CHAPTER 5 : RESULTS OF THE EMPIRICAL ANALYSIS

5.1 Introduction

This chapter presents and discusses the results of the empirical analysis. A discussion of the procedures followed to estimate the model parameter is given in section 2. The estimated results of the regression of the net revenue are presented followed by the simulations undertaken to capture the sensitivity of the South African field crops sector to global warming.

5.2 Parameters' estimation procedures

Using the Ricardian technique discussed in chapter four, the study estimated the value of climate in the South African field crops sector. The model for South African field crops assumed a quadratic relationship between district net revenue hectare and climate factors but a linear relationship with others variables. The quadratic terms were included to reflect the nonlinearities in the relationship between crop output and climate variables that are apparent from various field studies and also other Ricardian studies applied elsewhere (Mendelshon *et al.*, 1994 and 1996; Dinar *et al.*, 1998; Poonyth *et al.*, 2002; Deressa, 2003; and Mendelshon and Dinar, 2003). When the quadratic term is positive, the farm value function is U-shaped, and when the quadratic term is negative, the function is hill-shaped.

The model for South African field crops is a multiple regression model that was estimated using the White Heteroskedasticity-Consistent Standard Errors and Covariance consistent estimator employing the econometric software Eviews. Ordinary Least Squares (OLS) method parameter estimators have desirable statistical properties. They are known as the best linear unbiased estimators often denoted with the acronym "BLUE." However, the optimality of OLS estimators relies heavily on six key assumptions (Pindyck and Rubinfeld, 1998):

1. The relationship between the dependent variable (Y) and the independent variables (X's).
2. The X's are nonstochastic.

3. No exact linear relationship exists between two or more of the independent variables.
4. The error term has 0 expected value and constant variance for all observations (homoscedasticity).
5. Errors corresponding to different observations are independent and therefore uncorrelated (no serial correlation).
6. The error variable is normally distributed.

When examining, cross-sectional data, there may be reason to believe that the assumptions of homoscedasticity and no serial correlation of the error term are violated. With data from different sub-populations, when an independent estimate of the error variance is available, OLS estimators will place more weight on observations with large error variance, therefore the estimators will be unbiased and consistent, but not efficient (the variances of estimated parameters are not the minimum variances). Furthermore, the estimated variances of the estimated parameters will be biased estimates of the true variances. White (1980) has derived a heteroskedasticity consistent covariance matrix estimator, which provides correct estimates of the coefficient covariances in the presence of heteroskedasticity of unknown form. The White covariance matrix assumes that the residuals of the estimated equation are serially uncorrelated. Newey and West (1987) have proposed a more general covariance matrix estimator that is consistent in the presence of both heteroskedasticity and autocorrelation of unknown form. EViews provides the option to use the White Heteroskedasticity-Consistent Standard Errors and Covariance consistent estimator in place of the standard OLS formula to avoid heteroscedasticity and serial correlation.

This study used the above method to estimate the empirical Ricardian model specified for South African field crops.

Several runs have been tried in order to find the model estimates that describe best the relationship between net revenue hectare and climate, soil and other socio-economic variables. In the preliminary runs, to describe the climate, three seasons were included in the model namely Spring, Summer and Winter. However, because of the high correlation between spring temperature and both summer and winter temperature and spring rainfall and summer rainfall, the data have been rearranged into two seasons (summer and winter). To control for extraneous factors influencing net revenue, a set of variables have been included in the regression. Firstly, three soil dummies to represent the three main soil types in the country were considered but soil dummy 2 was found statically insignificant and therefore was dropped out. However, since none of the districts in the dataset has only one soil type, the removal of soil dummy 2 in the regression did not affect the results. None of the observations have been lost. On the other hand, the other variables (soil, irrigation, population density, labour and geographical coordinates) were found significant. Labour is expected to show diminishing marginal productivity. Accordingly a quadratic term for labour was included but was found not significant and therefore dropped out.

Moreover, the model was first estimated using absolute values of variables, which produced residuals of the estimated linear equation that were not normally distributed. Thus the empirical model was then estimated in a semi-log functional form with the logarithm district net revenue per hectare as the dependent variable:

$$\log(NRHA) = \beta_0 + \beta_1 T + \beta_2 T^2 + \beta_3 R + \beta_4 R^2 + \beta_5 T * R + \beta_6 Z + \beta_7 G + u \qquad (5.1)$$

where: T is the vector of temperature variables (summer and winter), R is the vector of rainfall variables , Z is the set of soil variables (soil dummy 1 and soil dummy 3), G is the set of others variables (population density, irrigation, labour and geographical coordinates: altitude and latitude) and u the error term.

5.3 Results of the regression analysis

The results of the regression showed that climate variables (temperature and rainfall), soil indicators, labour, irrigation, population and geographic variables (altitude and latitude) have significant influences on the behaviour of net revenue hectare of the South African major field crops. Statistically, the coefficients, except that of rainfall, were all significant at a 5% level of significance. The model, according to the F statistic gave a good fit at a 5% level of significance. According to adjusted R², the model explained 63% of the variation in net revenue hectare (Table 5-1).

Table 5-1: Parameter estimation of the Ricardian field crops model

Dependent variable: log (NRHA) in R/ha

Variable	**Coefficient**	**Variable**	**Coefficient**
Intercept	10.25 (2.79)**	Temp*Rain Summer	-0.0009 (-1.96)*
tempSummer	-1.25 (-3.71)**	Temp*Rain Winter	0.0025 (1.64)
tempSummer2	0.03 (4.06)**	Popd	5.09E-05 (2.23)*
tempWinter	0.72 (3.58)**	Soildum1	-0.22 (-1.89)*
tempWinter2	-0.027 (-3.79)**	Soildum3	0.067 (1.84)*
rainSummer	-0.0007 (-1.43)	Labour	2.20E-05 (2.16)*
rainSummer2	0.0001 (3.18)**	Irrigation	0.96 (4.23)**
rainWinter	0.01 (1.22)	Latitude	0.13 (4.09)**
rainWinter2	-0.0004 (-2.57)**	Altitude	-0.0004 (-2.29)*
R-squared	0.66	Adjusted R-squared	0.63
F-Statistic	40.11		

Number of observations = 300
* Level of significance at 5%
** Level of significance at 1%

The results showed that the quadratic terms of climate variables are significant, which denotes a quadratic relationship between climate and net revenue as hypothesised earlier. Winter climate variables have a hill shaped relationship with net revenue whereas summer climate variables have a U shaped relationship. Net revenue seems to benefit from warmer and wetter winter with diminishing marginal benefits up to a turning point after which Net revenue starts declining. Also, above a minimal point, net revenue seems to benefit from higher rainfall and higher temperature.

The estimated parameters that control for farm production technology (irrigation and labour) are positively correlated to net revenue as expected. Irrigation has strong positive effects and increases net revenue per hectare substantially. Thus, irrigation may allow crops to grow well in warmer temperatures and dryer regions. These results suggest that irrigation could be an effective mitigation measure to climate change adverse impacts. Furthermore, the positive correlation between population density (proxy for urbanisation) and net revenue indicated that net revenue increases in a more denser and wealthier regions. Indeed because of the higher local demand for food and the potential for conversion of land to non-farm uses, farm values are higher in more urbanised areas.

Soil type 1 which is the category of the red-yellow latosols is negatively related to net revenue. In contrary soil type 3, the category of black to very dark grey brown with high clay content, influence net revenue positively as expected. Soil type 1 has rapid infiltration and low water holding capacities and is very low in plant nutrients, whereas soil type 3 is a very productive soil.

The altitude (proxy for day length) has a negative effect on net revenue as expected. Indeed, the longer the day, the higher is the photoperiod of the plant. At higher altitudes, days are shorter and hence reduce the photosynthesis activity of the plant. Additionally, because the presence of light during the daytime enhances absorption of mineral nutrients and water from the soil, latitude has been included in the regression as a proxy for solar radiation. We expected a negative relationship between latitude and net revenue since regions at low latitude receive more solar radiation than those at higher latitude. However this is not the case in our results.

In general, all the parameters are significant and have the expected signs except for the latitude variable (proxy for solar radiation), which gives high confidence in the model to use for further analysis.

5.4 Climate sensitivity of the South African field crops

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 (Deressa, 2003). Thus, the climate sensitivity of the South African field crops sector is analysed in this section through calculation of seasonal elasticity and identification of climate critical damage points.

5.4.1 Elasticity measures

Elasticity measures the percentage change in the response variable induced by a percentage change in the independent variables. The economic interpretation of the coefficients of a semi-log model is not that straightforward, further complicated by climates interaction terms. The estimated coefficients of the semi-log model are neither marginal values nor elasticity, but can be easily converted to the right measures (Studenmund, 1992).

Elasticity (ε) is defined as:

$$\varepsilon = \frac{(\Delta NRHA)}{(\Delta F_i)}\left(\frac{\overline{F}_i}{\overline{NRHA}}\right) \tag{5.2}$$

Where *NRHA* is the net revenue hectare, F_i is the level of climate variable i (temperature and rainfall).

The calculated elasticity estimates[10] evaluated at mean values indicated that at current levels of rainfall, increasing temperatures in both seasons reduce net revenue. On the other hand, at current levels of temperature, increasing precipitation in winter is beneficial whereas increase summer rainfall affected negatively net revenue (Table 5-2).

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[10] $\ln nrha = \beta_1 T + \beta_2 T^2 + \beta_3 R + \beta_4 R^2 + \beta_5 R * T$ Note that β_i cannot be directly interpreted as elasticities unless you use a double-log term. With the inclusion of interaction term in the equation, the elasticity for Temperature (T) for example will therefore be:

$$\varepsilon = \frac{\partial \ln NRHA}{\partial T} * \overline{T} = \left(\beta_1 + 2\beta_2 \overline{T} + \beta_5 \overline{R}\right) * \overline{T}$$

Table 5-2: Estimates of elasticity to climate factors

	Temperature	Rainfall
Winter season	-0.08	0.89
Summer Season	-0.115	-0.406

For a typical specification of agricultural technology, there exits an optimal configuration of seasonal temperatures and rainfall. Climate change will be costly (or beneficial) if, on average climatic conditions in the area modelled move further away from (or closer to) the climatic optimum. Thus as Quiggin and Horowitz (1999) observe, for further insights into the relationship between net revenue and climate, one needs to determine whether current levels of climate variables are below or above the climatic optimum levels (turning points). In the next section, the climatic optimum points will therefore be calculated and compared to current climate normal.

5.4.2 Climatic optimum points

The climatic optimum points for the two seasons were calculated from the first order conditions of optimisation:

$\frac{\partial LNNRHA}{\partial X_j} = 0$, Where NRHA is the net revenue hectare and X_j is the level of climate variable j (temperature or rainfall).

At first, the net revenue hectare estimated graphs (Figure 5-1 to 5-4) were obtained by changing only a specific season's temperature or rainfall in the estimated above net revenue function, keeping other factors constant at mean values. However, since in the estimated model of field crops net revenue, interaction terms between rainfall and temperature were included, we also investigate how the optimum points of a specific climate variable will change with changes in the other (Figure 5-5 to 5-8).

5.4.2.1 Identification of climatic optimum points

A. Temperature level analysis

Assuming rainfall constant at current levels, the optimum temperature points for South African field crops' sector were calculated at 14.78^0C and 22^0C for winter and summer, respectively.

With a hill shaped relationship between net revenue and winter temperature, increasing winter temperature was found to increase net revenue hectare for temperature levels below 14.78^0C and to reduce net revenue beyond 14.78^0C (Figure 5-1). At very low temperatures, most plants may not grow well and therefore incremental increase in temperature will be beneficial until a certain point. Indeed the decline in net revenue for winter temperature higher than 14.78^0C could be attributed to the moisture stress occurring in the plant due to higher temperature that induces higher evaporation coupled with very low rainfall in winter. Additionally, occurrence of temperatures higher than 14.78^0C in winter season may be favourable for pests and diseases. The current average winter temperature in South Africa is 14.5^0C that is very close to the critical damage point. The critical damage point of 14.78^0C falls in the range of agronomic optimal temperature for the growth of wheat, the main winter crop in South Africa (Table 5-3). Therefore additional rises in winter temperature will induce yield reduction at national level. Indeed a 1% increase in winter temperature will reduce national net revenue by 0.08% (table 5-2). However, this may differ across regions. Indeed cooler regions below the optimal winter temperatures may benefit. Examples include the Eastern Cape (13.5^0C), the Free State (12.3^0C), the Gauteng (13.35^0C) and the Northern Cape (13.62^0C). Whereas, climate change would be costly to regions currently above the winter optimum temperatures such as the Kwazulu Natal (16.5^0C), Mpumalanga (14.80^0C) and Limpopo (18^0C).

On the other hand, with a U shaped relationship between summer temperature and net revenue hectare, the minimum optimum temperature for plant growth is 22^0C. Thus, temperature higher than 22^0C will increase net revenue (Figure 5-2). There is a positive response of net revenue per hectare to increased summer temperature because the optimal temperatures for summer crops (maize, sugar cane, sorghum, groundnut, sunflower and soybean) are around 25^0 to 35^0 C (Table 5-3).

Figure 5-1: The sensitivity of net revenue to winter temperature

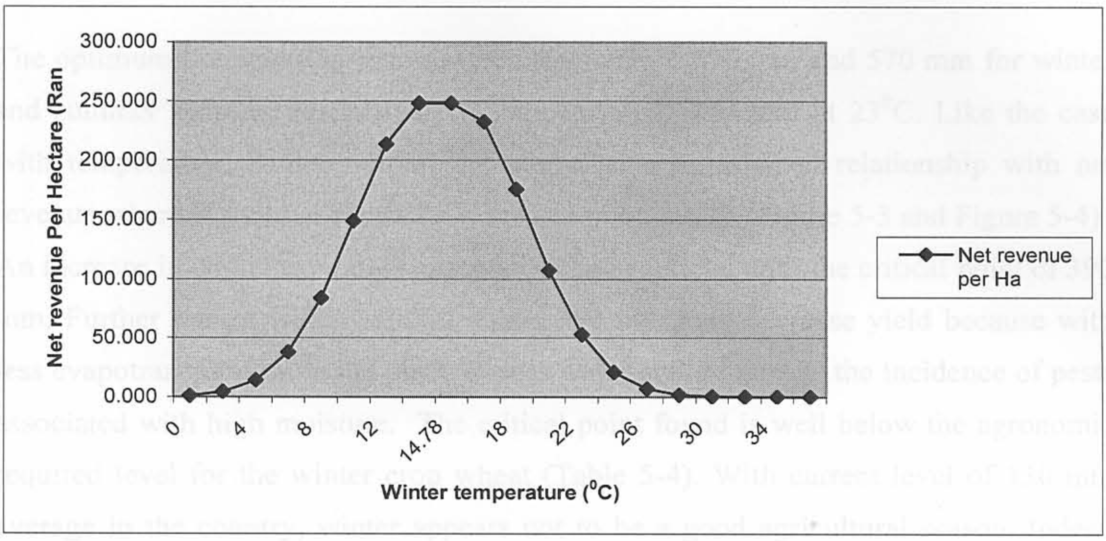


Figure 5-2: The sensitivity of net revenue to summer temperature

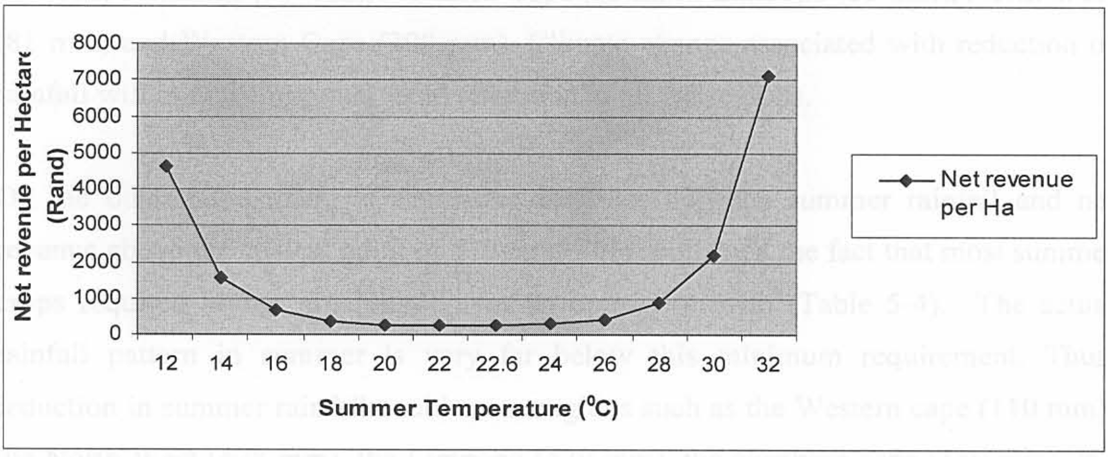


Table 5-3: Current level, critical point and agronomic optimal temperatures

Seasons	Crops produced	Current temperature levels (°C)	Critical damage points (°C)	Agronomic optimal range of average temperature[1] (°C)
Winter	Wheat	14.5	14.78	10-20
Summer	Maize	23	22	18- 30
	Sugar cane			22-35
	Sorghum			25-35
	Groundnut			22-32
	Sunflower			17-34
	Soybean			20-33

1) Source: Illinois State Water Survey (2004) and Deressa (2003)

B. Precipitation level analysis

The optimum precipitation points were calculated at 390 mm and 570 mm for winter and summer seasons, respectively if temperature is constant at 23^0C. Like the case with temperature, winter rainfall depicted also a hill shaped relationship with net revenue whereas summer rainfall a U shaped relationship (Figure 5-3 and Figure 5-4). An increase in winter rainfall is expected to be beneficial until the critical point of 390 mm. Further rise in winter rainfall above 390 mm may decrease yield because with less evapotranspiration in the plant, excess water could increase the incidence of pests associated with high moisture. The critical point found is well below the agronomic required level for the winter crop wheat (Table 5-4). With current level of 130 mm average in the country, winter appears not to be a good agricultural season. Indeed actual winter rainfall level across the country is well below the optimal level: the Eastern Cape (176 mm), Free State (110 mm), Gauteng (97 mm), Kwazulu Natal (186 mm), Mpumalanga (87 mm), Northern Cape (65 mm), Limpopo (55 mm), North West (81 mm) and Western Cape (300 mm). Climate change associated with reduction of rainfall will induce important yield reduction in all the regions.

On the other hand, there is a positive response between summer rainfall and net revenue above the critical point of 570 mm. This confirmed the fact that most summer crops required higher precipitation for an optimal growth (Table 5-4). The actual rainfall pattern in summer is very far below this minimum requirement. Thus, reduction in summer rainfall could cause regions such as the Western cape (110 mm), the North West (478 mm), the Limpopo (429 mm), the Northern cape (180 mm), the Free State (408 mm) and the Eastern cape (420 mm) severe damages as opposed to the Mpumalanga (600 mm), Kwazulu Natal (670 mm), Gauteng (617 mm) regions that are currently above optimal summer rainfall.

As observed, current rainfall levels are far from estimated climatic optimum points in contrary to current temperature levels. This therefore implies that the field crops will be very sensitive to marginal changes in temperature as the remaining range of tolerance to increased temperature is narrow compared to changes in precipitation. This finding is in line with Deressa (2003) study that was focussed only on sugar cane.

Figure 5-3: The sensitivity of net revenue to winter rainfall

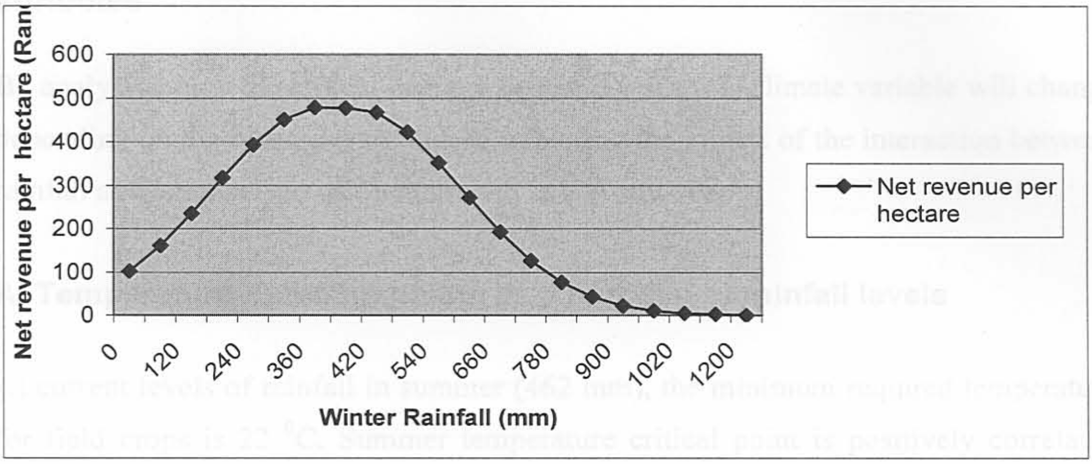


Figure 5-4: The sensitivity of net revenue to summer rainfall

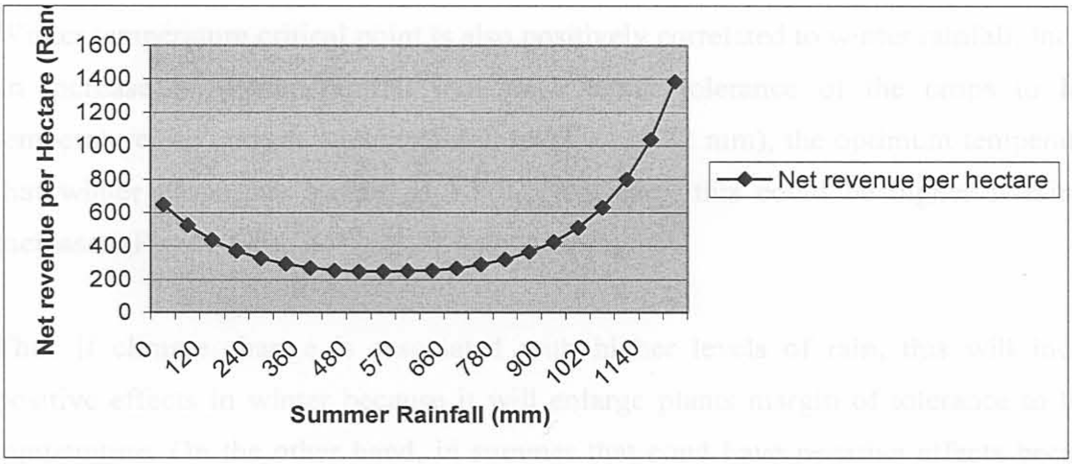


Table 5-4: Current level, critical damage point and agronomic optimal level of precipitation

Seasons	Crops produced	Current precipitation levels (mm)	Critical damage points (mm)	Agronomic optimal precipitation[1] levels (mm)
Winter	Wheat	130	390	750
Summer	Maize	462	570	1200
	Sugar cane			1200
	Sorghum			900
	Groundnut			1200
	Sunflower			1200
	Soybean			1200

1) Source: Illinois State Water Survey (2004) and Deressa (2003)

5.4.2.2 The sensitivity of climatic optimum points to other climate attributes

By analyzing how the critical damage points of a specific climate variable will change depending on the other, we are indeed exploring the effects of the interaction between rainfall and temperature on plant growth in a given season.

A. Temperature optimum points as a function of rainfall levels

At current levels of rainfall in summer (462 mm), the minimum required temperature for field crops is 22 ^{0}C. Summer temperature critical point is positively correlated with summer rainfall. Increasing rainfall will raise the required minimum temperature and a reduction in rainfall will reduce the required minimum temperature (Figure 5-5).

Winter temperature critical point is also positively correlated to winter rainfall. Indeed an increase in winter rainfall induces a better tolerance of the crops to high temperature. At current winter rainfall level (130.62 mm), the optimum temperature that winter crops can sustain is 15 ^{0}C. However, this could be higher if rainfall increases (Figure 5-6).

Thus if climate change is associated with higher levels of rain, this will induce positive effects in winter because it will enlarge plants margin of tolerance to high temperature. On the other hand, in summer that coud have negative effects because higher rain, increased the minimum required level of temperature. A reverse situation could happen if climate change is associated with low rainfall in South Africa (negative effects in winter and positive effects in summer).

Figure 5-5: Variation of temperature critical points to rainfall in summer

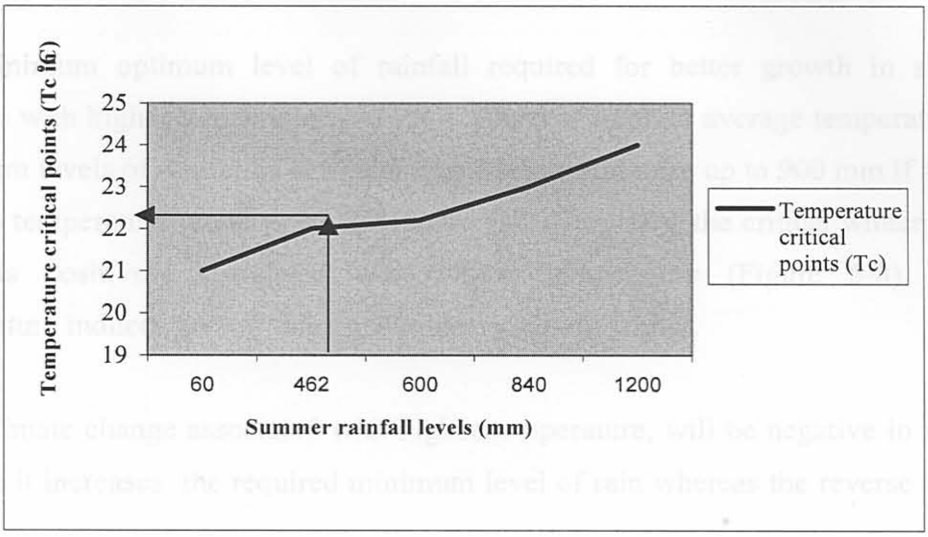
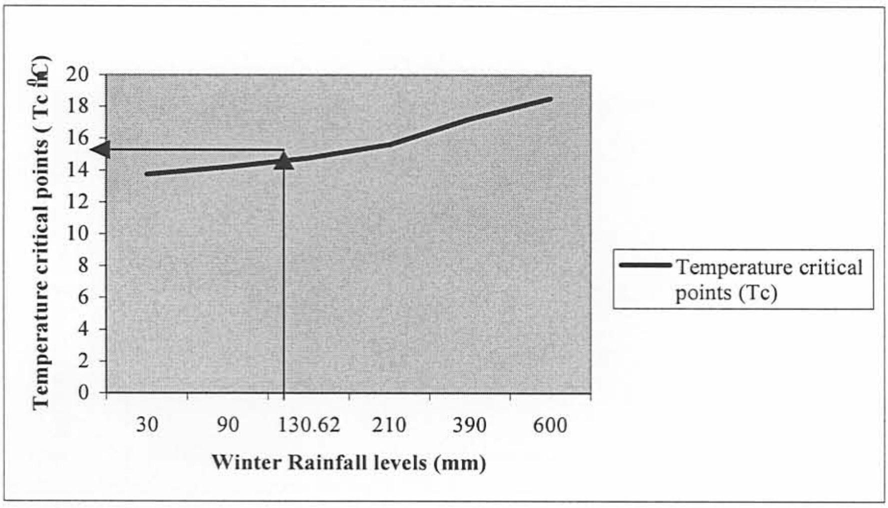


Figure 5-6: Variation of temperature critical points to rainfall in winter



N.B.: The narrows indicate actual climate levels and their respective critical points in Figure 5-5 and 5-6.

B. Rainfall optimum points as a function of temperature levels

The minimum optimum level of rainfall required for better growth in summer, increase with higher temperature. At 23 ^{0}C, current summer average temperature, the minimum levels of rainfall is at 570 mm, and this could raise up to 900 mm if summer average temperature go up to 30 ^{0}C (Figure 5-7). Similarly, the critical winter rainfall point is positively correlated with winter temperature (Figure 5-8). Higher temperature induces greater tolerance to heavy rain in winter.

Thus climate change associated with higher temperature, will be negative in summer because it increases the required minimum level of rain whereas the reverse holds in winter.

In general we observe that high temperature is benefecial with high rain in both seasons.

Figure 5-7: Variation of Rainfall critical points to temperature levels in summer

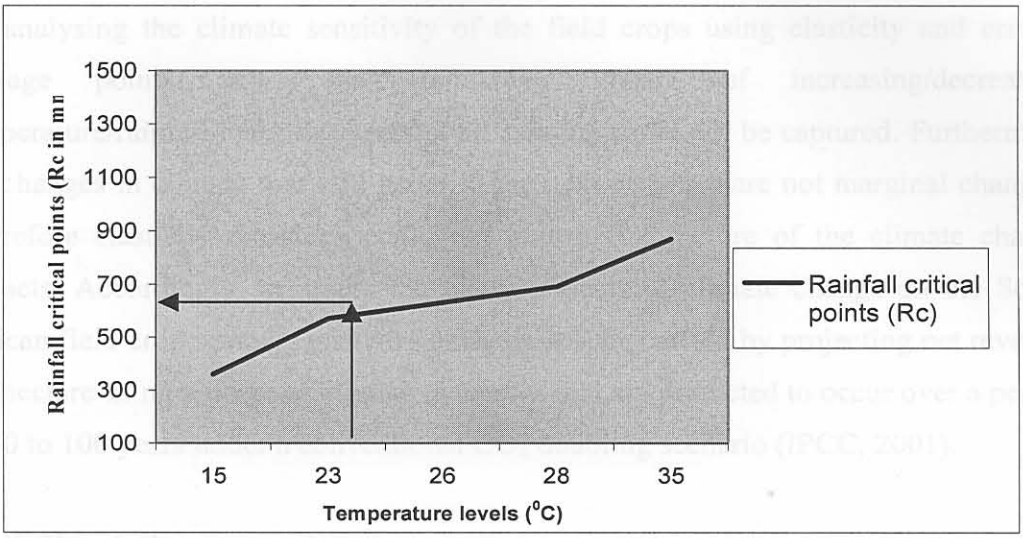
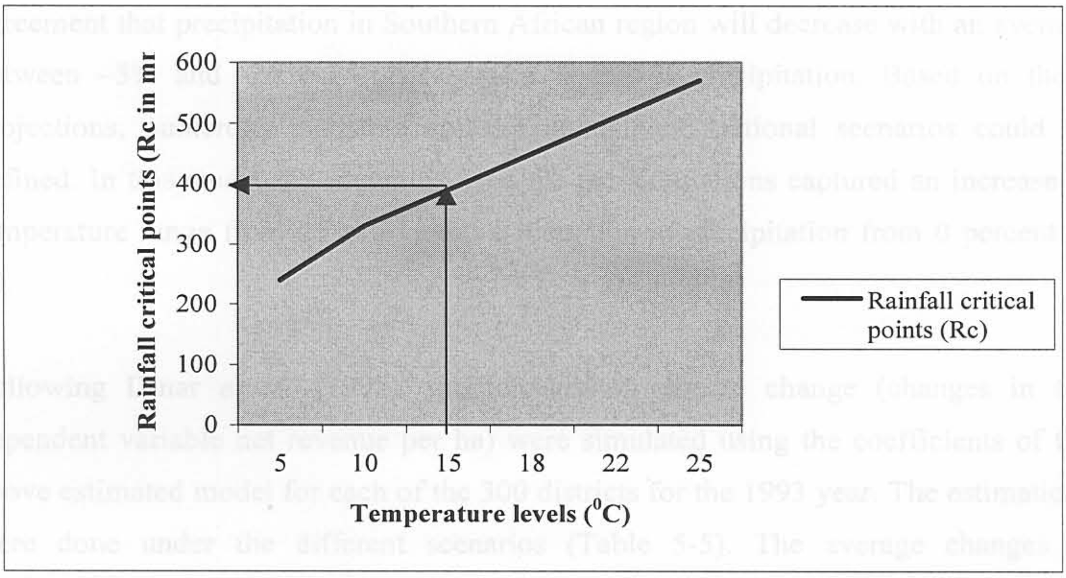


Figure 5-8: Variation of Rainfall critical points to temperature levels in winter



N.B.: The narrows indicate actual climate levels and their respective critical points in Figure 5-7 and 5-8.

5.5 Likely impacts of climate change on the South African Field Crops

By analysing the climate sensitivity of the field crops using elasticity and critical damage points only, the cumulative impact of increasing/decreasing temperature/rainfall marginally across all seasons could not be captured. Furthermore the changes in climate that will occur in the next 50 years are not marginal changes. Therefore elasticity measures could not give a full picture of the climate change impacts. Accordingly, to assess the likely impacts of climate change on the South African field crop sector, sensitivity analysis will be carried by projecting net revenue per hectare using a range of climate outcomes that are predicted to occur over a period of 30 to 100 years under a conventional CO_2 doubling scenario (IPCC, 2001).

5.5.1 Simulation procedures

Following Mendelshon *et al.* (2001), instead of relying on the direct outputs of GCMs this study examined a set of uniform climate change scenarios. According to IPPC (2001a), the Southern African region is expected to warm greater than the average global warming of 1.5^0 to 4.5^0C (warming in excess of between 0-40%). There is an agreement that precipitation in Southern African region will decrease with an average between –5% and -20% of their current levels of precipitation. Based on these projections, numerous plausible uniform annual and national scenarios could be defined. In this study, the scenarios used for the simulations captured an increase in temperature range from 2^0 to 3^0C and a reduction in precipitation from 0 percent to 20.

Following Dinar *et al.* (1998), the impacts of climate change (changes in the dependent variable net revenue per ha) were simulated using the coefficients of the above estimated model for each of the 300 districts for the 1993 year. The estimations were done under the different scenarios (Table 5-5). The average changes in temperature were added to the baseline temperatures, while the baseline rainfall was multiplied by the percentage changes in precipitation.

Table 5-5: Simulations scenarios

Scenarios		**Temperature changes in ^{0}C**		**Changes in rainfall in %**	
		Summer	**Winter**	**Summer**	**Winter**
Baseline	**Scenario 0**	0	0	**0**	**0**
Partial Effects	Scenario I	+2	+2	0	0
	Scenario II	0	0	-5	-5
Seasonal Effects	Scenario III	+2	0	0	0
	Scenario IV	0	+2	0	0
	Scenario V	0	0	-5	0
	Scenario VI	0	0	0	-5
	Scenario VII	+2	0	-5	0
	Scenario VIII	0	+2	0	-5
Total Effects	Scenario IX	+2	+2	-5	-5
	Scenario X	+2	+2	-20	-20
	Scenario XI	+3	+3	-5	-5
	Scenario XII	+3	+3	-20	-20

Additionally, in this study we are interested in exploring if moving from rain-fed to irrigated agriculture could be an effective adaptation option to reduce the harmful effects of climate change for the field crops. Thus, the irrigation variable in the model has been used to make simulations. Indeed the irrigation variable in the model describes the intensity of irrigation in district i. To investigate adaptations options, we assume that farmers will responded to climate change by increasing their intensity of irrigation. Two alternatives were considered:

Alternative 1: no adaptation, farmers do nothing; therefore no change is made on the irrigation variable in the model, (baseline scenario).

Alternative 2: Farmers undergo some adaptations to climate change by increasing intensity of irrigation. The modification to the irrigation variable is not uniform across the districts. We assumed that the development of irrigation infrastructures could be restraint by natural, physical and economic factors. Districts with high shares of their land under irrigation were assumed to have approached their maximum potential for irrigation, whereas those with low intensity have more opportunity for expanding area under irrigation. Therefore, when share of land under irrigation is higher than 50%, no change was made on the dataset, for shares between 20% and 50%, intensity was increased by 25%, and for observations with less than 20% intensity increased by 50%.

Using the Ricardian approach, a regression of national farmland values or net revenues that combines both dryland and irrigated farming regions, is likely to understate future capital costs in the farming areas that need additional surface water for irrigation due to the effects of climate change (Schlenker *et al.*, 2003). Indeed dams and irrigation systems are long lasting investment. The value of these facilities depends on a number of climatic factors including precipitation in the catchments areas, evapotranspiration rates and the suitability of the irrigated areas for growing different crops. All these will be affected by climate change and likely will lead to increased water shortage. One the other hand, higher temperatures significantly raise crop evapotranspiration, which is likely to lead to both an increase in the acreage under irrigation and also an increase in the amount of water applied per irrigated acre. On the other hand, hydrological studies suggest that climate change will lead to a reduction in the effective supply of water in some areas. This could be met in various ways by developing new water surface, water storage and conveyance facilities, through water rights reallocation and water marketing, through increased conservation, or through land retirement. Although these adjustments to climate change are likely to entail economic costs, they are not fully reflected in the Ricardian approach adopted for this study[11].

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[11] Most relevant effects of climate change are unpredictable on the basis of present knowledge. The only thing that can be predicted with certainty is that the optimal location of irrigation infrastructures will change and this change will be costly. In general, the full cost of supplying agricultural users is generally not completely capitalized in the current farmland values. The economic cost of climate change in irrigated areas could be substantial. A region-specific analysis accounting for the relevant hydrology and institutional framework of water deliveries will be required to evaluate these costs in more detail (Cline, 1996; Quiggin and Horowitz, 1999 and 2003 and Schlenker *et al.*, 2003).

5.5.2 Climate change impacts results

5.5.2.1 Partial effects analysis

The partial effect analysis evaluates the impact of changing only temperature or precipitation levels one at a time on net revenue while keeping all other variables constant. Every season is expected to experience the same climate change from their current condition. In this section, partial temperature and precipitation effects were analysed with and without adaptation options.

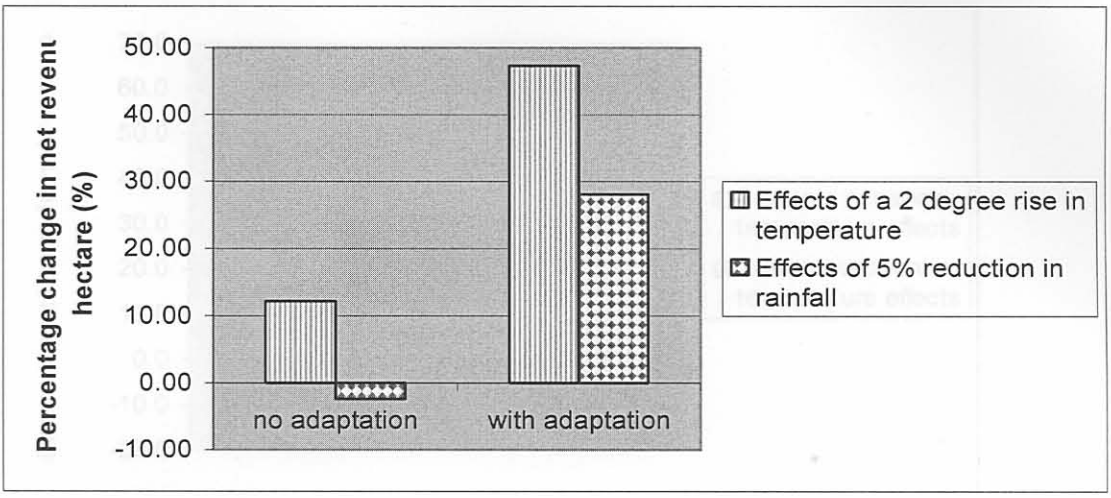
5.4.2.1.1 Partial temperature effects

The partial effect of 2^0C increase in temperature was evaluated in this section (scenario I). The results show that by increasing only temperature in all the seasons, the net revenue of the field crops sector will increase by 12%. The rise in net revenue could even be greater if farmers increased their irrigation intensity. This may be attributed to the fact that most field crops are summer crops and also in South Africa the current levels of summer temperature are above the minimum optimum point of 22^0C (Figure 5-9).

5.4.2.1.2. Partial Precipitation effects

The partial effect of 5% decrease in precipitation is evaluated in this section (scenario II). A decrease of 5% in rainfall could drop the net revenue per hectare by 2%. However, with irrigation as an adaptation option, the situation could be reversed. Thus, net gains could be achieved in net revenue (Figure 5-9).

Figure 5-9: The partial effects of a 2^0C increase in temperature and 5% reduction in precipitation on net revenue



5.4.2.2 Seasonal effects analysis

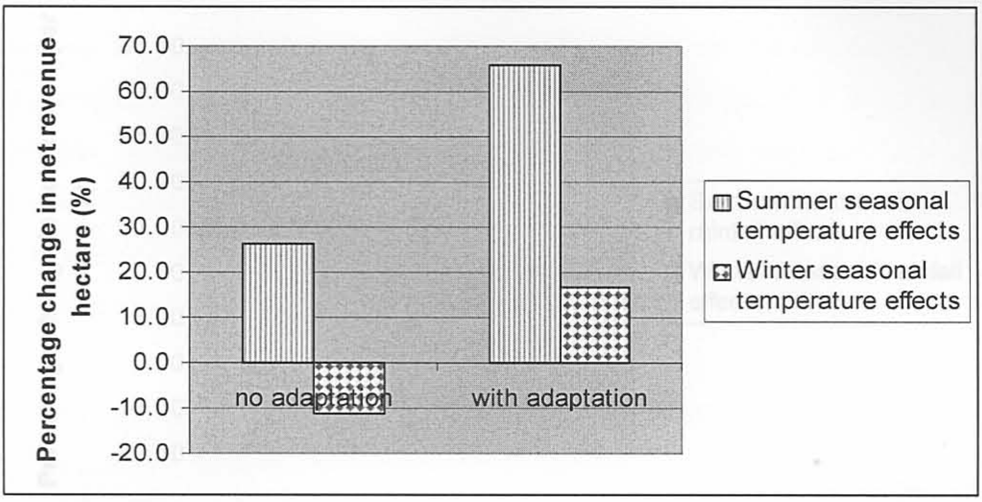
The seasonal effect analysis evaluates the impact of changing only one season temperature or precipitation on net revenue by keeping all others factors constant. In this section, seasonal temperature and precipitation effects are analysed with and without adaptation options.

5.4.2.2.1 Seasonal temperature effects

The seasonal effect of 2^0C increase in temperature for summer and winter respectively, is evaluated in this section (scenario III and scenario IV). Figure 5-10 depicts the results.

With no adaptation, increasing winter temperature by 2^0C will reduce net revenue by about 11%. This is consistent with the fact that current winter temperature is close to the critical point; therefore additional warming will impact negatively on net revenue. On the contrary, further warming in summer is expected to increase net revenue per hectare by 26%. For both seasons, adaptation will have significant positive effects on net revenue.

Figure 5-10: Impact of a 2^0 C increase in winter and summer temperature on net revenue



5.4.2.2.2 Seasonal precipitation effects

This section evaluated the seasonal rainfall effects of 5% decrease in precipitation in both seasons respectively (Scenario V and VI).

Again, the results confirmed that adaptation in form of irrigation is an effective option to reduce the harmful effects of climate change. Furthermore the magnitude of the impacts of climate change differs from one season to another. In fact a 5% decrease in rainfall will reduce the net revenue hectare by 4% and 1% in winter and summer, respectively (Figure 5-11).

5.4.2.2.3 Combined seasonal effects of rainfall and temperature

In this section we simultaneously raise temperature by 2^0C in and reduce rainfall by 5% in each season (scenario VII and scenario VIII). Overall, the change in climate during winter season, characterised by a dryer and hotter winter, will have a negative impacts on net revenue hectare of about 15%. On the other hand, a dryer and hotter summer would be beneficial. The benefits from higher temperature will compensate harmful effects of a decrease in rainfall, inducing a total net benefit of 28%.

Figure 5-11: Impact of 5% decrease in winter and summer precipitation on net revenue

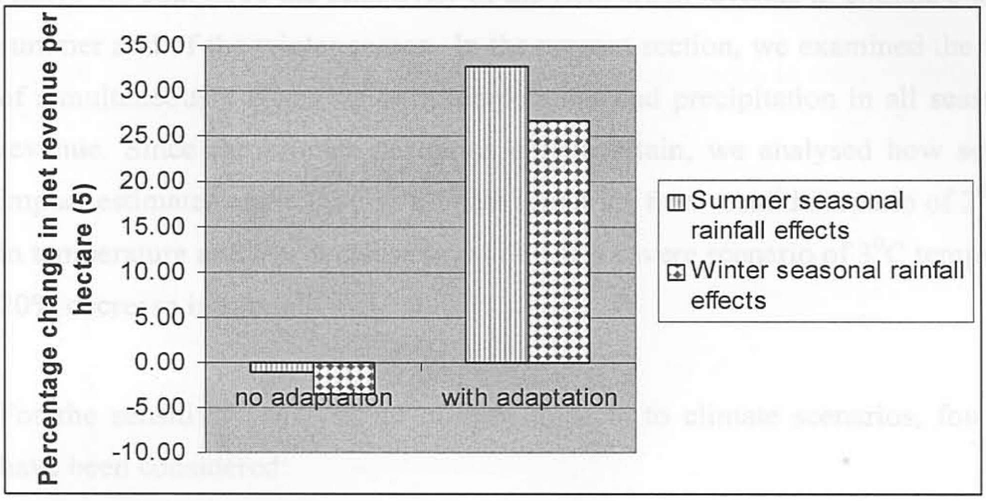
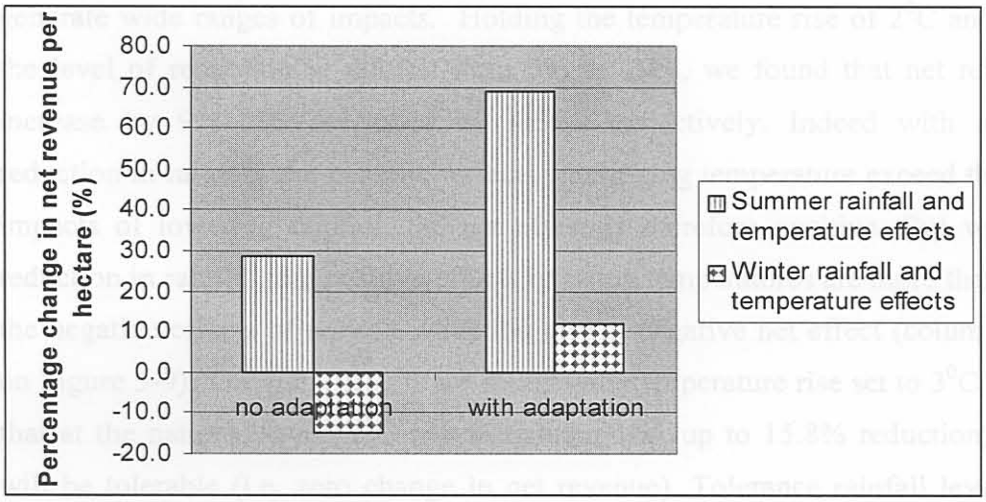


Figure 5-12: Cumulative seasonal impacts of a 2^{0}C increase in temperature and a 5% decrease in rainfall for summer and winter



5.4.2.3 Total effects

Above we compared the sensitivity of the field crops revenue to climate change of the summer and of the winter season. In the present section, we examined the total effect of simultaneously changing both temperature and precipitation in all seasons on net revenue. Since the climate scenarios are uncertain, we analysed how sensitive the impact estimates are to diverse climate scenarios from a mild scenario of 2^0C increase in temperature and 5% decrease in rainfall to a severe scenario of 3^0C temperature and 20% decrease in rainfall.

For the sensitivity analysis of climate impacts to climate scenarios, four scenarios have been considered:

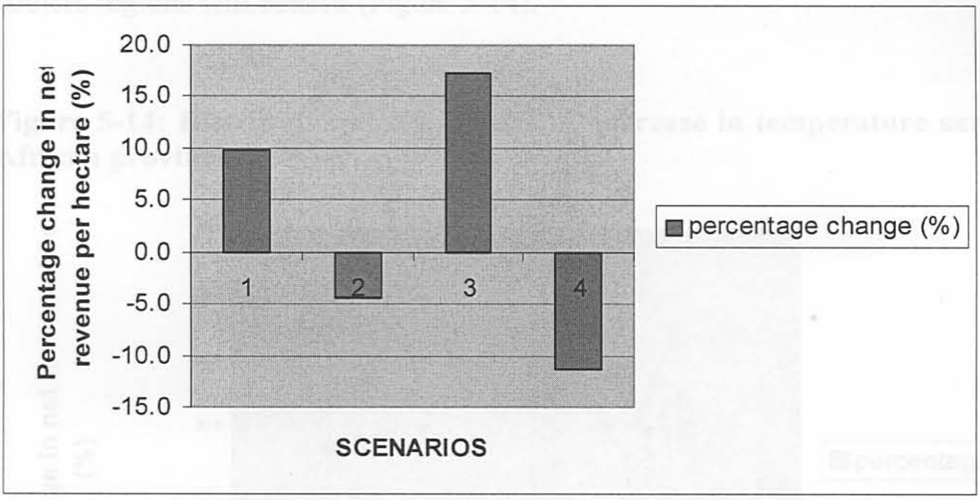
Scenario IX: An increase of 2^0C in temperature and 5% decrease in rainfall
Scenario X: An increase of 2^0C in temperature and 20% decrease in rainfall
Scenario XI: An increase of 3^0C in temperature and 5% decrease in rainfall
Scenario XII: An increase of 3^0C in temperature and 20% decrease in rainfall

The results show that differences among climate scenarios are important and these can generate wide ranges of impacts. Holding the temperature rise of 2^0C and changing the level of reduction in rainfall from 5% to 20%, we found that net revenue will increase by 9% and decreased by 4.5%, respectively. Indeed with a marginal reduction in rainfall, the benefits' effects from rising temperature exceed the negative impacts of lowering rainfall, the net effect is therefore positive. But with further reduction in rainfall, the positive effects of rising temperatures are more than offset by the negative effects of rainfall reduction giving negative net effect (columns 1 and 2 on Figure 5-9). The same results are found with temperature rise set to 3^0C. We found that at the national level, 2^0C rise in temperature; up to 15.8% reduction in rainfall will be tolerable (i.e. zero change in net revenue). Tolerance rainfall levels drop to 13.6% reduction in rainfall at 3^0C.

On the other hand, holding reduction in rainfall by 5% and changing the level of rise in temperature from 2^0C and 3^0C, we found that net revenue increased by 9% and by 12%, respectively. Thus, these results confirmed the fact that higher temperatures are beneficial for the field crops in South Africa. Moreover, the increase in temperature

(+2^{0}C or +3^{0}C) has not put the level of temperature (27^{0}C = 25+3) close to the limit tolerance temperature of the crops, which is 35^{0}C (columns 1 and 3 on Figure 5-13).

Figure 5-13: The sensitivity of climate change impacts on net revenue across different climate change scenarios



Note
1: An increase 2^{0}C in temperature and 5% decrease in rainfall
2: An increase 2^{0}C in temperature and 20% decrease in rainfall
3: An increase 3^{0}C in temperature and 5% decrease in rainfall
4: An increase 3^{0}C in temperature and 20% decrease in rainfall

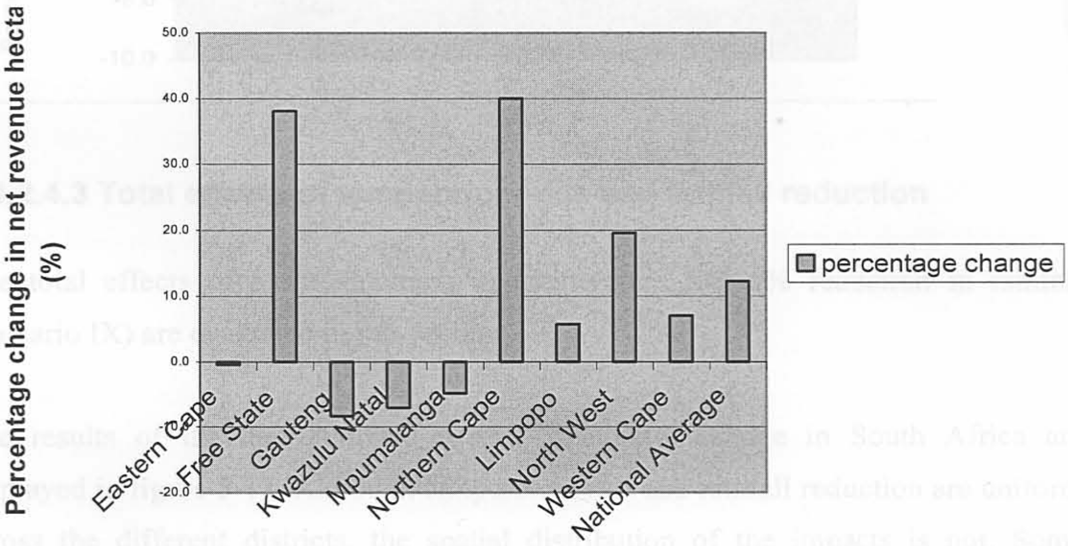
5.4.2.4 Distributional effects

The expected effects of climate change on the agriculture sector will not be uniform across continents, within continents and even within countries (Mendelshon and Williams, 2002). To assess how different provinces will be affected by climate change in South Africa, we applied a mild scenario of an increase of 2^{0}C in temperature and 5% decrease in rainfall. Individual districts changes in the net revenue per hectare were averaged over to yield an average impact at provincial level. In the following analysis, every location and every season is expected to experience the same climate change from their current condition.

5.4.2.4.1 Partial effects of rise in temperature

The partial effects of 2^{0}C increase in temperature (scenario I) across South Africa differ from region to region. The already hot regions of Gauteng, Kwazulu Natal, and Mpumalanga will suffer damages of about 10% reduction in net revenue whereas the coolers regions will benefit (Figure 5-14).

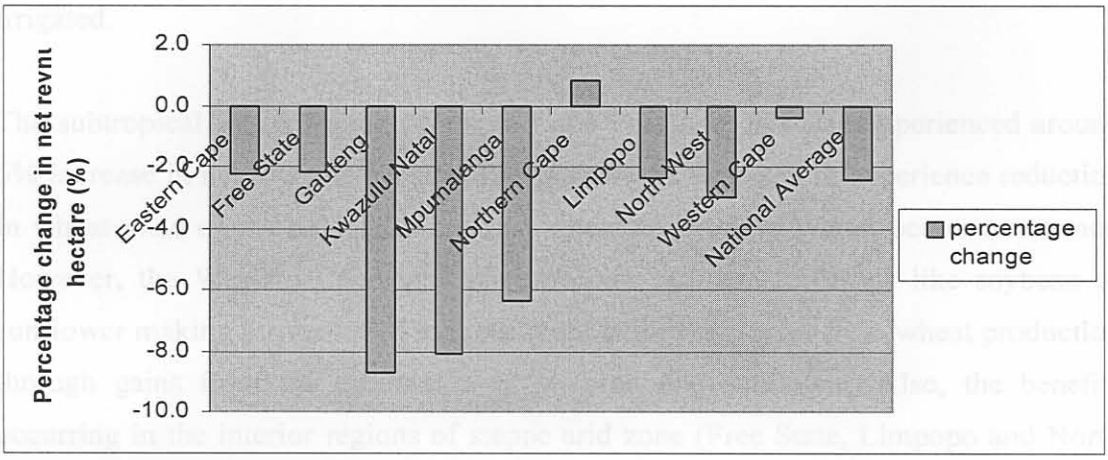
Figure 5-14: Distributional effects of 2^0 C increase in temperature across South African provinces



5.4.2.4.2 Partial effects of reduction in Rainfall

All regions in the country will suffer damages from the partial effect of 5% decrease in precipitation (scenario II) except the Northern Cape province. As outlined earlier, current rainfall patterns in the country are below optimum. The apparent positive effect of reduced rainfall on field crops in the Northern Cape (a desert area) reflect the fact that agriculture production in this province is highly dependent on irrigation. This confirms again the effectiveness of irrigation as an adaptation strategy (Figure 5-15).

Figure 5-15: Distributional effects of 5% reduction in rainfall across South African provinces



5.4.2.4.3 Total effects of temperature rise and rainfall reduction

The total effects of a 2^{0}C increase in temperature and 5% reduction in rainfall (scenario IX) are evaluated in this section.

The results of the distributional effects of climate change in South Africa are displayed in figure 5-17. Although temperature rise and rainfall reduction are uniform across the different districts, the spatial distribution of the impacts is not. Some provinces will experience gains while others will experience severe damages. The winners are the Free State, Northern Cape, North West, Western Cape and Limpopo. The losers are Eastern Cape, Gauteng, Kwazulu Natal and Mpumalanga. With the exception of Limpopo, the winners are from the western part (cooler and dryer regions) of the country and the losers from the eastern part (warmer and wetter zones) of the country (Figure 5-16 and Table 5-6).

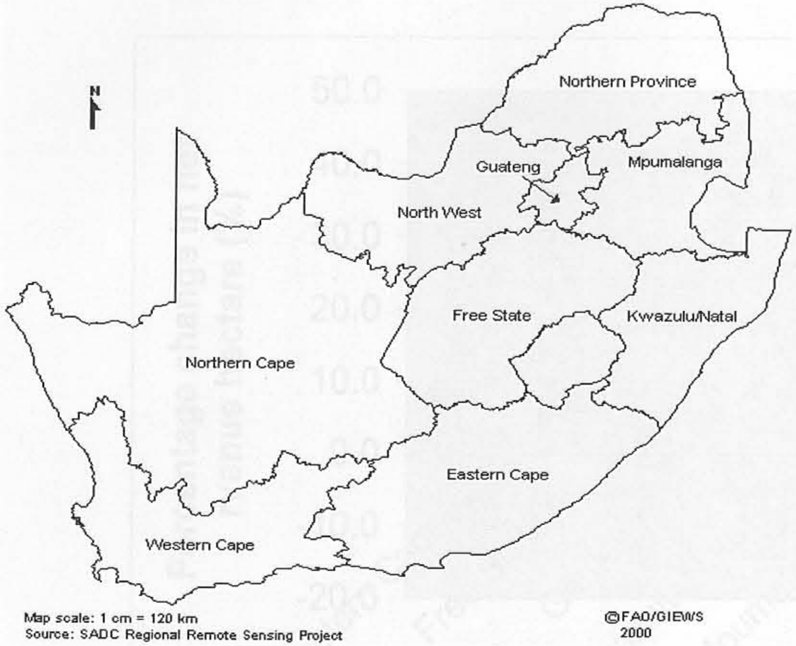
The benefits that occur due to rise in temperature and lower rainfall are somehow controversial. One would have expected that the Northern Cape Province characterized by the desert agro-ecological zone with lower rainfall region to experience damages instead of benefits. However, these results may be due to the fact farmers in a arid situations could be less sensitive because they have already adapted to harsher climatic conditions and have developed other alternatives such as irrigation to manage their unfriendly environment. Therefore they are less sensitive to climate adversities. Indeed, irrigation schemes in the country are been developed in these regions and 50% of the land under annual crops in Northern Cape province is irrigated.

The subtropical winter region (Western Cape Province) has also experienced around 5% increase in net revenue hectare. The region was expected to experience reduction in wheat yield or not be able to produce wheat anymore as winter becomes warmer. However, the Western Cape may have become suitable for crops like soybean or sunflower making farmers shift to those crops offsetting losses from wheat production through gains from the production of soybean and sunflower. Also, the benefits occurring in the interior regions of steppe arid zone (Free State, Limpopo and North West) may be due to the fact that the damages due to lowering of rainfall may be overcome by the benefits from warmer winter. Indeed with warmer winter, these areas may be able to produce summer cereals (maize, sorghum) during the winter season.

The magnitude of the losses in net revenue for a 2^0C increase in temperature and 5% decrease in rainfall, vary from 2% to 16% for Eastern Cape, Gauteng, Mpumalanga and Kwazulu Natal. Indeed, the relatively warmer regions of Kwazulu Natal and Mpumalanga are the most affected by the temperature rise and reduction in rainfall. These regions are the principal production areas of sugar cane in the country. For an optimal growth, sugar cane requires a long warm summer growing season with adequate rainfall. Therefore, it is likely that lower rainfall and further increases in temperature in regions already hot, can cause heat injury and water deficit for sugar cane production. As a result, Kwazulu natal and Mpumalanga sugar cane productivity may be significantly lowered to the extent that farmers may be forced to switch to other crops of lower value like sorghum that are heat tolerant.

Overall, the results of the simulation imply that field crops sector would experience different changes in cropping patterns. Cropping zones of major crops may shift from one region to another. At lesser extend, farmers in a given region may be obliged to shift their cropping calendar. For example, the sugar cane region may disappear. Western Cape may become suitable for crops like soybean or sunflower. The sowing period of most crops (maize, soybean, sunflower) could shift from October (summer season) to early March or April (winter season).

Figure 5-16: South Africa provinces delimitation



Source: FAO/GIEWS (2001)

Table 5-6: Current level of provincial rainfall and temperature

Agro-ecological zones	Provinces*	Rainfall Pattern (mm)		Average Temperature (^{0}C)	
		Summer	Winter	Summer	Winter
Desert	**Northern Cape**	200	100	23	14
Steppe (arid)	**Free State**	400	150	20	12
	North West	500	100	22	14
	Limpopo**	600	150	25	18
	Gauteng	600	150	20	13
	Eastern Cape	400	200	19	13
	Mpumalanga	600	150	21	15
Sub-tropical wet	Kwazulu Natal	800	200	23	16
Sub-tropical winter	**Western Cape**	150	400	19	14

* Provinces in bold are winners/ ** Previously Northern Province

Source : South African Weather Bureau

Figure 5-17: Distributional effects of 2^0 C increase in temperature and 5% reduction in rainfall across South African provinces