LONG TERM ADAPTATION SCENARIOS

TOGETHER DEVELOPING ADAPTATION RESPONSES FOR FUTURE CLIMATES

AGRICULTURE AND FORESTRY

environmental affairs
Department: Environmental Affairs
REPUBLIC OF SOUTH AFRICA

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Department: Agriculture, Forestry and Fisheries
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On behalf of
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

SANBI
Biodiversity for Life

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LONG-TERM ADAPTATION SCENARIOS FLAGSHIP RESEARCH PROGRAMME (LTAS)

CLIMATE CHANGE IMPLICATIONS FOR THE AGRICULTURE AND FORESTRY SECTORS IN SOUTH AFRICA

LTAS Phase 1, Technical Report (no. 3 of 6)

The project is part of the International Climate Initiative (ICI), which is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

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ACRU	Agricultural Catchments Research Unit
ARC	Agricultural Research Council
CA	Conservation agriculture
CBA	Community-based adaptation
CBD	Convention on Biological Diversity
CGCM3.1/T47	Coupled global climate model version 3.1 version T47 (Canadian Centre for Climate Modelling and Analysis (CCCma))
CNRM–CM3	Centre National de Recherches Meteorologiques France, coupled global climate model version 3
CSA	Climate-smart agriculture
CSIR	Council for Scientific and Industrial Research
DAFF	Department of Agriculture, Fisheries and Forestry
DEWFORA	Drought Early Warning and Forecasting
DMP	Dry matter productivity
DSSAT	Decision Support System for Agrotechnology Transfer
EBA	Ecosystem-based adaptation
ECHAM5/MPI-OM	Coupled global climate model version 3.1 version T47 (Canadian Centre for Climate Modelling and Analysis (CCCma)) CNRM–CM3 Centre National de Recherches Meteorologiques France, coupled global climate model version 3
EM	Empirical model
GAM	Generalised additive model
GCM	General circulation models
GHG	Greenhouse gas
GISS–ER	Goddard Institute for Space Studies (GISS), NASA, USA, ModelE-R
HFD	Hybrid frequency distributions

IPCC	Intergovernmental Panel on Climate Change
IPSL-CM4	Institut Pierre Simon LaPlace, Paris, France, climate system model version 4
LIS	Level I stabilisation
LSU/ha	Livestock standard unit per hectare
MAI	Mean annual increment
MAP	Mean annual precipitation
MIT	Massachusetts Institute of Technology
MM	Mechanistic model
NPC	National Planning Commission
NPP	Net primary productivity
PCU	Positive chill units
QnCD	Quinary Catchments Database
RCM	Regional circulation model
RHmin	Minimum relative humidity
SAWS	South African Weather Service
SRES	Special Report on Emissions Scenarios
START	Global change system for analysis, research & training
THI	Temperature-heat index
Tmxd	Maximum daily temperature
UCE	Unconstrained Emissions
WNCT	Water and nutrient conservation technologies

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THE LTAS PHASE 1

The Long-Term Adaptation Scenarios (LTAS) Flagship Research Programme (2012–2014) is a multi-sectoral research programme, mandated by the South African National Climate Change Response White Paper (NCCRP, para 8.8). The LTAS aims to develop national and sub-national adaptation scenarios for South Africa under plausible future climate conditions and development pathways. During its first Phase (completed in June 2013), fundamental climate modelling and related sector-based impacts and adaptation scoping were conducted and synthesised. This included an analysis of climate change trends and projections for South Africa that was compared with model projections for the same time period, and the development of a consensus view of scenarios for three time periods (short-, medium- and long-term). Scoping of impacts, adaptation options and future research needs, identified in the White Paper and guided by stakeholder engagement, was conducted for primary sectors namely water, **agriculture and forestry**, human health, marine fisheries, and biodiversity. This modelling and scoping will provide a basis for cross-sectoral and economic assessment work needed to develop plausible adaptation scenarios during Phase 2 (scheduled for completion in April 2014).

Six individual technical reports have been developed to summarise the findings from Phase 1, including one technical report on climate trends and scenarios for South Africa and five summarising the climate change implications for primary sectors, water, **agriculture and forestry**, human health, marine fisheries, and biodiversity. A description of the key messages emerging from the LTAS Phase 1 has been developed into a summary for policy-makers, as well as into seven factsheets constituting the LTAS Climate and Impacts Factsheet Series.

REPORT OVERVIEW

This technical report presents the LTAS Phase 1 findings for the agriculture and forestry sectors. It references existing South African research combined with insights from global projections to develop a preliminary picture of the potential effects of climate change on key agricultural and forestry activities. Specifically, it summarises climate change impacts as well as adaptation response options and future research needs for the agriculture and forestry sectors, based on the results of relevant past and current research, including the *Climate Change Adaptation and Mitigation Plan for the South African Agricultural and Forestry Sectors* (DAFF, 2013); the Department of Agriculture, Fisheries and Forestry (DAFF) funded *Atlas of Climate Change and the South African Agricultural Sector* (Schulze, 2010); and new simulations from recent modelling work from the Treasury and the National Planning Commission study (Treasury and NPC, 2013).

To illustrate the potential impacts of climate change on the South African agricultural sector it presents changes in yields and climatically optimum growth areas for selected crops, pasture grasses and commercially grown tree species, as well as changes in the life cycles of selected pests and in irrigation requirements. Additional work done on the climate change implications for farm labour through a human discomfort index approach is described. For the purposes of the LTAS Phase 1 work, in addition to reviewing previous work on climate change impacts on crop production and optimal growing areas, initial impacts assessments have been conducted on key crops (maize, wheat, sunflower and sugarcane) using a full range of potential future climate scenarios under an unconstrained emissions (UCE) scenario and a 450 ppm stabilisation, level 1 stabilisation (L1S), emissions scenario. Where possible, a synthesis of previous work on impacts is presented in relation to one of the four broad climate scenarios defined in the LTAS Climate Trends and Scenarios report, namely warmer/wetter; warmer/drier; hotter/wetter, hotter/drier. For example, the general circulation models (GCMs) used in Schulze (2010) are considered by climatologists to produce rainfall output somewhat on the wetter side of the spectrum (Hewitson, 2010; pers. comm.). A brief description of each chapter of the technical report follows.

Chapter 1 (Introduction) describes the factors influencing climate change vulnerability in South Africa as well as the climatic variables of importance to the agriculture and forestry sectors.

Chapter 2 (Climate change impacts on the agriculture and forestry sector) describes the climate change impacts on irrigation demand, field and horticultural crop yields, crop suitability, agricultural pest species, pasture crops, animal production, major forestry genera, and farm labour.

Chapter 3 (Climate change adaptation response options) provides an overview of adaptation response options for South Africa.

Chapter 4 (Research requirements) highlights research gaps related to climate forecasts and climate change uncertainties as well as general considerations for research priorities for the sector.

Chapter 5 (Conclusion) concludes the report highlighting the scope of Phase 2 in assessing adaptation response options.

EXECUTIVE SUMMARY

The South African agricultural sector is highly diverse in terms of its activities and socio-economic context. Only 14% of the country is currently considered potentially arable, with only one fifth of this land having high agricultural potential. Climate limitations are important in determining potential agricultural activities and suitability across the country, especially in small-holding and homestead settings. However, irrigation and conservation tillage practices can overcome rainfall constraints, especially in the high-value commercial agricultural sector. Irrigation for agricultural production is estimated to consume in excess of 60% of South Africa's surface water resources, and a significant fraction of extracted groundwater. This makes the sector the primary water user in South Africa, and therefore a key focus in developing adaptation responses that involve water and consider food security and other socio-economic implications.

This report summarises potential impacts under two broad sets of global fossil fuel emissions scenarios. These are outlined in more detail in the climate technical report, but briefly refer to unconstrained emissions (typified by IPCC SRES A2 and IPCC AR5 8.5 $W.m^{-2}$ RCP) and constrained emissions (typified by IPCC SRES B1 and IPCC AR5 4.5 $W.m^{-2}$ RCP). These emissions scenarios, combined with uncertainty relating to climate projections, lead to a wide range of potential climate scenarios over the short, medium and long term that can be grouped into one of four general outcomes nationally, namely warmer/wetter; warmer/drier; hotter/wetter; hotter/drier, with the threshold between warmer and hotter scenarios defined by an average warming nationally above the 1950–2010 average of 3°C.

Based on the results of a wide range of impacts modelling efforts, climate change impacts are projected to be generally adverse for a wide range of agricultural activities over the next few decades.

- **Irrigation demand** in South Africa is projected to increase over the next few decades under both unconstrained and constrained emissions scenarios. Increases in the range of 15–30% are plausible under a hotter/drier future climate scenario and would present substantial risk for The sector.
- **Some spatial shifts** in the optimum growing regions as well as **impacts on yields** for many key agricultural and forestry species are likely to occur by mid-century, especially under hotter scenarios. This includes field crops such as maize, wheat, sorghum, soybeans and sugarcane; pasture/rangeland grasses such as *Eragrostis curvula* and kikuyu (*Pennisetum clandestinum*); horticultural crops such as apples and pears; viticulture crops and major commercial forestry trees such as *Eucalyptus, Pinus*, and *Acacia*. Climate change-induced effects on **plant and animal diseases and insect distribution** could adversely affect both crop and livestock production, and animal health.
  - A range of impacts are possible on yields of rain-fed crops including a -25% to +10% change in maize yield. Global mitigation efforts to achieve CO_2 stabilisation at 450 ppm would reduce this range of impact to a -10% to +5% change in yields. Similar results are obtained for other crops such as wheat and sunflowers.
  - Maize production areas towards the west would become less suitable for maize production.
  - Optimal areas for viticulture in the western and southern Cape could be substantially reduced or move to higher altitudes and currently cooler, more southerly locations.
  - Projected reduced runoff in areas important for the deciduous fruit industry in the Western Cape will negatively affect the production of horticultural crops.
  - The total area suitable for commercial forestry plantations in KwaZulu-Natal, Mpumalanga and the Eastern Cape Provinces would increase over the eastern seaboard and adjacent areas.
  - Tropical crops, such as sugarcane, may increase in yield given the warmer/wetter projections in the tropical north-east. However, they would be more exposed to pests such as eldana – one of the most serious sugarcane pests in South Africa – which would increase throughout the climatically suitable area for sugarcane by ~10% to >30%.
  - The area subject to damage by chilo – a key pest of major tropical crops and sugarcane – and codling moth – a key pest of several high value temperate fruit types, including apples, pears, walnuts and quince – would increase substantially, and these pests could become more damaging due to higher reproductive rates.
- Climate change impacts on **livestock** have been less studied than those on key crops. However, studies do indicate a likely increase in heat stress as a result of climate change. Discomfort to livestock as a result of heat stress has known effects such as reducing milk yields in dairy cattle, and influencing conception rates across virtually all breeds of livestock. Furthermore, projected decreases in rainfall and hence herbage yields would result in negative health impacts for livestock.
- Increases in human thermal discomfort on more days of the year, and especially in summer months, have been projected over South Africa under future climate scenarios. This will have serious implications for the productivity of **agricultural labour**, specifically for those engaged in operations with summer and with multi-year crops.

It is projected that with effective international mitigation responses (i.e. under a constrained/mitigated emissions scenario) as well as with the implementation of appropriate adaptation responses adverse impacts could be significantly reduced – with large avoided damages. Potential adaptation responses in the agriculture sector range from national level strategies that relate, for example, to capacity building in key research areas, in extension, and to consideration of water resource allocation, all the way through to the local level where responses may be specific to production methods and local conditions.

Adapting agricultural and forestry practices in South Africa requires an integrated approach that addresses multiple stressors, and combines indigenous knowledge/experiences with the latest specialist insights from the scientific community. Promotion of sustainable alternative livelihoods – especially for smallholder and subsistence households – will be beneficial as climate change, and the resultant inability to farm, could prompt individuals to find other sources of income. For large-scale commercial farmers adaptation needs to focus on optimising practices for climatic conditions in order to maximise output in a sustainable manner and to maintain a competitive edge. As an overall adaptation strategy, benefits would be gained from practices based on best management and on climate-resilient principles; these are characteristic of concepts such as climate smart agriculture, conservation agriculture, ecosystem-based adaptation, community-based adaptation and agroecology.

It would be valuable for the agriculture sector to conduct a holistic assessment of future research needs relating to climate change impacts and adaptation. Such an assessment could distinguish needs at a range of scales of implementation and identify adaptation needs for specific agricultural activities at local scale. The feasibility of an approach for assessing activity-specific adaptation options needs to be explored. This should include defining the appropriate level of intervention and prioritising agriculture sub-sectors for implementation. Scientific support is needed to improve answers on the when, where, how much, what impact, and how to adapt to climate change, including reducing uncertainties on rainfall variability and its impact on agricultural production and agricultural livelihoods.

Irrigated agriculture is the largest single surface water user in the country. Dependence on water represents a significant current vulnerability for almost all agricultural activities. There is evidence that smallholder and subsistence dryland farmers are more vulnerable to climate change than commercial farmers, while large-scale irrigated production is probably least vulnerable to climate change, conditional upon sufficient water supply for irrigation being available. Adaptation plans would benefit by considering water curtailments to irrigators in times of drought, in the light of food security and conditional upon irrigators using water efficiently. The socio-economic implications of water use trade-off scenarios under plausible future climates need to be investigated to inform key decisions on development and adaptation planning in order to reduce impacts on the most vulnerable communities and groups. The LTAS Phase 2 process has the potential to assess large scale adaptation responses relating, for example, to water allocation; however, it will not address finer scale adaptation response options.

1. INTRODUCTION[1]

The South African agricultural and forestry sectors experience a range of vulnerabilities. This is due both to the diverse agricultural natural capital that supports a two-tiered, agricultural system (commercial versus smallholder and subsistence farmers), and a wide variety and high variability of climatic conditions across the country. Approximately 90% of the country is sub-arid, semi-arid, or sub-humid, while about 10% is considered hyper-arid (Schulze, 2008). Only 14% of the country is considered potentially arable, with one fifth of this land having high agricultural potential (DEA, 2011).

1.1 Factors influencing climate change vulnerability in the agriculture sector

1.1.1 Climatic factors – rainfall

Rainfall is, to a large extent, the most important factor in determining potential agricultural activities and suitability across the country. Rainfall variability introduces an inherently high risk to climate change at many time scales, especially in transitional zones of widely differing seasonality and amount of rainfall. These transitional zones seem particularly sensitive and vulnerable to geographical shifts in climate.

1.1.2 Climatic factors – evaporative losses

The exceedingly high atmospheric demand, i.e. the potential evaporation, in South Africa at 1 400–3 000 mm/year coupled with unreliable rainfall often results in semi-arid conditions due to high evaporation rates alone, despite often adequate rainfall.

1.1.3 Dependence on water

Dependence on water represents a significant, current vulnerability for almost all agricultural activities. Irrigated agriculture is the largest single surface water user consuming ~60% of total available water, and with all agriculture related activities consuming ~65%.

1.1.4 Soil properties

Agriculture's vulnerability is exacerbated by soil properties and topographical constraints that limit intensive crop production. South Africa's soil mantle is complex, diverse, often thin and susceptible to degradation. Soil organic matter is vulnerable to increasing temperatures that adversely affect soil biological, chemical, and physical properties resulting in more acid soils, soil nutrient depletion, a decline in microbiological diversity, weakened soil structure, lower water-holding capacity, increased runoff and soil degradation.

1.1.5 Land degradation related issues

Increasing population pressure, unsustainable land use and increasing competition for agricultural land, resulting in land use change and poor economic decisions, are leading to land degradation, aggravated by bush encroachment and invasive alien plants.

1.2 Temperature and rainfall changes of importance to agriculture[2]

Temperature affects a wide range of processes in agriculture and is used as an index of the energy status of the environment. It is the one climatic variable for which there is a high degree of certainty that it will increase with global warming.

1.2.1 Annual temperatures and variability

Into the intermediate future annual temperatures are projected to increase by 1.5–2.5°C along the coast (illustrating the moderating influence of the oceans) to

1 Factors listed and descriptions have been extracted from DAFF (2013) and were derived from a range of sources in the literature including Barnard et al., 2000; Reid et al., 2005; Benhin and Hassan 2006; Schulze 2006, 2007, 2009, 2010; the Department of Agriculture 2007; Blignaut et al., 2009 and DEA 2011.

3.0–3.5°C in the far interior. However, by the end of the century an accelerating increase in temperatures becomes evident with projected increases between 3.0–5.0°C along the coast and up to 6.0°C and more in the interior. Year-to-year variability of annual temperatures tends to increase in the northern half of the country and decrease in the south.

1.2.1.1 Heat waves

In regard to *heat waves* (i.e. maximum daily temperatures T_{mxd} >30°C on 3 or more consecutive days) and *extreme heat waves* (T_{mxd} ≥ 35°C on 3 or more consecutive days), the median number of *heat waves* per annum from the five GCMs used in the Schulze (2011) study is projected to increase by anything from 30% to more than double from the present in both the intermediate and more distant futures. In the case of *extreme heat waves*, the median number is projected to more than double into the intermediate future, with the most affected areas being those that are already hot, namely, the eastern and northern borders of South Africa and the Northern Cape.

1.2.1.2 Heat units

Heat units, so vital for crop growth but also for pest life cycles, are projected to increase into the intermediate future by an average of ~10% annually along the coast (where temperatures are moderated by oceanic influences) to >30% in the interior. Projected increases in the summer season are more moderate, but relatively high in ecologically sensitive mountainous areas, whereas increases in the winter season are markedly higher at >30% over most of South Africa and more than doubling in places in the Maluti and Drakensberg mountain ranges.

1.2.1.3 Cold spells

While the numbers of *cold spells* (i.e. ≥3 or more consecutive days with minimum temperatures <2.5°C) and *severe cold spells* (≥3 or more consecutive days with minima <0°C) are shown not to change along the coast of South Africa into the future, while in the more continental interior a reduction to <70% of present cold spells is projected.

1.2.1.4 Positive chill units

Certain biennial plants require a period of winter chilling to complete their dormant season to produce high quality fruit. This chilling is estimated by positive chill units (PCUs), derived from hourly temperatures above or below critical thresholds. From sensitivity studies, a 2°C temperature increase results in PCU reductions ranging from 14% to >60% in South Africa, with reductions commonly around 40%. Similarly, median reductions in ratios of PCUs computed from multiple GCMs are generally >30% into the intermediate future, with high confidence in these projections.

1.2.1.5 Reference crop evaporation

The accurate estimation of evaporation from agricultural crops is vital, for it is the driving force of the total amount of water which can be "consumed" by a plant system through the evaporation and transpiration processes. The reference for estimating crop evaporation was the Penman-Monteith equation, which has become the de facto standard method internationally. A sensitivity analysis shows that in January (summer) a 2°C temperature increase is simulated to increase reference crop evaporation by ~3.5% (2.9–3.8%), while in winter (July) the percentage increases are even higher than in summer. Using outputs from multiple GCMs, an increase in crop evaporation by the intermediate future of around 5–10% is projected, with the increase higher in the interior of the country. In the more distant future the projected increases range from 15–20%, again with the higher increases in the interior from ~100 km inland. The implications of these increases are higher water surface evaporation from dams and a more rapid drying out of soils.

1.2.2 Rainfall and its importance in agriculture

In agriculture, limitations in water availability are a restricting factor in plant development, since water is essential for the maintenance of physiological and chemical processes in the plant, acting as an energy exchanger and carrier of nutrient food supply in solution. In any regional study of agricultural production, rainfall, as a basic driving force in many agricultural processes, is therefore of fundamental importance. Focus is invariably on patterns of rainfall in time and space, by enquiring how much it rains, where it rains, when it rains, how frequently it rains, and what the duration and intensity of rainfall events are.

1.2.2.1 Annual rainfall and its variability

As a point of departure it is noted that even under current climatic conditions, South Africa is regarded as a semi-arid country with ~20% receiving <200 mm per annum, 47% <400 mm and only ~9% with mean annual precipitation (MAP) >800 mm. Inter-annual variability is high. Projected medians of changes in MAP from the ensemble of GCMs used show relatively little change into the intermediate future, with a slight wetting in the east, particularly in the more mountainous areas. By the more distant future, changes in MAP become more evident, with areas of decrease in the west and some increases along the eastern escarpment and in mountainous areas producing runoff. The period of significant change in the west appears to be in the latter half of the century. The inter-annual variabilities of rainfall show standard deviations to be intensifying into the intermediate future and more so into the more distant future, especially in the east, but with decreases in variability in the west. The overall increase in rainfall variability is likely to have severe repercussions on year-on-year consistency of agricultural production and on the management of water resources for irrigation through the operations of major reservoirs and smaller farm dams.

1.2.2.2 Monthly rainfall

Projections of monthly and seasonal changes in rainfall distribution patterns over South Africa *are not uniform*, but can vary markedly in direction, in intensity, as well as varying spatially within South Africa in a given month, between different months of the year for the same statistic, and between the intermediate future and the more distant future for the same statistic, with this last-named difference suggesting an intensification and acceleration of

2 See Schulze et al. (2010) for detailed information on the Global Circulation Models (GCMs) and downscaling methodology from which the information and projections below were derived. In general, five GCMs were used, viz. CGCM3.1 (T47), CNRM–CM3, ECHAM5/MPI-OM, GISS-ER and IPSL-CM4. Furthermore, in many cases results are derived from computations using downscaled daily climate output from a single emission scenario from a single GCM – ECHAM5/MPI-OM GCM (indicated in figure captions below where relevant). Climatic and/or hydrological and/or agricultural output in Schulze (2010) and DAFF (2013) was simulated for each of the 5 838 hydrologically interlinked quinary catchments that make up South Africa, Lesotho and Swaziland, using information from the Quinary Catchments Database, (QnCD) (Schulze and Horan, 2010; Chapter 2.2). The QnCD has been populated with 50 years (1950–1999) of daily rainfall, temperature and potential evaporation data, as well as with hydrologically relevant soils and land cover information for each quinary catchment. In order to simulate hydrological/agricultural attributes for the intermediate (2046–2065) and more distant (2081–2100) future climate scenarios, the downscaled daily rainfall and temperature values from the five GCMs are input into the Agricultural Catchments Research Unit (ACRU) and/or other models, whilst keeping each quinary's soils and land cover information constant (Schulze et al., 2010). The GCMs used in Schulze (2010) are considered by climatologists to produce rainfall output somewhat on the wetter side of the spectrum (Hewitson, 2010, pers. com.), and this has to be borne in mind in interpreting any impacts in which rainfall is an input variable. Furthermore, the use of a single projection – the limitations of which are well appreciated and documented (Hewitson et al., 2005b; IPCC, 2007; Schulze et al., 2007) – obviously fails to capture the range of possible futures projected by the >20 GCMs, for the various SRES scenarios, used in the IPCC's Fourth Assessment Report (IPCC, 2007). ECHAM5/MPI-OM GCM, however, was selected for this reason, as it is considered by the southern African climate modelling specialists, viz. The Climate Systems Analysis Group (CSAG) (2008), to represent a "middle of the road" projection of future climates for South Africa (Schulze et al., 2010).

impacts of climate change over time. A recurring feature is a slight *wetting trend* of varying intensity and distribution in *the east,* a trend which in general could be beneficial to South Africa's agricultural production and to water availability for agriculture, but could be detrimental due to flood damage. There is, however, a *drying trend* evident *in the west*, mainly towards the end of the rainy season, and also a drying trend *in northern* areas. Combined with increases in temperature, repercussions on agricultural production, irrigation demand and water resources could thus be severe in the west. The *transitional* area between the summer and winter rainfall areas frequently displays marked changes in rainfall.

For the period up to the intermediate future in the mid-2050s, summer and autumn months display a narrow strip of decreased rainfall variability along the coast into the future, but with a general increase over the interior which intensifies into autumn. By mid-winter virtually the entire South Africa displays significant increases in the inter-annual variability of rainfall. Over much of the country this has little impact on agriculture and water resources as mid-winter coincides with the dry season, but in the winter rainfall region of the southwest it does have an impact. By October, the start of the rainy season for much of the country, the eastern half of South Africa and the southwest show reductions in variability, with only the semi-arid central interior displaying averaged increases in variability.

1.2.2.3 Rainfall concentration

The rainfall concentration statistic indicates whether the rainfall season is concentrated over a short period of the year or spread over a longer period. Median changes in ratios of intermediate future to present rainfall concentration indicate a slightly more even spread of the rainy seasons over much of the country by mid-century, according to the GCMs used (i.e CGCM3.1 (T47), CNRM-CM3, ECHAM5/MPI-OM, GISS-ER and IPSL-CM4), but in the all year rainfall belt, as well as the transitional area between winter and summer rainfall regions, the rainy season is projected to become more concentrated than at present.

1.2.2.4 Rainfall seasonality

Large tracts of the current winter and summer rainfall regions are projected by the GCMs used by Schulze (2011) to remain as they are now. However, the models differ in their projections of changes of future seasonality in the transitional areas between the winter and summer regions in the west, and in the future location of the all year rainfall region.

1.2.2.5 Soil water content

Information on soil water content is vital since it determines when plant water stress sets in (and with that a reduction in transpiration losses), the need to irrigate and whether or not runoff will be generated, and how much, from a given amount of rainfall. Changes in soil water stress under projected future climates were derived from the output of the multiple GCMs used as input to the Agricultural Catchments Research Unit (ACRU) agro-hydrological model (Schulze, 1995).

For conditions of *no soil water stress*, the majority of South Africa is projected to experience more such days into the intermediate future, except in the southwest where desiccation is projected to result in plants experiencing more days with stress. For *mild stress conditions* decreases into the intermediate future are shown along the coast and especially in the Eastern Cape and Lesotho, with the remainder of the country displaying more days with mild stress. Similarly, based on the GCM projections used, days with *severe soil water stress* show a general reduction into the intermediate future, except along the west coast where more stress days are projected. *Stress due to waterlogging* is projected to increase into the intermediate future, except along the west coast where fewer waterlogged days are projected. These patterns intensify into the more distant future.

2. CLIMATE CHANGE IMPACTS ON THE AGRICULTURE SECTOR

Different emission scenarios, climate models and downscaling techniques complicate the projection of climate change impacts on agriculture in South Africa, making it extremely challenging to extract key messages that allow an assessment of, for example, the local economic benefits of global mitigation efforts. Projections of impacts have used different emissions scenarios, different climate models, and different downscaling techniques. Most of the focus has been on the SRES A2 scenarios, equating to CO_2 equivalent levels of above 500 ppm by 2050, and therefore representing the impacts of largely unmitigated climate change. The work that has been done suggests that even relatively small mean temperature and rainfall changes may be amplified by specific crop sensitivities. For example, as little as a 2°C increase in daily temperature would lead to a 10–35% annual increase in biologically important heat units, a 40–60% reduction in positive chill units, and a 5–13% increase in potential evapotranspiration (Schulze, 2010). However, this knowledge has not yet been translated into usable information on the economic impacts of climate change on the agricultural sector. It is only recently, with the work of the Treasury and NPC modelling effort, that it has become possible to begin to assess the potential economic impact of global mitigation efforts on the agricultural sector.

2.1 Impacts on irrigation demand

A simple crop water deficit model has been applied to determine the impacts of the full range of climate change scenarios on irrigation demands across South Africa. The analysis is based on estimates of the current crop areas and current crop mixes and a set of monthly crop coefficients. This allows the estimated impact of UCE (unconstrained emissions) and 450 ppm L1S (constrained emissions) scenarios on the average annual irrigation demand for the country by ~2050 (Figure 1) (Treasury and National Planning Commission, 2013).

Under both scenarios irrigation demand is certain to increase in the future due primarily to increases in temperature and evaporation. The unconstrained emissions scenario results in a very wide spread of possible impacts with some models showing a >10% increase. The median increase for the unconstrained emissions scenario is approximately 5% while the median impact for the constrained emissions scenario is only 2.5% with a much narrower range of possible impacts. None of the models predict more than a 5% increase in irrigation demand under the 450 ppm stabilisation scenario (Treasury and National Planning Commission, 2013).

The impacts of climate change on irrigation demand do vary across the country. For most parts of the country, there is an increase in the average annual irrigation demand of between 4% and 6% as a result of a relatively consistent increase in evaporation of 5% across the whole country. For the catchments along the eastern seaboard the increase in evaporative demand is offset by the increase in precipitation, resulting in no change in irrigation demand, even under the unconstrained emissions scenario (Treasury and National Planning Commission, 2013).

While it is possible that projected minor increases in irrigation demand would not be likely to have significant implications for the agricultural sector, under warmer/drier scenarios increases of between and 15 and 30% are plausible, indicating a substantial risk for greater water limitation in this sector and strong cross-sectoral implications given the current high allocation of surface water to this sector (Treasury and National Planning Commission, 2013).

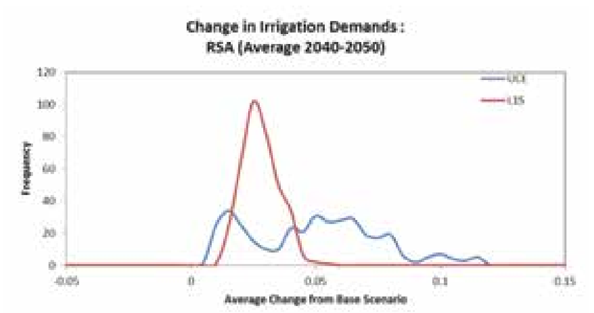


Figure 1. Preliminary results for hybrid frequency distributions (HFDs) of the impacts of the Unconstrained Emissions (UCE) and 450 ppm stabilisation (LIS, constrained emissions scenario) global climate scenarios on the average annual irrigation demands for all catchments for the period 2040–2050 relative to the base scenario based on the current crop mix and estimate of total irrigated area in each quaternary catchment (Treasury & National Planning Commission, 2013).

For example, Schulze (1995 and updates)[3] simulated changes in net irrigation demand for a fully grown crop under a warmer/wetter climate scenario for all months of the year with the ACRU model. With mean annual net irrigation demands over South Africa already high at ~800 mm in the wetter eastern and southern regions and up to 1 600 mm in the arid northwest, the composite results of the multiple GCMs used in the study by Schulze (2010) show a reduction in irrigation water requirements of ~10% in the central eastern areas into the intermediate future, indicating that in those areas the increased demand through higher temperatures, and hence enhanced evaporative demands, is more than offset by corresponding projected increases in rainfall. By contrast, in the drier western half and in the northern quarter of the country irrigation water demands are projected to increase by ~10%. By the more distant future (more representative of a hotter/wetter scenario) two differences emerge, namely, that the area of reduced irrigation demand has shrunk and that in ~90% of South Africa irrigation demands increase by 10–20% and in parts of the south-western Cape even becoming >20%.

The implications of these findings are first, that in the already drier parts of South Africa where agricultural production largely depends on supplementing rainfall with irrigation, even more additional water would be needed than at present to maintain current production, second, that this water would potentially need to be transferred from remote sources and third, that with rising temperatures a conversion to more heat and drought tolerant crops is likely to be needed (Figure 2) (Schulze, 2010).

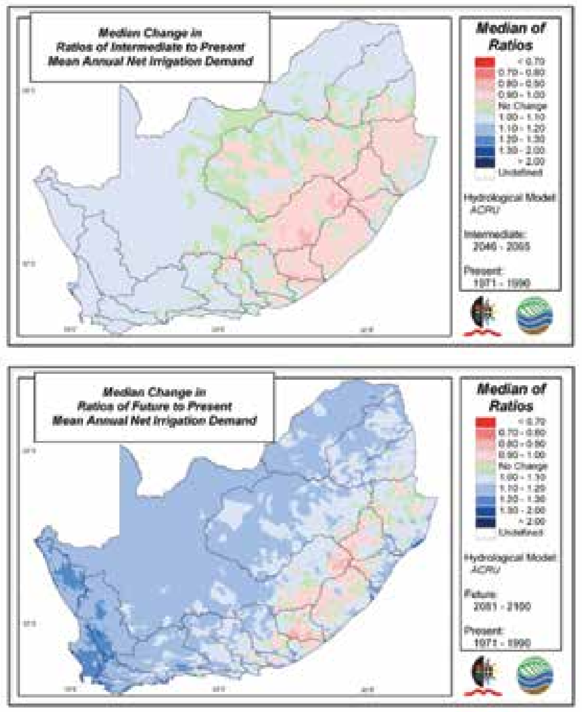


Figure 2. Median changes in ratios of intermediate future to present (top, representing a warmer/wetter future scenario), as well as of more distant future to present (bottom, representing a hotter/wetter future scenario) net annual irrigation demands, computed with the ACRU model from the output of multiple GCMs (Schulze & Kunz, 2010h)

3 Using demand irrigation scheduling, by which irrigation water is applied to the plant just before the soil has dried to a level where crop water stress sets in, and then recharging the soil profile to its drained upper limit.

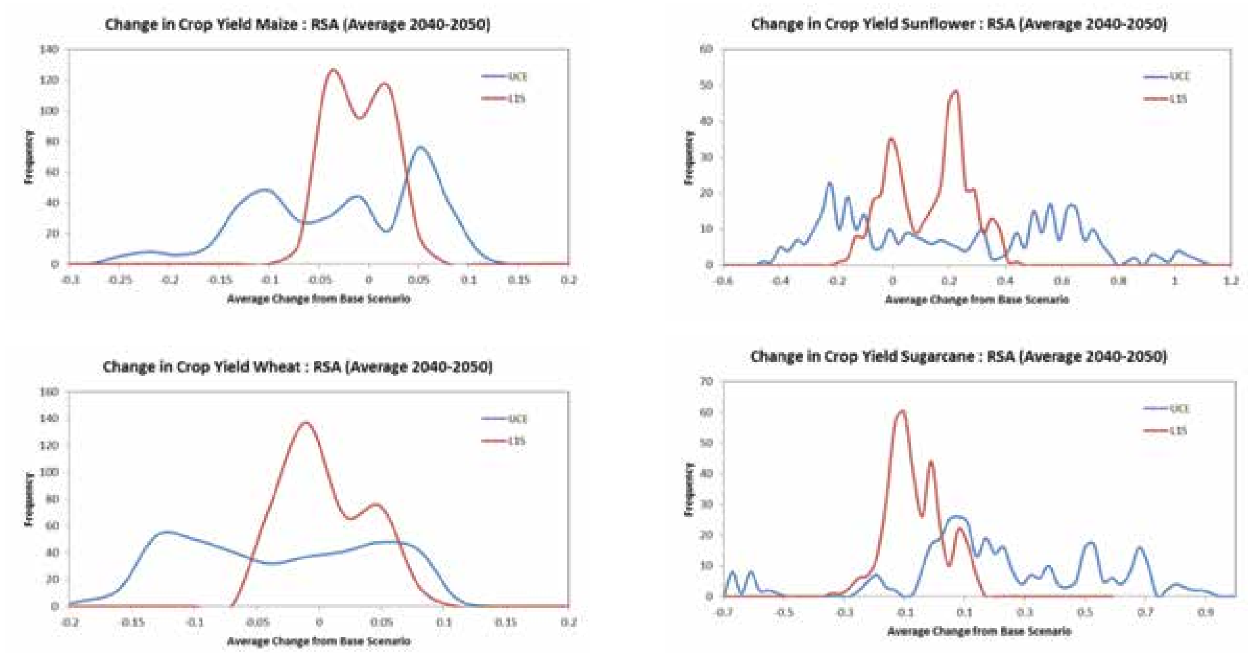


Figure 3. Preliminary results for combined impact of changes in precipitation and evaporation on dry land crop yields (t/ha) for South Africa for the period 2040–2050 relative to the baseline scenario for maize, wheat, sunflower and sugarcane (Treasury & National Planning Commission, 2013). *Climate scenarios: UCE = unconstrained emissions; LIS = 450 ppm stabilisation (constrained emissions scenario).*

2.2 Impacts on field and horticultural crop yields

For the purposes of the LTAS Phase 1 work, in addition to reviewing previous work on climate change impacts on crop production and on optimal growing areas, we have conducted initial impacts assessments on key crops using a full range of potential unconstrained and constrained emissions scenarios, as described above, for exploring impacts on irrigation demand. These impacts of climate change on field crop yields have been determined based on relationships between annual water availability and crop yields for the major field crops currently cultivated in South Africa. These are maize, sorghum, wheat, sunflowers, groundnuts, soybean, lucerne, sugarcane and cotton. The frequency distribution of the potential impacts on the yields for maize, wheat, sugarcane and sunflowers through a combination of changes in precipitation and evaporation are given below (Figure 3) (Treasury and National Planning Commission, 2013).

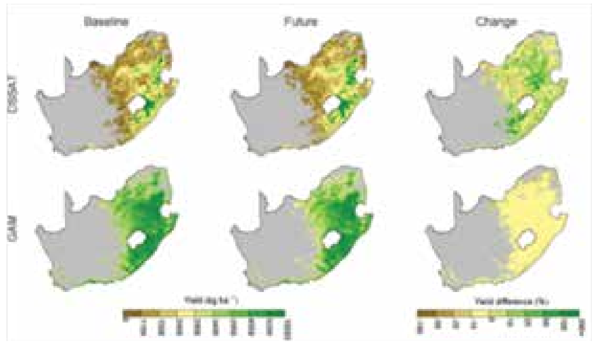
The results show a very wide range of possible impacts on the average annual yield of non-irrigated crops by 2050 under the UCE scenario. Overall, dryland crop yields amplify rainfall changes substantially. The impact on maize and wheat yields, for example, ranges from a reduction in the total national yield of 25% to a potential increase of 10% under an unconstrained emissions scenario. Mitigation to achieve 450 ppm stabilisation reduces this range of impact to between a less than 10% reduction and a 5% increase. Similar results are obtained for other crops with the exception of sugarcane (Treasury and National Planning Commission, 2013), which is one of the few crops that tends to show a strong potential for increased production even under hotter/drier future scenarios typical of an unconstrained future emissions trajectory.

These results are in line with previous studies. For example, as South Africa's staple food crop, maize has been under the spotlight since the late 1990s in vulnerability research (Du Toit et al., 2002) and with regard to productivity (Schulze et al., 1995), and subsequently from a sustainability perspective (Walker & Schulze, 2006; 2008). Yields have been simulated to be sensitive to both climate and CO_2 fertilisation, with doubled CO_2 offsetting much of the reduced profitability associated with a 2°C temperature rise, especially in core areas of maize production (Walker and Schulze, 2008).

2.3 Projected changes in crop suitability

One approach to assessing impacts on agricultural activities is via mapping areas of suitability, and their potential spatial shifts. A recent study (Estes et al. in press) used two independent impact modelling methods to project climate change impacts on wheat and maize yields, and suitable cropping areas in South Africa (Figure 4). This study points out that crop-model specific biases are a key uncertainty affecting the understanding of climate change impacts on agriculture, and thus they used both an empirical model (EM) and a mechanistic model (MM). The EM's median projected maize and wheat yield changes were -3.6% and 6.2%, for SRES emissions scenarios A1 and B2 respectively, compared to 6.5% and 15.2% for the MM. The EM projected a 10% reduction in the potential maize growing area, while the MM projected a 9% gain. Both models projected increases in the potential spring wheat production region (EM = 48%, MM = 20%). While these results appear to indicate positive prospects for increasing yields, most of these yield increases were projected in marginal areas, and yield reductions of up to 10% are projected in core production regions especially for wheat. Only in the case of maize were notable increases in yield projected in some currently high yield areas. The MM approach may provide a more useful output, given that the approach is able to account for the direct effects of rising CO_2 on productivity.

Maize



Wheat

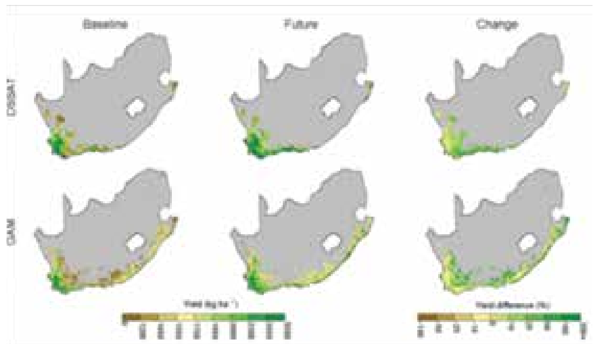


Figure 4. Median change in crop yields for rain fed maize (top) and wheat crops (bottom) by 2050 under a B1 SRES emission scenario. Two independent modelling methods are presented, DSSAT = mechanistic model, and GAM = empirical modelling approach (Estes et al. *in press*).

A description of specific impacts for key South African field crops is presented below (Schulze, 2010; DAFF, 2013):

2.3.1. Wheat and barley

These are generally winter rainfall crops. Dry spells occur naturally during the growing season in winter, and the projected decrease in winter rainfall would potentially accentuate this natural effect. In cases where areas are already close to threshold values for maximum temperature, a further temperature increase can have devastating effects on production potential (ERC, 2007). A study by Schulze and Davis (2012) using the Smith (2006) wheat yield model shows winter wheat yields to increase slightly by 0.5 to 1.5 t/ha/season into the intermediate

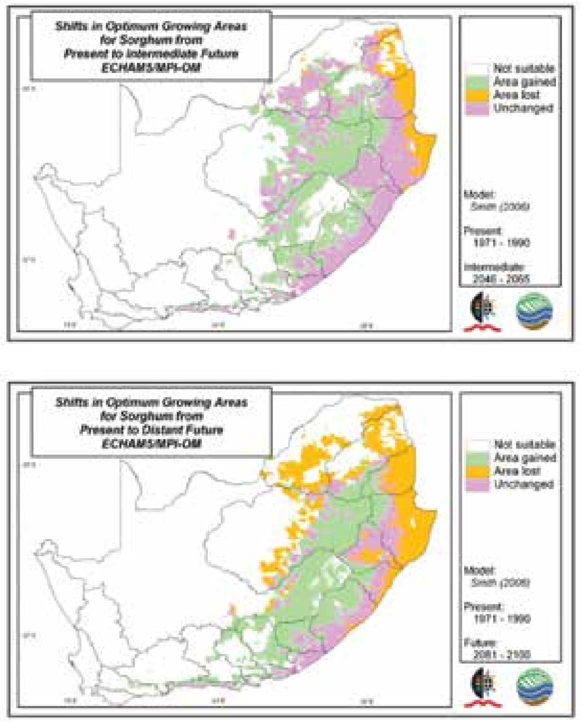


Figure 5. Shifts in optimum growing areas for sorghum between intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present climate scenarios (bottom, representing a hotter/wetter climate scenario), derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010c)

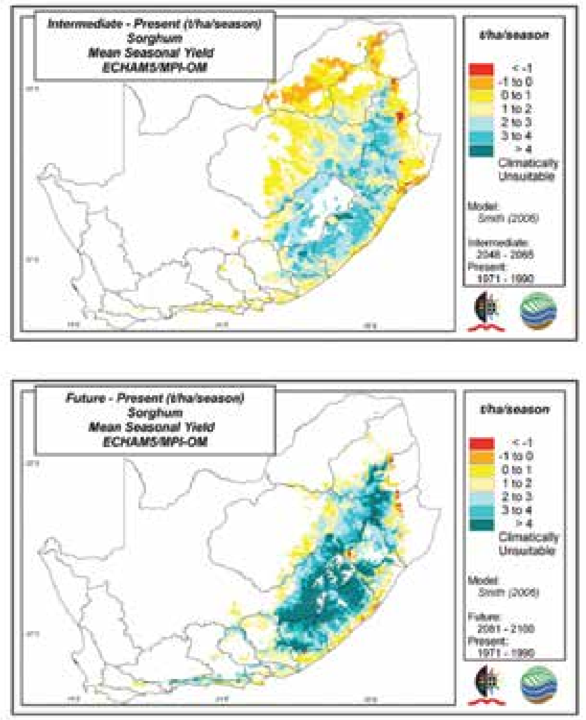


Figure 6. Differences between intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present (bottom, representing a hotter/wetter climate scenario) sorghum yields, derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010c)

future in the main wheat growing Swartland and Rûens regions of the Western Cape, with similar increases in the eastern Free State wheat belt, while into the more distant future most of the Western Cape's wheat belt is projected to show decreased yields of 0.5–1.0 t/ha from the present, but with the Free State continuing to display increases.

2.3.2 Sorghum

Sorghum (*Sorghum bicolour*) is a relatively drought resistant crop which can tolerate erratic rainfall. Areas for sorghum suitable under present climatic conditions are projected to become unsuitable by the intermediate future along the eastern border while considerable new areas, presently climatically unsuitable for sorghum, are projected to be gained in the Free State and Eastern Cape (Schulze 2010) (Figure 5). Sorghum yields are projected to potentially increase by 2–4 t/ha into the intermediate future in parts of western KwaZulu-Natal, the inland areas of the Eastern Cape and the eastern Free State, with some areas in the north registering losses compared with present climatic conditions. This translates to projected increases in excess of 30% in the central growing areas, with some yield decreases along the eastern periphery (Figure 6).

2.3.3 Soybeans

For soybeans the areas lost to potential production in both the intermediate and more distant future are in the east, with an expansion of climatically suitable areas inland towards the west into the future, and with areas gained and lost being more sensitive to changes in rainfall than increases in temperatures (Schulze, 2010). Projected changes of soybean yields between the intermediate

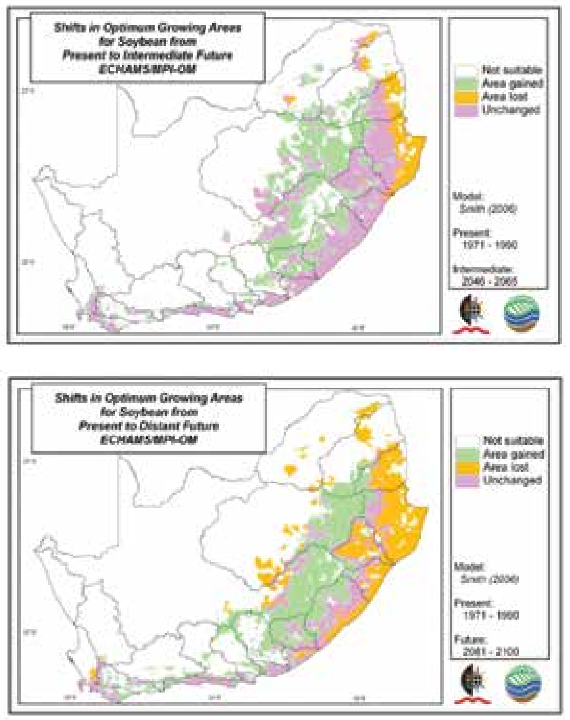


Figure 7.Shifts in optimum growing areas for soybean between intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present climate scenarios (bottom, representing a hotter/wetter climate scenario), derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010d).

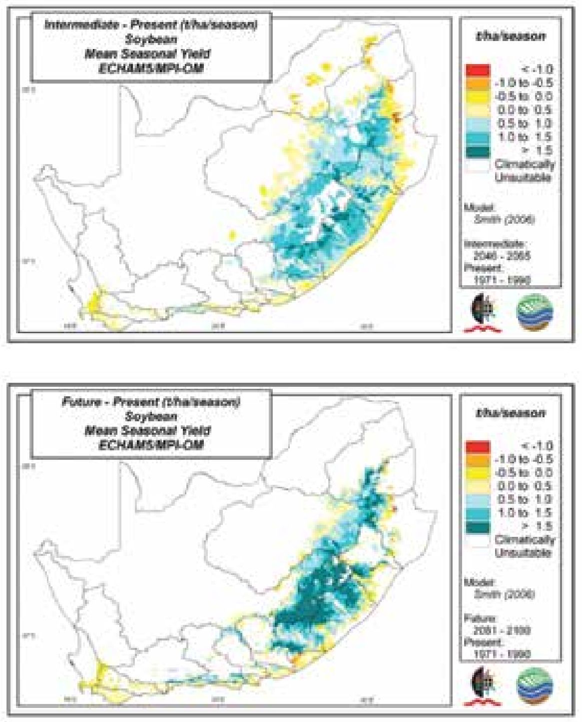


Figure 8. Differences between intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present (bottom, representing a hotter/wetter climate scenario), soybean yields, derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010d)

future and present climate scenarios display an *arc of yield decreases* for the climatically suitable growth areas surrounding a considerably larger *core area of median yield increases* (generally by >30%) (Figure 7). By the more distant future both the areas showing decreases and increases have become amplified. The implication is that while major expansion of climatically suitable areas for soybean production might occur, there is also a likelihood that the area of actual production may become more concentrated (Figure 8).

2.3.4 Sugarcane

If future climates change in accordance with the projections for temperature and rainfall used in Schulze (2010) then some major inland shifts in the climatically optimum growth areas for sugarcane may be expected (Figure 9). The harvest-to-harvest cycle, or ratoon time, could reduce by 3–5 months (i.e. by 20–30%) by the intermediate future and by >5 months (i.e. >30%) in the more distant future, while yields per ratoon are projected to increase by 5–15 t/ha along the coast and by up to 20–30 t/ha in the inland growing areas by mid-century, with major implications for the sugar industry (Schulze, 2010) (Figure 10). When a temperature increase of 2°C is associated with simultaneous changes in rainfall, yields were modelled to decrease by about 7% for a 10% reduction in rainfall, and to increase by a similar percentage for a 10 % increase in rainfall. Median changes in ratios of cane yields per ratoon are projected to increase by the intermediate future by <10% in many parts of the

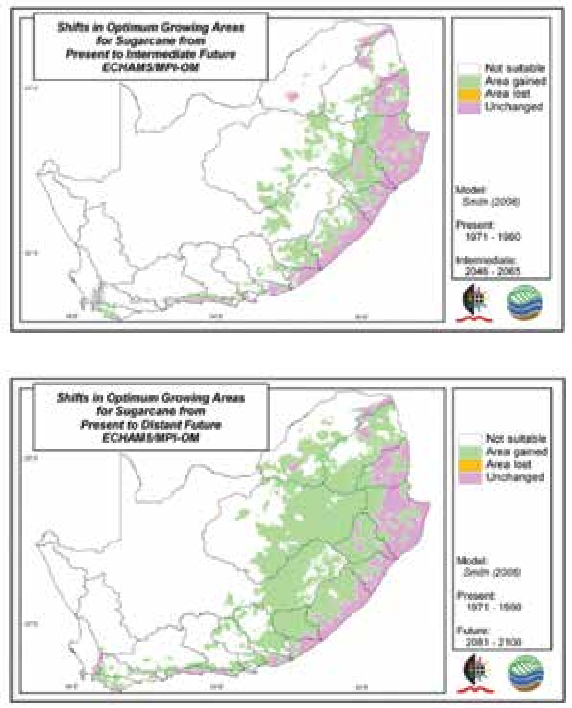


Figure 9.Shifts in optimum sugarcane growing areas between the present and intermediate future (top, representing a warmer/wetter climate scenario), and between the present and more distant future (bottom, representing a hotter/wetter climate scenario), derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010e)

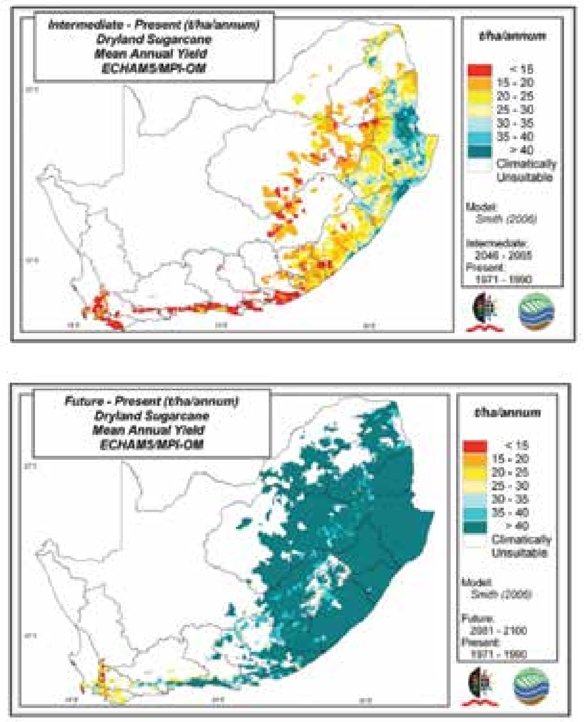


Figure 10. Differences between intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present (bottom, representing a hotter/wetter climate scenario), in mean annualised sugarcane yields, derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010e)

present cane growing areas, but by up to 30% and more in potentially new growth areas further inland. All the above projected changes are significant enough for the sugar industry to consider more in-depth studies of its entire value chain from production through transport and milling to export (Schulze, 2010; DAFF, 2013).

A description of specific impacts for selected South African horticultural and alternative crops is presented below (Schulze, 2010; DAFF, 2013):

2.3.5 Apples

Future temperature increases are projected to cause a 28% reduction of the area suitable for apple production by as early as 2020, with suitable apple producing climates limited to the high-lying areas of the Koue Bokkeveld and Ceres by 2050 (Cartwright, 2002). This projection is consistent with observed trends of reduced export apple volumes partly ascribed to adverse climatic conditions. Apples have stringent chilling requirements even under current climate conditions; this absolute need for cooling facilities and their high sensitivity to heat stress result in apples being vulnerable to increases in temperature and humidity.

2.3.6 Pears

Pears have similar climatic requirements to apples, but with less stringent chilling requirements and lower sensitivity to heat stress. Overall, the risks associated with producing export-quality pears are related to cultivar-specific sensitivities, with some cultivars at more risk than others. It is very likely that over the next 30 years most commercial pear producers should be able to make the adjustments needed to remain profitable.

2.3.7 Rooibos tea

Rooibos tea production is vulnerable to reduced rainfall and lack of rainfall at critical times, with yields projected to decrease 40% during a drought year (Oettle, 2006). Numerous adaptation strategies are, however, used or known by farmers, including changes in ground preparation and tea harvesting times, wind erosion prevention measures and water conservation measures. Not all these measures are implemented, often due to lack of finances.

2.3.8 Viticulture

The market is likely to dictate impacts and adaptations (ERC, 2007) with global trends in supply and demand, and resulting price volatility, being by far the most important factors in determining future profitability. Impacts and vulnerabilities will differ depending on scale (industry-wide versus farm level). The industry as a whole may shrink, but successful producers in core areas could capitalise on opportunities such as changing market demand due to adverse climate impacts on international competitors. Water for irrigation or rainfall in non-irrigated vineyards will be a much greater issue than temperature. Marginal non-irrigated vineyards could become uneconomical and total production area could decrease by up to 30% under projected changes by 2050, but increasing yields are possible in irrigated, well-managed vineyards in good areas (Schulze, 2010; DAFF, 2013).

Shifting the industry to other regions would be difficult and expensive, not so much due to the planting of vineyards as to the re-development of infrastructure (such as cellars). The mountainous regions of the eastern Overberg offer new opportunities on old lands provided there is sufficient water. The industry could usefully re-evaluate its cultivar mix and possibly make more use of early-season cultivars to avoid damaging effects of heat waves in mid-summer. Even within cultivars, the style of wine will likely change. There are new opportunities to acquire cultivars (or breed locally) with pest/disease resistance without forfeiting high quality and yield. It takes about ten years to source, quarantine, register, and certify a new cultivar for release (Schulze, 2010; DAFF, 2013).

Hannah et al. (2013) indicate that optimal areas for viticulture in the western and southern Cape could be substantially reduced and focus on higher altitude and currently cooler locations (southerly locations in South Africa). This trend is true of all major wine growing regions of the world, and South Africa's projected loss of 50% of surface area suitable for wine growing lies in the median loss range for Mediterranean-type regions (Chile shows a lower projected loss, Europe, California and Australia show much greater projected losses) (Figure 11).

2.4 Impacts on agricultural pest species

Stages in the development, or duration, of entire life cycles of agricultural pests and diseases are closely related to temperature thresholds, and are thus affected by global warming. Climate change acts to accelerate critical life stages of these pests, thus potentially increasing the potential for crop damage and increasing the costs of various forms of control. Examples of some impacts follow (Schulze, 2010).

Chilo is a key pest of a major tropical crop, sugarcane, and codling moth is a key pest of several high value temperate fruit types, including apples, pears, walnuts and quince. Results indicate that warming alone has the potential to significantly increase the area subject to both chilo (Figure 12) and codling moth damage in South Africa (Figure 13), thus exposing many high value regions for both sugarcane and fruit crops to increases in costs and damages.

For codling moth, the lower and upper temperature (°C) thresholds and accumulated degree days for one life cycle are, respectively, 11.1°C, 34.4°C and 603 degree days. Under current climatic conditions the number of life cycles per annum of codling moth ranges from <2 in the cooler mountainous areas of South Africa to >6 along its northern and eastern borders (Schulze, 2010). Using output from the ensemble of GCMs used in Schulze (2010), the number of life cycles per annum of the codling moth by the intermediate future is in excess of 30% greater than the present over the central areas of South Africa, 20–30 % along the periphery of the country and 10–20 % along the coast of KwaZulu-Natal and patches elsewhere.

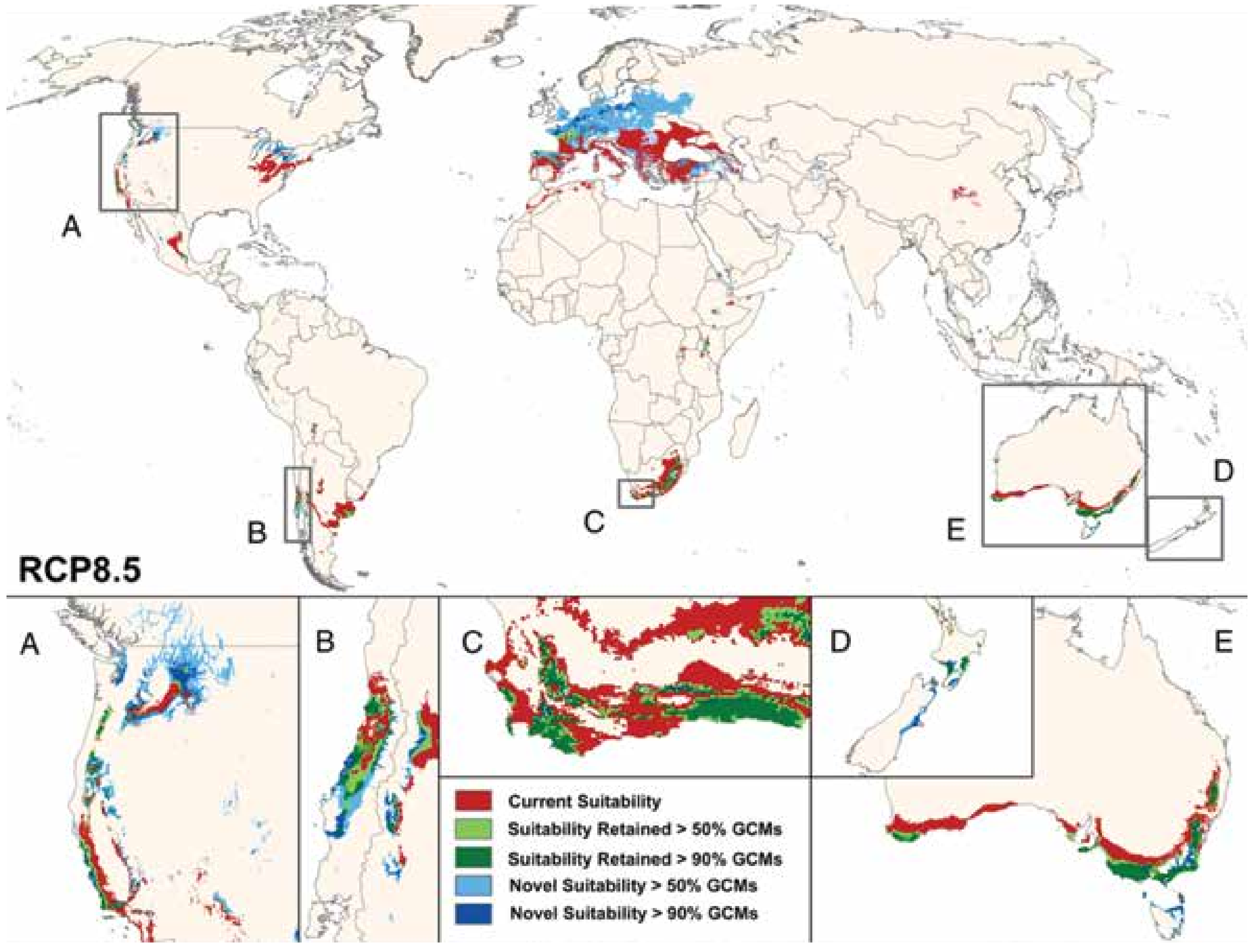


Figure 11. Global change in viticulture suitability under the RCP8.5 scenario. Change in viticulture suitability is shown between current (1961–2000) and 2050 (2041–2060) time periods, showing agreement among a 17 GCM ensemble. Areas with current suitability that decreases by mid-century are indicated in red (>50% GCM agreement). Areas with current suitability that is retained are indicated in light green (>50% GCM agreement) and dark green (>90% GCM agreement), whereas areas not currently suitable but suitable in the future are shown in light blue (>50% GCM agreement) and dark blue (>90% GCM agreement). Insets: Greater detail for major wine-growing regions: California/western North America (A), Chile (B), Cape of South Africa (C), New Zealand (D), and Australia (E) (taken from Hannah et al., 2013).

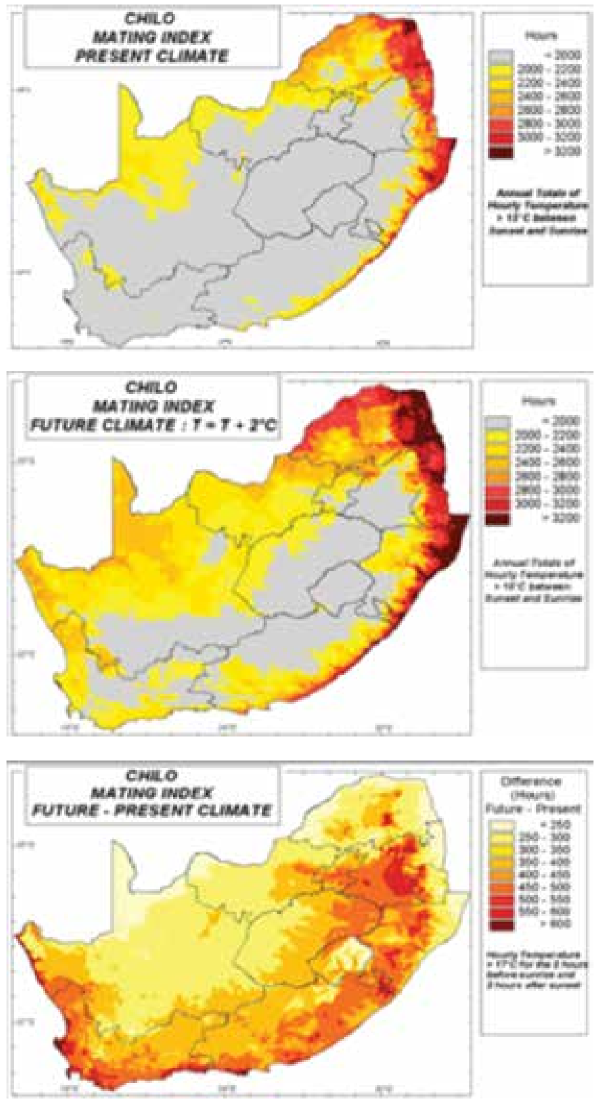


Figure 12. Distribution patterns of the mating index of chilo over South Africa for present climatic conditions, for a temperature increase of 2°C and the difference between present and future.

The African sugarcane stalk borer *Eldana saccharina* is one of the most serious sugarcane pests in South Africa, causing substantial losses in yields. Crucial to eldana infestations are the number of mating hours per annum. These depend on hourly night-time temperature thresholds being exceeded, with mean annual number of eldana mating hours ranging from <200 hours in the cooler inland regions of South Africa to >1000 hours in the hotter eastern parts of the region, with the so-called 'sugar belt' coming in at >800 hours per annum (Schulze, 2010). When the annual mating index of eldana is assessed in regard to projected changes into a warmer future by the GCMs used in Schulze (2010), these increase throughout the climatically suitable area for sugarcane by ~10% along the east coast to >30% further inland. This indicates that compared with present conditions the "new" inland climatically suitable areas for cane are relatively more vulnerable to eldana infestation (Figure 14).

In the case of the oriental fruit moth (*Grapholita molesta*), which affects apples, the lower and upper temperature (°C) thresholds and accumulated degree days for one life cycle are, respectively, 7.7°C, 32.2°C and 535 degree days. Under current climatic conditions the number of life cycles per annum of the oriental fruit moth ranges from <3 in the cooler mountainous areas of the RSA and Lesotho to >9 and even 10 along the northern and eastern borders of the country (Schulze, 2010). Projections of climate scenarios into the intermediate future indicate increases in the number of life cycles per annum of the oriental fruit moth by <1.2 in the southwest to ~1.5 life cycles along the east coast and almost parallel to the coast in the central north increasing to >2 additional life cycles, with high confidence in these projections (Schulze, 2010; DAFF, 2013).

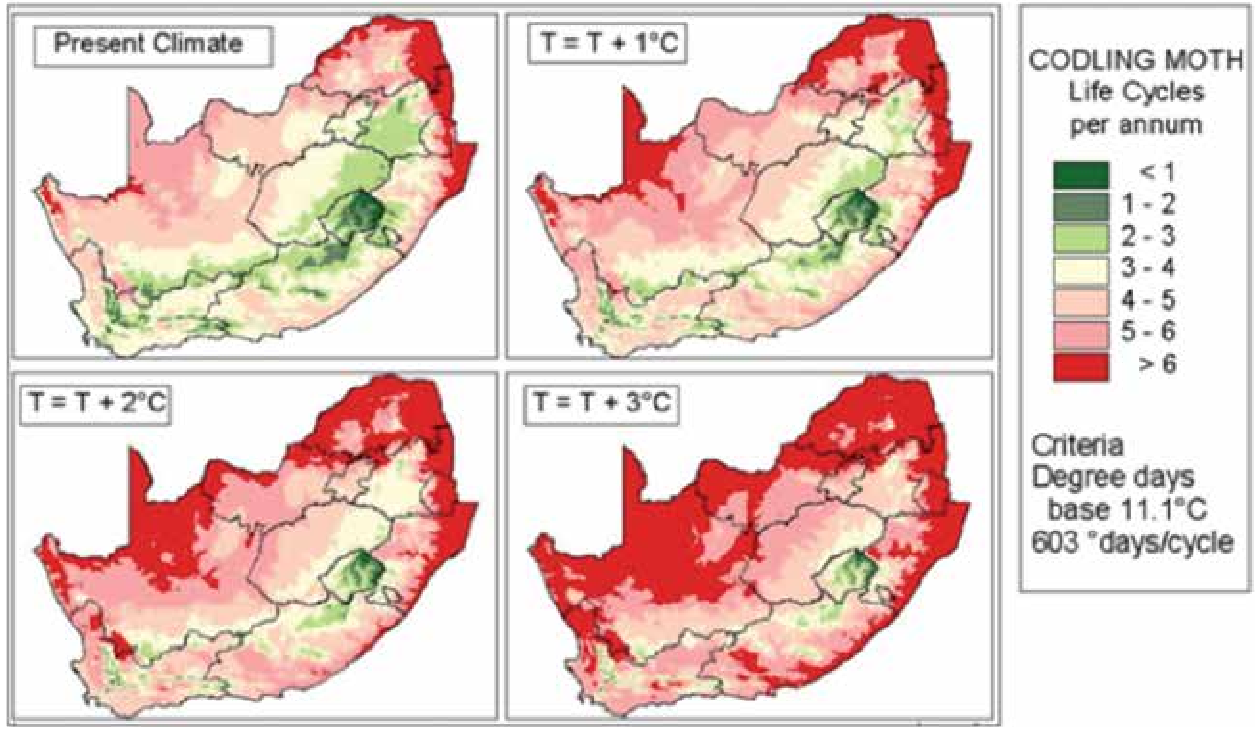


Figure 13. Mean annual numbers of life cycles of codling moth over South Africa for present climatic conditions and for temperature increases of 1°C, 2°C and 3°C.

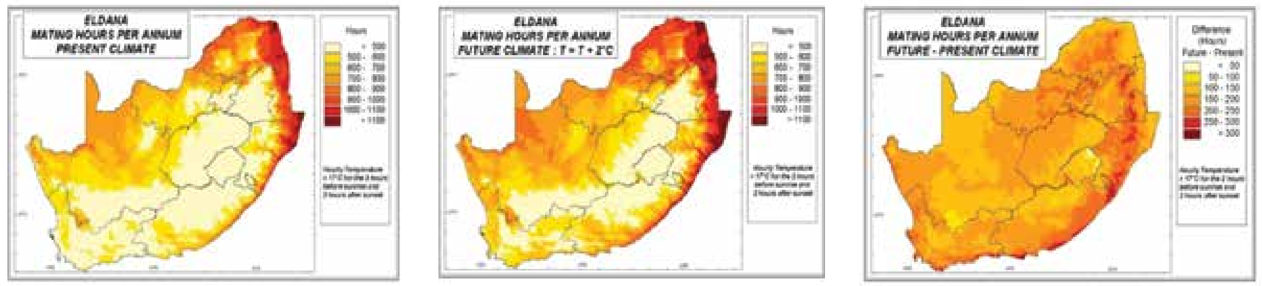


Figure 14. Distribution patterns of the mating index of Eldana over South Africa for present climatic conditions, for a temperature increase 2°C and the difference between present and future.

2.5 Impacts on pasture crops – rangelands and planted pastures

Climate change (including effects of increased atmospheric carbon) may complicate the existing problems of bush encroachment and invasive alien species in rangelands. Rising atmospheric CO_2 levels may increase the cover of shrubs and trees in grassland and savannah, with mixed effects on biodiversity and possible positive implications for carbon sequestration (Bond et al., 2003). Increased temperatures are likely to provide a more conducive niche for a variety of pests and pathogens critical to agricultural and livestock activities, including those undertaken in rangelands. Increased temperatures and increased evaporation may increase the incidence of heat stress as well as livestock water requirements in extensive rangeland livestock production.

Eragrostis curvula is one of the economically most important and highly productive pasture grasses in South Africa, yielding >12 t/ha/season in the cooler wetter areas but tapering off to <4 t/ha towards the western parts of its growth area (Schulze 2010). In both the intermediate and more distant future, areas lost to potential *E. curvula* production are found in the east, but with significant areas becoming climatically suitable mainly in the west (Figure 15). From multiple GCM analyses, *E. curvula* yields into the intermediate future are projected to decrease by ~10% in an arc from north to southeast around the core climatically suitable growth area, but to increase by up to 4–5 t/ha/season, in the core area (Figure 16). One implication may be that *while major expansion of climatically suitable areas for E. curvula might occur, there is also a possibility that the area of actual production may decrease* (Schulze, 2010).

Kikuyu (*Pennisetum clandestinum*) has become an important pasture grass in South Africa because it provides palatable and highly nutritious material, with yields into the intermediate future projected to decrease in an arc from the northwest through the north to the southeast around the core climatically suitable growth area, but to increase by up to 3–5 t/ha/season in the core area. Into the more distant future the climatically suitable area for kikuyu becomes spatially more compact (Schulze, 2010) (Figures 17 and 18). Kikuyu yield changes are relatively more sensitive to simultaneous changes in rainfall and temperature than to temperature alone. As was the case with *E. curvula*, major expansion of climatically suitable areas for kikuyu is projected to occur into the intermediate future, but there is also a possibility that the area of actual production may decrease (Schulze, 2010).

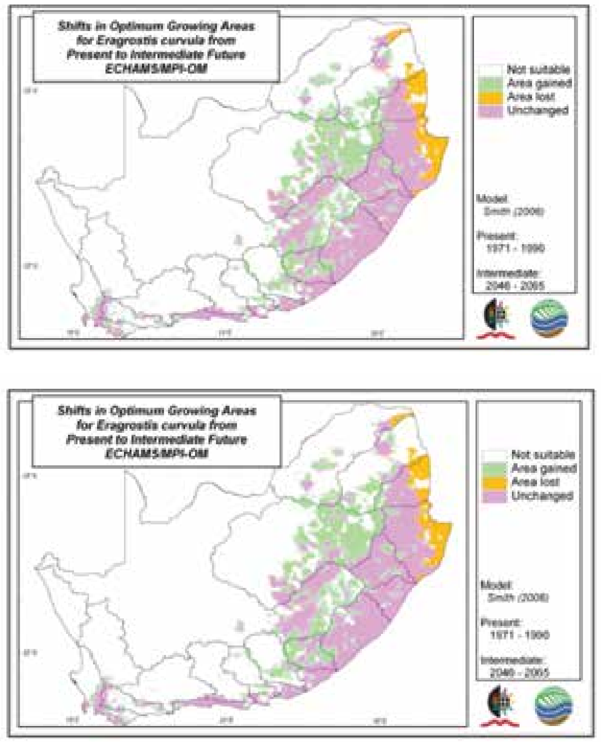


Figure 15 Shifts in optimum growing areas of *Eragrostis curvula* between intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present climate scenarios (bttom, representing a hotter/wetter climate scenario), derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010b).

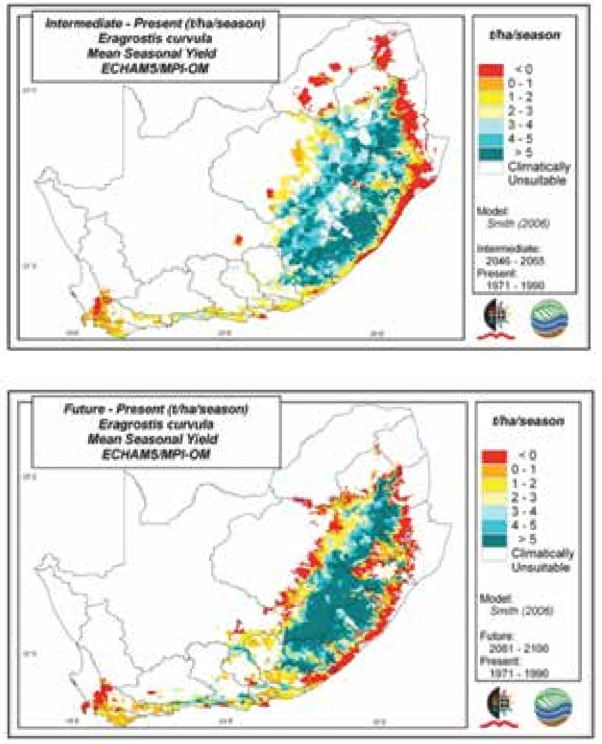


Figure 16. Differences between intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present (bottom, representing a hotter/wetter climate scenario), *Eragrostis curvula* yields, derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010b).

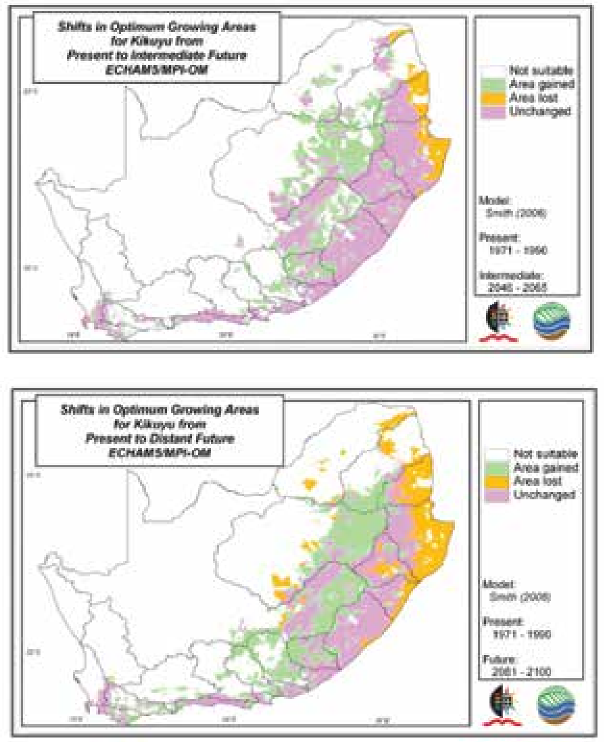


Figure 17. Shifts in climatically optimum growing areas of kikuyu between intermediate future and present (top, representing a warmer/wetter climate scenario), as well as between more distant future and present climate scenarios (bottom, representing a hotter/wetter climate scenario), derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010i).

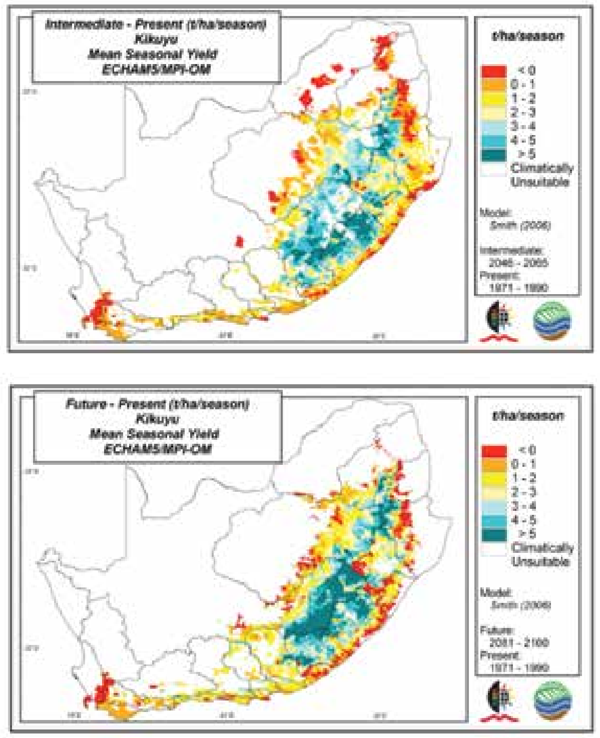


Figure 18. Differences between intermediate future and present (top, representing a warmer/wetter climate scenario), as well as between more distant future and present (bottom, representing a hotter/wetter climate scenario) kikuyu yields, derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010i).

2.6 Impacts on animal production – livestock sector

South Africa's livestock sector is critical to the agricultural economy, yet has traditionally received less attention than crops in considering the impacts of climate change. In *South Africa's Second National Communication under the United Nations Framework Convention on Climate Change* (DEA, 2011), for example, staple crops receive far more attention than does livestock, despite its significance, particularly in the arid and semi-arid parts of the country. Selected recent findings of relevance, as well as work in progress are described below.

To estimate the effects of climate change on the livestock sector, several approaches and simulations have been used in South Africa to develop heat stress and humidity indices for livestock. Lower and upper critical temperatures determine the thermally comfortable zone per livestock type to ensure optimum development and productivity.

In the case of heat stress, Nesamvuni et al. (2012) and Archer van Garderen (2011) show that heat stress probabilities are likely to increase in the future. Archer van Garderen (2011) uses two regional circulation models (RCM) for southern Africa to show areas exceeding the 30°C temperature threshold, using findings from literature (Figure 19). Figure 20 below shows areas that newly exceed the 30°C temperature threshold for all or at least two of the summer months considered given the projections (downscaling of both RCMs is taken into account). The Northern Cape Province of South Africa, bordering on Namibia and Botswana, is an area of particular concern, newly exceeding 30°C in all of the summer seasons, as does the eastern interior of Kenya (although it is recognised that the latter cannot strictly be considered as being restricted to 'summer' months).

Cattle	72 THI (22°C @ 100% humidity)	Comfort threshold for US Holsteins heat stress (Sanshez et al 2009, Ravagnolo et al 2000, Freitas et al 2006)
	72 THI (22°C @ 100% humidity)	comfort threshold for high producing dairy cows (Hernandez el at 2002, Amstrong 1994)
		Higher for *Bos Indicus* breeds (highly adapted to heat stress)
	27°C	Upper limit of comfort zone for maximum milk prodution in India -2°C higher than for temperate countries (Sichi & Michaelowa 2007)
	28°C and high humidity	Heat stress begins in most breeds (Agriculture Information Centre, Goverment of Alberta)
	30°C ambient temparature	"seems to be the critical point at which both Bos Taurus and Bos Indicus begin to differ in ability to maintain near normal rectal temperatures and respiratory rates." (Hermandez et al 2002)
	32°C	Accepted comfort threshold for most cattle breeds
	72THI	Critical limit for every kind of livestock

Figure 19. Heat tolerance thresholds for cattle derived from literature (Archer van Garderen, 2011).

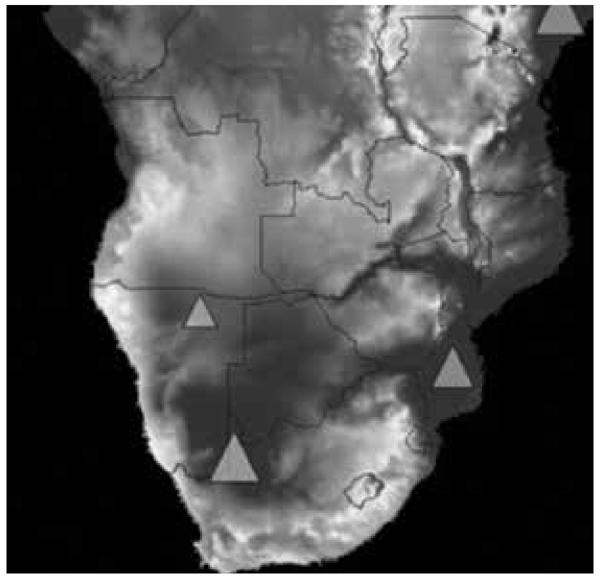


Figure 20. Areas exceeding the 30°C threshold for at least two summer months (Archer van Garderen, 2011).

Nesamvuni et al. (2012) use the Temperature-Heat Index (THI); incorporating climate change projections to show that dairy cattle are likely to experience more severe heat stress events in the future. Under the Drought Early Warning and Forecasting (DEWFORA) project (Winsemius et al., in preparation), THI is again used for thresholding to show the likelihood of heat stress over a single season with a view to tailored forecasts for the livestock sector.

For sheep and goats, the University of the Witwatersrand, Indigo Development and Change and the Council for Scientific and Industrial Research (CSIR) have begun a collaborative initiative, funded in part by START, to understand climate change implications for small stock, using participatory research methods. The study objectives are to better understand heat stress reactions and possible thresholds for goats and sheep in the Suid Bokkeveld area, as well as possible implications for future livestock farming under climate change (Figure 21).

Figure 21. Temperature measurement collars for Dorper sheep, Suid Bokkeveld, May 2013.

In the case of forage, the Agricultural Research Council (ARC) currently leads a collaborative initiative to update findings on climate implications for forage using both the seasonal and the longer term climate change projection timescale. Using dry matter productivity (DMP) calculated from net primary productivity (NPP) best predictors for DMP are currently being isolated; after which predictive modelling will be undertaken. DMP is subsequently converted to livestock standard unit per hectare (LSU/ha). Outstanding tasks include accounting for tree density in baseline carrying capacity calculation, a further task for the collaboration, and field assessment.

Experimental results from other heat and humidity simulation models suggest the following (DAFF, 2013):

2.6.1 Broilers

Research has shown that, with a heat stress increase of 10%, despite a 10% increase in energy consumption for additional ventilation, each crop of broilers took a day longer to reach the target weight. Considering an expected 2.5–3°C rise in temperature, substantial mortality can be expected. Options to be considered by farmers would be reducing stocking density by 12%, thereby reducing the frequency of heat stress to baseline levels, or improving ventilation, which implies a capital investment (DEA, 2011; DAFF, 2013).

2.6.2 Pigs

Increased heat stress was found to result in a small reduction in growth rate because of reduced food intake, with piglets taking one day longer to reach target weight. Solutions to counteract heat stress include a reduction in stocking rates per housing unit, so that the level of gross stress is reduced significantly, or to improve ventilation, which would require capital investment and elevated running cost (DEA, 2011; DAFF, 2013).

2.6.3 Feedlot cattle

Feedlot cattle are adversely affected by high temperatures, relative humidity, solar radiation, and low wind speeds. Tolerance thresholds have been reached in the North West, Northern Cape and Free State during the summer months of 1980–1999. It is projected, using climate scenarios, that thresholds can be expected to be exceeded in these provinces towards the end of the century (DEA, 2011) (DAFF, 2013).

2.6.4 Dairy cattle

The present climate scenario (1980–1999) indicates that the north-eastern parts of the Northern Cape are experiencing moderate to severe heat stress, while this was less severe in Mpumalanga, northern Free State and much of KwaZulu-Natal. Projected scenarios indicate that stress levels could increase to mild stress levels with a minimal effect on milk production. To counterbalance harmful effects without jeopardising milk production, high milk-producing exotic breeds have been cross-bred with heat-tolerant indigenous breeds (DAFF, 2013).

2.7 Impacts on forestry[4]

Commercial plantations, woodlands, natural and urban forests are complex ecosystems providing a range of economic, social and environmental benefits and ecosystem services to a wide range of people, and contributing significantly to national and provincial economies and employment (CCSPAFF, 2013). Most commercial plantations in South Africa are grown in KwaZulu-Natal, Mpumalanga and the Eastern Cape provinces with the three major genera being *Pinus*, *Eucalyptus* and *Acacia* (wattle). South Africa's commercial production forests are vulnerable as a result of the following (DAFF, 2010):

- Geographically production forests extend over a wide but fragmented area, with only ~1.5% of the country climatically suitable for tree crops.
- Individual tree species have climatically optimum growth areas dependent on a combination of rainfall and temperature conditions with sub-optimum conditions the result of either drought conditions, snow/frost damage or pest/disease prevalence. Timber farmers and companies are often vulnerable due to not matching site and species and thus subjecting themselves to losses and reductions in profit margins.
- Associated with the timber industry are fixed capital investments such as sawmills and pulp mills which need to be located optimally.
- The timber industry is vulnerable to competition from, and conversions to, more lucrative uses for the land, e.g. residential and industrial development, or sugarcane or sub-tropical fruit cultivation.
- Vulnerability and risks are likely to be higher on commercial plantations than in natural forests, particularly when one considers land availability, water demand, environmental sustainability and socio-economic factors.
- Plantations are, furthermore, vulnerable to lightning or arson induced fires, more so in some regions than in others, with vulnerability also strongly dependent on the degree to which pro-active fuel load reduction strategies are implemented.
- Climatically, forest plantations are also at risk of frost, snow and hail damage.
- Climate influences the survival and spread of insects and pathogens directly, as well as the susceptibility of their forest ecosystems, with inter- and intra-annual variations in temperature and precipitation affecting pest reproduction, dispersal and distribution.
- Indirect consequences of disturbance from pests and pathogens include the impacts of climate on competitors and natural enemies that regulate their abundance.
- With forestry plantations generally using more water than the native vegetation they replace, they can significantly reduce the flow in rivers, thus making them vulnerable as a competitor for scarce water resources.
- In addition, plantations reduce groundwater recharge where roots are able to tap into the groundwater table, with forest plantations having been shown to significantly depress low flows.

Positive climate change impacts on forests include increases in atmospheric CO_2 concentrations enhancing photosynthesis and root growth. However, the positive effects of enhanced CO_2 could be countered by increased respiration, carbon partitioning to roots and lower levels of available soil water or high vapour pressure deficits. Changes in photosynthetic efficiency may, in addition, be capped by soil fertility and nutrient supply, as soil water availability affects nutrient uptake. Under elevated CO_2 levels, nitrogen (N) levels of forest foliage, and levels in the litter layer decrease resulting in higher quality litter. The effect of elevated CO_2 on nutrient mineralisation and litter decomposition, however, remains uncertain.

Changes in temperature and rainfall regimes are likely to have a marked impact on the extent and location of land climatically suitable for specific genotypes. Area selection will be exacerbated by possible biotic and abiotic risks, including atmospheric pollutants (DEA, 2011). A number of studies (e.g. Warburton & Schulze, 2008; Schulze & Kunz, 2010a,f,g) have attempted to simulate potential future impacts of climate change on the extent and productivity of plantation forestry in South Africa using simple rule-based models with annual rainfall and temperature to map areas potentially suitable for afforestation with particular species. The studies have concluded that, in the medium and longer term, the total area of potential afforested land is projected to increase due to the wetting trend over the eastern seaboard and adjacent areas.

4. DAFF, 2013; Schulze, 2010.

2.7.1 Impacts on major forestry trees

2.7.1.1 *Eucalyptus grandis*

Eucalypts, grown as short rotation hardwoods (6–10 years) for pulpwood or as long rotation hardwoods (20–25 years) as sawlogs, make up ~40% of the area under commercial forests in South Africa, with mean annual increments (MAIs) from 14–30 t/ha/annum. With projected perturbations of temperature and rainfall, major climatically suitable areas could be added inland by the intermediate future, with possible MAI gains of 4–12 t/ha/season, while virtually no presently suitable areas for *E. grandis* are lost (Figures 22 and 23) (Schulze, 2010).

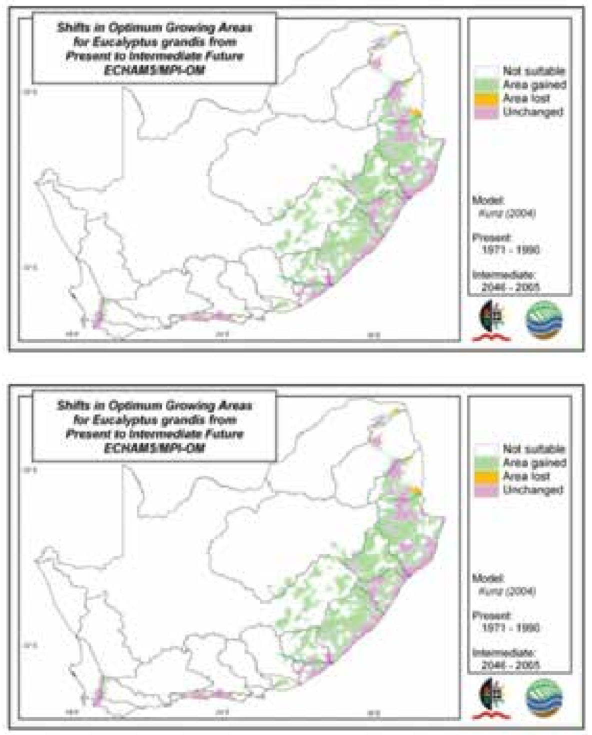


Figure 22. Shifts in climatically optimum growing areas of *Eucalyptus grandis* between the intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present climate scenarios (bottom, representing a hotter/wetter climate scenario), derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010f).

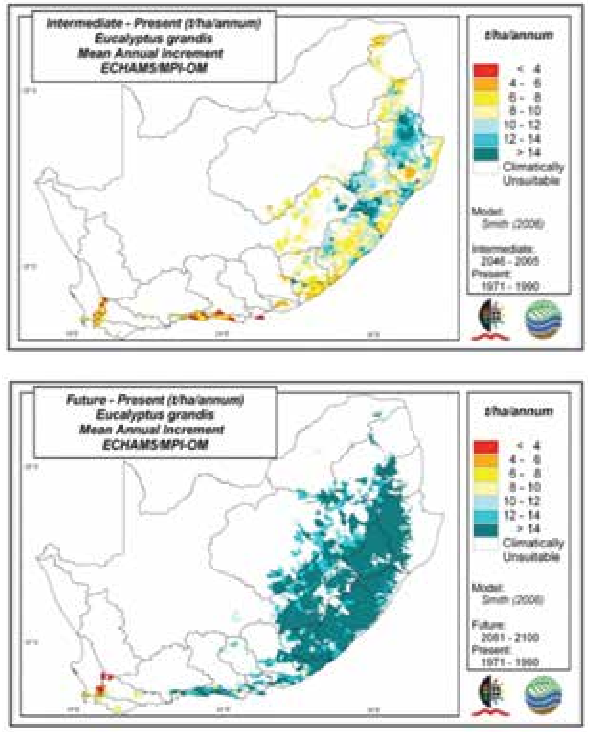


Figure 23. Differences between intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present (bottom, representing a hotter/wetter climate scenario) MAIs of *Eucalyptus grandis*, derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010f).

2.7.1.2 *Pinus patula*

Pinus species, making up ~49% of South Africa's commercial forests, are grown either as short rotation softwood for pulpwood (harvested at ~15 years) or as long rotation softwood for sawlogs (harvested at 25–30 years), with areas climatically suitable for *P. patula* occurring in a strip from the Eastern Cape to Limpopo and with MAIs in a narrow range of 16–20 t/ha/annum. By the intermediate future new climatically suitable areas for *P. patula* are in inland areas of the Eastern Cape and southern Mpumalanga, with yields projected to increase by ~3 t/ha/annum, while areas which are suitable under present conditions, but are projected to become unsuitable within the next four decades or so

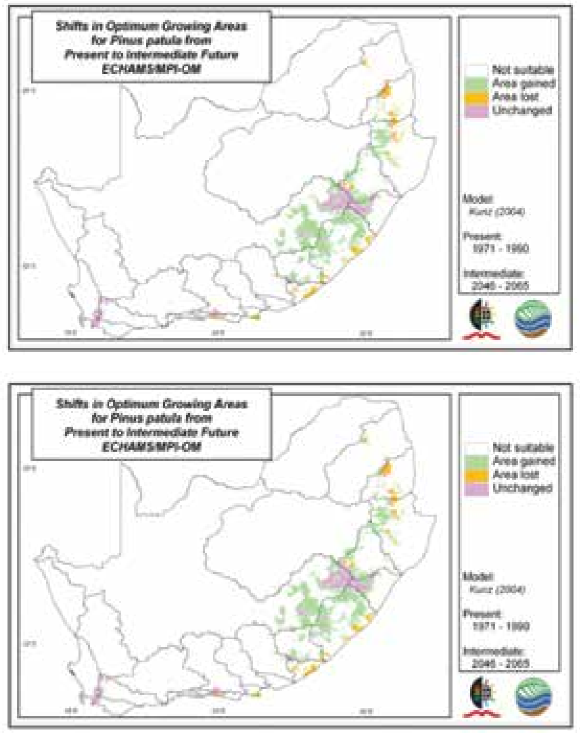


Figure 24. Shifts in climatically optimum growing areas of *Pinus patula* between the intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present climate scenarios (bottom, representing a hotter/wetter climate scenario), derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010g).

include the coastal areas of the Eastern Cape and parts of eastern Mpumalanga and Limpopo. A comparison of results between *P. patula* and *E. grandis* shows *P. patula* to be less sensitive to climate perturbations, but with yield increases also much more muted (Figures 24 and 25) (Schulze, 2010).

2.7.1.3 *Acacia mearnsii*

Acacia mearnsii (black wattle) has proved to be the most drought resistant of the commercial hardwoods grown in South Africa. With a rotation cycle averaging 10 years and a MAI of ~10–11 t/ha/annum, *A. mearnsii* is stripped for its

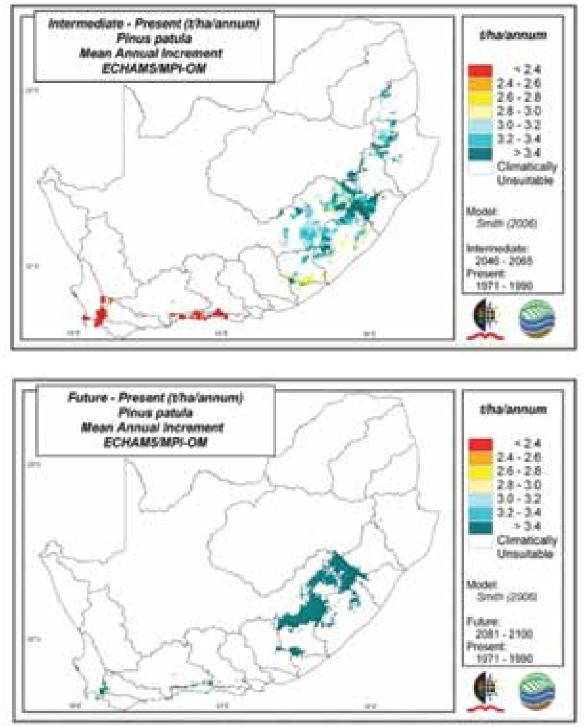


Figure 25. Differences between intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present (bottom, representing a hotter/wetter climate scenario) MAIs of *Pinus patula*, derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010g).

bark in addition to being used for its timber. Major shifts in the areas climatically suitable for *A. mearnsii* are expected, with areas which are presently climatically suitable being lost in an arc in the east, initially along the coast and then curving inland, while new climatically suitable areas are gained in the west, with many areas presently suitable no longer climatically suitable under projected future climates (Figure 26). By the intermediate future in the climatically suitable growth areas of *A. mearnsii* MAIs are projected to decrease by 1–2 t/ha/annum in the east and increase by 2–3 t/ha/annum in the newly suitable areas inland (Figure 27) (Schulze, 2010).

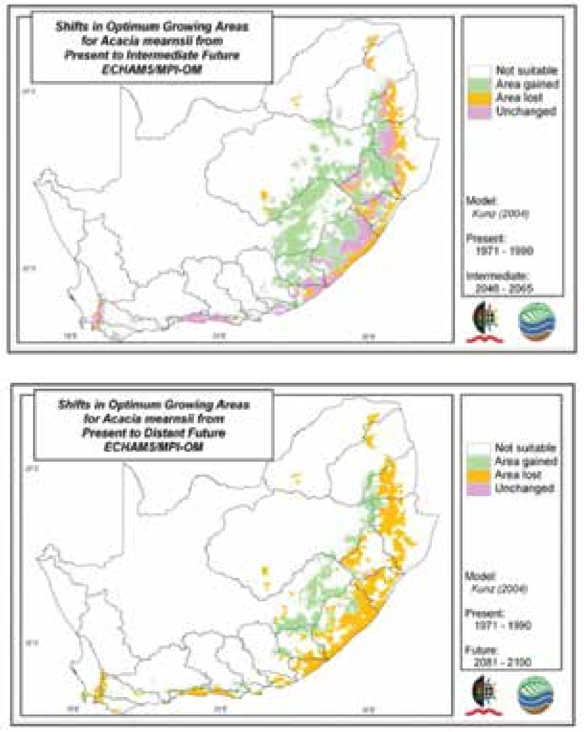


Figure 26. Shifts in climatically optimum growing areas of Acacia mearnsii between the intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present climate scenarios (bottom, representing a hotter/wetter climate scenario), derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010a).

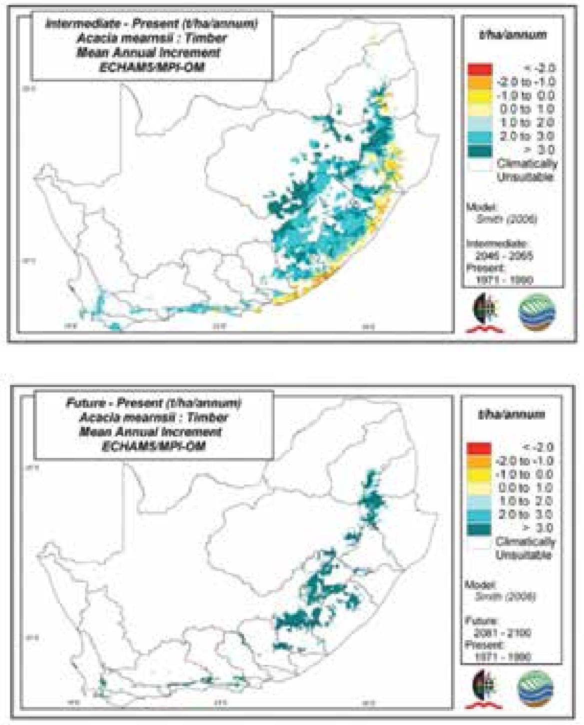


Figure 27. Differences between intermediate future and present (top, representing a warmer/wetter climate scenario), and between more distant future and present (bottom, representing a hotter/wetter climate scenario) MAIs of *Acacia mearnsii*, derived with the Smith model using output from the ECHAM5/MPI-OM GCM (Schulze & Kunz, 2010a).

2.8 Impacts on farm labour – human discomfort index

2.8.1 *The concept of human discomfort*

In order to be comfortable and function effectively, the human body must attain a stable heat balance with its surroundings. The concept of thermal comfort may be defined in several different ways (e.g. Moustris et al., 2010). All definitions are based on criteria of an energy balance between the human body and its environment. Thermal comfort is achieved when the heat production from the human organism counterbalances with the exchange of heat from the environment, aiming at the maintenance of constant body temperature between 36.5°C and 37°C, since increases or decreases in the body's temperature produce discomfort. For example, if the body's temperature exceeds 40°C blood circulation problems appear, and above 41–42°C, coma or total collapse can occur (Gomez et al., 2004). During the hot period of the year or hot times of a day the human body develops defensive mechanisms such as perspiration in order to maintain its temperature at normal-bearable levels. However, high levels of humidity in the environment – when combined with low wind speed and high temperature – may result in the suspension of such defensive mechanisms of the human body (e.g. Moustris et al., 2010). This then causes thermal discomfort and may eventually lead to heat stroke (Becker et al., 2003; Conti et al., 2005).

A considerable amount of literature has highlighted the influence of climate on human comfort, and even mortality. Results show a high increase in mortality in summer months during "heat wave" periods with very high temperature and humidity levels. This relationship with climate seems to be stronger than with other environmental factors, such as atmospheric pollution (Zauli Sajani et al., 2002)

2.8.2 *Comfortable and uncomfortable days per year in South Africa*

Figure 28 (top left) shows that for daytime conditions when temperatures are at maximum and relative humidity at minimum, the number of *comfortable* days per annum over most of South Africa averaged between 50 and 100 for the historical period 1950–1999. The exceptions are in north-eastern KwaZulu-Natal, eastern Limpopo and Mpumalanga where only about 20 days per year are classed as comfortable. The distribution of *partially comfortable* days per annum displays a different pattern, with the northern half of the region together with the eastern periphery at 200–300 days, reducing to 100–200 partially comfortable days in the southern half (Figure 28, top right).

Of prime concern is the distribution of the number of days per annum which, on average for the historical record, are *uncomfortable* on account of being too hot and humid around midday according to Thom's discomfort index using daily maximum temperatures and minimum humidity as inputs. Figure 28 (bottom) highlights the northwest as well as the northern and eastern borders of South Africa as having the most number of uncomfortable days per year at 50–100, with this number tapering off to fewer than 10 uncomfortable days in the cooler interior.

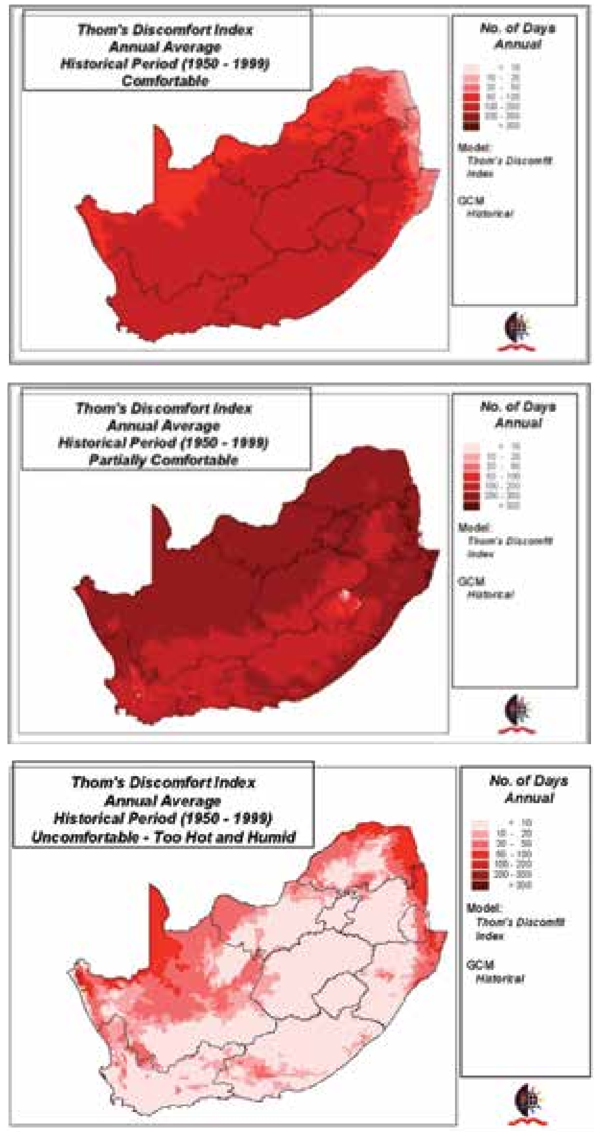


Figure 28. Average numbers of comfortable (top), partially comfortable (middle) and uncomfortable (bottom) days per year over South Africa for the historical time period 1950–1999, according to Thom's (1959) human discomfort index for the midday conditions.

On a shorter than annual time step Figure 29 shows that midday thermal discomfort is clearly a summer phenomenon, as illustrated by the month-by-month analysis at Ballito (~29°40'S) – a beach holiday destination in the sugarcane growing belt along the coast of KwaZulu-Natal – where the number of uncomfortable days per month peak from December to March. Partially comfortable days dominate throughout the year, with middle-of-the-day thermal conditions at this sub-humid location only really comfortable in the mild winter months June to August.

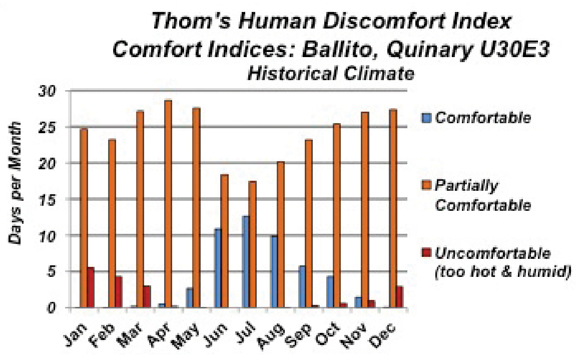


Figure 29. Average numbers of days per month, defined by the Thom's discomfort index, as either being comfortable, partially comfortable or uncomfortable around midday at Ballito along the coast of KwaZulu-Natal for each month of the year under historical climate conditions.

2.8.3 Projected changes to comfortable and uncomfortable days per year over South Africa

In order to assess impacts of projected climate change on indicators of human thermal comfort/discomfort, the number of comfortable days per annum and then the number of uncomfortable days were mapped for Thom's criteria using daily T_{max} and RH_{min} values generated from the GCM outputs for the 20 year time slices making up the present (1971–1990) climate scenarios as well as the intermediate future (2046–2065) and more distant future (2081–2100) climate scenarios. On the premise that no one single GCM's output of T_{max} and RH_{min} was perfect, the means of comfortable and uncomfortable days per year derived from the ensemble of the 5 GCMs used in this study were mapped at the spatial resolution of the 5838 Quinary catchments making up the RSA, Lesotho and Swaziland.

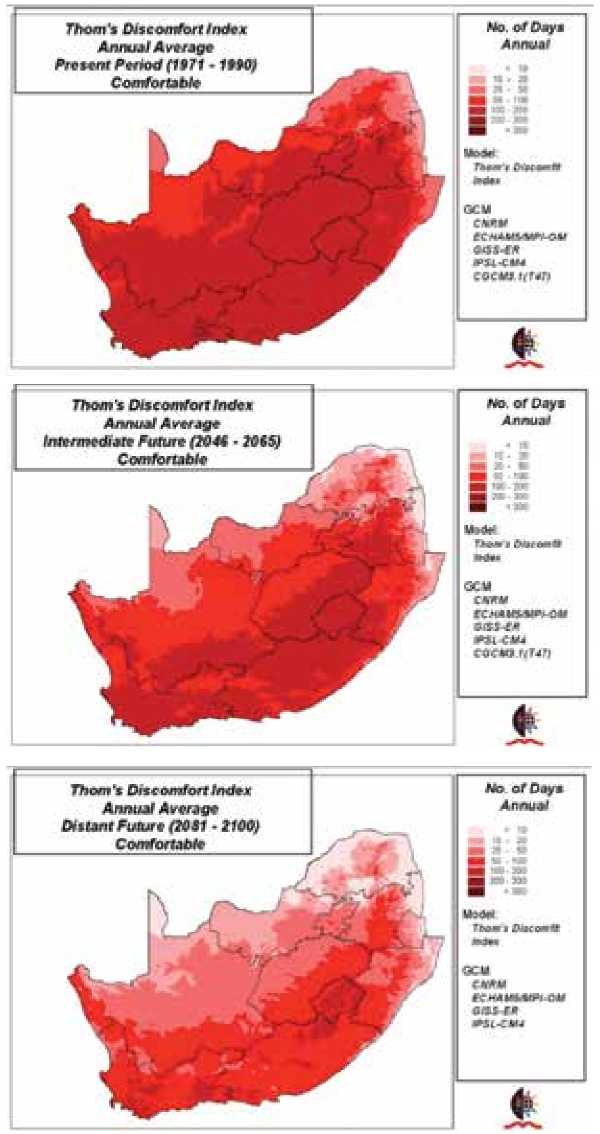


Figure 30. The average of the number of comfortable days per annum according to Thom's human discomfort index, derived from daily climate output of 5 GCMs for present (1971–1990), intermediate future (2046–2065) and more distant future (2081–2100) climate scenarios

Figure 30 shows that projections of the number of *comfortable* days per annum decreases distinctly in the 75 years from the present time slice to that of the intermediate future, and even more markedly in the 35 year gap between the intermediate future and the more distant future, with decreases mainly in the northern half of South Africa.

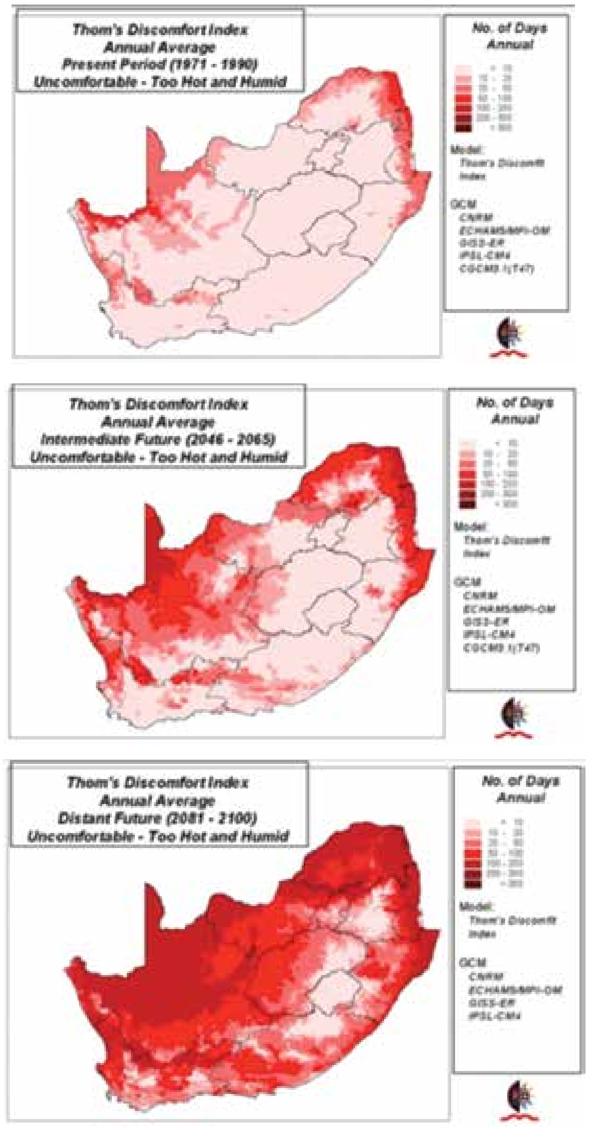


Figure 31. The average of the number of uncomfortable days per annum according to Thom's human discomfort index, derived from daily climate output of 5 GCMs for present (1971–1990), intermediate future (2046–2065) and more distant future (2081–2100) climate scenarios.

However, a more significant visual change is evident in Figure 31 which compares distribution patterns of *uncomfortable* days per annum according to Thom's human discomfort index between the present, intermediate future and more distant future climate scenarios derived from the multiple GCMs used in this study. It may be seen that the darker red shaded areas depicting more than 50 uncomfortable days per year expand considerably from the present into the intermediate future around 40 years from now (2013) and into the more distant future around the 2090s by which time output from the GCMs used in this study project that most of South Africa – except the south and high lying highveld and mountainous areas – could experience over 50, and in many places, over 100 thermally uncomfortable days.

An assessment of the distribution within a year of comfortable versus uncomfortable days is again illustrated for Ballito on the coast of KwaZulu-Natal. Figure 32 shows that from output of the 5 GCMs used in this study the average number of days that are *comfortable* around midday by Thom's criteria reduce from 8 per month for June to August under the present climate scenarios to 3 in the intermediate future and only 2 in the more distant future. More critical in the context of this paper, however, is that the number of *uncomfortable* days displays a marked increase from around 5 per month for the hot summer period January and February under present conditions to around 15 into the intermediate future and over 20 days per month for four months of the year into the more distant future.

2.8.4 Implications of increased human discomfort under future climate conditions

In this paper human thermal comfort/discomfort for midday conditions was assessed by applying Thom's discomfort index based on daily maximum temperatures in combination

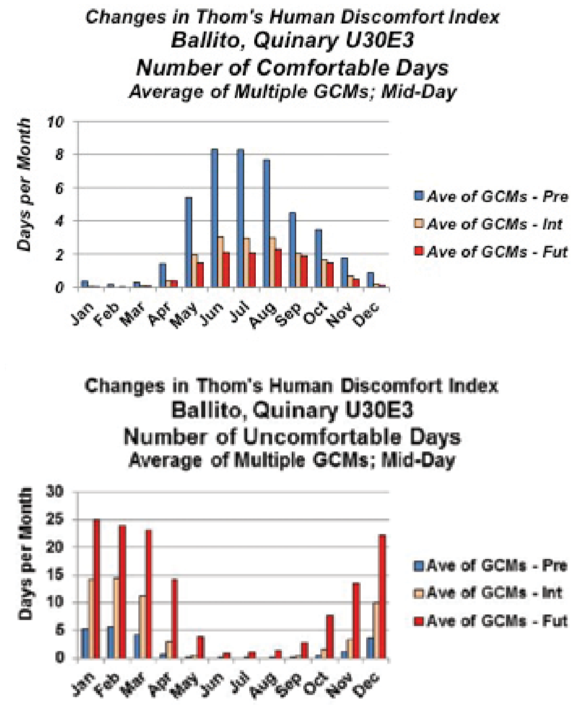


Figure 32.Changes in the number of comfortable (top) and uncomfortable (bottom) days per month at Ballito from the present through the intermediate future to the more distant future, computed using Thom's Human Discomfort Index and based on averages from multiple GCMs.

with daily minimum relative humidity. The study was undertaken at the spatial resolution of the 5838 quinary catchments covering the RSA, Lesotho and Swaziland with Thom's discomfort index computed for historical climatic conditions as well as for projections of future climate scenarios using output averaged from 5 GCMs forced with the A2 emissions scenario. Results showed a considerable *reduction in comfortable days* into the intermediate future in mid-century, with acceleration of this reduction towards the end of the century. More critically, results generated with projected future climate scenarios over South Africa displayed a marked *increase in uncomfortable days* per annum and per summer month with the index of daytime temperature maxima in combination with humidity being above the threshold of comfort, again with an acceleration of uncomfortable days into the more distant future.

While constrained by output from only 5 GCMs based on the A2 greenhouse gas emissions scenarios having been used, the results presented nevertheless have major implications for adapting to projected climate change impacts. Examples include the following:

- Thermal discomfort on more days of the year, and especially in summer months, implies a possible reduction in productivity of agricultural labourers, specifically those engaged in operations with summer and with multi-year crops. This may be offset by an earlier start to the workday or work in two distinct sessions with a longer midday break between sessions.
- Although the threshold values differ slightly, human discomfort equally implies discomfort to livestock which has the known effects, for example, of reducing milk yields in dairy cattle and influencing conception rates across virtually all breeds of livestock. Animal shading and other means of artificial cooling (e.g. spraying with water) are possible adaptation options.
- Increased human discomfort has major implications for the agri-tourism industry, for example, on where to go and when to go and how these decisions may change in future.
- Maps of discomfort indices would be valuable for housing needs, building material and heating/ cooling requirements.
- Cooling requirements, e.g. for fruit in packhouses and for food storage, will necessitate increased operation of air conditioners (longer periods in the year and/or more hours per day) and the need for cooling facilities and abilities with corresponding increases in electricity costs. It will be possible to offset this through, for example, conversion to "green" buildings.
- Similarly, medical geography should take cognisance of possible changes in human discomfort in regard to a range of diseases.

3. ADAPTATION RESPONSE OPTIONS[5]

It has to be emphasised that climate and climate change issues are superimposed upon the multiple other challenges, problems and stressors that the South African agriculture sector already faces (e.g. globalisation, urbanisation, environmental degradation, disease outbreaks, market uncertainties, higher fuel and machinery costs, policies concerning water, veld burning, overgrazing and land redistribution, and slow responses from authorities). Together these affect future planning strategies. However, up to a point, farming communities already cope with, and adapt to, a variable climate. The key to enabling communities to deal with an uncertain future climate is to understand what makes them vulnerable and to work towards reducing those factors (Andersson et al., 2009).

Adapting to projected climate change in South Africa's agriculture sector will be about large-scale commercial farmers optimising climatic conditions to maximise output in a sustainable manner and to maintain a competitive edge. At the rural livelihood scale, on the other hand, adaptation needs to focus on the most vulnerable groups and areas so that livelihoods are not eroded by climate events, but rather that the affected communities become more resilient to the expected changes in climate. For both sets of farmers, adaptation will require an integrated approach that addresses multiple stressors, and will have to combine the indigenous knowledge/ experiences of vulnerable groups with the latest specialist insights from the scientific community.

Most agricultural programmes and information are initiated at high levels in government for regional implementation and are not always adapted to local conditions. All agricultural programmes and planning strategies in regard to climate change will need to focus on local conditions, as climate change will have very local repercussions (Schulze, 2010).

As an overall adaptation strategy, benefits would be gained from practices based on best management and climate-resilient principles, which are characteristic of concepts such as climate smart agriculture, conservation agriculture, ecosystem-based adaptation, community-based adaptation and agroecology. This includes practices such as restoration and rehabilitation of ecosystems tailored for optimising climatic conditions, as well as minimising soil disturbance, maintaining soil cover, multi-cropping and integrated crop/livestock production for optimising yields, sequestering carbon and minimising emissions. Below is a summary of the findings on adaptation options for the South African agriculture sector presented in the DAFF Climate Change Adaptation and Mitigation Plan (DAFF, 2013).

3.1 Conservation agriculture, climate smart agriculture, ecosystem-based adaptation, community-based adaptation and agroecology

Conservation agriculture (CA) is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. It consists of three principles:

- practicing minimum mechanical soil disturbance, which is essential for maintaining minerals within the soil, stopping erosion, and preventing water loss
- managing topsoil to create a permanent organic soil cover for growth of organisms within the soil structure
- crop rotation with more than two species (FAO 2007).

CA is an integrated approach addressing multiple sectors, including in-field rainwater harvesting, collecting roof and road runoff water to supplement irrigation, and organic

5. Schulze, 2010; DAFF, 2013.

and precision farming with a focus on minimum or no tillage, maintaining soil cover and crop rotation. The benefits of CA are well established at small scales, and are currently being quantified at commercial farm level and compared to conventional production methods (Smith et al., 2010). Adoption of CA practices by the commercial and household food security sectors is comparatively low, as the adoption process is intricate and as on-farm experimentation/demonstrations are limited. However, those who have adopted and expanded these practices are reporting benefits such as increased crop yields even during periods of drought, productive soils, minimum input costs and thus larger profit margins, less soil degradation, better soil water-holding capacity, and all-year-round household food security.

Climate-Smart Agriculture (CSA) as defined and presented by the FAO at the Hague Conference on Agriculture, Food Security and Climate Change in 2010, contributes to the achievement of sustainable development goals. It integrates the three dimensions of sustainable development (economic, social and environmental) by jointly addressing food security and climate challenges. It is composed of three main pillars:

- sustainably increasing agricultural productivity and incomes
- adapting and building resilience to climate change
- reducing and/or removing greenhouse gases emissions, where possible.

The CSA approach is designed to identify and operationalise sustainable agricultural development within the explicit parameters of climate change (FAO, 2013).

Ecosystem-based adaptation (EBA) as defined by the Convention on Biological Diversity (CBD), "uses biodiversity and ecosystem services in an overall adaptation strategy. It includes the sustainable management, conservation and restoration of ecosystems to provide services that help people adapt to the adverse effects of climate change. EBA aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change (CBD, 2009)." The maintenance of genetic diversity is particularly important to the agriculture sector. EBA cuts across multiple economic sectors, including agriculture, water, energy, tourism, forestry and natural resources. There are several existing EBA related projects in South Africa, including sustainable management and/or restoration of upland wetlands and floodplains for maintaining water flow and quality; conservation and restoration of forests to stabilise slopes and regulate water flows; and establishing wind-breaks to increase resilience of rangelands.

Community-based adaptation (CBA) works to empower people to plan for and cope with climate change impacts by focusing on community led processes grounded in the priorities, needs, knowledge and capacities of communities (Chesterman & Hope in Midgley et al; 2011). CBA is an important component of the larger scope of adaptation to climate change impacts and pressures by local people. It provides information and concrete examples of potential climate change impacts and adaptation measures that are location specific and community managed. CBA also provides information that can be shared and replicated in an appropriate format and manner acceptable to communities. The need for information on adaptation that incorporates and builds on existing coping strategies of communities should be articulated and demonstrated through CBA projects (GEF, 2011).

Agroecology approaches include recycling nutrients and energy on the farm, rather than introducing external inputs; integrating crop and livestock management practices; diversifying species and genetic resources in agroecosystems over time and space; and focusing on interactions between production components and productivity across the agricultural system.

3.2 Sustainable water use and management

During the next decades South African people will face changes in rainfall patterns that will contribute to severe freshwater shortages or flooding resulting in negative impacts on agricultural production. Enhancing water availability through adaptation options that consider sustainable water use and management is a key strategy for increasing agricultural productivity and securing food security in South Africa. It is important that both the risks and opportunities of climate change are taken into consideration when planning adaptation options.

- **Impoundments:** In certain areas more water might have to be impounded as an adaptation strategy in order to cope with increased flow variability and higher irrigation demands. This will be conditional upon required environmental flow releases being made and impoundments not being a maladaptive practice for downstream water users.
- **Dam re-evaluation and/or modification:** Existing dams were dimensioned for size and safety on historical hydrological records. They will not necessarily be able to deal with future climate conditions in regard to projected increases in floods or lower inflows. Climate change therefore needs to be included as a factor when assessing the safety of current dams and in the design of new structures.
- **Maintaining ecological corridors:** Natural vegetation buffers along river systems on farms are critical to support water yield and for flood attenuation as well as to maintain natural biodiversity.
- **Water and nutrient conservation technologies (WNCT):** As an adaptation strategy WNCTs have the potential to make better use of precipitation and contribute substantially to reducing food insecurity and poverty by reducing vulnerability to risk and uncertainty. Examples include technologies to promote water use efficiency, especially irrigation efficiency; reduction in reticulation losses; socially acceptable water recycling; rainwater harvesting; adaptations such as changes in planting dates; selecting crops with shorter growing periods; high technology-intensive solutions such as the increased use of modern machinery to take advantage of shorter planting periods; and groundwater management systems, notably the artificial recharge of aquifers.
- **In-situ rainwater harvesting:** This includes tillage practices conducive to soil water conservation and water harvesting in its many forms.
- **Wetland conservation:** Wetlands need to be conserved as an adaptation measure as they not only perform vital ecosystems functions such as water storage, flood protection, erosion control and groundwater recharge/discharge, but they also provide a wide range of agriculturally related goods and services in supporting livelihoods in many communities, including provision of hydrological buffers and providing food, livestock grazing, domestic water, construction material and other natural products (Kotze & Silima, 2003; Mondi, 2009).
- **Distribution of water:** In the interests of future national food security consideration has to be given to agriculture receiving an equitable share of water in relation to urban demands and the environmental reserve. The extent to which water for agriculture is reallocated to other sectors during a drought will have to be planned carefully, depending on the value of different crops as staple foods or foreign exchange earners and their physiological response to reduced water, e.g. deciduous fruit trees may suffer for up to five years after a severe drought.

- **Flood management:** With flood magnitudes projected to increase over many parts of South Africa, the protection of agricultural lands will become an important component of adaptation.
- **Groundwater management:** Many farmers depend on borehole water which is drawn from widely varying depths, and will be impacted upon in different ways under future climatic conditions. Farmers will need to adapt to revised groundwater recharge rates for boreholes to remain sustainable.
- **Reduction of high salinity levels:** Where salinity levels are already high these will need to be reduced, elsewhere irrigation practices will need to adapt to prevent salinisation, especially where future climatic conditions will result in widespread rains which will mobilise salts.
- **Sewage management:** Sewage works becoming overloaded, no longer functioning properly and discharging sewage into rivers should be deemed an unacceptable practice under future climatic conditions.
- **Increasing the area under irrigation:** Where climate scenarios project lower rainfall, increasing the area under irrigation is an adaptation option, but only subject to water and suitable soils being available, farming practices being efficient and expansion not leading to maladaptive repercussions downstream (e.g. regarding environmental flows or reductions to other users).
- **Integrated water use planning:** This is an essential adaptation strategy, which focuses on developing comprehensive plans that guide all initiatives and infrastructure development within the water sector, takes into account the water needs of all users and identifies the appropriate interventions to ensure reliable water supply in the most efficient, sustainable and socially beneficial manner.
- **Drip irrigation:** Conversion to drip irrigation (from overhead or flood methods) is an obvious adaptation strategy because of its high water use efficiency. However, it entails expensive capital outlays in infrastructure and installation and government subsidies should be considered to assist the uptake of drip irrigation. Drip irrigation does have disadvantages in that it cannot be used for cooling (unlike sprinklers), nor can it be used effectively on sandy soils. Furthermore, it can work well for certain crops (e.g. vines), but not for others. This is mainly determined by the root structure of particular crops.
- **Local and crop specific irrigation scheduling:** This should be practised to avoid excessive loss of phosphates from irrigated fields due to surface runoff and of nitrates through deep percolation.
- **Mulching/crop residue:** This can save up to 20% of irrigation water requirements.
- **Viticulture specific:** The industry could usefully re-evaluate its cultivar mix and possibly make more use of early-season cultivars to avoid the damaging effects of heat waves in mid-summer. Even within cultivars, the style of wine will likely change. There are new opportunities to acquire cultivars (or breed locally) with pest/disease resistance without forfeiting high quality and yield. However, it takes ~10 years to source, quarantine, register, and certify a new cultivar for release (DEA, 2011).

- **Water curtailments:** Adaptation plans will need to consider carefully water curtailments to irrigators in times of drought in light of food security and conditional upon irrigators using water efficiently.
- **Water price increase trade-offs:** Water has become expensive to irrigators and price increases will, with climate change, have to be weighed carefully against the issues of national food security, export value and foreign earnings potential of crops. The latter is particularly pertinent to the deciduous fruit industry of the Western Cape, an area projected to experience reduced runoff.

3.3 Sustainable farming systems

Certain crops grown in South Africa are more resilient to climate change, while others are more sensitive. Similarly, climate change impacts for some crops can be projected with more confidence than for others. Additionally, there is evidence that food production/security is at risk especially due to future projected water supply constraints, declines in water quality, and competition for water from other sectors. There is evidence that smallholder, subsistence and urban homestead dryland farmers are most vulnerable, while commercial irrigated production is least vulnerable to climate change – given sufficient water supply for irrigation. Intensive livestock production systems need to reduce their water use, contain their GHG emissions and ensure improved grazing services.

Overgrazing, desertification, natural climate variability and bush encroachment are among the most serious problems facing rangelands (DEA, 2011). External stressors such as climate change, economic change and shifts in agricultural land uses may further negatively impact the productivity of these regions and deepen pre-existing vulnerability. Adaptation interventions would benefit from an integrated approach that incorporates both ecological and socio-economic dimensions of rangeland use. A purely sectoral approach, whether targeting climate change, desertification, or addressing both phenomena, is likely to be limited in its ability to address the resilience of key processes and their related socio-economic benefits (e.g. The protection and restoration of ecosystem services). Past policy shifts relating to advised and legislated stocking rates (as informed by estimated carrying capacity) have proven effective in reversing degradation trends in certain climatic and socio-economic settings. These mechanisms would benefit from science-based insights (i.e. ongoing observations and projections) relating to current and future carrying capacities (as they may be influenced by climate change and variability), and from efforts to understand the factors that determine observance of such advice and legislation (DEA, 2011).

As an overall adaptation strategy, concerted promotion of best management practices is required based on the principles of the least possible soil disturbance, permanent soil cover, multi-cropping and integrated crop and livestock production in order to optimise yields, sequester carbon and minimise methane and nitrous oxide emissions. Examples include:

- **Shifts in optimum growing areas**: Changes in the optimum geographic locations for crops and cultivars will need to be identified, with heat/drought tolerance and water use efficiency being paramount considerations in new or alternative crop selection, such as changing to yellow maize or late maturing fruit trees or relocating to climatically suitable areas. Progress has been made with the development of genetically modified crops with regard to heat resistance, drought tolerance, and water use efficiency (DEA, 2011). These include potatoes, sweet potatoes, soybeans, indigenous vegetables, maize and wheat. Other notable developments include low-cost alternatives to chemicals for organic production, a reduction in water consumption by vegetables, the production of indigenous and other vegetables crops under low input-cost conditions and hydroponics.

- **Climatically marginal land**: These areas will be more prone to reduced yields and even complete crop failures in the light of projected increases in climate variability. Such areas should be identified and crops selected with a view to maintaining soil productivity and preventing land degradation.
- **Climate-specific farms**: As an adaptation strategy, farmers may need to procure "climate specific" farms for specific crops, as well as looking to other African countries to produce their crops.
- **Growing indigenous species**: Indigenous species suitable for local conditions should be encouraged as well as the maintenance of natural corridors and buffers where possible within cultivated land and along river systems.
- **Farming indigenous and locally adapted breeds** which are heat and drought tolerant (e.g. Bonsmara, Nguni, Huguenot, and Boergoats).
- **Altering planting and harvesting times**: This is another adaptation strategy that will have to be considered on a year-to-year basis taking into account seasonal climate forecasts. In drier regions harvesting less frequently should be promoted to prevent nutrient depletion.
- **Diversifying crops**: Introducing new cultivated species and improved varieties of crops will enhance plant productivity, quality, health and nutritional value including building crop resilience to diseases, pests and environmental stresses. This can include the addition of new crops or cropping systems to agricultural production taking into account different returns from value-added crops and market opportunities.
- **Minimum or no-till practices:** Practising minimum and/or no-till as a soil conservation measure and following conservation laws and polices is already accepted by progressive farmers. However, many smallholder and subsistence farmers have limited resources and pressing needs and priorities that limit their options and motivation when it comes to putting effort into soil conservation practises as an adaptation measure.
- **Water harvesting**: In its many forms water harvesting should be promoted to capture additional rainfall for crop utilisation.
- **Cover crops:** These should be encouraged in the case of crops grown in widely spaced rows (e.g. vines) to reduce soil water evaporation.
- **Decreasing wind erosion:** Decreasing wind erosion (e.g. by mulch strips or shelter belts of natural vegetation) should become standard practice.

- **Stocking densities:** Veld cover and composition are likely to change in future climatic regimes, and farmers will need to adapt their livestock (and game) densities to changing grassveld carrying capacities. This will include reducing stocking densities, providing supplemental feed and water and/or shifting livestock to land with higher carrying capacity and implementing rotational grazing that includes rest periods for rangelands.
- **Losses of herbage yields:** These may be due to overgrazing, which will need to be minimised as an adaptation strategy, as will losses due to increased erosion through more surface runoff, where that is projected.
- **Alien invasive grasses:** These are largely unpalatable and tend to respond more favourably to elevated CO_2 availability than indigenous species. They will need to be kept to a minimum as they are likely to become a major threat to indigenous species, with huge potential (and partially unavoidable) losses in biodiversity with climate change.
- **Weed infestations in grasslands:** Severe weed infestations need to be minimised. Weeds are mostly pioneer species and tend to degrade ecosystems and adapt more rapidly to environmental changes than indigenous flora.
- **Fodder storage/banking:** In areas of projected rainfall decreases and hence decreases in herbage yields, there will be increased need to store fodder for livestock or to use alternatives such as maize stalks.
- **Animal health:** Adaptation will need to factor in animal health, as changes in rainfall and temperature will impact on the distribution, competence and abundance of vectors and parasites. Furthermore, dependence on river flows for water may become an important adaptation issue under future climatic conditions. Domestic animals (and wildlife) will become stressed or even die if they depend on river flows and if these provide insufficient water.

A number of adaptation strategies can be implemented to protect intensive livestock production. Major infrastructure investment (e.g. To minimise the effects of heat stress and enhance water provision), could add substantially to the already-high input cost of intensive animal production systems and further affect profitability of already financially burdened farmers. Best management technologies should be promoted by assessing the vulnerability of smallholder livestock farmers in marginal areas, and facilitating early adaptation to the effects of climate change. Programmes could be established to breed heat-tolerant animals.

Diversification of the agriculture sector is especially important in areas of projected decreases in rainfall, including increasing the amount of irrigated land (subject to water availability and not leading to maladaptation), finding new locations which are climatically suitable for crops, growing indigenous species, harvesting less often to prevent nutrient depletion, using local techniques to decrease wind erosion (e.g. mulch strips for shelter belts of natural vegetation), and planting drought-resistant maize varieties, alternative crops or late-maturing fruit trees. Climate change and the resultant inability to farm as before may prompt especially subsistence households to find other sources of income, through migrating for work (e.g. to urban areas) or through other activities such as making bricks, sewing, selling firewood.

3.4 Forestry

Short-term adaptation options for the forestry sector include:

- **Community-based climate-resilient forestry[6] and diversification of livelihood skills** (linked to community-based adaptation as described above): This will assist in the sustainability of ecosystems and dependent communities.
- **Extreme event preparedness and early response:** Benefits are derived from preparation for both extreme events and changes in the current average resource available to ameliorate predicted climate change impacts such as higher incidences of drought, hail, fire, and disease. In light of this, forest management paradigms may require revision. Furthermore, the impacts of extreme events should be assessed using currently available data.
- **Fire mitigation:** Reducing losses due to fire and rapid response to forest fires are imperatives in the forestry sector. Present-day initiatives to limit wildfire damage in forests include government support (the Working on Fire programme), as well as an integrated fire management approach by several industrial forestry companies. This involves the combination of proactive fuel reduction strategies in strategically created buffer strips in the landscape combined with reactive fire fighting at these locations, which has great potential to counter (to some extent) the potential increases in fire risk and severity. Intensively managed forest landscapes may thus play a significant role in landscape fire regimes in future. However, the necessary higher investments in fire management will undoubtedly impact economically on commercial forestry.

Short, merging to longer term adaptation options for the forestry sector include:

- **Integrating climate change into forestry curricula**: This should be done at both school and post-school levels.
- **Ecosystems based adaptation (EBA):** This would enhance biodiversity conservation, water conservation and overall environmental sustainability.
- **Multi-objective landscape level planning and implementation:** This should be undertaken in collaboration with other sectors such as biodiversity.
- **Quantified baselines:** For planning into the future, long-term monitoring plots/datasets need to be maintained.
- **Long term research funding:** Such funding should be sought for the sector as a whole, but more specifically for mitigation and adaptation research.
- **Diversify species production systems:** Introducing new tree species and improved varieties will enhance productivity, quality, health and timber value, while also building tree resilience to diseases, pests and environmental stresses.
- **Shift geographical location of key species to match areas of optimum potential**: Enhanced efforts to optimise site-species matching are likely to provide benefits. Empirical and mechanistic modelling techniques have to be applied to predict site suitability on a national scale and match it with available species, hybrids, or clones. First approaches in South Africa are promising (Fairbanks & Scholes, 1999; Warburton & Schulze, 2008), but still lack many important criteria to meet all the challenges of climate change. An integrated multi-criteria decision support system could be developed to adapt site-species matching iteratively to the latest updates of climate predictions.
- **Potential relocation:** The commercial forestry sector has to deal with long harvest to harvest cycles of 10 to 25 years as well as high transportation costs and high costs of relocating timber mills/plants when adaptations to climate change are assessed.
- **Climate resilient tree selection and breeding:** Since tree species and provenances differ in their ability to adapt to climatic change and their vulnerability to hazards, selection and breeding should be undertaken in light of climate projections, with hybridisation and clonal selection providing the potential to adapt to environmental changes. Despite a projected increase of precipitation in some parts of the tree growing area, the criteria for the selection of species, hybrids, and clones will have to focus more on water efficiency, drought and fire tolerance, as well as disease resistance, as future precipitation may be more erratic.

6 **Community forestry** is an evolving branch of forestry in which local communities play a significant role in forest management and land use decision making and act as change agents with government support and facilitation.

3.5 Early warning systems, risk management and decision support tools

Early warning systems, such as seasonal and shorter-term forecasts of climate, and in particular of extreme events, can be effective in enabling land managers to take appropriate action to minimise the adverse impacts of negative events, while benefitting from positive events (DEA, 2011). Climate information on a day-to-day basis is vital for farming operations such as irrigation scheduling, timing of fertiliser applications, in-field traffic control, cultivar and variety selection, timing of planting and harvesting, and response farming. A major concern is timely early warnings of adverse weather and the possibility of related pest and disease occurrences. Timely information is of particular importance to the most vulnerable farmers in remote areas, often without access to the electronic media used to issue early warnings. Both the South African Weather Service (SAWS) and ARC, which maintains the agricultural weather stations network, are providing such warnings by means of cell phones. Many food producers in remote areas, farming on marginal land, are prone to reduced yields and the impacts of climate change such as crop failure due to the increased frequency of drought, floods, and flash floods, as well as diminishing soil productivity and land degradation, will add additional stress (DEA, 2011).

Decision support tools should be developed and promoted to inform farmers in time of climate risks including extreme temperatures, droughts and floods, and to assist farmers with decision making regarding current and future agricultural operations in the face of changing climate. Risk assessments will be needed to inform the development of early warning systems and related decision support tools.

3.6 Integrated and simplified policy and effective governance systems

As a point of departure it needs emphasising that agriculture in many areas of South Africa is the *only* primary producer (e.g. in the Western Cape where there are no mines) and therefore in overall strategies to adapt to climate change the entire agriculture sector, and not only parts of it, require special attention from:

- **Integrated planning:** In adaptation studies this cannot be stressed too much, with joint planning for agriculture, mining and municipalities needed for managing water quantity and quality requirements.
- **Simplified and unambiguous legislation**: Complex and cumbersome legislation exists, for example, on taxes, minimum wages, municipal rates and AgriBEE, and policy decisions are often not clear to farmers, or are perceived to be inconsistent and even conflicting. To make adaptation to an additional stressor such as climate change easier policies, legislation and regulations will need to be simplified and unambiguous for all farmers.
- **Policy awareness:** For easier adaptation, smallholder and subsistence farmers need to be aware of policies concerning, for example, veld burning, overgrazing, or contour ploughing, as they do not always prioritise them because they tend to choose short term benefits over long-term sustainability.
- **Expanded extension services:** In order to expedite adaptation to the added uncertainties of climate change subsistence, smallholder and commercial farmers need efficient and informative agricultural extension services to provide advice and state-of-the-art knowledge on how to adapt for climate variability and change. These services need to be strengthened in number and capacity.
- **Expanded research services:** Research on climate change as well as integrating climate change into agricultural schools and university/college curricula is necessary.
- **Financing:** Finding means to finance and to use current and new technology and practices, especially targeted towards small scale farmers, will become important instruments of adaptation.
- **Climate sensitive land claims and land redistribution:** Adaptation to climate change implies an experienced, receptive, productive and adaptive farming community. Land reform and land redistribution will need to incorporate these attributes to be effective under conditions of climate uncertainty in order to curtail loss of production and degradation of productive agricultural areas.
- **Sustainable urban expansion**: Urban expansion is using up valuable high potential agricultural land which can never be recovered, in addition to enhancing flooding and reducing return flows. Urban expansion should be sustainably managed by authorities in order to address national food security issues with greater confidence in the face of rapid population growth under future climatic conditions.

3.7 Awareness, knowledge and communication

Awareness and knowledge of the impacts of climate change are essential to make the agriculture sector less vulnerable, to encourage the sector to adapt to climate change and, most importantly, adopt a soil protection ethos and conservation agriculture practices conducive to soil and water conservation, minimum greenhouse gas emissions, and carbon sequestration. Many within the farming community are either not aware of climate change and its impacts, or regard climate change as normal climate variability. A means of adaptation, targeted especially towards smallholder and subsistence farmers, would be to disseminate knowledge on and make finance available to use already established practices (e.g. soil sampling, conservation tillage), to embrace new technologies and to purchase appropriate equipment.

There is a dire need for scientists to create more awareness on potential climate change impacts now, and to get the message of the latest available science across to government, agri-business (e.g. seed companies), extension services and farmers related to the onset of rains, number of rain days, persistence of rain days, enhanced rainfall variability, the impacts of droughts on long and short cycle crops, and the uncertainties that remain about climate change. As highlighted above, the development and promotion of decision making tools are essential for informing decision making in the agriculture sector against the backdrop of a changing climate.

Experience shows that farmers not able to cope with disasters in the past are the ones least likely to be able to cope with, and adapt to, the vagaries of future climates. A clear communication strategy is therefore required for climate issues. Commercial farmers should have organised and operational networks of communication and information-sharing with one another (and extension services) on climate related issues (e.g. during the dry months to follow outbreaks and spreading of fires) in order to help one another and smallholder farmers in surrounding areas who require mentoring. An increase in communication and trust should be built up between authorities and all farming sectors (commercial, smallholder and subsistence) to disseminate as much relevant knowledge as possible on climate change in order to implement adaptation strategies. For this, human and economic resources need to be made available.

South African farmers with export crops need to know more about their competitors (e.g. Australia and South America in the case of deciduous fruit; Brazil in the case of sugarcane) and how global warming might change their competitive edge. There is, therefore, a need for market projections into the future in order to adapt. Agricultural subsidies in developed countries imply that it is often cheaper to import than to produce locally. The potential repercussions of changing climate might prompt government to reconsider ways of subsidising key agricultural commodities as an adaptation measure. Where the market is changing (e.g. from dairy to sugarcane), the impacts of projected climate change need to be considered in the interests of individual farmers and the nation.

4. RESEARCH REQUIREMENTS[7]

It is critical for the agriculture sector to conduct a holistic assessment of future research needs on climate change impacts and adaptation. Such an assessment could usefully distinguish needs across a range of scales of implementation (i.e. from national and regional governance issues through to local needs) for specific agricultural activities conducted in a variety of commercial and non-commercial contexts. Without such an assessment it is not currently possible to develop a practical and prioritised list of research needs for this sector. In the absence of this assessment, specific science-related research needs and general considerations are presented below.

4.1 Climate forecasts and climate change uncertainties

If climate variability increases as projected, it will be vital for farmers to use and trust climate forecasts (daily to seasonal) to make adaptation plans to counter climate variability. The fact that poorer farmers currently derive few benefits from forecasts may be attributed to their not having enough resources to act on the forecasts and this will need to be rectified.

For farmers to make and implement adaptation plans, there is a need for scientific insights to be combined with indigenous knowledge and experiences to continually improve answers on the when, where, how much, what impact, and how to adapt to climate change, including reducing uncertainties on, inter alia, enhanced rainfall variability and its impacts on crop production; multiple year droughts and long cycle crops with plant cycles of 10–30 years (such as commercial timber species or deciduous fruit trees) where successive droughts years are critical to the survival of the trees; persistence of rain days in regard to changes in wet/wet, wet/dry, dry/dry or dry/wet sequences, or the fewer long duration, multiple day gentle rains in the winter rainfall region which are being observed; number of rain days and future changes to them in the growing season; and whether the rainy season will start earlier or later and how long it will last.

4.1.1 CO_2 fertilisation effect

A better understanding of the Co_2 fertilisation effect is required, with its anticipated effect of enhancing growth through increased photosynthesis as a result of higher atmospheric CO_2 concentrations and reductions in transpiration, how these changes will interact with crop cover and plant water stress, and the acclimation effects for annual versus perennial crops.

4.1.2 Changing population dynamics of grazing lands

This is pertinent especially for natural vegetation and where entire ecosystems may suffer degradation or collapse.

4.1.3 C_3/C_4 grassland dynamics

C_3 and C_4 grass species generally occur within the same area and share the same resources. However, C_4 grass photosynthetic rates favour warmer regions compared to C_3 grasses. Furthermore the tall and horizontal growth from the C_4 grasses holds a competitive expansion/invasive advantage over the shorter, slower growth C_3 grasses in regard to light. C_3 and C_4 grassland dynamics need to be better understood in terms of their impact on the carrying capacity of grasslands for livestock and game.

4.1.4 Grassland/woody species dynamics

Improved understanding is required on grasslands becoming woodier with further atmospheric CO_2 enrichment, and on fires favouring the expansion of grasslands (both C_3 and C_4). More scientific understanding

7 Schulze, 2010; DAFF, 2013.

is also needed on, for example, alien invasive grass species, weed infestations in grassland, and C_3/C_4 grasslands and fire dynamics.

4.1.5 Livestock animal health

This is an issue where science needs to address how changes in rainfall and temperature will impact on animal health with changes in the distribution, competence and abundance of vectors and ectoparasites. At present, the research into the effects of climate change on the spread and boundaries of particular animal diseases and parasites is limited to basic estimations. This is despite the potentially large effects on costs (protection and treatment costs) and management.

4.1.6 Changing pest/disease distributions

Improved science includes better understanding of the likelihood of more pest attacks with significant repercussions; likely changes in the distribution of plant and animal diseases and insects, and the dynamics of insect pests and disease complexes; the possibility of new pests possibly emerging and of other pests expanding their ranges or increasing the intensity of outbreaks; and biological control agents/predators currently effective in controlling agricultural pests which may lose their efficacy.

4.1.7 Weed control

Further understanding is required on weeds as hosts, i.e. where different crop/grass species host different insects, pests and diseases; and the possibility of increased costs of weed control due to alien invasive plants. Indigenous weeds are expected to rapidly adapt to changing climate conditions.

4.1.8 Plant breeding

Geneticists need to breed more drought/heat resistant varieties of, for example deciduous fruits, with more rapidly responding phenologies and requiring lower positive chill units. Development and breeding of new varieties should be done now because deciduous fruit species, for example, have long response times.

4.1.9 Plant needs

Water requirements, pH and fertiliser requirements of plants among other things need to be re-examined.

4.1.10 Sizing and safety of dams

Existing dams were dimensioned for size and safety on historical hydrological records. They will not necessarily be able to deal with future climatic conditions (e.g. increased floods; or less water). Climate change needs to be taken into account when assessing the safety of current dams and in the design of new structures.

4.2 General considerations

The interaction between research and policy needs to be strengthened in the agriculture sector (DAFF, 2010) through significant capacity building. This will facilitate effective adaptation planning and implementation. Agricultural resilience is about retaining or improving the capacity of agricultural systems to provide agricultural goods and services despite climate risks. By implication it includes the following:

- Promoting climate-resilient rural development planning to address job creation, food security, sustainable livelihoods and to contribute to biodiversity.
- Using the results of vulnerability and risk studies to develop short-, medium- and long-term adaptation scenarios to identify climate-resilient land uses.
- Investing in and improving research into water, nutrient and soil conservation technologies and techniques; post-harvest technologies; cooling technologies in the fruit industry and for food storage; climate-resistant crops, livestock, pastures and plantations including suitable crossbreeding programmes to support adaptation (heat stress, drought tolerance, disease resistance); agricultural production; ownership and financing models to promote the development of "climate-smart agriculture" that lowers agricultural emissions, is more resilient to climate changes, and boosts agricultural yields.
- Using early warning systems to give timely warnings of adverse weather and possible related pests and disease occurrence.
- Developing and promoting decision support tools to assist farmers in making appropriate decisions on farming operations and adaptation options under a changing climate and to inform farmers of actions needed to respond to climate risks.
- Investing in education and awareness programmes in rural areas and linking these to agricultural extension activities.

Future agriculture adaptation is all about being progressive and acting to optimise changing climatic conditions in order to maximise output in a sustainable manner and maintain a competitive edge. Adapting to climate change at the rural livelihood scale will be critically important in the South African context, with a focus on the most vulnerable groups, and the most vulnerable areas necessary to ensure that livelihoods are not eroded by climate events and affected communities become more resilient to projected changes. This requires an integrated approach addressing multiple sectors, combining indigenous knowledge of vulnerable groups with the latest scientific insights.

Most agricultural programmes are initiated at high levels in government and are not always adapted to local conditions. All agricultural planning strategies need to focus on local conditions, especially in regard to climate change which can have very specific local repercussions. In order to adapt to local climatic conditions soil suitability studies need to be undertaken prior to future land use change and land use decisions. Soils will then need to be used in accordance with local properties and in conjunction with projected climatic regimes, e.g. shallow soils resulting in high surface runoff will need protection. Soil analyses should be linked to adaptation decision support systems to assist farmers to increase the resilience of agricultural operations under a changing climate.

Climate change adaptation measures in the agriculture sector should consider impacts on other sectors and ensure that any of the actions outlined above do not have negative implications for the sustainability of other sectors. There are issues including potential biodiversity loss and/or social implications that need to be taken into consideration before adaptation measures can be implemented (DAFF, 2010). For example, before new afforestation takes place, it should be borne in mind that forests generally use relatively large amounts of water in a catchment and under the National Water Act, No. 36 of 1998 plantation forests are a "stream flow reduction activity" and need to be licensed given that many South African catchments are already water stressed. Furthermore, before any new afforestation takes place, consideration has to be given to competition for suitable land from other, either more profitable or socially desirable, land uses such as cropping, bearing in mind that national and household food security is a priority in South Africa.

5. CONCLUSION

Impacts of climate change on food production, agricultural livelihoods and food security in South Africa are significant national policy concerns, and are also likely to have implications beyond the country's borders. Overall, many agricultural sub-sectors are sensitive to projected climate change. Certain crops in South Africa are more resilient to climate change, while others are more sensitive. Similarly, climate change impacts for some crops are projected with more confidence than for others. Additionally, much of the food production and food security which may be at risk is linked to future projected water supply constraints, declines in water quality and competition from non-agricultural sectors. There is evidence that smallholder and subsistence dryland farmers are more vulnerable to climate change than commercial farmers, while large-scale irrigated production is probably least vulnerable to climate change, conditional upon sufficient water supply for irrigation being available (Schulze, 2010; DAFF, 2013).

Potential adaptation responses in the agriculture sector range from national level strategies that include capacity building in key research areas, extension, and consideration of water resource allocation, all the way to the local level where responses may be specific to production methods and local conditions. Local adaptation options themselves will be unique to the very wide variety of agricultural practices in large scale commercial, smallholder and subsistence agriculture. These, however, need to be effectively communicated to farmers and in most cases training and extension services are required. Expanded research services on climate change as well as integrating climate change adaptation into school, college and university curricula will assist in this process.

Irrigation agriculture is the largest single surface water user in the country. This dependence on water represents a significant current vulnerability for almost all agricultural activities. Adaptation plans would benefit by considering water curtailments to irrigators in times of drought, in the light of food security and conditional upon irrigators using water efficiently. Water pricing incentives would need consideration in the context of issues of national food security, and the export value and foreign earnings potential of crops. The socio-economic implications of trade-off scenarios under plausible future climates need to be investigated to inform key decisions in development and adaptation planning to reduce impacts on the most vulnerable communities and groups. The LTAS Phase 2 process has the potential to assess large scale adaptation responses relating, for example, to water allocation, however, it will not address finer scale adaptation response options. There is therefore a need to explore the feasibility of an approach that would assess activity-specific options, the level at which this could be productively tackled, and for which agricultural sub-sectors.

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