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CLIMATE CHANGE AND SOUTH AFRICAN AGRICULTURE: IMPACTS AND ADAPTATION OPTIONS

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DEDICATION

This paper is dedicated to the memory of

Prof. Helmy Eid

a member of the project team for Egypt who passed away during the course of the study.

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The views in this paper and any errors are, however, entirely the author’s.

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PREFACE

The reports in this special series are the result of a multi-country research activities conducted under the GEF funded project: *Climate Change Impacts on and Adaptation of Agro-ecological Systems in Africa*. The main goal of the project was to develop multipliable analytical methods and procedures to assess quantitatively how climate affects current agricultural systems in Africa, predict how these systems may be affected in the future by climate change under various global warming scenarios, and suggest what role adaptation could play. The project has been implemented in 11 countries: Burkina Faso, Cameroon, Ghana, Niger and Senegal in west Africa; Egypt in north Africa; Ethiopia and Kenya in east Africa and South Africa, Zambia, and Zimbabwe in southern Africa. The study countries covered all key agro-climatic zones and farming systems in Africa. This is the first analysis of climate impacts and adaptation in the Africa continent of such scale and the first in the world to combine cross-country, spatially referenced survey and climatic data for conducting this type of analysis.

The analyses reported in this series focus mainly on quantitative assessment of the economic impacts of climate change on agriculture and the farming communities in Africa, based on both the cross-sectional (Ricardian) method and crop response simulation modeling. The cross sectional analysis also allowed for assessing the possible role of adaptation. Moreover, the project employed river-basin hydrology modeling to generate additional climate attributes for the impact assessment and climate scenario analyses such as surface runoff and streamflow for all districts in the study countries.

The Centre for Environmental Economics and policy in Africa (CEEPA) of the University of Pretoria coordinated all project activities in close collaboration with many agencies in the involved countries, the Agriculture and Rural Development (ARD) Department of the World Bank, the World Bank Institute (WBI), the Food and Agriculture Organization (FAO), Yale University, the University of Colorado, and the International Water Management Institute (IWMI). The project received supplemental funding from TFESSD, Finnish TF, NOAA-OPG, and CEEPA. We are grateful for the invaluable contributions of all these institutions and all individuals involved in this project. All opinions presented in this report series and any errors in it are those of the authors and do not represent the opinion of any of the above listed agencies.

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EXECUTIVE SUMMARY

This paper is part of a study of eleven African countries, *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa*, funded by the Global Environment Facility (GEF) and the World Bank's Trust Fund for Environmentally and Socially Sustainable Development (TFESSD) and coordinated by CEEPA, University of Pretoria.

Statistical evidence suggests that South Africa has been getting hotter over the past four decades, with average yearly temperatures increasing by 0.13°C a decade between 1960 and 2003, with relatively higher levels for the fall, winter and summer periods. There has also been an increase in the number of warmer days and a decrease in the number of cooler days. Moreover, the average rainfall in the country is very low, estimated at 450mm per year – well below the world's average of 860mm per year – while evaporation is comparatively high. In addition, surface and underground water are very limited, with more than 50% of the available water resources being used for only 10% of the country's agricultural activities.

Climate change, which may make temperatures climb and reduce the rains and change their timing, may therefore put more pressure on the country's scarce water resources, with implications for agriculture, employment and food security. Not only South Africa but also the sub-region will be affected, given that more than half of the region's staple, maize, is produced in South Africa.

This study attempts to assess the economic impact of the expected adverse changes in the climate on crop farming in the country. It estimates a revised Ricardian model for South Africa, using farm household crop farming data from selected districts in the nine provinces, long-term climate data, major soil types in the country, runoff in the districts, and adaptation related variables such as irrigation, livestock ownership, access to output markets and access to public and other extension services.

The analysis shows that climate change affects irrigated farms and dryland farms differently. Irrigated farms are cushioned against climate effects because they have alternatives to rain water. There are also some differences between the ways large- and small-scale farms are affected, but such differences are blurred by the influence of irrigation or dryland farming.

The results also show that climate variables, especially for precipitation, have a non-linear relationship with crop net revenues in South Africa. Certain soil types, such as vertisols and xerosols, may be harmful to crop farming and therefore aggravate the harmful effects of climate change, while other types, such as acrisols and arenosols, may help reduce them. Runoff will also benefit crop farming, but when it is excessive it can be harmful.

In general, adaptations such as irrigation may help reduce the harmful effects of climate change, but if not properly implemented they may aggravate them. Of relevance here is public extension service, which was found to rather negatively affect crop net revenues, suggesting that the information provided by this service may not be very relevant to farmers, even though it can be an important tool for controlling the harmful effects of climate change if properly managed.

One significant finding is that there are seasonal differences in the climate effects, and these differences must not be overshadowed by looking only at the mean annual effects. Increased temperatures will be harmful in the summer farming season but beneficial in the winter one.

The overall annual effects will therefore depend on the relative magnitudes of the positive and negative effects. This means that advantage should be taken of the positive effects, while controlling or reducing the negative effects. If this can be done, temperature changes should be beneficial rather than harmful to the country. Some of the adaptation strategies identified in the study could help achieve this. Changes in precipitation will also have different seasonal effects. Again there is the need to fine-tune policy to take advantage of the relative benefits.

The analysis also shows that the effects of changes in both temperature and precipitation may be different for the different farming systems in the country – irrigated, dryland, large-scale and small-scale farms. The effects would also be different at the provincial levels. This finding is important for knowing how and where to direct the relevant policies for controlling the effects of climate change.

Using selected climate scenarios, the study also predicts that crop net revenues are expected to fall by as much as 90% by 2100 and that small-scale farmers will be the most severely affected. However, if proper adaptations are made these losses are expected to be reduced.

Analysis of farmers' perceptions of a change in the climate shows that most farmers across the country are aware of it. They cite increased temperature and reduced volume and altered timing of rain as signs of the change, and they are using various strategies to cope with it. Policy makers must be aware of these strategies, assess their effectiveness and find ways of improving them so as to limit their harmful effects and enhance the benefits that may be had from climate change.

In general, climate change is expected to be harmful to crop farming in South Africa. However, there are expected to be gains and losses specific to each farming system and each province. If policy makers and farmers are able to identify where the gains and losses are, and direct the appropriate policies and adaptation strategies to these areas, the expected overall negative effect may be reduced, and it is even possible that the agriculture sector in South Africa may reap benefits from climate change.

1. Background and introduction

In the agriculture of the Republic of South Africa, the types of crops, cropping calendars and production levels are very diverse, owing to the influence of the different agro-climatic zones, from the dry northwestern region to the wet eastern region. The major crops are maize, wheat, sugar cane, sorghum and the minor ones are groundnuts, sunflowers, dry beans, tobacco and potatoes. Fruit of importance include apples, grapes, pears, peaches and dried fruits. In addition, the numbers of livestock on the country's commercial farms were estimated at 13.5 million head of cattle, 29 million sheep and 6.6 million goats in 2003 (NDA 2000; 2004). Agricultural land consists of 100.7 million hectares (81%) of the country's total land area of 122.3 million hectares. Other land uses include nature conservation, 11.8 million hectares (9.6%); forestry, 4.4 million hectares (1.2%); and 8.4 million hectares (6.9%) for other activities. Of the total agricultural land, 84 million hectares (68.6%) is under permanent pasture, while the rest, 16.7 million hectares, is potentially arable (NDA 2005). Of the total arable land, 22% has high productive potential. About 12.7 million hectares (10%) of the total land area is under cultivation, with slightly more than 1.2 million hectares (10%) under irrigation (NDA, undated).

In general, agriculture in South Africa is regarded as a highly sophisticated and successful sector. The dominant form of agricultural production in the country is the medium- to large-scale farm. These farms, which are commercially oriented, capital intensive, and generally produce a surplus, account for 90% of the value added and cover 86% of the agricultural land. On the other hand the small-scale farms, worked by a high proportion of the farming population (86%), are mainly subsistence in nature and rely mainly on traditional methods of production (NDA, 2002).[2]

The most important factor limiting agricultural production in South Africa is the availability of water. Rainfall is distributed unevenly across the country, with humid, subtropical conditions in the east and dry, desert conditions in the west. The country's average annual rainfall is 450mm per year, well below the world's average of 860mm, while evaporation is comparatively high (DWAF 2004). Only 10% of the country receives an annual precipitation of more than 750mm and more than 50% of South Africa's water resource is used for agricultural purposes. Both commercial farming and especially subsistence farming may be affected by less availability of water owing to adverse climate change. This is expected to vary across the different agro-climatic zones, provinces and different agricultural systems in the country.

The vulnerability of agriculture to climate change has become an important issue because of reduced crop productivity from adverse changes, especially in Africa. Although there have been some studies of climate change impacts on Africa (both agronomic and economic), it is still not very clear how Africa will be affected and what adaptation options are available to the continent. This paper presents the results of an economic impact assessment of climate

[2] Current land reform in the country – restitution, tenure reforms and redistribution of land – is likely to change the distribution of farm activities. Restitution deals with changing the historical rights to land and tenure reforms deal with the forms of land holding. Most important is the redistribution of more white-owned lands to historically disadvantaged groups, to transform the racial pattern of land ownership (Jacobs et al. 2003).

change on agriculture in South Africa. One area of focus is climate effects on water resources and the subsequent impact on agriculture. It also presents observations of adaptation mechanisms available to various groups of the farming population in the country.

Statistical evidence, though limited, suggests that South Africa has been getting hotter over the past four decades. Kruger and Shongwe (2004) analyzed climate data from 26 weather stations across the country. Of these, 23 showed that the average annual maximum temperature had increased, in 13 of them significantly. Average annual minimum temperatures also showed an increase, of which 18 were significant. In general, their analysis indicates that the country's average yearly temperatures increased by 0.13°C per decade between 1960 and 2003, with varying increases across the seasons: fall 0.21°C, winter 0.13°C, spring 0.08°C and summer 0.12°C. There was also an increase in the number of warmer days and a decrease in the number of cooler days.

These changes in temperature, together with the already scarce water resources in the country are expected to have a significant effect on all sectors of the economy, in particular agriculture. For example, anecdotal evidence suggests that climate change could lead to a fall of about 1.5% in the country's gross domestic product (GDP) by 2050 – a fall roughly equivalent to the total annual foreign direct investment in South Africa at present. Moreover, climate change and the resulting loss of biodiversity could do irreparable damage to the country's tourism industry, which is worth an estimated R100 billion per annum (about US$15 billion).

But agriculture is expected to be most affected by these changes because it is highly dependent on climate variables such as temperature and precipitation, and also because of (i) the semi-arid nature of the country with increased farming on marginal lands, (ii) the frequency of droughts, and (iii) the scarcity of water, which is exacerbated by a high spatial variability of rainfall. Domestic agriculture is of course the main source of food for the country's population of 46.9 million (StatsSA 2005), and it also contributes about 2.9% to the GDP – and even more if backward linkages, manifested in the direct purchases of inputs such as fertilizers and fuels, and forward linkages, in the form of agro-based industries dependent on the sector for raw materials, are taken into consideration. It is also a major source of foreign exchange. Adverse effects of climate change on agriculture would have severe implications not only for South Africa but also for the southern African region because South Africa is the region's major source of food. For example, 50% of the maize (the main staple) in the SADC (Southern African Development Community) region is produced in South Africa. Adverse effects in South Africa could therefore destabilize the whole region.

In spite of these concerns, not many studies have been done, either in South Africa or in most African countries, on the economic losses and social welfare impacts that would result from climate damage to agriculture. The existing studies in South Africa cover either a few crops or small parts of the country and mostly examine how individual crops behave in control experiments, addressing largely grain crops and of those mainly maize (Schulze et al. 1993; Du Toit et al. 2002; Kiker 2002; Kiker et al. 2002). The study by Du Toit et al. shows that in the dry western areas crop production will become more marginal, while in the high potential eastern areas there may be a slight increase. Poonyth et al. (2002) use a Ricardian model to explore the agricultural sector's performance with respect to climate change and conclude that rising temperatures will be detrimental to agriculture, and the effects will be even worse if farmers do not adapt appropriately. The focus of this study is commercial farming. However, the riskier sector is subsistence farming, as these farmers have very little ability to adapt. This study does not focus on the extent of adaptation – an analysis that incorporated subsistence farming might predict worse effects of climate change on agriculture in South Africa than these authors do. On the other hand, the overall impact may not be as bad as envisaged if the role of adaptation interventions is also considered. (See also Deressa et al. 2005 and Gbetibouo & Hassan 2005.)

Moreover, one of the most significant impacts of climate change is likely to be on the hydrological system, and hence on river flows and water resources in the country. This is especially important given the semi-arid nature of the country, where water resources are very sensitive to climate variability and change. The studies by Poonyth et al., Deressa et al. and Gbetibouo and Hassan suffer from the same limitation as earlier Ricardian studies of agriculture, in that they do not include water supplies in the analysis (see Mendelsohn & Dinar 2003 and Darwin 1999).

Using cross-sectional data for the 2002/2003 farming season, this study extends those done by Poonyth et al., Deressa et al. and Gbetibouo and Hassan, by using a revised Ricardian model that incorporates relevant hydrological variables in the analysis to assess the economic impact of climate change on agriculture in South Africa. It also investigates possible adaptation options for farmers in the country.

1.1 Study objectives

The study addresses the following specific objectives:

(i) To develop and estimate a Ricardian model to assess the potential impacts of climate change on South African agricultural economy.

(ii) To use the estimated model to predict the range of impacts on the agricultural sector under various climate change scenarios.

(iii) To evaluate alternative courses of action in terms of policies and strategies to help mitigate the likely climate change damage to agriculture in South Africa.

(iv) To assess the possible adaptation options for farmers in South Africa.

The above objectives are expected to achieve the following benefits:

(i) Improve South African scientists' capacity to use new analytical tools to measure and evaluate the expected impacts of climate change on agro-ecological systems in South Africa.

(ii) Generate results relevant for designing policies for sustainable development of the South African agricultural sector in the changing climate.

(iii) Identify sustainable and cost-effective adaptation measures and resources and provide guidance for their use.

1.2 Outline of the paper

The rest of the paper is organized as follows. Section 2 discusses the climate, vegetation and soil patterns across the country and the extent to which these influence the distribution of farming activities. This background provides a better understanding of the subsequent analysis of how the impacts of climate change on the agricultural sector are spatially distributed. Section 3 presents the structure of the country's agricultural sector and assesses the relationship between the trends in the sector and climate variables – temperature and precipitation. The Ricardian analytical framework for assessing the economic impact of climate change on South African agriculture is discussed in Section 4 and the data collection approach and empirical model are presented in Section 5. Section 6 discusses the estimated model of climate impacts. The results of the analyses of farmers' strategies for adapting to climate change are discussed in Section 7, and Section 8 concludes, and suggests policy implications.

2. Climate, vegetation and soil patterns in South Africa

The vulnerability of a country to climate change depends on the extent to which current temperatures or precipitation patterns are close to or exceed tolerance limits for important crops, per capita income, the percentage of economic activity based on agricultural production, and the existing condition of the agricultural land base (Watson et al, 1997). For example, it has been documented that, given the already high temperatures in Africa, including South Africa, climate change may displace many crops currently being cultivated, especially in rainfed farming areas. A better understanding of how these changes might occur will help in formulating appropriate policies to mitigate the impacts. This section describes the spatial climate, vegetation and soil conditions of the country which influence the different agricultural activities in the country discussed in Section 3.

South Africa is located at latitude 22°–34° south and longitude 16°–32° east. The country is bordered by the Atlantic Ocean on the west and the Indian Ocean on the south and east, with a coastline stretching over 2500km. On its northern border are Namibia, Botswana, and Zimbabwe, and to the north-east are Mozambique and Swaziland. Embedded in South Africa, and located on its eastern central part, is the independent kingdom of Lesotho (Palmer & Ainslie 2002). The country is divided into nine administrative provinces: the Eastern Cape, the Free State, Gauteng, KwaZulu-Natal, Limpopo (formerly the Northern Province), Mpumalanga, the Northern Cape, the North West, and the Western Cape (see Figure 1).

South Africa is geographically composed of three primary regions: a large central plateau with heights of 1220m to 1830m above sea level, comprised mainly of grassland (referred to as highveld); a nearly continuous escarpment of mountain ranges that encompasses the plateau on the west, south and east, with heights exceeding 3050m and its highest point in the Drakensberg mountains; and a narrow strip of low-lying land along the coast.[3]

[3] See http://www.geographia.com/south-africa for more details.

The country is predominantly semi-arid, with the climate varying from desert and semi-desert in the dry northwestern region to sub-humid and wet along the eastern coastal area. The diverse agro-climatic zones allow for huge diversity of agricultural production. There are four main climatic zones: the desert, the arid (steppe), the subtropical wet and the Mediterranean winter rainfall region (see Figure 2) (JWAF 1999). The desert borders most of the Northern Cape Province and the northeastern parts of the Western Cape Province. The arid zone comprises the whole of the Limpopo, Mpumalanga and the North West and Free State Provinces, the western parts of KwaZulu-Natal and the Eastern Cape, and the northern parts of the Western Cape. The sub-tropical wet zone comprises mainly the coastal strip of KwaZulu-Natal and the Eastern Cape, and the Mediterranean (winter rainfall) region comprises the southwestern coastal strip of the Western Cape (see Table 1).[4]

2.1 Temperature, rainfall and water availability

The country's climate is generally warm, with sunny days and cool nights. Rainfall mostly occurs in the summer (November to March), with winter rainfall (June to August) in the south-west around the Cape of Good Hope. Temperatures are more influenced by variations in elevation, terrain and ocean currents than latitudes. For example, the average annual temperature in Cape Town is 17°C and in Pretoria 17.5°C, although these cities are separated by almost ten degrees of latitude (see Figure 3) (US Library of Congress 2006; Palmer and Ainslie 2002).

The climatic conditions vary in response to the movement of the high-pressure belt that circles the globe between 25° and 30° south latitude during the winter and low-pressure systems that occur during the summer. There is very little difference in average temperatures from the south to north, but they 'vary noticeably between east and west, largely in response to the warm Agulhas ocean current, which sweeps southward along the Indian Ocean coastline in the east for several months of the year, and the cold Benguela current, which sweeps northward along the Atlantic Ocean coastline in the west. Air temperatures in Durban, on the Indian Ocean, average nearly 6°C warmer than temperatures in the same latitude on the Atlantic Ocean Coast. The effects of these two currents can be seen even at the narrow peninsula of the Cape of Good Hope, where water temperatures average 4°C higher on the east side than on the west' (US Library of Congress 2006).

Summer temperatures on average vary across the country between 20°C and 38°C, with high levels occurring in the far north. The highest maximum summer temperature (48°C) has been recorded in the Northern Cape and Mpumalanga Provinces. Winter temperatures range between 6°C and 20°C, with a record minimum (-6.1°C) occurring in north-west Cape Town. Record snowfalls (almost 50cm in June 1994) have also been experienced in the mountainous areas bordering the Kingdom of Lesotho. As noted above, temperatures are strongly determined by elevation and distance from the sea (see Figure 3). The high inland regions (1500–1700m) experience warm summers (26–28°C) and cool winters (0–2°C), frost during

[4] Schulze (1997) also classifies the country into six climatic zones (with percentage of land area): desert (22.8%); arid (24.6%); semi-arid (24.6%); sub-humid (18.5%); humid (6.7%); super-humid (2.8%). This classification is, however, not significantly different from the classification in Figure 2.

the coolest months and occasional snowfalls (NDA, 2001a; Schulze, 1997). The northern parts of the coastal zone experience warm winters (8–10°C) and warm summers (32°C). The vast interior (mostly the Kalahari basin and the Nama-Karoo) experiences more extremes of climate, with very cool winters (0–2°C) and very warm summers (32–34°C). The low-lying eastern coastal belt, with Durban in the KwaZulu-Natal Province as the centre, is hot and humid during summer. The southern and southwestern coastal zone experiences moderate winters (6–8°C). The mean daily minimum temperature on the west coast in July is 6–8°C, but there is little or no frost (see also Figure 5) (US Library of Congress, 2006; Palmer & Ainslie, 2002; NDA, 2001a).

The average rainfall for the country is about 450mm per year, which is well below the world average of about 860mm per year. Potential evaporation is also comparatively high, estimated at 1500mm/year, resulting in only 8.5% runoff, with a combined runoff of 42mm/year, compared with the average runoff for Africa (139mm/year) and the world (330/year). Not only is the runoff in the country very low, but it is also variable from year to year and from region to region (DWAF 2002; McKenzie & Van Rooyen 2003).

There is a wide regional variation in annual rainfall (see Figure 4 and Table 1). The rainfall decreases from east to west, from over 1000mm in the east to less than 100mm in the Namib and Namaqualand desert regions. A 500mm rainfall line divides the country into two main sections, with the land east of the rainfall line generally suitable for growing crops and the land west of the rainfall line mainly for livestock grazing or crop cultivation on irrigated land (NDA, 2001b; US Library of Congress, 2006). Three main rainfall regions can, however, be identified in the country:

(i) The winter rainfall region in the southwestern Cape with less than 500mm per year;

(ii) The area with rainfall throughout the year along the southern coastal region, with more than 700mm per year; and

(iii) The summer rainfall area in the rest of the country (approximately 86%) with rainfall between 500mm and 700mm per year.

The driest province is the Northern Cape and the wettest is KwaZulu-Natal. The Western Cape, the second driest province, receives mainly winter rainfall. The rest of the country receives summer rains in the form of thunderstorms. Only 10% of the country receives an annual precipitation of more than 750mm. This includes the northern parts of the Eastern Cape Province, the coastal belt and midlands of KwaZulu-Natal and the Mpumalanga lowveld (see Figure 4). Only about one-third of the summer rainfall area receives an annual precipitation of 600mm or more. This is close to the lowest limit for successful dryland crop production (NDA, 2001b). Figure 5 provides a summary of South Africa's meteorological profile.

Given the average amount of rainfall in the country, South Africa's water resources are, in global terms, scarce and extremely limited. Given also the rainfall distribution, the availability of natural water resources across the country is very unevenly distributed, with more than 60% of the surface flows arising from only 20% of the land area (Basson et al. 1997). There are also no really large or navigable rivers in South Africa and the total flow of all rivers in the country combined amounts to approximately 49,200 million m^3 per year, which is less than half of that of the Zambezi River, the closest river to South Africa. The four main rivers in the country: Limpopo, Inkomati, Pongola and Orange (shared with surrounding countries), together drain about 60% of the land area and contribute over 30% of the country's total surface runoff. South Africa is also poorly endowed with groundwater resources, as most of it has underlying hard rock formations which, although rich in minerals, do not contain any major groundwater aquifers, which could be used on a national scale (Basson et al. 1997).

In general, South Africa is a water scarce country and has also developed most of its water resources. It is expected to be among the worst water scarce countries by 2025. In the northern parts of the country, both surface and groundwater resources are nearly fully developed and used. The reverse applies to the well-watered southeastern region of the country where there are still significant underdeveloped and little used resources (Sally & Kamire 2002).

Water is indeed the factor that most limits agricultural development in the country, with more than 50% of South Africa's water already used for agricultural purposes. There is evidence that climate change could cause increased variability of climate over the eastern parts of South Africa (mainly sub-tropical wet zone), and a further decrease in rainfall from the west (desert and arid zones) and over the Western Cape region (winter rain zone) (DWAF 2002). Warmer climate conditions will necessitate allocating a higher proportion of the water resources to agriculture, and this allocation will need to be efficient for to all uses, including agriculture.

Given the temperatures and rainfall patterns, two main farming seasons are identified in the country: (i) the summer season from October/November to March/April and (ii) the winter season from April/May to August/September. The various farming activities are influenced not only by climate conditions but also by the different vegetation and soils. These are discussed in the next two sections.

2.2 Vegetation

The overall vegetation in South Africa consists largely of grassveld, ranging from desert grasses in the west to the grass plains of the plateau regions and the subtropical savanna area of the lowveld of Mpumalanga (NDA 2001a). Rutherford and Westfall (1986) define six biomes in the country. These are based on bio-climatic and growth form information. Low and Rebelo (1996) further subdivide the savanna biome to include a 'thicket' category which occurs predominantly in the river valleys of the eastern and southeastern coastal region (Figure 6) (Palmer & Ainslie, 2002).

The succulent Karoo biome is found in the winter rainfall regions of the southern and southwestern regions of the country. Its flora consists of shrubs (0.5–1.5m) and dwarf shrubs (<0.5 m) with succulent leaves and stems. The main farming activity is the production of mutton sheep, goats and ostriches. The Nama-Karoo is the largest of the biomes in South Africa, mostly found in central and western regions of the country. This biome is dominated by steppe type vegetation, comprising a mixture of shrubs, dwarf shrubs and annual and perennial grasses, and is ideal for sheep and goats. The savanna biome incorporates the northern and eastern portions of the country, with a flora comprising a woody layer (mainly single-stemmed, seasonally deciduous, trees and shrubs) and a ground layer of grasses and forbs. The standing biomass of shrubs and trees can exceed 16 tons per hectare. This biome is particularly important for both commercial and communal graziers, especially for those who use it for intensive browsing by goats. The grassland biome is found in the central, high-lying regions stretching about 350,000 km^2, with an annual rainfall of 400–1200mm, frost-free to snow-bound in the winter, and ranging in altitude from sea level to more than 3300m (Palmer & Ainslie 2002).

The extent to which these different biomes will shrink or expand as a result of climate change will affect the various farming activities to which these areas are conducive. Knowledge of these expected changes will help farmers to adapt better.

2.3 Soils

A hierarchical system has been used to classify soils in South Africa. This system incorporates a large number of soil bodies ranging from black soils, smectitic clay on dolerite, to yellow, kaolinitic clay. The system has two main levels, soil form and soil family; 73 Soil Forms are currently defined by the nature of the topsoil (organic, humic, vertic, melanic or othic), and numerous diagnostic sub-soil horizons (Palmer & Ainslie 2002).

The Nama-Karoo biome is predominantly mudstones and sandstones of the Karoo supergroup, which rise to shallow (<30cm) aridosols, with a calcareous hardpan layer, typically in the profile. The features of the soil include grass and associated phreatic woody shrubs, which represent refugia for many desirable plant species. The dolerite sills and dykes provide summer grazing, whereas the nutrient rich calcareous plains provide abundant, high quality winter forage. The grasslands biome consists of high nutrient status of basalt, and also of dolerite and andesitic origins. The savannas of the Mpumalanga lowveld are associated with the gabbros and granites of the Bushveld igneous complex. The granites are sandy soils of moderate nutrient status whereas the gabbros consist of nutrient rich Mispah rock complex. The Cape Fold Mountains are siliceous rocks, which give rise to immature, litholic soils (Palmer & Ainslie 2002).

These different climatic characteristics in combination with the vegetation and soils in the various agro-ecological zones and provinces play a major role in the spatial differences in the agricultural activities in the country which are further discussed in the next section.

3. Agriculture and climate in South Africa: Structure and trends

This section discusses the way agriculture activities across the landscape are influenced by the different climates and vegetation and soil patterns, and assesses the extent to which trends in these activities are related to trends in temperature and precipitation. It concludes with a discussion of the agricultural sector's importance to the South African economy, showing the extent to which not only agriculture but also the whole economy is vulnerable to adverse climate change.

3.1 Agricultural activities across the landscape

Of the total land area of 122 million hectares, 82% is farmland while the rest is used for nature conservation, forestry and other uses such as residential purposes (Figure A1). The majority of the farmland is located in the Northern Cape (30%), the Eastern Cape (15%) and the Free State (12%), with the least found in Gauteng (1%) (Figure A2). A larger proportion of total farmland is devoted to grazing activities (83%) while only 17% is potentially arable (Figure A3). The Northern Cape has the highest proportion of farmland, but most of it is used for grazing (Figure A4). Of the total potential arable land, 25% is located in the Free State, the North West (20%), the Western Cape (15%), Limpopo and Mpumalanga (10% each), the Eastern Cape and KwaZulu-Natal (7% each), and the least in Gauteng and the Northern Cape (3% each) (Figure A5). The distribution of farmland across the provinces is influenced by the climatic conditions, as discussed earlier, which also determine the importance of the provinces for crop and livestock farming activities and the extent to which these provinces may be affected by climate change.

As expected, the largest proportion of farmland is under livestock (76%), followed by field crops (12%), horticulture (5%), mixed farming and forestry activities (Figure A6). The distribution of farm activities in the nine provinces for 1993 indicates that all the provinces except Gauteng are important for farming, with varying degrees of importance in the four main farm activities. Large proportions of field crop farming are located in the arid zone of the Free State (32%), the North West (17%) and Mpumalanga (14%), and also in the winter rainfall zone in the Western Cape (14% each) with the least in Gauteng (see Figure A7). The implication is that if the arid zone becomes even warmer then the majority of field crop production in the country will be displaced. The winter rainfall zone of the Western Cape Province (45%) is also the most important area for horticulture, followed by the desert zone of the Northern Cape Province (16%). In the arid zone the most important provinces for this activity are Limpopo (14%) and the Eastern Cape and Mpumalanga (6% each), with the least important being Gauteng (Figure A8). For livestock the important provinces are the Northern Cape (44%) (desert zone), the Eastern Cape (14%) and the Free State (12%) (both in the arid zone), the Western Cape (10%) (winter rainfall zone), and the least important is Gauteng (Figure A9). Mixed farming is also more prominent in the Northern Cape (24%), the Western Cape and the Free State (15% each) and least prominent in Gauteng (Figure A10). This implies that field crop farming is most suitable in the arid zone, horticulture in the winter rainfall zone and livestock farming in the desert zone. The Free State, Limpopo, Mpumalanga, the North West, the Eastern Cape, the Western Cape and the Northern Cape are important provinces for farming activities in the three agro-ecological zones. The sub-tropical wet zone (mainly the KwaZulu-Natal Province) is particularly important for sugar cane.

Of the total cultivated land area estimated at 12.7 million ha (about 76% of total potentially arable land), 11.2 million ha is dryland farming, and 1.2 million ha irrigated (producing about 25–30% of the country's agricultural products) of which 4% is small-scale irrigation (NDA, undated). Given that already more than 50% of water resources is used in agricultural activities and only about 10% of farms are under irrigation, this means that if climate change obliges farmers to irrigate more, especially in the western parts of the country (arid and desert zones), further pressures will be put on the country's already scarce water resources.

South Africa has a dual agricultural economy: a well-developed commercial (mainly large-scale) sector and a predominantly subsistence oriented (mainly small-scale) sector in the traditionally settled rural areas. The commercial farming sector is mainly freehold land ownership, capital intensive and largely export oriented, occupying about 86% of farmland with approximately 55,000 farms, owned by about 45,000 individuals or agricultural enterprises. The sector also accounts for 90% of agricultural value added. The subsistence sector, mainly communal land ownership, differs markedly from the freehold areas in its production systems, objectives and property rights (Table 2); only the cropping areas are normally allocated to individual households, while the grazing areas tend to be shared by members of a community. This sector has a substantially higher human population per unit area than the commercial sector, with poor investment, especially in infrastructure. The production systems in the communal areas are pastoral and agro-pastoral, and the majority of households are subsistence based and labor intensive, with limited use of technology and external inputs (Palmer & Ainslie 2002). Small-scale farmers may therefore be less able to adapt to climate change than large-scale ones.

Distribution of the two scales of farming across the provinces indicates that KwaZulu-Natal, even though it has a relatively small share of farmland for all the different types of farm activity in the country, has the highest proportion of the country's small-scale farmers, followed by the Eastern Cape and Limpopo (Figure 7). The Northern Cape, the Western Cape and Gauteng have very small numbers of small-scale farmers. The majority of large-scale farmers are located in the Northern Cape (35%) (mainly livestock farming), the Eastern Cape and the Free State (13% each), and the Western Cape (12%) with the fewest in KwaZulu-Natal (5%) and Gauteng (1%). The distribution of large-scale farmers did not change significantly between 1993 and 1996 (see Figures 8a and 8b). If small-scale farmers are to be most affected by climate change then three provinces, KwaZulu-Natal, the Eastern Cape and Limpopo, should be of priority to policy makers.

3.2 Major crop and animal farming regions

South Africa farms an extremely wide variety of livestock, crops, fruit and vegetables, adapted to weather conditions ranging from temperate to sub-tropical, and diverse vegetation. The principal cropping or mixed farming regions, as observed above, are the summer highveld plateau of the Free State, the highveld and midlands of KwaZulu-Natal and the winter rainfall region of the Western Cape. The Free State and KwaZulu-Natal are mixed farming areas, combining the cultivation of maize, sorghum, groundnuts and potatoes with dairying and pig farming. The Western Cape, which has a Mediterranean climate, is the principal region for winter cereals, deciduous fruit and particularly grapes (NDA, 2001b).

Between the mixed farming areas of the north and the south is the Karoo, a large arid to semi-arid region covering most of the Northern and Western Cape Provinces, mostly used for sheep farming. The Limpopo and North West Provinces are mostly cattle farming regions, and the sub-tropical lowveld of Mpumalanga and the Limpopo Province also produces fruit and vegetables. The coastal belt of KwaZulu-Natal and the Eastern Cape, being frost-free, produces a variety of subtropical crops and is important for sugar cane, citrus, bananas, pineapples and timber.

South Africa's varied geophysical nature means that its cropping calendar varies considerably. For example, wheat is planted from May to mid-June and sorghum from December to January, and maize is planted between October and December in the eastern regions and between December and January in the west (see Figure 9). If farmers do not notice changes in the rainfall and temperature patterns conducive to these planting periods, the results will be devastating to total agricultural production.

Major crops in terms of land area and output are maize, wheat, sorghum and sugar cane (see Figure 10). Minor crops include groundnuts, sunflower seeds, dry beans, tobacco and potatoes. Maize is grown to a greater or lesser degree in almost every province, with the major producing areas in the arid regions of the Free State and parts of North West Province. Minor growing areas for maize include Mpumalanga, Gauteng and KwaZulu-Natal (see Figures 11a and 11b). major wheat-producing areas are the Free State and the southwestern parts of the Western Cape Province, while the minor ones are parts of the Western Cape Province, Gauteng, Mpumalanga and the eastern parts of the Northern Cape and North West Provinces (Figures 12a and 12b). Sugar cane is grown in 15 main areas extending from the northern parts of the Eastern Cape Province through to the coastal belt and midlands of KwaZulu-Natal (mainly in the sub-tropical wet zone) and the Mpumalanga lowveld (Figure 13). These regions have the highest average annual rainfall of 1200–1400mm. Sorghum is grown mainly in the arid region of the Free Sate, Mpumalanga and the North West Province (Figure 14). Groundnuts are grown mainly in the summer rainfall areas of the North West Province and the Free State (Figure 15).

3.3 Trends in the agriculture sector and climate variables

This subsection compares trends in key agricultural indicators and assesses how they relate to climate variables. The key indicators are the value of agricultural GDP and area of major crops planted and harvested (maize, wheat and sorghum), and the climate variables are precipitation and temperature. The objective is to find out whether the key indicators reflect the trends in climate variables.

Figure 16 indicates that temperature levels over most of the 1961–1989 period were above the average of 17.5°C, and were significantly higher after the 1980s. Precipitation levels were very variable, but showed a falling trend between the mid-1970s, and early 1980s after which they tended to increase again. Droughts occurred in 1982/83, 1991/92 and 2003/2004 farming seasons.

Figure 17 indicates that, in general, the value of agriculture followed the rise in the GDP between the period 1946 and 2004 but experienced some dips in the 1980s, and the early 1990s. This may have been because of the droughts in those periods. The contribution of agriculture to GDP, however, fell within the same period (Figure 18). This may have been because of negative climate trends, but also may be largely because other sectors increased their contributions to the GDP. To properly assess the extent of climate trends it is important to use not only the value of the agricultural GDP but also the trends in the production and harvest of key crops in the country.

The total land area under maize fell during the period 1966 to 2004, and total production experienced a fluctuating cycle with extreme deeps in the early 1980s and also in the 1990s – a reflection of agriculture's contribution to GDP, given that maize is the country's major crop (Figure 19). The fall in total production is more a reflection of the fall in total land area than in yield – maize yield did not change significantly over the period. This may be attributable to appropriate adaptation in the sector, such as the improved use of inputs. But the decrease in area under maize may indicate that some areas, especially in the arid agro-ecological zone, may be becoming too hot for this crop.

Wheat also experienced a fall in the area planted during this period, with no significant fall in total production even though there were some fluctuations (Figure 20). Again, the reason the area decreased may be that some areas of the Free State and the Western Cape became unsuitable for wheat production because of the increased temperature or the variability in precipitation. The reason production levels have not changed significantly may be that the appropriate adaptations have been made in response to these changes.

The area under sorghum decreased between 1971 and 2004, with some fluctuating trends (Figure 21). Available records indicate that during the last few years, sorghum production has shifted from the drier western to the wetter eastern production areas. This shift has led to the development of cultivars that are less sensitive to lower temperatures; that is, comparatively lower temperatures than those the crop was used to (NDA, 2004), a clear case of adapting to the increased temperature and rainfall variability. The shift and the development of new cultivars is the adaptation strategy in response to the higher temperatures in the former growing areas, and the rainfall variability in the country.

In the case of sugar cane, both the area planted and total production increased from 1966 to 2002 (Figure 22). This may be attributable to the relatively higher rainfall in the eastern parts of the country and also to an increase in irrigation given that water resources are still under-utilized in these areas. This indicates that access to other sources of water may reduce the negative impact of an increase in temperatures.

From these few examples, it is possible to deduce a clear link between temperatures and land area under crops, but not a similar link between precipitation and land area under crops. Higher temperatures over the period (see Figure 16) may have made some areas, especially the arid areas, less suitable for field crops, which is one reason why the total land area for crops such as maize, wheat and sorghum, has decreased, especially since the 1980s. But it can be observed that, in spite of the decrease in total area planted of certain crops in response to, especially, higher temperatures, the yields for each of these crops have not changed significantly over the years and total production has not seen a significantly fall (NDA, 2005). What one can conclude is that the various adaptation methods being used by farmers across the country may be helping to maintain the levels of production in spite of the increased temperatures and the high variability in the rainfall.

3.4 Importance of the agricultural sector to the economy

Agriculture, which includes all economic activities from the provision of farming inputs, farming and value adding, remains an important sector in the South African economy in terms of foreign exchange earnings and employment, and contribution to the gross domestic product (GDP). In 2000, with about 50,000 large commercial farmers, the sector exported about R16 billion worth of products, or nearly 10% of South Africa's total value of exports. However, the sector is most important for the number of people depending on it for their livelihoods. Commercial farms employ about one million people and provide livelihoods and housing for about six million family members of employees. There are also about 240,000 small-scale farmers who provide livelihoods to more than one million employees and their family members and occasional employment to another 500,000 people. Furthermore, there are an estimated three million farmers, mostly in the communal areas, who produce food primarily to meet their family's needs. In total, the agriculture sector employs about 13% of the labor force. More than half of the population are primarily dependent on agriculture and related industries.

In addition to providing employment, contributing to the GDP and being a source of foreign exchange earnings, the agricultural sector has strong backward and forward linkages in the economy. Its true contribution to the economy is obscured by a relatively low direct contribution of less than 5% to GDP and approximately 13% of employment. However, if the full impact of income and employment linkages and multipliers are included, its contribution to the national economy increases to approximately 12% and 30% respectively (NDA, 2000). Any adverse effects of climate change on the sector will therefore have a serious impact on the whole economy, and also on the SADC sub-region, to which South Africa supplies agricultural products. This gives urgency to the need to understand how climate change will affect the sector and find ways to lessen any damage.

4. Analytical framework of the Ricardian approach to economic impact assessment

Two major economic approaches, the agronomic-economic and the cross-sectional models, have been employed to study the interaction between climate, water and agriculture. The agronomic-economic approach begins with calibrated agronomic models and predicts outcomes, using economic simulations. The cross-sectional approach compares the choices and performances of existing farms with different soil conditions and facing different climate conditions. These two approaches have both confirmed a number of hypotheses such as the harmful effects of high temperatures on agricultural activities, an indication of the robust nature of the results across all the assumptions inherent in each model. One of the cross-sectional models is the Ricardian approach, which links farm values to climate (Mendelsohn & Dinar 2003).

Early Ricardian studies of agriculture (Mendelsohn et al., 1994; 1996) have been criticized because they did not include irrigation and other sources of water in the analysis (Darwin, 1999). These studies relied solely on a district/province/county's climate to predict agricultural outcomes. However, such defined area-specific climate does not provide a good indication of the availability of either surface or groundwater because these supplies often come from watersheds that extend far beyond a district/province/county (Mendelsohn & Dinar, 2003). Given the importance of water in agricultural outcomes, it is necessary to estimate the total flow of water to a given geographical area in order to assess the true impact of climate change on agriculture.

To address this shortcoming, Mendelsohn and Dinar (2003) used a revised Ricardian approach (using hydrological proxies) to assess the way surface water affects the value of farmland and the climate sensitivity of agriculture in the United States. This revised approach has been adopted by the present study for the economic assessment of climate impact on agriculture in the South Africa.

4.1 The Ricardian method

The Ricardian method is a cross-sectional approach to studying agricultural production. The method was named after Ricardo because of his original observation that land rents would reflect the net productivity of farmland (Ricardo 1817, 1822). Farm value (*V*) consequently reflects the present value of future net productivity. The principle is captured in the following equation (Mendelsohn & Dinar 2003)

$$\begin{aligned} V &= \int P_{LE} e^{-\delta t} dt \\ &= \int \left[\sum P_i Q_i (X, F, Z, G) - \sum RX\right] e^{-\delta t} dt \end{aligned} \tag{1}$$

where:

P_{LE} = net revenue per hectare

P_i = market price of crop *i*

Q_i = output of crop *i*

F = vector of climate variables

Z = set of soil variables

G = set of economic variables such as market access and access to capital

X = vector of purchased inputs (other than land)

R = vector of input prices

t = time

δ = discount rate

The farmer is assumed to choose *X* to maximize net revenues given the characteristics of the farm and market prices. The Ricardian model, following Equation 1, is a reduced form model that examines how the set of endogenous variables, *F*, *Z*, and *G*, affect farm value. The model is based on the observed response of crops and farmers to varying climate. That is, it uses actual observations of farm performance in different climatic regions (Mendelsohn et al. 1994, Mendelsohn & Dinar 1999; Sanghi et al. 1998; Kumar & Parikh 1998; Ouedraogo 1999; Mendelsohn 2001). Specifically, the method examines farm performance across different agro-climatic zones. It measures how long-term farm profitability varies with local climate while controlling for other factors. The model is also developed to correct the bias in the 'production-function' approach by using economic data on the value of land.[5]

The main interest of the analyses is measuring the impact of exogenous changes in environmental variables (*F*, *Z*, *G*) on land values as captured by changes in land values across different environmental conditions. By regressing farm values on climate, soil and other control variables, the method enables the measuring of the marginal contribution of each variable to land value. Cross-sectional observations, showing spatial variation in normal climate and edaphic factors, can hence be used to estimate climate impacts on production and land value.

The standard Ricardian model relies on a quadratic formulation of climate:

$$V = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + u \qquad (2)$$

where u is an error term. The quadratic functional form for climate captures the expected non-linear shape of the relationship between net revenues and climate. When the linear term is negative and the quadratic term is positive, the net revenue function is U-shaped, and when the linear term is positive and the quadratic term is negative, the function is hill-shaped. Several other shapes are possible depending on the relative signs of the linear and quadratic terms. However, based on agronomic research and previous cross-sectional analyses it is expected that farm values will have a hill-shaped relationship with temperature. That is, for each crop there is a known temperature where that crop grows best across the seasons (see Mendelsohn & Dinar 2003).

Because land markets are imperfect and agricultural farm values in the developing world weakly documented, and following the approach by Sanghi et al. (1998) and Kumar and

[5] The production-function approach relies upon empirical or experimental production functions to predict environmental damage. The approach takes an underlying production function and estimates impacts by varying one or a few input variables such as temperature, precipitation and carbon dioxide levels. The estimates might rely on extremely carefully calibrated crop-yield models (such as CERES or SOYGRO) to determine the impact upon yields. The results often predict severe yield reductions as a result of global warming. The approach has been criticized because of inherent bias, which tends to overestimate the damage; a bias sometimes referred to as the 'dumb farmers scenario', since it omits the variety of adaptations that farmers make in response to changing economic and environmental conditions (Mendelsohn et al. 1994).

Parikh (1998) for India, net farm revenue per hectare (*V*) is used as the response variable instead of land values.

Farm net revenue is the sum of the net revenues from crops, livestock and other farm activities. In this analysis, however, the focus is on crop net revenues. It is important to note that a complete assessment of the impacts needs to include revenues from livestock and other farm activities. However, the extent to which each of these activities responds to climate variables may be different. Such separate analyses are therefore important for formulating effective policy. On the other hand, there is the possibility of substitution or complementarity between and among these different farm activities (as possible adaptation options) as climate warms so it is important for this to be reflected in such impact analysis. We attempt to do this by including a livestock variable dummy (*L*) in the model to capture this.

Given Equation 2, the marginal impact of each of the climate variables (f_i) on farm net revenues is evaluated at the mean of each of the variables as follows:

$$E[dV / df_i] = E[\beta_{1,i} + 2 * \beta_{2,i} * f_i] = \beta_{1,i} + 2 * \beta_{2,i} * E(f_i) \quad (3)$$

4.2 Revised Ricardian method

The study follows Mendelsohn and Dinar (2003) to assess the influence of other sources of water: surface water, ground water and irrigation (*W*) on farm net revenues. Mendelsohn and Dinar (2003) noted that water comes to farms in the form of precipitation, which is already reflected in the Ricardian model. However, because surface and ground water can be remote from the farm, the climate at the farm may give little indication of the total amount of water accessible to the farm. Relevant hydrological variables of runoff and flow are used as proxies for this assessment. Irrigation is also expected to change the relationship between crops and climate. For example, irrigation may allow crops to grow well in warmer temperatures. This is an important adaptation option to help control the expected negative effects of warmer climates on crop production and crop net revenues. These other sources of water are introduced in the model in linear and quadratic terms.

Other socio-economic factors (*S*) may also influence farm values. Such variables include disease rates, literacy rates, family size, household income, and type of ownership of farm. Recent attempt at land reforms in South Africa where land has been re-allocated to previously disadvantaged groups is also expected to influence farm values. This could be an important variable affecting net revenues. It could be measured as the percentage of land reallocated to previously disadvantaged groups in each district.

High disease rates may impact negatively on farm values through the reduced availability of labor for agricultural activities. High literacy rates will impact positively on farm values since these enhance farmers' ability to easily adopt modern farm technologies. Higher incomes may lead to increased investments in farmland and possible higher farm returns. It is also expected that secured ownership of farmland, such as private ownership, encourages increased investment and higher farm returns as compared to other types of ownerships such as communal and open-access land. It is difficult to predict the impact of the land reforms on farm values in South Africa. However, it is expected that in the short term these may negatively affect farm values because of the lack of immediate access by the new landowners to capital, markets and inputs. We test for the influence of some of these socio-economic variables in the model. The influence of land reforms and some of these socio-economic variables could not, however, be tested owing to data limitations.

The revised Ricardian model for South Africa is indicated in Equation 4. By including the livestock dummy and socio-economic and irrigation variables we are able to assess the role of adaptation related variables in controlling the extent of climate impacts on crop net revenues in South Africa.

$$V = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + \beta_5 L + \beta_6 W + \beta_6 W^2 + \beta_7 S + u \qquad (4)$$

Given the possibility of different impacts in the different parts of the country and different agricultural subsectors, we examine such impacts in the four agro-ecological zones and the nine provinces in the country. We also examine whether the impacts are significantly different for irrigated and dryland farms (by assuming that the choice of either of these farming systems is exogenously determined), and also for large-scale and small-scale farms.

In spite of addressing the issue of the impact of other sources of water on farm net revenues, other shortcomings of the Ricardian approach have been identified (see Kurukulasuriya et al., forthcoming, for full discussion). Among them is the assumption of constant prices. The argument is that the Ricardian price schedule will overestimate the positive welfare effects of climate change since it underestimates damages and overestimates benefits (Cline 1996; Darwin 1999; Adams 1999). For globally traded goods, such as agricultural products, price changes are not likely to be a problem as local gains and losses in production are expected to offset each other for a small net change in global output (Reilly et al. 1994; Mendelsohn & Nordhaus 1999). But a dramatic reduction in the productivity of African agriculture could affect African wage rates. In order to capture this effect, a more completed analysis should include models for local labor markets as well as land productivity (Kurukulasuriya et al., forthcoming).

The Ricardian approach also does not measure the effect of different levels of carbon dioxide across space which may be relatively important in farm productivity and therefore farm revenue. But this is not a problem in this study since carbon dioxide levels do not vary across South Africa. Another drawback of the model is that variation in climate that is observed across space may not resemble the change in climate over time. In this case, the analysis will not be able to evaluate such an effect.

However, one main advantage of the Ricardian empirical model is the inclusion of adaptation responses by farmers to local climate, which are incorporated in the estimation of the value of land. The model reflects the cost to farmers of introducing a new crop as climate warms, such as costs of seeds, equipment, and land preparation, and the benefits. Thus, the model provides a more optimistic result than the generally pessimistic results found with purely agronomic studies.

5. Data and empirical model specification

The analysis uses cross-sectional data at the household and district levels on farm activities, climate, soils and hydrology. These four sets of data are discussed below.

Farm household data: A farm household questionnaire was used o collect information on selected households in sample districts in the nine provinces on their farm activities (see Appendix 1 for a discussion of the sample design)

The questionnaire attempted to capture information on pertinent variables required to calculate net farm revenues and to explain the variation in net farm revenues, land values and income across representative sample districts, and agro-climatic regions in the country. The periods of interest were the summer (April/May 2002 – September/October 2002) and winter (October 2002 – April/May 2003) of the 2002/2003 farming season. The questionnaire also aimed to capture farmers' knowledge about, attitudes to and perceptions of climate variation and climate change. The questionnaire had two main parts and six sections. Part 1 focused mainly on crop production and Part 2 was on livestock production activities. Sections 1 and 2 focused on household characteristics and the employment of the household head. The questions in Section 3 were on the household's land under farming activities (both crops and livestock), and the farm labor used for various farm activities and the respective costs. In Section 4, detailed information was obtained on crop farming activities with respect to the type of crops grown, the area of land planted, the amount harvested and sold, and other crop farming related costs such as, seeds, fertilizer and pesticides, and light, heavy and animal machinery, and farming related buildings. Parts of Section 4 collected information on the type of livestock and poultry farmed, and how many animals were purchased, lost and sold in the period of interest. It also collected information on livestock and poultry products, such as milk, beef, eggs and wool. In Section 5, the focus was on access to information on farming activities and the sources and cost of this information, while Section 6 attempted to estimate the total income of the farm household (for both farming and non-farming activities), taxes paid and subsidies received in the period of interest. Finally, Section 7 elicited information from farmers about their perception of short- and long-term climate change and their adaptation strategies in response to the changes they perceived.

In total, 416 farm households were interviewed in 17 districts across the nine provinces (see Figure 23).[6] Of these, 53% were large-scale farmers and 47% were small-scale farmers, and 29% were involved in crop farming only with maize as the major crop, 27% in livestock farming only, and 44% in mixed farming**.** The average farm size ranged from 50ha to 1,537ha for large-scale farmers and 1ha to 40ha for small-scale farmers. Average national farming experience for large-scale farmers was about 15 years, and seven years for small-scale farmers. This is not very surprising given that most of the small-scale farmers have only acquired access to land in the last decade. Table 3 presents a brief summary of the characteristics of farmers interviewed in the selected districts of the nine provinces and the four agro-ecological zones.

[6] The actual sample districts and respondents fell short of the planned sample mainly because of financial constraints. However, the farmers interviewed in the selected district provide adequate representation of farming activities in the country.

Climate data: Two main climatic data were used – satellite temperature and ARTES precipitation (wetness) data. The satellite data comes from the Department of Defense in the USA (Basist et al. 2001; Kurukulasuriya et al., forthcoming). The Defense Department data comes from a set of polar orbiting satellites that pass over the entire earth between 6am and 6pm every day. The satellites are equipped with sensors that detect microwaves that can pass through clouds and detect both surface temperature (Weng & Grody 1998) and surface wetness (Basist et al. 2001). The African Rainfall Temperature Evaluation System (ARTES) data is created by the National Oceanic and Atmospheric Association's (NOAA) Climate Prediction Centre of the USA (World Bank 2003). The ARTES data is based on ground station measurements of precipitation, minimum temperature, and maximum temperature.

The rationale for using these two different sources as proxies for climate are twofold. First, the ARTES dataset is at the provincial level as opposed to the satellite data that is at the district level, so the provincial data will pick up other characteristics in addition to the climate effects. It therefore becomes less clear whether the results reflect temperature effects or some other explanatory factors. Second, in the case of satellite wetness, this measure is an index which has temperature in it somewhere. It is not clear how to make climate predictions with such an index. So the best option is to use the ARTES precipitation data (Kurukulasuriya et al. 2006).

Soil data: These were obtained from the Food and Agriculture Organization (FAO). They provide information on major and minor soils by districts in the country (FAO 2003). The FAO classifies soils into 26 major units and 107 sub-categories based on soil texture (coarse, medium or fine) and the slope of the land. Three slope classes are distinguished: (a) level to gently undulating, with generally less than 8% slope, (b) rolling to hilly with slopes between 8 and 30% and (c) steeply dissected to mountainous, with more than 30% slope.

The classifications are indicated by the symbol of the dominant soil unit, followed by a number which refers to the descriptive legend. For example, associations where lithosols are dominant are marked by the lithosol symbol *I* combined with one or two association soil units or inclusions, and where there are no associated soils, the symbol *I* alone is used. When information on the texture of the surface layers (upper 30cm) of the dominant soil is available, a texture class (1, 2, 3) follows the association symbol, separated from it by a dash. Where two or three groups of textures occur that could be separated, two or three figures may be used, separated by a slash. Slope classes are indicated by a small (lower case) letter: *a, b*, or *c*, immediately following the texture notation. The major soil categories are measured as the proportion of total soil composition in the country. For simplicity of analysis, this study tested for the influence of only the major soil categories in the country. (See more details in FAO 2003.)

Hydrology data: These were provided by the University of Colorado, Boulder, and the International Water Management Institute (IWMI) as part of the GEF Africa-wide study. Using a hydrological model for Africa, estimates were provided for flow and runoff for each of the sample districts (Strzepek & McCluskey 2006).

5.1 The empirical model

Equation 4 is estimated for South Africa using seasonal means for summer (December, January and February), fall (March, April and May), winter (June, July and August) and spring (September, October and November).[7] Given that there are two major farming seasons in the country, we also examine the marginal impacts of temperature and precipitation for the summer farming season (December to May) and the winter farming season (June to November) using Equation 3. The rest of Section 5 discusses each of the variables in the model.

5.1.1 Description of dependent and explanatory variables

(a) Net crop revenue per hectare

The dependent variable (*V*) in Equation 4 is measured as crop net revenue per hectare of cropland as opposed to per hectare of farmland, which would include farmland under livestock and poultry production, and other farm activities such as forestry. (See Tables 4a–e for summary of all the variables included in the models.)

In simple terms, net revenue is gross crop revenue (which is the product of total harvest and price of the crop) less total cost of production. If more than one crop is grown on the same land then it is the sum of the products of the crop harvested and their prices less their associated cost of production. Total harvest of crops includes harvest used for household consumption, livestock feed and harvest sold. The cost element is mainly total variable costs (TVCs), which in this case include the depreciation or maintenance cost of fixed assets such as buildings, machinery, etc. TVCs include expenditure on transport, packaging, marketing, storage, post-harvest losses, fertilizer, pesticide, seeds, water use, labor, and other depreciation costs of the use of light and heavy machinery. Other costs include rent paid on the farmland, interest paid on loans, etc. What is excluded from the estimation of the cost is household labor because of the possibility of overestimation. We control for this by using household size as a proxy for household labor in the model.

From the sample of 416 farm households, crop gross revenues were estimated for 272 farm households. The rest were mainly in livestock farming or did not harvest any crop in the period of interest. Some households did not have other cost elements and therefore were also excluded. Excessive estimated net revenues which were judged to be outliers were also excluded from the dataset.

The estimated net crop revenue per hectare across South Africa for the 2002/2003 farming season was US$306. As expected, irrigated farms had the highest net revenues of US$467, large-scale farms US$358, small-scale farms US$254, and dryland farms had the least at US$159 (see Table 4). At the provincial level the Western Cape (WC) had the highest

[7] Other ways of incorporating climate variables in the model include using annual means, monthly means and the means of the two identified farming seasons (summer and winter) in the country. All these alternatives were tested but the three month averages for summer, fall, winter and spring were found to be more relevant for the analysis.

estimated gross revenue, followed by the North West (NW), the Eastern Cape (EC), Gauteng (GU), KwaZulu-Natal (KN), Mpumalanga (MP) and the Free State (FS). The lowest gross revenues were found in Limpopo (LP) (see Figure 23). Estimated net revenues at the provincial level also indicated that Limpopo was the lowest, with even a negative value; in this province not only is the value of output low, but the cost of production also seems to be high.

(b) Climate variables: temperature and precipitation

The long-term mean temperatures and precipitation for each of the provinces and South Africa as a whole are presented in Tables 5 and 6 respectively and follows the spatial climatic conditions described in Section 2. Table 5 indicates that summer periods, as expected have the highest temperatures followed by spring and fall then winter. The long-term mean annual temperature was about 17°C with a minimum of 13°C and a maximum of 20°C, with summer periods having as high as 24°C. At the provincial level, the hottest province in summer is the Northern Cape, followed by Limpopo and the North West. The province with the lowest temperature in summer is the Free State. In fall, Limpopo is the hottest province, followed by the Northern Cape and then Mpumalanga, while the coolest is the Free State. In the winter, Limpopo is still the hottest, followed by Mpumalanga, then the North West, with the coolest still the Free State. In spring, Limpopo is the hottest, then the North West and Mpumalanga with the Western Cape being the coolest.

Table 6 shows that the highest long-term average rainfall per month is in summer and the lowest in winter. At the provincial level, KwaZulu-Natal has the highest rainfall in the summer and Limpopo has the lowest, and this is the same in the fall. A surprising statistic is that during the winter, Limpopo has the highest rainfall, in fact exceptionally high, while Gauteng and the North West have the lowest. Similarly, in spring Limpopo has an exceptionally high rainfall, while the Northern Cape has the lowest. The exceptionally high rainfall for Limpopo in winter and spring introduced some bias into the estimation and therefore was controlled for using the mean average for the country.

(c) Soils

Out of the 26 major soil categories defined by the FAO, about ten are found in South Africa. Figure 24 shows that the major soil type in South Africa is luvisols. Other important ones are arenosols, xerosols, planosols and vertisols. One should note that although these soils seem to be more prominent in the country this does not imply that they are also important for crop farming activities.

The different types of soils are distributed unevenly across the nine provinces. Luvisols are found in most of the nine provinces, especially in Limpopo, the North West, Gauteng, and the Western Cape. Arenosols are also found in most of the provinces, particularly the Northern Cape, the Western Cape, Mpumalanga and Gauteng. Planosols are found mainly in the Free State, while ferralsols, cambisols and nitosols are found mainly in KwaZulu-Natal. Vertisols are found mostly in Mpumalanga, the Free State and KwaZulu-Natal and lithosols in the Free State and KwaZulu-Natal. We tested for the influence of these ten major categories of soil types in the models.

(d) Hydrology

Two relevant hydrology variables, runoff and flow, were tested in the model. The runoff variable seems to explain changes in crop net revenues better than the flow variable. The mean runoff is estimated at about 10mm/month (see Table 4a). The data also indicate that Limpopo Province has the highest mean annual runoff, followed by Mpumalanga and KwaZulu-Natal. The Eastern Cape and Western Cape have the lowest runoff (see Figure 25).

(e) Socio-economic factors

The variables tested in the models include total land under crops, livestock ownership, access to electricity used as a proxy for use of modern technology, access to markets as measured by the distance to output market, access to public extension services, and other sources of extension services, farming experience measured as the number of years respondents have been in farming activities, and household size used as proxy for household labor (see Tables 4a–e). Educational level of the household head used as a proxy for literacy rate was not significant in any of models so was excluded.

The mean crop area for the sample was 150 hectares, with relatively higher areas for large-scale (296), irrigated (162), dryland (140) and small-scale farms (14). In general, irrigated farms sell their output at the more distant markets, with an average distance to the market of 267km, with the least distance for small-scale farmers (21km). Small-scale farms have an average household size of about seven members, with the fewest for large-scale farms – an average of four. This is expected, given that small-scale farmers are likely to depend more on household labor than other types of farmers. (See Tables 4a–e.)

In general about 66% of crop farmers also keep livestock. This is the case on 54% of irrigated farms, on 77% of both dryland and large-scale farms, and on 56% of small-scale farms. Between 64% and 93% of the farmers use public extension services – these are least used by the small-scale farmers and most by the large-scale ones. More than 90% of all the types of farmers also use other sources of extension services, with almost all of large-scale farmers (99%) using this service (see Tables 4a-e).

5.2 Estimation procedure

A STATA statistical and econometric package was used to estimate the revised Ricardian model Equation 4 for South Africa (StataCorp 2003). Typical of most cross-sectional regressions are the problems of (i) endogeneity, (ii) heteroscedasticity in the error terms, (iii) multicollinearity among explanatory variables, and (iv) the impact of outliers.

The problem with endogeneity was dealt with by estimating a reduced form of the net revenue model rather than the structural model.

We control for multicollinearity by dropping the most problematic variables, especially in cases of detecting strong collinearity and where the explanatory variables do not improve on the model and are also not significant. For example, the flow variable, some of the soil variables, and some of the socio-economic variables such as the education of the household head were all excluded from the model. But multicollinearity is normally an issue of extent rather than absence and so cannot be completely eliminated (Gujarati 1995). Very obvious outliers, such as for net revenues and some of the winter and spring precipitation, were excluded from the estimation.

To correct for heteroscedasticity we estimate a quantile regression (*qreg*) instead of an ordinary regression. The *qreg* fits quantile (including median) regressions models, also known as least-absolute value models (LAV or MAD). The objective is to estimate the median of the dependent variable, conditional on the values of the independent variables. This is very similar to ordinary regression, where the objective is to estimate the mean of the dependent variable. In other words, median regression finds a line through the data that minimizes the sum of the *absolute* residuals rather than the sum of the *squares* of the residuals as in ordinary regressions. The quantile regression, *qreg*, is an alternative to regular or robust regressions. Unlike *qreg*, ordinary regression or robust regression fits ordinary (linear) regression and is concerned with predicting the mean rather than the median, so both are, in technical sense correct. Since both the mean and the median describe central tendencies, the question is always which of these methods best describes the central tendency of the data (see StataCorp 2003).

Means, and therefore ordinary regressions, are sensitive to outliers, and cross-sectional data has serious problems of this kind. In spite of removing the obvious ones from the dataset, these outliers dominate ordinary regression and produce results that do not reflect the central tendency well. Robust regression is an attempt to correct for the outlier-sensitivity deficiency in ordinary regressions. Both *qreg* and robust regression attempt to correct for the influence of outliers, but robust regression will have smaller standard errors since it is not sensitive to the exact placement of the observations near the median and therefore coefficient estimates may be termed significant even when they are not. Quantile regression, *qreg*, on the other hand is sensitive to this and tries to make the necessary corrections. The *qreg* produces a Pseudo R similar to the R^2 produced by the ordinary regression with the same interpretation (see StataCorp 2003).

6. Discussion of estimated models

We explore two main sets of the Ricardian model in Equation 4. The first includes only climate, soil and hydrology variables and is referred to as the 'without adaptation' model. The second includes the relevant socio-economic variables and is referred to as the 'with adaptation' model. This was to assess the extent to which these additional variables increase or decrease the effect of climate on the crop sector. These socio-economic variables are also possible policy instruments for policy makers to explore as tools for controlling or taking advantage of climate effects.

Within these two broad models we also investigate, as noted earlier, whether there are any significant differences in the effects between irrigated and dryland farms, and also between large-scale and small-scale farms. That is, we assess whether scale does matter in climate analysis in the agricultural sector in the country.

We also examine differences in the provincial effects of climate and assess which agro-ecological zones and provinces may be more affected by climate change. These helped us assess the distribution of winners and losers in the face of climate impacts.

Estimates indicate that irrigation is a significant positive influence on crop net revenues, as is the farm type (represented by the dummy for large-scale farms) in the three sets of models – with climate variables only, with climate and soil variables only, and with climate, soil and hydrology variables. That is, irrigated farms are expected to have relatively higher net revenues than dryland farms, and large-scale farms are expected to have significantly higher net revenues than small-scale ones. It is also a confirmation of the significant difference in the estimated net revenues for the two sets of farming systems. When both irrigation and farm type were considered in the models, the significance of the whole model improved, indicating that both variables are important influences on net revenue. However, the irrigation variable was found to be significantly more important than the size of the farm. It follows that even though scale is important, irrigation is even more so. Given this background we examine different models for irrigation and dryland farms, and large-scale and small-scale ones.

In the rest of this section we discuss the two broad models ('without' adaptation and 'with' adaptation) and also taking into account the four main types of farm system (irrigation and dryland, large-scale and small-scale). We also estimate the marginal effects of the climate variables using Equation 3 to examine the extent of the climate effects on net revenues in the 'without' and 'with' adaptation models and conclude the section by using selected climate scenarios to examine expected climate impacts on net revenues in 2050 and 2100.

6.1 Without adaptation models

6.1.1 Without adaptation models: Climate variables only

The estimated 'without adaptation' model with only the climate variables for the full sample and the four types of farm systems are presented in Table 7. The first column shows that climate variables have significant influences on crop net revenues in South Africa. It also shows that to a large extent there is non-linear relationship between climate variables and crop net revenues. Summer temperatures show an upward trend, fall temperatures show a downward trend, and winter and spring temperatures are hill-shaped That is, higher temperatures in winter and spring will be beneficial up to a certain extent point, after which the benefit will be negated. Precipitation for summer, fall and winter is U-shaped, while for spring it is U-shaped.

Climate variables in the irrigation model follow the same trend as the full sample model except for the fall temperature which is hill-shaped (Column 2 in Table 7). Except for winter and summer temperatures and fall precipitation, the effects of all the other climate variables in the dryland model are different from the full sample and the irrigation models (Column 3). This is to be expected given that the responses of irrigated farms and dryland farms to climate are expected to be different. In the dryland model, spring temperatures show a downward trend, summer precipitation is U-shaped, winter precipitation shows an upward trend, and spring precipitation has an inverse relationship with crop net revenues. It is important to note that while most of the climate variables, especially for precipitation, are significant in the dryland farm models, only the summer temperatures are significant in the irrigation model. This may be because dryland farms rely heavily on climate variables as they lack substitutes for rain water, while irrigation helps to reduce the effect of climate variables on farming activities.

Comparing the large-scale and small-scale farms, climate variables in both models follow a trend more or less similar to the full sample model, with a few differences. In the large-scale model (Column 4), except for summer, winter and spring temperatures, the trends in the other climate variables are different from the full sample model. The trends in all the precipitation variables, though not significant, are different from those of the full sample model. Summer and winter precipitation show an upward trend, while the fall and spring precipitation show a downward trend. For the small-scale farm model (Column 5), the climate variable trends are similar to those of the large-scale farms except for the fall precipitation which is hill-shaped. The similar trends in the climate variables in the large-scale and small-scale farms models may be due to the influence of irrigation and dryland farms in both models. This may suggest that whether a farm irrigates or not is more relevant to climate analysis in South Africa than the scale of the farm.

In general, the estimated models in Table 7 indicate that climate variables are very relevant for crop farming activities in South Africa, and particularly for dryland farming. Irrigation may help reduce the effect of climate variables on crop net revenue.

6.1.2 Without adaptation model: Climate and soil variables

Four main types of soil identified as important in South Africa – vertisols, acrisols, arenosols and xerosols – were included in the model in Table 7 to assess how soil variables influence the extent to which climate variables affect crop net revenues for the country as a whole and also for the four types of farming systems. The estimated models are presented in Table 8.

The inclusion of the soil variables improved the overall significance of the full sample and the irrigation models, as indicated by the slight increase in the Pseudo R of 0.1363 and 0.1564 for the two models respectively. There were, however, no significant improvements in the other three sets of models (dryland, large-scale and small-scale).

The results in Column 1 of Table 8 indicate that three of the four groups of soils have significant impacts on crop net revenues in South Africa. Both acrisols and arenosols are expected to have positive impacts on crop net revenues. That is, in general areas in the country where these types of soils can be found have significantly higher net revenues than other areas. This is true for all the other four models, except for arenosols in the large-scale model, which have a non-significant negative effect (see Columns 2 to 5 in Table 8). Vertisols and xerosols, on the other hand, may have a negative effect on net revenues. This is also the case for all the other four sets of models. That is, in general vertisols and xerosols have a negative effect on crop farming activities in the country.

Including the soil variables does not significantly change the trends of the impacts of most of the climate variables. One major change, however, is that fall temperatures in all the five models now have an inverse relationship with net revenues and are significant in the full sample, dryland and small-scale farm models. Winter temperatures now indicate a positive relationship with net revenues in all the five models and also significant in the full sample, dryland and small-scale farm models. The implication is that higher temperatures in the fall season may harm crop activities, while higher temperatures in winter may be beneficial to crop farming, especially for dryland and small-scale farms. Spring temperatures follow the same trend as in the model in Table 7 (the climate only model) except for the large-scale model which has changed from a hill shape to a downward slope, though this difference is not significant. The summer precipitation impact trends for all the five models are similar to those of the models in Table 7, except for dryland farms. The fall precipitation for the five models in Table 8 now shows a downward trend for all five, though these are not significantly different from the trend in Table 7. Winter precipitation is also similar to the trend in Table 7 for all five models except for the trend for large-scale farms, which has changed from upward sloping to downward, but again the difference is not significant. Spring precipitation also follows similar trend to that in Table 7 for all the five models and the few differences are not significant.

6.1.3 Without adaptation model: Climate, soil and hydrology

In this model the hydrology variable, runoff, is included in the models in Table 8. The linear and quadratic terms of the runoff variables are included to test the nature and extent of the impact. This also follows the assumption that such impacts are non-linear. The results of the revised estimated models are presented in Table 9.

The inclusion of the runoff variable did not significantly improve on any of the five models as the Pseudo R for all five remain the same as in their respective models in Table 8. However, the results indicate that the influence of the runoff variable is non-linear, with a hill shape in four of the five models, with the exception of the large-scale farms where it is U-shaped. The relationship is also more significant in the dryland model. This indicates that access to water other than rainfall may enhance net revenues, particularly for dryland farms mainly because it may affect the texture of the soil and positively affect net revenues. But excessive runoff may be detrimental to net revenues, as indicated by the negative coefficient of the quadratic term (see Table 9).

The inclusion of the runoff variable did not significantly change the trend of the impact of the climate variable on crop net revenues. The impact of the soil variables also remains the same except for vertisols, which are not important in explaining crop net revenues. Acrisols and arenosols still positively impact on crop net revenues, while xerosols have a negative impact.

The implication of the above three estimated models is that the extent and nature of the impact of climate variables on crop net revenues may be influenced by the type of soil and the runoff in a particular farming location. Acrisols and arenosols may enhance crop net revenues and therefore reduce any negative effect of climate change on net revenues, while vertisols and xerosols may rather reduce crop net revenues and therefore aggravate the negative effect. Runoff will increase net revenues and also reduce the negative effects of climate but only to a certain extent. In the next three models we assess the extent to which the inclusion of relevant socio-economic variables affects the crop net revenues of the five models.

6.2 With adaptation models

6.2.1 With adaptation models: Climate and socio-economic variables

In addition to irrigation and farm type, other socio-economic variables tested include the area of cropland, a dummy for livestock ownership, access to electricity, access to public extension services and other sources of extension services, distance to crop market, farming experience and household size. The results are presented in Table 10.

The inclusion of the socio-economic variables improved on all the models in Table 7, as indicated by the relative higher Pseudo *R* for all the five models in Table 10. This shows that these socio-economic variables are important for explaining crop net revenues in South Africa. Including the socio-economic variables in the models in Table 7 did not significantly change the trend of the impacts of the climate variables on crop net revenues for all the five models.

The results in Table 10 indicate that irrigation is again important in crop farming activities in the country. It has a positive influence on net revenues especially for small-scale farms. It is positive but not significant in the large-scale farms models. Cropland area is not relevant for large-scale farms because most of them have relative large areas, and not also relevant for small-scale farms because most have relatively smaller land. But the variable seems to be significant when the sample is divided into irrigated and dryland farms. The variable is positive in both models but more significant in the dryland farms. It may be important for dryland farms because they may be able to spread their climate risk over a large land area rather than a small one.

The livestock variable is not significant but the impact is different for irrigated farms and large-scale farms compared to dryland and small-scale farms. The positive impacts for the irrigated and large-scale farms may imply that livestock activities complement crop farming activities on these farms. On the other hand the negative coefficient of the variable for dryland and small-scale farmers may indicate that livestock is more of a substitute for crop farming. That is, these farmers may turn to livestock farming if crop farming becomes less productive because of adverse climate change. This seems to be true in most semi-arid and arid parts of the world.

Access to electricity, which is used as proxy for modern technology, is positive but not significant, though it is an indication that improved technology may enhance crop net revenues. This variable is not relevant for irrigated and large-scale farms, possibly because most of these farms may be using improved technologies.

Where farmers sell their crops is also relevant to their crop net revenues. The results in Table 10 indicate that the further away farmers sell their crops the higher the net revenues and this is very significant for small-scale farms, as indicated by the positive and significant coefficient of the distance to crop market variable. This indicates that if farmers have access to other markets apart from markets in their close vicinity it would help improve their net revenues and cushion them against adverse climate effects. The important policy message here is that access to markets may help reduce adverse climate effects.

Farming experience and household size impact positively on net revenues. These two variables seem to be more relevant for the whole sample and small-scale farms and not in the other models when only climate variables are considered. The positive impact implies farming experience and household size may play a role in crop net revenues. Access to other sources of extension services is also only relevant and positive in the full sample model but not significant.

A surprising result is the negative impact of the access to public extension services variable in all the five models. Though not significant it indicates that the services provided by public agricultural extension may not be beneficial to crop farmers. One expects that an important avenue for controlling climate effects is the provision of relevant information to farmers, and in most African countries the channel through which this could be done is public extension services. It is therefore important to ensure that information provided by public organizations benefits rather than harms the farmers.

6.2.2 With adaptation models: Climate, soil and socio-economic variables

In this model the socio-economic variables are included in the models in Table 8, again to test the extent of their impact of crop net revenues when soil variables are added to the climate variables (see Table 11).

Comparing the estimated models in Table 8 and Table 11, the overall significance of the model improved with the inclusion of the socio-economic variables. This is indicated by the relative higher Pseudo *R* for all the respective models. This implies that although climate and soil variables are important, socio-economic variables are also important in explaining crop net revenues in South Africa. The inclusion of the socio-economic variables in the models in Table 8 again did not significantly change the trend of the climate variables' impact on net revenues. The nature of the impacts of the soil and hydrology variables in Table 11 are also the same as in Table 8.

The impacts of the socio-economic variables are also similar to the results in Table 10 where only climate variables were considered. The difference is that in this model (Table 11) the socio-economic variables are more significant. The irrigation variable is still positive but now significant in the full sample and small-scale farms models. Cropland area is also still positive and significant in the dryland farms model. The livestock ownership variable is also still positive in the irrigated and large-scale farms, and significant in the irrigated farms models, while it is negative in the dryland and small-scale farms models, and significant in the small-scale farm models. This again suggests that keeping livestock may be an alternative farming activity for dryland farms and small-scale farmers suffering from adverse effects of climate change. Access to electricity is also positive, while distance to market is also still positive and significant, again suggesting that where farmers sell their produce is important. The farming experience variable is still positive and significant for the whole sample. Household size is positive and significant for the whole sample, and positive for large-scale farms but negative for small-scale farms, though in the latter two models the variable is not significant. Access to other sources of extension services is still positive in the full sample model, while the access to public extension services variable is still negative.

6.2.3 With adaptation models: Climate, soil, hydrology and socio-economic variables

In this model the socio-economic variables are included in the estimated model in Table 9, with the revised estimated model presented in Table 12. The inclusion of the socio-economic variables in this model again does not significantly change the nature and trend of the climate variables. The impact of the soil variables remains the same, as do the runoff variables. But the runoff variables are now very significant in the full sample, irrigated, dryland, and small-scale models (see Table 12). The implication again is that other sources of water are very important to crop farming activities for all types of farming systems in the country.

Comparing the results in Table 12 with those in Tables 10 and 11 (with adaptation models), the impact of the socio-economic variables does not change significantly, with a few exceptions. The irrigation variable is still positive but now very significant in all the three relevant models (full sample, large-scale and small-scale). Again this suggests that irrigation activities may help control the adverse effects of climate change. Cropland area is still positive and significant in the dryland farms model. Livestock ownership maintains its impacts, as in Tables 10 and 11, as do the access to electricity, distance to market, access to public extension services, farming experience, household size and access to other sources of extension services variables.

The analyses in the above six sets of models indicate that climate variables are very relevant for crop activities in South Africa, though the relationships are non-linear. Soil variables may also affect net revenues with some having a negative impact and others positive. Soil types such as acrisols and arenosols may positively influence crop net revenues while vertisols and xerosols may have the opposite effects. Access to other sources of water such as runoff to a given district would have positive influences in net revenue. This relationship is also non-linear with a negative quadratic term. That is, excessive runoff may not be beneficial for crop farming activities in the country.

The analyses also indicate that socio-economic variables are important in such climate analysis. More importantly, irrigation may be an important adaptation strategy for reducing adverse effects for all farm types in the country, be they large- or small-scale. Larger cropland area would also help to spread the risk from climate change, especially for dryland farms. Farmers' experience, especially for large-scale farmers would also help reduce the impacts, as would access to other sources of extension services. Access to modern forms of farm technologies will also help reduce adverse effects, as will access to output markets. One important result is that keeping livestock may also help, but the impacts are different for irrigated and large-scale farms on one hand and dryland and small-scale farms on the other. For irrigated and large-scale farms, livestock farming complements their crop farming activities; for dryland and small-scale farms, however, livestock is a substitute for crop farming and therefore acts as buffer against any adverse effect of climate on crop farming activities. Dryland and small-scale farmers may therefore find alternative incomes in livestock when climate affects crops adversely, but this is not the case for farmers who irrigate and most large-scale farmers. This is expected, given that most of these farmers are specialists and therefore cannot easily shift to other types of farm activities.

We have noted that climate does affect crop farming in South Africa, but to properly access such impacts we estimate the marginal effects, using the estimated models in Tables 9 and 12.

6.3 Marginal impact of climate

The estimated marginal effects of temperature and precipitation on crop net revenues are presented in Tables 13 and 14 respectively.

Table 13 shows the marginal effects of a 1°C increase in temperature on crop net revenues for the different types of farmers in the country and also for the summer farming season (summer and fall periods) and the winter farming season (winter and spring periods). It also shows the estimates for the 'without' and 'with' adaptation models.

The results show that temperature increases in the summer farming season would have a negative effect on crop net revenues for all types of farms in the country. More importantly, higher temperatures in the fall will not augur well for crop farming. On the other hand, increases in temperature in the winter farming season will positively affect crop net revenues. The net effects of the seasonal impacts indicate that a 1°C increase in annual temperatures will lead to an increase in crop net revenue of US$80 for the whole country, US$191 for irrigated farms, US$588 for large-scale farms and US$60 for small-scale farms. However, dryland farms will see a fall in their net revenues by about US$50 per hectare. Estimated elasticity indicates that a 1% increase in temperature will lead to 4% increase in net revenues for the whole of South Africa, 7% for irrigated farms, 27% for large-scale farms, 4% for small-scale farms, but a fall of 5% in net revenues for dryland farms (Table 13).

The policy lesson for adaptation is to take advantage of the positive effects of climate change while reducing the negative ones. In the second part of Table 13, one would therefore expect that including adaptation related variables (socio-economic variables) if they are effective will increase the magnitude of the relationship between climate variables and crop net revenues for positive values while reducing the negative values. This seems to be true for only the country as a whole (full sample) and irrigated farms, which implies that for the country as whole and for irrigated farms, adaptation variables may help reduce the negative effects and take advantage of the positive effects of high temperatures. For these sets of models, either the negative effects of the summer season have decreased or the positive effects of the winter season have increased, with the net annual effects higher than in the without adaptation estimates. For the whole sample, the net effect of a 1°C increase in temperature on net revenue has increased from US$80 to US$124, and for irrigated farms from US$191 to US$259, with higher elasticities of 7 and 9 respectively. In both instances the estimates are also significant. For dryland farms the inclusion of adaptation related variables rather aggravates the negative effects of increased temperature, with the annual negative effects increasing from -US$50 to -US$68 with an elasticity of -7.25. What this indicates is that though the adaptation related variables are important in helping to control adverse climate effects, if they are not properly implemented they may rather aggravate the problem. One important variable to mention is extension services, which if not properly undertaken may worsen the problem. For both large-scale and small-scale farms there is also a worsening of the impact. There is the possibility of a stronger dryland effect than the irrigation effect in the two models, resulting in reduced positive impacts for these two types of farming systems (Table 13).

The marginal impacts of precipitation on crop net revenues are presented in Table 14 for the 'without' and 'with' adaptation models. The with adaptation estimates indicate that increases in precipitation will lead to increases in net revenues for all the types of farms except for small-scale ones, with more significant impacts for dryland farms. Again the relative seasonal impacts are important. The summer farming season, surprisingly, indicates that increases in precipitation affect net revenues negatively. This is mainly due to the strong negative influence of the fall period. The implication is that the timing of the rainfall is important for agricultural activities. Early rainfall in the summer farming season would be more beneficial to crop farming than later rainfall in the fall season. Therefore shifts in the timing of the rainfall as a result of climate change may be damaging to crop activities unless farmers are aware of these shifts and adjust their farming activities appropriately in the summer farming season. Except for dryland farms, there the influence of increased precipitation in the winter season would be positive. The annual estimates indicate that an annual increase of 1mm/month of precipitation will have a positive effect on net revenues, with the exception of those of small-scale farmers, which indicate a negative value though not a significant one. As expected, dryland farms may benefit more, as indicated by the significance of their positive effects and relative estimated high elasticity of 7. For the country as a whole, an annual net gain of US$2 is expected with a 1mm/month increase in precipitation: US$29 for irrigated farms and US$25 for large-scale farms, but -US$28 for small-scale farms, with corresponding elasticities of 0.37, 3.12, 3.25 and -6.9. It follows that a decrease in precipitation by the same amount will reduce net revenues by similar amounts.

Including adaptation variables seems to have had a positive effect for both irrigated and dryland farms and significant for the latter. The results indicate that a 1mm/month increase in precipitation will now lead to increases of about US$17 and US$11 in crop net revenues for irrigated and dryland farms respectively. A decrease in precipitation will lead to similar falls in net revenues. The import is that with adaptation a fall in precipitation will lead to a reduced impact and a significant one for dryland farms. So with a decrease in precipitation adaptation strategies seem to work, especially for dryland farms. The annual impacts for the full sample, and large and small-scale farms are all negative, with values for small-scale farms being significant. For the full sample, even though the negative impacts in the summer season and the positive impacts in the winter farming seasons have both decreased, and therefore adaptation has helped reduce the link between precipitation decreases and net revenues, the relative negative impacts seem to overshadow the positive ones. For large- and small-scale farms, the annual impacts are negative, and they are significant for small-scale farms. That is, a decrease in precipitation will rather be beneficial and significant for small-scale farmers. Again, the relative impacts in the two main seasons affect the annual impacts.

In general for the whole of South Africa one would expect a range of –US$2.46 to US$2.04 change in annual crop net revenues if precipitation increases/decreases by 1mm/month, for irrigated farms a range of US$16 to US$28, for dryland farms US$11 to US$20, for large-scale farms -US$12 to US$25, and for small-scale farms -US$28 to -US$32. The impact is more significant for dryland and small-scale farms. Significant impacts are expected for dryland farms; what is surprising is the result for small-scale farms. One reason for this is the relative negative effect of the winter farming season that outweighs the positive effect in the summer farming season.

6.3.1 Provincial level marginal impacts of climate

Using the full sample estimates in Tables 9 and Table 12 the marginal impacts of climate at the provincial level are assessed. The results are presented in Tables 15 and 16. The marginal impact estimates of increased temperature indicate that in general almost all the provinces will experience positive mean annual impacts. A 1°C increase in temperature will lead to an increase in mean annual crop net revenue with a range of US$22 to US$175, with significant values for Gauteng, Limpopo and Mpumalanga. This follows the general trend for the whole country as indicated in Table 13. The only province which would experience a negative mean annual impact is the Northern Cape of -US$93 per hectare. Again, this annual estimate hides the significant difference in the seasonal impacts, which is crucial for policy. In Table 15 all the provinces experience negative impacts on net crop revenues in the summer farming season while all the provinces also experience positive impacts in the winter farming season. These differences are important in the sense that depending on the relative impacts of the two seasons a province may have a positive or negative impact. This is the particular situation in the Northern Cape, where even though the trends in the summer and winter farming seasons follow the general trend in the other provinces, the positive winter farming season impact is not high enough to offset the negative summer farming season impact. It is therefore important to take advantage of the positive impact while limiting the negative impacts. This is what adaptation is expected to do.

In the second part of Table 15 the influence of adaptation on these impacts is tested. What the results indicate is that in all the provinces the annual positive impacts have been enhanced, while negative impacts for the Northern Cape has been reduced. A 1°C increase in temperature now leads to an increase in net revenues in the range of US$60 to US$225, with the Northern Cape now experiencing a lower negative impact of -US$45. This is mainly because with adaptation most of the negative effects in the summer have been reduced (Table 15). The adaptation options tested in the model have therefore helped to control temperature effects in the summer. This does not, however, seem to work very well in the winter farming season, as the winter positive impacts have fallen somewhat.

The marginal impact of increased precipitation at the provincial level is, however, not very straightforward and follows the trend for the whole country. The results indicate that some of the provinces will experience mean annual benefits while others will experience negative effects (Table 16). With a 1mm/month increase in precipitation, the Free State, KwaZulu-Natal, the Northern Cape, the North West Province and the Western Cape will experience negative impacts in the range of -US$4 to -US$29. It follows that a fall in precipitation will rather lead to mean annual benefits for these provinces, though these impacts are not significant except for the North West Province. With the same increase in precipitation the Eastern Cape, Gauteng, Limpopo and Mpumalanga will experience a positive impact in the range of US$3 to US$116, or the same range of negative effects with decrease in precipitation, with significant values for Limpopo. It follows that these provinces will be more affected by a similar decrease in precipitation. Again there is a significant difference in the impacts in the farming seasons and the specific seasons. Higher precipitation levels will have a positive effect in the summer and winter farming seasons, but negative impacts in the fall season with both positive and negative impacts in the spring season. What this again indicates is that the timing of the rain is important. If it starts early in the summer farming season and also in the winter farming season, then most of the provinces will benefit. But if it does arrive late, especially in the fall season, farmers will not benefit. Such information should help policy makers plan when and how to help farmers, given information on the timing of the rain to reduce any negative effect. The marginal estimates using the with adaptation model either reduce the positive impacts of precipitation or increase the negative ones (Table 16).

The estimated marginal impacts of the climate variables indicate that there would be winners and losers from climate change amongst the different types of farmers in the country. One important focus is dryland farmers who generally have negative impacts from increased temperatures. Moreover, seasonal effects may also be different. It is therefore important for farmers and policy makers to take advantage of the gains while trying to limit the losses and by so doing controlling the adverse effects of climate change. It is important to know where the gains are and who the winners will be, so as to provide the necessary support to take advantage of the gains. Similarly, it is important to know who the losers are and where the losses are, to also provide the necessary support to limit the losses. By so doing, the net adverse effect could be reduced. The seasonal differences are important for policy makers, to know when and where to take advantage of climate change. For example, it may be possible to grow some of the current summer crops in the current winter growing areas such as the Western Cape. Policy makers may therefore need to inform farmers about this possibility. These seasonal differences of the impacts are extremely important if the adverse effects of climate are to be controlled.

Adaptation related variables may help reduce the negative effect and take advantage of the positive effect of temperatures in the winter seasons but if not properly implemented may worsen the adverse climate change effects.

6.4 Forecasts of climate impacts

We examined a set of climate scenarios predicted by the hydrology analysis for the GEF study (Strzepek & McCluskey, 2006. The study uses synthetic or GCM (General Circulation Model) based climate change scenarios as input to a Water Balance (WatBal) model to provide insights into the changes in hydroclimatic variables that can be expected under different climate change scenarios. The scenarios represent a range of equally plausible future climates (expressed as anomalies of the baseline 1961–1990 climate) with differences attributable to the different climate models used and to the different emission scenarios that the world would follow. We used three main scenarios derived by Strzepek and McCluskey (2006) using three different models (CSIRO2, HadCM3 and PCM) in conjunction with the A2 emission scenarios plausible for South Africa. We then examined the consequences of these climate change scenarios on net crop revenues in these two periods using the estimated model in Table 7. This is because the prediction relates mainly to climate variables and not the other variables in the model. The predicted changes for temperature and precipitation plus the impacts on crop net revenues for 2050 and 2100 are presented in Table 17. All three models predict increased temperatures in the range of 2.3°C to 3.9°C by 2050, and even higher levels of 3.9°C to 9.6°C by 2100. All three models also predict falls in precipitation in the range of 2% to 8% by 2050 and 4% to 8% by 2100.

The estimated climate scenarios impacts indicate that, comparatively, dryland farms will be more affected by increased temperatures and decreased rainfall. Comparing large- and small-scale farmers, the latter will also be more affected.

For 2050, given the A2 scenarios, crop net revenues are expected to fall by US$5.14 to US16.26 (or 1.7% to 5.3%) per hectare for the whole of South Africa, US$5.34 to US$20.23 (or 1.2% to 4.3%) for irrigated farms, US$41.63 to US$55.24 (or 26.2% to 27.7%) for dryland farms, US$20.65 to US$49.39 (or 5.8% to 13.8%) for large-scale farms, and US$25.05 to US$204.60 (or 9.9% to 20.7%) for small-scale farms. The negative effects are expected to increase by 2100, with a fall in crop net revenues ranging from 9% to as high as 90%, with small-scale farms to be most affected. The least to be affected are irrigated farms. This also indicates the crucial positive effects of irrigation as a cushion for adverse climate effects. Adaptation strategies, if properly implemented, are expected to reduce the negative impacts of the climate scenarios on crop net revenues, especially with respect to temperatures. In the next section we discuss some of the adaptations currently being used by farmers across the country.

7. Current adaptation of farmers to perceived climate variability and change

We noted in the previous section that adaptation if properly implemented helps control the adverse effects of climate change. This section presents the outcome of the survey of farmers' adaptation to climate variability and change, which investigated the extent of their awareness of climate variability and change and the types of adjustments they have made in their farming practices in response to these changes.

7.1 Farmers' perception of changes in the climate

Summary statistics indicate that about 72% of the respondents were of the opinion that there have been some changes in the climate over the years, with higher temperatures, delays in the timing of the rain and a reduction in the volume of the rain. Perceptions varied somewhat throughout the nine provinces (Table 18).

In the Eastern Cape, 45% of the respondents had noticed long-term change in the pattern of temperature and rainfall. This group think there has been a general increase in temperature and a decline in the volume of rainfall. Summers are becoming longer and hotter and winters shorter and warmer. However, about half of the respondents did not agree with this observation. For them, the changes that have occurred are not long-term changes but rather a consistent occurrence over a ten-year cycle in the climate, where in every tenth year the province experiences droughts and warmer temperatures (Table 18).

In the Free State, 75% of the respondents had noticed long-term changes in the climate of the province. For these farmers, it is becoming windy, dusty, drier and hotter. Temperatures are increasing and the volume of rainfall has decreased. There has also been an increase in the occurrence of droughts and the timing of the rainfall fluctuates from year to year. These changes in the climate have necessitated a shift in the agricultural season, with the planting period now starting three weeks later. The other 25% of the respondents in this province had not noticed any long-term changes in the climate, mainly because many of them have been farming for less than three years.

All the farmers in the Gauteng Province were of the opinion that the temperature has increased over the years. They have also observed a decrease in the volume of the rain, and a delay in the timing of the rains, especially the summer rain, which has shifted from early September to late October or early November.

In KwaZulu-Natal, 90% of the respondents had noticed a long-term change in the temperature and rainfall in the province. According to them, the province is becoming hotter, with the maximum temperature increasing from 28°C to 32°C since the late 1990s. They had also observed an increase in the occurrence of droughts. The beginning of the winter season has also shifted from early April to May. For most of them the rainfall has become erratic from year to year. The annual average rainfall has decreased and its distribution throughout the year has also changed, being concentrated into shorter periods and much heavier.

Eighty-eight percent of the respondents in the Mpumalanga Province have observed changes in the climate, indicated by higher temperatures and a decline in the rainfall. To them the climate is more dry and hotter. The occurrence of extreme events, such as heavy showers, hail and drought, has also increased over the years. The average annual rainfall has decreased by nearly half from about 500mm to 300mm per year. The summer rainy season has also shortened from the previous September – February to October – January (Table 18).

In the Northern Cape Province, 72% of the respondents observed that the climate is getting worse. The volume of rainfall has reduced and it fluctuates a lot from year to year. The temperature also varies from one extreme to another. They have experienced not only high temperatures but also very cold ones.

In the Limpopo Province, the views of the farmers were somewhat different. About half of them are of the opinion that there has been no noticeable change in the climate, while the other half have noticed less rainfall and higher temperatures.

Seventy-five percent of respondents in the North West Province perceived that the climate is changing, with the volume of rainfall decreasing and temperatures increasing. For them, there has been a shift in the duration of winter and summer. They have experienced longer and colder winters, and summers have become hotter.

In the Western Cape Province, for about 50% of the farmers the climate seems to have been more or less the same for the past few years except for very high temperatures during the last twelve months (2002/2003 farming season). However, the other 50% observed that the climate is becoming drier and hotter, the winter season has shortened and the rain is coming later than expected (Table 18).

7.2 Long-term and short-term adjustments to climatic change

This section focuses on the various adjustments that farmers in the survey have made in their farming activities in response to the perceived changes in the climate. About 30% of them did not have any adaptive strategies mainly because they lack the necessary funds, information and government support. Although money appears to be a constraint, the other 70% of the farmers interviewed across South Africa identified a number of adaptation options they are applying to address the changes they perceive in the climatic (higher temperatures and the changed timing and reduced volume of rainfall). There was, however, no significant difference between long-term and short-term adjustments. The main adjustments in farming activities are discussed below.

(a) Adjustments in farming operations

Some of the adjustments made by farmers in their operations include changes in the planting dates of some crops, planting crops with a shorter growing period such as cabbage, and planting short season maize (120 days – 140 days). Others include the increased use of crop rotation and the early harvesting of some crops. In Kwazulu-Natal for example, farmers prefer to cut their sugarcane at an early stage to avoid the loss of production due to the dryness of the cane (as a result of increased temperature) if they have to wait for the cane to mature in the field.

With the current situation of heavier rainfall, concentrated in shorter periods and starting earlier (previously early September and now late October in some provinces), farmers have responded by (i) delaying the start of the planting period, (ii) increased use of modern machinery to take advantage of the shorter planting period, (iii) collection of rain water by making furrows near the plants, and (iv) increased use of irrigation.

In response to higher temperatures, farmers have resorted to using (i) heat tolerant crop varieties, (ii) crop varieties with high water use efficiency, (iii) early maturing crop varieties, and increased crop and livestock farming (mixed farming). For example, because of the high temperatures, sugarcane farmers have shifted to producing macadamia nuts and tea, which they consider easier to irrigate than sugarcane.

Livestock farmers have also adopted numerous practices aimed at efficient use of water and scarce fodder. There is a general tendency to resort to more heat tolerant breeds rather than the traditional ones, and most livestock farmers now also produce their own fodder, such as lucerne or maize, and stock it for use during the long dry seasons. In response to the long drought periods, farmers have adjusted the stocking intensity of their livestock by selling their animals at younger ages. Another practice is to change the timing, duration and location of grazing.

(b) Increased chemical application

With higher temperature and increased evapotranspiration, farmers have resorted to increased application of chemicals such as Erian to slow down evapotranspiration. They also apply more farm manure to keep the moisture content of the soil higher and retain the soil fertility. More lime is also applied to maintain the soil's correct pH balance.

(c) Increased use of irrigation

With water being the most important factor limiting agriculture in South Africa, irrigation appears to be the most appropriate adaptive strategy. Hence 65% of the respondents choose irrigation as an option to adjust to climatic changes. Farmers have also shifted from flood irrigation to sprinkler irrigation for an efficient use of the limited water. Several farms have also built their own boreholes to make effective use of underground water. There has also been increased use of wetlands for agricultural production.

(d) Shade and shelter

When it is hot, livestock farmers plant trees to provide natural shades for their livestock or as a wind or hail storm break. In South Africa, farmers generally plant pine trees and *Acacia karoo* and *Celtis africana* trees for this purpose. In some instances, farmers use fishnets, grass, and plastics as coverings to protect their plants against dryness and heat, and cold and frost. Heating provided by firewood and paraffin heaters is also used by livestock farmers to protect their animals against the cold.

(e) Conservation practices

In response to the increased occurrence of droughts farmers have adopted various soil conservation practices in order to maintain or improve soil moisture and fertility. Principally to fight erosion, farmers have built many small dams or planted trees around their farms. Farmers have also increased their fallow periods by as much as one to two agricultural seasons (instead of continuous cropping), to allow the land to restore its nutrients. Another conservation technique farmers use to protect the soil against erosion is to keep the crop residues of the previous harvest on the land. To preserve soil moisture, cool the soil surface and stabilize soil temperature, they used mulching (layers of muck, peat, compost and plastics) to cover the land. To avoid excessive extraction of nutrients in the soil of their farms, farmers have also reduced the density of crops or livestock on their land.

(f) Other practices

To reduce the risk of losing income when farm produce decreases as a result of the increased variability in the climate, some (especially large-scale farmers) have insured their farms, while others (especially small-scale farmers) are increasing their involvement in non-farm activities. Most large-scale farmers have also opted to taking lower risks by reducing their cropping areas to manageable sizes.

8. Summary, conclusions and policy implications

This study is an attempt to assess the impact of climate change on crop farming activities in South Africa, using a revised Ricardian model for the economic assessment of impacts. The Ricardian model examines how long-term farm profitability varies with local climate, such as temperature and precipitation, while controlling for other factors. In the revised model applied in this study, other important sources of water, such as runoff and irrigation, are included in the model. Relevant socio-economic variables are also assessed for the extent to which they control or worsen the adverse impacts of climate change on the crop sector. Two main models of the Ricardian model were estimated: without adaptation and with adaptation. The former include only climate, soil and hydrology variables, while the later in addition to these variables include relevant socio-economic variables such as irrigation, access to market and agricultural extension services. These two main models were estimated for the full sample, irrigated farms, dryland farms, large-scale farms and small-scale farms to assess any significant differences in the impacts of climate change on these different farming systems. To clearly assess the impact of climate variables, we also estimated the marginal impacts of unit changes in temperatures and precipitation on crop farming activities for the different farming systems, and also for the nine provinces in the country, using the without adaptation and with adaptation estimated models. Using selected climate scenarios we were also able to predict the extent to which projected climate changes will affect net revenues in 2050 and 2100.

The results indicated that there is a significant difference between the impacts of climate on irrigation and dryland farms. The differences between the impacts on large-scale farms and small-scale farms are, however, not very clear-cut, because they are overshadowed by the impacts of whether a farm is irrigated or not. That is, whether a farm is irrigated or not seems to be more relevant in climate analysis than the scale of the farm.

Estimated results indicated that climate variables of temperature and precipitation are very relevant for agricultural activities in South Africa and more so for dryland farming, especially with respect to precipitation. Irrigated farms are cushioned against adverse climate effects by having a substitute for rainwater. Climate impacts were also found to have, to a large extent, a non-linear relationship with net revenue. That is, increases in climate variables, especially for precipitation, will be beneficial to crop farming but beyond a certain limit the impacts will be negative.

The types of soils in particular locations will also affect crops and net revenues and therefore the extent to which climate affects the crop faming sector. Of the ten major soil types identified in the country, four major ones were tested in the models. Two major types, acrisols and arenosols, were found to have a positive effect on crops and therefore may help control adverse climate effects. Two others, vertisols and xerosols, were found to affect crops negatively and therefore may worsen any adverse climate effects on the crop farming sector. This applies to all the main farming systems – irrigated, dryland, large-scale and small-scale.

In addition to irrigation, other sources of water also affect crops. We tested the influence of hydrology variable runoff to assess this. The outcome indicated that runoff affects crops positively, given that it positively influences the texture and therefore the productivity of the soils and this would also reduce the adverse climate effects in a given area. However excessive runoff will erode such expected benefits. The impact is also relevant for all the farming systems in the country.

More important are the relevance of socio-economic or adaptation related variables in controlling or worsening climate effects. As mentioned, irrigation will play a crucial role in this direction for both large-scale and small-scale farmers. The size of cropland area is also important, especially for dryland farmers, since a larger area enables them to spread their risk from adverse climate effects and therefore reduce the net effects from the change. Larger cropland area may provide for efficient use of resources and the possibility of growing different crops or embarking on different agricultural activities. Livestock farming was also found to be a possible adaptation option, but its effects are different for irrigated and large-scale farms on one hand and dryland and small-scale farms on the other. For the former group of farmers, livestock complements their crop farming activities while for the latter livestock more often substitutes for crop farming activities. This is expected given that large-scale farmers and those who irrigate are specialists and therefore find it difficult to switch to other types of farming in response to adverse climate effects. Small-scale farmers and dryland farmers, especially the latter, are more likely to switch to livestock farming in response to adverse climate effects because in most cases they have limited alternatives. Farmers' experience, in terms of their number of years in farming, would also help them cope positively with adverse climate effects, especially in the case of large-scale farmers. Access to markets also cushions farmers against adverse climate effects. Easy accessibility of markets means relatively higher prices for their products and therefore helps them to cover additional costs caused by the adverse effects of climate. One unexpected result is the negative impact on crop farming activities of public extension services. One would expect this to positively influence crop net revenues. However, it is possible that the information provided by this service is not very helpful for crop farmers in South Africa. On the other hand, other sources of extension services, such as the media, private extension services and neighboring farmers, seem to positively influence crop farming activities, which is why a majority of farmers in the country do consult these other sources.

Estimated marginal impacts of the climate variables on crop net revenues also indicated different results for temperature and precipitation and also for the four main farming systems. Unexpectedly, an annual increase of 1°C in temperature will have a positive impact on annual crop net revenues for all farms except dryland ones. A net increase of US$80 per hectare is expected for the whole of South Africa: US$191 for irrigated farms, U$S588 for large-scale farms and US$61 for small-scale farms, but a fall of US$50 for dryland farms. However, what these annual estimates hide is the seasonal differences in the impacts. Such an increase in temperature will affect crop farm net revenues negatively in the summer farming season but positively in the winter season. These differences are important to help find ways to limit the negative effects and take advantage of the positive ones. Adaptation related variables help to increase the positive impacts while reducing the negative impacts of increased temperature. The estimates show that including adaptation related variables in the estimation helps to increased the positive impacts while reducing the negative impacts for all the types of farming but not significantly for dryland farms. So dryland farms are still expected to have annual negative impacts from a 1°C increase in temperature. However, this could be controlled if the positive impacts in winter could be enhanced while reducing negative impacts in summer. All the provinces except the Northern Cape will also experience annual positive impacts from a 1°C increase in temperature. Again, the differences in the seasonal impacts are very important, with the summer farming season experiencing a negative impact while the positive impact is experienced in the winter.

Marginal impacts of increased or decreased precipitation on net revenues are, however, not that straightforward. Not considering adaptation related variables, estimates indicate that all the farming systems will experience positive annual net revenue impacts from increased precipitation, with the exception of small-scale farms. With a 1mm/month annual increase in precipitation, an increase in net revenue of US$2 is expected for the whole country, US$29 for irrigated farms, US$20 for dryland farms (which also very significant) and US$25 for large-scale farms, but a fall of US28 for small-scale farms (though this is not very significant). Similar decreases or increases are expected with a decrease in precipitation. Again, seasonal differences in the impacts are important. Rainfall in the early part of the summer farming season would be beneficial, while later rainfall would be harmful. Early winter rainfall will also be beneficial for the winter farming season. These differences will influence whether the annual impact of precipitation will be beneficial or not. This means that changes in the volume of rainfall and the timing of the rainfall significantly affect net revenues. Farmers not aware of these possible shifts will be negatively affected, so information provided by extension and other agriculture related organizations may be helpful. Including adaptation related variables changes the extent of the estimated marginal impacts but not very significantly, except for dryland and small-scale farmers. For dryland farmers, the positive impacts from increased precipitation are reduced while the negative impacts for small-scale farmers are increased. For dryland farmers, the implication is that with adaptation the link between precipitation and crop net revenue weakens and therefore a decrease in precipitation will reduce the drop in crop net revenues.

At the provincial levels, some farmers would experience positive impacts from increased precipitation while others will experience negative impacts. This is a reflection of the unclear impact of change in precipitation on crop activities in the country. It is also a reflection of the high degree of variability of the rainfall experienced the recent past. Again, the seasonal differences are important, with late summer and winter rainfall being more harmful to crops than rain early in the season. Again adaptation related variables change the extent of these relationships.

Three climate scenarios which are plausible for South Africa indicate that temperatures will increase by between 2.3°C and 9.6°C while precipitation will decrease by between 2% and 8% by 2100. Using these estimates, the study predicts that crop net revenues will fall by as much as 90% by 2100, with small-scale farms being the most affected. But there is the possibility that adaptation could reduce these negative effects.

The study also assessed farmers' perceptions of climate change and the extent to which these perceptions have influenced their current practices with respect to adapting to the perceived changes in temperature and precipitation. Most farmers were of the view that they have observed increased temperature and changes in precipitation, such as the reduced volume of the rainfall, shift in the timing of the rainfall and the shortened period of the rain, especially in the summer season. They also asserted that these changes have been and are affecting their farming activities in the summer season. Given this perception, and depending on the farming system, farmers have adopted several coping mechanisms which could be categorized into six main types: (i) adjustments in farming operations, (ii) increased chemical application, (iii) irrigation, (iv) provision of shelter and shade for crops, (v) soil conservation practices and (iv) insurance policies and other sources of income to cover their risks. However, the most common adaptation options across all types of farming activities in the country in response to higher temperatures and lower rainfall are adjustments in farming operations, specifically changes in the variety of crops and livestock breeds, and increased irrigation.

These results have several policy implications for the way climate change could be managed so as to reduce the damage to the crop farming sector. Policy makers may need to accept the fact that climate impact on agriculture, especially in the summer, is real and that farmers are doing their best to adapt to it. It is expected that there will be winners and losers. Policies may therefore be needed, and they should be directed at taking advantage of the gains and reducing losses by identifying and assessing the efficiency of current coping mechanisms and finding ways to support them.

Assessment of the relative importance of irrigation and farm type indicated that whether a farm is irrigated or not is more important in climate impact assessment than the scale factor. Scale does matter, but what is crucial for controlling any negative impact on crop net revenue in the country is the access to sources of water other than rain, such as irrigation. Given also that 65% of the respondents chose irrigation as a way of adjusting to climatic changes indicates its importance as an adaptation option. Policy makers should therefore see this as an important policy instrument in controlling the adverse effects of climate, for both temperature increases and decreasing precipitation. There would therefore be a need to build more dams and increase the capacity of existing ones in the country. But given that water is already scarce in the country and that 50% of the water resources are already being used for agriculture, as the demand increases with climate change further pressures will be put on the resources. This means that the country’s water resources must be efficiently managed. The 19 defined Water Management Areas (WMAs) would therefore be important in the efficient distribution of water. But increasing water scarcity will mean more research needs to be done into new crop varieties and new animal breeds that are heat tolerant and less affected by water stress.

Related to new crop varieties is improved technology. Our analysis indicates that improved technologies would also help control adverse effects of climate change. Access to markets, both local and international, is also a crucial adaptation option for farmers. Most large-scale farms have this access and therefore can better manage excessive costs from adverse climate impacts. Policy makers must therefore help improve access to markets for all types of farmers, especially small-scale ones, to control the adverse impact of climate on this sector. Farming experience also helps control the impacts. This means that training for farmers, especially small-scale ones, in various modern farming practices is important.

Proper and efficient extension services are also possible adaptation options. As our results indicate, public extension services may be important, but if information provided by these services is not relevant it may rather aggravate than mitigate the adverse effects of climate change on the sector. It is therefore important to assess the extension services in the country and improve their efficiency, especially for small-scale farmers who seem to rely very much on information provided by this service.

The study also indicates that when assessing the effect of climate change in a country with diverse climate and cropping patterns, it is not only the overall effect, (which does tell a story) that is relevant but also and more importantly the effects in the different seasons, different farming systems and different agro-ecological and provincial levels. In this way we can assess where the losses are and who the winners are and reduce the losses while taking advantage of the gains. If this is done it is possible that the overall expected negative effects can be reduced. Because this study shows higher temperatures will be beneficial in winter but harmful in summer, and changes in rainfall will have varying effects, keeping farmers informed will be crucial. Ways must be found to take advantage of the benefits and limit the damages, so as to achieve overall positive net benefits. For example, it has been observed that even though increased temperatures may harm dryland farms in the summer they tend to benefit them in winter, which may override the damage done in summer. Relevant policies and adaptation options should be directed at making this possible, so that climate change damage can be reduced and benefits enhanced.

The study has also indicated the importance of irrigation and to some extent scale factor in climate impact analysis. But the scale effect may have been unclear because of the influence of irrigation. A possible extension of this study would be to compare and contrast the effects for large- and small-scale irrigated farms and large and small-scale dryland farms, to clearly assess the scale effect of climate change in South Africa. It would also be interesting to undertake such analysis at the agro-ecological and provincial levels. This would help in the formulation of more targeted policies, especially at the provincial level

There are also other important socio-economic influences on crop net revenues which have not been considered in this report owing to lack of data. One important factor is the current land reform in the country. It should be relevant for policy to access how this will affect long-term investments in, for example, irrigation and heavy machinery, which have been identified as crucial for controlling climate effects, and also how to take advantage of the benefits

Our analysis also shows that keeping livestock may be a possible adaptation strategy, especially for dryland farms. This could be explored further by assessing the effects on total farm income. An assessment of which varieties of livestock complement crop production and which kinds are substitutes for crop faming would be important for implementing this possible adaptation strategy. In the former case it would help enhance the benefits from climate for crop farming and in the latter farm incomes could still be maintained even if crop farming activities are negatively affected since farmers can easily switch to livestock farming to maintain their income levels.

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Appendices 1 - 3: Methods for survey design, sampling and data collection

A1 Introduction

The South African sampling design was based on two publications by Statistics South Africa, (StatsSA 1998 and 2002). The 1998 publication refers to the census of agriculture in 1993 at the district level in each of the nine provinces and the second is a survey of large- and small-scale farms in 2000 at the provincial level.

The 2002 report indicated that there were about 1,100,000 farming operations (both large- and small-scale) in the country. It noted, however, that a farmer could run more than one farming operation. The number of farm households therefore do not necessarily equal the number of farming operations. However, since there was no information on the number of farming households in the report this sample methodology uses the number of farming operations as a proxy for the number of farming households, and as the basis for the allocation of the farm households sample at the provincial level.

The 2002 report also has no information on farming operations at the district level; the sampling design therefore relied on the 1998 report (which is the only available information on farming operation at the district level) as the basis for the selection of the district sample in each province. The two reports were then used as the basis for the allocation of the farm household sample for each of the selected districts in each of the provinces.

A2 Sample design and sample

The design of the samples attempts to capture the diverse agricultural patterns, farming strata, type of cultivation (dryland and irrigation), major crops and cropping areas and livestock areas in South Africa.

There were ten main stages in the sample design. These involved the distribution of the farm household sample at the provincial level, the selection of districts in each province and the distribution of the farm household sample at the district level. In the selection process, the magisterial districts were used instead of the municipal districts, because there was better information on farming activities on the former district demarcation than the latter.

A2.1 Farm households sample size (Stage 1)

The starting point for the sample design was to select 800–1000 farm households from 30–60 districts in the nine provinces in the country.

A2.2 Sample size for large-scale and small-scale farm households (Stage 2)

Here we estimate the proportion of the total sample size of 800–1000 farm households to be allocated to large-scale farms and small-scale farms. According to the SSA (2002), there are an estimated 150,000 large-scale farm operations and 943,000 small-scale farming operations in South Africa. That is large-scale farming operations forms about 14% of total farming operations and small-scale farming operation consists of 86% (Table A1. It follows that a good representation of these two farm types in the sample should also have the same proportionate share in the sample size. It was estimated that the total sample for South Africa should have 112–140 large-scale farms and 688–860 small-scale ones for each of the nine provinces (Table A1).

A2.3 Distribution of sample at the provincial level (1) (Stage 3)

We followed the same procedure as in Stage 2 for allocating the sample size of large- and small-scale farms, in Table A1, for each province, based on the proportion of the provinces' farming operations in the total number of farming operations in the country (Table A2).

The following observations could be inferred from Table A2:

(i) Gauteng (GU) Province is the least active farming province.

(ii) KwaZulu-Natal (KZ) and to some extent the Eastern Cape (EC) are the most important farming provinces for both large- and small-scale farming.

(iii) For large-scale farming, the most important provinces in order of priority are the Free State (FS), KwaZulu-Natal, the Western Cape (WC), the North W (NW) and the Eastern Cape.

(iv) For small-scale farming the most important provinces in order of priority are the Eastern Cape, Limpopo (LP), KwaZulu-Natal, Mpumalanga (MP), the North West (NW) and the Free State (FS). For the Western Cape, the Northern Cape and Gauteng there was no information on the existence of small-scale farming operations.

A2.4 Distribution of sample at the provincial level (2) (Stage 4)

Given the basis of the sample distribution for each province, in Table A2, there would not have been enough sample to analyze large-scale farming activities in the country, even though they contribute about 86% of the country's agriculture GDP. We therefore decided to revise the sample. We increased the large-scale farms sample by about 184% and decreases the small- scale sample by 30%. These revisions seem arbitrary; however, they took into consideration the proportion of the two types of farms in the total number of farms in the country and the relative contribution of the two types to total farm revenue. The objective of these revisions was not only to have a reasonable sample size for large-scale farming operations in the country but also to maintain the higher proportion of the small-scale farms in the sample (Table A3).

A2.5 District sample in each province (Stage 5)

There are about 374 magisterial districts in the nine provinces in South Africa. A good representation of the district sample should also reflect the proportion of the total sample to the number of farming operations in the country (that is, {[Farm household sample/total number of farm households] * number of districts}). However, given the small number of the sample size (800–1000) in relation to the large number of farming operations (1,100,000), this estimate would have resulted in an insignificant number of districts, which would not be in the expected range of 30–60 districts as agreed upon at the project's workshop.

The design therefore started with an arbitrary district sample of 33. Given the farm household sample size of 800–1000, and a district sample of 33, there was the possibility of a farm household sample size in the range of 30–35 for each selected district, which would have provided a reasonable sample size for a district level analysis.

The arbitrary district sample of 33 and the total number of districts of 374 was used as the basis of the sample of districts in each province. The sample district in each province is the proportion of the province's number of district in the total number of districts in the country (Table A4).

A2.6 Farm household sample size in each selected district in each province (Stage 6)

Using Tables A3 and A4 we were able to allocate the farm household sample to each of the sample districts in each province. The result reflects both the farming density in each province and the size of the province in terms of the number of districts. The farm household sample for each province was divided equally among the number of sample districts in each province. Where the sample size for a type of farm in the province was less than 30, it was allocated to one district and the sample in the other type of farm was distributed equally among the rest of the sample districts in the province (Table A5).

In order to be able to make a district level comparison in KZ between large- and small-farmers given the same characteristics in the district we reduced the number of districts in KZ from 6 to 5 and sampled a significant number of both large- and small-scale farms in a given district.

A2.7 Selection of districts in each province (Stage 7)

Given that the sample size for some of the districts in Table A5 were less than 30 we revised the sample sizes for all the districts to 35. This revision was expected to make it possible for a reasonable number of farm households in each district for a district level analysis. We then arrived at a total sample size of 1190 farm households in 32 districts (Table A7.. The choice of districts in each of the nine provinces was based on the weighted criteria indicated in Table A6.

Total dry land crop farming was allocated the most weight because it is the most affected by climate change. Moreover, small-scale farmers most vulnerable to climate change are associated with this type of farming. The number of farms has the next highest weight, since the higher the number of farm units in a district the more the district is susceptible to climate change. Irrigation activities follow next, given that the activity would be affected by changes in runoff due to climate change. The total land under farming followed next. Even though this was an important factor it was not as important as the preceding three agricultural indicators in terms of the expected impact of climate change. Total land under animal farming was the least important criterion because the focus of the study was on crop farming.

Information provided at the magisterial district level by SSA (1998) on the census of agriculture in 1993 was the basis for the above analysis in Table A6 to select the districts in each province as indicated in Table A7. It is true that farming activities may have changed over the period since 1993, so such information may not be a good basis for choosing the districts. However, this is only information available and it was the best available basis for selecting the districts.

The number of district in KZ was increased from 5 (in Table A5) to 7 because the initial sample size for small-scale farms for the districts is relatively higher than 35.

A2.8 Large-scale and small-scale sample farms in each district (Stage 8)

One major problem associated with the district samples in Table A7 was the fact that in districts with only small- or large-scale farms, estimated net revenues may be biased in favor of only one type of farming. However, given the higher proportion of large-scale farms in total revenues, in districts where there were predominantly small-scale farms, and therefore the reason to sample higher numbers of small-scale farms, we still needed to have a reasonable number of the sample farms as large-scale farms in order to avoid such bias. Similarly the contribution of small-scale farms to the district sample net revenue should also be reflected in districts with small-scale farms. The exceptions to this are the districts in the Western Cape, the Northern Cape and Gauteng, where there was no information on small-scale farms (see Table A2). However, in these districts we also needed to have a reasonable sample for small-scale farms since anecdotal evidence suggests the existence of small-scale farms in the three provinces. This was also done to avoid having a much higher proportion of the total sample as large-scale farms, which would not be reflective of the farm type proportion in the total number of farms in the country.

Following our arguments in Stage 4 and Table A3, we revised Table A7. In Table A3 we arrived at a countrywide sample proportion of about 60% small-scale and 40% large–scale farms. We used this proportion to revise some of the district samples in Table A7. In districts with only a small-scale sample, we divided the sample into 60% small-scale and 40% large-scale. In districts with only a large-scale sample, the proportion is the reverse: 40% small-scale and 60% large-scale. The latter proportion has no very good basis, but it still reflects the relative strength of large-scale farms in the district in terms of both the number of farms and contribution to total farm net revenue. The small- and large-scale samples in each district following these revisions are indicated in Table A8.

A2.9 Distribution sample in the different climatic gradients (Stage 9)

The small- and large-scale sample indicated in Table A8 is a very good reflection of the importance of the selected districts in agricultural production in the country. However, one other important consideration is how well these selected districts reflect the different rainfall gradients in the country. When the districts were placed in the rainfall gradient in the country it was observed that some rainfall gradients were very well represented but others were not represented at all in the sample (see Figure A11). This necessitated further revisions of the sample in Table A8. In some provinces one or two more districts were selected (Western Cape and Northern Cape), in other some of the districts were replaced by other districts (Eastern Cape and KwaZulu-Natal), while in other provinces the number of districts were reduced (Eastern Cape and Limpopo). In addition to these district revisions, the sample size in one of the districts in Limpopo, Potgietersrus, was doubled to reflect its enormous size. The final sample districts and number of household in each district are shown in Table A9.

A2.10 Selection of farm households at the district level (Stage 10)

This was done in conjunction with the SSA Office and the district level extension officers of the Department of Agriculture.

The sample design worked mainly on the basis of capturing two main farm types in the country: large-scale and small-scale. Two other important farm types were not specifically considered in the design not only because of the complexities they might introduce in the design, but also because of the lack of detailed information at the provincial and district levels. These farm types are as follows:

a. Water source for farming activity: Dryland farming and/or irrigated land

b. Farm activity: Field crops, horticultural products, and livestock and livestock products.

With regard to (a) we attempted to survey about 70% of dryland farming households and 30% farming household with irrigated land. This proportion was based on the relative higher number of dryland farming operations countrywide. The problem with this was that there may be some farm households operating both types of farm activity.

With regard to (b) these farm types were indirectly reflected in our design, given the diverse vegetation in the provinces which is influenced by the temperature and rainfall patterns and in turn influences the type of agricultural activities in the provinces and districts. We hoped that the selected districts, given the agro-ecological patterns in the provinces, would reflect all these three farming activities.

A3 Data collection procedures

The initial plan was to use enumerators from StatsSA who have immense experience with interviewing farmers. Unfortunately this was not possible. Therefore we selected 25 undergraduate and postgraduate students from the University of Pretoria to undertake the survey. The selected interviewers received a series of training and review sessions in order to familiarize themselves with the objectives of the study and the survey instrument. The interviewers were split into five groups of five members each assigned to specific districts for the interviews.

Extension officers from the National Department of Agriculture and representatives of the large-scale farmers' union (SA-AGRIC) helped select sampled farmers in each district. The extension officers were the main contact for small-scale farmers and some large-scale farmers prior to each planned interview. The SA-AGRIC was the main contact for most of the large-scale farmers. The survey focused on the winter 2002 and summer 2002/2003 agricultural seasons, that is April/May 2002 – April/May 2003, and was undertaken within the period September 2003 to January 2004.

Table 1: Current rainfall and temperature in main agro-ecological zones and provinces in South Africa

Agro-ecological zone	Provinces	Mean rainfall (mm)		Mean temperature (°C)	
		Summer	Winter	Summer	Winter
Desert	Northern Cape	200	100	23	14
Steppe (Arid)	Eastern Cape	400	150	20	12
	Free State	500	100	22	14
	Gauteng	600	150	25	18
	Limpopo	600	150	20	13
	Mpumalanga	400	200	19	13
	North West	600	150	21	15
Sub-tropical wet	KwaZulu-Natal	800	200	23	16
Mediterranean (Winter rainfall)	Western Cape	150	400	19	14

Source: Joint Agricultural Weather Facility (1999); Gbetibouo & Hassan (2004)

Table 2: Land areas (million ha) of the major land-use types in South Africa

	Total area	Farm land	Potential arable	Arable land used	Grazing land	Nature conser-vation	Forestry	Other
Developing agriculture /subsistence	17	14	2.5	N/A	11.9	0.78	0.25	1.5
Commercial agriculture	105	86	14.1	12.9	71.9	11	1.2	6.8

Source: Development Bank of South Africa (1991); Palmer & Ainslie (2002)

Table 3: Distribution and typology of farm households in the sample

Agro-ecological zone	Province	District	Farming system Number (%)			Major crops	Major livestock	Large-scale			Small-scale		
			Cropping only	Mixed farming	Livestock only			Number (%)	Average farm size (ha)	Average experience (years)	Number (%)	Average farm size (ha)	Average experience (years)
ARID (STEPPE)	Eastern Cape	Aberdeen	2 (10)	7 (35)	11 (55)		Cattle, goats, sheep	13 (65)	5144	17	7 (35)	12	7
		Humansdorp	4 (36)	3 (28)	4 (36)		Cattle	10 (91)	241	12	1 (9)	1.5	30
		Kirkwood	19 (79)	2 (8)	3 (13)	Citrus fruit		6	430	10	18	40	10
	Province average		**25 (45)**	**12 (22)**	**18 (33)**	**Citrus fruit**	**Cattle**	**29 (52)**	**2472**	**14**	**26 (48)**	**30**	**10**
	Free State	Bethlehem	6 (21)	8 (27)	15 (52)	Maize, wheat	Cattle, pigs, poultry	17 (59)	711	16	12 (41)	1	3
		Kroonstad	7 (26)	12 (44)	8 (30)	Wheat, sunflower, maize	Cattle, sheep	21 (78)	870	7	6 (22)	8	8
	Province average		**13 (23)**	**20 (36)**	**23 (41)**	**Wheat, maize**	**Cattle**	**38 (68)**	**798**	**11**	**18 (32)**	**3**	**5**
	Gauteng	Bronskhorspruit	4 (36)	6 (54)	1 (10)	Maize, vegetables	Cattle	4 (36)	50	5	7 (64)	34	14
	Mpumalanga	Lydenburg	8 (38)	13 (62)	0 (0)	Maize, wheat, vegetables	Cattle	7 (33)	1778	9	14 (67)	40	15
		Middelburg	9 (36)	12 (48)	4 (16)	Maize, vegetables	Cattle	13 (52)	1450	13	12 (48)	1	3
	Province average		**17 (37)**	**25 (54)**	**4 (9)**	**Maize, vegetables**	**Cattle meat**	**20 (43)**	**1565**	**11**	**26 (57)**	**22**	**9**
	Limpopo	Soutpansberg	11 (41)	11 (41)	5 (18)	Maize	Cattle, chickens	7 (26)	115	9	20 (74)	9	9

Agro-ecological zone	Province	District	Farming system Number (%)			Major crops	Major livestock	Large-scale			Small-scale		
			Cropping only	Mixed farming	Livestock only			Number (%)	Average farm size (ha)	Average experience (years)	Number (%)	Average farm size (ha)	Average experience (years)
	North West	Vryburg	6 (14)	19 (44)	18 (42)	Maize	Cattle, sheep, goat	32 (74)	1925	19	11 (26)	7	17
DESERT	**Northern Cape**	Hopetown	3 (7.5)	6 (15)	31 (77.5)	Maize, wheat	Cattle sheep	34 (85)	2688	16	6 (15)	19	4
SUB-TROPICAL WET	**KwaZulu-Natal**	Estcourt	5 (25)	15 (75)	0 (0)	Maize, potato	Cattle	2 (10)	1520	24.5	18 (90)	5	23
		Hlabisa	10 (26)	28 (74)	0 (0)	Maize, sugar cane	Cattle, chickens	0 (0)	-	-	38 (100)	4	15
		Mont Currie	2 (18)	9 (82)	0 (0)	Maize, sugar cane	Cattle	7 (64)	1550	23	4 (36)	18	3.5
		Port Shepstone	13 (50)	12 (46)	1 (4)	Maize, sugar cane	Cattle	11 (52)	640	15	15 (58)	3.5	12
	Province average		**30 (31.5)**	**64 (67)**	**1 (10.5)**	**Maize sugar cane**	**Cattle**	**20 (21)**	**1047**	**19**	**75 (79)**	**5**	**16**
MEDITERRANEAN (WINTER RAINFALL)	**Western Cape**	Caledon	3 (16)	8 (42)	8 (42)	Citrus fruit, wheat	Cattle	17 (89)	500	4	2 (11)	32.5	20
		Piketberg	10 (42)	11 (46)	3 (12)	Citrus fruit, wheat	Cattle	20 (83)	1150	18	4	3	4.5
	Province average		**13 (30)**	**19 (44)**	**11 (26)**	**Citrus fruit, wheat**	**Cattle**	**37 (86)**	**851**	**20**	**6 (14)**	**13**	**9.5**
NATIONAL AVERAGE			**122 (29)**	**182 (44)**	**112 (27)**	**Maize**	**Cattle**	**221 (53)**	**1537**	**15**	**195 (47)**	**12.5**	**7**

Table 4a: Summary statistics for full sample model

Variable	N	Mean	Std. Dev.	Min	Max
Crop net revenue per hectare (US$)	191	305.525	573.2045	-884.26	2388.555
Summer temperature	195	21.04021	1.885267	17.42128	25.11124
Fall temperature	195	16.45474	1.953028	12.95221	19.52127
Winter temperature	195	11.91574	2.121216	8.943912	15.44466
Spring temperature	195	17.35215	2.064975	14.07367	20.7483
Summer precipitation	195	86.47312	40.70835	5.224444	127.3267
Fall precipitation	195	50.39756	13.68931	24.09667	68.70222
Winter precipitation	195	23.24021	10.15982	7.175556	34
Spring precipitation	195	61.10941	21.05057	17.35556	85.84666
Temperature - Annual mean	195	16.69071	1.83374	13.41389	19.74844
Precipitation - Annual mean	195	55.30507	18.54841	20.43583	78.60667
Soil vertisols	195	0.114872	0.245232	0	0.8
Soil acrisols	195	0.067692	0.175077	0	0.6
Soil arenosols	195	0.204615	0.425997	0	1.6
Soil xerosols	195	0.196923	0.580607	0	2
Mean runoff	195	10.40746	9.828292	5.33E-05	27.58459
Irrigated farms (1/0)	195	0.466667	0.500172	0	1
Farm type (Large-scale farms (1/0))	195	0.482051	0.500964	0	1
Cropland area (hectares)	195	150.5542	355.8825	0.068	3615.3
Livestock ownership (1/0)	195	0.661539	0.474404	0	1
Access to electricity (1/0)	195	0.805128	0.397122	0	1
Distance to crop market (km)	195	136.0541	1008.9	0	10000
Access to public extension services (1/0)	195	0.65641	0.476129	0	1
Farming experience (Number of years)	195	14.72051	13.18221	1	60
Household size	195	5.276923	2.858381	1	19
Access to other sources of extension services (1/0)	195	0.958974	0.19886	0	1

Table 4b: Summary statistics for irrigation model

Variable	N	Mean	Std. Dev.	Min	Max
Crop net revenue per hectare (US$)	91	466.5265	741.8728	-884.26	2388.555
Summer temperature	91	21.08773	1.982854	17.42128	25.11124
Fall temperature	91	16.21907	1.572543	12.95221	19.52127
Winter temperature	91	11.32505	1.662513	8.943912	15.44466
Spring temperature	91	16.86289	1.908246	14.07367	20.7483
Summer precipitation	91	81.56874	38.73156	5.224444	127.3267
Fall precipitation	91	48.051	14.09331	24.09667	68.70222
Winter precipitation	91	23.14366	9.590301	7.175556	34
Spring precipitation	91	56.60618	22.2879	17.35556	85.84666
Temperature - Annual mean	91	16.37368	1.549957	13.41389	19.74844
Precipitation - Annual mean	91	52.3424	18.8852	20.43583	78.60667
Soil vertisols	91	0.112088	0.246232	0	0.8
Soil acrisols	91	0.085714	0.196396	0	0.6
Soil arenosols	91	0.235165	0.460042	0	1.6
Soil xerosols	91	0.4	0.77746	0	2
Mean runoff	91	6.275916	8.690598	5.33E-05	27.58459
Irrigated farms (1/0)	91	1	0	1	1
Farm type (Large-scale farms (1/0))	91	0.516484	0.502497	0	1
Cropland area (hectares)	91	162.1496	450.6189	0.068	3615.3
Livestock ownership (1/0)	91	0.538462	0.50128	0	1
Access to electricity (1/0)	91	0.846154	0.3628	0	1
Distance to crop market (km)	91	267.061	1469.708	0	10000
Access to public extension services (1/0)	91	0.758242	0.430521	0	1
Farming experience (Number of years)	91	14.7033	13.16286	1	51
Household size	91	4.736264	2.594161	1	18
Access to other sources of extension services (1/0)	91	0.978022	0.147424	0	1

Table 4c: Summary statistics for dryland model

Variable	N	Mean	Std. Dev.	Min	Max
Crop net revenue per hectare (US$)	100	159.0135	291.077	-280.93	1286.005
Summer temperature	104	20.99864	1.804208	17.42128	23.27953
Fall temperature	104	16.66095	2.220691	12.95221	19.52127
Winter temperature	104	12.4326	2.341321	8.943912	15.44466
Spring temperature	104	17.78024	2.11024	14.07367	20.7483
Summer precipitation	104	90.76444	42.07885	5.224444	127.3267
Fall precipitation	104	52.4508	13.04942	30.18889	68.70222
Winter precipitation	104	23.32469	10.67881	7.175556	34
Spring precipitation	104	65.04973	19.15671	25.66667	85.84666
Temperature - Annual mean	104	16.96811	2.016878	13.41389	19.74844
Precipitation - Annual mean	104	57.89742	17.93954	27.4825	78.60667
Soil vertisols	104	0.117308	0.24552	0	0.8
Soil acrisols	104	0.051923	0.153269	0	0.6
Soil arenosols	104	0.177885	0.394121	0	1.6
Soil xerosols	104	0.019231	0.196116	0	2
Mean runoff	104	14.02255	9.363015	5.33E-05	27.58459
Irrigated farms (1/0)	104	0	0	0	0
Farm type (Large-scale farms (1/0))	104	0.451923	0.500093	0	1
Cropland area (hectares)	104	140.4081	246.7744	0.34	1400
Livestock ownership (1/0)	104	0.769231	0.423365	0	1
Access to electricity (1/0)	104	0.769231	0.423365	0	1
Distance to crop market (km)	104	21.42308	36.4054	0	240
Access to public extension services (1/0)	104	0.567308	0.497848	0	1
Farming experience (Number of years)	104	14.73558	13.26283	1	60
Household size	104	5.75	3.004043	1	19
Access to other sources of extension services (1/0)	104	0.942308	0.23429	0	1

Table 4d: Summary statistics for large-scale farms model

Variable	N	Mean	Std. Dev.	Min	Max
Crop net revenue per hectare (US$)	94	358.5129	548.4736	-884.26	2264.86
Summer temperature	94	21.18888	2.019431	17.42128	25.11124
Fall temperature	94	16.0849	1.659212	12.95221	19.52127
Winter temperature	94	11.18385	1.55778	8.943912	15.44466
Spring temperature	94	17.02597	2.029286	14.07367	20.7483
Summer precipitation	94	74.45561	37.51038	5.224444	127.3267
Fall precipitation	94	43.97448	12.41083	24.09667	68.70222
Winter precipitation	94	20.30487	9.988053	7.175556	34
Spring precipitation	94	50.06643	20.81874	17.35556	85.84666
Temperature - Annual mean	94	16.3709	1.604616	13.41389	19.74844
Precipitation - Annual mean	94	47.20035	17.11135	20.43583	78.60667
Soil vertisols	94	0.106383	0.250079	0	0.8
Soil acrisols	94	0.076596	0.18632	0	0.6
Soil arenosols	94	0.332979	0.543463	0	1.6
Soil xerosols	94	0.174468	0.529747	0	2
Mean runoff	94	6.045097	7.263967	5.33E-05	23.18291
Irrigated farms (1/0)	94	0.5	0.502681	0	1
Farm type (Large-scale farms (1/0))	94	1	0	1	1
Cropland area (hectares)	94	296.4485	467.9027	3.12	3615.3
Livestock ownership (1/0)	94	0.765957	0.425669	0	1
Access to electricity (1/0)	94	0.978723	0.145079	0	1
Distance to crop market (km)	94	162.0537	1029.392	0	10000
Access to public extension services (1/0)	94	0.595745	0.493379	0	1
Farming experience (Number of years)	94	16.28723	12.10383	1	51
Household size	94	4	2.084247	1	18
Access to other sources of extension services (1/0)	94	0.989362	0.103142	0	1

Table 4e: Summary statistics for small-scale farms model

Variable	N	Mean	Std. Dev.	Min	Max
Crop net revenue per hectare (US$)	97	254.1759	594.513	-664.539	2388.555
Summer temperature	101	20.90185	1.749989	17.42128	23.27953
Fall temperature	101	16.79895	2.142723	12.95221	19.52127
Winter temperature	101	12.59691	2.345244	8.943912	15.44466
Spring temperature	101	17.65571	2.061449	14.07367	20.7483
Summer precipitation	101	97.65772	40.5496	5.224444	127.3267
Fall precipitation	101	56.37548	12.05945	30.18889	68.70222
Winter precipitation	101	25.97211	9.583078	7.175556	34
Spring precipitation	101	71.38703	15.33847	25.66667	85.84666
Temperature - Annual mean	101	16.98836	1.985767	13.41389	19.74844
Precipitation - Annual mean	101	62.84809	16.61115	27.4825	78.60667
Soil vertisols	101	0.122772	0.241612	0	0.8
Soil acrisols	101	0.059406	0.164425	0	0.6
Soil arenosols	101	0.085149	0.217893	0	1.6
Soil xerosols	101	0.217822	0.626162	0	2
Mean runoff	101	14.46747	10.18756	5.33E-05	27.58459
Irrigated farms (1/0)	101	0.435644	0.498314	0	1
Farm type (Large-scale farms (1/0))	101	0	0	0	0
Cropland area (hectares)	101	14.77131	58.89423	0.068	500
Livestock ownership (1/0)	101	0.564356	0.498314	0	1
Access to electricity (1/0)	101	0.643564	0.481335	0	1
Distance to crop market (km)	101	111.8564	993.9749	0	10000
Access to public extension services (1/0)	101	0.712871	0.454679	0	1
Farming experience (Number of years)	101	13.26238	14.01474	1	60
Household size	101	6.465347	2.975111	1	19
Access to other sources of extension services (1/0)	101	0.930693	0.255242	0	1

Table 5: Long-term temperature in the nine provinces for four seasons

		Mean temperatures (^oC)				
Agro-ecological zone	**Province**	**Summer**	**Fall**	**Winter**	**Spring**	**Annual**
Arid (steppe)	Eastern Cape (EC)	20.50	14.55	10.56	14.59	16.04
	Free State (FS)	18.42	12.16	9.52	15.07	14.59
	Gauteng (GU)	19.65	14.11	11.48	16.88	16.22
	Limpopo (LP)	22.78	18.35	15.44	20.02	19.75
	Mpumalanga (MP)	21.02	15.80	13.14	18.42	17.75
	North West (NW)	22.25	15.84	12.93	19.26	18.35
Desert	Northern Cape (NC)	23.85	15.10	10.24	17.08	17.86
Sub-tropical wet	KwaZulu-Natal (KN)	19.11	14.99	12.30	15.92	16.19
Mediterranean (winter rainfall)	Western Cape (WC)	20.83	15.16	10.81	14.26	16.29
	South Africa	20.62	14.95	11.68	16.48	16.75
		Minimum temperatures (^oC)				
Agro-ecological zone	**Province**	**Summer**	**Fall**	**Winter**	**Spring**	**Annual**
Arid (steppe)	Eastern Cape (EC)	19.21	14.19	9.84	13.85	15.40
	Free State (FS)	17.56	11.45	8.94	14.12	13.81
	Gauteng (GU)	19.65	14.11	11.48	16.88	16.22
	Limpopo (LP)	22.78	18.35	15.44	20.02	19.75
	Mpumalanga (MP)	20.93	15.36	12.81	18.27	17.65
	North West (NW)	22.25	15.84	12.93	19.26	18.35
Desert	Northern Cape (NC)	23.85	15.10	10.24	17.08	17.86
Sub-tropical wet	KwaZulu-Natal (KN)	16.75	11.78	9.05	13.26	13.41
Mediterranean (winter rainfall)	Western Cape (WC)	19.41	13.66	9.53	13.09	14.93
	South Africa	16.75	11.45	8.94	13.09	13.41
		Maximum temperatures (^oC)				
Agro-ecological zone	**Province**	**Summer**	**Fall**	**Winter**	**Spring**	**Annual**
Arid (steppe)	Eastern Cape (EC)	21.45	14.89	11.10	14.85	16.24
	Free State (FS)	19.33	12.92	10.13	16.10	15.42
	Gauteng (GU)	19.65	14.11	11.48	16.88	16.22
	Limpopo (LP)	22.78	18.35	15.44	20.02	19.75
	Mpumalanga (MP)	21.10	16.33	13.54	18.55	17.87
	North West (NW)	22.25	15.84	12.93	19.26	18.35
Desert	Northern Cape (NC)	23.85	15.10	10.24	17.08	17.86
Sub-tropical wet	KwaZulu-Natal (KN)	21.29	17.83	15.19	18.35	18.70
Mediterranean (winter rainfall)	Western Cape (WC)	21.95	16.35	11.83	15.19	17.36
	South Africa	23.85	18.35	15.44	20.02	19.75

Source: Basist et al. (2001)

Table 6: Long-term precipitation in the nine provinces in four seasons

		Mean precipitation (mm/month)				
Agro-ecological zone	**Province**	**Summer**	**Fall**	**Winter**	**Spring**	**Annual**
Arid (steppe)	Eastern Cape (EC)	69.37	37.90	25.15	47.13	49.36
	Free State (FS)	79.85	34.52	13.31	43.97	49.68
	Gauteng (GU)	101.76	33.00	9.23	52.85	59.02
	Limpopo (LP)	14.26	57.35	218.75	166.16	97.88
	Mpumalanga (MP)	103.47	34.86	12.63	54.28	61.13
	North West (NW)	76.67	30.02	7.18	33.42	44.31
Desert	Northern Cape (NC)	27.92	20.13	11.65	15.20	20.44
Sub-tropical wet	KwaZulu-Natal (KN)	118.56	53.52	32.55	72.90	78.61
Mediterranean (winter rainfall)	Western Cape (WC)	23.86	31.64	31.69	26.08	27.48
	South Africa	75.13	38.64	33.53	54.59	55.22
		Minimum precipitation (mm/month)				
		Summer	Fall	Winter	Spring	Annual
	South Africa	14.26	20.13	7.18	15.20	20.44
		Maximum precipitation (mm/month)				
		Summer	Fall	Winter	Spring	Annual
	South Africa	118.56	57.35	218.75	166.16	97.88

Note: ARTES data provides only mean values for the districts in each province.

Source: World Bank (2003)

Table 7: Without adaptation models – Climate variables only

Dependent variable: Crop farming net revenue

Variable	Col. 1 Full sample	Col. 2 Irrigated	Col. 3 Dryland	Col. 4 Large-scale	Col. 5 Small-scale
Summer temperature					
Summer temperature squared	27.48***	30.345*	27.53***	28.58*	44.91***
	(3.34)	(1.88)	(4.4)	(1.98)	(3.35)
Fall temperature	-1020.7	228.729		566.21	2450.26
	(-1.03)	(0.12)		(0.32)	(0.46)
Fall temperature squared	-26.76	-63.826	(-47.28***	-38.61	-182.5
	(-0.97)	(-1.37)	(-4.33)	(-0.64)	(-0.95)
Winter temperature	2346.96***	2186.54	1531.43***	5459.5	-785.34
	(2.79)	(1.31)	(5.11)	(0.9)	(-0.2)
Winter temperature squared	-26.35	-17.288	-6.338	-211.19	162.93
	(-0.78)	(-0.28)	(-0.39)	(-0.59)	(0.85)
Spring temperature	551.94	794.96	-375.49	2408.73	2814.24
	(0.26)	(0.21)	(-0.38)	(0.49)	(0.91)
Spring temperature squared	-43.53	-57.092	-16.76	-124.25	-132.07
	(-0.7)	(-0.51)	(-0.54)	(-0.72)	(-1.41)
Summer precipitation	145.26	239.104	(-161.58*	261.524	268.33
	(0.64)	(0.58)	(-1.88)	(0.43)	(0.81)
Summer precipitation squared	-0.59	-0.507	1.841***	0.446	1.983
	(-0.75)	(-0.36)	(4.85)	(0.31)	(1.47)
Fall precipitation	1198.96	1014.11	1211.19***		631.1
	(1.57)	(0.71)	(4.48)		(0.61)
Fall precipitation squared	-11.95*	-10.407	-10.109***	-2.185	-8.011
	(-1.75)	(-0.8)	(-4.67)	(-0.39)	(-1.07)
Winter precipitation	114.66	182.268	87.718	123.816	594.59
	(0.63)	(0.55)	(0.88)	(0.28)	(1.55)
Winter precipitation squared	-1.50**	-1.048	0.816**	0.744	2.767**
	(-2.03)	(-0.73)	(2.41)	(0.56)	(2.34)
Spring precipitation	-831.68*	-862.82		-349.354	
	(-1.92)	(-1.05)		(-0.45)	
Spring precipitation squared	6.45**	5.34	-2.914***	-0.406	-8.137**
	(2.04)	(0.88)	(-3.02)	(-0.12)	(-2.43)
Constant	-21774	-32343	-31884	-52807	-68252
	(-1.27)	(-1.06)	(-3.01)	(-0.7)	(-1.74)
Pseudo R	0.1328	0.1533	0.253	0.194	0.1516
Number of observations	191	91	100	94	97

t-Statistics in parenthesis
***Significant at 1%; **Significant at 5%; *Significant at 10%

Table 8: Without adaptation models – Climate and soil variables only

Dependent variable: Crop farming net revenue					
	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
Variable	Full sample	Irrigated	Dryland	Large-scale	Small-scale
Summer temperature					
Summer temperature squared	14.58*	39.381	13.199	42.781	37.76**
	(1.75)	(0.8)	(0.67)	(1.02)	(2.2)
Fall temperature					
Fall temperature squared	-47.77**	-146.09	-35.59*	-95.362	-94.73**
	(-2.34)	(-1.18)	(-1.79)	(-0.81)	(-2.38)
Winter temperature					
Winter temperature squared	51.86**	152.21	35.844*	126.994	110.83**
	(2.22)	(1.07)	(1.96)	(0.93)	(2.39)
Spring temperature	1431.61	4187.12			2950.35
	(0.89)	(0.48)			(0.98)
Spring temperature squared	-51.52	-139.81	-6.603	-30.803	-123.08
	(-0.97)	(-0.48)	(-0.45)	(-1.22)	(-1.22)
Summer precipitation	260.59	954.61	46.026*	-55.921	355.62
	(1.33)	(0.86)	(1.87)	(-0.12)	(1.65)
Summer precipitation squared	-1.095*	-3.77	-0.169**	-0.381	0.7302
	(-1.66)	(-1.02)	(-2.58)	(-0.17)	(1.54)
Fall precipitation					
Fall precipitation squared	-1.75	-7.233	-0.284	1.245	-2.661
	(-1.21)	(-0.88)	(-1.28)	(0.42)	(-1.36)
Winter precipitation	191.32	775.36	58.941	-68.916	526.551
	(1.24)	(0.89)	(1.42)	(-0.18)	(1.55)
Winter precipitation squared	-0.47*	-1.582	0.085*	-0.411	2.130*
	(-1.8)	(-1.07)	(0.68)	(-0.37)	(1.73)
Spring precipitation	-369.96	-1279.8		25.3	
	(-1.35)	(-0.83)		(0.04)	
Spring precipitation squared	2.65	8.925	-0.224*	0.835	-5.974*
	(1.58)	(0.95)	(-0.63)	(0.16)	(-1.75)
Soil vertisols	-322.39**	-974.96	-240.54	-11.276	-135.5
	(-2.02)	(-1.05)	(-1.540	(-0.010	(-0.43)
Soil acrisols	943.08***	1487.38	1011.20***		631.37
	(3.19)	(0.88)	(3.05)		(1.03)
Soil arenosols	450.24***	1220.76	287.859	-24.76	
	(2.9)	(1.31)	(1.45)	(-0.04)	
Soil xerosols	-80.57	-310.73		-265.27	-63.63
	(-0.66)	(-0.55)		(-0.78)	(-0.29)
Constant	-11053	-36297	-1532.	979.9	-41324
	(-0.8)	(-0.48)	(-0.69)	(0.34)	(-1.15)
Pseudo R	0.1363	0.1564	0.253	0.194	0.1516
Number of observations	191	91	100	94	97

t-Statistics in parenthesis

***Significant at 1%; **Significant at 5%; *Significant at 10%

Table 9: Without adaptation models – Climate, soil and hydrology variables only

Dependent variable: Crop farming net revenue

Variable	Col. 1 Full sample	Col. 2 Irrigated	Col. 3 Dryland	Col. 4 Large-scale	Col. 5 Small-scale
Summer temperature					
Summer temperature squared	22.11***	62.434	(-11.80*	43.637*	36.69***
	(3.8)	(1.8)	(-1.78)	(1.89)	(2.85)
Fall temperature					
Fall temperature squared	-50.26***	-154.10*	(-17.65**	-98.86	-75.008**
	(-4.07)	(-1.91)	(-2.23)	(-1.56)	(-2.66)
Winter temperature					
Winter temperature squared	62.9***	186.93**	38.55***	130.61*	95.31***
	(4.66)	(2.05)	(5.01)	(1.88)	(3.05)
Spring temperature					
Spring temperature squared	-20.46***	-50.174	1.796	-30.73**	-38.86***
	(-3.24)	(-1.28)	(0.35)	(-2.2)	(-2.65)
Summer precipitation	147.77**	628.59	73.87***	-44.41	187.63**
	(2.16)	(1.49)	(3.27)	(-0.36)	(2.52)
Summer precipitation squared	-0.68**	-2.562	0.0166	-0.449	0.442*
	(-2.21)	(-1.4)	(0.3)	(-0.54)	(1.83)
Fall precipitation					
Fall precipitation squared	-0.85	-4.605	-0.515**	1.174	-0.992
	(-1.62)	(-1.41)	(-2.42)	(1.22)	(-1.08)
Winter precipitation	86.67	471.22	141.03***	-58.27	242.31*
	(1.6)	(1.41)	(3.66)	(-0.53)	(1.88)
Winter precipitation squared	-0.34**	-1.154	0.3804***	-0.445	1.213***
	(-1.99)	(-1.2)	(3.42)	(-0.88)	(3.0)
Spring precipitation	-222.12**	-853.38		9.873	
	(-2.34)	(-1.49)		(0.06)	
Spring precipitation squared	1.71**	6.188	1.22***	0.979	-3.438***
	(2.22)	(1.38)	(-3.84)	(0.56)	(-3.03)
Soil vertisols					
Soil acrisols	881.94***	1281.57			978.28**
	(3.57)	(0.97)			(2.07)
Soil arenosols	371.96**	989.95	551.74***		
	(2.19)	(1.01)	(5.12)		
Soil xerosols	-63.05	-262.09		-270.47	15.55
	(-0.57)	(-0.54)		(-0.74)	(0.08)
Mean runoff	44.14	130.68	65.18***	-3.254	63.33
	(1.42)	(0.79)	(2.91)	(-0.04)	(1.07)

Table 9: Without adaptation models – Climate, soil and hydrology variables only

Mean runoff squared	-2.28*	-6.77	-3.363***	0.157	-2.715
	(-1.79)	(-0.99)	(-3.62)	(0.04)	(-1.09)
Constant	1046.71	-909.67	18.24	934.431	-8550.65
	(0.97)	(-0.19)	(0.02)	(0.32)	(-2.19)
Pseudo R	0.1363	0.1564	0.253	0.194	0.1516
Number of observations	191	91	100	94	97

t-Statistics in parenthesis
***Significant at 1%; **Significant at 5%; *Significant at 10%

Table 10: With adaptation models – Climate and socio-economic variables

Dependent variable: Crop farming net revenue

Variable	Col. 1 Full sample	Col. 2 Irrigated	Col. 3 Dryland	Col. 4 Large-scale	Col. 5 Small-scale
Summer temperature					
Summer temperature squared	24.17*	31.904	19.979***	22.14	41.44***
	(1.7)	(1.31)	(4.04)	(1.46)	(4.5)
Fall temperature	-1031.63	-619.5		-287.45	3455.58
	(-0.61)	(-0.22)		(-0.16)	(0.94)
Fall temperature squared	-21.33	-69.369	-37.44***	-3.196	-211.72
	(-0.46)	(-1.0)	(-5.12)	(-0.05)	(-1.57)
Winter temperature	2282.66	2501.38	1247.33**	7017.57	-2078.06
	(1.56)	(1.03)	(4.8)	(1.12)	(-0.78)
Winter temperature squared	-30.13	2.388	-3.957	-291.44	214.56
	(-0.52)	(0.03)	(-0.35)	(-0.81)	(1.6)
Spring temperature	222.78	5126.95	193.16	1938.99	3754.98
	(0.06)	(0.83)	(0.32)	(0.37)	(1.65)
Spring temperature squared	-29.65	-182.74	-28.2436	-105.25	-157.15**
	(-0.28)	(-0.99)	(-1.55)	(-0.6)	(-2.29)
Summer precipitation	78.12	602.05	-106.62*	260.478	362.26
	(0.2)	(0.92)	(-1.69)	(0.42)	(1.55)
Summer precipitation squared	-0.329	-1.75	1.557***	0.431	1.856**
	(-0.24)	(-0.78)	(4.94)	(0.25)	(2.02)
Fall precipitation	785.35	759.46	950.967***		397.94
	(0.59)	(0.34)	(4.26)		(0.57)
Fall precipitation squared	-7.65	-11.038	-8.095***	-2.413	-6.794
	(-0.65)	(-0.55)	(-4.63)	(-0.43)	(-1.34)
Winter precipitation	58.64	485.43	105.794*	122.35	689.48**
	(0.19)	(0.92)	(1.76)	(0.27)	(2.48)
Winter precipitation squared	-0.98	-1.344	0.821***	0.725	3.024***
	-0.79	-0.61	3.88	0.5	3.61
Spring precipitation	-536.24	-1268.48		-346.92	
	(-0.74)	(-1.0)		(-0.43)	
Spring precipitation squared	4.18	7.715	-2.805***	-0.303	-8.734***
	(0.78)	(0.82)	(-4.57)	(-0.07)	(-3.69)
Irrigated farms (1/0)	153.1			294.44	154.62*
	(1.1)			(1.6)	(1.69)
Cropland area	-0.00332	0.0035	0.1451**		
	(-0.03)	(0.02)	(2.22)		
Livestock ownership (1/0)	15.021	136.92	-33.583	290.17	-93.27
	(0.11)	(0.57)	(-1.01)	(1.54)	(-1.16)
Access to electricity (1/0)	79.81		7.986		6.1
	(0.48)		(0.2)		(0.07)
Distance to crop market (km)	0.1163**	0.141**	0.803*		0.145***
	(2.38)	(2.36)	(1.89)		(10.52)

Table 10: With adaptation models – Climate and socio-economic variables

Access to public extension services (1/0)	-92.24	-468.47	-12.08	-247.09	-29.82
	(-0.66)	(-1.55)	(-0.4)	(-1.42)	(-0.31)
Farming experience	3.909			6.424	
	(0.82)			(0.99)	
Household size	5.411			9.30	
	(0.24)			(0.29)	
Access to other sources of extension services (1/0)	55.103				
	(0.18)				
Constant	-13807	-59258	-30076	-50327	-74799
	(-0.47)	(-1.22)	(-4.85)	(-0.69)	(-2.62)
Pseudo R	0.1607	0.1833	0.2645	0.287	0.2398
Number of observations	191	91	100	94	97

t-Statistics in parenthesis
***Significant at 1%; **Significant at 5%; *Significant at 10%

Table 11: With adaptation models – Climate, soil and socio-economic variables

Dependent variable: Crop farming net revenue

Variable	Col. 1 Full sample	Col. 2 Irrigated	Col. 3 Dryland	Col. 4 Large-scale	Col. 5 Small-scale
Summer temperature					
Summer temperature squared	12.98*	43.62***	17.003	30.29	43.88***
	(1.75)	(2.68)	(1.45)	(0.66)	(7.69)
Fall temperature					
Fall temperature squared	-48.47***	-186.35***	-32.89***	-81.48	-100.87***
	(-2.7)	(-4.41)	(-2.89)	(-0.62)	(-7.15)
Winter temperature					
Winter temperature squared	53.29***	195.067***	33.44***	109.398	119.92***
	(2.61)	(4.03)	(3.08)	(0.71)	(7.41)
Spring temperature	2488.75*		8724.10***		3584.59***
	(1.76)	(2.76)			(3.24)
Spring temperature squared	-81.45*	-273.82***	-11.315	-18.519	-149.6***
	(-1.77)	(-2.64)	(-1.19)	(-0.69)	(-4.13)
Summer precipitation	327.89*	1367.41***	25.537	-48.186	415.71***
	(1.93)	(3.55)	(1.34)	(-0.09)	(5.54)
Summer precipitation squared	-1.317**	-5.234***	-0.0849	-0.58542	0.889***
	(-2.31)	(-4.09)	(-1.57)	(-0.22)	(5.51)
Fall precipitation					
Fall precipitation squared	-2.22*	-10.476***	-0.093	1.148239	-3.152***
	(-1.77)	(-3.67)	(-0.54)	(0.34)	(-4.5)
Winter precipitation	243.90*	1117.22***	21.5	-64.361	602.9***
	(1.83)	(3.7)	(0.75)	(-0.15)	(5.0)
Winter precipitation squared	-0.57**	-2.216***	0.058	-0.568	2.492***
	(-2.4)	(-4.32)	(0.61)	(-0.43)	(5.88)
Spring precipitation	-467.63**		-1875.08***	5.379	
	(-1.98)	(-3.51)		(0.01)	
Spring precipitation squared	3.232	12.778***	-0.128	1.331	-6.931***
	(2.21)	(3.92)	(-0.5)	(0.22)	(-5.89)
Soil vertisols	-416.9***	-1070.1***	-141.31	-193.4	4.624
	(-3.07)	(-3.38)	(-1.32)	(-0.19)	(0.04)
Soil acrisols	806.24***	1131.08**		1040.10***	327.162
	(3.16)	(2.05)	(6.25)		(1.63)
Soil arenosols	388.33***	1420.96***	138.34	116.87	
	(3.01)	(4.56)	(1.06)	(0.15)	
Soil xerosols	-154.14	-289.85		-250.34	-160.90**
	(-1.47)	(-1.56)		(-0.77)	(-2.23)
Irrigated farms (1/0)	155.73***			294.44	154.46***
	(2.92)			(1.6)	(3.41)
Cropland area	0.00596	0.00287	0.145**		

Table 11: With adaptation models – Climate, soil and socio-economic variables

	(0.12)	(0.04)	(2.22)		
Livestock ownership (1/0)	29.56	216.02**	-33.58	290.17	-95.47**
	(0.55)	(1.7)	(-1.01)	(1.54)	(-2.37)
Access to electricity (1/0)	78.3		7.986		1.196
	(1.28)		(0.2)		(0.03)
Distance to crop market (km)	0.137***	0.148***	0.803*		0.145***
	(7.16)	(4.910	(1.89)		(22.77)
Access to public extension services (1/0)	-103.66*	-389.43***	-12.08	-247.08	-27.46
	(-1.94)	(-2.77)	(-0.4)	(-1.42)	(-0.61)
Farming experience	3.73**			6.424	
	(2.08)			(0.99)	
Household size	17.33**			9.296	-2.371
	(2.02)			(0.29)	(-0.34)
Access to other sources of extension services (1/0)	18.19				
	(0.17)				
Constant	-20063	-72975	-1186.88	1798.63	-50304
	(-1.66)	(-2.71)	(-0.75)	(0.6)	(-3.89)
Pseudo R	0.1699	0.1963	0.2645	0.287	0.2407
Number of observations	191	91	100	94	97

t-Statistics in parenthesis
***Significant at 1%; **Significant at 5%; *Significant at 10%

Table 12: With adaptation models – Climate, soil, hydrology and socio-economic variables

Dependent variable: Crop farming net revenue

Variable	Col. 1 Full sample	Col. 2 Irrigated	Col. 3 Dryland	Col. 4 Large-scale	Col. 5 Small-scale
Summer temperature					
Summer temperature squared	21.32***	61.87***	-15.87***	30.02***	37.13****
	(3.81)	(6.9)	(-3.3)	(3.23)	(8.74)
Fall temperature					
Fall temperature squared	-45.08***	-158.75***	-5.765	-65.65**	-68.68***
	(-3.89)	(-7.66)	(-0.94)	(-2.6)	(-7.25)
Winter temperature					
Winter temperature squared	61.09***	197.75***	26.562***	96.4***	88.46***
	(4.87)	(8.36)	(4.1)	(3.46)	(8.3)
Spring temperature					
Spring temperature squared	-21.92***	-51.28***	3.424	-26.97***	-40.67***
	(-3.78)	(-5.01)	(0.84)	(-4.36)	(-8.52)
Summer precipitation	114.47*	565.22***	48.61***	-59.7	199.66***
	(1.86)	(5.24)	(2.73)	(-1.19)	(8.16)
Summer precipitation squared	-0.57**	-2.482***	0.082*	-0.273	0.483***
	(-2.08)	(-5.33)	(1.77)	(-0.78)	(5.95)
Fall precipitation					
Fall precipitation squared	-0.54	-4.219***	-0.294*	1.099***	-1.054***
	(-1.13)	(-5.03)	(-1.75)	(2.86)	(-3.5)
Winter precipitation	53.79	420.55***	105.22***	-93.21**	245.03***
	(1.1)	(4.87)	(3.65)	(-2.13)	(5.82)
Winter precipitation squared	-0.31**	-1.25***	0.326***	-2.13	1.286***
	(-2.0)	(-5.1)	(3.71)	(-1.65)	(9.66)
Spring precipitation	-184.84**	-798.97***		19.99	
	(-2.19)	(-5.45)		(0.28)	
Spring precipitation squared	1.48**	6.204***	-1.084***	0.788	-3.60***
	(2.15)	(5.44)	(-4.36)	(1.05)	(-9.68)
Soil vertisols					
Soil acrisols	823.18***	1536.98***			899.13***
	(3.47)	(4.28)			(5.27)
Soil arenosols	258.34*	1004.14***	450.797***		
	(1.72)	(3.95)	(5.03)		
Soil xerosols	-111.31	-123.06		-209.36	-50.95
	(-1.08)	(-0.99)		(-1.54)	(-0.78)
Mean runoff	71.84**	216.51***	67.72***	41.42	67.94***
	(2.45)	(4.49)	(6.05)	(1.38)	(3.1)
Mean runoff squared	-3.51***	-10.433***	-3.358***	-2.34	-2.663***

Table 12: With adaptation models – Climate, soil, hydrology and socio-economic variables

	(-2.92)	(-5.21)	(-6.91)	(-1.48)	(-2.88)
Irrigated farms (1/0)	155.73***			294.44***	154.46***
	(2.76)			(4.18)	(3.41)
Cropland area	0.006	0.00287	0.145**		
	(0.12)	(0.04)	(2.22)		
Livestock ownership (1/0)	29.56	216.02**	-33.58	290.17***	-95.47***
	(0.51)	(2.17)	(-1.01)	(4.15)	(-2.37)
Access to electricity (1/0)	78.3		7.986		1.196
	(1.2)		(0.2)		(0.03)
Distance to crop market (km)	0.137***	0.148***	0.803*		0.141***
	(6.68)	(6.26)	(1.89)		(22.77)
Access to public extension services (1/0)	-103.66*	-389.43***	-12.081	-247.1***	-27.46
	(-1.81)	(-3.67)	(-0.4)	(-3.66)	(-0.61)
Farming experience	3.73*			6.424**	
	(1.93)			(2.53)	
Household size	17.33*			9.296	-2.371
	(1.88)			(0.75)	(-0.34)
Access to other sources of extension services (1/0)	18.19				
	(0.16)				
Constant	980.74	942.19	1105.63	2002.62	-9778.87
	(0.96)	(0.74)	(1.15)	(1.73)	(-7.62)
Pseudo R	0.1699	0.1963	0.2645	0.287	0.2407
Number of observations	191	91	100	94	97

t-Statistics in parenthesis
***Significant at 1%; **Significant at 5%; *Significant at 10%

Table 13: Marginal effects of temperature (1°C increase) on crop net revenue (US$/hectare)

Without adaptation models: Climate, soil and hydrology variables model

	Full sample	Irrigated	Dryland	Large-scale	Small-scale
Summer temperature	952.68***	2695.66*	-507.20*	1892.91*	1570.30***
Fall temperature	-1704.2***	-5182.81*	-605.65**	-3279.3	-2595.2***
Summer farming season	-751.53***	-2487.15	-1112.85***	-1386.4	-1024.85
Winter temperature	1561.95***	4420.82**	997.20***	3052*	2496.52***
Spring temperature	-730.56***	-1742.35	65.63	-1077.3**	-1411.20***
Winter farming season	831.39***	2678.47	1062.83***	1974.73	
Annual temperature	79.86	191.31	-50.02	588.34	60.48
Annual elasticity	4.36	6.71	-5.33	26.87	4.04

With adaptation: Climate, soil, hydrology and socio-economic variables model

	Full sample	Irrigated	Dryland	Large-scale	Small-scale
Summer temperature	918.38***	2671.3***	-682.28***	1302.1***	1589.1***
Fall temperature	-1528.6***	-5308.3***	-197.88	-2177.6**	-2376.1***
Summer farming season	-610.21**	-2637***	-880.15***	-875.42*	-786.94***
Winter temperature	1516.99***	4676.71***	687.02***	2252.66***	2317.18***
Spring temperature	-782.62***	-1780.7***	125.17	-945.37***	-1476.9***
Winter farming season	734.37***	2896***	812.19***	1307.28**	840.32***
Annual temperature	124.16**	259.04***	(-67.96**	431.86***	53.38
Annual elasticity	(6.78)	(9.09)	(-7.25)	(19.72)	(3.56)

Estimated annual elasticities in parenthesis
***Significant at 1% **Significant at 5% *Significant at 10%

Table 14: Marginal effects of precipitation (1mm/month increase) on crop net revenue (US$/hectare)

Without adaptation: Climate, soil and hydrology model

	Full sample	Irrigated	Dryland	Large-scale	Small-scale
Summer precipitation	30.34	210.66	76.88**	-111.31	273.99***
Fall precipitation	-86.09	-447.12	-54.55**	104.41	-112.86
Summer farming season	-55.75	-236.47	22.33	-6.89	161.13**
Winter precipitation	70.97	417.79	158.78***	-76.3444	305.29**
Spring precipitation	-13.18	-152.81	-160.97***	107.9519	-494.34***
Winter farming season	57.79	264.98	-2.19	31.60367	-189.05**
Annual precipitation	2.04	28.52	20.14**	24.71	-27.92
Annual elasticity	(0.37)	(31.2)	(7.33)	(3.25)	(-6.9)

With adaptation: Climate, soil, hydrology and socio-economic variables model

	Full sample	Irrigated	Dryland	Large-scale	Small-scale
Summer precipitation	16.67	160.29***	63.53***	-100.33**	294.04***
Fall precipitation	-54.69	-409.69***	-31.08*	97.75**	-119.84***
Summer farming season	-38.02	-249.40***	32.46**	-2.58*	174.19***
Winter precipitation	39.47	362.67***	120.43***	(-108.27***	311.84**
Spring precipitation	-3.91	-96.61***	-142.12***	98.93**	-517.61***
Winter farming season	35.56	266.07***	-21.7	-9.34	-205.77***
Annual precipitation	-2.46	16.67	10.77**	-11.91	(-31.58***
Annual elasticity	(-0.45)	(1.87)	(3.92)	(-1.56)	(-7.81)

Estimated annual elasticities in parenthesis
***Significant at 1% **Significant at 5% *Significant at 10%

Table 15: Marginal effects of temperature at the provincial level

TEMPERATURE – WITHOUT ADAPTATION							
PROVINCE	Summer	Fall	Summer farming season	Winter	Spring	Winter farming season	Annual
Eastern Cape	965.51***	-1682.924***	-717.41***	1407.15***	-667.50***	739.64**	22.23
Free State	871.46***	-1429.52***	-558.07**	1262.66***	-675.8***	586.77**	28.7
Gauteng	918.64***	-1610.27	-691.63***	1506.74***	-741.72***	765.02***	73.39
KwaZulu-Natal	896.50***	-1684.89***	-788.39***	1622.01***	-703.19***	918.82***	130.44**
Limpopo	1051.72***	-2012.44***	-960.72***	2005.90***	-869.54***	1136.36***	175.63***
Mpumalanga	975.90***	-1783.15***	-807.25***	1724.47***	-800.53***	923.94***	116.69**
Northern Cape	1132.73***	-1784.21***	-651.48**	1350.61***	-791.69***	558.92**	-92.56
North West	1035.01***	-1800.38***	-765.37**	1688.94***	-846.05***	842.89***	77.513
Western Cape	993.67***	-1747.097***	-753.43***	1432.94***	-663.99***	768.95***	15.52

TEMPERATURE – WITH ADAPTATION							
PROVINCE	Summer	Fall	Summer farming season	Winter	Spring	Winter farming season	Annual
Eastern Cape	930.76***	-1509.50***	-578.74**	1366.64***	-715.07***	651.57**	72.83
Free State	840.09***	-1282.21***	-442.12**	1226.31***	-724.05***	502.26**	60.14
Gauteng	885.57***	-1444.33***	-558.76**	1463.36***	-794.57***	668.79***	110.04**
KwaZulu-Natal	864.23***	-1511.26***	-647.03**	1575.32***	-753.30***	822.02***	174.99***
Limpopo	1013.86***	-1805.06***	-791.20***	1948.16***	-931.50***	1016.65***	225.45***
Mpumalanga	940.77***	-1599.39***	-658.63**	1674.83***	-857.57***	817.26***	158.63***
Northern Cape	1091.95***	-1600.35***	-508.40*	1311.73***	-848.10***	463.63**	-44.76
North West	997.75***	-1614.85***	-617.1**	1640.32***	-906.34***	733.98***	116.88**
Western Cape	957.90***	-1567.06***	-609.16**	1391.69***	-711.3***	680.38***	71.23

Table 16: Marginal effects of precipitation at the provincial level

PRECIPITATION – WITHOUT ADAPTATION

PROVINCE	Summer	Fall	Summer farming season	Winter	Spring	Winter farming season	Annual
Eastern Cape	50.31	-79.48	-29.17	69.68	-37.37	32.30	3.13
Free State	32.02	-80.45	-48.43	77.68	-40.51	37.16	-11.2692
Gauteng	-3.65	-81.05	-84.70	80.43	10.1	90.54	5.84
KwaZulu-Natal	-25.14	-117.05	-142.19*	64.67	71.4	136.08*	-6.12
Limpopo	140.67**	-71.20	69.47***	63.69	-16.97	46.73	116.20*
Mpumalanga	-5.88	-83.55	-89.43	78.14	16.66	94.79	5.36
Northern Cape	108.88**	-41.60	67.27**	78.8	-162.78**	-83.98***	-16.7
North West	32.77	-71.29	-38.52	81.82	-72.54*	9.28	-29.24**
Western Cape	117.37**	-51.91	65.46**	65.26	-134.35**	-69.10*	-3.64

PRECIPITATION – WITH ADAPTATION

PROVINCE	Summer	Fall	Summer farming season	Winter	Spring	Winter farming season	Annual
Eastern Cape	33.3	-50.49	-17.19	38.3	-24.86	13.43	-3.76
Free State	18.07	-51.11	-33.04	45.59	-27.58	18.006	-15.03
Gauteng	-11.63	-51.49	-63.12	48.103	16.25	64.35	1.23
KwaZulu-Natal	-29.53	-74.36	-103.89	33.74	69.33	103.07	-0.83
Limpopo	108.56*	-45.23	63.33***	32.843	-7.2	25.65	88.97**
Mpumalanga	-13.49	-53.08	-66.57	46.006	21.93	67.93	1.36
Northern Cape	82.08*	-26.43	55.65**	46.61	-133.45**	-86.84***	-31.19
North West	18.7	-45.29	-26.59	49.37	-55.317	-5.95	-32.54**
Western Cape	89.15*	-32.98	56.17**	34.27	-108.85**	-74.58***	-18.41

Table 17: Impacts of selected climate scenarios on net revenues (US$/hectare)

	CGCM2 2050	CGCM2 2100	HadCM3 2050	HadCM3 2100	PCM 2050	PCM 2100
Change in temperature (^{0}C)	3.6	9	3.9	9.6	2.3	5.6
Change in precipitation (%)	-4	-8	-8	-15	-2	-4
Impacts						
Full sample	-12.88	-40.79	-16.26	-93.24	-5.14	-29.99
	(-4.22)	(-25.65)	(-5.32)	(-30.52)	(-1.68)	(-9.82)
Irrigated	-15.91	-113.99	-20.23	-134.55	-5.34	-41.16
	(-3.4)	(-24.43)	(-4.34)	(-28.84)	(-1.15)	(-8.82)
Dryland	-43.2	-55.24	-44.1	-59.06	-41.63	-46.29
	(-27)	(-34.74)	(-27.74)	(-37.44)	(-26.18)	(-29.12)
Large-scale	-43.11	-220.16	-49.39	-248.21	-20.65	-92.99
	(-12.01)	(-61.41)	(-13.78)	(-69.23)	(-5.76)	(-25.94)
Small-scale	-47.29	-204.6	-52.73	-227.2	-25.05	-93.86
	(-18.61)	(-80.49)	(-20.74)	(-89.39)	(-9.86)	(-36.93)

Note: Percentage changes in parenthesis

Table 18: Perception of change in temperature and rainfall pattern by the interviewed farm households

Province	District	Total number of household	Temperature change Number (%)			Changes in rainfall Number (%)		
			Yes	**No**	**No resp-onse**	**Yes**	**No**	**No resp-onse**
Eastern Cape	Aberdeen	20	9	8	3	9	7	4
	Humansdorp	11	5	6	0	4	7	0
	Kirkwood	24	11	11	2	11	11	2
		Total	**25 (45)**	**25 (45)**	**5 (10)**	**24 (44)**	**25 (45)**	**6 (11)**
Free State	Bethlehem	29	22	5	2	21	5	3
	Kroonstad	27	19	5	3	21	3	3
		Total	**41 (73)**	**10 (18)**	**5 (9)**	**42 (75)**	**8 (15)**	**6 (10)**
Gauteng	Bronkhorstpruit	**11**	**10 (90)**	**1 (10)**	**0 (0)**	**11 (100)**	**0 (0)**	**0 (0)**
Kwazulu-Natal	Estcourt	20	19	1	0	19	1	0
	Hlabisa	38	37	1	0	36	2	0
	Mont Currie	11	9	2	0	9	2	0
	Port Shepstone	26	20	6	0	21	3	2
		Total	**85 (90)**	**10 (10)**	**0 (0)**	**85 (90)**	**8 (8)**	**2 (2)**
Mpumalanga	Lydenburg	21	17	3	1	19	1	1
	Middelburg	25	23	2	0	21	4	0
		Total	**40 (88)**	**5 (10)**	**1 (2)**	**40 (88)**	**5 (10)**	**1 (2)**
Northern Cape	Hopetown	40	**29 (72)**	**8 (20)**	**3 (8)**	**29 (72)**	**8 (20)**	**3 (8)**
Limpopo (Northern) Province	Soutpansberg	27	**16 (60)**	**11 (41)**	**0 (0)**	**9 (33)**	**18 (66)**	**0 (0)**
North West	Vryburg	43	**32 (75)**	**9 (20)**	**2 (5)**	**31 (72)**	**11 (25)**	**1 (3)**
Western Cape	Caledon	19	8	11	0	8	11	0
	Piketberg	24	16	8	0	20	4	0
		Total	**24 (56)**	**19 (44)**	**0 (0)**	**28 (65)**	**15 (35)**	**0 (0)**
NATIONAL TOTAL		**416**	**302 (72)**	**98 (24)**	**16 (4)**	**299 (72)**	**98 (23.5)**	**19 (4.5)**

Table A1: Type of farm/sample size at the country level

	Type of farming operation		Total
	Large-scale	Small-scale	
Number of farming operations (%)	150,000 (14%)	943,000 (86%)	1,100,000 (100%)
Sample size range	112 – 140	688 - 860	800 - 1000

Source: SSA (2002) and own estimations

Table A2: Type of farm/sample size at the provincial level (1)

Province	Type of farming operation					
	Large-scale			Small-scale		
	Number of farming operations ('000)	% of total farming operations	**Sample range**	Number of farming operations ('000)	% of total farming operations	Sample range
Western Cape (WC)	23	15	**17 – 21**	-	-	**-**
Eastern Cape (EC)	15	10	**11 – 14**	392	41	**282 – 353**
Northern Cape (NC)	12	8	**9 – 11**	-	-	**-**
Free State (FS)	40	27	**30 – 38**	17	2	**14 – 17**
KwaZulu-Natal (KZ)	26	17	**19 – 24**	189	20	**138 – 172**
North West (NW)	17	11	**12 – 15**	35	4	**27 – 34**
Gauteng (GU)	4	3	**3 – 4**	-	-	**-**
Mpumalanga (MP)	8	5	**6 – 7**	37	4	**27 – 35**
Limpopo (LP)	5	4	**5 – 6**	273	29	**200 – 249**
TOTAL	150	100	**112 - 140**	943	100	**688 - 860**

Source: SSA (2002) and own estimates

Table A3: Types of farm/sample size at the provincial level (2)

(Large-scale sample increased by 184% and small- scale decreased by 30%)

Province	Type of faming operation (Sample range)	
	Large-scale	Small-scale
Western Cape (WC)	48 – 60	-
Eastern Cape (EC)	31 – 40	197 – 247
Northern Cape (NC)	26 – 31	-
Free State (FS)	85 – 108	10 – 12
KwaZulu-Natal (KZ)	54 – 68	97 – 120
North West (NW)	34 – 42	19 – 24
Gauteng (GU)	9 – 11	-
Mpumalanga (MP)	17 – 20	19 – 25
Limpopo (LP)	14 – 17	140 – 174
TOTAL	318 – 398	482 - 602

Table A4: District sample at the provincial level

Province	Type of farming operations (Sample range)		Total number of sample farms (large-scale + small-scale farms)	Total number of districts	Number of sample districts
	Large-scale	Small-scale			(Actual) **Revised**
Western Cape (WC)	48 – 60	-	48 – 60	41	(4) **2**
Eastern Cape (EC)	31 – 40	197 – 247	228 – 287	80	(7) **7**
Northern Cape (NC)	26 – 31	-	26 – 30	26	(2) **1**
Free State (FS)	85 – 108	10 – 12	95 – 120	53	(5) **4**
KwaZulu-Natal (KZ)	54 – 68	97 – 120	151 – 188	67	(6) **6**
North West (NW)	34 – 42	19 – 24	53 – 66	24	(2) **2**
Gauteng (GU)	9 – 11	-	9 – 12	23	(2) **1**
Mpumalanga (MP)	17 – 20	19 – 25	36 – 45	26	(2) **2**
Limpopo (LP)	14 – 17	140 – 174	154 – 191	34	(3) **6**
TOTAL	318 – 398	482 - 602	800 - 1000	374	(33) **(31)**

Notes:

(1) District sample = {[Number of districts in the province/ Total number of districts] * 33 (Total number of sample districts)}

(2) The number of districts in each province was further revised depending on the size of the farm household sample in each province. For example the sample districts in the Northern Cape, given the number of districts in the province, is estimated to be two. However, this was revised downwards to one given that the farm household sample in the province is only in the range of 26–30 and the objective was to have a range of 30–35 households in each selected district. A similar approach was used to revise the number of districts in the other provinces.

Table A5: District level farm sample (large- and small-scale)

Province	Type of farming operation (Sample range)		District number	Number of farm household sample		Number of sample districts
	Large-scale	Small-scale		Large-scale	Small-scale	
Western Cape (WC)	48 – 60	-	1	24 - 30	0	2
			2	24 - 30	0	
Eastern Cape (EC)	31 – 40	197 – 247	1	31 - 40	28 - 35	7
			2	0	28 - 35	
			3	0	28 - 35	
			4	0	28 - 35	
			5	0	28 - 35	
			6	0	28 - 35	
			7	0	28 - 35	
Northern Cape (NC)	26 – 31	-	1	26 -31	0	1
Free State (FS)	85 – 108	10 – 12	1	0	10 -12	4
			2	28 - 36	0	
			3	28 - 36	0	
			3	28 - 36	0	
KwaZulu-Natal (KZ)	54 – 68	97 – 120	1	27 - 34	0	5
			2	27 - 34	48 - 60	
			3	0	0	
			4	0	48 - 60	
			5	0	48 - 60	
			6	0	48 - 60	
North West (NW)	34 – 42	19 – 24	1	34 – 42	0	2
			2	0	19 - 24	
Gauteng (GU)	9 – 11	-	1	9 - 11	0	1
Mpumalanga (MP)	17 – 20	19 – 25	1	17 – 20	0	2
			2	0	19 – 25	
Limpopo (LP)	14 – 17	140 – 174	1	14 – 17	0	6
			2	0	28 - 35	
			3	0	28 - 35	
			4	0	28 - 35	
			5	0	28 - 35	
			6	0	28 - 35	
TOTAL	318 – 398	482 - 602		318 - 398	482 - 602	30

Table A6: Weighted criteria for the choice of districts in each province

	Criteria	Weight
1.	Total dryland crop farming (annual and perennial crops)	8
2.	Total number of farm units	6
3.	Total crop land under irrigation (annual and perennial)	3
4	Total land under farming	2
5	Total land under animal farming	1
	Total	20

Table A7: Sample size at the district level (large- and small-scale farms)

Province	Type of farming operation (Sample size)		Name of district	Number of farm household sample		Number of sample districts
	Large-scale	Small-scale		Large-scale	Small-scale	
Western Cape (WC)	70	-	Caledon	35	0	2
			Piketberg	35	0	
Eastern Cape (EC)	35	245	Kirkwood	35	35	7
			Aliwal North	0	35	
			Barkly East	0	35	
			Humansdorp	0	35	
			Somerset East	0	35	
			Stutterheim	0	35	
			Wodehouse	0	35	
Northern Cape (NC)	35	-	Calvinia	35	0	1
Free State (FS)	105	35	Kroonstad	0	35	4
			Bethlehem	35	0	
			Lindley	35	0	
			Senekal	35	0	
KwaZulu-Natal (KZ)	70	210	Port Shepstone	35	0	7
			Lower Tugela	35	35	
			Camperdown	0	35	
			Mount Curie	0	35	
			Utrecht	0	35	
			Ixopo	0	35	
			New Hanover	0	35	
North West (NW)	35	35	Vryburg	35	0	2
			Lichtenburg	0	35	
Gauteng (GU)	35	-	Bronkhorstspruit	35	0	1
Mpumalanga (MP)	35	35	Ermelo	35	0	2
			Middleburg	0	35	
Limpopo (LP)	35	175	Soutpansberg	35	0	6
			Potgietersrus	0	35	
			Waterberg	0	35	
			Thabazimbi	0	35	
			Pietersburg	0	35	
			Warmbad	0	35	
TOTAL	455	735		455	735	32

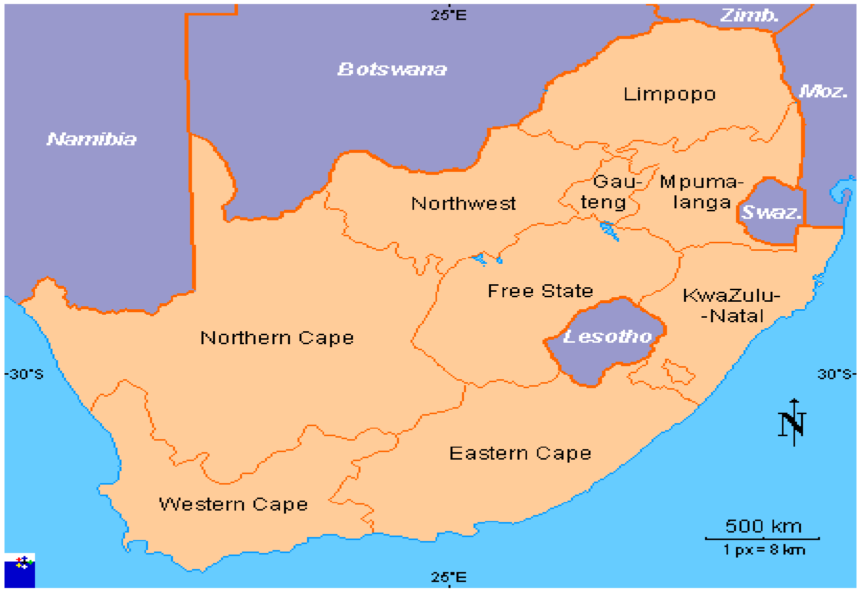
Table A8: Sample size for South Africa survey at district level (large- and small-scale farms)

Province	Type of farming operation (Sample size)		Name of district	Number of farm household sample		Number of sample districts
	Large-scale	Small-scale		Large-scale	Small-scale	
Western Cape (WC)	**42**	**28**	Caledon	**21**	**14**	**2**
			Piketberg	**21**	**14**	
Eastern Cape (EC)	**119**	**161**	Kirkwood	**35**	**35**	**7**
			Aliwal North	**14**	**21**	
			Barkly East	**14**	**21**	
			Humansdorp	**14**	**21**	
			Somerset East	**14**	**21**	
			Stutterheim	**14**	**21**	
			Wodehouse	**14**	**21**	
Northern Cape (NC)	**21**	**14**	Calvinia	**21**	**14**	**1**
Free State (FS)	**77**	**63**	Kroonstad	**14**	**21**	**4**
			Bethlehem	**21**	**14**	
			Lindley	**21**	**14**	
			Senekal	**21**	**14**	
KwaZulu-Natal (KZ)	**126**	**154**	Port Shepstone	**21**	**14**	**7**
			Lower Tugela	**35**	**35**	
			Camperdown	**14**	**21**	
			Mount Curie	**14**	**21**	
			Utrecht	**14**	**21**	
			Ixopo	**14**	**21**	
			New Hanover	**14**	**21**	
North West (NW)	**35**	**35**	Vryburg	**21**	**14**	**2**
			Lichtenburg	**14**	**21**	
Gauteng (GU)	**21**	**14**	Bronkhorstspruit	**21**	**14**	**1**
Mpumalanga (MP)	**35**	**35**	Ermelo	**21**	**14**	**2**
			Middleburg	**14**	**21**	
Limpopo (LP)	**91**	**119**	Soutpansberg	**21**	**14**	**6**
			Potgietersrus	**14**	**21**	
			Waterberg	**14**	**21**	
			Thabazimbi	**14**	**21**	
			Pietersburg	**14**	**21**	
			Warmbad	**14**	**21**	
TOTAL	**567**	**623**		**567**	**623**	**32**

Table A9 : Final sample size for South Africa survey at district level (large- and small-scale farmers)

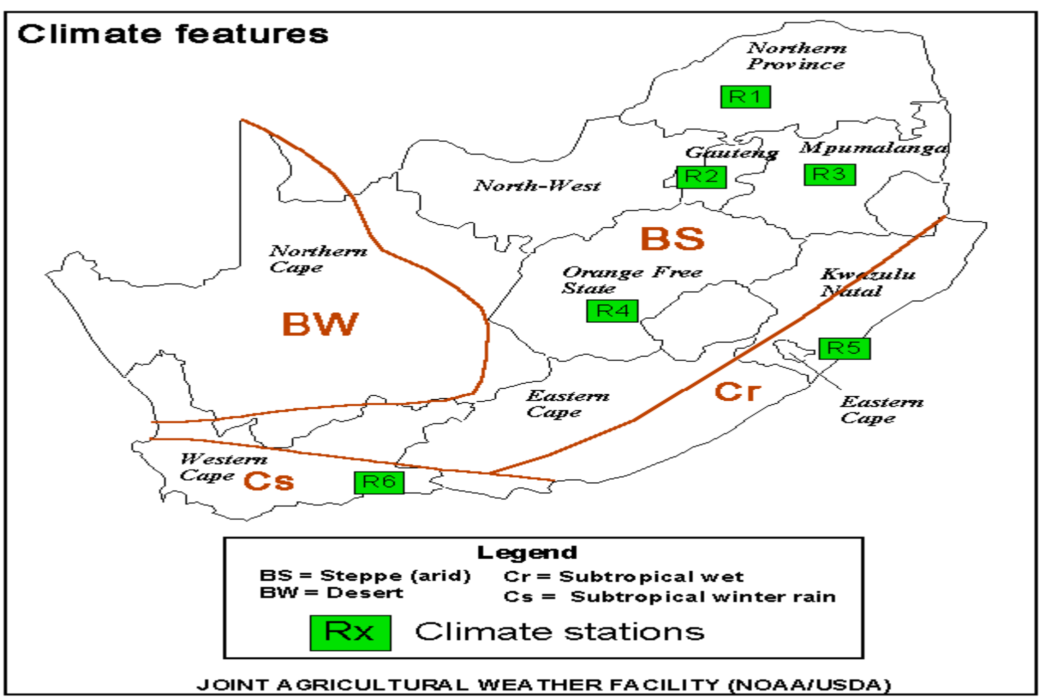
Province	Type of farming operation (Sample size)		Name of district	Number of farm household sample		Number of sample districts
	Large-scale	Small-scale		Large-scale	Small-scale	
Western Cape (WC)	**63**	**42**	Caledon	**21**	**14**	
			Piketberg	**21**	**14**	
			Prince Albert	**21**	**14**	**3**
Eastern Cape (EC)	**105**	**140**	Kirkwood	**21**	**14**	
			Humansdorp	**14**	**21**	
			Somerset East	**14**	**21**	
			Stutterheim	**14**	**21**	
			Wodehouse	**14**	**21**	**7**
			East London	**14**	**21**	
			Aberdeen	**14**	**21**	
Northern Cape (NC)	**63**	**42**	Calvinia	**21**	**14**	
			Gordonia	**21**	**14**	**3**
			Hopetown	**21**	**14**	
Free State (FS)	**77**	**63**	Kroonstad	**14**	**21**	
			Bethlehem	**21**	**14**	**4**
			Bloemfontein	**21**	**14**	
			Boshof	**21**	**14**	
KwaZulu-Natal (KZ)	**126**	**154**	Port Shepstone	**21**	**14**	
			Lower Tugela	**35**	**35**	
			Halbisa	**14**	**21**	**7**
			Mount Curie	**14**	**21**	
			Utrecht	**14**	**21**	
			Estcourt	**14**	**21**	
			New Hanover	**14**	**21**	
North West (NW)	**35**	**35**	Vryburg	**21**	**14**	**2**
			Lichtenburg	**14**	**21**	
Gauteng (GU)	**21**	**14**	Bronkhorstspruit	**21**	**14**	**1**
Mpumalanga (MP)	**35**	**35**	Lydenburg	**21**	**14**	**2**
			Middleburg	**14**	**21**	
Limpopo (LP)	**77**	**98**	Soutpansberg	**21**	**14**	
			Potgietersrus	**28**	**42**	
			Thabazimbi	**14**	**21**	
			Pietersburg	**14**	**21**	**4**
TOTAL	**602**	**623**		**602**	**623**	**33**

Figure 1: South Africa's nine provinces



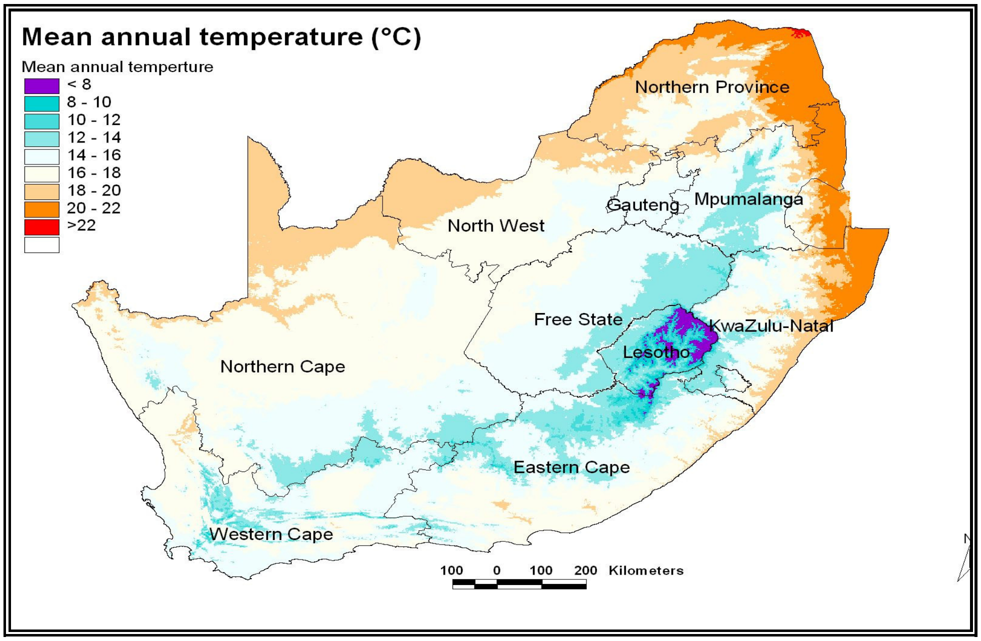
Source: FOTW (Flags of the World), 2006

Figure 2: Major climate zones in South Africa



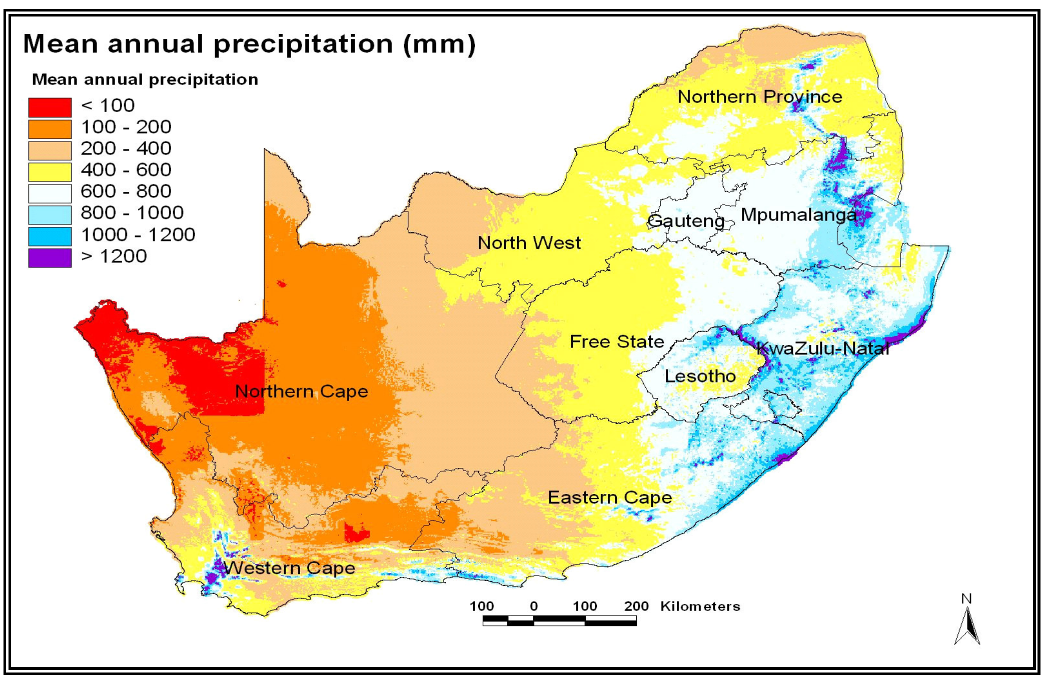
Source: Joint Agricultural Weather Facility (1999)
Notes: (1) Northern Province is now the Limpopo Province; (2) The 'subtropical winter rain' zone is better referred to as the Mediterranean (winter rainfall) zone.

Figure 3: Distribution of mean annual temperature in South Africa



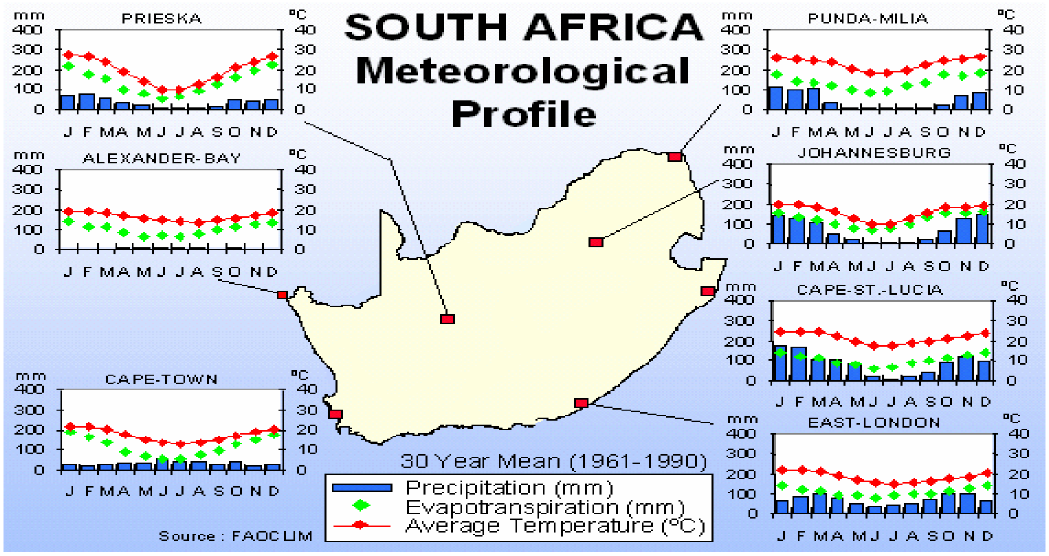
Source: Durand (2005)
Note: Northern Province is now the Limpopo Province.

Figure 4: Distribution of mean annual precipitation (mm) in South Africa



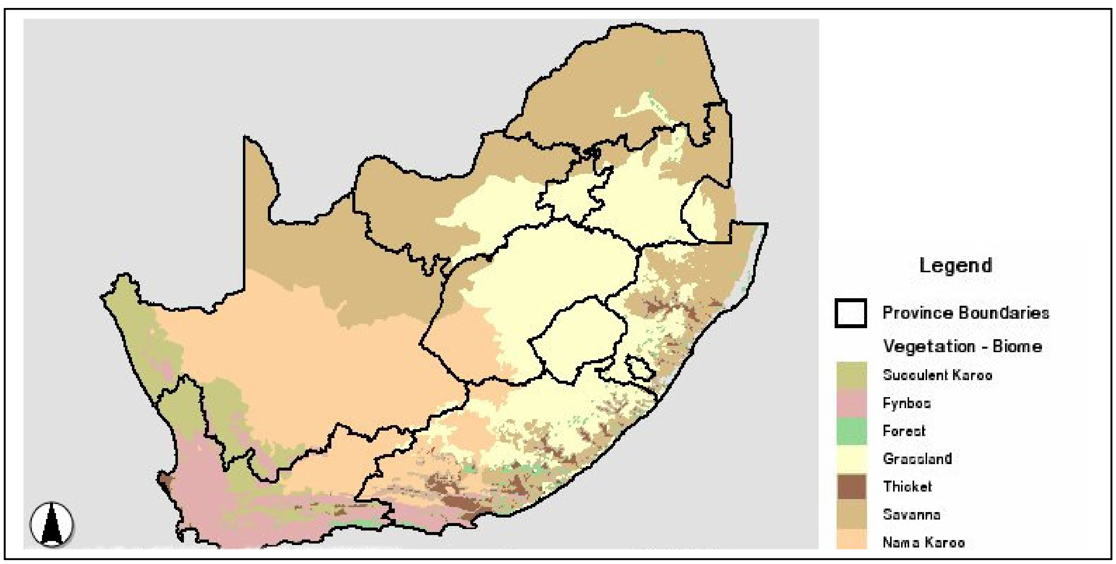
Source: Durand (2005)
Note: Northern Province is now the Limpopo Province.

Figure 5: South Africa's meteorological profile



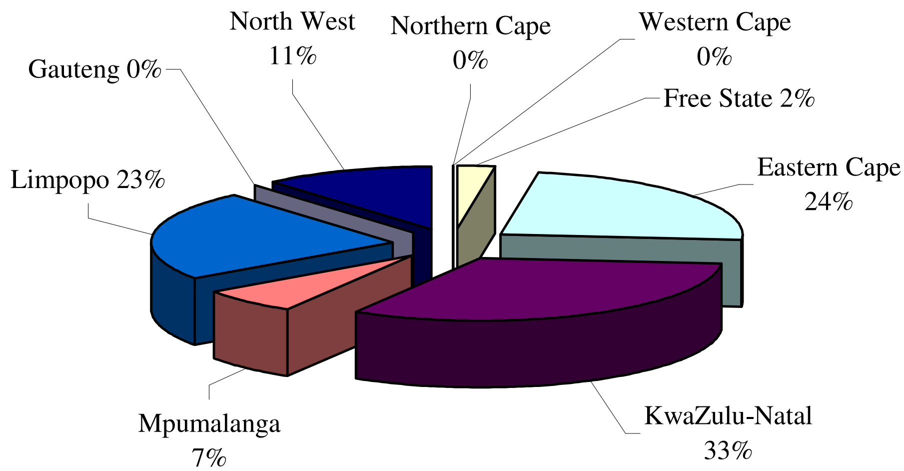
Source: FAO/GIEWS (2001)

Figure 6: Distribution of biomes in South Africa



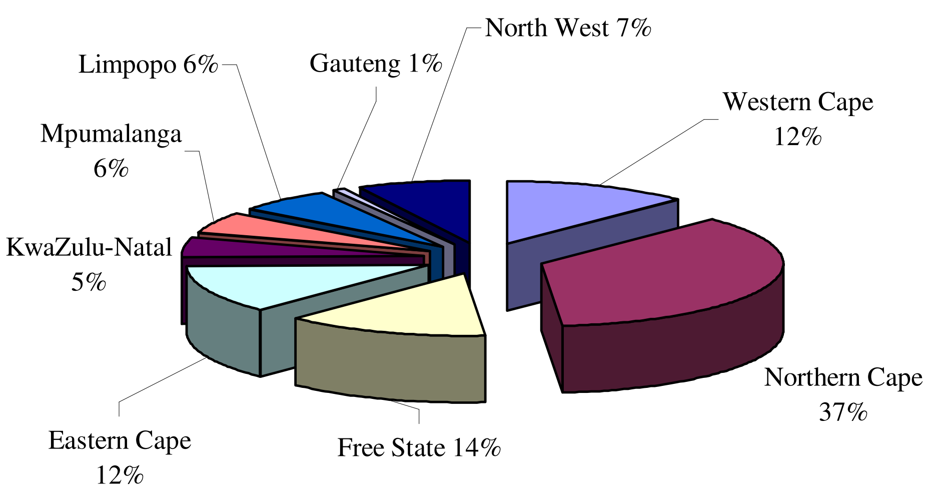
Source: Rutherford & Westfall (1986); Low & Rebelo (1996); South African Agricultural Geo-referenced Information System (2000)

Figure 7: Distribution of small-scale farmland in the nine provinces (1991)



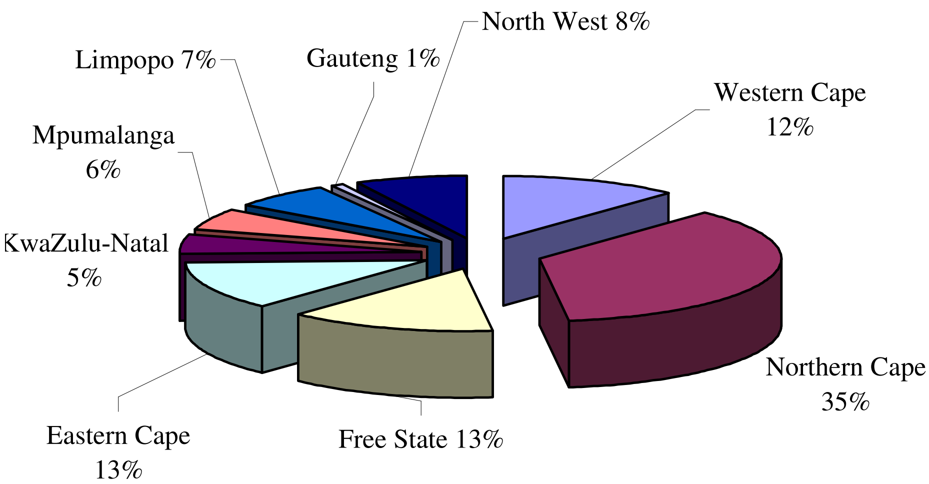
Source: NDA (2005)

Figure 8a: Distribution of large-scale farmland in the nine provinces (1993)



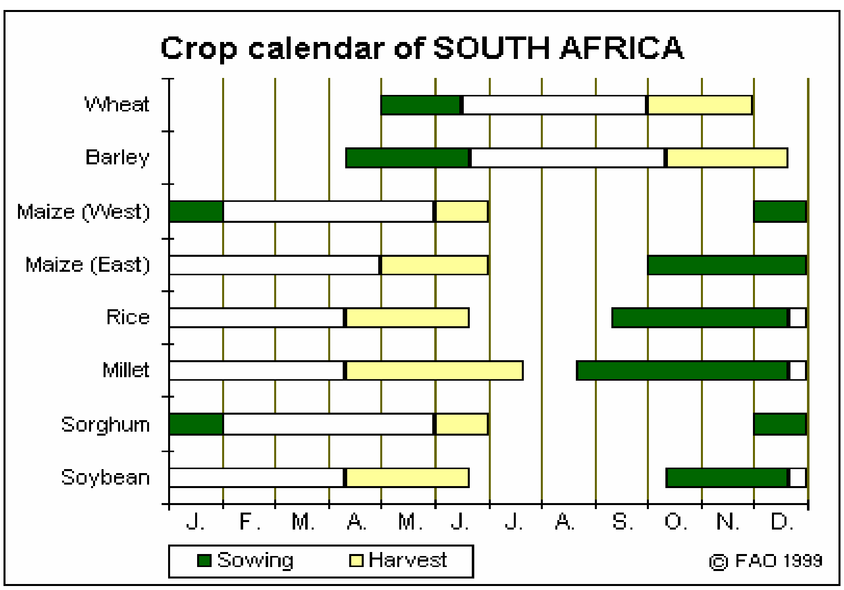
Source: NDA (2005)

Figure 8b: Distribution of large-scale farmlands in the nine provinces (1996)



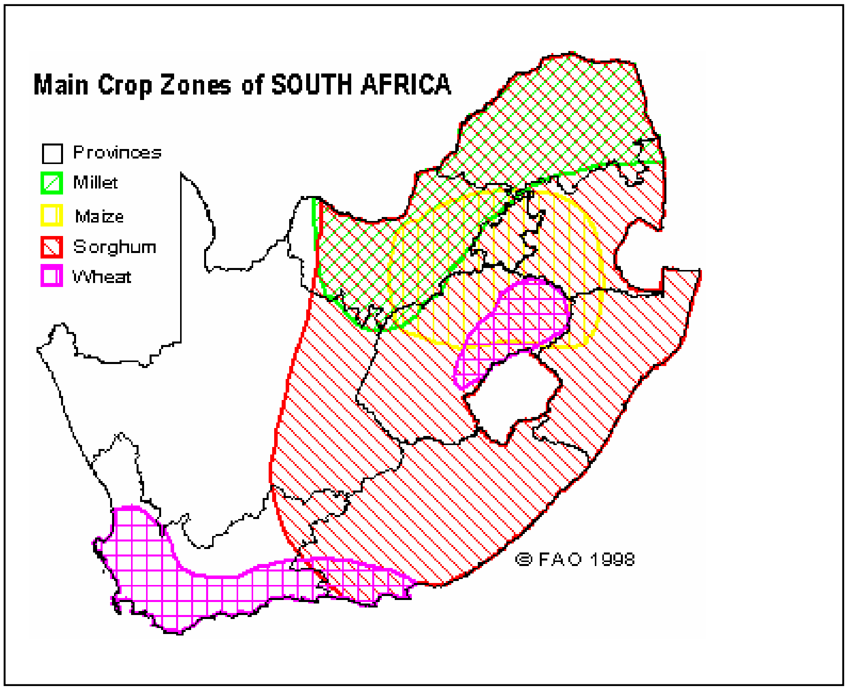
Source: NDA (2005)

Figure 9: Crop calendar of South Africa



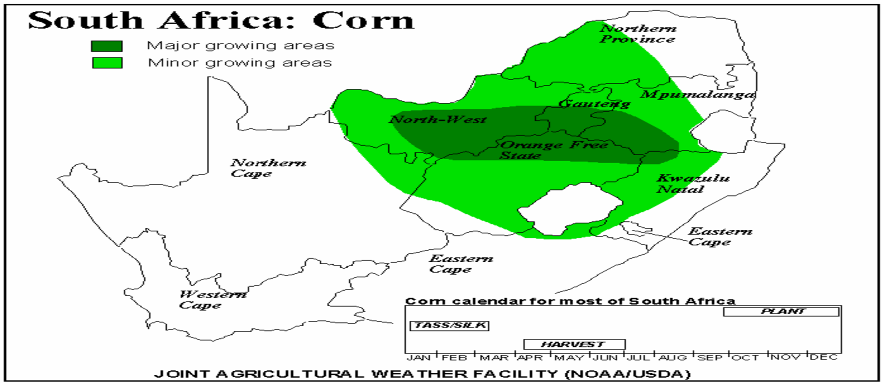
Source: FAO/GIEWS (2001)

Figure 10: Main crop zones of South Africa



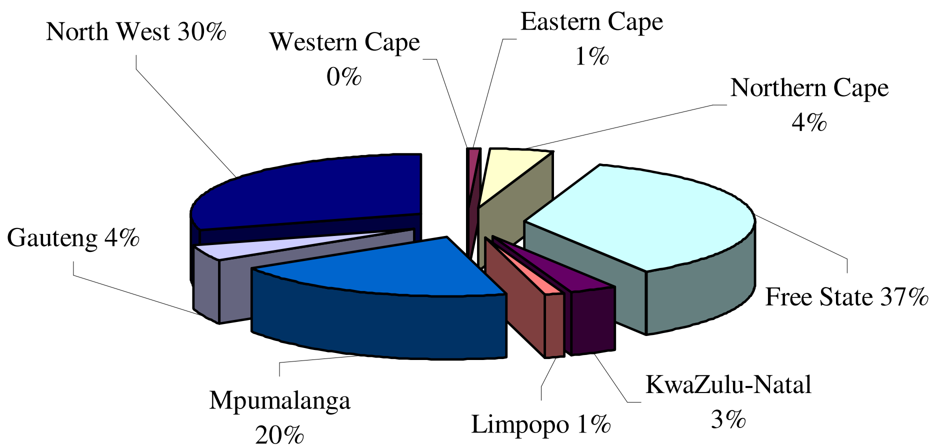
Source: FAO/GIEWS (2001)

Figure 11a: South Africa's maize growing areas



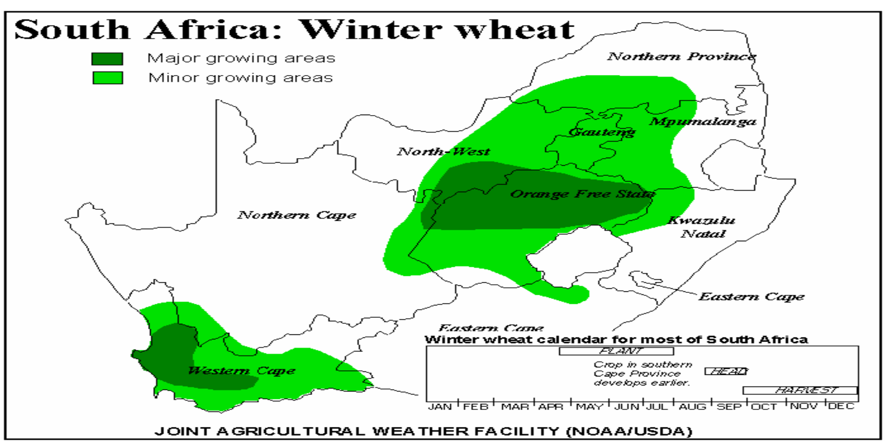
Source: Joint Agricultural Weather Facility (1999)
Note: Northern Province is now the Limpopo Province.

Figure 11b: Distribution of maize output in the nine provinces (2001)



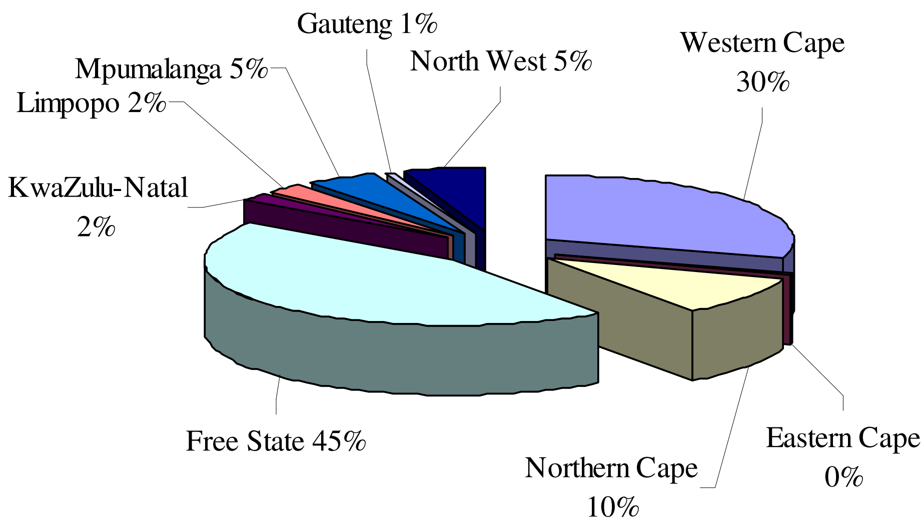
Source: NDA (2005)

Figure 12a: South Africa's wheat growing areas



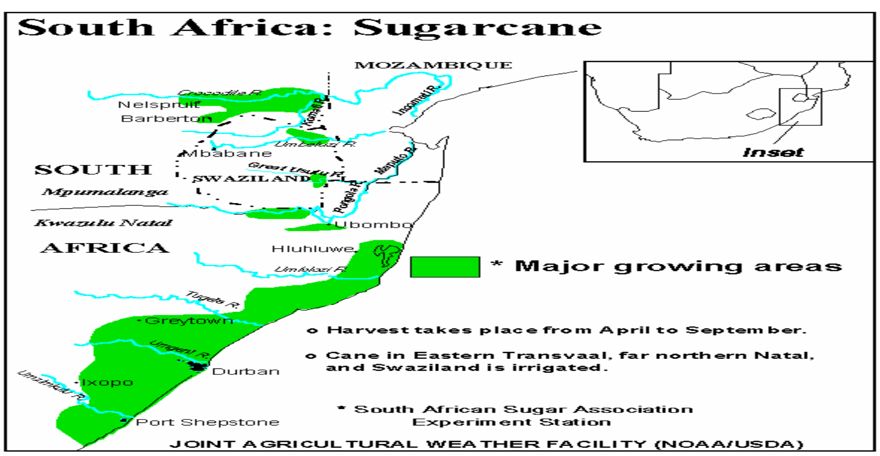
Source: Joint Agricultural Weather Facility (1999)
Note: Northern Province is now the Limpopo Province.

Figure 12b: Distribution of wheat output in the nine provinces (2001)



Source: NDA (2005)

Figure 13: South Africa's sugar cane growing areas



Source: Joint Agricultural Weather Facility (1999)

Figure 14: Distribution of output of sorghum in the nine provinces (2001)

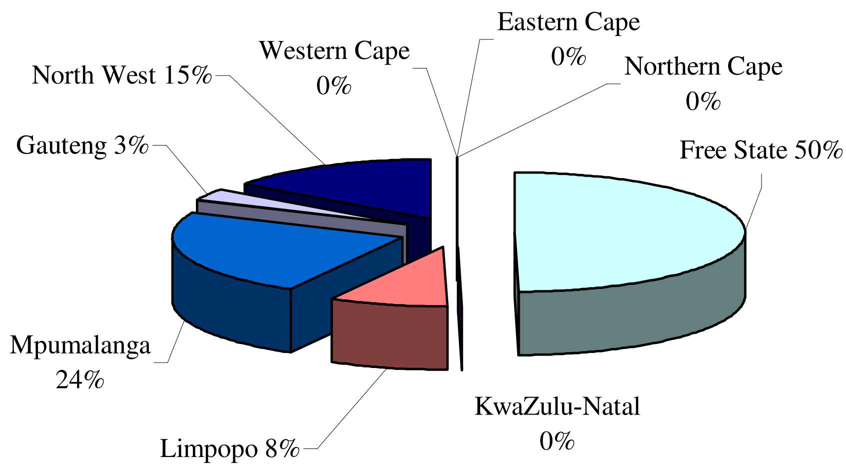


Figure 15: Distribution of output of groundnuts in the nine provinces (2001)

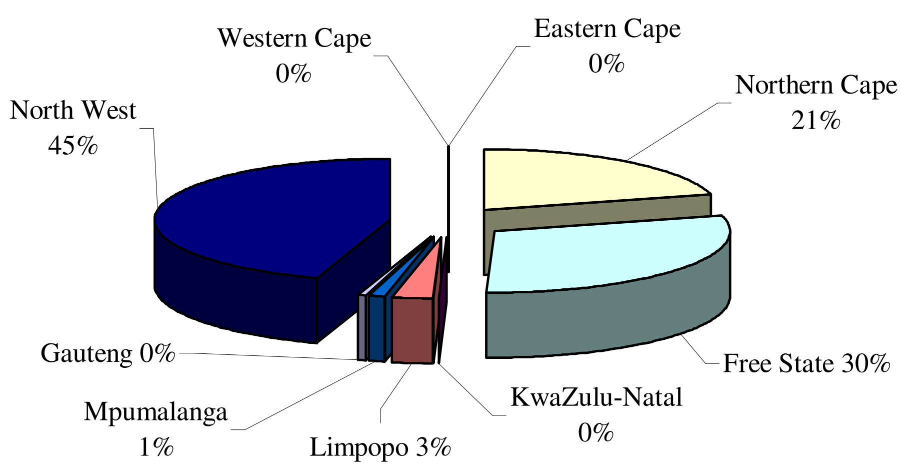


Figure 16: Mean annual precipitation and temperature in South Africa (1960–1989)

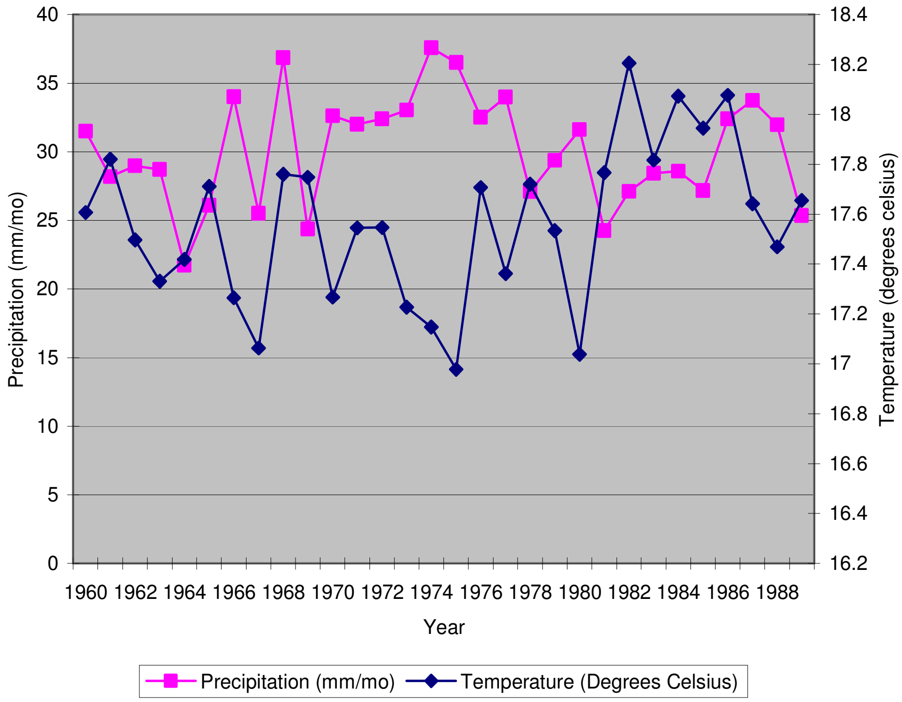
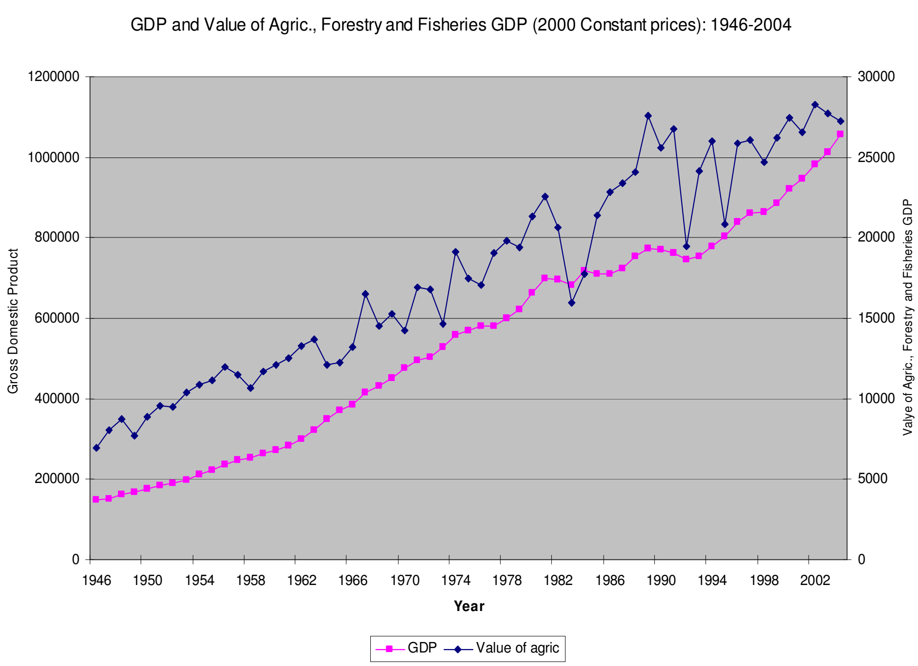


Figure 17: GDP and value of agriculture, forestry and fisheries (2000 constant prices): 1946–2004



Source: South Africa Reserve Bank (2006)

Figure 18: Agriculture, forestry and fisheries as % of GDP (1946–2004)

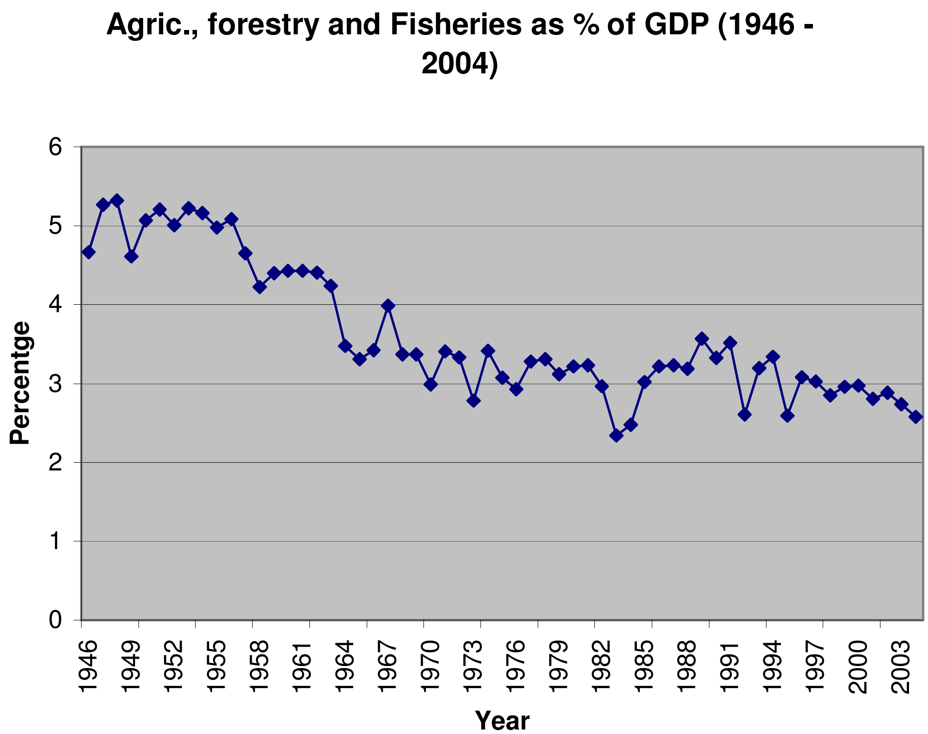


Figure 19: Maize area planted and harvested (1966–2004)

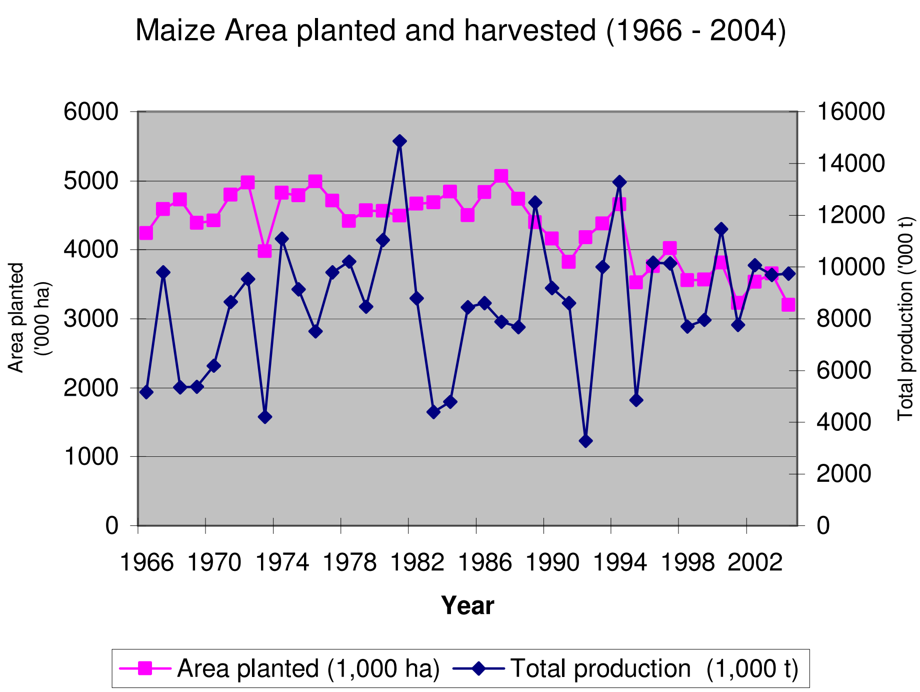


Figure 20: Wheat area planted and harvested (1966–2004)

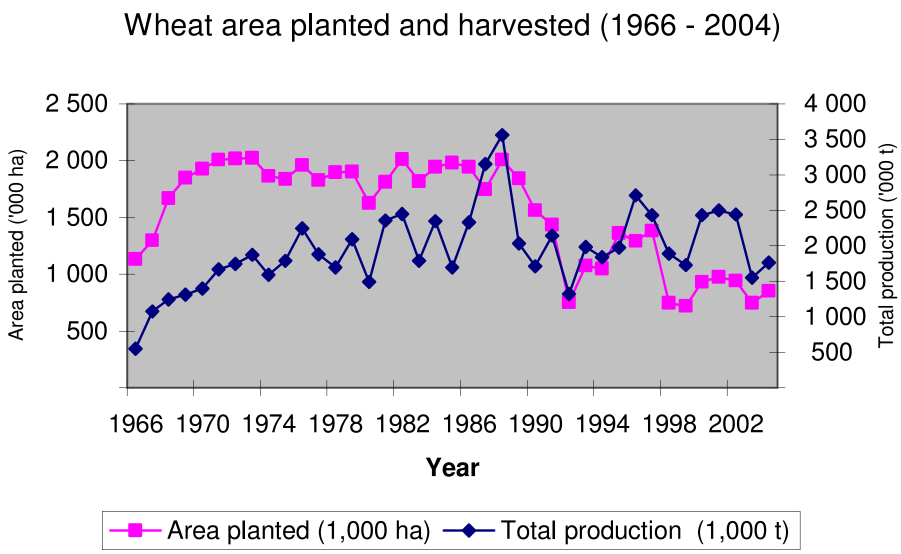


Figure 21: Sorghum area planted and harvested (1971–2004)

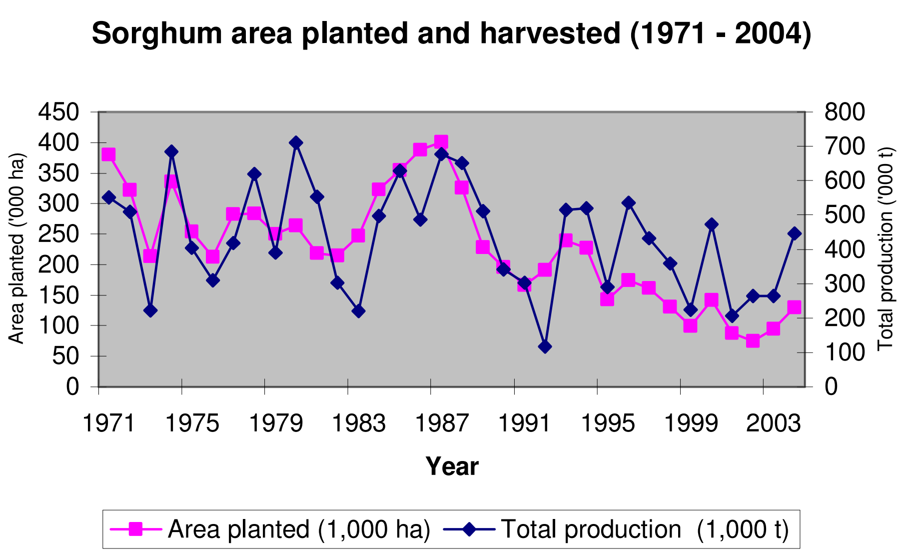


Figure 22: Sugar cane area planted and harvested (1966–2002)

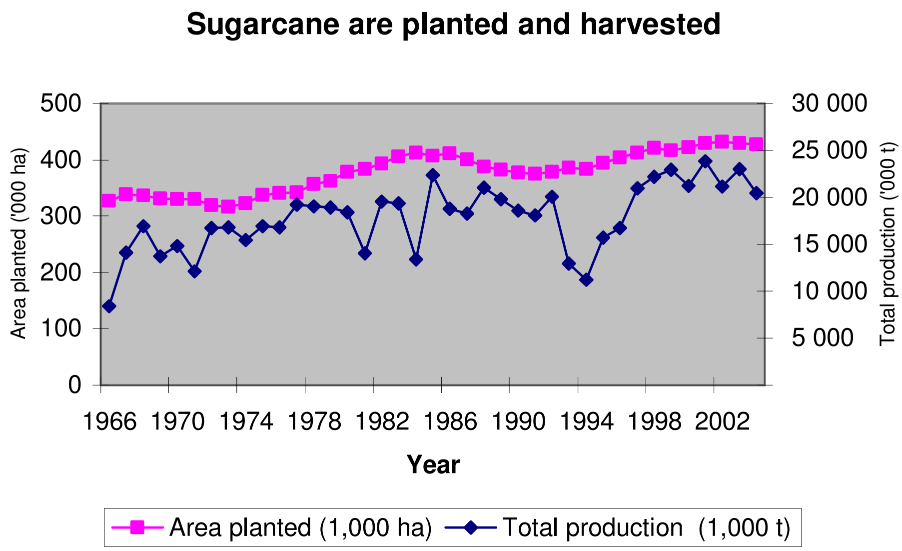


Figure 23: Mean gross and net revenues in the nine provinces (US$/ha)

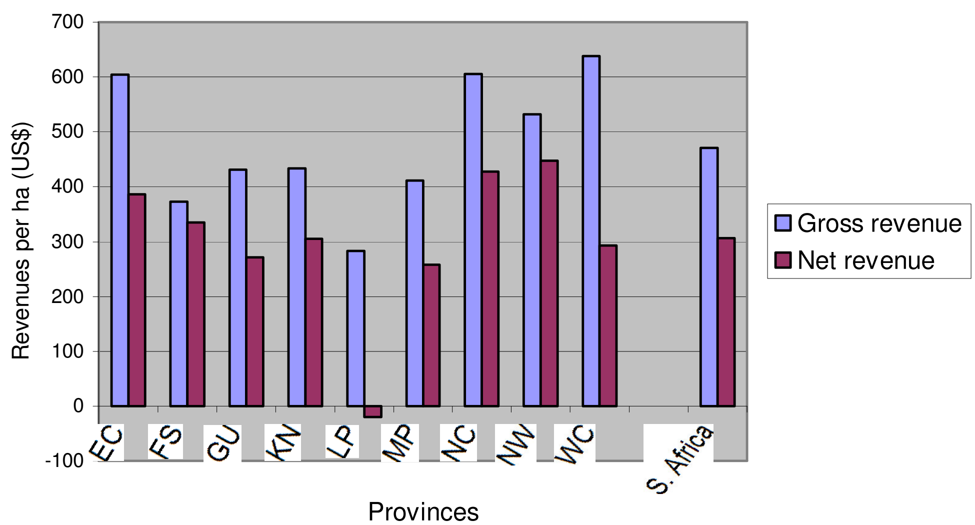


Figure 24: Distribution of major soil types in South Africa

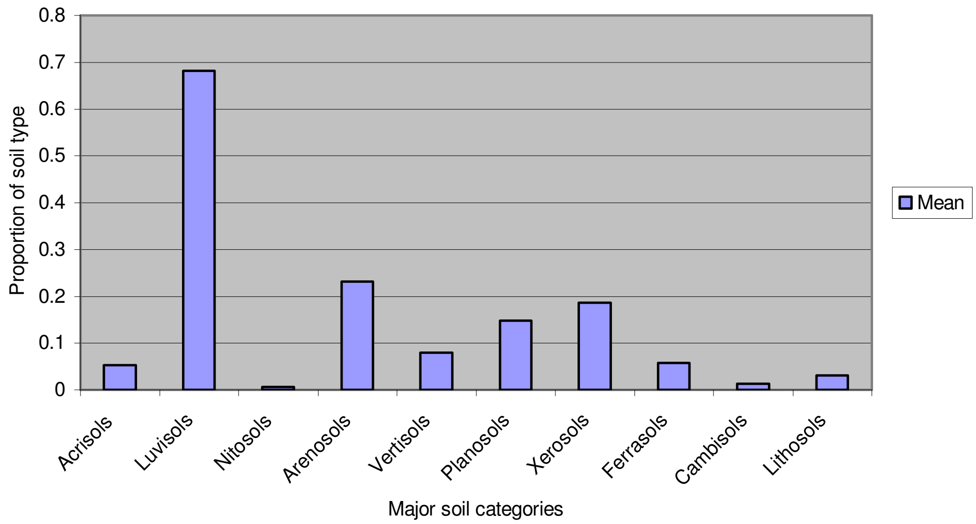
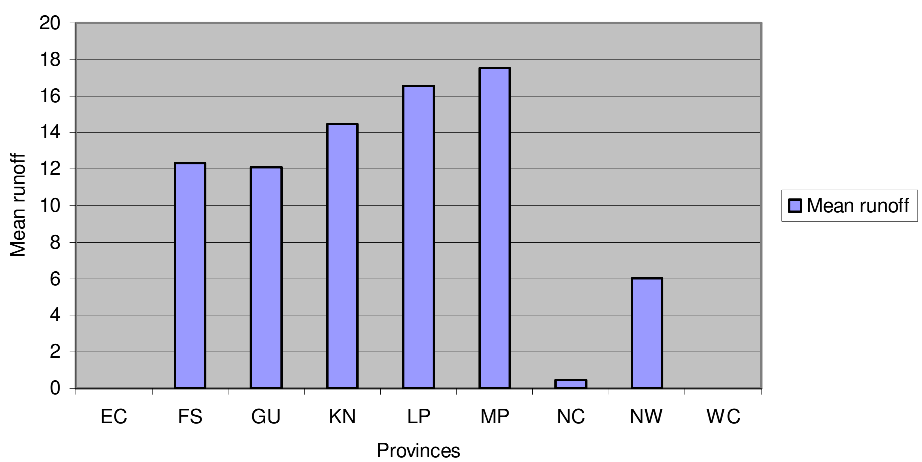


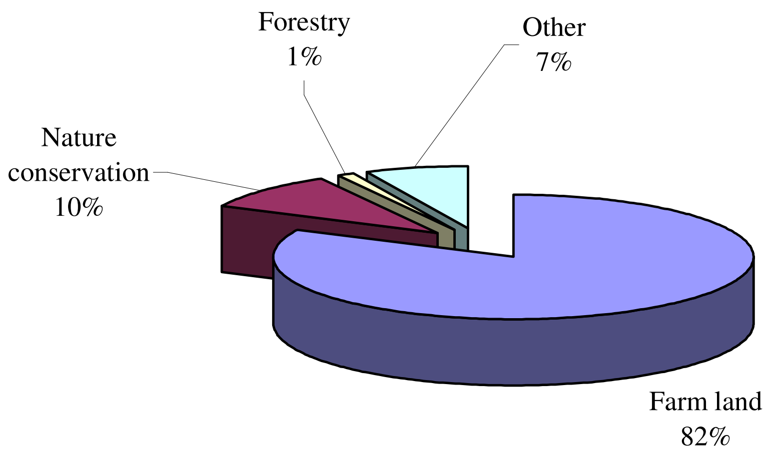
Figure 25: Distribution of mean runoff in the nine provinces



APPENDICES

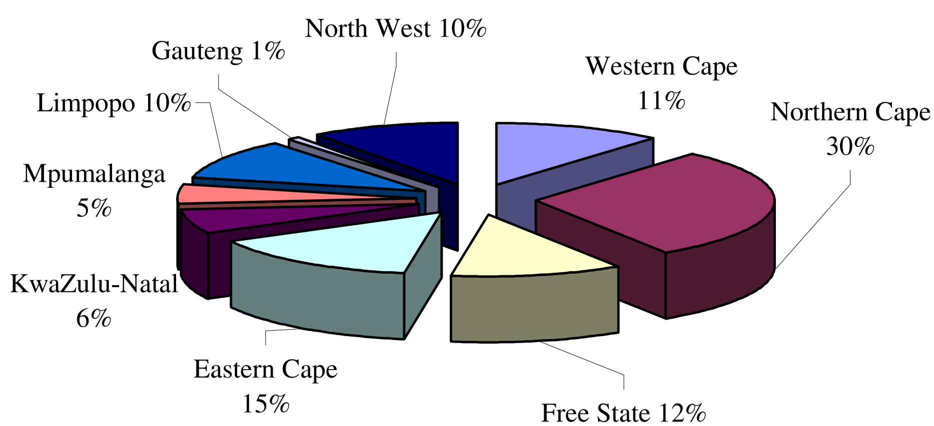
Figures A1 to A10: Distribution of agricultural activities across South Africa landscape

Figure A1: Land use in South Africa (1991)



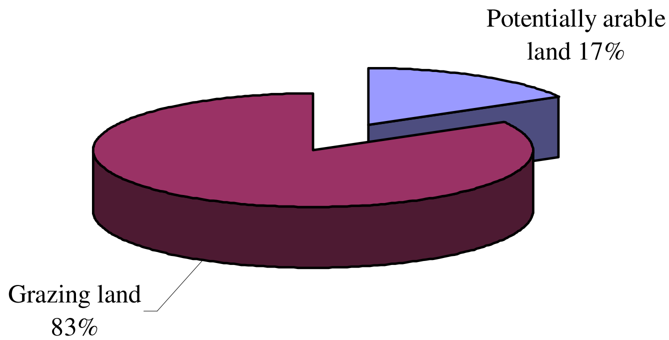
Source: NDA (2005)

Figure A2: Distribution of farm land in the nine provinces



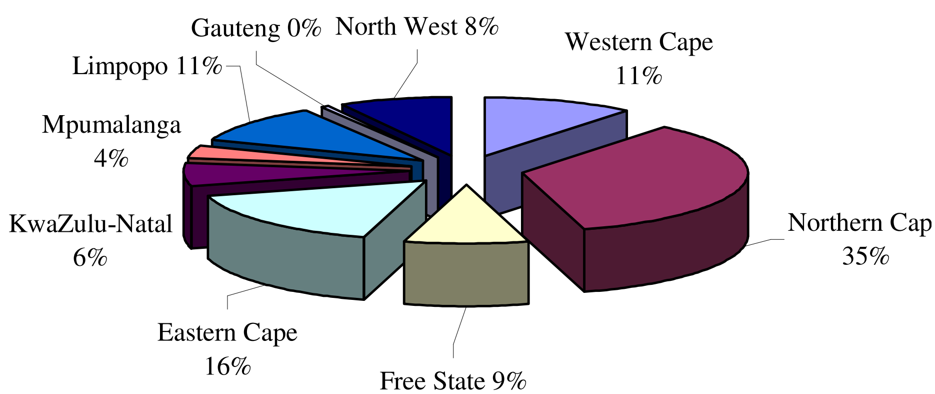
Source: NDA (2005)

Figure A3: Farmland use in South Africa



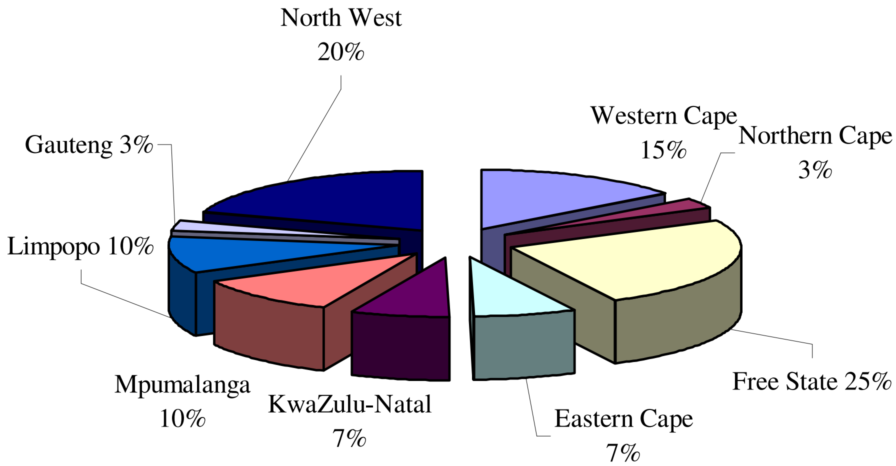
Source: NDA (2005)

Figure A4: Distribution of grazing land in the nine provinces



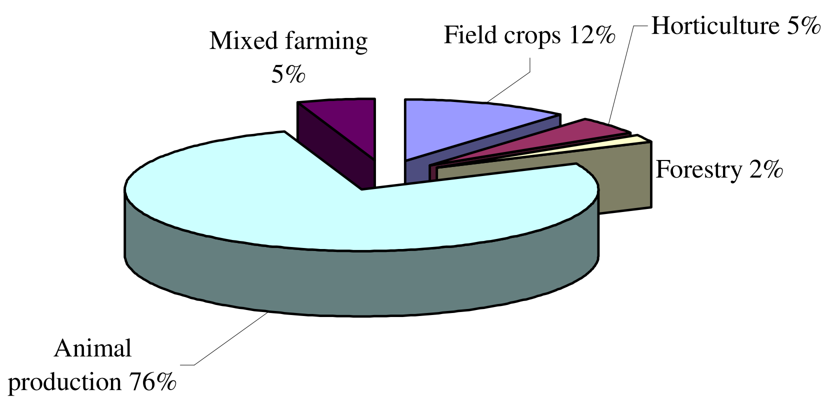
Source: NDA (2005)

Figure A5: Distribution of potentially arable land in South Africa



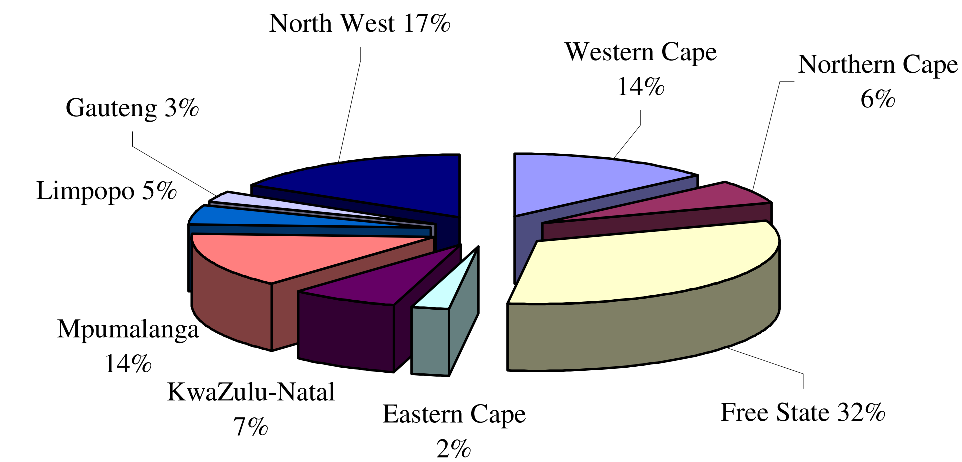
Source: NDA (2005)

Figure A6: Farm land use in South Africa (1993)



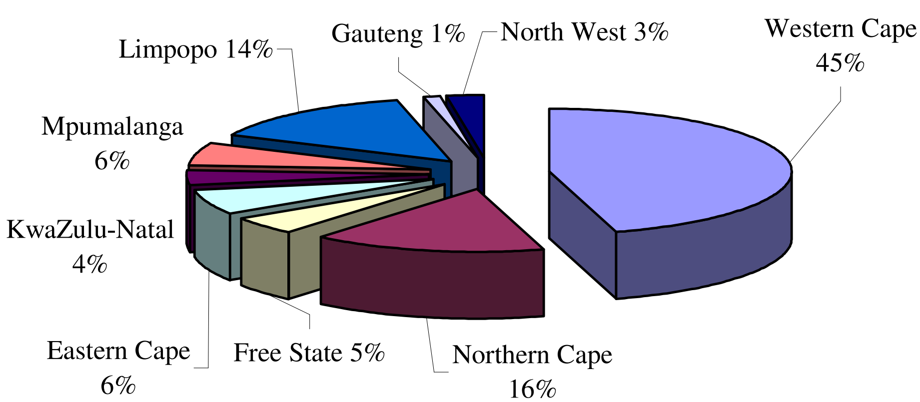
Source: NDA (2005)

Figure A7: Distribution of field crop farming in the nine provinces (1993)



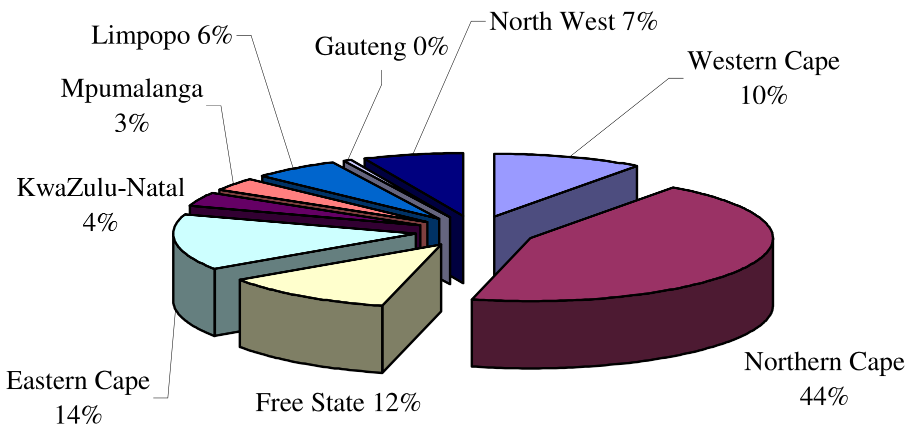
Source: NDA (2005)

Figure A8: Distribution of horticultural activities in the nine provinces (1993)



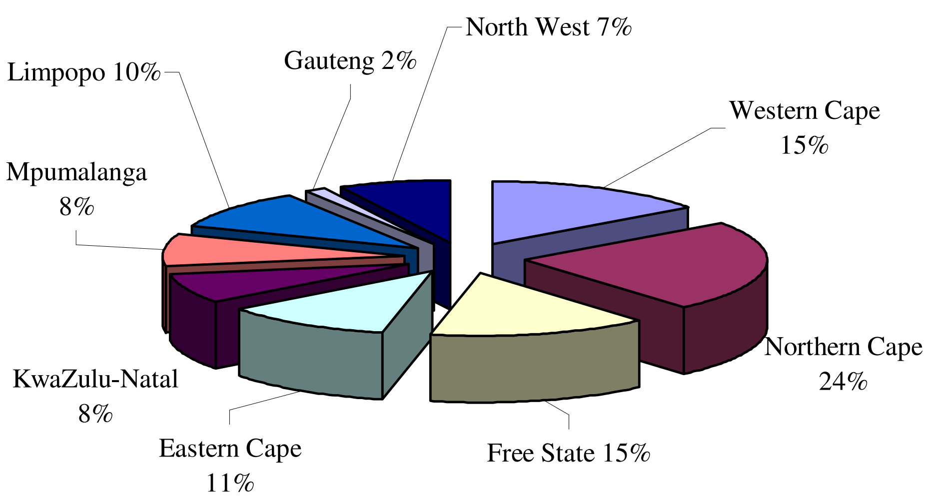
Source: NDA (2005)

Figure A9: Distribution of animal production in the nine provinces (1993)



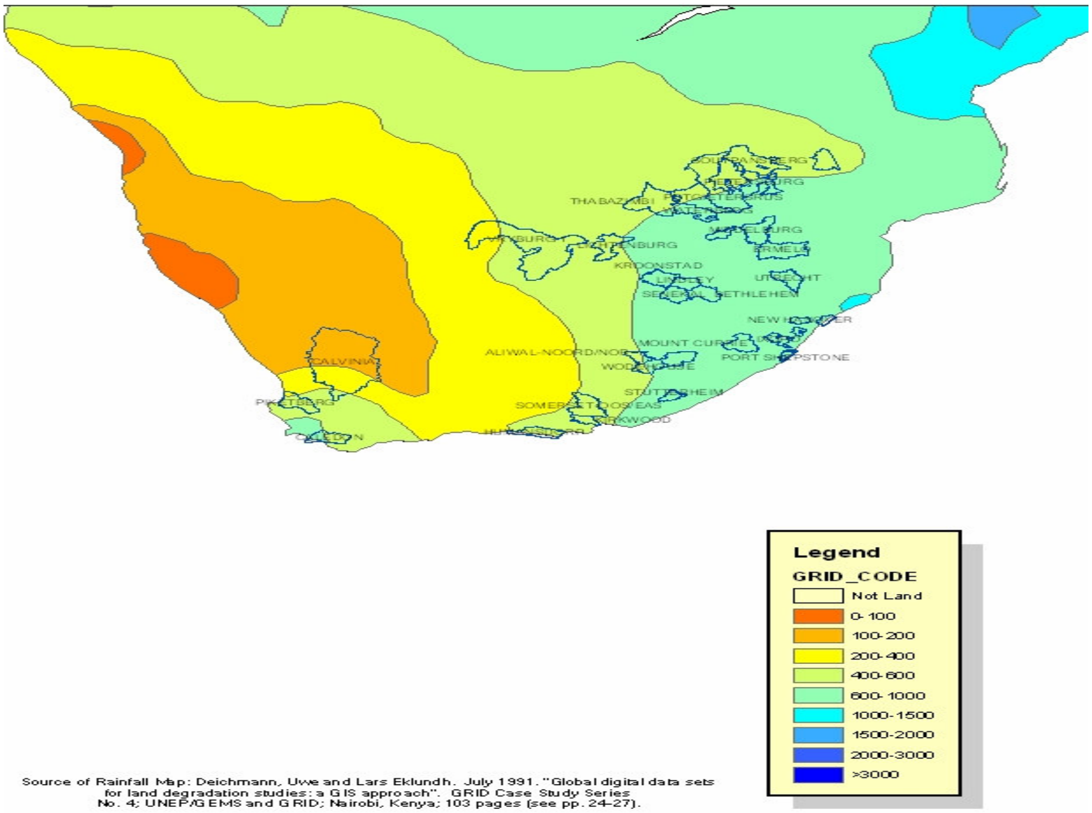
Source: NDA (2005)

Figure A10: Distribution of mixed farming in the nine provinces



Source: NDA (2005)

Figure A11: South Africa sample and rainfall gradient



Source of rainfall grids: Deichmann & Eklundh (1991)