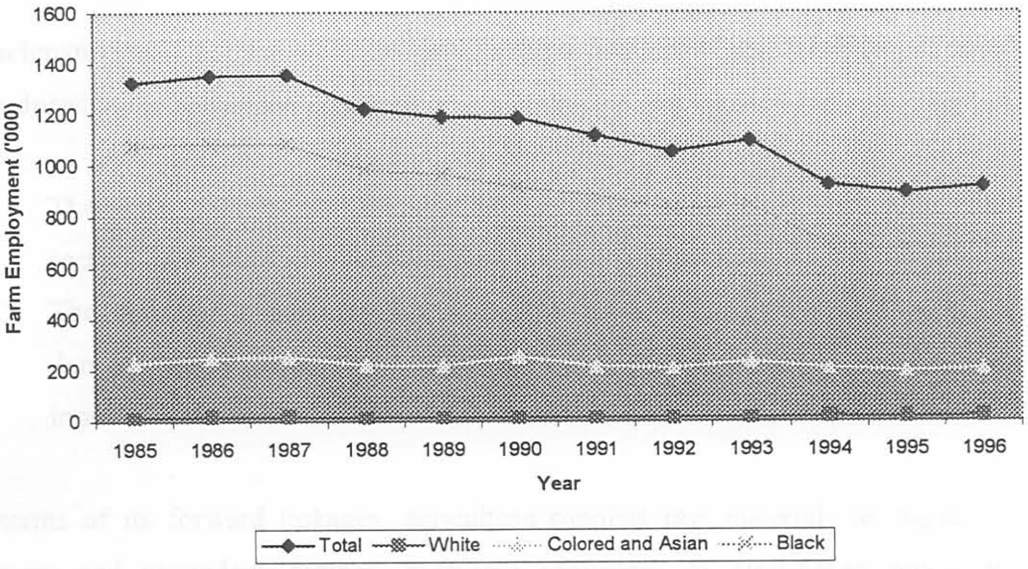
1) Percent of trade balance due to agriculture equals agricultural exports as % of total exports minus agricultural imports as % of total imports. It is the percent of the excess balance of payment generated by agriculture.

2.2.4 Agriculture as a Source of Employment

The agricultural sector of South Africa is an important source of employment. Although the agricultural sector is not the leading sector in employment-creating economic development, it was and will always be an important source of employment (Meyer, 1998; Vink and Kirsten, 1999). Agriculture has traditionally been the largest employer in the South African economy (Meyer, 1998). In 1970, agriculture employed 30.6 % of the economically active population compared to 13 % in 2001 (AAS, 2001). This reduction in share of employment is an indication of the economic growth that South Africa underwent. In all economic development theories, as the economy grows, surplus labor is released and transferred from agriculture to the rest of the economy, which is true for South Africa (Lewis, 1955; Hirischman, 1961; Solow, 1970).

Agricultural labor is dominated by black laborers, followed by colored and Asians and least by whites. Figure 2.3 below gives the trend of commercial farm employment by race over the 1985 to 1996 period.

Figure 2. 3: Farm employment in commercial agriculture (1985-1996)



Source: AAS (2001)

2.2.5 Economy-wide Benefits and Economic Multipliers of Agriculture

A key contribution of the agricultural sector is found in the forward and backward linkages and income and employment multipliers (Van Zyl, 1988; McDonald *et al.*, 1997; Townsend, 1997; Groenwald, 1997; Poonyth *et al.*, 2001). The total SAM (social accounting matrix) multiplier of agriculture in South African economy ranges from 4.39-5.54. This value is greater than the international (1.26 - 2.88), Asian (1.64 - 1.82), and African (1.48 - 2.88) figures (Hassan, 1998; Hassan *et al.*, 2001). This high level of multiplier indicates that a unit investment in the agricultural sector induces a remarkable effect on the overall economy.

Growth in agricultural sector is closely related to processes in the rest of the economy and plays a crucial role in stimulating overall economic growth by:

- Increasing the supply of food and fiber for domestic consumption.
- Releasing excess labor to the industrial sector.
- Increasing income (rural purchasing power), which leads to a higher demand for output from the emerging manufacturing sector.
- Increasing domestic savings
- Supplies inputs for domestic industries (processing)

Hirschman (1961) put foreword two mechanisms through which development could be induced in the rest of the economy:

1. The output utilization or foreword linkage effects. This is the demand by other sectors for the agricultural outputs.
2. The derived demand for inputs, or backward linkage effects. This is the demand by agriculture for outputs of other sectors to use as intermediate inputs.

In terms of its forward linkages, agriculture supplies raw materials as inputs for primary and secondary sectors. Extensive sequences of agro-based processing industries in South Africa are dependent on agriculture for raw materials.

The backward linkage of the sector to the economy is indicated through the direct purchases of inputs such as fertilizers and fuels and the value of fixed investments as a percent of gross farm income (Table 2. 3).

Table 2.3: Purchases by agriculture from other sectors as a percent of gross farm income, at 1999 basic prices.

Intermediate Input use and gross capital formation	Purchase as percent of gross farm income
Purchases of intermediate inputs	35.07
Packaging material	4.15
Fuel	6.49
Fertilizers	5.29
Stock Feed	13.64
Dips and sprays	5.50
Gross capital formation	9.08
Fixed improvements	4.62
Tractors and Machinery	4.46
Gross farm income (R Million)	**40,729.7**

Source: AAS (2001)

2.3 Sensitivity of Agriculture to Climate Change

Agriculture is sensitive to climate change because activities in this sector are dependent on natural factors. The nature and distribution of rainfall, temperature, soil type and a host of environmental factors affect agriculture. The severity of the impact of climate change on agriculture is influenced by the geographic location of a given area as environmental factors vary over space.

The agricultural sector of temperate and tropical regions is differently affected by climate change. Countries in temperate and polar locations might benefit from global warming, as it will have positive impacts on their agricultural sectors. On the other hand, many countries in tropical and sub-tropical regions are expected to be more vulnerable to global warming because higher temperatures can affect their marginal water balance and harm their agriculture (Mendelson et *al.*, 2000).

Different agricultural activities in South Africa are expected to be affected differently by changing climate based on their specific agro-ecological characteristics. It is therefore important to know the agro-ecological location and characteristics of a specific area to analyze the severity of climate impact and the level of adaptation, which in turn assist in planning area specific policies.

2.4 Agro-Ecological Features of South Africa

As argued earlier, the sensitivity of agricultural sector to climate change is influenced by its geographic place. According to the Department of agriculture (1947), the most suitable form of farming for a specific place is mainly determined by:

- Physical factors (topography, soil, climate and specially rainfall)
- Biological factors (illness, pests)
- Economic factors (market and transport facilities, production costs); and
- Historical factors (culture, norms and traditions)

South Africa was divided into six agro-economic zones to conduct analysis on regional agricultural trade and changing comparative economic advantage in South Africa (Jooste and Van Zyl, 1999). An agro–economical region was defined as the area of land that through its physical, biological, economical and historical characteristics is more or less homogeneous. This definition is similar to the concept of agro- economical zones adopted by the National Department of Agriculture (NDA, 1947).

In addition, the Joint Agriculture and Weather Facility (JAWF) and the National Oceanic and Atmospheric Administration (NOAA) of the United States Department of Commerce delimited the climatic features of South Africa in to four main climatic zones based on crop areas and climate profiles (JAWF, 1999). These are the Steppe (arid), dessert, subtropical wet and the sub-tropical winter rain zones (Figure 2. 4)

The South African Sugarcane producing regions are located in two of the climatic zones defined by NOAA/JAWF. The northern irrigated regions are located in the steppe (arid) zone, while the dryland farming regions are located in the sub-tropical wet zones (Figure 2. 5). Sugarcane production under these different agro-ecological zones with different climatic features is expected to be differently affected by climate change.

Figure 2. 4: Climatic features of South Africa

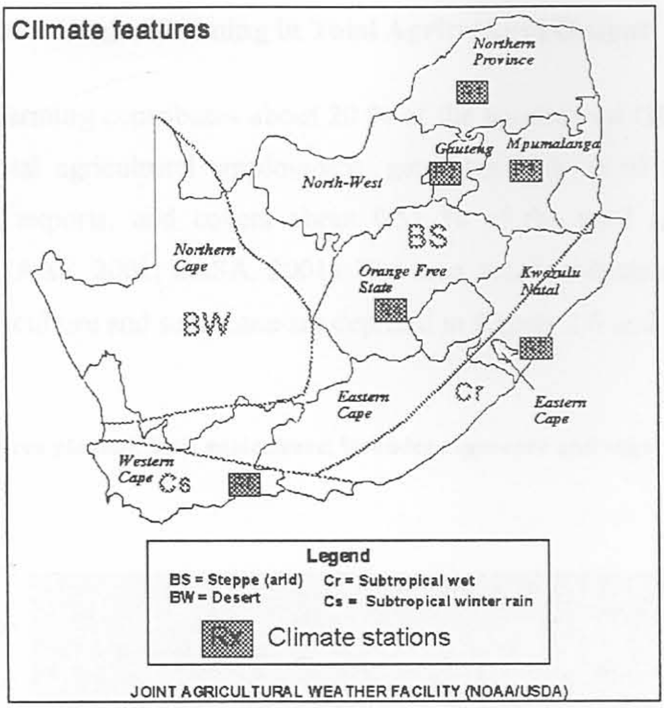
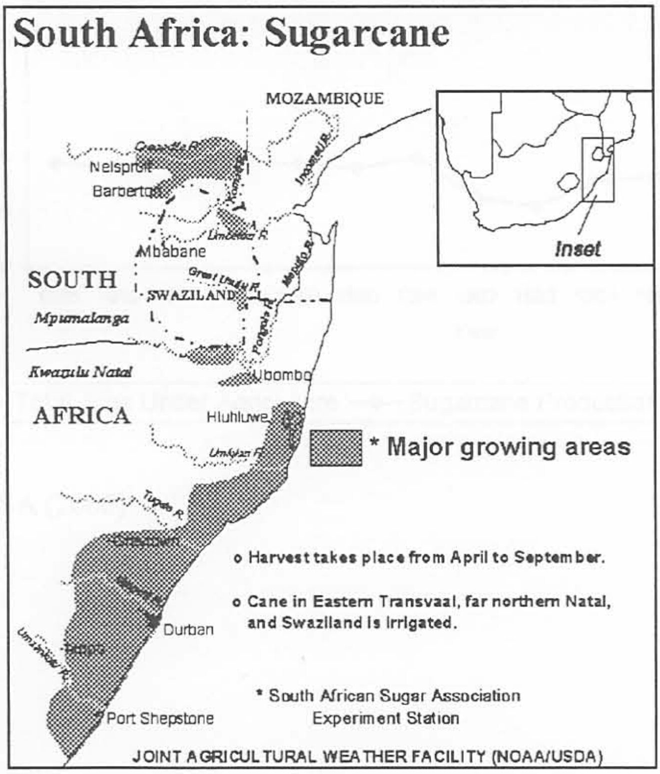


Figure 2. 5: Sugarcane-producing regions of South Africa

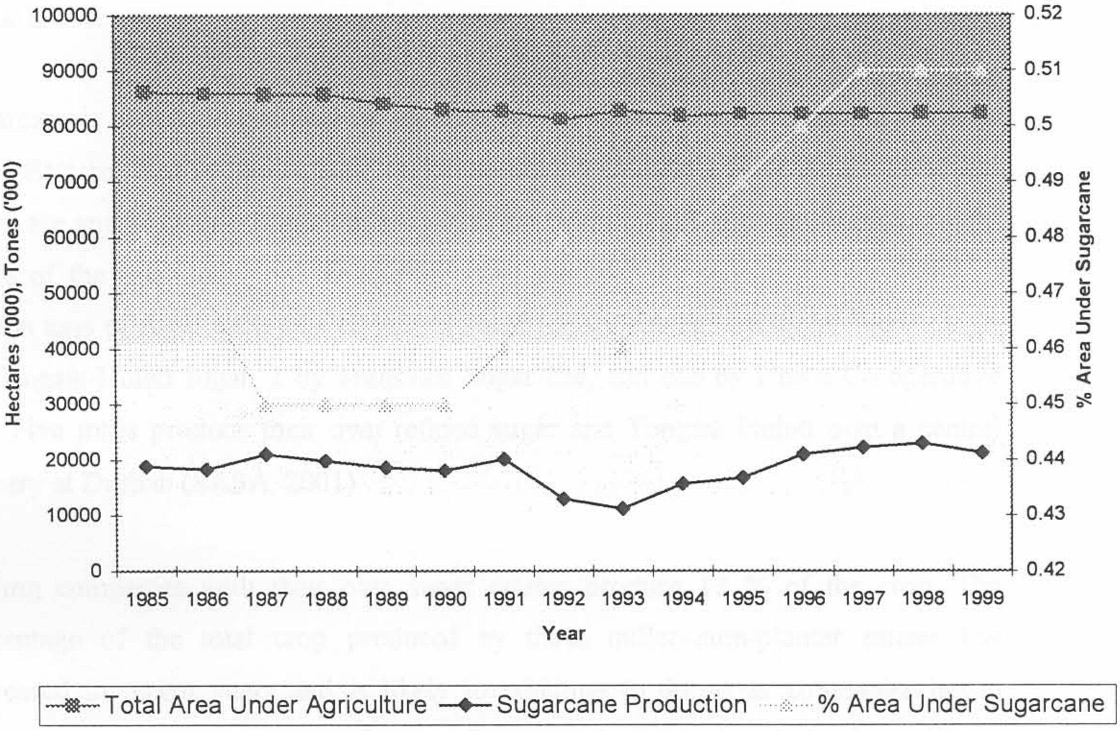


2.5 Sugarcane and the South African Agriculture

2.5.1 Share of Sugar Farming in Total Agricultural Output

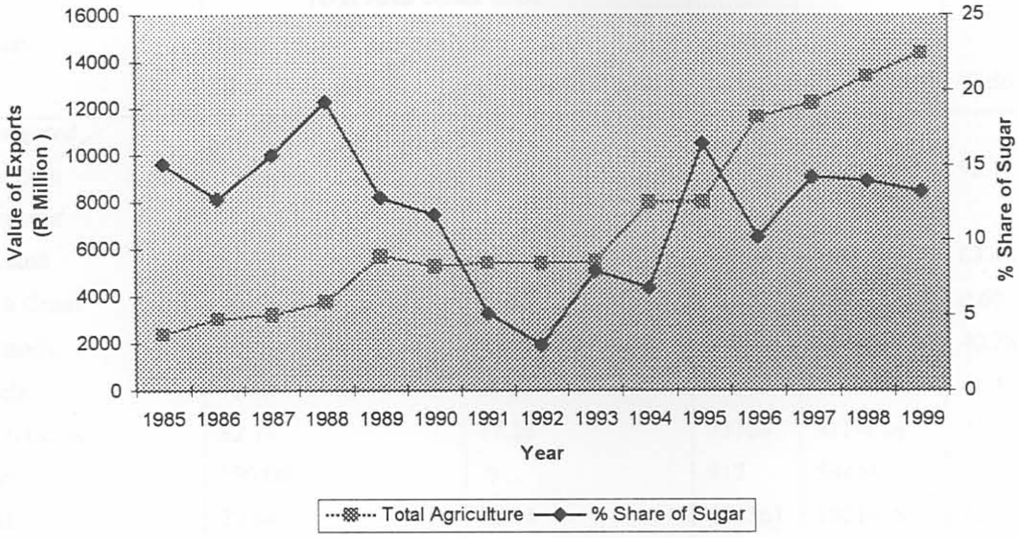
Sugarcane farming contributes about 20 % of the agricultural GDP, accounts for about 38 % of total agricultural employment, generates 13.8 % of the value of the total agricultural exports, and covers about 0.51 % of the total area under agricultural production (AAS, 2001; SASA, 2001). The area, total production and value of exports for total agriculture and sugarcane are depicted in figures 2.6 and 2.7.

Figure 2. 6: Area planted: total agriculture, % under sugarcane and sugarcane Production (1985-1999)



Source: SASA (2000)

Figure 2. 7: Value of exports: total agriculture and sugar (1985-1999)



Source: SASA (2000)

Sugarcane is produced over a large area of land extending from the northern Ponland in the Eastern Cape to the irrigated regions of the Mpumalanga Lowveld (Figure 2.5). There are approximately 2000 large-scale sugar farms, which produce approximately 72 % of the total sugarcane production. The industry produces an average of 2.5 million tons of sugar each year. It has 15 sugar mills, 7 owned by Illovo sugar Ltd, 5 by Tongaat-Hulett sugar; 2 by Transvaal Sugar Ltd, and one by Union Co-operative Ltd. Five mills produce their own refined sugar and Tongaat Hulett own a central refinery at Durban (SASA, 2001)

Milling companies with their own sugar estates produce 13 % of the crop. The percentage of the total crop produced by these miller–cum-planter estates has decreased in recent years and is likely to continue to do so as companies began promoting more medium-scale farms. Sugar produced under dryland conditions accounts for 80 % of total sugar production and mainly comes from KwazuluNatal and the Eastern Cape provinces (Table 2. 4). The remaining 20 % is produced under irrigation mainly in Mpumalanga (SASA, 2001).

Table 2. 4: Area under cane and area harvested under irrigated and dryland agriculture, 1999.

Region	Total Area Under Cane		Total hectare	Tones harvested	Yield
	Large scale growers % of total	Small scale growers % of total			
1. Irrigated					
Northern	79.92	19.92	38326	3530210	92.11
2.Dryland					
Zululand	73.14	26.86	76354	4846831	63.48
North Coast	76.78	23.22	75834	45508	0.60
Midlands	92.52	7.48	79572	3205008	40.28
Tugela	73.65	26.35	80654	3333063	41.33
South Coast	82.74	17.26	73704	3219686	43.68
Other	100.00	0	917	38444	41.92
Total	79.84	20.14	425361	18218750	42.83

Source: SASA (2000)

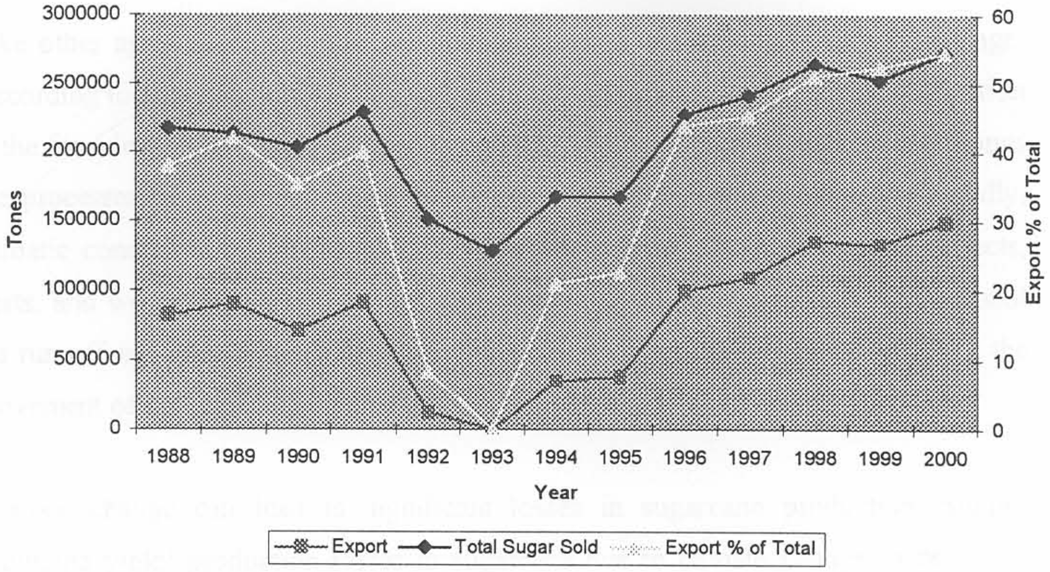
2.5.2 Organizational Structure of the Industry

The South African sugar industry is a proceeds-sharing partnership between millers and growers. It consists of two members, the South African Millers' Association (SAMA) limited and the South African Cane Grower's Association (SACGA) limited. The SAMA limited represents the interests of all sugar millers and refineries while the SACGA limited represents the interests of independent sugarcane growers. The partnership arrangements provide the essential cooperation in supply, crushing and proceeds sharing arrangements, which ensure that growers and millers share equitably the proceeds of sugar and molasses sales.

2.5.3 Sugar Marketing

The industry is one of the world's leading cost competitive producers of high quality sugar. Sugar exports have increased over the past years reaching about 50 % of all sugar produced domestically (Figure 2.8). Unlike producers in other countries such as the EU and USA, cane farmers and processors in South Africa are not subsidized or protected in the world market (SASA, 2001). South Africa ranks tenth in the world in terms of sugar production (Table 2.5).

Figure 2. 8: Total sugar sold, export % of total (1988-2000)



Source: SASA (2001)

Table 2. 5: International comparison of sugar production

Country	Production (Million tons)	% of total
India	20	0.15
EU	18	0.14
Brazil	16	0.12
USA	8	0.06
China	7	0.05
Thailand	6	0.05
Mexico	5	0.04
Australia	4	0.03
Cuba	4	0.03
South Africa	2.7	0.02
Others	39.3	0.30
Total	130	100

Source: SASA (2001)

South Africa has long-term marketing arrangements with importers in the Far East such as Korea and Japan and several others. The Middle East and the Far East have great potential for sugar imports from South Africa.

2.5.4 Sugarcane Farming and Climate Change

Like other agricultural activities, sugarcane farming is sensitive to climate change. According to Hennessy (2002), the impact of climate change on sugarcane production at the farm level takes place through three effects. Firstly, climate directly determines the processes of yield accumulation and the amount of sugar produced. Secondly, climatic conditions control the development and spread of fungal diseases, insects, pests, and weeds, which can restrict crop growth. Thirdly, climate sets the potential for run-off and deep drainage with possible environmental impact associated with the movement of nutrients and pesticides.

Climate change can lead to significant losses in sugarcane production. Studies estimated yield/ production losses in sugarcane due to climate change to be in the order of 9% in Fiji (Campbell, 2000) and 15 % in Taiwan (Change, 2002). The fact that sugarcane production is sensitive to climatic variables and the need for understanding this plant's response to various environmental factors to achieve maximum productivity was summarized by Hunsgi (1993) in table 2.6.

Table 2. 6: Climatic elements influencing yield and quality of sugarcane

Climate elements	Processes affected
Air	
Carbon dioxide concentration	Alters rate of photosynthesis
Density of Pollutants	Plants injury with possible reduction in yield and quality
Ozone	Ultraviolet injury, growth retardation
Light	
Day Length	Influences flowering
Intensity	Controls photosynthesis
Rainfall	
Amount	Causes flood or drought
Distribution	Requires special management
Number of rainy days	Determines planting and harvesting seasons
Humidity	Desired at vegetative phase and but hinders ripening and sugar accumulation. Affects evapotranspiration and accentuates incidence of disease.
Temperature	
Seasonal and daily fluctuations	Alters rate of photosynthesis and accumulation of photosynthetic
Low temperatures	Cold injury, low germination, reduced tilering
High temperatures	Heat injury and water deficit
Wind	Lodging with poor quality cane
Cyclones and hurricanes	Canes uprooted with heavy yield losses

Source: Hunsgi (1993)

According to Mangelsdorf (1950), ideal climatic conditions for the production of sugar from sugarcane are:

- A long warm, summer growing season with adequate rainfall
- A fairly dry, sunny and cool but, frost free ripening and harvesting season
- Freedom from typhoons and hurricanes.

Given these ideal conditions of climate for sugarcane production, the scientifically proved fact of climate change is therefore expected to influence sugarcane production in South Africa like anywhere else in the world. The impact of such influence from climate change on the sugar sector and the rest of the South African economy span the many socio economic benefits of sugar farming outlined above.

Chapter 3: Review of Relevant Literature

3.1 Introduction

It has long been recognized that climate change has an impact on agriculture. Researchers from different disciplines have been investigating the potential harmful effects of climate change on agriculture using different models. Those models were in general used to predict changes in climate associated with different economic activities, assess and quantify the level of damage caused so that corrective measures can be taken through policy intervention for mitigation. This chapter reviews approaches and models developed to predict the level of climate change, assess and quantify the sensitivity of different economic sectors in general and agriculture in particular to climate change. The detailed theoretical background, strengths and weaknesses of each model are presented. The chapter also provides detailed review of literature on climate change impact studies on different sectors of South African economy with special emphasis on agriculture. Review of the state of current literature on climate impact in South Africa will help identifying existing knowledge gaps and the needs for further research.

3.2 Climate Prediction Models

Human activities such as the burning of fossil fuels and deforestation increase the concentration of carbon dioxide (CO_2) and other trace gasses in the atmosphere, which in turn alters the energy balance of the earth (Rosenzweig, 1989). These gasses affect the energy balance of the earth through absorbing long wave radiations emitted by the earth to balance the incoming short wave solar radiation. Over the long run, if the absorbed solar radiation is not balanced by out-going thermal radiation, global warming will occur. The warming caused by trapping of the long wave radiation is known as 'green house effect' and the trace gasses responsible are known as ' green house gasses' (Rosenzweig, 1989).

The behavior of a climate system, its components and their interactions are studied and simulated using climate prediction models. These models are designed mainly for studying climate processes and natural climate variability, and for projecting the response of climate to human induced forces. The most complex climate prediction models developed and used are called the global climate models or general circulation models (GCMs). They are mathematical representations of the atmosphere, ocean, and land surface processes involving mass, momentum, energy and water and their interactions. These models are based on physical laws describing the dynamics of atmosphere and ocean expressed in mathematical equations. The equations in the models incorporate numerical representations of the physical processes of radiation, turbulent transfers at the ground atmosphere boundary, cloud formations, condensation of rain and transport of heat by ocean currents (Barron, 1995).

Through mathematical simulations GCMs enable prediction of what should happen to climate around the world in response to wide variety of changes in the concentrations of green house gasses in the atmosphere (Barron, 1995; IPCC, 2001). Two different strategies are applied to make projections of future climate changes using GCMs. These are the equilibrium and the transient methods (IPCC, 2001).

Equilibrium models (as the case in comparative statics) are not dynamic, e.g. do not trace changes over time but compare two points of equilibrium. In these models, first, the base-line climate is simulated under present conditions (emission levels) to determine the current equilibrium. Then, climate is simulated under a new scenario, such as the doubling of CO_2, which leads to a new equilibrium. The differences between the climate levels of the two simulations provide an estimate of the climate change corresponding to the doubling of CO_2. While this method is relatively cheap and easy to apply, it does not provide insight into the time dependence of climate change (IPCC, 2001).

Transient models trace changes over time at various points of disequilibria or paths to new equilibrium. These models project climate change based on different emission levels, which are developed based on assumptions concerning future socio-economic and demographic changes such as the growth of world population, energy intensity and efficiency, and economic growth, which lead to different emissions scenarios. The difference between the simulated climate change under different emission scenarios and the original base-line simulation provides a time dependent projection of climate change. Thus, these methods are more realistic ways of projecting future climate than forcing the GCMs with an abruptly doubled concentration of atmospheric carbon dioxide as in the case of the equilibrium method (Rosenzweig *et al.*, 1998).

Though very crucial in climate research, the GCMs have limitations. Important limitations include poorly understood ocean circulation processes, lack of knowledge on cloud formation and feedbacks, crudely formulated hydrological processes, coarse spatial resolution, and inability to simulate current regional climate accurately (Rosezwieg, 1989; Dinnar and Beach, 1998). In addition, Barron (1995) indicated that predictions of future climate using climate models are imperfect as they are limited by significant uncertainties that stem from: 1) the natural variability of climate; 2) our inability to predict accurately future green house gases and aerosol emissions; 3) the potential for unpredicted or unrecognized factors, such as volcanic eruptions or new unknown human influences, to perturb atmospheric conditions and 4) our as-yet incomplete understanding of the total climate system.

3.3 Economic Impact Assessment Models

There are two main types of economic impact assessment models in the literature: economy-wide (general equilibrium) and partial equilibrium models. Economy-wide models are analytical models, which look at the economy as a complete system of interdependent components (industries, factors of production, institutions, and the rest of the world). Partial equilibrium models on the other hand, are based on the analysis of part of the overall economy such as a single market (single commodity) or subsets of markets or sectors (Sadoulet and De Janvry, 1995).

3.3.1 Economy-Wide Models of Climate Change

Computable general equilibrium (CGE) models are one of the economy-wide policy impact assessment models. Currently economic analysis of environmental issues and policies is a principal area of CGE model applications (Oladosu *et al.*, 1999). This class of economic modes is suitable for environmental issues because it is capable of capturing complex economy-wide effects of exogenous changes while at the same time providing insights into micro level impacts on producers, consumers and institutions (Mabugu, 2002; Oladosu *et al.*, 1999).

As climate change directly or indirectly affects different sectors of the economy, the use of economy-wide models, which incorporate the complex interactions among different sectors, is required. Accordingly, the use of these models is growing in the areas of climate change impact assessment studies. For instance, Winters *et al.* (1996) studied the impact of global climate change on the less developed countries using a CGE model for three economies representing the poor cereal importing countries of Africa, Asia and Latin America. The said study showed that all these countries would lose and that their agricultural outputs would fall as a result of climate change and Africa to be the most severely affected. Yates and Strezepek (1996) also applied a dynamic CGE model to assess the impact of climate change on the Egyptian economy, which concluded that the net effects of climate change on per capita GDP was not significant.

Nodrhaus *et al.* (1996) used a dynamic general equilibrium model to analyze different national strategies in climate change policies such as, pure market solutions, efficient cooperative outcomes, and non- cooperative equilibra. This study revealed that there are substantial differences in the levels of controls in both the cooperative and the non-cooperative policies among different countries and that the high-income countries may be the major losers from cooperation. In addition to these, Deke *et al.* (2001) used the CGE model approach in a regionally and sectorally disaggregated framework to analyze adaptation to climate change in different regions of the world. The study result showed that vulnerability to climate impact differs significantly across regions and that the overall adjustment of the economic system quite reduces the direct economic impacts.

Although CGE models can analyze the economy-wide impacts of climate change, there are some drawbacks in using them. Key limitations include difficulties with model selection, parameter specification, and functional forms, data consistency or calibration problems, the absence of statistical test for the model specification and the complexity and requirement of high skill to develop and use CGE models (Gillig and Mc Carl, 2002).

3.3.2 Partial Equilibrium Models of Climate Change Impacts

One can classify the partial equilibrium models available in the literature into two approaches to the analysis of the sensitivity of agriculture to climate change. The first approach is based on crop growth simulation models and the second uses econometric procedures. The approaches are compared and discussed in further detail in the following sub-sections.

3.3.2.1 Crop Growth Simulation Models

The two approaches commonly used for analyzing the impact of climate change on agriculture under this group of models are discussed here under.

3.3.2.1.1 Crop Suitability Approach

This approach is also referred to as the agro-ecological zoning (AEZ) approach, which is used to assess the suitability of various land and biophysical attributes for crop production. In this approach, crop characteristics, existing technology, and soil and climate factors, as determinants of suitability for crop production, are included (FAO, 1996). By combing these variables, the model enabled the identification of and distribution of potential crop producing lands. As the model includes climate as one determinant of agricultural land suitability for crop production, it can be used to predict the impact of changing climatic variables on potential agricultural outputs and cropping patterns (Schulze *et al.*, 1993; Du Toit, 2001; FAO, 2002; Xio *et al.*, 2002).

The AEZ framework contains three basic elements (FAO, 2002). The first is land utilization types (LUTs), which refer to selected agricultural production systems with defined input and management relationships, and crop specific environmental requirements and adaptability characteristics. The second is agro-referenced climate, soil, and terrain data, which are combined into a land resource database. The third element is the procedure for calculating potential yields by matching crop/LUT environmental requirements with the environmental characteristics captured in the database. These models were developed to look at potential production capacity across various ecological zones by using a simulation of crop yields rather than measured crop yields (Mendelson, 2000).

Xia *et al.* (2002) used the AEZ approach to estimate the area and spatial distribution of global potential croplands under contemporary and different climate change predictions. The Xia *et al.* (2002) study indicated that the area of global potential croplands is about $32.91*10^6$ km^2 under contemporary climate, with a tendency to increase substantially over the period of 1977 - 2100 as a result of global warming. In the said analysis, developed countries accounted for most of the increase in global potential croplands, while developing countries showed little change in area of cropland. A similar, FAO study (FAO, 2002) showed that a temperature increase of 3°C, paired with a 10 % increase in rainfall, would lead to about 4% more cultivable rain-fed land. The cultivable land in developed countries would grow by 25 % whereas it drops by 11% in developing countries, clearly indicating the uneven distribution of climate benefits.

Adoption and adaptation to changing climatic conditions can be addressed within this model by generating comparative static scenarios with changes in technological parameters (Mendelson, 2000). The disadvantage of the AEZ methodology is that it is not possible to predict final outcomes without explicitly modeling all relevant components and thus the omission of one major factor would substantially affect the prediction of the model (Mendelson, 2000).

3.3.2.1.2 The Production Function Approach

The production function approach to analyzing impacts of climate change on agriculture is based on an empirical or experimental production function measuring the relationship between agricultural production and climate change (Mendelson, 1994). In this approach, a production function, which includes environmental variables such as temperature, rainfall and carbon dioxide as inputs into production, is estimated. Based on the estimated production function, changes in yield induced by changes in environmental variables are measured and analyzed at testing sites (Adams, 1989; Kaiser *et al.*, 1993; Lal *et al.*, 1999; Olsen, 2000; Southworth *et al.*, 2000; Alexandra, 2000). The estimated changes in yield caused by changes in environmental variables are aggregated to reflect the overall national impact (Olson, 2000) or incorporated into an economic model to simulate the welfare impacts of yield changes under various climate change scenarios (Adams, 1989; Kumar and Parikh, 1996; Chang, 2002).

Production as a function of yield and area can be presented by,

$$Q_i = y_i * A_i \tag{3.1}$$

$$y_i = F_i(K_i, E) \tag{3.2}$$

$$A_i = f_i(E, Z, y_i) \tag{3.3}$$

Where Q_i is production, y_i is yield and A_i is area,

$\mathbf{K}_i = [\, K_{i1}, \ldots K_{ij}, \ldots K_{iJ} \,]$

Where K_{ij} is the purchased input j (j = 1,… J) in the production of product i, and:

$\mathbf{E} = [E_1, \ldots E_m \ldots E_M]$ is a vector of exogenous environmental inputs such as temperature, precipitation, and soils, which are common to the production site. Z is access to market (distance to market, infrastructure like roads and the availability of transportation).

A is commonly expressed in terms of share of land area H_i and hence a land share equation rather than area in hectares is generally employed:

$$H_i = h_i\,(\mathbf{E}, \mathbf{Z}, y_i) \tag{3.4}$$

Where H_i measures the share of crop i in total land area.

The production function approach assumes that firms seek to maximize total profit from a mix of crops on a piece of land:

$$\max N = \sum_{i=1}^{n} H_i . \left[P_i Q_i - \sum_{j=1}^{m} w_{j.} k_{ij} \right] \tag{3.5}$$

Subject to the physical conditions facing the farm (soil, climate and water).

Where N is net income per unit of land, i.e. per hectare

P_i is market price of crop i,

k_{ij} is amount of input j used to produce units of crop i, and

w_j is unit cost of input j.

One advantage of this model is that it has more dependable prediction of how climate affects yield because the impact of climate change on crop yields is determined through controlled experiments. However, one problem with this model is that its estimates do not control for adaptation (Mendelson *et al.*, 1994). Farmers are likely to respond to changing climate and other environmental factors by varying among other things, the crop mix, planting and harvesting dates, irrigation scheduling and application of fertilizers and pesticides to mitigate the potential harmful effects of climate change. Moreover, this model does not consider the introduction of new crops, technological changes and changes in land use, and thus the main bias or weakness of the model is in its failure to allow for economic substitution as conditions change (Mendelson *et al.*, 1994).

In order to properly apply the production function approach, farmers' adaptations should be included in the model (Dinar *et al.*, 1998). Moreover, simulations should be run with a variety of different farm methods such as varying planting dates, crop variety, date of harvesting and tilling and irrigation methods. This allows identifying activities, which maximize profit under changing climatic conditions. A successful introduction of adaptation to the production function approach is found in Kaiser *et al.* (1993), who altered crop mix, crop varieties, sowing times, harvesting dates and water saving technologies (tillage) for farms in the United States and found that these adaptation activities reduce the damages from climate change. Although this model included adaptation, it was restricted to limited test sites and general conclusions about climate change and agriculture at the national level could not be made.

In addition to the failure to consider farmers' adaptations, each crop considered under this model, in general required extensive experimentation (high cost). Due to this fact, the use of this methodology has been restricted to the most important crops and few test locations and hence limited value for generalization of the results.

3.3.2.2 Econometric Approaches: The Ricardian Model

The Ricardian model analyses a cross-section of farms under different climatic conditions and examines the relationship between the value of land or net revenue and agro climatic factors (Mendelson *et al.*, 1994; Sanghi *et al.*, 1998; Kumar and Parikh, 1998; Polsky *et al.*, 2001). The model has been applied to value the contribution that environmental factors make to farm income by regressing land values on a set of environmental inputs thereby measuring the marginal contribution that each input makes to farm income. Net revenue or price of land can be used to represent farm income. Mendelson *et al.* (1994) used both net revenue and land value where as Polsky *et al.* (2001) used only land value as the dependent variable in the studies of the impact of climate change on the United States agriculture. Additionally, Sanghi *et al.* (1998) used land value for Brazil, while Kumar and Parikh (1998) used net revenue as the dependent variable in analyzing the impact of climate change on Indian agriculture.

The most important advantage of the Ricardian model is its ability to incorporate private adaptations (Mendelson, 2000). Farmers adapt to climate change to maximize profit by changing the crop mix, planting and harvesting dates, and a host of agronomic practices. The response of farmers induces costs causing economic damages that are reflected in net revenue. Thus to fully account for the cost or benefit of adaptation the relevant dependent variable should be net revenue or land value (capitalized net revenues) not yield. Accordingly, the Ricardian approach takes into account adaptation by measuring economic damages as reductions in net revenue or land value induced by climatic factors. The other advantage of the model is that it is cost effective since secondary data on cross-sectional sites can be relatively easy to collect on climatic, production and socio-economic factors.

One of the weaknesses of the Ricardian approach is that it is not based on controlled the experiments across farms. Farmers' responses vary across space not only due to climatic factors, but also due to many socio-economic conditions. Such non-climatic factors are seldom fully included in the model. Attempts were made to include soil quality, market access and solar radiation to control for such effects (Mendelson *et al.*, 1994; Kumar and Parikh, 1998). In general however, it is often not possible to get perfect measures of such variables and thus all of them may not be taken into account in the analysis using this method (Mendelson, 2000).

The other weakness of the Ricardian model is that it does not include price effects (Cline, 1996). If relative prices change due to the impact of climate change on aggregate supply, the method underestimates or overestimates the impact depending on whether the supply of a commodity increases or decreases. Overlooking of price changes in response to changing aggregate supply leads to a bias in the calculations of producer and consumer surplus and hence lead to biased welfare calculations (Cline, 1996).

Mendelson (2000) argues that it is difficult to include price effects carefully using any method for a number of reasons. First, for most crops prices are determined in global markets and the prediction of what would happen to each crop needs global crop models. But global crop models are poorly calibrated so that it is difficult to predict what will happen to the global supply of any single crop in a new world climate. Second the few global analyses completed so far (Reilly *et al.*, 1994) predicted that the range of warming expected for the next century have a small effect on aggregate supply. Third, if aggregate supply changes by only a moderate amount, the bias from assuming constant prices is relatively small. Thus based on the above points Mendelson (2000) justifies that keeping prices constant does not pose a serious problem in using the model.

The fact that the model does not take into account the fertilization effect of carbon dioxide concentrations (higher CO_2 concentration can enhance crop yield by increasing photosynthesis and allowing more efficient use of water) is another weakness of the model (Cline, 1996; Mendelson, 2000). In spite of these weaknesses, the model can be used to analyze the impact of climate change on agriculture by fully considering adaptations farmers make to mitigate the harmful impact of changing climate.

Climate models such as the GCMs enable the prediction of climatic levels based on the levels of different economic activities (like CO_2 emission). Impact assessment models rely on predictions from GCMs and analyse the impacts of the predicted climate levels on the economic system.

3.4 Climate Impact Studies in South Africa

3.4.1 Studies of Impact on Agriculture

Some studies have been conducted to assess the impact of climate change on South African Agriculture. For instance, Schulze *et al.* (1993) assessed the potential production of maize under different climatic conditions and concluded that under elevated carbon dioxide and temperature conditions, there is an overall increase in potential maize production even though there are places in which yield of maize decreases. In contrast, result the study by Du Toit *et al.* (2001) was pessimistic in explaining the vulnerability of maize production to climate change in South Africa. The Du Toit *et al.* (2001) study indicated that South African maize production is characterized by high variation in yield due mainly to fluctuations in seasonal precipitation. The results of crop model simulation showed that maize yields would either remain at current levels or decrease by ten to twenty percent according to the climate scenarios used. Some of the marginal western areas may become unsuitable for maize production under current management strategies while some of the eastern production areas may remain unchanged or increase production levels. It was additionally indicated that specially crops grown in specific environmentally favorable areas may also be at risk as both rainfall and temperature effects may cause changes in areas suitable for specialized production.

Erasmus *et al.* (2000) studied the effects of climate change on the Western Cape farm sector using a GCM. A sectoral mathematical programming model was employed to incorporate predicted climate change specifically rainfall from GCM for determining the effects on key variables of the regional farm economy. The results indicated that there would be a negative overall effect on the western cape farm economy and it was further shown that producers would switch to extensive farming. The said study also showed that the total decline in welfare falls disproportionately on the poor.

Poonyth *et al.* (2002) studied the impact of climate change on South African agriculture by using the Ricardian method and found that an increase of 2^{0}C in average temperature decreases net revenue per hectare by 25 %. Although Poonyth *et al.* (2002) applied a methodology that allows for integrating farmers' adaptations, the data used in the study were aggregated to provincial levels and cost of production data by each of the crops considered for the study were not available. Thus, the study failed to fully capture the costly adaptations that farmers situated at different agro-ecological places in South Africa and producing different crops make to mitigate the potential harmful impact of climate change.

Kiker (2002) and Kiker *et al.* (2002) developed sugarcane growth models to simulate growth factors and sucrose yields and indicated that climatic factors (rainfall and temperature) affect different sites differently across the sugarcane producing regions. In addition to the failure to present the level of damage induced by climate change across production regions, the methodology adopted for the cited studies (the production function approach) did not include farmers' adaptations.

3.4.2 Other Climate Change Impact Studies

Efforts are also increasing in studying the impact of climate change on non-agricultural sectors in South Africa. For example, van Jaarsveld and Chown (2001) summarized the studies conducted on climate change and its impacts on South Africa. According to van Jaarsveld and Chown (2001), the arid interior and moister northeastern regions of South Africa are likely to be subject to elevated evapo-transpiration rates, increased stress, and more frequent flood events compared to the southwestern regions, which are most likely to experience increased early winter frontal and orographic rainfall. Additionally, it was indicated that the grassland component of rangelands would be least affected by this change compared to the savannah component of rangelands, which appear to be more sensitive. Moreover, livestock production was reported to remain relatively unaffected with marginal impacts on cattle production.

Fecher and Moodly (2002) reported an initial economic valuation of the increased incidence of malaria due to projected changes in the climate of South Africa. Fecher and Moody (2002) showed that, by 2010 the costs of increased malaria due to climate change could reach at least R1.2 billion or almost 0.2 % of the total GDP. Although a good indication of the economic impact of climate change is provided, costs and benefits of prevention and adaptation have not been included in the said study.

Turpie (2002) estimated the existence value of biodiversity threatened by climate change by using a contingent valuation method (CVM) in which 814 residents of the Western Cape province were interviewed. The study indicated that most of the respondents were willing to pay towards biodiversity conservation in South Africa, favouring the policy to reduce the impacts of climate change by passing external costs on to consumers of products such as fuel. This study estimated the potential loss of existence value to South Africa to be R 2.63 billion per year. Moreover, in another study based on the analysis of estuarine fishery production data, Turpie *et al.* (2002) showed that 35 % of natural estuarine catch might be reduced by 2050, under increasing warming conditions.

3.5 Summary

In general, two approaches are found in the literature on measuring the sensitivity of agriculture to climate change. These are the general equilibrium and partial equilibrium models. The general equilibrium models look at all sectors of the economy and analyse the impact of a shock from a policy change of one sector on the rest of the economy. While, very useful for policy simulation these models were not adopted for this study due to high data requirements and methodological complexity.

The partial equilibrium models look at single or multiple market or commodity in part of the economy. These models are divided in two main sub-divisions to the analysis of climate change on agriculture: the crop growth simulation and the econometric approaches. The crop growth simulation models have two sub-divisions, which are the crop suitability and the production function approaches. The crop suitability/agro-ecological zoning approach relies on crop models and land resource inventory to determine potential yields. The disadvantage of this model is that it is not possible to predict final outcomes without explicitly modelling all relevant components. Using this model can capture adaptation to climate change but it requires a high level of effort in data collection and it is therefore costly. The production function approach is based on experimental or empirical analysis of the relationships between yield and environmental factors. It has the advantage of reliable results in terms of the relationship between yield and climatic variables, but it does not take adaptation into account, and it is also costly.

The econometric / Ricardian approach regresses net revenue over a set of climatic and social variables, and enables capturing adaptations farmers make in response to climate change. One of the weaknesses of the Ricardian studies is the assumption of constant prices, but it is practically difficult to include price effects carefully by using any of the other methods (Mendelson, 2000). The Ricardian method is successfully adopted and used to analyse the climate sensitivity of agriculture in different countries (Brazil, India, and USA). It can be used with lesser cost than the other methods and equally important information can be gained for policy purpose in countries where time series data on climate, price of land and production data are found. The sugar cane producing regions of South Africa are one of the places where these kinds of data can be obtained from the well-organised database of the South African Sugarcane Producers Association (SASPA).

The above reviewed literature indicates that studies on the impacts of climate change in South Africa are growing. In spite of these increasing scientific investigations, so far there has been no attempt to analyse the economic impact of climate change on different crops in different regions in the country. Impacts of climate change on different crops and different production systems are different. Also socio-economic groups and geographical regions involved are different, and hence climate change is expected to have different implications for different crops, regions and social groups involved. Moreover, none of the cited studies controlled for adaptation by farmers. Thus, this study uses the Ricardian approach which accounts for farmers' adaptations in analysing the impact of climate change on agriculture as applied to climate change impact studies in the United States, Brazilian and Indian agriculture.

Chapter 4: Approach and Methods of the Study

As explained earlier, this study will use the Ricardian model as it allows for the incorporation of farmers' adaptation in measuring the impact of climate change on agriculture. The study applied the Ricardian model to the analysis of the impact of climate change on sugarcane production in various regions of South Africa. The rest of this chapter discusses the Ricardian approach, sampling procedures, data and the empirical model adopted.

4.1 The Ricardian Approach

Ricardian method, adopted by this study is an empirical approach developed by Mendelson *et al.* (1994) to measure the value of climate in the United States agriculture. The technique has been named the Ricardian method because it is based on the observation made by Ricardo (1817), that land values would reflect land productivity at a site under perfect competition. It is possible to account for the direct impact of climate on yields of different crops as well as the indirect substitution among different inputs including the introduction of different activities by directly measuring farm prices or revenues by using the Ricardian model.

The value of land reflects the sum of discounted future profits, which may be derived from its use. Any factor, which influences the productivity of land, will be reflected in land values or net revenue. Therefore the value of land or net revenue contains information on the value of climate as one attribute of land productivity. By regressing land values on a set of environmental inputs, the Ricardian approach enables measuring the marginal contribution of each input to farm income as capitalized in land value.

4.2 The Analytical Model

The model used in this study is based on a set of well- behaved production function of the form:

$$Q_i = Q_i(K_i, E) \tag{4.1}$$

Where, Q_i is quantity produced of good i, K_i = (K_{i1}, K_{i2}... K_{iJ}) is a vector of purchased inputs such that K_{ij} is the input j (j =1 ... J) used in the production of good i, and;
E = (E_1, E_2... E_k) is a vector of exogenous environmental inputs such as temperature, precipitation, and soil, which are common to production sites.

Given a set of factor prices w_j , E and Q, cost minimization gives the cost function:

$$C_i = C_i(Q_i, W, E) \tag{4.2}$$

Where C_i is the cost of production of good i and W (w_1,w_2... w_n) is the vector of factor prices. Using the cost function C_i at given market prices, profit maximization by farmers on a given site can be specified as:

$$Max.\ \pi = \left[P_iQ_i - C_i(Q_i, W, E) - P_L L_i\right] \tag{4.3}$$

Where P_L is annual cost or rent of land at that site.

Perfect competition in the land market will derive profit to zero:

$$P_iQ_i^* - C_i^*(Q_i^*, W, E) - P_L L_i^* = 0 \tag{4.4}$$

If the production of good i is the best use of the land given E, the observed market rent on the land will be equal to the annual net profits from the production of the good. Solving for P_L from the above equation gives land rent per hectare to be equal to net revenue per hectare.

$$P_L = (P_i Q_i^* - C_i(Q_i^*, W, E))/L_i \tag{4.5}$$

The present value of the stream of current and future revenues gives the land value V_L:

$$V_L = \int_0^\infty P_L e^{-rt} dt = \int_0^\infty \left[(P_i Q^*_i - C_i(Q_i^*, W, E)/L_i \right] e^{-rt} dt \tag{4.6}$$

The issue to be analyzed is the impact of exogenous changes in environmental variables on net economic welfare (ΔW). Consider an environmental change from the environmental state *A* to *B*, which causes environmental inputs to change from E_A to E_B. The change in annual welfare from this environmental change is given by:

$$\Delta W = W(E_B) - W(E_A) = \int_0^{Q_B} [(P_i Q_i - C_i(Q_i, W, E_B)/L_i] e^{-rt} dQ - \int_0^{Q_A} [(P_i Q_i - C_i(Q_i, W, E_A)/L_i] e^{-rt} dQ$$

If market prices do not change as a result of the change in E, then the above equation reduces to:

$$\Delta W = W(E_B) - W(E_A) = \left[PQ_B - \sum_{i=1}^{n} C_i(Q_i, W, E_B) \right] - \left[PQ_A - \sum_{i=1}^{n} C_i(Q_i, W, E_A) \right] \tag{4.7}$$

Substituting for $P_L L_i = P_i Q_i^* - C_i(Q_i^*, W, E)$ from (4.5)

$$\Delta W = W(E_B) - W(E_A) = \sum_{i=1}^{n} (P_{LB} L_{Bi} - p_{LA} L_{Ai}) \tag{4.8}$$

Where P_{LA} and L_A are at E_A and P_{LB} and L_B are at E_B

The present value of the welfare change is thus:

$$\int_0^\infty \Delta W e^{-rt} dt = \sum_{i=1}^{n} (V_{LB} L_{Bi} - V_{LA} L_{Ai}) \tag{4.9}$$

The Ricardian model takes either (4.8) or (4.9) depending on whether the dependent variable is annual net revenues or capitalized net revenues (land values V_L). The model in (4.8) was employed for this research, as data on land prices for the selected samples were not available. This is the same approach followed by Sanghi *et al.* (1998) and Kumar and Parikh (1998) for India.

4.3 Specification of the Empirical Model Variables and Data

As seen in chapter two, the South African sugarcane producing regions extend from the Eastern Cape province through Mpumalanga province in the north. Over these areas, sugarcane is produced under two main climatic conditions: the stepped (arid) zones in the irrigated northern parts and the sub-tropical wet climate in the dryland farming areas of Kwazulunatal.

A total of 11 districts were selected for this study. Two districts (Malelane and Pongola) were selected from the northern irrigated region; nine districts (Umfolozi, Entumeni, Amatikulu, Noodsbureg, Union Coop, Sezela, Darnall, Gledhow, and Maidstone) from the sub-tropical wet climate in KwazuluNatal (the dryland farming region).

Data on farm-level net-revenue were obtained from the South African Sugar Producers Association. Those included, price per tone, production per hectare, cost of labor, chemicals, fertilizer, fuels and lubricants, mechanical and fixture maintenance, and irrigation per tone of sugarcane produced. The net revenue per hectare was deflated using the agricultural GDP deflator and is in 1995 prices.

Data on climatic (rainfall & temperature) and geographic (altitude and latitude) variables were collected from experiment stations, which compile data for each of the cane producing districts. The soil data were collected from the Institute for Soil, Climate and Water of the CSIR.

The climatic variables included were the monthly average temperature and rainfall for each district over the periods 1976/77 to 1997/98. As the net revenue per hectare is expected to be influenced by factors other than climatic variables, control variables like soil type and altitude were also included. The soil type, which varies across the sample districts, was included as it affects yield. Altitude was included to proxy solar energy. In addition, the irrigation dummies for irrigated and dryland farming were included to compare the impact of climatic variables on irrigated and dryland farming. Finally, time trends were included for both irrigated and dryland farming to observe the net revenue per hectare over time for both regions. Table 4.1 gives a description of the variables included in the empirical model.

Table 4. 1: Description of model variables

Variable name	Definition and data (measurement)
Net revenue (NR_i)	Net revenue for district *i* measured in R/ha
Winter temperature (WT_i)	Average of the winter growing temperature (May to August) for district *i* measured in degree centigrade
Winter temperature square ($WTSQ_i$)	
Summer temperature (ST_i)	Average of the summer growing temperature (September to January) for district *i* measured in degree centigrade
Summer temperature square ($STSQ_i$)	
Harvesting temperature (HT_i)	Average of the harvesting season temperature (May to September of the second cropping year) for district i measured in degree centigrade
Harvesting temperature square ($HTSQ_i$)	
Winter precipitation (WP_i)	Average of the winter growing precipitation (May to August) for district *i* measured in millimeters
Winter precipitation Square ($WPSQ_i$)	
Summer precipitation (SP_i)	Average of the summer growing precipitation (September to January) for district *i* measured in millimeters
Summer precipitation square ($SPSQ_i$)	
Harvesting precipitation (HP_i)	Average of the harvesting season precipitation (May to September of the second cropping year) for district i measured in millimeters.
Harvesting precipitation squared ($HPSQ_i$)	
Winter temperature * winter precipitation (WTP_i)	
Summer temperature * summer precipitation ($STSP_i$)	
Harvesting temperature * harvesting precipitation ($HTHP_i$)	
Soil dummy 1 (SD_1)	The type of soil in the sample district. This variable takes the value of one if the soil is red, excessively drained sandy soil and zero other wise.
Altitude (ALT_i)	The distance above sea level measured in meters.
Irrigation dummy (ID_1)	The irrigation dummy, takes the value of one if irrigated and zero if dryland.
Dryland dummy (ID_2)	The dryland dummy, takes the value of one if dryland and zero if irrigated
Trend (ID_1T)	Time trend for irrigated farming.
Trend (ID_2T)	Time trend for dryland farming

Chapter 5: Results of the Empirical Analysis

This chapter presents and discusses the results of the empirical analysis. It starts with a presentation of estimation procedures employed then presents the results of the empirical estimation followed by the simulations undertaken to evaluate the implications of global warming scenarios associated with doubling of carbon dioxide on dry land and irrigated sugar farming in South Africa. Finally, it presents a synthesis of the likely impacts of climate change on South African sugar farming.

5.1 Estimation Procedures

As discussed in chapter four, this study employed the Ricardian approach using net revenue per hectare (NRH) for each district as the dependent variable calculated as:

$$NRH_i = P_i\,Q_i - K_i \tag{5.1}$$

Where, NRH_i is the net revenue per hectare for district *i*,

P_i is the farm level price of sugarcane for district *i*,

Q_i is the per hectare production of district *i*,

K_i is the cost of all inputs per hectare for district *i*,

The Ricardian approach estimates the importance of climate and other variables on the capitalized value of farmland. Net revenues were regressed on climatic and other control variables. A non-linear (quadratic) model was chosen, as it is easy to interpret (Mendelson *et al.*, 1994).

The data was pooled over districts and one equation for all districts was estimated. In the preliminary runs, district dummies (10 dummies for the 11 districts) were included to capture the variability among districts, but most of the district dummies were statistically insignificant. In the second run, regional dummies (4 dummies for the 5 agroecological sub-regions) were included and again found insignificant except for the irrigated regions. This is an indication that location effects were adequately captured by other physical conditions or variables (climate and soil) rendering regional location dummies redundant except for irrigation. Accordingly, an irrigation dummy was included to capture and compare the net revenue impact of climatic variables on irrigated and dry land farming. Additionally, the trend of net revenue per hectare for both irrigated and non-irrigated regions were captured by including a time trend for both regions.

Therefore the final net revenue function estimated was:

$$NR_i = B_1WT_i + B_2WTSQ_i + B_3ST_i + B_4STSQ_i + B_5HT_i + B_6HTSQ_i + B_7WP_i + B_8WPSQ_i \\ + B_9SP_i + B_{10}SPSQ_i + B_{11}HP_i + B_{12}HPSQ_i + B_{13}WT_i * WP_i + B_{14}ST_i * SP_i + B_{15}HT_i * HP_i + \\ B_{16}SD_1 + B_{17}ALT_i + B_{18}ID_1 + B_{19}ID_2 + B_{20}ID_1T + B_{21}ID_2T + e_i \qquad (5.2)$$

The independent variables include the linear and quadratic temperature and precipitation terms for the three seasons (winter, summer and harvesting), the temperature precipitation interaction terms, edific and geographic variables (soil type and altitude), the irrigation dummies and time trends. The quadratic climate terms were included to capture second order effects of climate on net revenues and e_i is the error term.

Initially, the planting season temperature, and precipitation were included but were found statistically insignificant and hence omitted. Population density as a proxy for urbanization and hence its influence on the price of land (net revenue) was also included in the initial run but was also found insignificant and consequently dropped. The winter and summer temperature and precipitation represent the first year growing seasons and the harvesting temperature and precipitation were taken from the second production year based on the sugarcane crop production calendar.

5.2 Results and Discussion

The regression results indicated that climate variables, altitude, the soil and irrigation dummies and the time trend have significant impacts on net revenue from sugar farming. The estimated coefficients of most of the linear, quadratic and interaction terms of the climate variables (temperature and rainfall) were statistically significant (Table 5.1).

As expected, temperature and precipitation significantly affected net revenue per hectare across production seasons. The dummies for both irrigated and non-irrigated regions were also statistically significant. The parameter estimate for the irrigated region is greater than that of the dryland region indicating higher yields and hence net revenue as irrigation controls for rain fluctuations. The estimated parameters of the time trend for both irrigated and dryland farming were negative and statistically significant. The negative parameter values indicate the general trend of decline in net revenue per hectare in both regions. The results further indicated that net revenue per hectare in the dryland farming areas was decreasing at a higher rate than that in the irrigated region. This is again an indication of reduced damages to net revenue made possible through irrigation.

Altitude, which was included to proxy solar radiation was negatively related to net revenue per hectare, this could be attributed to the fact that at higher altitudes, temperature is cooler and makes sugarcane production period longer before maturity. The soil type (drained sandy soil) positively affected sugarcane production compared to the shallow and high lime content soils. This suggests that sugarcane grows better on sandy-loam soils compared to shallow and high lime soils (Smith, 1994).

5.3 Simulation of Climate Change Impacts

The impact of climate change can be evaluated in two ways. The first approach uses estimated measures of the elasticity of net revenue to change in climate variables. The second approach employs the estimated regression coefficients of the empirical model to simulate impacts of changes in levels of climate variables on net revenue. This study attempted both approaches the results of which are presented in the following sections.

Table 5. 1: Results of the regression analysis of determinants of net revenue from sugarcane production in South Africa.

Dependent variable: net revenue per hectare		
Independent variable	Parameter	t value
Winter growing temperature (WT$_i$)	3729.67	3.08**
Winter growing temperature square (WTSQ$_i$)	-108.94	-3.17**
Summer growing temperature (STi)	-4460.22	-2.43**
Summer growing temperature square (STSQ$_i$)	89.47	2.28*
Harvesting temperature (HT$_i$)	-1633.84	-1.34
Harvesting temperature square (HTSQ$_i$)	37.92	1.10
Winter growing precipitation (WP$_i$)	20.76	0.85
Winter growing precipitation square (WPSQ$_i$)	-0.04	-1.14
Summer growing precipitation (SP$_i$)	-79.92	-2.49*
Summer growing precipitation square (SPSQ$_i$)	0.01	0.23
Harvesting precipitation (HP$_i$)	-65.59	-2.65**
Harvesting precipitation square (HPSQ$_i$)	-0.05	-1.38
Winter temperature* winter precipitation (WTWP$_i$)	-0.76	-0.53
Summer temperature * summer precipitation (STSP$_i$)	3.24	2.5*
Harvesting temperature * harvesting precipitation (HTHP$_i$)	3.96	2.78**
Soil type1	375.78	1.38
Altitude	-1.41	-1.43
Irrigation dummy	44877	2.5*
Dryland dummy	43830	2.45*
Time trend for irrigated land	-43.15	-1.8
Time trend for dryland	-70.90	-5.82**

Number of observations = 253 * significant at 5% **significant at 1 %

5.3.1 Simulation Using Elasticity Measures

Measures of elasticity estimate the percentage change in the response variable induced by a percent change in the independent variables. Therefore, the sensitivity of net revenue to changes in climate variables was evaluated in this section by making use of elasticity measures. These elasticities were calculated for the two production zones modeled here, namely irrigated and dryland areas (Table 5.2).

$$\frac{\partial NR}{\partial X_j}\left(\frac{\bar{X}_j}{\overline{NR}}\right) \tag{5.3}$$

Where, *NR* is net revenue per hectare

X_j is the level of climate variable j (rainfall and temperature)

$\overline{NR}$ is the mean net revenue

$\overline{X}_j$ is mean level of climate variable j (rainfall and temperature)

The elasticity estimates evaluated at mean values indicated that increasing winter and harvesting temperatures reduce net revenue, while increasing summer temperature increases net revenue of irrigated sugar. On the other hand, increasing temperature reduces net revenue in all seasons in the dryland region. Increasing precipitation in winter and harvesting seasons are beneficial to both irrigated and dryland farming while increasing summer growing precipitations are damaging to both the irrigated and dryland farming regions (Table 5.2).

Table 5. 2: Estimates of elasticity of net revenue of sugar farming to climate variables in the three growing seasons and the two production zones.

Seasons	Temperature		Precipitation	
	Irrigated	Dryland	Irrigated	Dryland
Winter growing	-0.113	-0.017	0.002	0.002
Summer growing	0.052	-0.046	-0.0001	-0.002
Harvesting	-0.099	-0.088	0.001	0.051

The use of elasticity measures requires evaluation of elasticities at mean levels of involved variables, which complicates the interpretation of the results. The fact that the value of elasticity parameters change with levels of climate variables makes the evaluation based on mean levels to be of little help in forecasting climate impacts. Therefore, it makes a huge difference whether current levels of climate variables are below or above the critical levels. Accordingly, simulations using the estimated regression coefficients were applied in the following section to explain the impacts of climate change on sugarcane production.

5.3.2 Simulations Utilizing Estimated Regression Model Coefficients

Following Sanghi *et al.* (1998), and Kumar and Parikh (1998) in analyzing the impact of climate change on Indian agriculture, this section used estimated coefficients of the regression model to simulate the impacts of changing temperature and precipitation on net revenue per hectare of sugarcane. In this approach, the change in the response variable (net revenue per hectare) is simulated utilizing estimated regression coefficients from the pooled analysis (Table 5.1) for both the irrigated and dryland farming for the 1976/77 to 1997/98 period.

The total and partial impacts of increasing temperature and precipitation, keeping other factors constant, were simulated. The total impact was simulated for a 2^0C rise in temperature and a 7% increase in precipitation, a scenario associated with the doubling of carbondioxide for the whole world (IPCC, 1990). The partial impact of increasing only temperature or precipitation across all seasons was also simulated to evaluate the impact of increasing temperature or precipitation on sugarcane production. The partial impact of increasing temperature was evaluated for the most likely scenario of a 2.75^0C rise in temperature on average for South Africa, a scenario associated with the doubling of carbon dioxide (Hewitson, 1998), to arrive at a more realistic estimate of the impact of climate change on South African sugarcane production. Additionally, seasonal impacts were also simulated to evaluate the seasonal effects of changing temperature and precipitation levels. The seasonal impact of say, winter growing temperature (precipitation) was calculated by changing only winter temperature (precipitation) keeping all other variables constant.

The change in net revenue per hectare of a given climate scenario for a given year in a production system (irrigated or dryland farming) is given by:

$$\Delta NR_i = NR_{i,t} - NR_{i,t-1} \tag{5.4}$$

Where, $NR_{i,t}$ *is* $NR_i\,(T_t,\; P_t)$, (5.5)

$NR_{i,t-1}$ is $NR_i\,(T_{t-1}, P_{t-1})$ (5.6) and, $T_t = T_{t-1} + \Delta T$ and $P_t = P_{t-1} + \Delta P$ (5.7)

ΔNR_i is the change in net revenue per hectare

NR_{it} is the forecasted value of net revenues per hectare under a new climate scenario.

$NR_{i,\,t-1}$ is predicted value of net revenue per hectare of the base climate scenario.

T_t, P_t is temperature and precipitation under the new climate scenario.

T_{t-1}, P_{t-1} is temperature and precipitation for the base climate scenario.

ΔT, ΔP is change in temperature and precipitation.

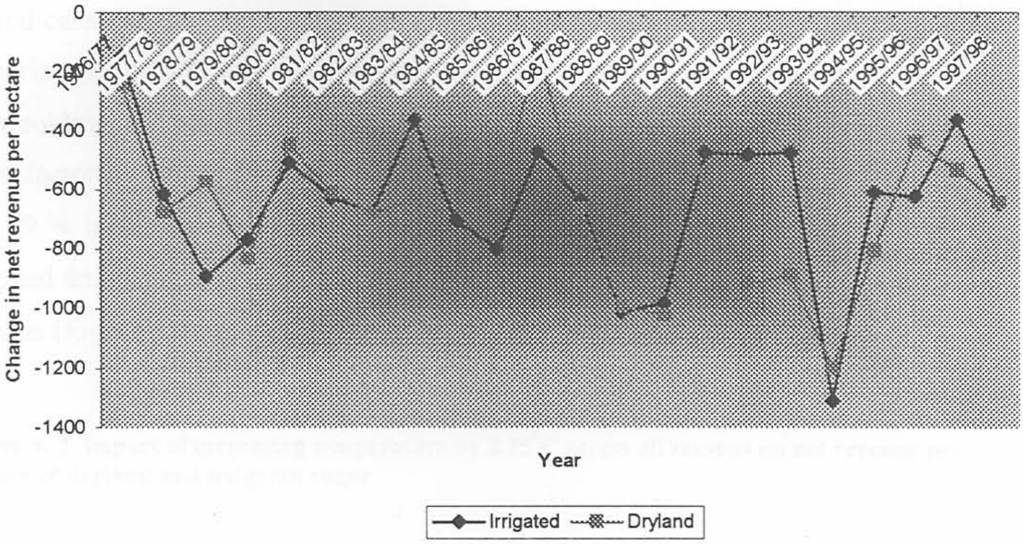
5.3.2.1 Total Effect Scenarios

As mentioned above, the total effect is the net revenue impact of simultaneously changing both temperature and precipitation in all seasons. In this case, the change (i.e. difference between actual trend and total scenario levels) in net revenue per hectare was calculated for the benchmark[1] warming scenario of 2 ^{0}C rise in mean temperature and a 7 % increase in mean precipitation levels for both irrigated and dryland farming (Figure 5.1).

Increasing temperature by 2°C and precipitation by 7 % (Doubling of CO_2) have negative impacts on sugarcane production in all zones. As expected, this impact is not equally distributed between the irrigated and dryland farming regions. The difference however, is negligible as the reduction in average net revenue per hectare was 26 % under irrigation compared to 27 % under dryland farming. This is an indication that irrigation is not a very effective adaptation measure for mitigating climate change damage on sugar farming in South Africa.

The values of net revenue per hectare for the years 1988/89, 1989/90 and 1993/94 were low due to relatively higher temperature levels, which reduced production over these years. The higher changes in net revenue per hectare (i.e. the difference between the actual trend and the new IPCC's scenario) over these years (Figure 5.1) were associated with the yield reducing effects (hence reduced net revenue) of further increments in temperature levels under the new IPCC's scenario, which is warmer.

Figure 5. 1: Impact of 2°C and 7% rise in temperature and precipitation, respectively, on net revenue per hectare of dryland and irrigated sugar



While results of the total effect of climate change on sugar farming in South Africa indicate a negative impact, partial effects may be useful to analyze to understand the relative strength of seasonal variability in climate conditions. Two types of partial impact analysis were simulated. The first partial effect experiments were run to separate the effects of changing temperature from rainfall shifts across all seasons. This was done to determine to which of the two climate change factors (rainfall versus temperature) sugar production is more sensitive or vulnerable. The second partial impact experiments separated changes in rainfall and temperature by season e.g. summer and winter. This will be useful for determining vulnerability to seasonal climate effects and for targeting mitigation and adaptation measures to seasonal changes to which sugar farming is more sensitive, e.g. prioritize management conditions.

5.3.2.2 Partial Effects' analysis

The partial effect analysis evaluates the impact of changing only temperature or precipitation on net revenue across seasons or for a given season by keeping all other factors constant. In this section, partial temperature and precipitation effects are analyzed for both irrigated and dryland sugar farming.

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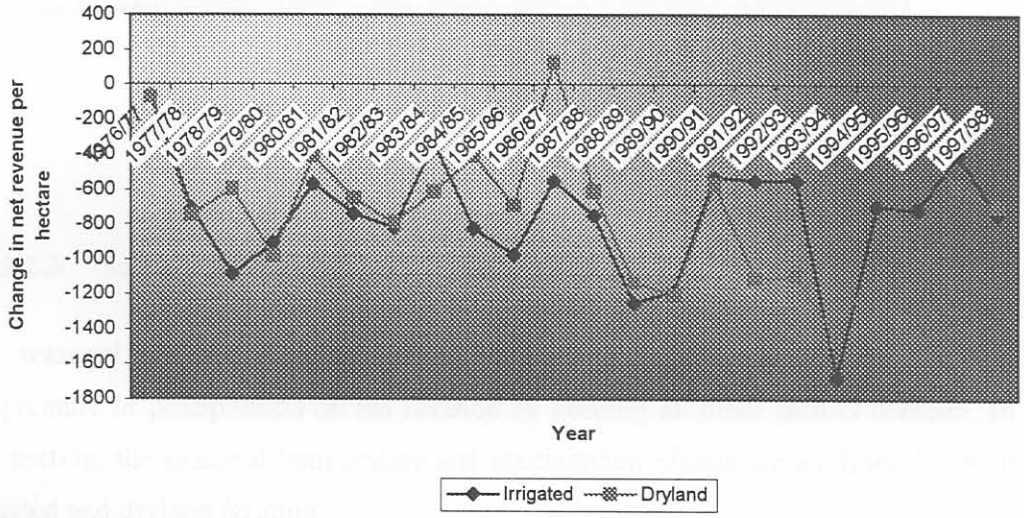
[1] The level of climate change associated with the doubling of carbon dioxide (IPCC, 1990)

5.3.2.2.1 Partial Temperature Effects

As indicated earlier, the partial temperature effect was evaluated for the most likely scenario of a 2.75°C rise in temperature for South Africa, a scenario associated with the doubling of carbon dioxide. Increasing temperature across all seasons, keeping other factors constant, reduce net revenue per hectare by 30 % in the irrigated zone and 29 % in the dryland-farming region. These figures confirm again that both the irrigated and dryland regions are equally affected by increasing temperature across all seasons (Figure 5.2).

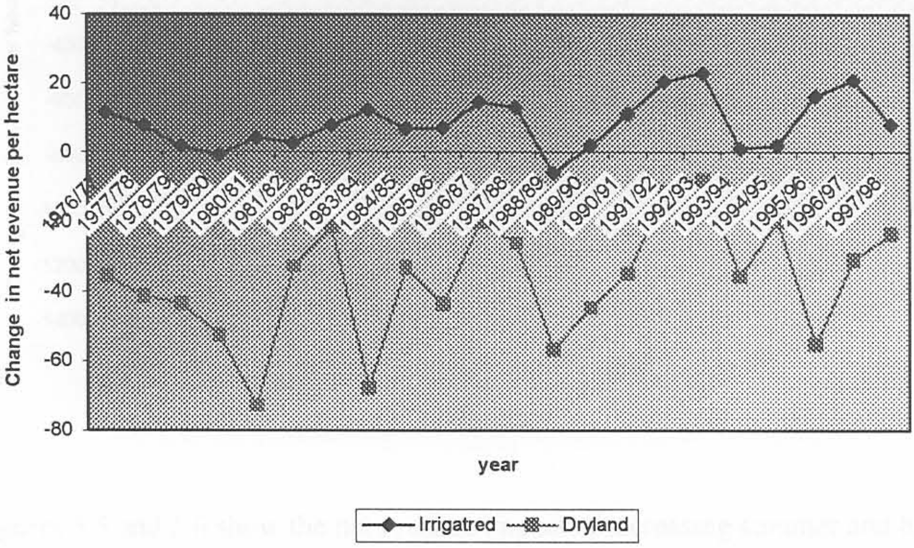
Figure 5. 2: Impact of increasing temperature by 2.75°C across all seasons on net revenue per hectare of dryland and irrigated sugar



5.3.2.2.2 Partial Precipitation Effect

The partial precipitation effect was simulated for a 7% increase in precipitation levels based on the IPCC (1990) estimate across all production seasons keeping other factors constant. The results indicated that increasing precipitation by 7% increase net revenue for the irrigated farming by 0.35% and reduce net revenue per hectare by 1.5 % for the dryland farming (Figure 5.3). This result is contrary to expectations as higher moisture regimes were expected to benefit dryland agriculture more than irrigation agriculture and hence requires more thorough investigation using agronomic research.

Figure 5. 3: Impact of increasing precipitation by 7 % across all seasons on net revenue per hectare of dry land and irrigated sugar



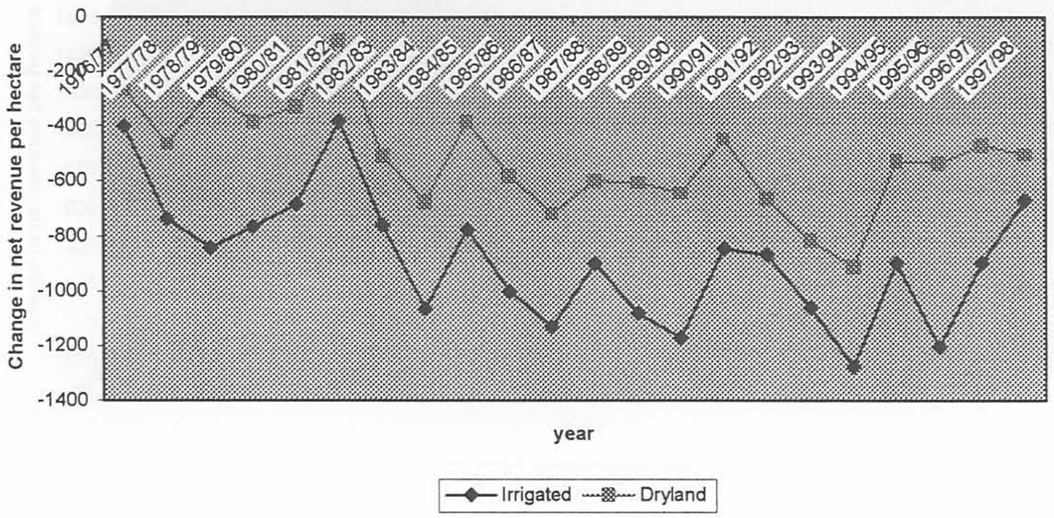
5.3.2.2.3 Seasonal Effects

The seasonal effect analysis evaluates the impact of changing only one season's temperature or precipitation on net revenue by keeping all other factors constant. In this section, the seasonal temperature and precipitation effects are analysed for both irrigated and dryland farming.

5.3.2.2.3.1 Seasonal Temperature Effects

Increasing temperature by 2.75° C while keeping other factors constant was found to have different net revenue impacts across the different seasons and production regions/zones. Figures 5.4 to 5.6 provide a visual display of the net revenue impacts of increasing temperature by 2.75°C. Figure 5.4 shows that increasing winter temperature has a negative net revenue impact on both irrigated and dryland farming, with the irrigated farming more severely affected. The fact that irrigated farming is affected more could be due to the availability of irrigation water, which aggravates the effects of flourishing pests and insects during the winter season.

Figure 5. 4: Impact of increasing winter temperature by 2.75^{0}C on net revenue per hectare of dry land and irrigated sugar



Figures 5.5 and 5.6 show the net revenue impact of increasing summer and harvesting temperatures, respectively. As figure 5.5 shows, both irrigated and dryland farming benefit from increasing summer temperature. This finding is in line with the fact that sugarcane production requires high temperature (22-32^{0}C) during the main growing season (Mangelsdorf, 1950; Blackburn, 1984; Hunsgi, 1993; Smith, 1994). The higher benefit to irrigated farming could be due to the possibility of adapting through irrigation to increased temperature levels to meet plant requirements for optimal yield. Increasing harvesting temperature reduces net revenue per hectare in both irrigated and dryland farming regions almost equally (Figure 5.6). The reduction of net revenue per hectare caused by increasing harvesting temperature could be due to the fact that increasing temperature during ripening and harvesting initiate growth and reduce sucrose accumulation (Hunsgi, 1993; Humbert, 1968).

Figure 5. 5: Impact of increasing summer temperature by 2.75^{0}C on net revenue per hectare of dryland and irrigated sugar

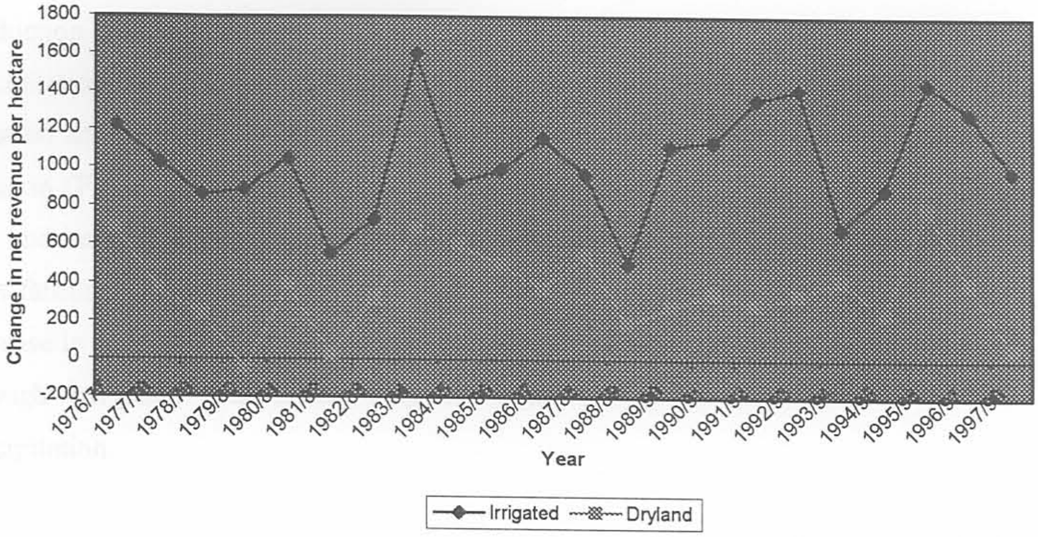
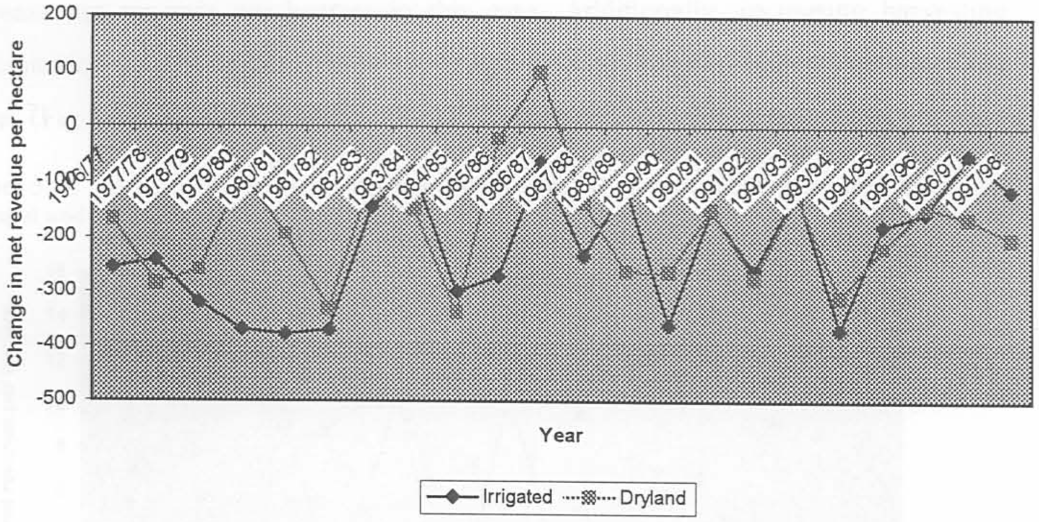


Figure 5. 6: Impact of increasing harvesting temperature by 2.75^{0}C on net revenue per hectare of dryland and irrigated sugar



5.3.2.2.3.2 Seasonal precipitation Effect

Like temperature, increasing precipitation also has different effects across seasons and production zones. Figurers 5.7-5.9 show the net revenue impact of increasing precipitation by 7%. Increasing winter precipitation increases net revenue for both irrigated and dryland farming. Dryland sugarcane production benefits more from this scenario (Figure 5.7). This is because precipitation during the winter season is very low and hence increasing precipitation by 7 % increased net revenue per hectare in both farming systems. The reason that the dryland farming benefited more from an increase in winter precipitation could be due to the fact that soil moisture is regulated through irrigation and hence irrigated sugar is less responsive to increased precipitation.

On the other hand, increasing summer precipitation by 7% was not beneficial to both irrigated and dryland farming (Figure 5.8). Even though sugarcane requires a relatively higher summer growing precipitation for optimal growth (Mangelsdorf, 1950; Humbert, 1968; Smith, 1994), increasing summer precipitation by 7% did not increase net revenue per hectare in this case. Additionally, increasing harvesting precipitation by 7% is marginally beneficial to both irrigated and dryland farming zones (Figure 5.9).

Figure 5. 7: Impact of increasing winter precipitation by 7% on net revenue per hectare of dryland and irrigated sugar

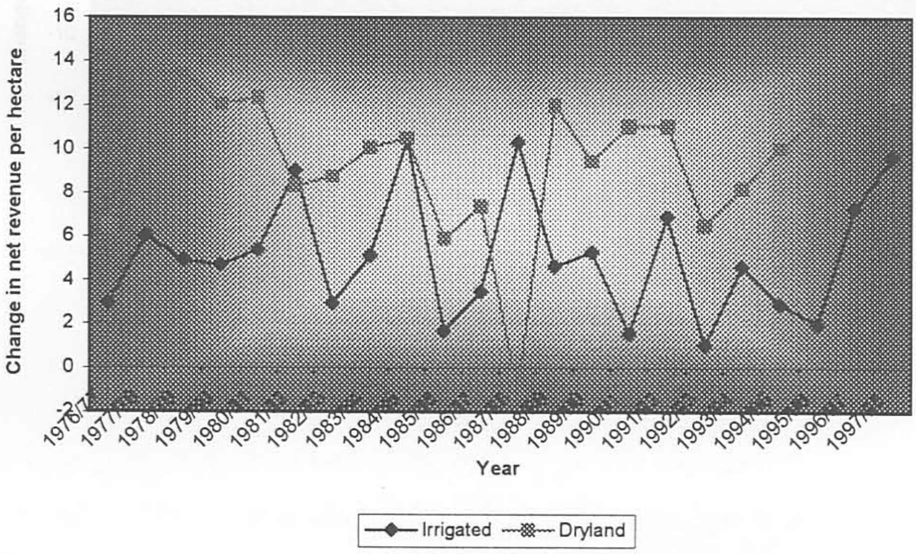


Figure 5. 8: Impact of increasing summer precipitation by 7% on net revenue per hectare of dry land and irrigated sugar

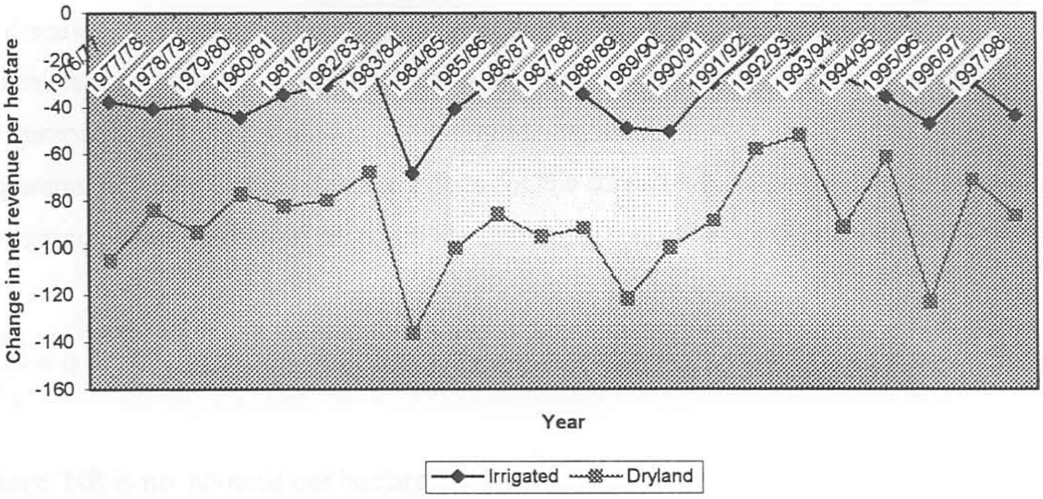
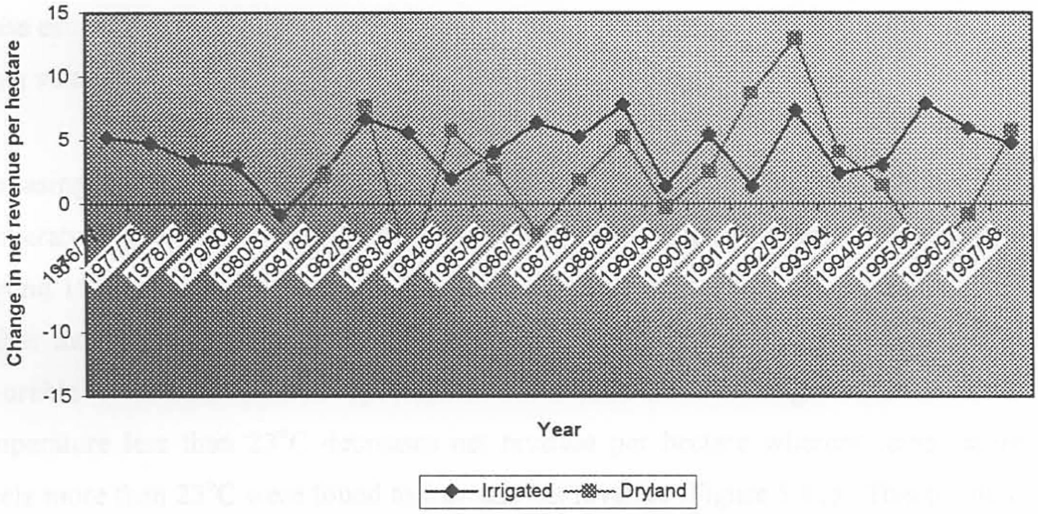


Figure 5. 9: Impact of increasing harvesting precipitation by 7% on net revenue per hectare of dryland and irrigated sugar



5.4 Synthesis of the Likely Impacts of Climate Change on Sugar Farming in South Africa

As discussed earlier, the likely impact of changing climate conditions will depend on current temperature and rainfall levels in the various seasons and where those levels are compared to critical damage points. By taking the estimated net revenue function (Equation 5.2), the critical damage points for the three seasons (winter, summer and harvesting), were calculated based on the first order conditions of optimization:

$$\frac{\partial NR}{\partial X_j} = 0 \qquad (5.8)$$

Where, NR is net revenue per hectare

X_j is the level of climate variable j (temperature and rainfall)

The net revenue estimates in each graphs (5.10-5.15) in the critical damage point analysis were calculated by changing only a specific season's temperature or rainfall in the estimated net revenue function (Equation 5.2), keeping other factors constant at mean values[2].

Increasing winter temperature was found to increase net revenue per hectare for temperature levels lower than 18°C (Figure 5.10). But, increasing winter temperature beyond 18°C reduces net revenue. The decline in net revenue for winter temperatures higher than 18°C could be associated with the incidence of pests and insects due to favorable conditions created by warmer winter, which reduce growth. Summer temperature less than 23°C decreases net revenue per hectare whereas temperature levels more than 23°C were found to increase net revenue (Figure 5.11). This positive response of net revenue per hectare to increased summer temperatures beyond 23°C may be attributed to the fact that sugarcane requires high temperature 30-32°C (Hunsgi, 1993) during the main growing season (the summer season in the case of South Africa). Even though higher temperature is recommended for cane growth, increasing temperature beyond 35°C curtails growth irrespective of water supply (Blackburn, 1984). Additionally, net revenue per hectare was found to decrease for

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[2] The impact on net revenue, of say winter temperature, was calculated by changing only winter season temperature in the net revenue function, by keeping other factors constant at mean values.

harvesting temperature levels less than 19°C (Figure 5.12). Ripening requires low temperature levels to allow for sucrose accumulation, but very low temperature, below 10°C rupture cells and cause irrevocable deterioration (Humbert, 1968). The result of increasing net revenue with increased harvesting temperature should be seen with caution, because high temperature is not recommended as it initiates growth and reduces sucrose accumulation during the harvesting season (Hunsgi, 1993).

Figure 5. 10: Impact of increasing winter temperature on net revenue per hectare

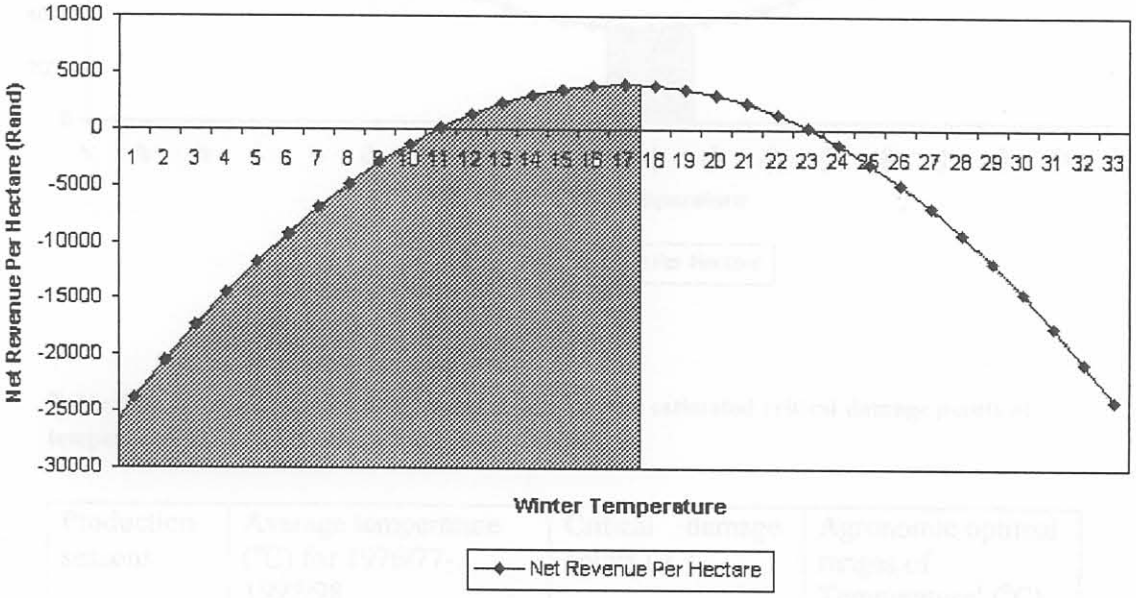

Figure 5. 11: Impact of increasing summer temperature on net revenue per hectare

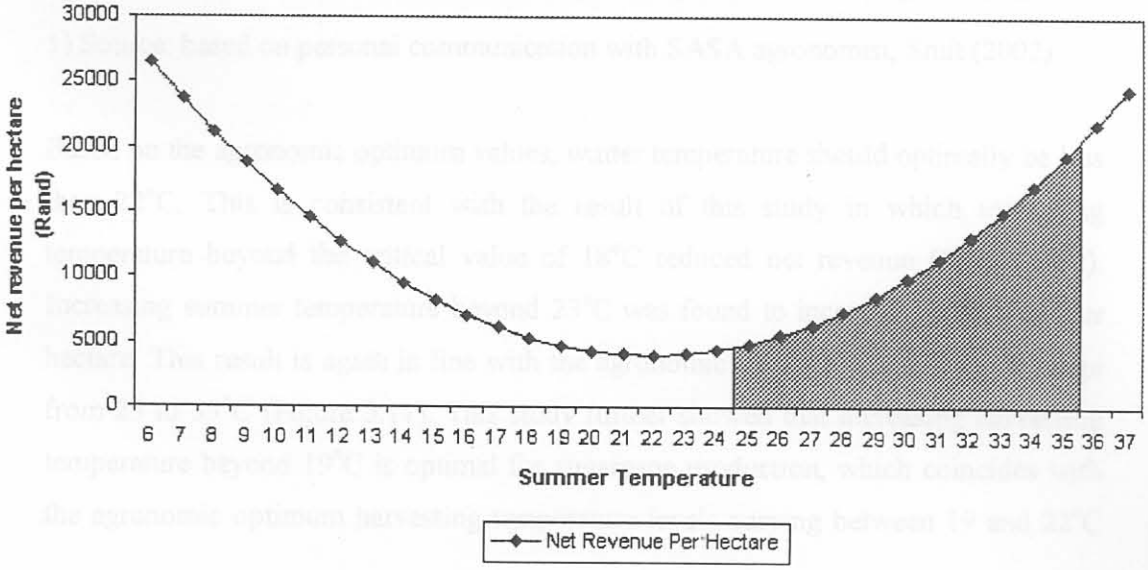

Figure 5. 12:Impact of increasing harvesting temperature on net revenue per hectare

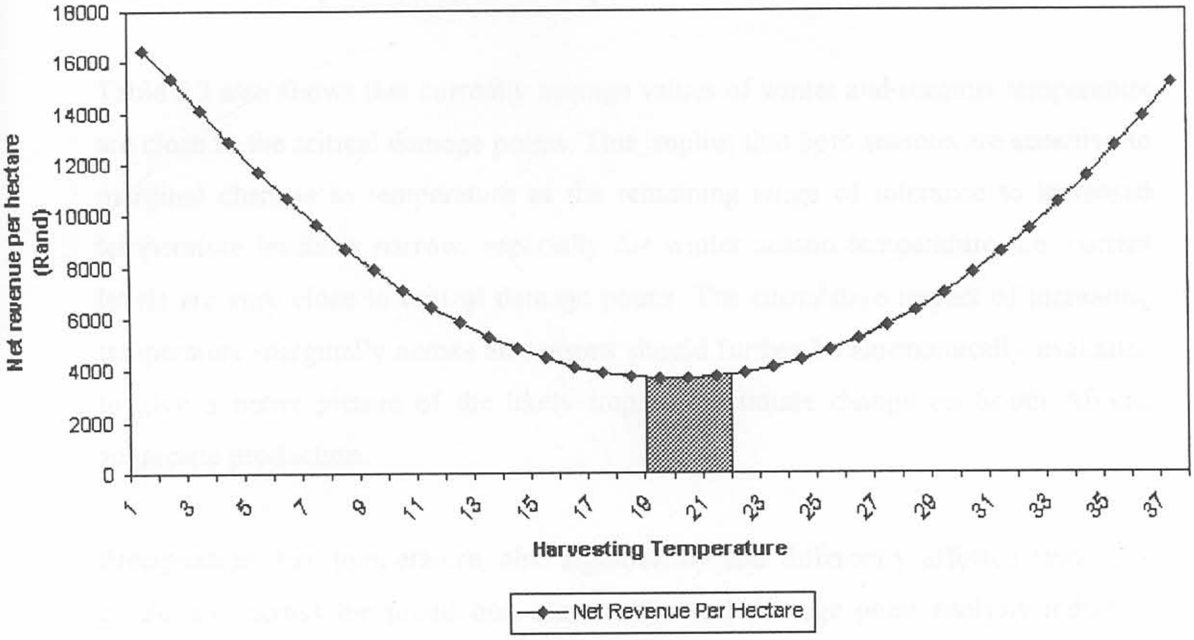

Table 5. 3: Average, agronomic optimal ranges and the estimated critical damage points of temperature for South African sugarcane production.

Production seasons	Average temperature (°C) for 1976/77-1997/98	Critical damage points (°C)	Agronomic optimal ranges of Temperature[1] (°C)
Winter	17.38	18	< 22
Summer	22.48	23	25-35
Harvesting	16.66	19	< 22

1) Source: based on personal communication with SASA agronomist, Smit (2002)

Based on the agronomic optimum values, winter temperature should optimally be less than 22°C. This is consistent with the result of this study in which increasing temperature beyond the critical value of 18°C reduced net revenue (Figure 5.10). Increasing summer temperature beyond 23°C was found to increase net revenue per hectare. This result is again in line with the agronomic optimum values, which range from 25 to 35°C (Figure 5.11). This study further showed that increasing harvesting temperature beyond 19°C is optimal for sugarcane production, which coincides with the agronomic optimum harvesting temperature levels varying between 19 and 22°C

(Figure 5.12). The shaded areas in each graph indicate the areas of overlap of the results of this study and the agronomic optimum values.

Table 5.3 also shows that currently average values of winter and summer temperature are close to the critical damage points. This implies that both seasons are sensitive to marginal changes in temperature as the remaining range of tolerance to increased temperature levels is narrow, especially for winter season temperature, i.e. current levels are very close to critical damage points. The cumulative impact of increasing temperature marginally across all seasons should further be agronomically evaluated to give a better picture of the likely impact of climate change on South African sugarcane production.

Precipitation, like temperature, also significantly and differently affected sugarcane production across the production seasons. Critical damage point analysis indicated that increasing winter precipitation levels up to 94mm increases net revenue per hectare, whereas precipitation level beyond 94mm decreases net revenue (Figure 5.13). This negative relationship between increased precipitation beyond 94mm and net revenue could again be due to the possible outbreak of pests and insects, which are depressed under low precipitation but start reproducing under the conducive environment created by high precipitation. Increasing summer precipitation more than 354 mm was found favorable to sugarcane production (Figure 5.14). As it was indicated earlier, in the main growing season (summer) sugarcane requires high level of precipitation to facilitate growth and the result of this study is in line with this fact. Finally, increasing harvesting precipitation beyond 4mm (Figure 5.15) was found to be damaging to sugarcane production. This finding is in line with the fact that sugarcane production requires a very low precipitation level during ripening and harvesting, as increasing precipitation initiates growth and reduces sucrose accumulation (Hunsgi, 1993).

Figure 5. 13: Impact of increasing winter precipitation on net revenue per hectare

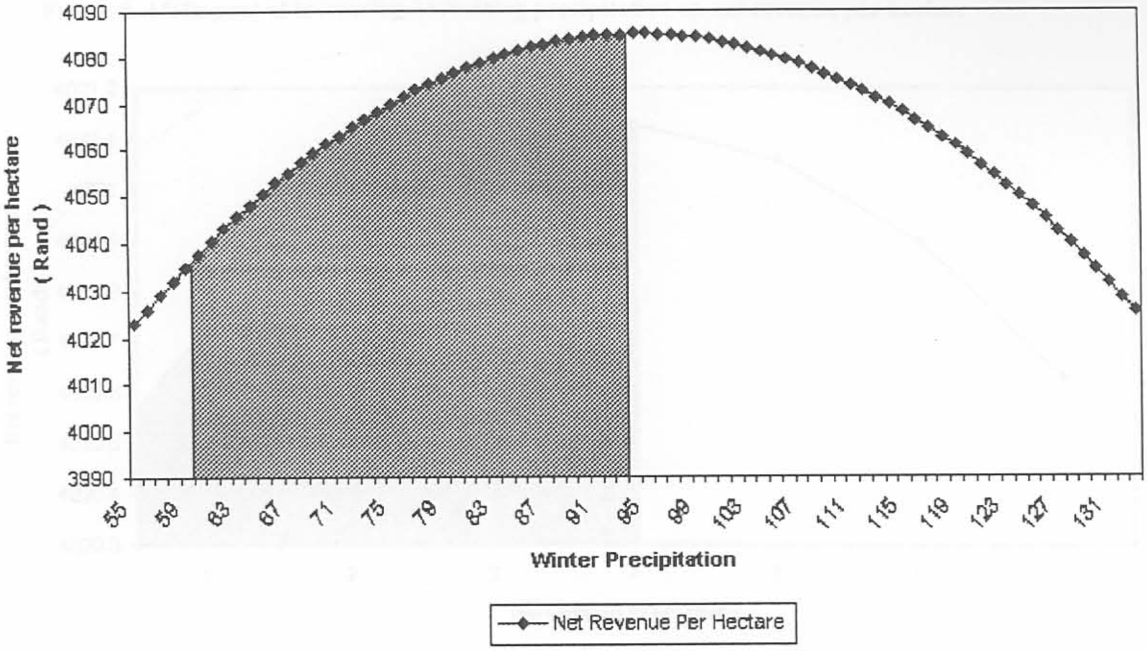

Figure 5. 14: Impact of increasing summer precipitation on net revenue per hectare

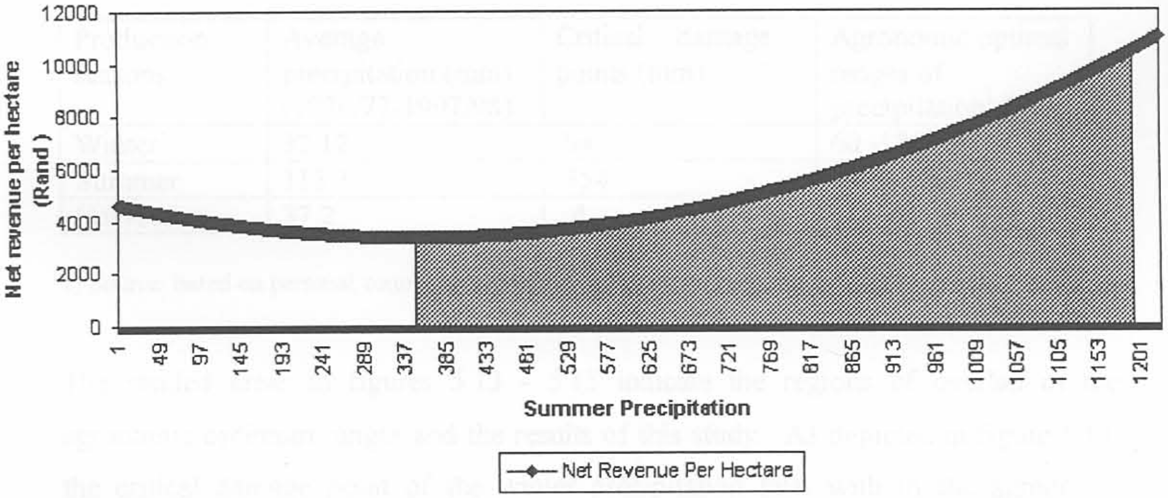

Figure 5. 15:Impact of increasing harvesting precipitation on net revenue per hectare

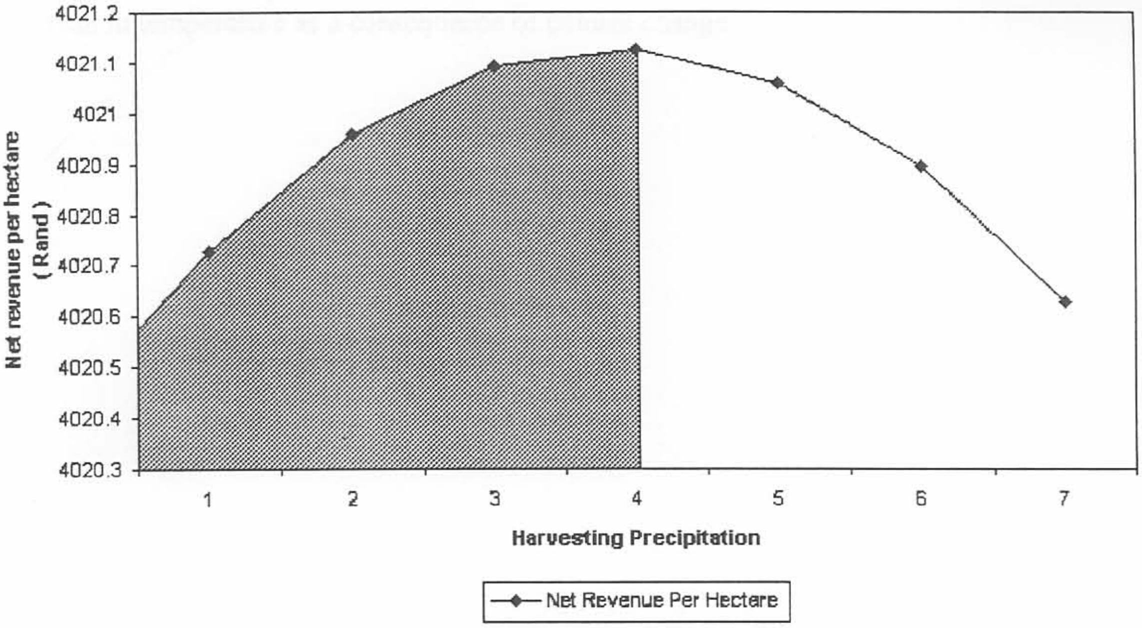

Table 5. 4: Average, agronomic optimal ranges and the estimated critical damage points of precipitation for South African sugarcane production.

Production seasons	Average precipitation (mm) (1976/77-1997/98)	Critical damage points (mm)	Agronomic optimal ranges of precipitation[1] (mm)
Winter	37.12	94	60 -120
Summer	113.3	354	270-1200
Harvesting	37.2	4	< 60

1) Source: based on personal communication with SASA agronomist, Smit (2002)

The shaded areas in figures 5.13 - 5.15 indicate the regions of overlap of the agronomic optimum ranges and the results of this study. As depicted in figure 5.13, the critical damage point of the winter precipitation falls with in the agronomic optimum range. Moreover, the critical damage points identified for summer and harvesting precipitation levels are also within the agronomic optimum range (Figures 5.14 & 5.15).

Fortunately, current rainfall levels are far from estimated critical damage points e.g. wider range of remaining tolerance (Table 5.4). This indicates that, sugarcane production in South Africa will be less sensitive to future increases in precipitation than in temperature as a consequence of climate change.

Chapter 6: Summary and Conclusions

This study made an attempt to evaluate the impact of climate change on sugarcane production in South Africa. The analysis utilized the Ricardian methodology that captures farmer adaptations to varying environmental factors.

Data from 11 districts for the period 1976/77 to 1997/98 were analyzed to explain farmer-adapted responses to climate variations across seasons and production zones. Three main seasons (winter, summer and harvesting) and two main production zones (irrigated and dryland) were considered for the study. Out of the 11 sample districts, nine were selected from the dryland farming contributing 80 % of the total sugar production while; the remaining two districts were selected from the irrigated north, which contribute the remaining 20 % of the total production.

Based on pooled analysis, district level net revenues per hectare were regressed on temperature, rainfall, soil type, altitude, dummies for irrigated and dryland areas and time trends. It was found that climate has a non-linear and significant impact on net revenue per hectare. The soil type, which affects productivity and altitude, which proxies solar energy, were also statistically significant. The dummies for irrigation and dryland including time trends, which were included to compare the trends of climate change on net revenue per hectare for both farming zones were also statistically significant.

The total and partial impacts of increasing temperature and precipitation, keeping other factors constant, were also simulated based on the estimated regression coefficients of the empirical model. The total impact was simulated for a 2^0C rise in temperature and a 7% increase in precipitation, a scenario associated with the doubling of carbondioxide for the whole world. Increasing temperature by 2°C and precipitation by 7 % (Doubling of CO_2) have negative impacts on sugarcane production in all zones. As expected, this impact is not equally distributed between the irrigated and dry farming region. The average loss in net revenue indicated that the dryland farming sustains more damaged under this climate change scenario. The reduction in average net revenue per hectare amounts to 26 % in the case of the irrigated farming, while it is 27 % in the dryland farming. This indicates that with irrigation, the damage from changing climate can be reduced not significantly though. The partial impact of increasing only temperature or precipitation across all seasons was also simulated to evaluate the impact of increasing temperature or precipitation on sugarcane production. The partial impact of increasing temperature was evaluated for the most likely scenario of a 2.75^{0}C rise in temperature on average for South Africa. Additionally, seasonal impacts were also simulated to evaluate the seasonal effects of changing temperature and precipitation levels.

Increasing temperature across all seasons, keeping other factors constant, reduce net revenue per hectare by 30 % in the irrigated farming and by 29 % in the dryland farming. These figures show that both the irrigated and dryland regions are almost equally affected by increasing temperature across all seasons. Increasing precipitation by 7% increase net revenue for the irrigated farming by 0.35% and reduce net revenue per hectare by 1.5 % for the dryland farming, a result that contradicts expectations and warrants further research.

The seasonal effects of a rise in temperature (2.75°C) and rise in precipitation (7%) were also analyzed to find out the impact of changing a specific season's temperature or precipitation on net revenues of both production zones. It was found that increasing winter and harvesting temperatures are damaging to both irrigated and dryland farming, while increasing summer temperature is beneficial to both farming zones. Additionally, increasing winter and harvesting precipitations were found beneficial whereas increasing summer precipitation was damaging to both farming zones.

To summarize, the yearly changes in net revenue per hectare caused by changes in temperature and precipitation were averaged over the 22 years period for both irrigated and dryland farming to get the average impact at each season (Table 6.1)

Table 6. 1: Average change in net revenue per hectare (1995 R) for irrigated and dryland farming for increasing temperature by 2.75°C and Precipitation by 7%.

Climate variables	Winter		Summer		Harvesting		Total
	Irrigated	Dryland	Irrigated	Dryland	Irrigated	DryLand	
Temperature	-844.69	-495.82	591.8	260.54	-211.3	-183.86	-893.33
Precipitation	5.13	9.5	-36	-89	4.3	1.2	-104.87
Total	-839.56	-486.32	555.8	171.54	-207	-182.66	-998.2

As showed in table 6.1, increasing temperature and precipitation across all seasons have negative impacts on sugar farming. Based on the most likely climate change scenario of increasing temperature by 2.75°C across all seasons, the contribution of sugar farming to agricultural GDP and to the overall economy decrease by 6 % and 0.2 % respectively. This clearly indicates that increasing temperature has a negative impact on the contribution of sugar farming to the South African economy.

Based on critical damage point analysis, it was found that increasing winter temperature beyond 18°C and decreasing summer temperature below 23°C were found damaging to sugarcane production. Winter precipitation levels beyond 94mm were damaging, whereas summer precipitation levels beyond 354mm were beneficial. Additionally, increasing harvesting temperature beyond 19°C was beneficial while increasing precipitation level more than 4mm was damaging to sugarcane production in South Africa.

Moreover, the critical damage points were compared with agronomic optimum temperature and precipitation levels for South African sugar farming to give more realistic interpretation of the results. Most of the critical damage points identified were found consistent with and fall within the agronomic optimum ranges. The likely impact of climate change on sugarcane production in South Africa was analyzed based on this critical damage point analysis compared to where current temperature and rainfall levels are. The critical damage points (temperature and precipitation) identified for each seasons were compared with the average current temperature and precipitation levels to evaluate the likely net revenue impacts of marginal changes in temperature and precipitation levels. It was found that winter and summer temperature levels are currently very close to the critical damage points identified for these seasons indicating the high sensitivity to winter and summer temperatures. The case however was different with rainfall as current rainfall levels are far from the identified critical damage points providing better range of tolerance to future rises in precipitation.

These results suggest a priority to intervention and adaptation strategies that target mitigation of increased temperature impacts. Therefore, future research has to focus on cost-effective methods of controlling yield-reducing factors associated with increased temperature especially during the winter growing season and the availability of sugarcane varieties, which are relatively not sensitive to increased temperature during ripening and harvesting.

While the general agreement is that arid and semi- arid regions of the world are more vulnerable to warming, management options, such as irrigation, are thought to provide an adaptation mechanism. This however, was not the case for sugar farming in South Africa, as irrigation did not reduce the harmful impacts of climate change significantly. As the result includes only one crop, generalization for the whole country cannot be made. Therefore an overall study, which includes all crops and other sub-sectors like livestock, should be conducted to get the full picture of the impact of climate change on agriculture and design mitigation strategies. Moreover, the model adopted for this study does not include the corbondioxide fertilization and price movements' effects, which if included could highly improve our understanding of the likely impacts of climate change on agriculture in South Africa.

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