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:

$$NRH_i = P_i\, Q_i - K_i \qquad (5.1)$$

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:

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

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).

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

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

$\bar{X}_j$ 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.

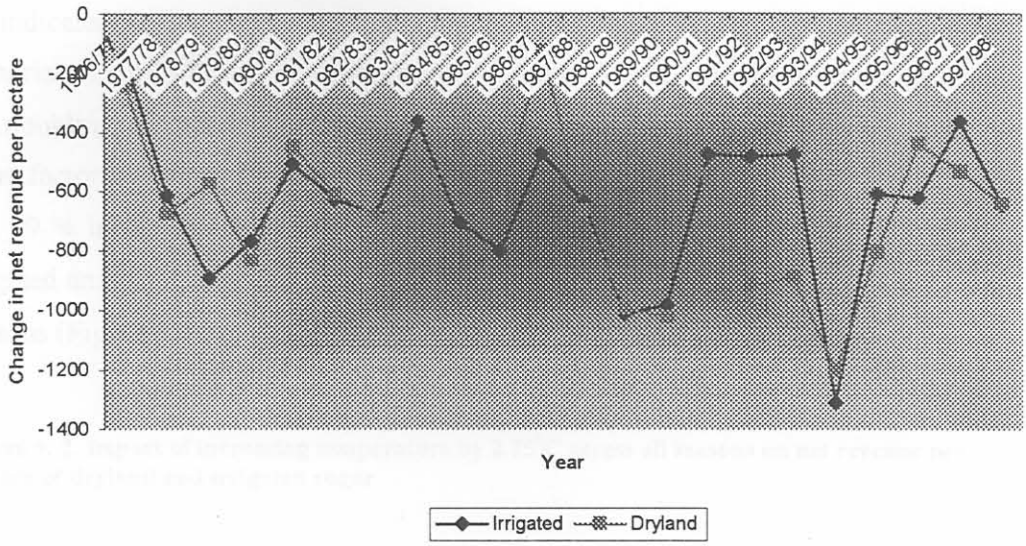
5.3.2.1 Total Effect Scenarios

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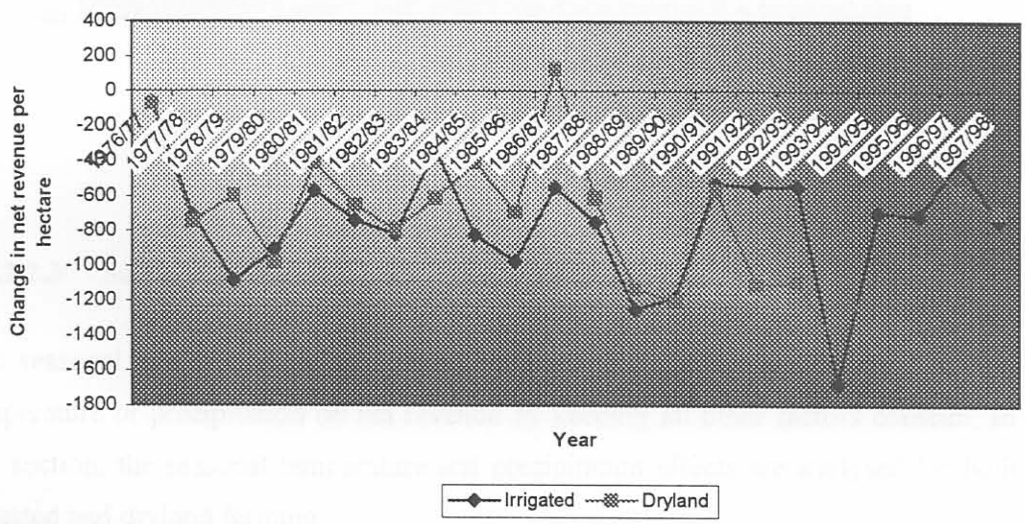
[1] The level of climate change associated with the doubling of carbon dioxide (IPCC, 1990)

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^{0}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).

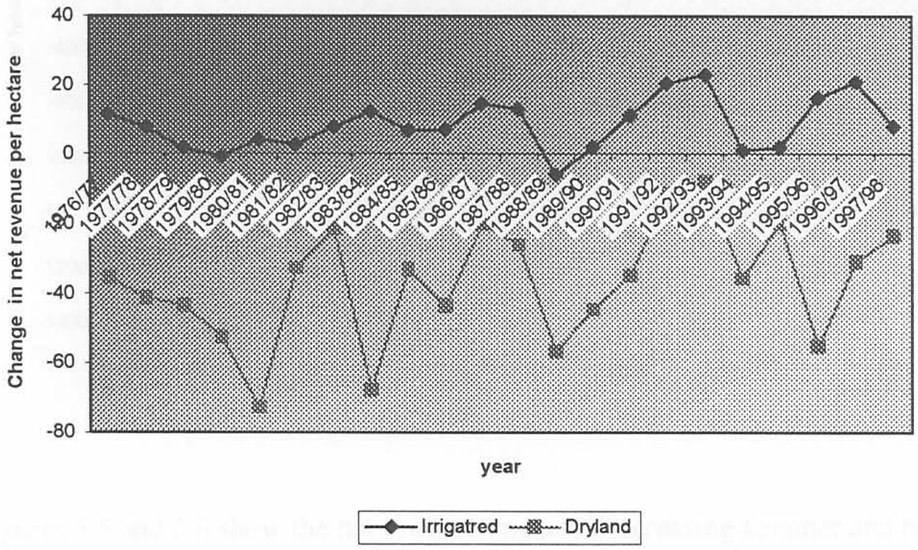
Figure 5. 2: Impact of increasing temperature by 2.75^{0}C across all seasons on net revenue per hectare of dryland and irrigated sugar



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



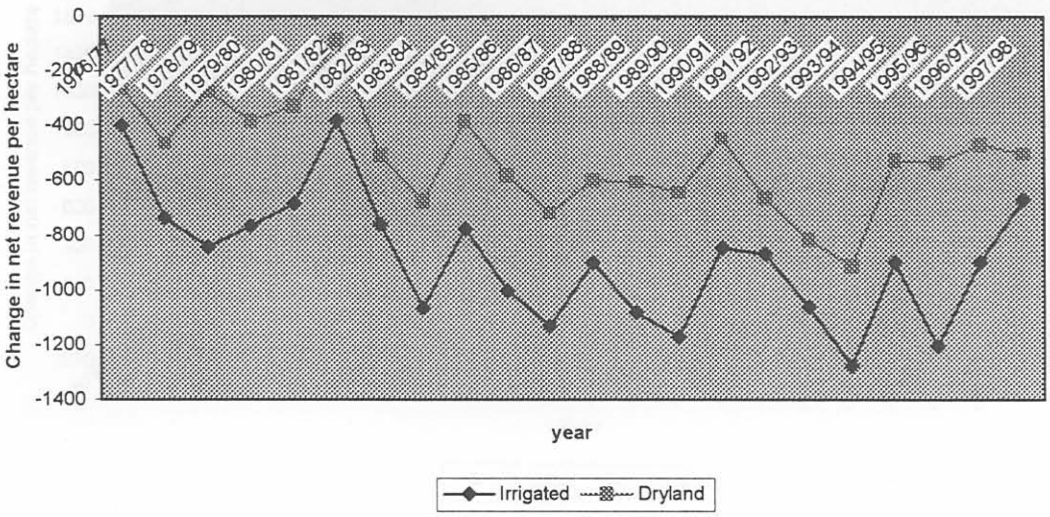
5.3.2.2.3 Seasonal Effects

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

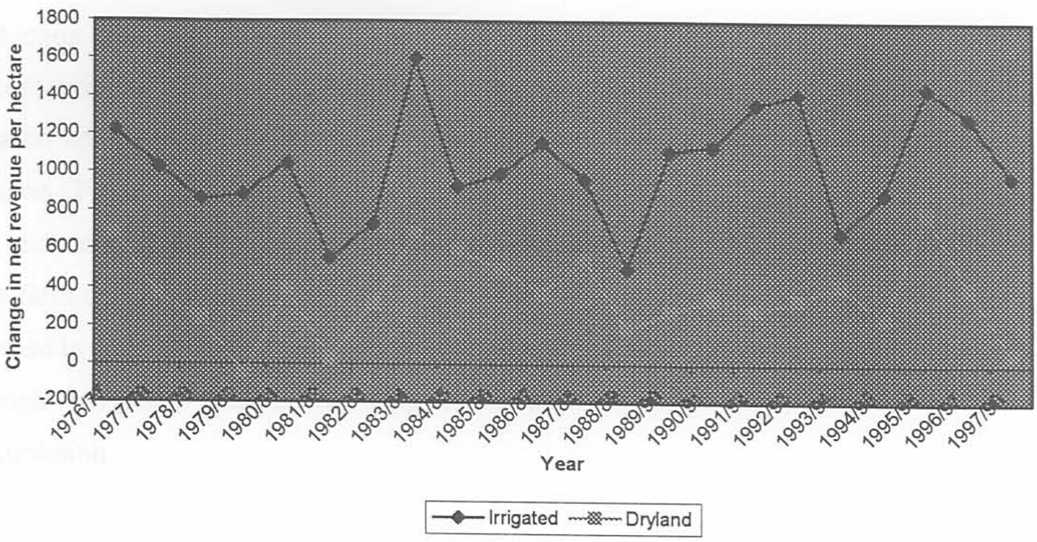
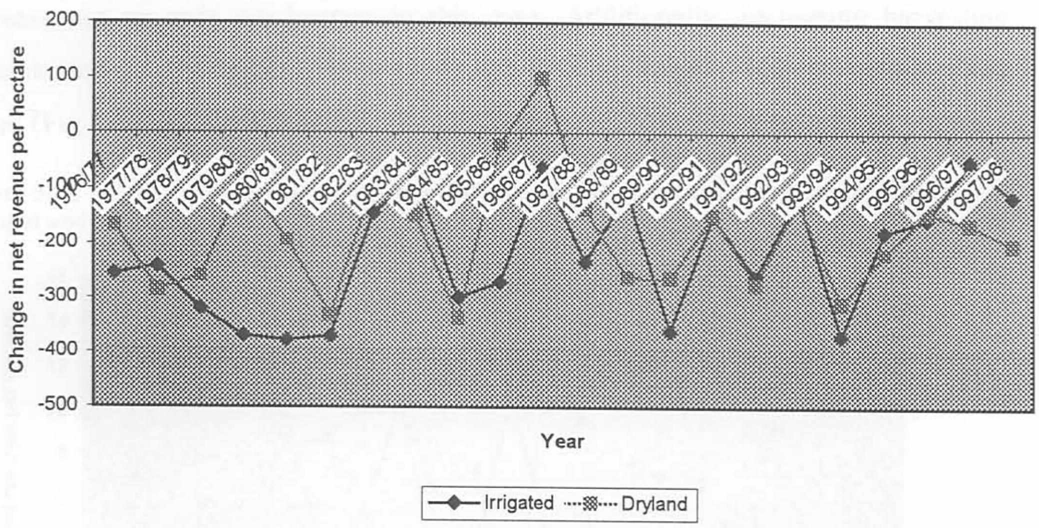


Figure 5. 6: Impact of increasing harvesting temperature by 2.75^{0}C on net revenue per hectare of dryland and irrigated sugar



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

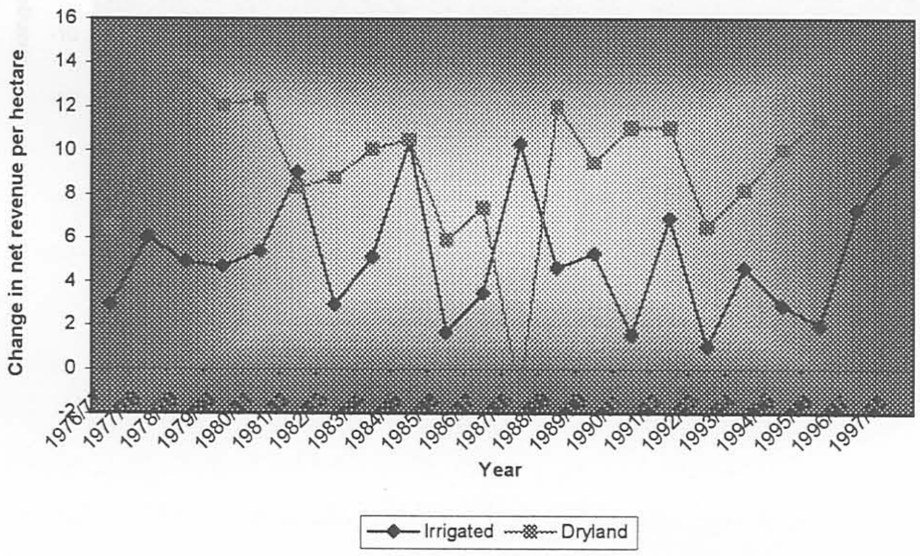


Figure 5. 8: Impact of increasing summer precipitation by 7% on net revenue per hectare of dry land and irrigated sugar

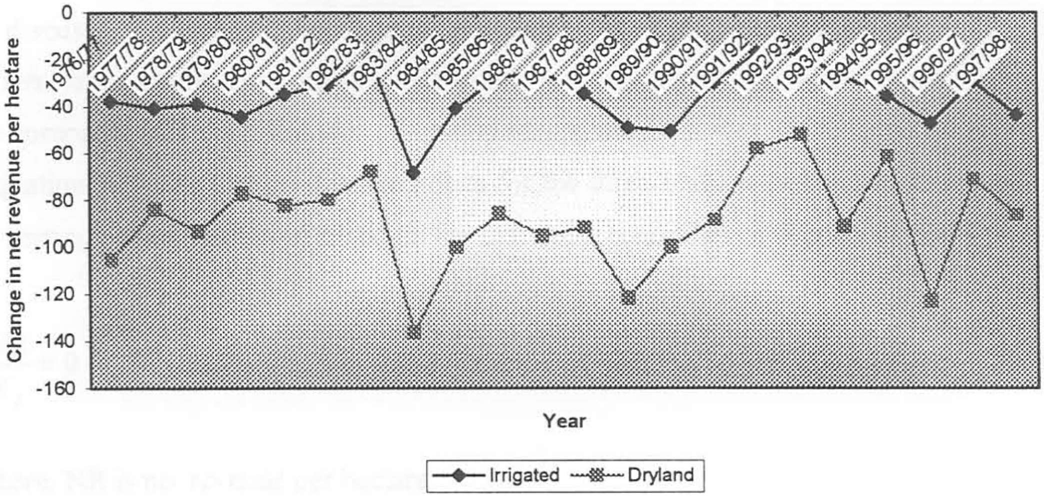
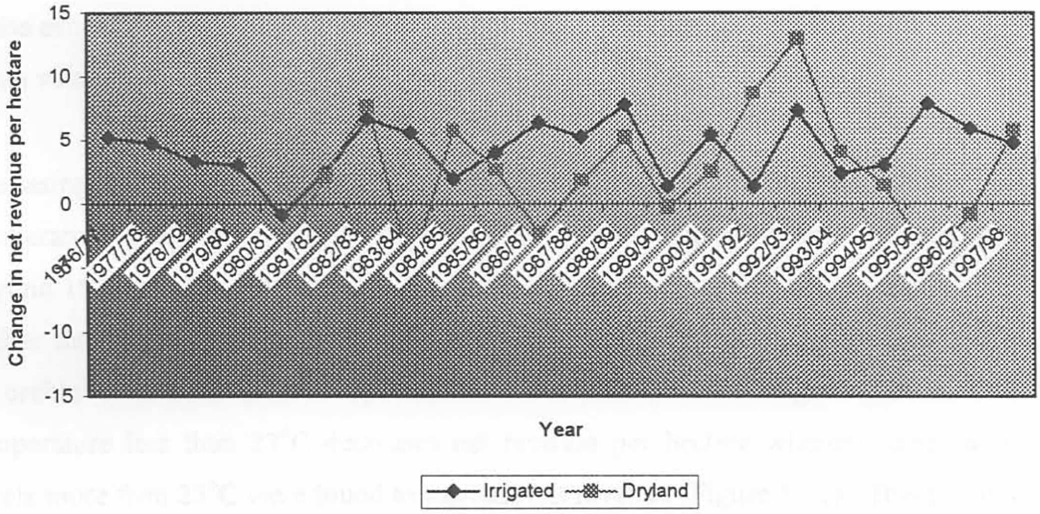


Figure 5. 9: Impact of increasing harvesting precipitation by 7% on net revenue per hectare of dryland and irrigated sugar



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

[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

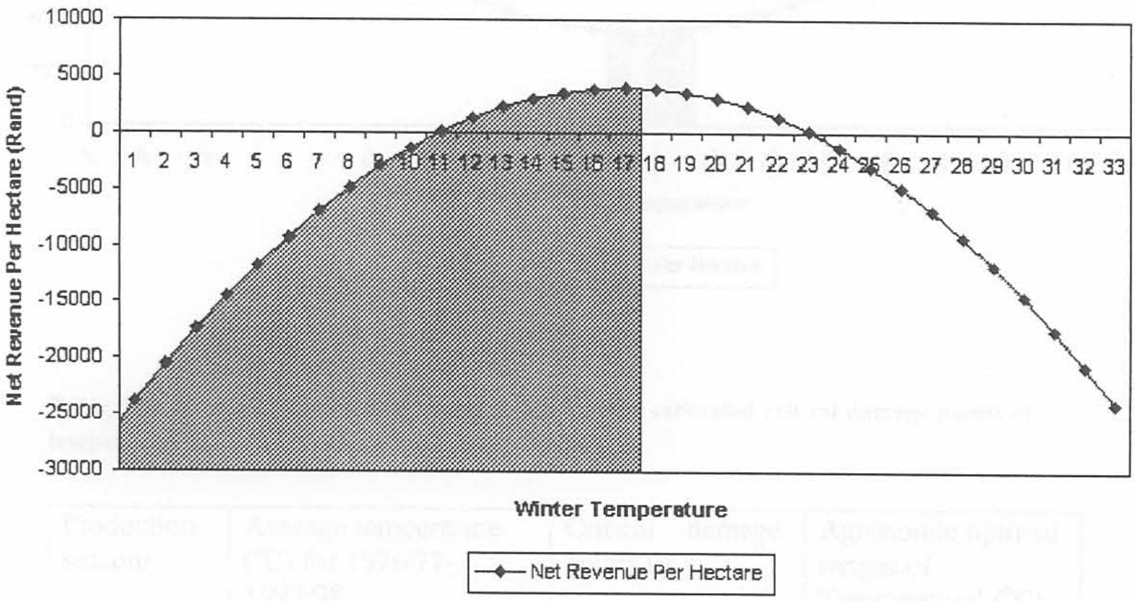


Figure 5. 11: Impact of increasing summer temperature on net revenue per hectare

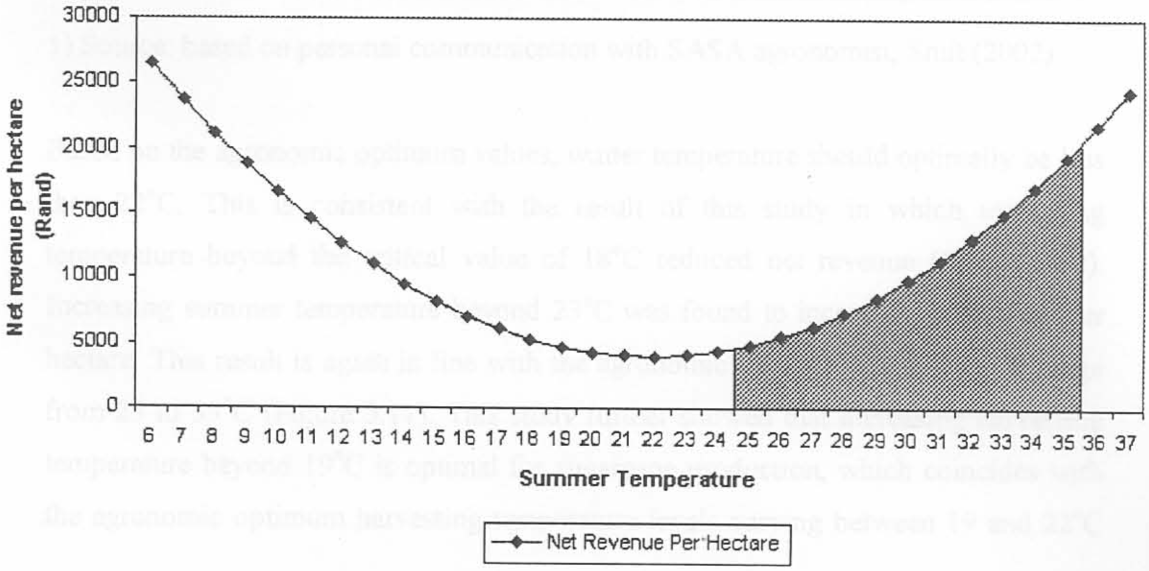


Figure 5. 12:Impact of increasing harvesting temperature on net revenue per hectare

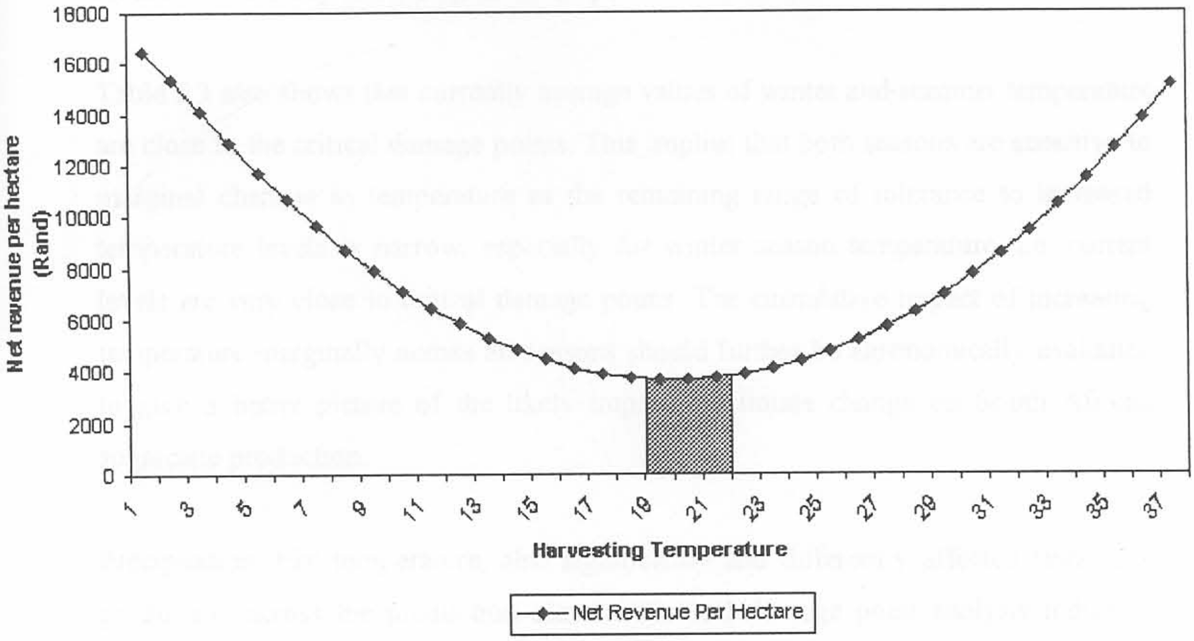


Table 5. 3: Average, agronomic optimal ranges and the estimated critical damage points of temperature for South African sugarcane production.

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

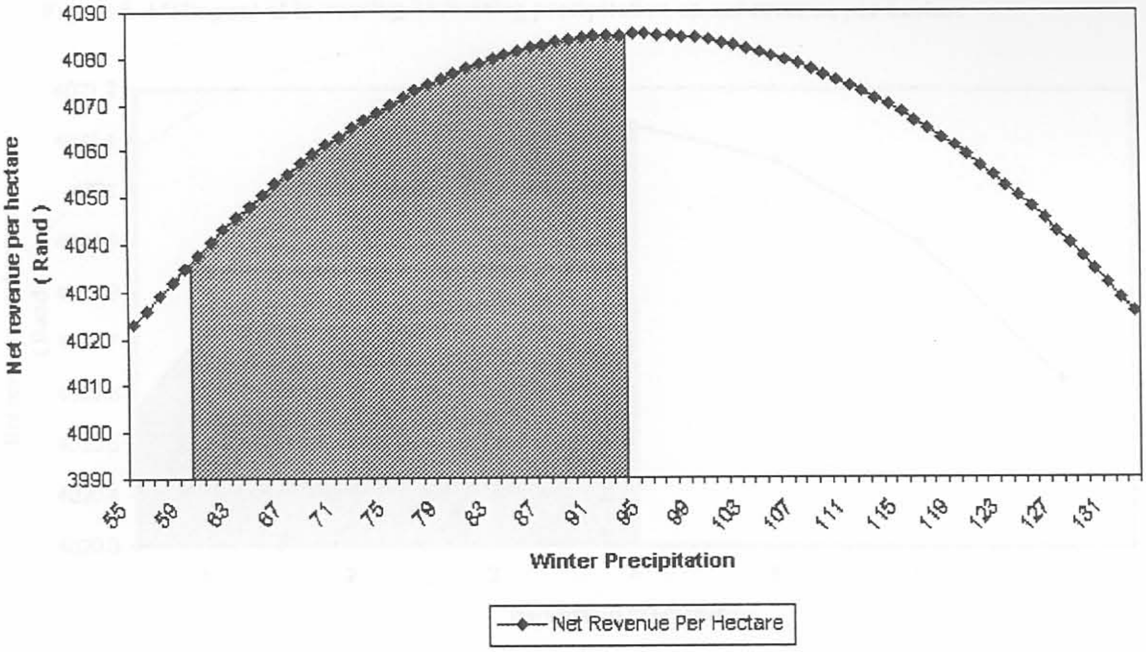


Figure 5. 14: Impact of increasing summer precipitation on net revenue per hectare

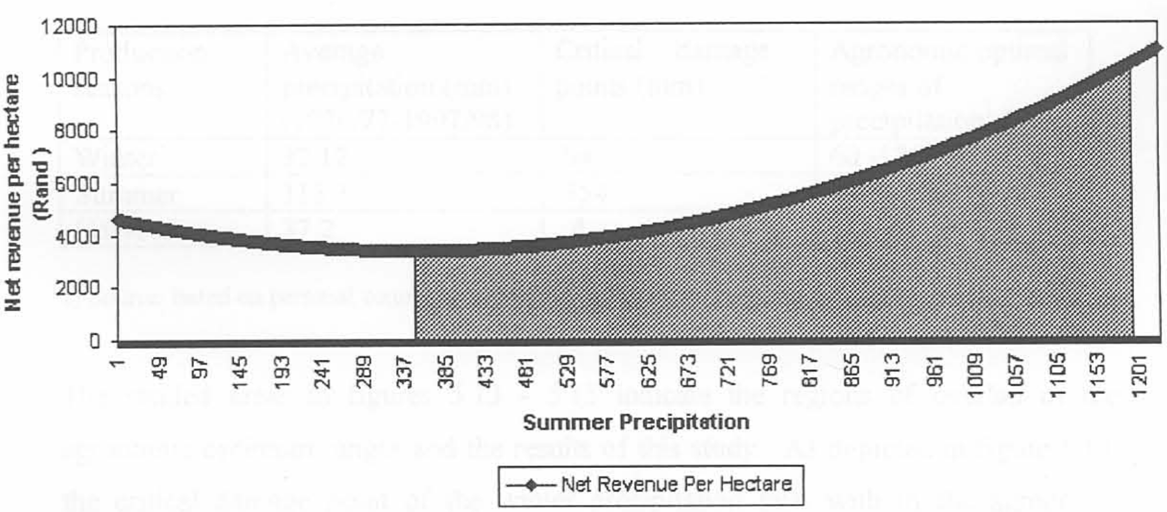


Figure 5. 15:Impact of increasing harvesting precipitation on net revenue per hectare

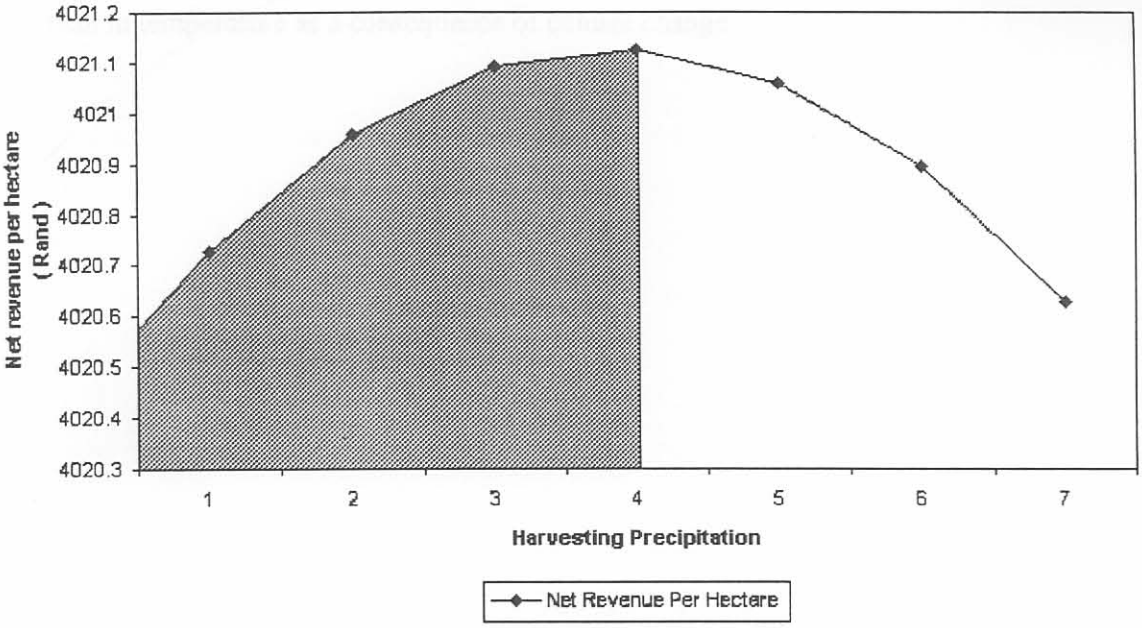


Table 5. 4: Average, agronomic optimal ranges and the estimated critical damage points of precipitation for South African sugarcane production.

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.