Thematic Booklet 1

Agriculture and Climate Change in South Africa: On Vulnerability, Adaptation and Climate Smart Agriculture

R.E. Schulze (Ed)

A Selection of Extracts from

HANDBOOK ON ADAPTATION TO CLIMATE CHANGE FOR FARMERS, OFFICIALS AND OTHERS IN THE AGRICULTURAL SECTOR OF SOUTH AFRICA

Chapters A1, A2, A3, A4, K1 and Appendices
DISCLAIMER

While every reasonable effort has been made by the authors to obtain objective and realistic results in this study, neither the authors, the School of Bioresources Engineering and Environmental Hydrology nor the University of KwaZulu-Natal, nor the Department of Agriculture, Forestry and Fisheries nor any of their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness or usefulness of any information, product or process disclosed by this report.
BACKGROUND TO THE HANDBOOK’S THEMATIC BOOKLETS

The “Handbook on Adaptation to Climate Change for Farmers, Officials and Others in the Agricultural Sector of South Africa” contains 47 Chapters in 11 Sections and is over 670 pages in length. For greater ease of use, the full document is also presented in the form of 16 thematic booklets, of which this is one. The Chapters making up this specific booklet are listed on the cover page. Each booklet, in addition to its theme chapters, also contains the introductory Chapter A1, the concluding Chapter K1 and Appendices (Chapters A5 and A6) on tools used in the analyses as well as clarifications of terms commonly used in climate change studies. In the table of contents below these chapters are highlighted. Please note that page numbers in this thematic booklet do not correspond with those in the full Handbook.

HANDBOOK ON ADAPTATION TO CLIMATE CHANGE FOR FARMERS, OFFICIALS AND OTHERS IN THE AGRICULTURAL SECTOR OF SOUTH AFRICA

Thematic Booklets

Booklet 1 Agriculture and Climate Change in South Africa: On Vulnerability, Adaptation and Climate Smart Agriculture
Booklet 2 Agriculture’s Natural Capital in South Africa 1: The Biophysical Environment
Booklet 3 Agriculture’s Natural Capital in South Africa 1: Weather and Climate – Now and into the Future
Booklet 4 Crops and Climate Change in South Africa 1: Cereal Crops
Booklet 5 Crops and Climate Change in South Africa 2: Other Crops, Including Biofuel Feedstock Crops
Booklet 6 Crops and Climate Change in South Africa 3: Indigenous Crops
Booklet 7 Natural and Planted Grasslands and Climate Change in South Africa
Booklet 8 Horticultural Crops and Climate Change in South Africa: Potatoes
Booklet 9 Horticultural Crops and Climate Change in South Africa: Deciduous Fruits - Viticulture
Booklet 10 Horticultural Crops and Climate Change in South Africa: Selected Sub-Tropical Fruits
Booklet 11 Livestock and Climate Change in South Africa: Selected Themes
Booklet 12 Tree Crop Systems and Climate Change in South Africa
Booklet 13 Irrigation and Climate Change in South Africa
Booklet 14 Hazards and Climate Change in South Africa: Fire Danger Rating under Natural Conditions
Booklet 15 Agriculture’s Human Dimension in South Africa and Climate Change: Some Selected Themes
Booklet 16 Biofuel Feedstock Production in South Africa and Climate Change
## Table of Contents of the Entire Handbook

<table>
<thead>
<tr>
<th>SECTION A</th>
<th>AGRICULTURE AND CLIMATE CHANGE IN SOUTH AFRICA: SETTING THE SCENE</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch A1</td>
<td>On Observations, Climate Challenges, the South African Agriculture Sector and Considerations for an Adaptation Handbook</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch A2</td>
<td>Vulnerabilities and Challenges Related to the South African Agricultural Sector</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch A3</td>
<td>Adaptation to Climate Change in South Africa’s Agriculture Sector</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch A4</td>
<td>Climate Smart Agriculture: From Concept to Practice, From Mainstreaming to Policy - An Introductory Overview with Relevance to Climate Change</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch A5</td>
<td>Tools Used in this Handbook</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch A6</td>
<td>On Clarification of Terms and Concepts Used Frequently in this Handbook</td>
<td>R.E. Schulze</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SECTION B</th>
<th>AGRICULTURE’S NATURAL CAPITAL IN SOUTH AFRICA: A CLIMATE CHANGE PERSPECTIVE</th>
<th>104</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch B1</td>
<td>What do We Understand by Agriculture’s Natural Capital?</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch B2</td>
<td>Topographic Indices and Farming</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch B3</td>
<td>Key Climate Variables, their Importance in Agriculture, and how these Variables are Projected to Change into the Intermediate Future</td>
<td>R.E. Schulze (Ed.)</td>
</tr>
<tr>
<td>Ch B3.1</td>
<td>Solar Radiation</td>
<td>R.E. Schulze, S. Schütte &amp; S.L.C. Thornton-Dibb</td>
</tr>
<tr>
<td>Ch B3.2</td>
<td>Temperature</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch B3.3</td>
<td>Mean Annual Temperature</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch B3.4</td>
<td>Day-Time Maximum and Night-Time Minimum Temperatures</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch B3.5</td>
<td>Critical Threshold Temperatures</td>
<td>R.E. Schulze &amp; S. Schütte</td>
</tr>
<tr>
<td>Ch B3.6</td>
<td>Heat Units</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch B3.7</td>
<td>Frost</td>
<td>R.E. Schulze &amp; S. Schütte</td>
</tr>
<tr>
<td>Ch B3.8</td>
<td>Chill Units</td>
<td>R.E. Schulze &amp; S. Schütte</td>
</tr>
<tr>
<td>Ch B3.9</td>
<td>Potential Evaporation from a Crop and Open Water Body Perspective</td>
<td>R.E. Schulze &amp; M. A. Taylor</td>
</tr>
<tr>
<td>Ch B3.10</td>
<td>Rainfall</td>
<td>R.E. Schulze &amp; S. Schütte</td>
</tr>
<tr>
<td>Ch B4</td>
<td>Climate Zones and Climate Change</td>
<td>R.E. Schulze &amp; M.A. Taylor</td>
</tr>
<tr>
<td>Ch B5</td>
<td>Soils as Natural Capital for South African Agriculture</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch B6</td>
<td>Water and the Farmer 1: Challenges in South Africa Even Before Considering Climate Change</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch B7</td>
<td>Water and the Farmer 2: Challenges in South Africa with Climate Change</td>
<td>R.E. Schulze &amp; M.A. Taylor</td>
</tr>
<tr>
<td>SECTION</td>
<td>CROPS IN SOUTH AFRICA AND CLIMATE CHANGE</td>
<td>PAGE</td>
</tr>
<tr>
<td>----------</td>
<td>----------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Ch C1</td>
<td>Maize Production in South Africa and Climate Change</td>
<td>214</td>
</tr>
<tr>
<td>Ch C2</td>
<td>Wheat Production in South Africa and Climate Change</td>
<td>235</td>
</tr>
<tr>
<td>Ch C3</td>
<td>Sugarcane Production in South Africa and Climate Change</td>
<td>254</td>
</tr>
<tr>
<td>Ch C4</td>
<td>Soybean Production in South Africa and Climate Change</td>
<td>268</td>
</tr>
<tr>
<td>Ch C5</td>
<td>Grain Sorghum Production in South Africa and Climate Change</td>
<td>282</td>
</tr>
<tr>
<td>Ch C6</td>
<td>Taro (Amadumbe) in South Africa and Climate Change</td>
<td>295</td>
</tr>
<tr>
<td>Ch C7</td>
<td>Bambara Groundnut in South Africa and Climate Change</td>
<td>301</td>
</tr>
<tr>
<td>SECTION D</td>
<td>NATURAL GRASSLANDS AND PASTURES IN SOUTH AFRICA AND CLIMATE CHANGE</td>
<td>307</td>
</tr>
<tr>
<td>Ch D1</td>
<td>Short and Tall Natural Grasslands in South Africa and Climate Change</td>
<td>307</td>
</tr>
<tr>
<td>Ch D2</td>
<td>Planted Pastures in South Africa and Climate Change: Kikuyu, Eragrostis curvula and Coastcross II</td>
<td>320</td>
</tr>
<tr>
<td>SECTION E</td>
<td>HORTICULTURAL CROPS IN SOUTH AFRICA AND CLIMATE CHANGE</td>
<td>329</td>
</tr>
<tr>
<td>Ch E1</td>
<td>Potato Production in South Africa and Climate Change</td>
<td>329</td>
</tr>
<tr>
<td>Ch E2</td>
<td>Viticulture in South Africa and Climate Change</td>
<td>349</td>
</tr>
<tr>
<td>Ch E3</td>
<td>Banana Production in South Africa and Climate Change</td>
<td>374</td>
</tr>
<tr>
<td>Ch E4</td>
<td>Citrus Fruit Production in South Africa and Climate Change</td>
<td>386</td>
</tr>
<tr>
<td>SECTION F</td>
<td>LIVESTOCK IN SOUTH AFRICA AND CLIMATE CHANGE</td>
<td>397</td>
</tr>
<tr>
<td>Ch F1</td>
<td>Dairy Cattle in South Africa and Climate Change</td>
<td>397</td>
</tr>
<tr>
<td>Ch F2</td>
<td>The Pig Industry in South Africa and Climate Change</td>
<td>411</td>
</tr>
<tr>
<td>Ch F3</td>
<td>Wildlife Ranching in South Africa and Climate Change</td>
<td>423</td>
</tr>
<tr>
<td>Ch F4</td>
<td>Fodder Banking with Eragrostis curvula in South Africa and Climate Change</td>
<td>446</td>
</tr>
<tr>
<td>SECTION G</td>
<td>TREE CROP SYSTEMS IN SOUTH AFRICA AND CLIMATE CHANGE</td>
<td>461</td>
</tr>
<tr>
<td>Ch G1</td>
<td>Climatically Optimum and Sub-Optimum Growth Areas of Major Production Forestry Species and Hybrids in South Africa under Present and Projected Future Climate Scenarios</td>
<td>461</td>
</tr>
<tr>
<td>Chapter</td>
<td>Title</td>
<td>Authors</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>Ch G2</td>
<td>How Many Production Forestry Species can be Grown Successfully at any Specific Location in South Africa, Given Present and Projected Future Climatic Conditions?</td>
<td>R.E. Schulze &amp; N.S. Davis</td>
</tr>
<tr>
<td>Ch G3</td>
<td><em>Eucalyptus grandis</em> in South Africa and Climate Change</td>
<td>R.E. Schulze &amp; M.A. Taylor</td>
</tr>
<tr>
<td>Ch G4</td>
<td><em>Pinus patula, Pinus elliottii</em> and <em>Pinus taeda</em> in South Africa and Climate Change</td>
<td>R.E. Schulze &amp; S. Schütte</td>
</tr>
<tr>
<td>Ch G5</td>
<td><em>Acacia mearnsii</em> in South Africa and Climate Change</td>
<td>R.E. Schulze &amp; S. Schütte</td>
</tr>
<tr>
<td>Ch G6</td>
<td>Contentious, Complex and Challenging Issues of Streamflow Reductions by Commercial Plantation Forests in South Africa under Varying Climatic Scenarios: The Case of <em>Eucalyptus grandis</em></td>
<td>R.E. Schulze &amp; S. Schütte</td>
</tr>
<tr>
<td>section H</td>
<td>Irrigation in South Africa and Climate Change</td>
<td></td>
</tr>
<tr>
<td>Ch H1</td>
<td>Irrigation in South Africa and Climate Change: Setting the Scene</td>
<td>R.E. Schulze</td>
</tr>
<tr>
<td>Ch H2</td>
<td>Net Irrigation Demands in South Africa and Climate Change</td>
<td>R.E. Schulze &amp; M.A. Taylor</td>
</tr>
<tr>
<td>Ch H3</td>
<td>Environmental Impacts of Irrigation on Water Resources in South Africa and Climate Change: The Case of Surface Water and Deep Percolation Losses from Irrigated Areas</td>
<td>R.E. Schulze &amp; M.A. Taylor</td>
</tr>
<tr>
<td>section I</td>
<td>Hazards and Climate Change in South Africa</td>
<td></td>
</tr>
<tr>
<td>Ch I1</td>
<td>Fire Danger Rating under Natural Conditions in South Africa and Climate Change</td>
<td>R.E. Schulze &amp; S. Schütte</td>
</tr>
<tr>
<td>Ch I2</td>
<td>The African Sugarcane Stalk Borer <em>Eldana saccharina</em> in South Africa and Climate Change</td>
<td>R.E. Schulze &amp; N.S. Davis</td>
</tr>
<tr>
<td>section J</td>
<td>Overarching Adaptation Perspectives in South Africa and Emerging Issues</td>
<td></td>
</tr>
<tr>
<td>Ch J1</td>
<td>Early Warning Systems and Agriculture</td>
<td>R.E. Schulze &amp; T.G. Lumsden</td>
</tr>
<tr>
<td>Ch J2</td>
<td>Perceptions of Smallholder Farmers in South Africa on Impacts of, and Adaptation to, Climate Change</td>
<td>L. Ntsangwane, R.E. Schulze &amp; S. Schütte</td>
</tr>
<tr>
<td>Ch J3</td>
<td>Indigenous Knowledge, Smallholder Farmers and Climate Change: A Perspective from the Semi-Arid Karoo</td>
<td>B. Ncube &amp; R.E. Schulze</td>
</tr>
<tr>
<td>Ch J4</td>
<td>Human Discomfort over South Africa and Climate Change</td>
<td>R.E. Schulze &amp; N.S. Davis</td>
</tr>
<tr>
<td>Ch J5</td>
<td>Biofuel Feedstock Production in South Africa and Climate Change</td>
<td>R.P. Kunz &amp; R.E. Schulze</td>
</tr>
<tr>
<td>section K</td>
<td>Where to from here?</td>
<td></td>
</tr>
<tr>
<td>Ch K1</td>
<td>In the Final Analysis... Where to from Here?</td>
<td>R.E. Schulze</td>
</tr>
</tbody>
</table>
SECTION A  AGRICULTURE AND CLIMATE CHANGE IN SOUTH AFRICA:
SETTING THE SCENE

CHAPTER A1  ON OBSERVATIONS, CLIMATE CHALLENGES, THE SOUTH
AFRICAN AGRICULTURE SECTOR AND CONSIDERATIONS FOR AN
ADAPTATION HANDBOOK

R.E. Schulze

Setting the Scene

What are We Already Observing in Regard to Our Climate? A Global Perspective

What are We Observing in Regard to Our Climate? A South African Perspective

Figure A1.1  Annual CO₂ emissions (in Gigatons) into the atmosphere (top) and annual
(red pluses) as well as decadal (red bars) global temperature differences relative to the 20th century average (bottom), showing 2015 to be the hottest
year on record (Sources: USGS and NOAA, 2016)

Figure A1.2  Annual mean temperature anomalies (base period 1961-1990) of 20 climate
stations in South Africa for the period 1961-2014, with the red line indicating
the linear trend and the black line the 5-year moving average (SAWS, 2015)

Climate and Climate Change as Drivers of Agricultural Production in South Africa

The Climate Hand We have been Dealt with

Climate as a Driver of Agricultural Production in South Africa

Climate Change: The Added Challenge

A Little More on the Science of Climate Change from a South African Perspective

Climate Projections into the Future

Figure A1.3  Increases in GHG emissions in the recent past (left), with more detail on
recent global monthly mean CO₂ concentrations in the atmosphere
(Sources: IPCC, 2007; www.NOAA, 2015)

Figure A1.4  Representative Concentration Pathways (Source: IPCC, 2014)

Why a Focus in South Africa on the Agricultural Sector?

First, What Does Our National Climate Change Response Strategy State from an
Overall Perspective?

Secondly, What are Our National Climate Change Response Strategy’s More
Specific Mandates on South Africa’s Agriculture and Forestry?

The South African Farming Scene: The Complexity of Farming Types in South Africa

A Typology of Farming Systems

Figure A1.5  A typology of South African farming systems (Original conception: Jordaan,
Ncube and Schulze, 2014; later published in Ncube and Lagardien, 2015)

Subsistence Farmers

Smallholder Farmers

Emerging Farmers

Semi-Commercial Farmers

Commercial Farmers

Figure A1.6  Trends in commercial farming units in South Africa over time (DAFF
Abstracts of Agricultural Statistics, 2013)

What Needs to be Considered in a Handbook on Adaptation to Climate Change in
the Agriculture Sector of South Africa?
The Geographical Area Covered in this Handbook

Figure A1.7  Provinces, countries, major roads and towns
Table A1.1  Areal information (Sources: Statistics SA, 2013)

The Scope Covered in this Handbook

In Conclusion: What to Expect and Not to Expect from the Handbook

Further Reading

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A1 ON OBSERVATIONS, CLIMATE CHALLENGES, THE SOUTH AFRICAN AGRICULTURE SECTOR AND CONSIDERATIONS FOR AN ADAPTATION HANDBOOK

Setting the Scene

The world’s climate is changing fast, and will continue to do so for the foreseeable future, no matter what measures are now taken. The effects of climate change on agriculture should therefore be seen in terms of both

- productivity of farming operations, and
- the risk of disruption of production,

with implications for food security and income for millions of households in South Africa. The increase in average temperature that characterises climate change, when taken together with changing rainfall patterns, is likely to shift optimum growing areas for key crops, generate an increase in the frequency and severity of extreme and moderate weather events, and result in pests and diseases finding new ranges. This converts into increased vulnerability in agriculture over the medium to long term and poses new risks to farming and food production unless measures are taken now already to strengthen the resilience of production systems and to learn to adapt to cope with climate change – a recognition that has led to the concept of “climate smart agriculture”.

The above realisation becomes even more relevant because agriculture is generally considered to be one of the most high-performance motors of growth in national and global economies, and it has been shown that in developing countries such as South Africa, agricultural growth:

- contributes more than most other sectors to overall growth of revenue in those rural environment where the major part of the vulnerable populations live and work,
- stimulates growth in the other sectors of the economy by amplifying the demand for goods and services produced within the agricultural sector, and
- reduces levels of poverty, famine and malnutrition by increasing the supply of food and improving access to a better diet.

Early planning to adapt to the risks of climate change, and also being aware of the opportunities that climate change may have to offer, will help minimize the impacts on farm productivity and protect farm operations.

This Handbook is designed as a starting point for identifying decisions which need to be made to help farmers and officials be better prepared for the projected consequences of climate change and to support farmers to adapt timeously.

What are We Already Observing in Regard to Our Climate? A Global Perspective

The effects of climate change resulting from steady increases in carbon dioxide (CO$_2$) emissions into the atmosphere (Figure A1.1 top) can no longer be denied or ignored, with 2015 having been the planet’s warmest year on record (Figure A1.1 bottom) since these started in the 1860s, and up to the end of 2015, 14 of the 15 hottest years on record had been in this century. All South Africans, including farmers and ranchers, are already facing devastating impacts of climate – from severe floods to extreme heat and drought to increased challenges due to wildfires, disease and pests. That is why the South African government is taking action to cut the carbon pollution that drives climate change and protect our communities from its impacts.
What are We Observing in Regard to Our Climate? A South African Perspective

While not as steady as the global temperature trend, South Africa’s temperature is also showing an overall upward trend in temperatures (Figure A1.2).

Figure A1.1 Annual CO₂ emissions (in Gigatons) into the atmosphere (top) and annual (red pluses) as well as decadal (red bars) global temperature differences relative to the 20th century average (bottom), showing 2015 to be the hottest year on record (Sources: USGS and NOAA, 2016)

Figure A1.2 Annual mean temperature anomalies (base period 1961-1990) of 20 climate stations in South Africa for the period 1961-2014, with the red line indicating the linear trend and the black line the 5-year moving average (SAWS, 2015)
Climate and Climate Change as Drivers of Agricultural Production in South Africa

The Climate Hand We have been Dealt with
South Africa’s climate has many influences ranging from seasonal synoptic circulations and frontal systems, the El-Niño-Southern Oscillation, the inter-Tropical Convergence Zone, occasional Tropical cyclones, coastal cut-off lows and many more. Jointly, these have provided South Africa not only with summer, winter and all year rainfall regions, but also with one of the world’s most variable climates. Living with, and managing the impacts of, climate variability on agricultural systems has thus always been a major challenge.

As a result of the above,
- Over 80% of the RSA’s land surface may be classified semi-arid to arid, with only 18% being dry sub-humid to sub-humid; the potential for crop production is therefore limited;
- In fact, of the RSA’s total surface area, only ~ 13% can be used for arable crop production, and of that, only 22% has high potential, with less than 10% of the total arable land under irrigation.
- The most limiting factor in agriculture is available water, with rainfall generally low and erratic for rain fed agriculture, while the relatively small irrigated sector utilises ~ 60% of the RSA’s stored water.

Climate as a Driver of Agricultural Production in South Africa
There are many “drivers” of the agricultural sector in South Africa, each of which can have wide-ranging repercussions not only in the production of food, fibre and forests, but also on GDP, employment or foreign exchange earnings. One such “driver” that varies markedly from year to year, and within any given year, is climate.

Climate is vital for the selection of appropriate crops for a given locality or site, irrespective of whether farmers are planning for maximum economic returns or for sustaining their immediate family’s livelihood, and the more detailed the knowledge, the more intelligently the land use can be planned on all scales, be they at the macro, farm or plot scales.

Climate information is equally important for optimising seasonal and longer term agricultural practices as it is for day-to-day operational planning ranging from when and how much to irrigate, to timing of fertilizer application, the selection of cultivars / varieties or to deciding when to plant.

The influence exercised by climate on living organisms is, however, exceedingly complex, not only because the individual climatic variables play important roles, but also because of the constant interaction between the variables.

Climate Change: The Added Challenge
Now, in addition to the highly variable and challenging climate described above, there is increasing evidence that changes in temperatures, rainfall patterns, wind fields and climate extremes are already occurring that cannot be explained by natural causes alone, and that there is a strong human “fingerprint” at the cause of these change. These climatic changes affect agricultural activities and output, and they are projected to change non-uniformly in magnitude, direction and variability over the next few decades, not only on a global scale, but more specifically so regionally and locally within South Africa. Again, such human-induced climate change is projected to occur in addition to the already high natural climate variability which we experience, and in addition to the other stresses that beset the agriculture sector in South Africa.

Climate change will likely cause a range of impacts on South African agriculture with a consequent need for adaptation responses to emergent risks and opportunities. This
Handbook is intended to be a step towards effective climate change adaptation responses across South African agriculture.

Climate change, often perceived and described by many simply as “global warning”, has climatic ramifications well beyond merely averaged temperature increases, and through higher order perturbations in rainfall and temperature characteristics these changes present serious challenges to agriculture and forestry, which are the providers of food, feed, fibre, timber and energy, and which contribute significantly to the GDPs of economies worldwide, either directly or through knock-on effects. As such, climate change is causing grave concern at all levels of society worldwide because plants and animals may not be able to cope with, and adapt to, the progressive and projected changes in climate as well as we humans can, and this poses a serious threat to ecosystems. Climate change dynamics are extremely complex and not yet well enough understood, especially regarding the extent, timing and impacts of projected changes. South Africa’s already high risk climatic environment by virtue of its straddling the 20-35°S latitudinal range which is transitional to winter, all year and summer rainfall producing synoptic regimes, renders it particularly sensitive and vulnerable to geographical shifts in climates. What is currently known, however, points to many serious effects that climate change can have on South Africa’s food security, socio-economic activities, human health, water resources, extreme weather events, low lying areas and infrastructure. The effects are not necessarily always negative, however, and positive spin-offs are likely to occur. These need to be identified and maximised.

As agriculture and forestry are the mainstay of livelihoods and economic growth, the South African national Department of Agriculture, Forestry and Fisheries (DAFF), together with other non-governmental role players (NGOs) in the broader agricultural sector, has been proactive in initiating sector related climate change strategies and scenarios to promote climate change awareness and knowledge, advocate sustainable terrestrial and aquatic ecosystems-based production practices which minimise emissions of greenhouse gases, conserve the sector’s natural environments, promote adaptation and mitigate effects of climate change as far as possible. This Handbook is the outcome of one such DAFF initiative.

Rather than dealing only with short-term weather events such as droughts, floods, heat waves and cold spells, farmers must now respond to climatic changes that will alter irrevocably the way they farm. Around the world, and for us specifically in this country, farmers urgently need to understand better the projected impacts of climate change in order for them to become innovative so that they will be able to produce enough to support themselves and the ever-growing local, regional and global population. Their added challenge is to do so in ways that will protect the environment, especially soil and water, and minimise agriculture’s contribution to climate change.

A Little More on the Science of Climate Change from a South African Perspective

Climate Projections into the Future

Climates are changing as a result of an increase in concentrations of greenhouse gases (GHGs; mainly carbon dioxide CO$_2$, methane CH$_4$ and nitrous oxide N$_2$O) in the earth’s atmosphere (Figure A1.3). This increase has occurred over the past two centuries, and has been accelerating more recently, due to anthropogenic (human driven) factors, particularly industrialisation through burning of fossil fuels such as coal, oils and natural gases mainly for energy generation, but also to unsustainable land use systems, increases in livestock and clearing of forests, all resulting in increasing the concentration of GHGs.

Such GHG emitting activities have significantly increased the atmosphere’s absorption of the earth’s outgoing infrared radiation, thereby enhancing the existing greenhouse effect,
and then re-radiating part of it back to earth, resulting in the rising trend in global temperatures shown in Figure A1.1. Climate change thus refers to the changes of climate which are attributed directly or indirectly to human activities that alter the composition of the global atmosphere. This change in climate is superimposed onto natural climate variability which is experienced world-wide, but which is particularly severe over South Africa.

Future climate projections (which are NOT forecasts nor predictions) are scenario descriptions of possible future conditions based on the current understanding of the physics of the atmosphere, on assumptions about changing GHG emissions and their atmospheric concentrations, as well as on assumptions of future technological, economic and demographic trends. The skill of projections (i.e. their accuracy) depends strongly on how far into the future projections are made, which of a number of possible future GHG emissions pathways is considered (the thicker lines in Figure A1.4), and on the climate variable considered (e.g. temperature projections are generally thought to be more skilful than rainfall projections). Deriving key regional messages about future potential change thus requires assessing multiple lines of evidence. Climate projections are therefore assessed in this Handbook from a range of climate models generically termed GCMs, i.e. General Circulation Models or Global Climate Models, as it is not possible to identify a “best” model for all relevant climate variables for South Africa (Schulze, 2012). This range of outcomes from different GCMs for a specific future pathway is shown by the different thin coloured lines in Figure A1.4 for each of the thicker coloured lines of an emissions pathway.

Projections of impacts in the agricultural sector in South Africa (and other sectors as well) are often complicated by different scientists applying different sets of climate scenarios and using different modelling approaches, thus making it challenging to extract coherent key
messages. The various climate projections used in the agricultural impact studies presented in this Handbook have been based, in many of the case studies, on the Intergovernmental Panel on Climate Change’s (IPCC) Special Report on Emission Scenarios (SRES) so-called A2 emission scenario, which is essentially a “business as usual” scenario representing CO\textsubscript{2} equivalent levels of above 500 ppm by 2050. Other case studies have used outputs from GCMs which are driven by the various so-called RCPs, or Representative Concentration Pathways (thick lines in Figure A1.4). Again, the “business as usual” RCP8.5 has been used as all the latest carbon emissions point in that direction (see 2014 estimate on the RCP8.5 trajectory in Figure A1.4), certainly for the forthcoming few decades which are considered in this Handbook.

![Figure A1.4](image)

**Figure A1.4** Representative Concentration Pathways (Source: IPCC, 2014)

Future rainfall projections remain challenging,
- first, because rainfall is a derived rather than a direct output from GCMs and,
- secondly, because complex rainfall-generating processes such as cloud formation and land surface-atmosphere interactions are not yet fully understood and resolved in climate models.

Overall, projections for South Africa’s winter rainfall region in the southwest of the country suggest future rainfall decreases, while summer rainfall region projections deviate less from present rainfall, with possible increases in rainfall amounts. In summary, some key findings, elaborated upon in other sections, show the following:
- All regions are very likely to be warmer in the future.
- Patterns of projected decreases in winter rainfall in the southwest occur across many GCMs.
- Similarly, projected increases in summer rainfall in the east seem stable and physically consistent with the projected circulation changes; however, there remains uncertainty in the magnitude of responses and with some local scale deviations.
- There is uncertainty about the location of the boundary between regions that show less rainfall in the west and similar or more rainfall in the east.
- The roles of mountain ranges and topography are critically important, especially in enhancing the projected east coast increases in precipitation and ameliorating the projected rainfall reductions on the Cape Mountains in the southwest of the country.
Why a Focus in South Africa on the Agricultural Sector?

First, What Does Our National Climate Change Response Strategy State from an Overall Perspective?

South Africa’s official standpoint at this point in time (2016) on adapting to climate change is encapsulated in the National Climate Change Response Strategy (NCCRS) of 2011. Here is a broad view that this document takes on responses to climate change:

- Ecosystems provide important services to society, and agricultural ecosystems include the provision of food, wood, fibre and fuel, in all of which water is also utilised.
- The rate of change to the earth’s climate compromises the ability of service providing ecosystems, including agriculture, to function effectively, and the rate can exceed the capacity of ecosystems to adapt.
- South Africa’s agriculture is highly vulnerable and exposed to the impacts of climate change due, on the one hand, to our socio-economic context (e.g. the many land-dependent rural poor) and, on the other hand, to an already high risk natural environment (including high season to season climate variability, extreme weather events, times of severe water stress).
- Agriculture urgently has to strengthen its resilience to climate change impacts and has to develop and implement policies, measures, mechanisms and infrastructure that protects its various components (commercial, emerging, rainfed, irrigated, crops, livestock, plantation forestry etc.).

- This strengthening of resilience is to be done cognisant of:
  - the Intergovernmental Panel on Climate Change’s (IPCC’s) conclusions on unequivocal global warming forced by anthropogenic (human) activities;
  - the threat that climate change becomes to undermining South Africa’s positive development goals;
  - our continued legally binding obligations to strengthening and ensuring full implementation of our international commitments to, for example, the United Nations Framework Convention on Climate Change (UNFCCC) and the (now superseded) Kyoto Protocol through, for example,
    - Formulating, implementing, publishing and regularly updating policies, measures and programmes to mitigate our emissions of Greenhouse Gases (GHGs) and to adapt to the adverse effects of inevitable climate change;
    - Monitoring and periodically reporting to the international community the country’s GHG inventory (which includes agriculture’s contribution);
    - Managing, conserving and enhancing GHG sinks and reservoirs sustainably, including those from agricultural (terrestrial) ecosystems and forests;
    - Developing a climate change response plan to address, inter alia, the agriculture sector, also in its integration with land protection / rehabilitation and water resources;
    - Mainstreaming climate change considerations into social, economic and environmental policy;
    - Further developing and supporting research and systematic observation, as well as research and technical capacities within South Africa and beyond its borders; and
    - Developing and implementing education, training and public awareness programmes on climate change within the broader agriculture sector and highlighting its effects in order to promote and facilitate scientific, technical and managerial skills as well as providing public access to information, public awareness of and participation in addressing climate change.
Secondly, What are Our National Climate Change Response Strategy’s More Specific Mandates on South Africa’s Agriculture and Forestry?

- In both the agriculture and commercial forestry sectors there exists synergy and overlap between adaptation and mitigation measures.
- Climate-resilient sectoral plans such as the one on Agriculture, Forestry and Fisheries have the potential to directly address the plight of those most impacted by climate change, e.g. the rural poor.
- Climate resilience needs to address issues of strategic national importance, e.g. to food security and its links to water, health (human, livestock and plant) and land reform.
- Being the largest consumer of water in South Africa (mainly through irrigation), agriculture is vulnerable to changes in water availability as well as to increased water pollution and soil erosion, from a combination of projected spatial changes in rainfall patterns, increases in intense rainfall events and increased evapotranspiration.
- Under-resourced, small scale and subsistence farmers are particularly vulnerable to the impacts of climate change.
- Commercial agriculture is a significant contributor to GDP and to employment. With its full contribution, including multipliers, agriculture contributes up to 12% of South Africa’s GDP and 30% of its national employment. Crop failures through the vagaries of climate can thus have a significant impact on the nation’s economy.

The following should be considered, either directly or indirectly, in an agriculture adaptation plan in light of projected climate change:
- Climate-resilient agricultural responses depend on the recognition that agriculture provides not only food, but also other environmental and socio-economic benefits.
- Important as input-intensive commercial agriculture is, it can sometimes have negative environmental, social and economic externalities, and these may be exacerbated by climate change.
- The appropriate use of small-scale labour-intensive agriculture techniques and its various overall benefits (e.g. job creation, empowerment, food security, contribution to biodiversity) should also be considered from a climate change perspective.
- Modelling of climate change scenarios is vital to informing land use planning decisions in agriculture in as much as they determine the mix of livestock and crop cultivation, as well as the types of crops that are likely to be commercially viable under projected future climate scenarios.
- Impacts of alien invasive plant species, which reduce streamflow and may consequently compromise already scarce water resources as well as reducing biodiversity, need to be evaluated through a climate change lens.
- The overall role of carbon sequestration in agriculture needs to be reviewed. More specifically, the role of natural and plantation forests functioning as carbon sinks, thereby reducing the effects of enhanced GHG emissions in the atmosphere, need to be assessed.
- The potential for sustainable biofuel production under conditions of climate change, and its possible impacts on food security, needs to be evaluated.
- Issues surrounding grassland degradation through injudicious grazing and burning regimes, as well as the reversal of those negative effects through veld rehabilitation, need to be addressed from a climate change perspective.

The South African Farming Scene: The Complexity of Farming Types in South Africa

The RSA has a distinct dual agricultural economy, comprising of a well-developed commercial sector which produces ~ 95% of the marketed agricultural output, and a predominantly subsistence oriented sector residing mainly in what were, historically, the so-called “homelands”, although an emerging sector is now evolving out of the subsistence sector.

A Typology of Farming Systems
Many farming typologies have been developed to try and capture the complexities of the South African farming types. The one shown below in Figure A1.5, and also now published in Ncube and Lagardien (2015) is used in this Handbook. It distinguishes, in the first instance, between freehold and communal farmers, and amongst the freehold between commercial (small vs. large family vs. company owned), emerging (owned vs. leased), subsistence and contract farmers while the communal farmers are sub-classified into subsistence, commercial and contract farmers, all of whom are associated with different farming activities.

Figure A1.5  A typology of South African farming systems (Original conception: Jordaan, Ncube and Schulze, 2014; later published in Ncube and Lagardien, 2015)

Working definitions, taken from DAFF (2013), of some (but not all) of the farmer types listed in Figure A1.5 are as follows:

**Subsistence Farmers**

Subsistence farming is self-sufficiency household farming wherein farmers produce mainly for household consumption and production is based on the family requirements rather than markets. Production is further reduced by limited technology and access to resources. Subsistence farmers are resource poor farmers producing mainly for household consumption and according to their family food requirements rather than markets.

**Smallholder Farmers**

Smallholder farmers produce for household consumption and markets, subsequently earning ongoing revenue from their farming businesses, which form a source of income for the family. Farming is not always the main source of income, however, and diverse non-farm sources of income exist to sustain the family. They have the potential to expand their
farming operations and to become commercial farmers, but need access to comprehensive support (technical, financial and managerial instruments).

**Emerging Farmers**
Emerging farmers are part of the smallholder farmers. The term “emerging” farmer is used with different connotations depending on the institution being consulted. Farmers (and some institutions) do not like the term, and farmers often see themselves as being “in transition” towards becoming commercial farmers.

**Semi-Commercial Farmers**
Semi-commercial farmers produce on medium sized holdings and grow at least one commercial product that may be sold at the farm gate or to the distributors.

**Commercial Farmers**
Commercial farming is defined as the established farming venture undertaken by an individual or business entity for the purpose of the production and sale of agricultural products to make a profit. A dilemma is emerging in that fewer and fewer commercial farmers (~61 000 in 1996; ~ 46 000 in 2002; ~ 40 000 in 2007) have to feed a steadily increasing and rapidly urbanising South African population, with the decline in commercial farming units having been most acute in Limpopo (Figure A1.6).

![Figure A1.6](image_url) Trends in commercial farming units in South Africa over time (DAFF Abstracts of Agricultural Statistics, 2013)

**What Needs to be Considered in a Handbook on Adaptation to Climate Change in the Agriculture Sector of South Africa?**

The vulnerability of South Africa’s agriculture sector to climate, and the potential impacts of climate change on components of the sector, form the backdrop in this Handbook on assessing what to adapt to, and how to adapt. Therefore, one needs to consider responses to the

- **magnitudes of change**, i.e. how much the change is projected to be and how much impact that can have, where the magnitude of an impact is determined by
  - its scale, e.g. the area affected or the number of people / animals affected and
  - its intensity, i.e. the degree of damage caused, with the most widely used quantitative measures for climate impacts being
  - monetary units such as welfare, income or revenue losses,
  - costs of anticipating and adapting to certain biophysical impacts,
  - estimates of peoples’ willingness to pay to avoid (or accept as compensation for) certain climate impacts, or the
- number of people affected by certain impacts such as food and water shortages, morbidity and mortality from diseases, and forced migration;

- **direction**, i.e. is it a positive or negative change, and what that implies;

- **timing**, i.e.
  - when, in the course of a year, the change is projected to occur and how that affects management decisions, or
  - whether a harmful impact is more likely to happen sooner rather than in the more distant future;

- **rate**, i.e.
  - how rapidly change is projected to occur in years or decades ahead, and
  - how that affects priorities of action,
  - with adverse impacts which occur suddenly (and / or surprisingly) being perceived as more significant than the same impacts occurring gradually, because the potential for adaptation for both human and natural systems would be much more limited in the former case, and
  - with very rapid change in a non-linearly responding system (such as the availability of water for agriculture) possibly exacerbating other vulnerabilities (e.g. impacts on agriculture and nutrition which aggravate human vulnerability to disease), particularly where such rapid change curtails the ability of systems to prevent and prepare for particular kinds of impacts;

- **location**, i.e. where will it occur first or most severely by considering, *inter alia*, income, gender and age in addition to regional, national and sectoral groupings;

- **persistence and reversibility**, i.e. where impacts could become important due to persistence of, say, the emergence of near-permanent drought conditions or intensified cycles of extreme heat waves or flooding that were previously regarded as “one-off” events;

- **levels of confidence / uncertainty** of projected impacts in regard to likelihood of impacts and confidence, where
  - likelihood is the probability of an outcome occurring and
  - confidence is either the subjective or a statistically more objective, assessment that any statement about an outcome may prove correct;

- **potential for adaptation**, which differs between and within regions and sectors, and where the potential considers not only the technical feasibility of certain adaptations, but also the availability of required human resources, the costs and side-effects of adaptation, the knowledge about those adaptations, their timeliness, the (dis-)incentives for adaptation actors to actually implement them, and their compatibility with individual or cultural preferences; and the

- **importance of the system at risk**, in this instance agriculture in South Africa, in regard to the value attached to the system by different societies, be that value related to infrastructure, the uniqueness of a habitat or an ecosystem or agricultural commodity, or the livelihoods of many people depending crucially on the functioning of the system (IPCC, 2007; Schulze, 2012).

These are some of the challenges which this Handbook wishes to address.

**The Geographical Area Covered in this Handbook**

While the Handbook’s title refers to *South Africa*, the geographical entity covered in this Handbook comprises the Republic of South Africa with its nine provinces (viz. Limpopo, Mpumalanga, North West, Northern Cape, Gauteng, Free State, KwaZulu-Natal, Eastern Cape and Western Cape) plus the Kingdoms of Swaziland and Lesotho. Where a focus is specifically on the Republic of South Africa, the abbreviation RSA is used, with the term
“South” used here in preference to “southern”, as the latter has a different political connotation (e.g. as in SADC, which includes over a dozen member states). The provinces of the RSA plus the two other countries, as well as major roads and towns, are shown in Figure A1.7 while information on areas is given in Table A1.1.

![PROVINCES, COUNTRIES MAJOR ROADS AND TOWNS](image.png)

**Figure A1.7** Provinces, countries, major roads and towns

**Table A1.1** shows the Northern Cape to be the largest of the nine provinces at 363,389 km², while Gauteng is 19 times smaller at only 18,760 km². The total study area is 1,223,201 km², of which the RSA covers just over 96%.

**Table A1.1** Areal information (Sources: Statistics SA, 2013)

<table>
<thead>
<tr>
<th>Province / Country</th>
<th>Area (km²)</th>
<th>Area of Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limpopo</td>
<td>119,606</td>
<td>9.4</td>
</tr>
<tr>
<td>Mpumalanga</td>
<td>81,816</td>
<td>6.4</td>
</tr>
<tr>
<td>North West</td>
<td>118,710</td>
<td>9.3</td>
</tr>
<tr>
<td>Northern Cape</td>
<td>363,389</td>
<td>28.6</td>
</tr>
<tr>
<td>Gauteng</td>
<td>18,760</td>
<td>1.5</td>
</tr>
<tr>
<td>Free State</td>
<td>129,437</td>
<td>10.2</td>
</tr>
<tr>
<td>KwaZulu-Natal</td>
<td>91,481</td>
<td>7.2</td>
</tr>
<tr>
<td>Eastern Cape</td>
<td>170,616</td>
<td>13.4</td>
</tr>
<tr>
<td>Western Cape</td>
<td>129,386</td>
<td>10.2</td>
</tr>
<tr>
<td>RSA (total)</td>
<td>1,223,201</td>
<td>96.3</td>
</tr>
<tr>
<td>Swaziland</td>
<td>17,404</td>
<td>1.4</td>
</tr>
<tr>
<td>Lesotho</td>
<td>29,558</td>
<td>2.3</td>
</tr>
<tr>
<td>Totals</td>
<td>1,270,163</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**The Scope Covered in this Handbook**
In this Handbook the following Sections have been covered, each with a number of Chapters making up the Section, viz.

- **Section A: Agriculture and Climate Change in South Africa: Setting the Scene**  
  (including Chapters on Vulnerability, Adaptation, Tools Used, Terminology)

- **Section B: Agriculture’s Natural Capital in South Africa: A Climate Change Perspective**  
  (including Chapters on Concepts, Terrain, Climates – Present & Future, Climate Zones, Soils, Water)

- **Section C: Crops in South Africa and Climate Change**  
  (including Chapters on Maize, Wheat, Sugarcane, Soybeans, Grain Sorghum, Taro, Bambara Groundnuts)

- **Section D: Natural Grasslands and Pastures in South Africa and Climate Change**  
  (including Chapters on Natural Grasslands, Pasture Grasses)

- **Section E: Horticultural Crops in South Africa and Climate Change**  
  (including Chapters on Potatoes, Viticulture, Bananas, Citrus Fruits)

- **Section F: Livestock in South Africa and Climate Change**  
  (including Chapters on Dairy Cattle, Pigs, Wildlife Ranching, Fodder Banking)

- **Section G: Tree Crop Systems in South Africa and Climate Change**  
  (including Chapters on Optimum & Sub-Optimum Growth Areas, What can be Grown Successfully Where, Specific Species, Streamflow Reduction)

- **Section H: Irrigation in South Africa and Climate Change**  
  (including Chapters on Net Irrigation Requirements, Percolation Losses)

- **Section I: Hazards and Climate Change in South Africa**  
  (including Chapters on Fire, Pests)

- **Section J: Overarching Adaptation Perspectives in South Africa and Emerging Issues**  
  (including Chapters on Early Warning Systems, Indigenous Knowledge, Perceptions of Smallholder Farmers, Human Discomfort, Biofuels)

Past experience demonstrates that all these agricultural sectors have sensitivity to climate variations ranging from minor to substantial. Consequently, there are many management responses to climate variability and these provide the basis of many initial adaptation strategies. This aspect is covered in each of the chapters. Also included, as seen above, are cross-cutting issues such as those related to water resources, as well as overarching perspectives and what are seen as emerging challenges, as these are perceived to be highly sensitive to potential climate changes and they have significant implications for components of the agricultural sector.

**In Conclusion: What to Expect and Not to Expect from the Handbook**

This Handbook, written specifically for farmers, officials and other stakeholders in the South African agriculture sector, should be used with the following in mind:

- It is a Handbook and not a scientific document in the purist sense of the word, thus written without equations and without major sections on methodology, and with only key references given for further reading by interested parties.

- The Handbook is nevertheless informed by sound science and it was inevitable that some Chapters appear to be more scientific than others.

- It should ideally be viewed as a “living and dynamic document” with the impacts maps to be replaced by updated ones as and when new information on climate projections comes to light.

- Individual Chapters, although being parts of broader Sections, are written as entities in themselves, although users can refer to prior Chapters on tools and methods.

- The Handbook’s existing chapter content should be updated as and when feedback on adaptation options / strategies is obtained from the wider South African agricultural fraternity (farmers, farmer unions, government, specialised sectors).
• It is in many ways thus a “work in progress” with numerous field and horticultural crops, as well as other broader facets of climate change in the agricultural sector, still to be covered.
• Any feedback to improve subsequent versions of this Handbook are welcome!

Further Reading

DAFF, 2013. Definitions of Farming Categories. Department of Agriculture, Forestry and Fisheries, Pretoria, RSA.
SECTION A   AGRICULTURE AND CLIMATE CHANGE IN SOUTH AFRICA: SETTING THE SCENE

CHAPTER A2   VULNERABILITIES AND CHALLENGES RELATED TO THE SOUTH AFRICAN AGRICULTURAL SECTOR

R.E. Schulze

Setting the Scene

Vulnerability: What do we Imply by the Term?

Vulnerability Within the Context of Climate Change

What Determines how Vulnerable the Agricultural System is?

Approaches to Conceptualising Vulnerability
  Vulnerability as the “End Point”
  Vulnerability as the “Starting Point”

Vulnerability in Practice in the South African Agriculture Sector: The Commercial Farmer vs Small Scale Subsistence Farmer Duality
  The Commercial Farming Sector
  The Subsistence Farming Sector

Vulnerabilities and Challenges Facing Small Scale Subsistence Farmers in South Africa
  Points of Departure
  Climate Related
  Water Related
  Crop Related
  Livestock Related
  Hazard Related
  Policy / Authority Related
  Culture and Tradition Related
  External and / or Finance Related
  External and / or Finance Related
  Knowledge and Trust Related

Vulnerabilities and Challenges Facing Large Scale Commercial Farmers in South Africa
  Points of Departure
  Climate Change – An Overarching Question
  Climate - Temperature Related
  Climate - Rainfall Related
  Related to Other Climate Variables
  Water Related - General
  Water Related - Floods and Droughts
  Water Related - Groundwater
  Water Related - Water Quality
  Dryland Crop Related
  Irrigation Farmer Related
  Livestock Related
Challenges which Authorities Need to Address

Quantifying Vulnerability: A Case Study in Agriculture Sector Vulnerability Mapping Over South Africa

Figure A2.2 The aggregation of the different indicators towards overall vulnerability (After Gbetibouo and Ringler, 2009)

Figure A2.3 An exposure-sensitivity index (top left), an adaptive capacity index (top right) and an overall vulnerability index (bottom) of agriculture in South Africa to climate change (After Gbetibouo and Ringler, 2009)

Further Reading

Please cite as follows:
Setting the Scene

South Africa's agriculture is particularly vulnerable to climate change, as productive farming is affected directly by the quality of the rainy season, by temperature, climate variability, extreme weather events and CO₂ concentrations in the atmosphere. These impacts extend beyond food security and can negatively affect the national economy should the country's ability to export crops and generate foreign revenue be reduced, while food has to be imported. It is, above all, poorer farming groups that will be the most adversely affected by climate change since they suffer most from its impacts, in being mostly directly dependent on the natural environment and ecosystem services for their survival and livelihoods. As a result of poverty, insufficient knowledge, financial constraints and poor infrastructure, there is little chance of poverty-stricken farmers switching to other sources of income.

What follows in the remainder of this Chapter is an overview of facets of vulnerability and some of the challenges faced by the South African agriculture sector. It should be noted at the outset that effective adaptation to climate change and climate variability requires an understanding of vulnerability, and that is why vulnerability (i.e. the factors which either enhance or reduce susceptibility to climate change) is discussed first.

Still by way of introduction, the following should be borne in mind:
• Many natural systems, as well as the human drivers and respondents of such systems, are able to adapt naturally to change and, if they can do so, it is likely that they will be less vulnerable to potential impacts of climate change. However, many systems and components of such systems are likely to be vulnerable to certain climate impacts and not be able to adapt adequately or rapidly enough themselves. It is, therefore, important to identify who and what are most vulnerable to impacts of climate change, in order for support for adaptation to be targeted appropriately to reach the most vulnerable groups.
• Vulnerabilities to climate change in the South African agriculture sector will depend on many unique features, including whether one is dealing with
  - dryland (i.e. rainfed) vs irrigation farming
  - supplementary vs permanent irrigation
  - crops vs livestock farming
  - summer vs winter crops
  - commercial vs subsistence farming
    phenologically sensitive vs less sensitive crops
  - highly productive areas (with high natural capital and resources) vs areas already climatically marginal
  - the potential for irrigation (from remote sources or locally dependent) vs no potential.

Following these introductory thoughts, definitions of vulnerability are first presented, followed by a brief look at vulnerability in a context of climate change, what determines vulnerability, approaches to conceptualizing and quantifying vulnerability, assessing vulnerability in practice in the South African agriculture sector in regard to the commercial farmer - subsistence farmer duality, addressing vulnerabilities and challenges faced by subsistence farmers as well as commercial farmers and authorities and dispelling some misconceptions on climate change impacts on agriculture in South Africa.

Vulnerability: What do we Imply by the Term? [Further Reading: Ziervogel, 2008; Gbetibouo and Ringler, 2009]
Vulnerability may be broadly defined as “the ability or inability of individuals or social groupings to respond to (in the sense of coping with), recover from, or adapt to, any external stress placed on their livelihoods and well-being”. The concept of vulnerability is often used interchangeably with terms such as resilience, risk, marginality, adaptability and exposure. This diversity of the concept is due to the term “vulnerability” having been used in different policy and practical contexts when referring to different systems such as agriculture, which may then be exposed to different climatic hazards, e.g. droughts or frost. The points which follow highlight some of the concepts we need to bear in mind regarding the term “vulnerability”.

• Vulnerability implies different things to different people and in different contexts. For this reason vulnerability is conceptualized, and may therefore be defined and interpreted, in different ways both within, for example, the agriculture sector.

• Vulnerability, as shown in Figure A2.1, may be viewed as the interrelationships, or intersections, which occur between
  - exposure to a hazard or a stress (i.e. the risk that such an event may occur, and its characteristics), with the exposure known before the hazard occurs, the
  - susceptibility, or sensitivity, of the system (e.g. livestock farming) to the exposure (e.g. a heat wave) and the
  - adaptive capacity, or resilience, of the system to cope with these exposures, recover or adapt, either during the hazard or after the hazard has occurred.

![Figure A2.1](image)

**Figure A2.1** The elements of vulnerability

• Vulnerability can have both external and internal dimensions (This is also termed the “double” structure of vulnerability through exposure and coping).

• The external dimension involves exposure to risks, to hazards and to shocks, and the factors that make a system (e.g. crop farming) vulnerable to a hazard will depend on the nature of the system and the type of hazard in question (is it a flood or a drought?).

• The internal dimension is a variable condition which is generated by multiple environmental and social processes. These include climate change, and they relate to defenselessness and insecurity, as well as the capacity to anticipate, cope with, and resist, and also the potentiality to recover from the impacts of a hazard. Here the focus is on actions taken to overcome (or at least mitigate) the negative effects either of an economic or an ecological nature, or both.
  - Capacity in this case implies the risk of having inadequate capacity to mobilise resources to deal with hazards, while
  - Potentiality implies the ability to overcome severe consequences.

**Vulnerability Within the Context of Climate Change** [Further Reading: Gbetibouo and Ringler, 2009; Oosthuizen, 2014]
Within the context of climate change, various IPCC reports have defined vulnerability as: "the extent to which climate change may damage or harm a system", while in other IPCC definitions, vulnerability is "the degree to which a ...natural or social ...system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and ...the ability to adapt the system to changes in climate, i.e. its ...adaptive capacity".

Hence, a highly vulnerable system is one that is highly sensitive to modest changes in climate and one for which the ability to adapt is severely constrained.

In a more agricultural context, and addressing vulnerability from a food security perspective, one definition would be the presence of factors that place people at risk of becoming food insecure or malnourished. Clearly, this definition encompasses causes of food insecurity other than climate change (it could be armed conflict, landlessness, etc.). Nevertheless, this concept of vulnerability includes hunger vulnerability, which refers to the vulnerability of individuals or households, as is the case in areas of the former Homelands, in addition to that of climatic regions or economic sectors.

From a climate change perspective, the external dimension mentioned in the previous section is represented by the exposure of, in our case, the agricultural system within South Africa to climate variations, while the more complex internal dimension comprises of a sensitivity even to modest perturbations in climate on the subsistence and / or commercial sector. Again, with respect to climate change,

- **Exposure** thus includes climate variability and extremes, and vulnerability depends on
  - what changes (be it, for example, rainfall characteristics or frost occurrences),
  - by how much it changes (e.g. only slightly or drastically), and
  - how rapidly the climate perturbation takes place in regard to the agricultural system, while
- **Sensitivity** refers here to the
  - responsiveness of a system to climatic influences, and the
  - degree to which this responsiveness might be affected by climate changes, with sensitivity including the potential for substantial harmful effects, and for which the ability to adapt may be severely constrained, and
- **Resilience**, i.e. adaptive capacity, is the
  - ability of a farming community or the entire agricultural system to adapt to new / changing environmental and socio-economic conditions, including climatic conditions.
- **Adaptive capacity** is a form of “social vulnerability,” since we are concerned about social systems. The vulnerability of any individual farmer or farming community (social group) to some particular form of natural hazard (e.g. a drought) is determined primarily by their present-day (i.e. existent) state, which is their capacity to respond to that hazard now, rather than by what may or may not happen in the future.

Another focus of vulnerability, predominantly in the commercial agricultural sector, could well be on the ability or inability of individual farmers to respond to, or cope with, climate change effects on crop yields from a financial vulnerability perspective. Some details on this follow below.

In regard to financial vulnerability, lenders (e.g. banks) would traditionally apply the five Cs, or vulnerability criteria, of credit when determining the creditworthiness of farmers wanting to borrow in order to adapt to, or mitigate against, climate change (Oosthuizen, 2014):
• **Capacity**: The first criterion is the borrower’s capacity to repay the loan obligation for the adaptive measure and bear the associated financial risks, calculated by analysing both past and projected profitability and cash flow of the farm business. For example, if a farmer has previously installed drainage and now wanted to install more as an adaptation strategy, increased return as a result of drainage records will be useful; otherwise data from a close neighbour with similar conditions who has installed drainage, or verified simulation models, can also be used.

• **Capital**: The second criterion is the borrower’s capital available for adaptive farm operations, assessed from balance sheets with liquidity and solvency calculations to gauge equity investment in the farm and how effectively it generates cash flows. Without sufficient capital (and managerial expertise) to optimise the returns from the investment in a future measure such as drainage (e.g. planting more capital intensive and higher value long term crops), the investment may be underutilised.

• **Collateral**: This is the borrower’s security collateral as a final source of repayment if the borrower defaults on the terms of the loan agreement or dies. The higher the risk of the operation for which the loan is requested, the higher level of collateral required. For example, as drainage *per se* has no salvage value, the full costs of the drains often need to be covered by some form of collateral. The higher the percentage of a farmer’s total land that needs to be drained, the less likely it is that the land itself can cover the collateral obligations.

• **Conditions**: The conditions for use of the funds, or the intended purpose of the funds required by the borrower are considered in terms of general economic conditions, interest rates, inflation and the demand for money in order to come up with a discount rate with which to calculate the net present value (NPV), benefit cost ratio (B/C) and internal rate of return (IRR), all useful in comparing funding alternatives.

• **Character**: The character of the borrower, i.e. the attitude of the borrower towards risk and financial track record available from credit bureaus, is also a very important factor for commercial lenders considering a loan application for projected climate change adaptation measures. In the case of subsidised state funding and grants the potential recipients character in terms of “money grabbing” and not applying the funds productively also needs to be evaluated to ensure efficient use of public funds.

In the above, ‘collateral’, ‘conditions’ and ‘character’ cannot be calculated using quantitative inputs only and will differ for each analysis and also for different financiers. However, the financial vulnerability model addresses ‘capacity’ and ‘capital’ using the following ratios, viz. the

• **Cash flow ratio** (an indicator of repayment ability and the enterprise's ability to survive financial setbacks, especially those of a climatic nature); and the

• **Debt ratio** (an indicator of solvency): To determine the financial vulnerability of a farming system into the era of climate change, the financial model provides a set of criteria, including the IRR (Internal rate of return), NPV (Net present value), cash flow ratio, highest debt ratio and highest debt.

**What Determines how Vulnerable the Agricultural System is?** [Information: Ziervogel, 2008]

• **Vulnerability is Determined Primarily by the Present Capacity to Respond (i.e. the Existent State)**
  
The vulnerability of any individual farmer or farming community to some particular form of natural hazard is determined primarily by their capacity at present to respond to that hazard, rather than by what may or may not happen in the future.

• **Vulnerability Varies at Different Scales**
  
It is critical to recognise that definitions and perceptions of vulnerability vary at different scales of analysis.
- Questions change with scale as there are often very different factors that are key drivers at different scales. For example, interaction between a subsistence farmer’s crop failure might drive vulnerability to food insecurity at the household or local scale, yet at the national level there may be no shortage of the crop and of food security.
- Identifying the role of scalar drivers of vulnerability is complex, yet critical, when deciding how to reduce vulnerability at different scales.

- **Vulnerability is Determined Largely by One’s Location (Locale)**
  Investigations into the dynamics of vulnerability to climate change soon identify that where one is located, i.e. one’s locale, plays a large part in determining vulnerability. Place-based, i.e. local, studies are therefore necessary to identify vulnerability.

- **Some People, Places or Sectors are More Vulnerable than Others**
  While overall we are all vulnerable to some or other stressor related to climate change, some people or places being more vulnerable than others.

**Approaches to Conceptualising Vulnerability** [Further Reading: Gbetibouo and Ringler, 2009]

Approaches to vulnerability assessments attempt to explore questions about

- who and what are vulnerable?
- to what are they vulnerable?
- their degree of vulnerability?
- the causes of their vulnerability? and
- what responses can reduce their vulnerability.

Two distinct approaches exist to conceptualising vulnerability exist, viz. viewing vulnerability as the “end point” vs. viewing vulnerability as the “starting point”:

**Vulnerability as the “End Point”** [Information: Gbetibouo and Ringler, 2009; Schulze, 2011]

- In this approach vulnerability is viewed in terms of the amount of (potential) damage caused to a system by a particular climate related event or hazard. Vulnerability is thus effectively understood as the net impact of climate change, i.e. what remains (the residual) of climate change impacts minus adaptation.
- Emphasis is on the physical dimensions of vulnerability, with the assessment of vulnerability as the end point of an analytical sequence that begins with projections of future emission trends, moves on to the development of climate scenarios, and then progresses through biophysical impact studies and the identification of adaptive options.
- Adaptations and adaptive capacity in this approach thus refer to future adaptations, and adaptive capacity would mean the ability to carry out specific technological adaptations to climate change. The end point interpretation focuses on technology and its transfer as adaptation options. As such, the concept of vulnerability as an end point has played a useful role in increasing the scientific understanding of climate sensitive systems under changing climate conditions.
- Thus, the end point represents a strong scientific understanding of climate change (and other environmental problems), with an assumed knowledge of future climate being deeply embedded in end-point analyses in terms of both impacts and adaptations.

**Vulnerability as the “Starting Point”** [Information: Gbetibouo and Ringler, 2009; Schulze, 2011]

- Here a state of vulnerability is assumed to exist within a farming system (e.g. subsistence maize farming) before it encounters a hazard event (e.g. a drought), and this approach thus identifies and diagnoses inherent social and economic processes of existing marginalisation (e.g. forced onto a specific piece of land) and inequalities (e.g. poor access to markets) as the causes of climate vulnerability, and then seeks to identify ways to address these processes.
• The main purpose of using this approach to vulnerability assessments is to prioritise political and research efforts toward particularly vulnerable communities (e.g. subsistence farmers), sectors and regions (e.g. former homelands). In this approach the geopolitical and economic contexts in which the vulnerable system or society exists, are therefore addressed.
• Adaptation options in this case are therefore related to existing levels of development and the adaptation strategy is geared to reducing climate-sensitive risks independent of their cause.

In reality, any assessment of the consequences of climate change will utilise a combination of these two approaches, and that certainly is the case in this Handbook.

Vulnerability in Practice in the South African Agriculture Sector: The Commercial Farmer vs Small Scale Subsistence Farmer Duality [Information: Andersson et al., 2009]

The historical and socio-economic realities in South Africa between commercial farmers and small scale subsistence farmers are highly different. This hugely affects how they farm now and what opportunities they have to progress and to adapt for the future.

The Commercial Farming Sector [Information: Gbetibouo and Ringler, 2009; Schulze, 2011]
• The commercial sector dominates agricultural production in South Africa, being large-scale, capital-intensive, export-led, and accounting for ~ 90% of total value added in agriculture. There are currently ~ 39 000 commercial farms (down from > 60 000 in 1996), with a labour force of ~ 773 000 (down from 1.18 million in 1990), and with a net farming income making up 20-25% of the gross farming income (down from ~ 34% in 1980), contributing ~ 2.6% to the national GDP (down from 6.1% in 1980).
• From the perspective of commercial farmers, adapting for the future is about staying ahead and being progressive.
• Many of these attributes come to the fore again in the section on vulnerabilities and challenges of the commercial farming sector in South Africa.

The Subsistence Farming Sector [Information: Andersson et al., 2009; Gbetibouo and Ringler, 2009]
• In contrast to the commercial farming sector, the subsistence sector is generally impoverished and dominated by low-input, labour intensive production. Despite initiatives in regard to land reforms in place since the mid-1990s, the estimated 2-4 million smallholders are settled predominantly in the former homelands and largely produce for own purposes. It is partly a legacy of traditional practices and partly of social engineering during years of Apartheid government that land holdings are generally very small (often < 1 ha) and are frequently under a communal land tenure system. Livestock densities generally exceed the carrying capacity of the grassland, with overgrazing having severely affected the quality of arable land in many areas.
• From perspective of experiencing multiple stresses, these small scale farmers are generally in need of better opportunities to finance equipment for farming. They are relatively optimistic about aid from government regarding finance, schooling, electricity, subsidised housing and household water.
• They deem the problem of climate change at par with high food costs, but lower than HIV/AIDS and poor opportunities for higher education.
• Many of these attributes are highlighted again and elaborated upon below in the section on vulnerabilities and challenges of smallholder agriculture.

Vulnerabilities and Challenges Facing Small Scale Subsistence Farmers in South Africa [Information: Reid et al., 2005; Andersson et al., 2009; SNC Agriculture, 2009; Schulze, 2011]
Given below is a list of points under suitable sub-headings. These were identified from a number of recent key studies in South Africa and are therefore not all-embracing. The lists should be viewed as a starting point for further discussions.

**Points of Departure**
- The current constraints faced by subsistence and emerging farmers (e.g. lack of finance, access to markets and extension services, culture bound), especially when they operate in what may be termed “second” or developing economies, contribute hugely to those farmers’ vulnerability to climate change. The agricultural practices, frequently associated with improper farming techniques, often contribute to the steady degradation of soil (lack of nutrient replenishment), water (high sediment yields) and plant (e.g. overgrazing) resources.
- An understanding of how best to support these farmers, who are highly vulnerable to climate stress, is therefore vital, given expected changes in climate variability.

**Climate Related** [Information: Schulze, 2011]
- **Direct Dependence on Climatic Conditions:** Much of subsistence farmers’ vulnerability may be attributed to their direct dependency to climatic conditions.
- **Historical Inertia:** The inability of farmers to cope with disasters in the past paints a dark picture of disasters that are likely to be faced under future climates.
- **Lack of Predictability of Rains:** Factors here include
  - a late start to the rainy season (after December nothing can be planted in the summer rainfall region),
  - too little rain at plant and flowering stages, and
  - perceived increased rainfall variability over time.

**Water Related** [Information: Schulze, 2011]
- **Too Much Water:** Included here are
  - flooding, resulting in reduced yields
  - waterlogged fields, make planting difficult
  - large flood events, causing soil and gully erosion
  - long periods of heavy rainfall, resulting in plant animal disease with likely, catastrophic consequences.
- **Too Little Water:** including low water levels in springs and boreholes making it difficult to irrigate home gardens.

**Crop Related** [Information: Schulze, 2011]
- **High Input Costs:** including costs of fertilizer, pesticides and transport.
- **Lack of Water Harvesting:** to capture rainfall in the wet season.
- **Lack of Growing Cover Crops:** during the dry season.
- **Non-Sustainability of Small Plots of Land:** in terms of profit, its vulnerability, obtaining maximum production and environmental sustainability.

**Livestock Related** [Information: Andersson et al., 2009; SNC Agriculture, 2009; Schulze, 2011]
- **Reduction in Resilience to Extremes:** Less resilience against more intense, more frequent droughts and floods, largely because of unstable or denuded soil and weaker soil structure.
- **Dependence of Water on River Flows:** Domestic animals (and wildlife) become stressed or die if they depend solely on river flows as these are often low or yield insufficient water, especially where flows are ephemeral or only episodic.
- **Effects of Flooding:** Livestock and wildlife may become diseased if flooding occurs.
- **Loss of Herbage Yields:** due to overgrazing, with high likelihood and significant severity.
- **Loss of Herbage Yields:** due to increased erosion resulting from more surface runoff during summer (the likelihood is high; the severity significant).
• **Animal Health:**
  - Changes in rainfall and temperature will impact on animal health as the distribution, competence and abundance of vectors and ectoparasites will change.
  - Increased incidence of diseases associated with heavy floods and increased rainfall such as Rift Valley Fever causing acute abortions.

• **Change in Veld Composition:** Veld cover and composition are likely to change, negatively impacting carrying capacity for livestock and game.

• **Alien Invasive Grass Species:** Alien invasive grass species, largely unpalatable, tend to respond more favourably to elevated CO$_2$ availability than indigenous species and are likely to become a major threat to indigenous species, with huge losses in biodiversity unavoidable with climate change.

• **Weed Infestations in Grasslands:** Severe weed infestations will degrade ecosystems as weeds, being mostly pioneer species, adapt more rapidly to environmental changes than indigenous flora.

• **In Summary:** Stock unit rates, where these are high in South Africa, generally far exceed the theoretical grazing capacity which, together with unsustainable management practices, regular periods of severe drought and high energy rainstorms, has led to widespread denudation and soil degradation through soil nutrient and soil organic matter content depletion, as well as a shift in species composition towards an abundance of unpalatable plants.

**Hazard Related** [Information: Andersson et al., 2009; Schulze, 2011]

• **Veld Fires:** Loss of grass (and other vegetation) for grazing due to veld fires during dry and hot winters and spring in the summer rainfall regions of South Africa, and during summer and autumn in the winter rainfall region, with a high likelihood of occurrence and with sometimes catastrophic consequences, especially if combined with Berg winds.

• **Pests:** More pest attacks (Likelihood certain; severity significant).

• **Water Borne Diseases:** In the summer rainfall region, more outbreaks of insects due to warmer water and lower streamflows, especially in August-September.

• **Loss of Biodiversity / Alien Invasives:** Advantaged conditions for alien species due to riparian vegetation being stressed by low flows or change in channel erosion.

• **Lack of Stone Packing** and other means to decrease water loss is not encouraged and supported enough.

**Policy / Authority Related** [Information: Reid et al., 2005; Andersson et al., 2009; Schulze, 2011]

• **Policy Awareness:** Although subsistence farmers are aware of policies concerning, for example, veld burning, overgrazing, or ploughing up and down slopes, they do not always prioritise them, as they often choose short term benefits over long-term sustainability.

• **Fulfilling Short Term Needs:** There are, understandably, pressing short-term needs and priorities to be fulfilled in the subsistence farming sector of South Africa. Identified vulnerabilities associated with climate change, such as improved soil conservation as an adaptation measure, will probably only become realised once the more pressing needs have been addressed.

• **Need for Improved Extension Services:** Small scale farmers’ vulnerability to climate and climate change would be reduced if improved agricultural extension services were available to provide advice on how to adapt for climate variability and change.

• **Financing:** Vulnerability would be reduced if means were found to finance and to use current and new technology and practices, including procedures and implements for soil sampling, ploughing, planting etc., with equipment especially targeted towards small scale farmers.

• **Lack of Bargaining Power:** Small scale farmers’ vulnerability is increased because they frequently lack bargaining power.
• **Economic Resources and Knowledge Dissemination**: is needed to make this process possible.
• **Lack of skills, planning, co-operation, trust, support and knowledge** all add to small scale farmers’ vulnerability to climate and climate change.

**Culture and Tradition Related** [Information: Reid et al., 2005; Andersson et al., 2009; SNC Agriculture, 2009; Schulze, 2011]
• **Traditional Cultural Practices 1 - Communal Lands**: Lack of land ownership and land distribution / sub-delineation policies have resulted in small fields that are generally unprofitable and farmers might be unmotivated to use the land in a sustainable way. Many farmers have user rights, but not ownership of land since the land belongs to the chief, which in itself creates uncertainty. If, for example, small scale sugarcane cultivation takes place, this requires large amounts of land / cane for farming to become profitable.
• **Traditional Cultural Practices 2 - Cattle Culture**: The culture of maintaining a large number of cattle also puts heavy pressure on the land and increases risk for soil erosion.
• **Non-sustainability of Small Plots of Land**, for example for sugarcane growing in terms of profit, obtaining maximum production and environmental sustainability increases small scale farmer’s overall vulnerability.

**External and / or Finance Related** [Information: Reid et al., 2005; Schulze, 2011]
• **Poverty Trap**: The vulnerability to vagaries of climate faced by the poorer farmers is partially due also to non-climatic factors such as limited opportunities to access resources such as fertilizer, transport and alternative income opportunities, but these factors may be exacerbated by climatic Uncertainties.
• **Farmers’ Constraints**: The main constraints to farmer’s low farm income may be attributed to 3 main causes:
  - **poor commercialisation**, i.e. farmers’ lack of knowledge on markets and their inability to make the most of the domestic and international markets;
  - **poor infrastructure**, i.e. farmers’ limited access to resources such as credit, thereby inhibiting them to investment in on-farm infrastructure, and the system in operation not being equipped to support these small-scale farmers’ transition to commercial production with the appropriate technical advice; and
  - **low farm productivity**, said to be a result of the reduction in productivity of land, labour resources and crops, which result from the poor or lack of land and water management, poorly skilled labour availability and management thereof, and farming techniques.

**Knowledge and Trust Related** [Information: Schulze, 2011]
• **Use of, and Trust, in Climate Forecasts**: The lack of knowledge and trust of climate forecasts, including limited resources to overcome climate variability, has a great impact on farmers, including impacts under projected future climatic change conditions. The fact that relatively few benefits have, to date, been derived from present-day forecasting by poorer farmers’ may, additionally, be attributed to the fact that they do not have enough resources to act on the climate forecasts.

Again, many of the above-named vulnerabilities can only be overcome with a strong extension service and good communication and trust between local government and the entire farming community (commercial and emerging) to bring about concrete changes, and thus facilitate preparedness for climate change.
Vulnerabilities and Challenges Facing Large Scale Commercial Farmers in South Africa [Information: Andersson et al., 2009; Schulze, 2009; SNC Agriculture, 2009; Schulze, 2011]

Given below is a list of points under suitable sub-headings which were identified from a number of recent key studies among commercial farmers in South Africa. Again, the points listed are not all-embracing as they come from a sample of stakeholder meetings the author has been involved in, and they should be viewed as a starting point for further discussions.

**Points of Departure**
- The point of departure in commercial agriculture re. climate information is to optimise climatic conditions in order to maximise output in a sustainable manner.
- **Adaptation:** In adaptation for future climates it is all about staying ahead and being progressive, maintaining a competitive edge and continuing to be sustainable and profitable.
- **Perceptions:** Farmers (and others) now hear so much about climate change that they are beginning to “experience” what they are told should be happening, i.e. they are being “conditioned” by expectations of climate change.

**Climate Change - An Overarching Question**
- **The Uncertainty about Climate Change:** This is raising questions on when, where, how much, what impacts to expect, and how to adapt, and for many commercial farmers the mixed messages they get from scientists implies that they simply continue with “business as usual”.

**Climate - Temperature Related** [Information: Andersson et al., 2009; Schulze, 2011]
- **Threshold Temperatures:** Farmers are vulnerable to reduced winter yields of, for example, wheat, due to more frequent hot days above 32°C, the consequence of which could be significant.
- **Increased Convectivity:** If exposed to more frequent severe thunderstorms, surface runoff and erosion could be increased, with negative consequences on productivity.
- **Winter Temperatures:** Winter days are perceived to have become warmer, and winter to be arriving later, affecting disease incidence and quality of deciduous fruits.
- **Frost Days:** The same applies to frost days, with the perception of fewer days with frost than in the past, and a possibility of fewer shade cloths having to be used in future to minimize frost damage.
- **Snowmelt:** Snow, if / when it falls, now melts more rapidly than before, according to farmers in areas where snowfalls occur.
- **Chill Units:** Farmers report that chill units are no longer recorded in May in many parts of the Western Cape; they now start only in June. In some areas (e.g. Grabouw) farmers are changing from apples to pears, which require fewer chill units.
- **Enhanced Variability:** Variability, e.g. in frost occurrences per annum, appears higher.
- **Heat Island Effect:** With urban expansion, the urban heat island effect is expanding outwards into agricultural lands – now already to the detriment of farmers.

**Climate - Rainfall Related** [Information: Reid et al., 2005; Andersson et al., 2009; Schulze, 2011]
- **Rains at Planting Time:** Farmers believe they nowadays get too little rain at plant time, especially in the case of summer crops, with this rendering them more vulnerable to crop failures.
- **Enhanced Rainfall Variability:** This will add to the vagaries of sustainable crop production.
- **Droughts and Long Cycle Crops:** When farming with multi-year crops with long plant cycles of 20-30 years, such as deciduous fruit or commercial production forestry,
farmers are vulnerable to 2-3 successive droughts years, which do considerable long
term and sometimes permanent damage to the trees.

- **Persistence of Raindays:** Fewer long duration, multiple day gentle rains in winter rainfall
  region are being observed, according to farmers.
- **Rainfall Intensity:** Rainfalls are nowadays perceived to be more intense in the winter
  rainfall region than previously, resulting in mudslides / landslides as well as soil erosion.
- **Number of Raindays:** There are now fewer days with rain in winter rainfall region,
  according to farmers.
- **Onset of Rains:** Onset of winter rains is now perceived to be later, and the rains are
  extending later into November.

**Related to Other Climate Variables**

- **Wind Erosion:** Where soils dry out rapidly, there is an increase in wind erosion.

**Water Related - General** [Information: Schulze, 2011]

- **Agriculture as Primary Producer:** Agriculture in many areas of South Africa is the only
  primary producer (e.g. in the Western Cape where there is no mining of significance). In
  those areas, especially, the agriculture sector becomes vulnerable and needs to be
  protected in regard to its geographic extent and to water demands.
- **Competition for Water:** Many areas in South Africa (e.g. the Western Cape) are
  characterised by strong competition between the agriculture sector, urban demands and
  the environmental reserve for a finite quantity of water which, additionally, has a highly
  unequal seasonal distribution. These areas are thus, agriculturally, highly vulnerable to
  any further climatic perturbations.
- **Water Curtailment and Re-Allocation during Drought:** Water is often re-allocated to
  other sectors in a drought. However, this has to be done judiciously as crops such as
  deciduous fruit may suffer in regard to yields for up to 5 years later.

**Water Related - Floods and Droughts** [Information: Andersson et al., 2009; Schulze, 2011]

- **Too much water**
  - flooding results in poor yields
  - waterlogged fields make planting difficult and later result in soil compaction
  - more frequent large flood events will cause soil and gully erosion.
- **Flood Magnitudes:** Bigger floods have occurred in the winter rainfall region in more
  recent years, with reports of the 50 year floodlines having been exceeded 3 times in two
  years in the recent past. Events such as those render areas more vulnerable to the
  vagaries of climate.
- **Drying up of Small Rivers:** Many smaller rivers are already drying up (in the winter
  rainfall region in summer and in the summer rainfall region in winter), posing the
  question whether more 1st order streams will dry up in future.
- **Effects on Shallow Soils:** Many areas have shallow soils which saturate rapidly when it
  rains, resulting in high surface runoff. This may be exacerbated under future climatic
  conditions.

**Water Related - Groundwater** [Information: Schulze, 2011]

- **Dependence on Boreholes:** Many farmers are dependent on borehole water, some at
  10 m, others at > 100 m depth. These will be impacted upon differently under climate
  change, dependent on rates of recharge under future climatic conditions.
- **Poor Quality Groundwater:** Groundwater is, however, often brackish and of poor quality
  for irrigation.

**Water Related - Water Quality** [Information: SNC Agriculture, 2009; Schulze, 2011]

- **High Salinity Levels:** Irrigators are highly vulnerable to salination, which is largely due to
  the injudicious management of soil and water and is likely to get progressively worse.
Salinity levels in many irrigated areas (e.g. in the Berg catchment) are already high. Certain areas (e.g. parts of the Breede catchment) do not welcome widespread rains as these mobilise salts. Farmers actually prefer rains to fall upstream of irrigated areas.

- **Sewage Works' Overloading:** Another facet of vulnerability is the poor quality water for irrigation in parts of the Western Cape, caused by municipalities' sewage works being overloaded, no longer functioning properly and discharging sewage into rivers.
- **Rivers Used as Conveyors of Sewage:** Many rivers are then used as a conveyance of sewage because these rivers pass through municipalities.
- **Algal Blooms:** Farmers insist that there are more algal blooms than previously.

**Dryland Crop Related** [Information: SNC Agriculture, 2009; Schulze, 2011]

- **The Urban Sprawl:** The agriculture sector has become vulnerable to rapid urban expansion, often into valuable high potential agricultural land which can never be recovered, and oftentimes by low density urbanisation.
- **Cover Crops:** More cover crops should be grown between grape rows to reduce soil water evaporation.
- **Climate-Specific Farms:** Vulnerability to the vagaries of climate and the prospect of a changing climate implies that farmers need to procure “climate specific” farms for their crop. This may include looking to other African countries to produce specific crops.
- **Shifts in Optimum Growing Areas:** Changes in the geographic locations crops and cultivars are expected, with heat tolerance and water use efficiency being paramount considerations.
- **Climatically Marginal Land:** for example, in the western margins of the summer rainfall areas, are likely to be more prone to reduced yields (e.g. maize) and even complete crop failures due to the increased variability of climate. Continued cropping in these areas not only diminish soil productivity, but also enhance land degradation.
- **CO₂ Fertilization Effect:** Vulnerability could be reduced, however, and increased growth expected through increased photosynthesis as a result of the enhanced CO₂ fertilization effect brought about by climate change, and this could boost crop yields in certain areas.
- **Sustainability of Dryland Agriculture:** This could be endangered under future climates as a result of an increase in rainfall variability.

**Irrigation Farmer Related** [Information: Andersson et al., 2009; Schulze, 2011]

Stakeholder workshops have identified irrigation farmers to being vulnerable to the following:

- **Decreased Water Supply from Single Dry Seasons,** for example, in the dry winter months in the summer rainfall region, resulting from an increased number of single years with insufficient streamflow generation, with significant economic impacts; or
- **Decreased Water Supply from Multiple Dry Seasons,** as above, but with more catastrophic consequences because of reduced yields; or
- **Decreased Water Quality,** which will present problems to irrigators; or
- **Impacts of Upstream Dams,** the abstractions from which can have severe downstream repercussions; or
- **Multi-Purpose Dams** with curtailment rules during droughts, which could affect irrigators severely; or
- **Sizing and Safety of Dams,** where existing dams were dimensioned on historical hydrological records (e.g. sizing; dam safety), but where they will not necessarily be able to deal with future climate conditions (e.g. increases in design floods; or less water), implying also that climate change needs to be factored in when assessing the safety of current dams and in the design of new structures; or
- **Increased Sediment Yields,** should rainfall intensities increase into the future, with resultant increases in surface runoff and sedimentation which could impact on the
dam’s yield used for water supply, with possible significant longer term repercussions; or

- **Change to Drip Irrigation** which, while highly water use efficient, implies higher infrastructure and installation capital outlays which ideally should attract government subsidies on drip irrigation installations because of their potential enhancement of water use efficiency, with
  - water used by the plant, not by inter-row weeds
  - it working well for some crops, e.g. vines, but not for others such as some deciduous fruits because of their root structure
  - it having some disadvantages in that it cannot be used as a cooling agent (as can sprinkler irrigation), nor can it be used effectively on sandy soils; or

- **Dependence on External Water Sources**, where in many parts of semi-arid South Africa the water for irrigation has to be conveyed in from external sources, and irrigators become highly vulnerable to changes in water supply / demand elsewhere, with the apparent abundance of water in such areas possibly being a delusion; or

- **Not Enough Use of Mulching/Crop Residues** which can saves up to 20 % of irrigation water requirements.

**Livestock Related** [Information: SNC Agriculture, 2009; Schulze, 2011]

Various stakeholders and scientists identified the following vulnerabilities in regard to the South African livestock sector:

- **Changing Population Dynamics of Grazing Lands**: Within agriculture it is of importance to reiterate that the distribution and population dynamics of natural vegetation will change and that entire ecosystems may suffer degradation or collapse.

- **Grassland / Woody Species Dynamics**: Grasslands are postulated to becoming woody with further atmospheric CO₂ enrichment in both wet and dry conditions. However, some climate projections foresee more frequent fires to favour the expansion of grasslands (both C₃ and C₄) until ~ the 2070s, beyond which C₄ grasslands are projected to continue expanding due their high competitive advantage at high temperature regimes. Grasslands are more likely to dominate the landscape if the woodlands are temporarily opened after a large fire event or land disturbance.

- **C₃ / C₄ Grassland Dynamics**: C₃ and C₄ grass species generally occur within the same area and share the same resources. However, the C₄ grass photosynthetic rates favour warmer regions compared to C₃ grasses, and with the tall and horizontal growth form the C₄ grasses hold a competitive expansion / invasive advantage over the shorter, slower growth C₃ grasses in regard to light.

- **C₃ / C₄ Grasslands and Fire Dynamics**: If the frequency of fires increases in C₃ / C₄ composite and / or intact grasslands, the C₃ grass competitiveness will be reduced by fires. Thus, the increased frequency in fires could prevent an invasion of grassland by woody species, or dominance by C₃ grasses.

- **Causes of Veld Denudation**: Generally where stock unit rates are high in South Africa, they far exceed the theoretical grazing capacity which, together with unsustainable management practices, regular periods of severe drought and high energy rainstorms, has led to widespread denudation and soil degradation through soil nutrient and soil organic matter content depletion, as well as a shift in species composition towards an abundance of unpalatable plants.

- **Fire Risk**: There is fear of loss of grazing lands and livestock due to fires resulting from dry and hot conditions in winter / spring, especially if combined with Berg winds.

- **Animal Health**:  
  - Changes in rainfall and temperature will impact on animal health as the distribution, competence and abundance of vectors and ectoparasites will change.
  - Increased incidence of diseases associated with heavy floods and increased rainfall such as Rift Valley Fever can cause acute abortions.

- **Change in Veld Composition**: Veld cover and composition are likely to change, negatively impacting carrying capacity for livestock and game.
- **Alien Invasive Grass Species**: Alien invasive grass species, largely unpalatable, tend to respond more favourably to elevated CO$_2$ availability than indigenous species and are likely to become a major threat to indigenous species, with huge losses in biodiversity unavoidable with climate change.

- **Weed Infestations in Grasslands**: Severe weed infestations are likely to degrade ecosystems as weeds, being mostly pioneer species, adapt more rapidly to environmental changes than indigenous flora.

- **Reduction in Resilience to Extremes**: Less resilience against more intense, more frequent droughts and floods, is possible largely because of unstable or denuded soil and weaker soil structure.

**Hazard Related - Pests and Diseases** [Information: Andersson et al., 2009; SNC Agriculture, 2009; Schulze, 2011]

- **More Pest Attacks** are likely, with significant repercussions to crop yields.

- **Changing Pest / Disease Distributions**: Plant and animal disease and insect distribution are likely to change, for example:
  - The dynamics of insect pests and disease complexes are likely to change;
  - New pests may emerge while other pests may expand their ranges or increase their intensity of outbreaks;
  - Insect breeding areas are already expanding; and
  - Biological control agents / predators currently effective in controlling agricultural pests may lose their efficacy.

**Hazard Related - Weed Control** [Information: SNC Agriculture, 2009; Schulze, 2011]

- **Cost of Weed Control**: Costs of weed control could increase as alien invasive plants and indigenous weeds are expected to rapidly adapt to changing climate conditions.

- **Weeds as Hosts**: Different crop / grass species host different insects, pests and disease, and these are likely to change in future.

**Hazard Related - Fires**

- **Increased Incidence**: Farmers perceive an increased incidence of natural fires started by thunderstorms.

**Hazard Related - Water-Borne Diseases** [Information: Andersson et al., 2009; Schulze, 2011]

- **Water Borne Diseases**: More outbreaks of insects are reported in the summer rainfall region as a result of warmer water and lower flows in late winter-early spring (August-September).

**Hazard Related - Infrastructure**

- **Rural Infrastructure Degradation**: Rural infrastructure degradation and / or collapse, especially regarding rail and roads, is already evident and is adding to farmers’ costs.

**Hazard Related - HIV/AIDS Pandemic** [Information: SNC Agriculture, 2009; Schulze, 2011]

- **HIV/AIDS**: Effects of HIV/AIDS on skilled and unskilled labour is becoming a critical issue in the agriculture sector.

**Alien Infestations / Biodiversity Loss Related** [Information: Andersson et al., 2009; Schulze, 2011]

- **Loss of Biodiversity / Alien Invasives**: Better conditions for alien species may emerge as a result of riparian vegetation being stressed by low flows or change in channel erosion.

- **Aliens Invasive Problems**: Western Cape farmers perceive a marked growth in riparian aliens, and some problems are
  - Working for Water initiative has “come, done and gone”
  - Alien invasives use huge amounts of water
  - Only downstream users benefit from upstream clearing
- The problem of continued alien clearance is left to farmers, but clearance is costly and labour intensive.
- Policies on clearance (e.g. subsidies) should be revisited.
- There has to be a long term strategy, not just a once off clearance.
- There needs to be an economic benefit to clearing in order to make it economically worthwhile.

**Policy and Authority Related** [Further General Information: Reid et al., 2005; Andersson et al., 2009; SNC Agriculture, 2009; Schulze, 2011]

- **Slow Response from Authorities:** Commercial farmers stress the slow response from authorities as one of the major obstacles that inhibits sustainability, expansion and progress. It is difficult, for example, to get permits to increase irrigation.
- **Complex / Cumbersome Legislation** exists, for example, on taxes, minimum wages, municipal rates, AgriBEE and policy decisions are often unclear and even conflicting.
- **Land Claims and Land Redistribution:** Farmers perceive this to inhibit effective farming and forward planning, resulting in uncertainty, loss of production and degradation of productive agricultural areas.
- **Labour Issues** include minimum wages and availability of labour.
- **Importance of Integrated Planning:** In the Western Cape, for example, this cannot be overstressed, with both agriculture and municipalities needing to be planned conjunctively in regard to water quantity and quality.
- **Lack of Planning:** This includes financial and farm planning, as well as training to cope with changes (climatic and other) into the future.
- ** Provision of Access to New Technologies and Knowledge.**

**Science Related** [Information: Schulze, 2011]

- **Plant Breeding:**
  - There is a need for geneticists to breed more drought / heat resistant varieties of, for example, deciduous fruit with more rapidly responding phenologies and requiring lower Positive Chill Units.
  - Such breeding / developing of new varieties needs to be done now, because response times for the deciduous fruit industry are long.
- **Re-Look Plant Needs:** There is a need to re-look plant needs in regard to, for example, water requirements, optimal pH and fertilizer needs.

**External and Finance Related** [Information: Reid et al., 2005; SNC Agriculture, 2009; Schulze, 2011]

- **Low World and Domestic Prices:** In the first instance it could be cheaper to import commodities, in the second farmers’ profits are reduced.
- **The Vagaries Relating to the Strength / Weakness of the Rand.**
- **Reduction of GDP from the Agriculture Sector:** A substantial reduction in the contribution of agriculture to South Africa’s gross domestic product is the result, partially, of more frequent and intense drought and floods.
- **Barriers to Trade**
- **Increases in Input and Production Costs** reduce profitability.

**Water Pricing Related** [Information: Schulze, 2011]

- **High Water Costs:** Water has become expensive and farmers cannot tolerate further price increases. Agriculture cannot afford further water price hikes, nor water curtailments in times of drought, because irrigators already use water much more efficiently than other sectors do.
- **Water Price Increase Trade-Offs:** The water price and increases thereof have to be weighed up against the export value / foreign exchange potential of the crops grown in, for example, the Western Cape, compared with crops grown elsewhere.
Labour Related [Information: Reid et al., 2005; Schulze, 2011]

- **Labour Issues** include minimum wages and availability of labour.
- **Labour / Hectare Ratio**: There is a high labour / ha ratio, especially in the Western Cape’s agriculture.
- **Seasonal Employment**: Because of the seasonal nature of much of the employment in (especially the Western Cape’s) agriculture, this needs to be considered in government decision making because livelihoods are at stake.

Markets Related [Information: SNC Agriculture, 2009; Schulze, 2011]

- **Competitive Edge**: 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.
- **Market Projections**: There is therefore a need for market projections into the future.
- **Subsidies in Developed Countries** imply that it is often cheaper to import than to produce locally.
- **Changing Markets**: e.g. dairy to sugarcane.

Communication Related [Information from Schulze, 2011]

- **Communication by Scientists**: There is a dire need for scientists to create more awareness on potential climate change impacts now, and to get the message across to government, seed companies and farmers in regard to more exact crop optimum growing areas, water requirements, and projected future shifts in climates.
- **Communication by Extension Services**: Targeted information on direct and indirect effects of climate change and adaptation strategies.
- **Access to New Technologies and Knowledge**, also in regard to adaptation.

Challenges which Authorities Need to Address [Information: Andersson et al., 2009; SNC Agriculture, 2009; Schulze, 2011]

As a point of departure, the authorities, including policy makers, must enable communities to effectively deal with an uncertain future climate by allowing, supporting and enabling them to deal with their present challenges, which include current climate variability. Challenges identified below from recent studies are not necessarily new and also need to be viewed in conjunction with those challenges already identified in the sections on small scale and commercial farmers.

- **Slow Response from Authorities**: Commercial farmers mention slow response from authorities as one of the major obstacles that inhibits sustainability, expansion and progress. It is difficult, for example, to obtain permits to increase the area under commercial forestry or irrigation.
- **Need for Effective Extension Services**: Small scale and commercial farmers need effective agricultural extension services to provide timely advice on how to adapt for climate variability and change.
- **Financing**: This includes finding means to finance the use of established as well as new technologies and practices. For small scale farmers this would include finance for:
  - soil sampling, ploughing or planting
  - purchasing appropriate equipment.
- **Incentives**: Incentives need to be provided that encourage individuals to use technology and management practices that are good for the environment, e.g. no-till farming. Incentives must lead the way instead of only control measures.
- **Enforcement**: Making laws is not enough as long as there are too few resources to enforce the laws.
- **Prioritising Actions**: If poor farmers do not have the means to prioritising actions that promote sustainable environmental conditions, they will continue to make only short term decisions.
• **Communication**: Communication and open discussions must be encouraged with people who can influence environmental consciousness and matters related to water use with commercial farmers and union associations.

• **Education Programmes**: Appropriate educational programmes need to be promoted to increase awareness of climate change for all citizens.

• **Mentoring Programmes**: More mentoring programs need to be set up between commercial and small scale farmers to bridge the enormous knowledge gaps that exist.

• **Support for Commercial Farmers**: Assurance needs to be given to commercial farmers of the important part they play in maintaining good ecosystems and providing sustainable food security for southern Africa. If grain is being grown with subsidies in other parts of the world, levies must be put on imported grain from subsidised countries to allow South African farmers to compete. Many commercial farmers are today sinking deeper and deeper into debt. After one good year they can continue for the short-term, but with uneven conditions between South African farmers and those in the rest of the world, it will be difficult for South African farmers to compete. Instead of supporting many unproductive small farmers, it may be more effective to support commercial farmers who actually want to farm profitably and sustainably.

• **Ensuring National Food Security**: Without South Africa’s commercial farmers, it will be difficult to ensure the food security of the nation.

• **Targeting Emerging Farmers**: Those small scale farmers who want to become commercial farmers need to be targeted and guided in the right direction, rather than supporting many unproductive small farmers, by providing incentives for them to farm sustainably.

• **Water Allocation for Irrigation**: Water allocators need to allow permits for reservoirs and irrigation structures in areas that are abundant in water and then allow farmers in these regions to produce food for the nation. Water must be allocated in an equitable manner.

• **Training in Regard to Water Allocation**: Ongoing training is needed for water allocation planners to incorporate new climate change information as it is released.

• **Hydrological Design of Dams**: Existing dams were dimensioned on historical hydrological records in regard to sizing and dam safety. They will not necessarily be able to deal with future climate conditions (e.g. increases in design floods; or less water). Climate change needs to be included as one of the factors to be taken into account when assessing the safety of current dams and in the design of new structures.

• **Political Will**: The political situation in terms of land claims and conflicting legislation needs to be cleared up.

**Quantifying Vulnerability: A Case Study in Agriculture Sector Vulnerability Mapping Over South Africa** [Information: Gbetibouo and Ringler, 2009]

There are numerous methods of quantifying vulnerability, and problems which farmers may identify could be ranked according to

- **severity** (i.e. insignificant, minor, moderate, significant or catastrophic) and then, based on a comparison of present climatic conditions vs. climate change information, ranking the

- **likelihood** of specific problems in a specific area occurring more frequently or less frequently in the future (i.e. remote, unlikely, possible, likely or certain) in order to compile severity-likelihood matrices.

The case study described here is from seminal research on agriculture sector vulnerability by Gbetibouo and Ringler (2009) who used an indicator approach to map zones of vulnerability at provincial level over South Africa using the three components which are influenced by a range of biophysical and socio-economic factors, viz.

- **exposure**, interpreted as the direct danger, i.e. the stressor, and the nature and extent of changes to a region’s climate variables, and represented by two elements, viz. the frequency of extremes and projected changes in temperature and rainfall by 2050;
- **sensitivity**, which describes the human-environmental conditions that can worsen the hazard, or ameliorate the hazard, or trigger an impact, and which was expressed by five factors, viz. an irrigation index, a land degradation index, a crop diversification index, a small-scale farmer index and rural population density; and
- **adaptive capacity**, which represents the potential to implement adaptation measures that help avert potential impacts, is considered to be a function of wealth, technology, education, information, skills, infrastructure, access to resources, and stability and management capabilities, and is described as being dependent upon four livelihoods assets, viz.
  - social capital (represented by the number of farmers in organised agriculture),
  - human capital (represented by literacy rate and HIV prevalence),
  - financial capital (represented by farm income, farm holding size, farm assets, percentage of people below the poverty line, share of agricultural GDP and access to credit), and
  - physical capital (related to infrastructure and access to markets).

These were then integrated by Gbetibouo and Ringler (2009) and geared towards reflecting overall vulnerability, as illustrated in Figure A2.2.

Vulnerability was then formulated mathematically by Gbetibouo and Ringler (2009) by use of principal component analysis after standardising the data and attaching weights to the vulnerability indicators.

![Figure A2.2](image)

The combined effect of the sensitivity and exposure indicators produce the potential impact of climate change and variability on the various provinces, and Figure A2.3 (top left) show that KwaZulu-Natal, Limpopo and the Eastern Cape are predicted by the approaches used in this case study to experience the largest potential impacts, while the Northern and Western Cape, Free State and Gauteng show the lowest potential impacts, as they are largely composed of large commercial farms and do not suffer from too much land degradation.

Figure A2.3 (top right), which presents the adaptive capacity index, shows that there are large differences across South Africa’s nine provinces, with coping capacity greatest in the
Western Cape (index value 4.4) because of the combined effects of a well-developed infrastructure network, high levels of literacy and income, low levels of unemployment and of HIV prevalence as well as relatively high wealth capital. Low coping capacities to impacts of climate change are computed for KwaZulu-Natal, the Eastern Cape, Free State, Limpopo, and North West, i.e. those provinces which suffer from high agricultural dependency, unemployment and HIV prevalence, and relatively low infrastructure development.

The Overall Vulnerability Index for each province in South Africa (Figure A2.3 bottom) shows the Western Cape and Gauteng, the two most developed provinces associated with high levels of infrastructure development, high literacy rates and low shares of agricultural GDP, to have the lowest vulnerability indices while the three most vulnerable provinces are the Eastern Cape, KwaZulu-Natal and Limpopo, with many small scale farmers, high dependencies on rainfed (dryland) agriculture, high levels of land degradation and densely populated rural areas where many people rely on subsistence agriculture for their livelihoods.

Figure A2.3    An exposure-sensitivity index (top left), an adaptive capacity index (top right) and an overall vulnerability index (bottom) of agriculture in South Africa to climate change (After Gbetibouo and Ringler, 2009)

Gbetibouo and Ringler’s (2009) framework for a quantitative expression of climate change vulnerability across the provinces of South Africa has thus combined exposure with sensitivity to give the potential impact, which was then compared with the adaptive capacity to yield an overall index of vulnerability. This case study was limited to mapping vulnerability at the provincial level. There is, however, enormous heterogeneity within provinces and districts with regard to household-level resource access, poverty levels and the ability to cope with climate change and variability and the authors stress that ultimately future work should be undertaken at higher spatial resolutions, such as the district and villages levels.
This section on vulnerability covering first conceptual issues, then practical concerns and finally a South African case study provides the backdrop for the next Chapter on adaptation.

Further Reading


Adaptation: What Do We Understand by that Concept?

Defining Adaptation
Types of Adaptation
What are the Drivers of Adaptation?
Adaptive Management vs. Adaptive Governance
Dimensions of Adaptation Practices
Adaptive Capacity
The Role of Technology in Adaptive Capacity

Adaptation in Agriculture: Introducing the Concept

Why Should We Adapt to Projected Climate Change in the Agriculture Sector? A South African Perspective

Setting the Scene for Approaches to Adaptation Strategies for South African Agriculture

1. From a More General, International Perspective
2. From a More Specific South African Perspective

Considerations in the Development of Climate Change Strategies for South Africa’s Agriculture Related Sector

1. We have an Obligation to Develop National Strategies of Adaptation to Climate Change
2. We Need to Respond to Recent International Findings
3. We Need to Acknowledge what is Already Known on Climate Change and Agriculture in South Africa
4. There are Key Issues We Need to Consider when Climate Change Impacts are Assessed in Light of an Adaptation Strategy?
5. There are Other Considerations Regarding Adaptation Strategies for the South African Agriculture Related Sector
6. We Need to Take Cognisance, and Understand the Implications, of the Most Up-to-Date Scientific Findings on Impacts of Climate Change as a Springboard for Effective Adaptation Strategies
7. We Need to Take Cognisance, and Understand the Implications, of Other Constraints and Gaps in Developing Effective Adaptation Strategies

The Rationale Behind Adaptation Plans in South Africa

Levels of Implementation of Climate Change Adaptation

Some Realities on Adaptation in the South African Agriculture Sector

Further Reading
Please cite as follows:
Schulze, R.E. 2016. Adaptation to Climate Change in South Africa’s Agriculture Sector. In: Schulze, R.E. (Ed.) Handbook for Farmers, Officials and Other Stakeholders on Adaptation to Climate Change in the Agriculture Sector within South Africa. Section A: Agriculture and Climate Change in South Africa: Setting the Scene, Chapter A3.
ADAPTATION TO CLIMATE CHANGE IN SOUTH AFRICA'S AGRICULTURE SECTOR

Adaptation: What Do We Understand by that Concept?

Farmers and others down the agricultural value chain who depend on agriculture have always developed ways to cope with climate variability by ingenuity and experience as and when it was needed. However, the rapidity at which the current climate is changing will alter what has up now been experienced in patterns of variability across South Africa, in regard to the frequency of extreme events such as droughts, floods or heat waves, as well as their magnitude and spatial extent, and the extent to which the agricultural sector will be confronted with situations they are not generally equipped to handle.

This requires adaptation to climate change, and the first section of this Chapter deals with understanding better the concept around adaptation.

Defining Adaptation

- Adaptation may be defined as actual adjustments we make in the natural system we farm in (e.g. when, what and where we plant a crop, how much fertilizer we apply), or
- in the human systems in which we operate (how and why we make decisions), or
- in changes in decision environments (e.g. because of the price we get for the crop), in response to actual or expected climatic events or their effects, which could moderate or modify the harm from that event and which might therefore ultimately
  - enhance our resilience to that climatic event, or
  - reduce our vulnerability to what we observe in the climate or what we expect could happen / change in climate, or
  - allow us to exploit beneficial opportunities through a change in climate.
- We can also express adaptation in a more formal way according to the UN Framework Convention on Climate Change (UNFCCC, 2007) definition as being “a process through which societies make themselves better able to cope with an uncertain future” and where “adapting to climate change entails taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making the appropriate adjustments and changes”.

Types of Adaptation

Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation:

- Anticipatory Adaptation is adaptation that takes place before impacts of climate change are observed. It is also referred to as proactive adaptation.
- Autonomous Adaptation is adaptation that does not constitute a conscious response to climatic stimuli, but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. This is also referred to as spontaneous adaptation.
- Planned Adaptation is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to either return to, or to maintain, or to achieve, a desired state.
- Private Adaptation is initiated and implemented by individuals, households or private companies, usually in the individual’s rational self-interest.
- Public Adaptation is initiated and implemented by governments at all levels and is usually directed at collective needs of the country or province or the farming sector.
- Proactive rather than Reactive Adaptation: Adaptation should not take place after the event, i.e. it should not be re-active, but should rather be proactive, i.e. it should become more planned (anticipatory), as well as being more location-specific. Through a process of adaptive management, farming communities can make decisions appropriate to their
needs taking into account their resources, the information available to them and the skills they have acquired. The basic uncertainty in weather and climate projections means that sometimes very specific measures can be taken (e.g. flood defenses), whereas at other times so-called ‘no-regret’ measures are more appropriate, where these are robust to a wide range of possibilities (e.g. conservation tillage or fodder banking). Reactive approaches are seen as inefficient and not always successful.

- **Adaptive vs. Mal-Adaptive Measures**
  
  Some responses which are thought to be desirable in the short term can turn out to be harmful over longer time periods because they either increase vulnerability (e.g. building of agricultural infrastructure in disaster-prone areas), or they are capital-intensive, but wasted or little used, assets (e.g. expensive dams that are not used or wineries which become under-utilised as the climate shifts). This is mal-adaptation rather than adaptation, and should be avoided at all costs.

**What are the Drivers of Adaptation?** [Adapted from Theesfeld et al., 2011]

The drivers of adaptation differ, mainly dependent on the administrative setting. Thus.

- **Adaptation at “higher” levels (e.g. central government)** tends to be planned and is driven by
  - planned institutional adaptation,
  - meeting in-country environmental policy targets,
  - meeting international obligations and commitments (e.g. to UNFCCC), and
  - co-ordination across various government departments with climate change agendas.
- **Adaptation at higher levels** is, as a rule, therefore
  - intentional
  - anticipatory
  - proactive
  - long term and
  - strategic.
- **At so-called “lower” levels (e.g. local government, farmer association)** adaptation tends to be *autonomous* and is driven by
  - hydro-climatic drivers such as experiences of floods and droughts
  - with often rules and procedures put in place to facilitate technical coping solutions
  - with a mix of climate and non-climate factors and
  - with bottom-up initiatives by farmer associations, NGOs and / or local media and
  - blending local-*cum*-indigenous experience and knowledge with more scientifically determined anticipated change.
- **Adaptation at lower levels thus tends to be more**
  - spontaneous
  - reactive
  - short term and
  - practical.

**Adaptive Management vs. Adaptive Governance**

A distinction needs to be made between *adaptive management vs. adaptive governance*, where

- adaptive management is more about the operational aspects of water allocation, while
- adaptive governance refers to the making of rules (e.g. assigning irrigation rights, where and whether one is allowed to plant production plantations, handling trade-offs).

**Dimensions of Adaptation Practices**

Adaptation practices can be differentiated along several dimensions, for example,

- by spatial scale (individual farm, local farmers’ association, provincial, national);
- by sector (e.g. agriculture, water etc., and within agriculture by dominant crop type);
- by type of action (physical, technological, investment, regulatory, market);
• by actor (national or local government, international donors, private sector, NGOs, local communities and individuals);
• by climatic zone (semi-arid, sub-humid, etc.);
• by terrain type (e.g. floodplain, mountains etc.);
• by dryland (i.e. rainfed) vs. irrigated agriculture;
• by farming typology (e.g. subsistence, emerging, commercial etc.)
• by baseline income / development level of the farming systems in which they are implemented (e.g. developing vs developed countries); or
• by some combination of these and other categories.

From a temporal (i.e. over time) perspective, adaptation to climate risks can be viewed at three levels, viz. responses to:
• current variability (which also reflects learning from past adaptations to historical climates);
• observed medium and long-term trends in climate; and
• anticipatory planning in response to GCM based scenarios of long-term climate change.

The responses across the three levels are often intertwined, and indeed might form a continuum.

**Adaptive Capacity**
Closely related to the concept of adaptation *per se* is that of the capacity to adapt, usually termed adaptive capacity. Adaptive capacity may be defined as the ability or potential of a system to respond successfully (i.e. adjust in both behaviour and in resources and technologies) to climate change (including climate variability and extremes), to moderate potential damages (by changing exposure to climate or sensitivity to climate), to take advantage of opportunities, or to cope with the consequences of impacts (by recovering or maintaining welfare / system function in the face of climatic change) and to profit from new opportunities (assuming climate change affects agents differentially).

The following should be noted:
• Systems with high adaptive capacity are able to reconfigure themselves more easily after a shock due to an extreme event than systems with a low adaptive capacity.
• The presence of adaptive capacity has been shown to be a necessary condition for the design and implementation of effective adaptation strategies so as to reduce the likelihood and the magnitude of harmful outcomes resulting from climate change.
• Research on vulnerability and adaptive capacity shows clearly that some dimensions of adaptive capacity are generic, while others are specific to particular climate change impacts.
  - Generic indicators include factors such as education, income and health.
  - Specific indicators to a particular impact, such as drought or floods, may relate to institutions, knowledge and technology.
• Technology can potentially play an important role in adapting to climate change, with both engineering and ecological solutions representing some of the options that can lead to improved outcomes and increased coping under conditions of climate change.
• Adaptive capacity is influenced not only by economic development and technology, but also by social factors (e.g. a willingness to adapt, or constraints related to culture and tradition) and by human capital (e.g. expertise) and governance structures (e.g. are authorities implementing their own policies).
• Adaptive capacity is uneven across societies, and while national-level indicators of vulnerability and adaptive capacity may be used by our climate change negotiators at, for example, the annual Conference of the Parties (COP), or by government decision makers in determining policies and allocating priorities for funding and interventions, the usefulness of indicators of generic adaptive capacity and the robustness of the results is not entirely convincing at the level of the farmer.
Adaptive capacity is unevenly distributed and highly differentiated within a country due to multiple processes (stresses) of change which interact to influence vulnerability and shape outcomes from climate change at a local level.

Social and economic processes determine the distribution of adaptive capacity, which can be highly differentiated (i.e. heterogeneous) within a society or locality, and for individuals and communities it is differentiated by age, class, gender, health and social status.

Adaptive capacity can change over time, because it may be enhanced or constrained or eroded by factors such as regulations or economic policies determined at the regional or national level that either limit or enhance the freedom of individuals and communities to act, or that make certain potential adaptation strategies either viable or unviable, including violent conflict in the farming community, the spread of diseases among humans, livestock or crops, or a move towards urbanization, or even trade liberalization or trade constraints (IPCC, 2007).

The Role of Technology in Adaptive Capacity

In the agricultural sector, technology clearly plays an extremely important part in productive potential and adaptive capacity. It includes

- **hardware**, i.e. physical infrastructure, machinery and equipment, for example, irrigation systems,
- **software**, i.e. knowledge and skills, for example farmer training and awareness raising,
- **orgware**, i.e. the capacity to organise for the greater benefit of members, for example, farmer co-ops or water user associations for irrigators,
- **techware**, i.e. the biological technology with which farmers produce, for example, use of correct seed varieties, crop nutrition, crop protection or correct pesticide application.

All of these have stood the farmer in good stead as the primary drivers of increased productivity, but they should be re-evaluated and improved in the light of evolving climatic and economic situations and needs. For the farmer appropriate technologies are those which they can manage and maintain themselves over the long term, and which integrate environmental, economic and social sustainability principles. Irrespective of production system, location or resource status, if producers have access to a wider choice of appropriate technology options, they are able to be innovative and improve their practices. The capacity to differentiate and decide between technologies will become very necessary when adapting to climate change in future.

Why Should We Adapt to Projected Climate Change in the Agriculture Sector? A South African Perspective

There is, even under present climatic conditions already, great concern about climate related problems among South African farmers and the authorities alike. It has to be emphasised that climate and climate change issues are superimposed upon the many other challenges, problems and stressors faced by the South African agriculture sector (e.g. globalisation, urbanisation, environmental degradation, disease outbreaks, market uncertainties, higher fuel and machinery costs, policies concerning water / field burning / overgrazing and land redistribution, or slow responses from authorities), and that together these affect future planning strategies. However, up to a point, farming communities already cope with, and adapt to, a climate that varies from day to day, month to month and from year to year. The key to enabling farming communities to deal with an uncertain future climate is to understand what makes them vulnerable and then to work towards reducing those factors, so that adaptation for the future is about staying ahead and being progressive.

Adapting to projected climate change in South Africa’s agriculture sector will be about
• **large-scale commercial farmers** staying ahead and being progressive by optimising climatic conditions to maximise output in a sustainable manner and by maintaining a competitive edge, while for
  
  • **rural livelihood farmers** 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 it will have to combine the indigenous knowledge and experiences of vulnerable groups together with the latest specialist insights from the scientific community. Most agricultural programmes are initiated at high levels in government (e.g. at DAFF) for regional implementation (e.g. by province) and those programmes are not always adapted to local conditions (i.e. on the specific farm). However, all agricultural programmes and planning strategies in regard to climate change will need to focus on local conditions, as climate change has very local repercussions. An in-depth understanding of the ramifications of climate change and adapting to the projected climate changes has become an imperative for South Africa on the basis not only of having been prompted by various directives from global bodies such as the United Nations Framework Convention on Climate Change (UNFCCC) as well as by policies from the South African government, but because

• agriculture responds non-linearly to the day-to-day and season-to-season changes in key climate variables such as rainfall and temperature within South Africa with its already high risk agro-climatic environments,

• there is a close association between agricultural production, food security and economic development, and because

• there are close and interactive links between agricultural production over space and time with
  - health,
  - national and community level food security,
  - poverty,
  - gender issues,
  - disaster risk management, and
  - water.

This implies that we need to focus, *inter alia*, on

• investment in South Africa's scientific capacity (including the growth of centres of expertise),

• facilitating strong leadership by state institutions,

• working trans-nationally,

• encouraging trans-disciplinarity,

• enabling healthy interactions between agricultural sciences and allied science in an agricultural context, between science and policy and between science and other industry stakeholders, and

• engaging in communication between science and the farmer on the ground (Schulze, 2012).

**Setting the Scene for Approaches to Adaptation Strategies for South African Agriculture**

1. **From a More General, International Perspective** [Further reading: Schulze, 2012]

• Internationally, there is a growing recognition of the potential implications of climate change in the agriculture related sector, with farmers and agri-business managers in many parts of South Africa already facing consequences of
  
  - more frequent and more intense drought and / or flood events, either perceived or real,
  - non-sustainable soil water availability for plants during critical growth periods,
- higher inter-annual and intra-annual variability of rainfall,
- unreliable onset of and cessation of the planting season,
- increasing evaporation from water bodies supplying irrigation water, and / or
- increasing evapotranspiration from plants,
with all of the above coupled to
- rapid population growth and growing food demands,
- changing diets and
- rising expectations of improved nutritional levels resulting from improved living standards.

• To ensure a sustainable supply of food to South Africans into the future, not only will
  - technical innovations need to be introduced, but
  - new institutional initiatives in land reform and agricultural governance will need to be
implemented.

• The global scientific community argues that projected future events require additional or
  modified initiatives to prevent emerging worsening of agriculture related problems since,
  once certain thresholds of change have been exceeded without appropriate coping
  mechanisms in place, catastrophic consequences may become more likely and
  adaptation strategies become very difficult to initiate and implement.

• There is, therefore, an overriding need to understand the potential impacts of climate
  change on agricultural policy and practice in order to design country and region
  appropriate strategies for adaptation. This implies, to a large extent, reducing
  vulnerability to the impacts of current climate variability, and taking effective measures
  to prevent (where feasible) and respond positively to future impacts.

• The “art of adaptation” in the agricultural sector is therefore seen as finding the right mix
  of the three I’s, viz.
  - information,
  - institutions and
  - infrastructure,
  in order to achieve the desired balance between the three E’s, viz.
  - equity,
  - environment and
  - economics.

• Since food production is one of the primary means through which climate change will
  impact upon people, upon the environment and upon economies, any adaptation
  process should include the coherent and effective management of agricultural
  production so as to achieve multiple objectives, which include
  - management and conservation of water for the provision of agriculturally related
    water services,
  - efficient use of water for irrigation and food production,
  - strengthening coordination within overall spatial planning by integrating with
    agricultural, water, and urban planning in order to promote sustainable economic
    development and
  - reducing risks to human livelihoods arising from extreme hydro-climatic events such
    as floods and droughts.

• Key components in this process of adaptation are to
  - reduce the gap between current scientific knowledge and associated decision making
    processes and institutions in the agricultural community in collaboration with civil
    society,
  - reduce the gap between scientific and indigenous knowledge, and to
  - enhance what may be required in agricultural governance under conditions of climate
    change.

• To close this gap, it is essential to
  - enhance society’s understanding of the possible implications of climate change, and to
- facilitate a continuous dialogue process among high-level experts, civil society organizations and decision makers in relevant institutions in the region, in order to move forward with a joint effort in adaptation which includes capacity building and institutional development.

- This Handbook sets out to address many of these world-wide issues in a South African context.

2. *From a More Specific South African Perspective* [Further Reading: Schulze, 2012]

Agricultural production, which is inextricably interlinked with the natural capital of a region (i.e. what the environment provides by way of land, soil, climate and water resources), is essential to the continued economic development of South Africa and to the sustainable livelihoods of its people. Because

- rainfall shortages are already evident in many regions within the country, and
- a large proportion of South Africa’s society consists of impoverished people (when compared to a relatively small middle and wealthy class), which renders the poor particularly vulnerable to the vagaries of climate and impacts of climate change. 
  and, furthermore,
- many of this country’s fragile provisioning ecosystems, both terrestrial and aquatic, are directly (i.e. explicitly) or indirectly (i.e. implicitly) dependent on climate and water, strategies and practical plans of action to adapt to climate change through an integrated approach towards land and water management are therefore urgently needed in order to establish effective resilience to the projected impacts of climate change.

The commitment to act on matters pertaining to climate change, and to shape policy informed by best-available science, is recognised by the South African government in various resolutions and initiatives (e.g. from the 2005 National Climate Change Conference; or the 2009 National Climate Change Summit; or the South African Climate Change Mitigation and Adaptation Plan for Agriculture which was made public in a Government Gazette in 2015), with additional emphasis on fostering local level resilience to climate change and a participatory process to climate change policy development. Furthermore, vulnerability and adaptation feature in many governments’ broad policy direction themes with briefs, for example,

- to continue identifying and describing its vulnerability to climate change;
- to describe, prioritise and initiate adaptive interventions and to identify who should be driving these interventions and how they should be monitored;
- to ensure that in affected government departments (e.g. agriculture, water, health) climate change adaptation be included as a departmental key performance area;
- that roles and responsibilities of all stakeholders, particularly organs of state in the various levels of government, be clearly defined and articulated;
- that structures are required to ensure alignment, co-ordination and co-operation and that these be clearly defined and articulated; and
- that climate change response policies and measures be mainstreamed with existing structures of co-ordination and co-operation.

Implementing such strategies and plans of action on adaptation will necessitate three-pronged information needs, *viz*.

- identifying biophysical, socio-economic, cultural and policy issues which may render various agricultural commodities or communities within the agricultural sector vulnerable to climate change,
- determining impacts of projected climate change on Africa’s agriculturally related biophysical environment, and
- articulating practical measures to overcome, on the one hand, pre-existing shortcomings in coping with climate drivers and, on the other hand, planned measures to adapt to anticipated changes to those climate drivers.
This Handbook sets out to addressing many of these strategies and plans of action for the South African agriculture sector.

Considerations in the Development of Climate Change Strategies for South Africa’s Agriculture Related Sector [Further Reading: Andersson et al., 2009; Schulze, 2011; Schulze, 2012]

1. **We have an Obligation to Develop National Strategies of Adaptation to Climate Change** (Further Reading: Schulze, 2012)
   - National strategies of adaptation (NAS) are currently being developed in many countries,
     - often taking the form of strategy documents and guidelines of proposed frameworks,
     - conforming to the precautionary principle, and
     - integrating various affected sectors.
   - There are numerous political and ecological drivers of such strategies, including
     - the increased perception / awareness of climate change at all decision making levels,
     - the UNFCCC’s obligations to take precautionary measures to adapt,
     - socio-economic concerns of not taking action,
     - the economic interests of the private sector, and
     - obligations towards their respective Constitutions as well as various national acts and strategies.
   - Objectives, in a South African context, should include
     - the establishment of a transparent and structured medium-term process
     - involving all relevant actors, be they from the public or private sector or from NGOs, but
     - co-ordinated at government level across various ministries, considering furthermore
     - broader development national agendas (e.g. in South Africa, the National Development Plan),
     - emphasising adaptive land and water management, and
     - taking due cognizance of the links between agriculture and, for example,
       ▪ biodiversity
       ▪ water
       ▪ forestry
       ▪ coastal zones
       ▪ mountainous (water producing) regions
       ▪ human health
       ▪ transport
       ▪ energy and
       ▪ insurance
     in a holistic, integrative manner.

2. **We Need to Respond to Recent International Findings**
   Recent research published, for example, by the IPCC in 2013, has updated some of the findings from previous IPCC reports in stating, *inter alia*, that
   - there is new and stronger evidence than before (at very high confidence) of observed impacts of climate change on vulnerable sectors such as agriculture, with increasing levels of adverse impacts as temperatures increases and rainfall patterns change; furthermore,
   - there is new evidence that observed climate change is likely to have already increased the risk of certain extreme events such as floods and droughts (very high confidence), and it is more likely than not that warming has contributed to the intensification of some tropical cyclones, with increasing levels of adverse impacts as temperatures increase; that
   - the distribution of impacts and vulnerabilities is still considered to be uneven, with less-developed areas (such as large parts of South Africa) generally at greatest risk due to
both higher sensitivity and lower adaptive capacity, but with evidence also that vulnerability to climate change is highly variable within countries; and that

- adaptation can significantly reduce many potentially dangerous impacts of climate change and reduce the risk of many key vulnerabilities.

3. **We Need to Acknowledge what is Already Known on Climate Change and Agriculture in South Africa**

- In the South African agriculture related sector there already exists
  - a rich history of academic type research, and
  - international collaboration in matters of climate change (e.g. active participation in the International Geosphere-Biosphere Programme, the Intergovernmental Panel on Climate Change, the Global Water Systems Project), but
  - a poorer history of converting the findings into strategies for adapting to climate change and an even poorer history of conversion to actual coordinated action plans.

- From recent climatic studies it is evident that climate change is already occurring and can be detected over many parts of South Africa. Climate change is no longer a matter of conjecture and it is not only an issue of something that could begin to happen only 30-50 years from now.

- Accounting for potential effects of climate change in South Africa’s agriculture related sector is therefore an imperative; indeed, non-consideration of potential effects of climate change should be viewed as an act of omission.

- We already live in, and already have to cope with, a high risk and generally harsh agro-climatic environment in South Africa, which experiences high variability both over space and over time (see subsequent sections of this chapter).

- Climate change is not going to be experienced evenly throughout the country, nor even within individual provinces - some areas will be "winners", other areas will be "losers" and others still are likely to be identified as real “hotspots of concern” requiring priority action.

- Climate change does not occur on a “clean sheet” of ecosystems which have not been impacted by human interventions on the landscape and the associated waterscape; rather it will be superimposed onto already
  - agro-climatically stressed areas with often complex land uses,
  - water engineered systems of dams, canals and inter-basin transfers which often focus on irrigated agriculture and a
  - strong economic development footprint, as well as a
  - deeply engrained historical socio-political footprints (from colonial times, post-colonial times in the Apartheid era, and the present, with land redistribution) and a
  - emerging new colonial type footprint through “land grabbing” by so-called foreign direct investment, the medium to longer term consequences of which have often not been thought through by governments.

4. **There are Key Issues We Need to Consider when Climate Change Impacts are Assessed in Light of an Adaptation Strategy?**

- When we assess potential impacts of climate change on the agriculture related sector, we will need to evaluate projected changes of critical climate variables such as CO₂ concentrations, rainfall and temperature (as it manifests itself through floods and droughts, through heat units or chill units or exceedance of critical high temperatures, enhanced pest and disease occurrences, or evaporative demand from the soil and from dams) and how, in interaction with one another, they translate to changes in agricultural responses in regard to
  - **magnitudes of change**, i.e. how much the change is projected to be and how much impact that can have, where the magnitude of an impact is determined by
    - its scale, e.g. the area or number of people affected and
    - its intensity, i.e. the degree of damage caused, with the most widely used quantitative measures for climate impacts being
monetary units such as welfare, income or revenue losses,
- costs of anticipating and adapting to certain biophysical impacts,
- estimates of people's willingness to pay to avoid (or accept as compensation for) certain climate impacts, or the
- number of people affected by certain impacts such as food and water shortages, morbidity and mortality from diseases, and forced migration;
- direction of the impact, i.e. is it a positive or negative change, and what that implies;
- timing of the impact, i.e.
  - when, in the course of a year, the change is projected to occur and how that affects agronomic and on-farm as well as wider agri-business management decisions, or
  - whether a harmful impact is more likely to happen sooner rather than in the more distant future;
- rate, i.e.
  - how rapidly is change projected to occur in years or decades ahead, and
  - how that affects priorities of action,
  - with adverse impacts which occur suddenly (and surprisingly) being perceived as more significant than the same impacts occurring gradually, as the potential for adaptation for both human and natural systems would be much more limited in the former case, and
  - very rapid change in a non-linear system (such as the hydrological system) possibly exacerbating other vulnerabilities (e.g. impacts on agriculture and nutrition aggravating human vulnerability to disease), particularly where such rapid change curtails the ability of systems to prevent and prepare for particular kinds of impacts;
- location, i.e. where will it occur first or most severely considering, inter alia, income, gender and age in addition to regional, national and sectoral groupings;
- persistence and reversibility, where impacts could become key issues due to persistence of, say, the emergence of near permanent drought conditions or intensified cycles of extreme flooding that were previously regarded as rare 'once-off' events; and the
- level of confidence / uncertainty of projected impacts in regard to the likelihood of impacts and the confidence we have, scientifically, of the impact occurring, where
  - likelihood is the probability of a climate change related outcome occurring, and
  - confidence is the scientifically objective assessment that any statement about an outcome will prove correct (cf. Schulze, 2012; Chapter 2.4), and
  - where we need to appreciate that we are more confident of the "correctness" of changes in some climatic and climate derived variables than of others; the
- potential for adaptation, which differs between regions within South Africa and between the various sectors of agriculture, and where the potential considers not only the technical feasibility of certain adaptations, but also the availability of required human resources, the costs and side-effects of adaptation, the knowledge about those adaptations, their timeliness, the incentives for adaptation actors to actually implement them (and the dis-incentives), and their compatibility with preferences of individual farmers or of cultural/traditional preferences; and the
- importance of the agricultural system(s) at risk in regard to
  - the value attached to the system by different societies, be the value related to
  - the uniqueness of an ecosystem to grow specific crops, or
  - national food security (e.g. in regard to maize) or
  - the livelihoods of many people who may depend crucially on the functioning of a system, considering her the entire value chain of the specific farming system from production to transportation to manufacturing / processing.

5. There are Other Considerations Regarding Adaptation Strategies for the South African Agriculture Related Sector
• Adaptation will need to start by implementing those agricultural practices what we ought to be doing in any event.
• Some communities within South Africa and some agro-ecosystems will be more vulnerable than others to effects of climate change, and are likely to have a lower adaptive capacity than others. These may require priority consideration in any agricultural adaptation strategy.
• At the end of the day practical and pragmatic adaptation is a local issue, but it has to take place within a broader policy framework.
• Adaptation to climate change is not a once-off event, nor is it a linear process; rather it should be seen as a process which continually needs to be re-visited.
• The capacity to adapt to climate change impacts in South Africa is a pre-condition for successful adaptation.
• Given South Africa’s complex social and political structures and the overlay (juxtapositioning) of subsistence / livelihood and commercial farming economies, adaptive capacity in South Africa will depend on:
  - Experience + knowledge (scientific and indigenous) + incentives to adapt + ability to take risks + access to finance + leadership (“champions”).
• For adaptation to be effective, we need to have good observational networks climate variables of long duration as well as high quality agro-climate records in order for timely detection of any shifts in climatic forcing.
• For effective adaptation we will need to understand the mechanisms and the thresholds / sensitivities (“tipping points”) between drivers of environmental change and responses in the different agro-climatic regions of South Africa.
• For adaptation to be effective, we will need flexible agricultural management procedures in South Africa at different levels of agricultural governance and that related to agriculture (e.g. water).
• Overall, the 8 “E”s of adaptation will need to drive a South African climate change adaptation strategy for the broader agriculture related sector, viz.
  - Empowering the agricultural sector to adapt at all levels, through
  - Education at all levels,
  - Effectiveness in management,
  - Engineering skills,
  - Environmental consciousness,
  - Economic incentives,
  - Emergency responses from the disaster risk management sector, and
  - Enforcement of policies and strategies through sound governance.

6. We Need to Take Cognisance, and Understand the Implications, of the Most Up-to-Date Scientific Findings on Impacts of Climate Change as a Springboard for Effective Adaptation Strategies
The conceptualisation and implementation of climate change adaptation strategies for agriculture related sectors within South Africa can only be effected if they are informed by the latest scientific findings. This implies
• a sound understanding and appreciation of the most up-to-date projected impacts of climate change on agriculture related responses and hence production potential, which may have advanced considerably and even be partially at variance with past findings contained in older South African literature (e.g. in South Africa, the Country Studies Report based on work of the late 1990s; DEAT, 2000) on which many misconceptions may still rest in many official circles and the media, and
• a sound appreciation (and current understanding where this is already available) on projected impacts of climate change on agriculture related decision making in South Africa, such as agronomic practices, agricultural water demands, subsidies and/or international change, to name but a few key areas.
7. We Need to Take Cognisance, and Understand the Implications, of Other Constraints and Gaps in Developing Effective Adaptation Strategies (Further Reading: Schulze, 2012)

In addition to compelling reasons given in the aforegoing sections which outline the need for country-relevant climate change adaptation strategies for the South African agriculture related sector, some real world constraints and gaps are identified. These include the following (Schulze, 2012):

- **Policy Constraints** revolve primarily around South Africa to urgently requiring the completion of adaptation policies and action plans specific to the agriculture related sector, some principal components of which should include that
  - our present agricultural resources / potential, crop production related vulnerabilities and the food security requirements (from community to national levels) be fully understood, well documented and up-to-date (and continue to be updated);
  - adaptation in the agriculture sector take place within legal and policy frameworks which display the government’s commitments to adapt on the international level, on national levels as well as on sub-national levels;
  - an adaptive approach to integrated management be followed;
  - the development principle be adhered to, bearing in mind that within South Africa the poor and marginalized groups are most vulnerable, that
  - adaptation is an integral part of development, and that
  - climate change is but one of several drivers of global change;
  - the principle be followed that greater resilience today implies more effective adaptation tomorrow;
  - that sound agricultural governance, and that linked to agriculture (such as water) is an imperative;
  - that stakeholder participation at all levels be an important principle;
  - inter-sectoral integration be promoted since the agriculture related sector (which includes forestry) is intimately interwoven with water, health, spatial planning, as well as coastal zone and disaster risk management;
  - that adaptation be practised at appropriately fine (i.e. local) spatial scales;
  - that uncertainties be assessed, addressed and factored into decision making re. adaptation;
  - that climate change information be communicated and disseminated relevantly;
  - that appropriate budgets be set aside for adaptation; and that
  - a balance be found between structural and ecological (non-structural) adaptation measures.

Some of the points listed above are elaborated upon in some detail in later chapters.

- **Capacity Constraints** of those involved in research, management, as well as those in the effective operation of the agri-business infrastructure revolve around constraints within universities as well as within State and parastatal institutions, with often a dependence on externally funding and on NGOs and, particularly, that the relevant national as well as provincial and local departments do not undertake enough dedicated and sustained agriculture related research and with a thorough understanding in regard to climate change and agriculture.

- **Physical Constraints** include diminishing areas suitable for future agricultural development in addition to the constraints of climate, topography and soils.

- **Developmental Constraints** have to do with our lack of understanding of the interactions of climate change being superimposed on operational agri-systems of already existing land uses, urban areas, dams, mines, roads etc. and what the feed-forwards and feedbacks might be.

- **Economic Constraints** focus on the relatively high cost of new agricultural infrastructure to cope with possible added effects of climate change, and of maintaining acceptable levels of soil fertility and crop production under future warmer climates and expanding / maintaining agro-climatic monitoring networks.
Therefore, accounting for, and adapting to, potential effects of climate change on South Africa’s agriculture sector are imperatives — indeed, non-consideration of potential effects of climate change in national policies / strategies and adaptation on our agriculture sector should be viewed as an act of omission.

**The Rationale Behind Adaptation Plans in South Africa** [Further Reading: Schulze, 2011]

Adaptation plans in the agriculture sector aim at identifying existing climate related problems and current mechanisms of coping with those problems, then undertaking local assessments of vulnerability to projected changes in climate and, on the basis of those, to make recommendations on adaptation strategies for action in the future. The plans need to be joint productions of various stakeholder groups in agricultural and allied management (e.g. water), with climate / agriculture / water resource experts acting as information providers and facilitators. Since, in essence, adaptation is all about staying ahead and being progressive by optimising climatic conditions in order to maximise output in a sustainable manner and maintaining a competitive edge, the rationale behind adaptation plans is that

- adaptation strategies emanating from authorities and/or experts should be ratified and accepted by local farmers; that
- knowledge and information flows between agricultural stakeholders, planners and researchers should be multi-directional (i.e. from researcher to authorities to farmer as much as from farmer to authorities to researcher); that
- the process must be seen to increase understanding between involved groups; and that
- the time has arrived that we move from rhetoric (talking) to action (doing).

**Levels of Implementation of Climate Change Adaptation**

Climate change adaptation technologies can be developed and implemented at various levels below that of the national level, for example, at sub-national levels of

- individual farms, e.g. the farmer’s choice of crop or production system
- agricultural companies/enterprises, e.g. Mondi for timber or Tongaat-Hulett for sugarcane production
- co-operatives or farming communities or farming sector organisations, e.g. farmers’ associations, or the SA Sugar Association,
- catchment level organisations, e.g. water user association
- local government initiatives, e.g. district infrastructure
- intermediate level institutions such as NGOs, or
- provincial government services, e.g. provincial departments of agriculture and extension services.

**Some Realities on Adaptation in the South African Agriculture Sector**

The recently completed and very comprehensive climate change study of the Western Cape Province (SmartAgri, 2015) contains some important realities on adaptation in the South African agriculture sector, viz.

- Adaptation and mitigation are frequently interlinked and often mutually beneficial, although trade-offs will be encountered.
- Risk management in agriculture needs to be iterative, with multiple back-and-forth feedbacks being a useful approach for adaptation in agriculture.
- The agricultural sector of South Africa is adapting by responding to the demands posed by current climate variability and extremes in the context of other equally challenging socio-economic drivers and pressures.
- Although there are some anticipatory responses, most of the current responses remain reactive and focused on the short term.
• Producers need a wide range of hard and soft technologies and approaches from which to make appropriate choices tailored to their own situation and needs. ‘No-regret’ measures should be robust to a wide range of future climate possibilities.
• Adaptation must be aligned with sustainable development and job creation.
• Underpinning research is inadequate due to lack of access to databases, insufficient climate monitoring, lack of research capacity (linkages to climate change) and lack of funding. Often the private sector has taken the lead in providing some research support in certain areas which should be the domain of government (e.g. certain data collection and extension services).
• Water planning and adaptive initiatives for the agricultural sector are often hampered by multiple policy, regulatory and institutional frustrations.

Further Reading
SmartAgri, 2015. Chapter 9 Climate change risk and impact, and Chapter 10 Current responses: Adaptation and risk management. A Status Quo Review of Climate Change and the Agriculture Sector of the Western Cape Province. Western Cape Department of Agriculture and Department of Environmental Affairs and Development Planning, Cape Town, RSA.
The Challenge of Climate Change: Some Points to Ponder as a Prelude to Focusing on Climate Smart Agriculture

What Does the Concept of Climate Smart Agriculture (CSA) Embrace?

What, then, are the Specific Challenges of CSA for South Africa?

Some Examples of CSA in Practice for Climate Change Adaptation and Mitigation

**Setting the Scene: Cost Effective Practices with Positive Climatic Impacts**

*Crop Rotation*

*Conservation Agriculture (CA)*

*Photo A4.1* Examples of (left) a cover crop and (right) of intercropping (Smith, 2014)

*Catch Crops*

*Zero Tillage*

*Reduced Tillage*

*Residue Management*

*Photo A4.2* Crop residue (R.E. Schulze)

*Extensification*

*Optimising Fertilizer Application*

*Fertilizer Type*

*Adding Legumes*

*Permanent Crops*

*Agroforestry*

*Photo A4.3* Example of agro-forestry (R.E. Schulze)

*Grass in Orchards and Vineyards*

*Optimising Grazing Intensity*

*Photo A4.4* Non-optimal grazing intensity (R.E. Schulze)

*Length and Timing of Grazing*

*Grassland Renovation*

*Optimising Manure Storage*

*Application Techniques for Manure*

*Application of Manure to Cropland vs. Grassland*

*Management of Organic Soils (Peatland Restoration and Management)*

*Conservation, Preservation and Management of Ecosystem Services*

*Photo A4.5* Examples of land degradation in the Eastern Cape (R.E. Schulze)

*Integrated Soil Management (ISM)*

*Organic Agriculture*

Barriers to the Adoption of CSA by South African Farmers

Overcoming Some of the Barriers to the Adoption of CSA, Especially Among Smallholder Farmers: A Public Sector Perspective

*Photo A4.6* Examples of incentives following the adoption of CSA (Chauke et al., 2014)

*Photo A4.7* Example of training session and social learning (Chauke et al., 2014)
Overcoming Some of the Barriers to the Adoption of CSA, Especially Among Smallholder Farmers: A Private Sector Initiative and Perspective

Figure A4.8 Central concepts of the enabling environment for mainstreaming CSA embodied in The Maize Trust / Grain SA’s CA-Farmer Innovation Programme (Smith, 2014)

Figure A4.9 Key strategic objectives of The Maize Trust / Grain SA’s CA-Farmer Innovation Programme (Smith, 2014)

More on Technological Innovations in CSA, Barriers to Technological Solutions and Interventions to Address Barriers

Where to, South Africa, with Climate Smart Agriculture, from a Policy Perspective?

Figure A4.10 The building blocks for CSA policy implementation at country level (Source: Not known)

Some Concluding Thoughts

Further Reading

Please cite as follows:
Schulze, R.E. 2016. Climate Smart Agriculture: From Concept to Practice, From Mainstreaming to Policy – An Introductory Overview with Relevance to Climate Change. In: Schulze, R.E. (Ed.) Handbook for Farmers, Officials and Other Stakeholders on Adaptation to Climate Change in the Agriculture Sector within South Africa. Section A: Agriculture and Climate Change in South Africa: Setting the Scene, Chapter A4.
The Challenge of Climate Change: Some Points to Ponder as a Prelude to Focusing on Climate Smart Agriculture [Further Reading: COMESA et al., 2015; Long et al., 2016]

- Agriculture both contributes to and is affected by climate change.
- Globally, the agricultural sector contributes around 12% of anthropogenic greenhouse gas (GHG) emissions according to some estimates while in South Africa the sector is responsible for ~ half that percentage.
- The agricultural sector, like all others, is facing growing pressure to reduce its emissions to mitigate climate change.
- Agriculture is also increasingly impacted on by climate change through changes to weather patterns and more frequent extreme weather events.
- Drought and flood events are common climate related hazards that ravage the South African agricultural landscape under current climatic conditions already, with large numbers of people affected by drought.
- Projected increases in the frequency, duration and intensity of extreme weather events are likely to reduce crop yields and livestock productivity. Decreases in yields may also affect incomes used for accessing food and, in agriculture-based economies, can affect overall economic growth.
- Current farming technologies and practices among many South African farmers are still basic and for many, their farming incomes have remained quite low, suggesting that many farmers will have few options to adapt to the impending adverse effects of climate change. Additionally, in the absence of adaptation, yields could fall even more.
- Climate change is expected to aggravate these impacts.
- Agriculture is also confronted with the challenge of feeding a growing population and ensuring the country’s food security.
- Current evidence (this Handbook; IPCC, 2013) indicates that South Africa is expected to be more vulnerable to climate change than many other parts of the world because the projected additional warming will affect, inter alia, its already stressed water resources and harm many facets of the agricultural sector.
- Furthermore, the fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2013) considers it very likely that the entire Africa, including South Africa, will continue to warm during the 21st century.
- Even without any anticipated climate change into the future, there are serious concerns about agriculture in South Africa because of constraints and variability in water supply for irrigation and soil water availability for dryland crops, especially since a considerable portion of South Africa is characterized as arid and semi-arid.
- With the projected climate change, agricultural and food systems will be additionally affected adversely as climate change has a multiplier effect on already degraded natural resources and ecosystems upon which South Africa’s agriculture depends. For example, land degradation, alien invasive plants, soil degradation, declining water quality, water scarcity and loss of biodiversity – all are affected by climate change and all affect agricultural production and food systems, as well as the livelihoods that depend on them.
- As already alluded to, the most affected will be the rural poor, who have to rely on resource-dependent livelihoods, and due to their poverty, have a very low adaptive capacity to respond to climate change impacts, which may be faster and more intense than in the past and for which traditional methods of adaptation may no longer be effective.
- The reliance of the poor farmers on local ecological resources and knowledge, coupled with existing stresses on their health and well-being, limited access to credit and technology makes them least able to adapt to the impacts of climate change.
• Frequently in the poor rural farming communities, it is the women who lack the resources, knowledge and information vital to overcoming the challenges posed by climate change. This means that poor and illiterate women will have to struggle with the challenges deriving from the adverse impacts of climate change.

Given the above challenges and “points to ponder”, a new paradigm is emerging in agriculture, viz. “climate smart agriculture”, or CSA.

**What Does the Concept of Climate Smart Agriculture (CSA) Embrace?** [Further Reading: COMESA *et al.*, 2015]

According to an approach developed by the Food and Agriculture Organization of the United Nations, FAO, the concept of Climate Smart Agriculture strives to contribute to the three dimensions, or pillars, of sustainable development (economic, social and environmental) by jointly addressing food security and climate challenges through the three pillars by:

• Sustainably increasing agricultural productivity and incomes (food security);
• Adapting and building resilience to climate change (adaptation); and
• Reducing and/or removing greenhouse gases emissions (mitigation), where possible.

As the accompanying figure shows, the idea is that CSA should

• Provide / address adaptation and builds resilience to shocks;
• Generate adaptation and mitigation as co-benefits by considering climate change mitigation as a potential co-benefit;
• Embrace a location-specific and knowledge-intensive approach;
• Identify / provide integrated options that create synergies and reduce trade-offs;
• Identify barriers to adoption and provide appropriate solutions;
• Strengthen livelihoods by improving access to services, knowledge and resources; and
• Integrate climate financing with traditional sources of agricultural investment.

In summary, Climate Smart Agriculture

• is a holistic and innovative approach;
• incorporating vulnerability, mitigation, adaptation and resilience;
• which applies to the three pillars of sustainability, *viz.* people, planet and prosperity;
• implicates all groupings of farming related people and producers; and
• addresses food security and sustainable production.

**What, then, are the Specific Challenges of CSA for South Africa?** [Further Information: Chauke *et al.*, 2014; COMESA *et al.*, 2015]

Not all agricultural practices in South Africa, in all contexts, can achieve these three broad objectives. Based on past and ongoing experiences, there is a need to determine the specific biophysical and socio-economic factors that could encourage the adoption of CSA by small-, medium- and large-scale farmers in South Africa. However, every situation is site /
farm specific (i.e. according to local or farmer resources, constraints, solutions), so farmers will have to be empowered to apply CSA themselves in their own realities.

In this regard to the three broad objectives of CSA, South Africa should have in place the necessary policy, institutional, technical and financial means to mainstream climate information, including climate change considerations, into its agricultural sector in its many facets and provide a basis for operationalising sustainable agricultural development under changing climatic conditions. These means seek to integrate climate variability and change into the planning and implementation of sustainable agricultural strategies. In essence, CSA requires transitioning to agricultural production systems that are more productive, use inputs more efficiently, have less variability and greater stability in their outputs, and are more resilient to risks, shocks, climate variability and long-term climate change impacts.

More productive and more resilient agriculture requires a major shift in the way land, water, soil nutrients and genetic resources are managed to ensure that these resources are used more efficiently and sustainably.

**Some Examples of CSA in Practice for Climate Change Adaptation and Mitigation**

[Further Reading: Long et al., 2016; Schulze, 2015]

**Setting the Scene: Cost Effective Practices with Positive Climatic Impacts**

Above and beyond technological solutions, there are also many practices which are both cost-effective and have a positive climatic impact, such as better manure management, integrated crop-livestock management, use of renewable energy, use of legumes or cover crops, improved animal feeding, and practices which increase soil carbon. Some of these will be elaborated upon below.

There are, however, many technological innovations which could help solve climate-mediated problems in agriculture. Although some new CSA technologies are already being implemented (such as software to optimize yields, remote-sensing technologies for precision farming and life-cycle assessment tools), adoption has been slow and diffusion rates pose a problem. A barrier to adoption of such technologies in South Africa is the financial cost; but conflicts with traditional methods, use of scientific jargon and lack of understanding of farmers’ reality by technology producers are also problems in the supply and demand chains of technology uptake (See more on technological innovations and barriers later).

**Crop Rotation**

This practice consists of the inclusion of different crop types in crop rotations (i.e. growing various crops on the same piece of land in a planned sequence), which can considerably increase carbon sequestration. In South Africa’s winter rainfall region, for example, this includes

- use of more forage crops in rotations;
- replacement of continuous two-course rotations of row crops with crop rotations of winter cereals;
- elimination of summer fallow;
- use of more winter crops;
- winter cover crops.

The overall benefit of crop rotation in reducing production risk involves three distinct influences,

- rotations *per se*, as opposed to monoculture cropping, which may result in overall higher crop yields as well as reduced production costs;
- rotation cropping generally reducing yield variability compared to monoculture practices, and
crop rotation involving diversification, with the theoretical advantage that low returns in a specific year for one crop is combined with a relatively high return for a different crop.

Drought however, is usually detrimental to all crops, often preventing this advantage from occurring. An obvious benefit of diversification is the reduction of risk through the inclusion of alternative crops with relatively low risk.

Other important considerations of crop rotation include that:
- higher yields associated with rotated crops will increase the per hectare cost of activities such as harvesting; however,
- weed and often pest control costs are less on rotated than monoculture crops, which will increase the net return, while it is also known that
- nitrogen fertilization of grain crops can be reduced when grown in rotation with oil and protein rich crops without affecting the yield.

Overall, the savings on inputs most probably outweigh the extra costs of harvesting higher yields, which suggests that the net returns and risk for the rotation systems are conservative estimates.

**Conservation Agriculture (CA)**

Conservation agriculture (CA) is an integrated system built on the following basic principles:
- Minimum mechanical soil disturbance, by which conventional tillage methods are replaced by reduced or no-tillage and crops are planted by adapted planting equipment;
- Implementation of crop diversification, including cover crops, intercropping and crop rotations, as opposed to mono-cropping (see Photo A4.1);
- Permanent organic soil cover, through the establishment and maintenance of an organic soil cover in the form of a mulch;
- Integrated soil fertility and acidity management;
- Integrated weed management;
- Integrated pest and disease management; and
- Integration of livestock and crop farming.

**Photo A4.1**  Examples of (left) a cover crop and (right) of intercropping (Smith, 2014)

In the case of smallholder farmers, the overall goal is to mainstream sustainable use and management of natural resources to and through farmers, to ensure food security and income.

Extensive research has shown that CA can definitely serve as an adaptation strategy, with significant economic and biological benefits, through increased crop yields and net farm income.
Successful adoption of CA has already taken place among grain and sugarcane farmers in Kwa-Zulu Natal, as well as among grain farmers in the Western Cape and Free State, but has remained rather slow in other production areas of South Africa. The main reasons for adopting CA relate to the improved water conservation properties and the ability to substantially lower production costs. To date, South Africa has lagged behind in adapting to long term sustainable production practices. Some aspects of CA are elaborated upon below.

**Catch Crops**

The provision of temporary vegetative cover between agricultural crops, which is then ploughed into the soil is termed a catch crop, or green manure. Winter cover crops are also in this category. These catch crops add C to soils and may also extract plant-available N unused by the preceding crop, thereby reducing N$_2$O emissions and reducing amount of fertilizer N that needs to be added.

**Zero Tillage**

Advances in weed control methods and farm machinery now allow many crops to be grown without tillage (zero tillage or no till). In general, tillage promotes decomposition, reducing soil C stores and increasing emissions of GHGs, through increased aeration, crop residue incorporation into soil, physical breakdown of residues, and disruption of aggregates protecting soil organic matter. Therefore zero tillage often results in soil C gain.

**Reduced Tillage**

Reduced, or conservation, tillage can take many forms including ridge tillage, shallow ploughing and rotovation, or scarification of the soil surface. All result in less soil disturbance than conventional deep tillage with a mouldboard plough. Reduced tillage decreases decomposition, increases soil carbon stocks and decreases GHG emissions via decreased aeration and crop residue incorporation. Adopting no-till may also affect emissions of N$_2$O, but the net effects are inconsistent and not yet well-quantified.

**Residue Management**

Residue incorporation, where stubble, straw or other crop debris is left on the field, and then incorporated when the field is tilled, is used in some areas for water conservation, but it also enhances C returns to the soil, thereby encouraging C sequestration. However, incorporation can increase N$_2$O emissions and thus net benefits in terms of climate mitigation may be highest when residues with high N content are removed. Composting these residues, then returning them to the soil may reduce N$_2$O emissions in relation to incorporation untreated, while retaining benefits in terms of reduced requirements for mineral fertilizer. Therefore the main types of residue management have different effects on carbon and nitrogen, such as leaving crop residues on the field instead of burning or removal, or composting of crop residues and returning them to the field (See Photo A4.2).
Extensification
This implies decreasing crop production per ha, achieved by decreasing fertilization rates (fertilizer and animal manure) and reduced tillage (number of times and/or depth).

Optimising Fertilizer Application
This measure can be subdivided into three options, viz.
- changing fertilizer rates,
- fertilizer placement / precision farming and
- fertilizer timing / split application.

Being more efficient in one’s fertilizer application (at the right time of the crop growth and under the most optimal weather and soil conditions) gives a change to lower the fertilizer rates. Precision farming and placement is giving the right amount of fertilizer at the right time and can reduce fertilizer use. A correct timing of fertilizer application, e.g. not under wet conditions which lead to a higher emission, as well as split applications of N, will lower the emission of N₂O.

Fertilizer Type
Three types of fertilizer exist, viz.
- standard fertilizers,
- fertilizers with nitrification inhibitors, and
- slow release fertilizers.

Each type and each sub-type within the types have their own influence on the emission of ammonia (related to crop type, e.g. arable / grass, and also temperature, soil type etc.). Optimising the choice of fertilizer might therefore decrease emissions of N₂O. Nitrification inhibitors are compounds which prevent the turnover of ammonia into nitrate. They can be applied in animal manure and fertilizer and can lead to a decrease in fertilizer use or a higher N uptake in arable crops and grassland. Slow release fertilizers are fertilizers in which N is slowly released. So there might be less losses of fertilizer and fertilizer application can be reduced. They also reduce the emission factor of N₂O from fertilizer.

Adding Legumes
Adding nitrogen-fixing crops such as beans, peas, soya or clover to rotations of cereals reduces N fertilizer requirements and related emissions, and can increases soil organic carbon. Legumes can be included into cereal rotations as a separate crop, as a second crop (when the land would otherwise be bare fallow) or under the major crop.

Permanent Crops
Transition from row crops to perennial grasses can increase carbon sequestration. Perennial grasses contribute to an increase in soil organic carbon (SOC) through deposition and decay of plant material on the surface and by root growth. When grasses are established on previously cultivated land, the process not only improves grassland conditions, it also results in an increase of SOC. The rate at which this occurs is determined by the particular species of grass as well as regional specific climatic and soil conditions.

Agroforestry
Growing farmland trees (e.g. tree crops, shelterbelts, hedgerow, alley cropping; see Photo A4.3) is a practice of allowing trees and crops to grow together. Windbreaks and shelterbelts are single or multiple rows of trees or shrubs planted for environmental purposes. Alley cropping can be implemented in marginal agriculture. Research has documented optimal
tree planting levels to be from 3 to 6% of the cropped field area. The species, location, layout, and density of the planting depend on the purpose and planned function of the practice. The best trees to grow together with crops are those with deep roots so they do not compete with crops for water and nutrients.

Photo A4.3  Example of agroforestry (R.E. Schulze)

**Grass in Orchards and Vineyards**
Growing grass will protect soil the soil against erosion and improve soil properties on orchards and vineyards. Grass usually is ploughed under or desiccated to accommodate the primary crop being produced on the site. This practice is used to control erosion, add fertility and organic material to the soil, improve soil texture, and increase infiltration and aeration of the soil.

**Optimising Grazing Intensity** [see Photo A4.4]
This method consists of adjusting the size of the herd to the grazing capacity of the area. This practice enhances soil C sequestration by reducing soil disturbance and increasing the amount of plant biomass carbon added to the soil. Furthermore, grazing leads to higher C stocks compared with cutting. A good implementation of rotational grazing may greatly improve manure distribution across growing pastures, reducing maintenance fertilizer requirements or even eliminated them.

Photo A4.4  Non-optimal grazing intensity (R.E. Schulze)
Length and Timing of Grazing
This measure can be subdivided into two measures:

• Emission of N₂O is higher under wet conditions so no grazing during wet periods will decrease emission of N₂O. Wet conditions in South Africa depend on whether one is in the summer, winter or all year rainfall regions, the locations of which are projected to change under future climates.

• The emission factors for grazing are higher than the sum of emissions from a stable and applying animal manure (liquid manure). So for the emission of N₂O it would be better to have animals kept in the stable (in case of liquid housing systems).

An advantage of both measures is that stable manure can be applied under more controlled circumstances than deposited manure (and urine patches). This therefore reduces use of fertilizer and decreases emissions of N₂O. However, stabled animals require feed to replace grazing and therefore may require more use of concentrates and/or conserved grass. This will lead to a higher energy consumption which will enlarge the emission of CO₂.

Grassland Renovation
In order to establish new and better consociations, a direct human-controlled effect on grasslands species composition can be achieved by a controlled deferred grazing, temporarily closing to the animals the areas chosen to freely evolve, normally by letting the desired grasses to enter the graining phase and disseminating the seeds, consequently increasing their presence in the community of plants. The practice must be followed by a thorough grazing management in order to allow the growth of the chosen species. Clearly fundamental, therefore, is the timing of grazing on the grasslands, paying particular attention to the flowering/graining phases of the species and the subsequent presence/absence of the livestock over the area. Deferred grazing is a particular kind of the practice described above.

Optimising Manure Storage
Improper management of manure or slurry, including poorly designed storage, can lead to significant GHG emissions. It is estimated that between 5 to 30% of global CH₄ emissions are derived from livestock manure. Such emissions are affected by

• the type of livestock,
• storage conditions (slurry, solid etc...) and temperature.

Therefore, appropriate storage and management of manure are of special importance. The following activities should be considered:

• Covered storage in tanks: This reduces surface area.
• Composting: CH₄ originated from manure is produced by anaerobic decomposition of organic matter, therefore the processes that promote aerobic decomposition, such as composting, will result in less CH₄ emissions. A good composting process, as well as sufficient oxygen supply, has to be guaranteed in the manure heap, especially after solid fraction separation from slurry, otherwise overall emissions may not decrease.
• Passively aerated compost: To increase aeration and promote the composting process, it is possible to place plastic pipes on the bottom of compost bins, which have a chimney-like effect, caused by exothermic reactions occurring inside the manure, that force outside intake oxygen to pass through the composting material.
• Reducing airflow: Emissions may be reduced by preventing air exchange between the stored excreta and the atmosphere, either by covering slurry or by reducing air exchanges between the slurry pit and the air in indoor storage.
• Lowering pH: Changes in the balance between ammonia and ammonium inside slurry storage may reduce emissions, and can be achieved by lowering the pH value of the slurry using either inorganic or organic acids.
• Cooling: Reducing stored manure temperature, as well as providing better aeration, may result in a decrease CH\(_4\) emissions since, as temperature increases, higher rates of methanogenesis occurs in all manure storage types, especially in slurry.

**Application Techniques for Manure**
The application techniques used to supply manure to fields may strongly affect GHG emissions, e.g. avoiding application of manure in autumn / winter results in higher use efficiency of N manure, thus causing a general decrease of emissions. Also, application techniques such as deep incorporation or injection can contribute to reductions of emissions, as slurry is introduced under the topsoil layer.

**Application of Manure to Cropland vs. Grassland**
There are two scenarios for manure application at a location and what other additions will be necessary on the land which it is not applied to, viz. applying all manure to grassland and using mineral fertilizers on cropland only, or applying all manure to cropland and using mineral fertilizers only on grassland.

**Management of Organic Soils (Peatland Restoration and Management)**
Organic soils contain high densities of C, accumulated over many centuries, because decomposition is suppressed by absence of oxygen under saturated / flooded conditions. To be used for agriculture, these soils are drained, which aerates the soil, favouring decomposition and therefore high fluxes of CO\(_2\) and N\(_2\)O. Methane (CH\(_4\)) emissions are usually suppressed after draining, but this effect is far outweighed by pronounced increases in N\(_2\)O and CO\(_2\). Therefore, organic soils used for agriculture make a significant contribution to climate change. The most important mitigation practice, is avoiding the drainage of these soils in the first place, or re-establishing a high water table where GHG emissions are still high.

Many areas of organic soils in South Africa which are currently used for agriculture were drained in the past and therefore have artificially reduced water tables. Measures to undo this artificial drainage, such as blocking drainage pipes, mitigate GHG emissions and have a beneficial impact on carbon storage. A full GHG budget reveals a clear climatic benefit of rewetting drained peats. Blocking old drains may also be worthwhile to reduce erosion and physical removal of C stocks, as research suggests that subsurface piping increases over time causing particulate carbon loss from drained peat slopes to increase exponentially. Once the measure is in place, the mitigation effects will continue year on year without further intervention.

**Conservation, Preservation and Management of Ecosystem Services**
Agriculture related ecosystem services include providing biodiversity, enabling optimal primary production as well as maintaining hydrological and nutrient cycles. The following inter-related factors should therefore be prevented, viz.
• **Land Degradation**, i.e. the persistent reduction or loss of land ecosystem services, notably the primary production service (see Photo A4.5);
Photo A4.5  Examples of land degradation in the Eastern Cape (R.E. Schulze)

- **Soil Degradation**, i.e. the processes by which soil declines in quality and is thus made less fit for a specific purpose, such as crop production;
- **Soil Erosion**, i.e. the loss of soil through water or wind and a major cause of degradation; and
- **Soil Fertility Decline**, defined either as the loss of key nutrients or as the decline in the capacity of soil to support high biological production.

**Integrated Soil Management (ISM)**
This may be defined as a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm, combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles.

**Organic Agriculture**
This relies on natural or non-synthetic resources to provide nutrients to the soil and control pests, diseases and weeds. By “mimicking nature” and making use of natural ecological processes such as building up soil organic matter and biota, recycling and composting crop residues and integrating the nitrogen fixing properties of legumes, organic agriculture seeks to improve soil fertility while exerting minimal environmental impact.

**Barriers to the Adoption of CSA by South African Farmers** [Adapted from Chauke et al., 2014]

Despite scientific evidence on the threat of climate change, knowledge on options to mitigate GHG emissions, or options to sequester carbon, as well as widely known options to conserve soil, water, nutrients, biodiversity and the atmosphere, and knowledge on cost-effective food production technologies, there remain some major constraints as to why CSA is being adopted so slowly in South Africa. These include a number of risks and uncertainties, including

- **Production risk** in respect of complex soil-water-climate-plant-animal interrelationships, degraded natural resources and climate change;
- **Economic risk**, which have to do with markets, price fluctuations, currency volatility and trade barriers / constraints;
- **Financial risk**, which implies credit and capital availability, production costs or cash flow;
- **Social and human capital risk**, i.e. on knowledge, skills and confidence to manage risk, socio-cultural issues in communal areas, labour aspects, and/or poor local and farmer institutions; and
- **Institutional / legal risks** in regard to labour, as well as environmental / conservation legislation frameworks.

The essence of the inability and / or unwillingness of especially poorer farmers to adopt CSA is that they are often not empowered to do so because of

- a lack of awareness of, and knowledge on, CSA,
- the complexity of technology and new systems,
- technology being too expensive,
- the farmer’s mindset and perceptions not yet geared towards CSA,
• constraints as a result of traditions,
• labour and physical implications,
• the farmer’s planning horizon being short, and therefore longer term benefits are not appreciated,
• management conflicts, e.g. mulch retention on the field vs. mulch as livestock feed,
• a lack of managerial skills, e.g. when it comes to irrigated food production, or
• not being in total control on decisions because of insecurity regarding land tenure, partners, landlords or dealings with financial institutions

Overcoming Some of the Barriers to the Adoption of CSA, Especially Among Smallholder Farmers: A Public Sector Perspective [Adapted from Chauke et al., 2014]

Adoption of CSA among especially poorer smallholder farmers is a long term learning and innovation process which requires facilitation and incentives as enablers. It should be remembered that

• the process is an iterative one, is life-long and requires facilitation, monitoring, reflection, evaluation, adoption, adaptation and, once achieved, also celebration; and

• incentives are needed (see Photo A4.6) not only to kick-start the adoption process, but also to reward positive behaviour / good practices and to support continuation, with incentives including, inter alia,
  - Payment for Ecosystem Services (PES), which could be very effective to stimulate adoption, or
  - the distributing of appropriate equipment and materials, preferably awarded on performance

Photo A4.6  Examples of incentives following the adoption of CSA (Chauke et al., 2014)

Furthermore, the adoption of CSA implies
• Season-long training processes and social learning, with training sessions on
  - sustainable land management and soil health,
  - an introduction to conservation agriculture and land preparation,
  - integrated soil nutrient management,
  - integrated weed management, and
  - integrated pest and disease management as well as
• Monitoring and evaluation, with
  - an M&E committee,
  - farmers assessing and analysing indicators, and possibly
  - a tool - farm quality card,
  and also
• Social learning in frequent forum and small group meetings (see Photo A4.7).
Photo A4.7  Example of training session and social learning (Chauke et al., 2014)

Overcoming Some of the Barriers to the Adoption of CSA, Especially Among Smallholder Farmers: A Private Sector Initiative and Perspective [From Smith, 2014]

An example of a private sector / non-governmental initiative to providing an enabling environment for mainstreaming CSA in South Africa is that of The Maize Trust / Grain SA’s CA-Farmer Innovation Programme (Figure A4.8), the central tenet of which is that

‘Everything we do for (preferably 'with') farmers, will only be sustainable and successful to the extent that we respect, acknowledge and accept farmers as innovators’

and that the initiative is

‘driven by farmers and encouraged and supported by outsiders’,

implying that farmers empowerment is a central issue. The key strategic objectives of this initiative are illustrated in Figure A4.9.

![Figure A4.8](image_url)  Central concepts of the enabling environment for mainstreaming CSA embodied in The Maize Trust / Grain SA’s CA-Farmer Innovation Programme (Smith, 2014)
Principles of farmer-centred Innovation include the following:

- learning is a process, not a package, and one learns by doing, by actions and by discovering,
- learning activities are farmer-led;
- farmers learn from mistakes, by trial and error;
- one has to learn how to learn (and how to adapt);
- the farmer’s field is the learning ground;
- extension workers are facilitators, not teachers; and
- the systematic (season-long) training process should take place in the farmer’s real environment (and not in a city conference centre)

In regard to farmer-led experimentation

- the aim is to build on, and improve, the farmers’ inherent capacity to being a researchers by improving their capacity to be innovative, i.e. the farmer is the researcher (i.e. farmer-led)
- while others, such as colleagues or advisors are facilitators;
- with the farmers’ observations and analyses to be used and improved upon;
- and farmers doing their own trials, including monitoring and evaluation;
- with all others being interested and willing co-researchers.

More on Technological Innovations in CSA, Barriers to Technological Solutions and Interventions to Address Barriers [Further Reading: Long et al., 2016]

The major barriers experienced by providers of technological innovations to CSA include

- difficulty in demonstrating value,
- access to investment,
- an ‘unsympathetic’ regulatory landscape, and
- difficulty reaching customers.

By contrast, users identified

- lack of awareness,
- high costs,
- long return on investment periods,
- lack of verified impact, and
- regulatory issues.

In regard to interventions to address these obstacles, research indicates that many of the demand-side barriers can be traced back to limited understanding of user needs by those who design innovations. On the supply side, providers struggle to access customers and demonstrate the impact of their technologies. One solution to this may be that greater engagement with users early on in the design process (“co-creation”) could alleviate both problems. Policymakers also have a role to play in climate-smart agri-technological innovation, including state support for start-ups and equivalent demand-side measures such as tax breaks, which could reduce cost and increase return on investment for users. Furthermore, providers should be helped to develop business models and demonstrate the
benefits of their technologies, potentially with a labelling scheme, to provide reassurance to end-users. There should also be support for increasing compatibility between CSA objectives and regional, national and even pan-Africa wide policies, while awareness of CSA should be improved through education programmes and campaigns.

Where to, South Africa, with Climate Smart Agriculture, from a Policy Perspective? [Further Reading: COMESA et al., 2015]

Using some ideas developed in the “Concept Note on Enhancing African Countries’ Readiness to Upscale Climate Smart Agriculture” as a point of departure, the building blocks for CSA policy implementation at country level (Figure A4.10) consist of

- assessing the situation
- identifying barriers and enabling factors,
- managing climate risk
- defining coherent policies, and
- guiding investments.

The overall objective is to enhance a country’s readiness to adopt and upscale CSA, and some more specific objectives for South Africa could be to

- support an integrated approach to the development and implementation of national climate change, agriculture and sustainable land management policies, strategies and action plans;
- support the establishment / strengthening of CSA centres of excellence with a robust CSA knowledge management (technological and indigenous) with strong links to centres of excellence in climate knowledge and information services (regional, sub-regional and national), policy makers and farmer and community institutions; and to
- support the development of financing mechanism for both innovators and users, be they subsistence or commercial farmers.

Figure A4.10 The building blocks for CSA policy implementation at country level (Source: Not known)

In regard to policy instruments for agriculture, climate change and for sustainable land management to be in place and be implemented, some key activities of, say, the South African Department of Agriculture, Forestry and Fisheries could be to take the initiative and lead (where it has not already done so) in
• formulating and implementing integrated agriculture and agriculture related climate services, in initiating regular updates on climate change adaptation and mitigation, strategies and action plans;
• taking stock of, and engaging a move towards greater policy integration and coherence across agricultural, sustainable land management, environmental, water and energy policies and investment frameworks in order to maximize adaptation co-benefits;
• mainstreaming CSA into the equivalent of the South African National Agriculture Investment Plan; and
• upscaling CSA in all its facets to becoming a central issue in the nation’s agricultural vision for the future.

Private sector involvement in CSA should also be enhanced, for example by
• identifying policy interventions and incentives to unlock private sector investment and engage governments on policy reforms to facilitate their engagement in CSA value chain; and
• identifying areas of possible Public Private Partnership for investment in the CSA value / production chain,

while farmer and community institutions should be strengthened by
• an assessment of the capacity needs of especially the subsistence farmer and farmer organisations / community institutions involved in the CSA value chain, and by
• provision of technical and financial support to farmers and farmer organisations / community institutions to enable them play the critical role in upscaling CSA in their respective regions.

In regard to strengthening national and SADC level institutions, there is a need for
• further provision of technical and financial support to meteorological / climate services to enable them develop tailored climate forecast products to inform decisions across all stages of the CSA value chain; and for the
• further development and implementation of a weather based agricultural advisory tool for decision making in CSA, ideally to be centrally hosted, but with dynamic web-links to farmers and stakeholder institutions.

Climate smart agriculture needs to be upscaled, which can be achieved, inter alia, by
• support for a number of pilot CSA projects as a learning ground for farmer and agricultural institution alike, as well as by
• developing and disseminating tools and indicators for measuring, reporting and verification of CSA interventions at the landscape level.

Some Concluding Thoughts [Adapted from Chauke et al., 2014; Smith, 2014]

CSA is needed to gain permanent, long-term food security in South Africa, as well as being a key concept in adaptation to, and mitigation of, climate change, and carbon sequestration benefits. The following are therefore important to note:
• Farmers must be aware of the threats of climate change and, for reason alone, should adopt CSA practices.
• CSA is site specific, but is never applied in isolation - crop and livestock farmers, pastoralists, fishers and foresters are integrated land management partners.
• Any enabling policy environments, or technologies or methodologies, are incomplete without adoption of CSA by farmers, and farmers need to be empowered for this adoption. This empowerment requires explicit and constructive attention – an element that is not currently a significant dimension of most (mainstream) agricultural research and development agendas.
• Adoption is highly complex and multi-factor issue and it is a subjective-objective decision process underpinned by risks / uncertainties of production, to which climate change adds another layer of stress.
• Scientists, practitioners, policy makers and strategists should not underestimate the intricate, essential innovation / adoption process involved with CSA and they should be sensitive to the situation and needs of potential adopters, i.e. the farmers.
• State and private initiatives build and channel resources (funding, capacity, etc.) to facilitate farmer empowerment approaches, which are needed to transform food producers to climate smart food production and food security.

Furthermore,
• Local CSA systems can only be improved in situ (“where they are”) and by those who are managing them (the farmer).
• Agricultural Innovation Systems are the bridges between Science and Society (i.e. the farmers), potentially allowing different schools of R&D thinking to inform and complement each other well (if it is explicitly included and structured).
• Finally, and to reiterate: Farmers should be the key (central) partner for CSA mainstreaming.

Further Reading

COMESA, ACPC, CGIAR and CCAFS, 2015. Concept Note on Enhancing African Countries’ Readiness to Upscale Climate Smart Agriculture.
Smith, H. 2014. Climate-smart dissemination methodologies. GrainSA, Pretoria, RSA. Presentation at the CSA DAFF Workshop, Kempton Park, RSA (Available from the Chapter Author)
SECTION K  WHERE TO FROM HERE?

CHAPTER K1  IN THE FINAL ANALYSIS... WHERE TO FROM HERE?

R.E. Schulze

Where to From Here?
Economic Perspectives
Relevant Issues on the Way Forward
Other Key Questions
Continuing to Monitor, Analyse and Learn
Further Reading

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K1 IN THE FINAL ANALYSIS… WHERE TO FROM HERE?

Where to From Here?

An obvious question which arises at the conclusion to this Handbook is “Where to from here?” Listed below are some issues that require further attention:

• climate change impacts on South Africa’s agriculture sector must be viewed as part of a continuum of climate related impacts, which cross the spectrum from the
  - immediate future, with timeframes from the “now” state of climate from the near real time and to lead times of a few days only, and in which operational decisions of immediacy need to be made, to the
  - near future, in which tactical decisions for the next weeks and months up to a season ahead need to be made, to the more
  - long term future, which has been the focus of this Handbook and which requires strategic decisions to be made with timeframes of years to decades, and which include mainstreaming climate change more explicitly into legislation and policy, and through that also into practice; that
• outputs from more, and from the next generation of, appropriately downscaled and bias corrected GCMs based on a range of emissions scenarios, need to be evaluated and many sections of this Handbook need to be re-assessed with outputs from those GCMs so as to gain further confidence in results for South Africa; that
• in addition to assessing projected changes to crop yields or shifts in optimum growing areas solely from a perspective of climatic suitability, some real world constraints and factors be introduced, for example, in regard to
  - physical constraints, factors such as slope gradients, soil suitability, occurrence of wetlands, floodplain buffer zones and the like,
  - developmental constraints, considerations on existing urban areas, mines, roads, rail lines and their reserves, or proclaimed conservation areas (e.g. game reserves, heritage sites etc.) which cannot be used for agricultural expansion,
  - economic constraints, such as crop prices, or the cost effectiveness of producing alternative crops etc., or
  - political constraints, such as potential impacts of land transformation on national and local food security under conditions of climate change.

Furthermore, other
• higher order consequences of ramifications and knock-on effects of climate change in the agricultural sector of South Africa need be addressed through sector and region targeted workshops with farmers and officials on both adaptive (autonomous) management options (i.e. learning by experiencing) and on planned adaptation strategies.

Economic Perspectives

From an economic perspective a number of issues raise their head as being important:

• It will be important to undertake impact and adaptation studies “beyond the farm gate” of crop yields into crop related value chain analyses of those components where climate and climate change are relevant.
• Additionally, large-scale and long time-horizon estimates of potential damages associated with climate change are useful in assessing the order of magnitude of what climate change could cost on a sectoral basis (e.g. the agriculture sector as a whole or specific crops / commodities) as well as on a geographical basis (e.g. the costs to individual farmers, to provinces within South Africa, or to the country as a whole, or to the SADCC region).
• When the certainty of impacts of projected climate change on South Africa’s agricultural sector becomes better understood as we head into the future, attention has to turn to a
more detailed and holistic view of the economic consequences of climate change that focus even more on the benefits of adapting vs. the potential costs of not adapting, than has been the case in this Handbook.

Relevant Issues on the Way Forward

Howden et al. (2007) raise very relevant issues regarding the way forward, and some of those which are relevant to the South African situation are highlighted here:

• **Baseline Studies as a Point of Departure**
  Robust estimates of baseline impacts are necessary before reliable assessments of the costs and benefits of adaptations can be made.

• **Improved Understanding**
  There is substantial room for improving our understanding of how combinations of various factors such as CO₂, temperature and rainfall, as well as pests and diseases affect various agricultural systems and how management responses will interact with these.

• **Adaptive Capacity**
  - Agriculture in South Africa remains sensitive to climate variability and the capacity to manage this risk is highly variable from location to location and from farming sector to farming sector within the country.
  - Given that climate change is highly likely going to be expressed, *inter alia*, through changes in variability into the future and to individual events (e.g. exceedance of critical thresholds), enhancing the capacity to manage climate risk is a core adaptation strategy.
  - The ability to map this adaptive capacity would provide critical information for policy and the agriculture sector to better target capacity-development programmes. However, this adaptive capacity mapping and analysis needs to be refined to being localised and tuned to the needs of specific agricultural commodities and issues such as needs of, for example, subsistence farmers vs. those of commercial farmers.
  - Developing adaptive capacity involves increasing the “climate knowledge” of farmers, commodity sectors and decision makers alike, so that they become more cognisant of climate impacts on their systems and of how to use management options to intervene, thereby reducing negative impacts and optimising opportunities that might arise.
  - It also means moving the focus from adaptation to climate change towards management of climate risk, i.e. integrating climate change into a broader research domain.

• **Effectiveness of Adaptation vs. Rates of Adaptation**
  The results of adaptation will be a function of both the likely technical *effectiveness* of adaptations and the *rates* at which they can be adopted. However, there is a paucity of studies in South Africa (or globally for that matter) that have assessed these two components in a thorough way, especially for higher levels of climate change and for more vulnerable systems.

• **Stakeholder Engagement**
  In particular there is a need to engage with stakeholders in a structured way to assess how fast adaptation options can be adopted. These could focus on the acceptability of adaptation options in terms of the factors important to the stakeholders and their perceptions of synergies and barriers. Particular interest to major commercial players within the South African agriculture sector may be on issues concerning:
  - the costs and benefits of adaptation when both market and non-market values are taken into account,
  - the feasibility and costs of simultaneously reducing greenhouse gas emissions and adapting to climate change,
  - the effect of limitations in capital and other resources such as irrigation water, energy and fertilizer and pesticides (due to environmental concerns), and
the adoption rates of adaptation in highly impacted areas if food prices were to decline as a result of positive climate change impacts, and / or land use intensification in temperate regions, or if demand for biofuels increases competition for land.

Other Key Questions

Some other key questions, which have important implications for both research and public policy in South Africa, have also been identified:

• One central question is on the mix between adaptation in agriculture that is specifically driven by policy decisions vs. adaptation that takes place autonomously in response to the conditions that farmers, and the sector as a whole, experience. In South African agriculture this mix will depend critically on how well information (for example, from this Handbook) can be assimilated by both farmer and policy maker, and acted upon, again by both farmer and policy maker. This implies making use of
  - workshops at provincial, farmer association and farming commodity (e.g. the dairy industry) levels, and
  - the literature read by the farmer on the ground, e.g. Farmers Weekly and learning as much from those workshops as teaching / informing.
• A second, more conceptual, key question is whether climate change poses a discontinuous set of challenges which are different from those faced by, for example, poor livelihood farmers who are vulnerable to both environmental and economic stressors. This question is related to the broader one on how adaptation fits into the more overarching question of economic and social development. The question is essentially whether the move out of the poverty trap and into a position of more wealth is a more effective adaptation strategy than specific environmental and infrastructure investments and actions. In South Africa this move will depend on a number of factors, including farmers (especially subsistence farmers) being subject to cultural constraints, being hampered by poor service delivery by government and on the nature of the disruption of environmental services by climate change.
• A third question posed in the policy and economic literature is whether adaptation is merely a substitute for mitigation, or whether it complements mitigation by asking whether efforts to reduce the risks of climate change through adaptation reduce (or increase) the value of reducing greenhouse gases. In a lesser developed South African context the more appropriate question posed is rather, which is a higher priority for the use of the relatively scarce domestic resources available in our country to address the risks of climate change: mitigation or adaptation?
• The priority for South Africa’s agricultural sector at this point in time must surely be adaptation.

Continuing to Monitor, Analyse and Learn

In the final analysis, and reiterating partially what has already been mentioned indirectly above,

• when assessing the risks of climate change and developing effective response strategies, we have to take into account the many uncertainties in the underlying socio-economic, political and technological drivers of climate change, as well fundamental uncertainties in understanding the climate system.
• Given these uncertainties there is a need for directed focus in management, science and policy to continue to monitor, analyse and learn, so as to iteratively and effectively adjust one’s planning and decisions to the actual climate changes that are likely to be experienced by the various South African farming communities in the coming decades.
Further Reading


Appendix 1: Tools Used in this Handbook

R.E. Schulze

Spatial Databases 1: The Concept of Quinary Catchments

*Before Quinaries*

| Figure A5.1 | Primary and Quaternary catchments covering the RSA, Lesotho and Swaziland (After Midgley et al., 1994) |

*The Development of Quinary Catchments*

| Figure A5.2 | Flowpaths between Quinary and Quaternary Catchments |
| Figure A5.3 | Delineation of the RSA, Lesotho and Swaziland into 5 838 agriculturally and hydrologically relatively homogeneous Quinary Catchments (Schulze and Horan, 2010) |

Further Reading

Spatial Databases 2: From Quinaries to a Quinary Catchments Database

- Daily Rainfall Input per Quinary Catchment under Baseline Historical Conditions
- Daily Temperature Input per Quinary Catchment
- Soils Information
- Baseline Land Cover Information

Further Reading

Climate Databases: Present and Future Climate Scenarios Based on Global Climate Models (GCMs)

- The ‘Generic’ Dilemma of Projecting Future Climates with GCMs
- Uncertainties Inherent in GCMs
- Addressing Shortcomings of GCMs for Applications in this Handbook

Further Reading

Climate Change Scenarios Used in this Study

- Introduction
- The GCMs Used

Further Reading

Simulation Models: Crop Yield Models

- What are Crop Yield Models?
- On Issues of Model Complexity in Crop Yield Models and the Approaches Adopted in this Study

| Table A5.1 | Attributes of biomass/crop yield models of different complexity (After Schulze et al., 1995) |

*The Smith Rule Based Suite of Models: Application of a Simple Crop Yield Model*

| Box A5.1 | Estimation of Dryland Winter Wheat Yield, Based on Smith’s Climatic Criteria |

*The DSSAT Crop Systems Model: Application of a Complex Crop Yield Model*

*APSIM, the Agricultural Production Systems Simulator: Application of a Further Complex Crop Yield Model*

*The AQUACROP Model*

Further Reading

Simulation Models: The ACRU Agro-Hydrological Model

- Background 1: The Use of Models to Evaluate Agro-Hydrological Responses
- Background 2: From Model Input to Model Output

*Concepts of the ACRU Model*

| Figure A5.4 | ACRU: Concepts of the modelling system (Schulze, 1995) |
| Figure A5.5 | ACRU: Model structure (Schulze, 1995) |
In a Handbook on adaptation to climate change in the South African agriculture sector a number of “tools” are used in various assessments. These are outlined below.

Spatial Databases 1: The Concept of Quinary Catchments [Schulze and Horan, 2010]

Before Quinaries
Forerunners to the present Department of Water and Sanitation delineated the RSA, Swaziland and Lesotho into 22 Primary Catchments, which in turn were disaggregated into Secondary, then Tertiary and finally, into 1 946 interlinked Quaternary Catchments (QCs), as shown in Figure A5.1. This “fourth level” of discretisation has, to date, constituted the most detailed spatial level of operational catchment in the DWS for general planning purposes.

![Figure A5.1 Primary and Quaternary catchments covering the RSA, Lesotho and Swaziland (After Midgley et al., 1994)](image)

The Development of Quinary Catchments
Schulze and Horan (2010) showed that many fourth level Quaternary Catchments in southern Africa are physiographically too diverse for agricultural and hydrological responses from them to be considered relatively homogeneous. By applying Jenks’ optimisation procedures available within the ArcGIS software suite, a three-fold altitude break based sub-delineation of QCs into fifth level Quinary Catchments (the Upper, Middle and Lower Quinaries of a QC) was then carried out. These Quinary Catchments were then configured within the QC configuration, such that the outflow of the Upper Quinary enters the Middle, which in turn flows into the Lower Quinary. However, the Lower Quinary outflow of a QC does not enter the Upper Quinary of the next downstream Quaternary Catchment, because that QC’s Upper Quinary may be at a higher altitude than the Lower Quinary of the immediate upstream Quaternary. Therefore, the outflow of the Lower Quinary has been configured to rather enter the downstream Quaternary at its exit (Schulze and Horan, 2010). A schematic of the flowpath configuration between Quinaries and Quaternaries is illustrated in Figure A5.2.

![Figure A5.2 Flowpaths between Quinary and Quaternary Catchments](image)

The sub-delineation of Quaternary into Quinary Catchments resulted in 5 838 hydrologically interlinked and cascading Quinaries (Figure A5.3) covering the RSA, Lesotho and Swaziland. These have been demonstrated to be physiographically considerably more homogeneous than the
Quaternaries (Schulze and Horan, 2010) and on a national and smaller scale are considered to be relatively homogeneous hydrological as well as agricultural response zones.

![Figure A5.3 Delineation of the RSA, Lesotho and Swaziland into 5 838 agriculturally and hydrologically relatively homogeneous Quinary Catchments (Schulze and Horan, 2010)](image)

Further Reading


Spatial Databases 2: From Quinaries to a Quinary Catchments Database [Further Information: Schulze et al., 2010]

Following the delineation of the southern African countries of the RSA, Lesotho and Swaziland into Quinary Catchments, a Quinary Catchments Database, QnCDB, was established. A summary of the key climatic and catchment input into the QnCDB, and the link to the ACRU agro-hydrological model (see later in this Chapter) is described below.

**Daily Rainfall Input per Quinary Catchment under Baseline Historical Conditions**

Rainfall is generally considered to be the most important input into any agricultural or hydrological model. Methods for the estimation of daily rainfall values for simulations under baseline historical climatic conditions are described below.

A comprehensive database (1950-1999) of quality controlled (and infilled where necessary) rainfall data consisting of > 300 million rainfall values from 12 153 daily rainfall stations in southern Africa was compiled by Lynch (2004). From that database, a rainfall station had to be selected for each of the 5 838 Quinary Catchments, with that station's data considered representative of the daily rainfall of that Quinary (see Schulze et al., 2010 for details). In total 1 240 high quality rainfall driver stations selected to generate the 50 years of daily rainfall for each of the 5 838 Quinary Catchments. The
selection of driver stations was followed by the determination of multiplicative month-by-month rainfall adjustment factors (from the one arc minute raster of median monthly rainfalls created by Lynch, 2004) for each Quinary Catchment and these were then applied to the driver station’s daily records in order to render the driver station’s daily rainfall to be more representative of that of the Quinary. This resulted in a unique 50 year daily rainfall record for each of the 5 838 Quinaries for application with the ACRU model (Schulze, 1995).

**Daily Temperature Input per Quinary Catchment**

Daily maximum and minimum temperature values facilitate estimations to be made, either implicitly or explicitly, of solar radiation, vapour pressure deficit and potential evaporation. Using these variables, in addition to rainfall, as input into agricultural and hydrological models, the generation of crop yields, soil moisture content, runoff and / or irrigation demand becomes possible. A summary of the methodology for estimations of daily maximum and minimum temperature values, as described in detail by Schulze et al. (2010) under baseline historical climatic conditions, is given below.

Procedures outlined in detail by Schulze and Maharaj (2004) enable the generation of a 50 year historical time series (1950-1999) of daily maximum and minimum temperatures at any unmeasured location in the RSA, Lesotho and Swaziland at a spatial resolution of one arc minute of latitude / longitude (~1.7 x 1.7 km) for the 429 700 grid points covering the region. At each of these 429 700 grid points the maximum and minimum temperatures were computed for each day of the 50 year data period from two selected, independent temperature stations and by use of regional and monthly lapse rates (Schulze and Maharaj, 2004). At each grid point the daily values derived from these two stations were then averaged in order to modulate any biases (from lapse rates or station data) emanating from either of the two stations’ generated records (Schulze et al., 2010). Excellent verifications of results from this methodology were achieved (Schulze and Maharaj, 2004).

From the study of Schulze and Maharaj (2004) representative grid points were determined for each of the 5 838 Quinary Catchments covering the study area, using techniques outlined in Schulze et al. (2010). The resulting 50 year series of daily maximum and minimum temperatures for each Quinary Catchment was then used to generate daily estimates of solar radiation and vapour pressure deficit, details of which are described in Schulze et al. (2010). From these, daily values of reference potential evaporation as well as potential crop evapotranspiration could be computed.

**Soils Information**

For multi-soil horizon water budgeting using the QnCBD the following soils variables were input to each Quinary:

- thickness (m) of the topsoil and the subsoil;
- soil water contents (m/m) at saturation (porosity), drained upper limit (also commonly referred to as field capacity), and permanent wilting point (i.e. the lower limit of soil water availability to plants);
- rates of saturated drainage from topsoil horizon into the subsoil, and from the subsoil horizon into the intermediate groundwater zone, and the erodibility of the soil (Schulze et al., 2010).

Values of these variables, derived by Schulze and Horan (2008) using the AUTOSOILS decision support tool (Pike and Schulze, 1995 and updates) and applied to the soils database from the Institute for Soil, Climate and Water, were then determined for each Quinary using methods described in Schulze et al. (2010).

**Baseline Land Cover Information**

In order to assess impacts of climate change on hydrological responses, a baseline land cover is required as a reference against which to evaluate the impacts. For the RSA, Lesotho and Swaziland the 70 Veld Types delineated by Acocks (1988) are currently the recognised baseline (i.e. reference) land cover. Based on a set of working rules, month-by-month hydrological attributes, determined by Schulze (2004), were assigned to each of the 70 Acocks Veld Types and were incorporated into the Quinary Catchments Database. These attributes are the water use coefficient, interception loss per rainday, fraction of roots in the topsoil, root colonisation in the subsoil, a coefficient of infiltrability dependent on rainfall intensity estimates, and soil surface cover by litter, an index of suppression of soil water evaporation by a litter / mulch layer. For each of the 5 838 Quinaries in the database the
spatially most dominant Veld Type was then selected as the representative baseline land cover (Schulze et al., 2010).

**Further Reading**


**Climate Databases: Present and Future Climate Scenarios Based on Global Climate Models (GCMs)**

Weather and climate forecasts and projections of globally warmed climates into the longer term future are made with GCMs, i.e. Global Climate Models, sometimes also termed General Circulation Models.

**The ‘Generic’ Dilemma of Projecting Future Climates with GCMs** [Further Reading: Schulze et al., 2014]

Interactions between the many processes that govern the Earth’s climate are very complex and extensive, so that quantitative predictions of the impacts of increasing concentrations of greenhouse gases (GHGs) on climate cannot be made with any certainty through simple intuitive reasoning. The result is that the GCMs that have been developed, and which are mathematical representations of the Earth’s system in which physical and biogeochemical processes are described numerically to simulate the climate system as realistically as possible, are founded on assumptions of the evolution of drivers of climate change (e.g. the distributions of aerosols and GHGs), and their respective concentrations in the atmosphere all contain high levels of uncertainty. The GHG concentrations, for example, depend directly upon natural and human derived (anthropogenic) emissions, which can only be estimated through emission scenarios, developed using so-called “storylines” or “representative concentration pathways” which describe possible developments in global population growth and other aspects of the socio-economic system. These uncertain emission scenarios are then used to drive atmospheric chemistry and carbon cycle models that simulate changes in the concentration of GHGs and aerosols. The resulting concentration scenarios are then input into GCMs, which generate climate scenarios into the future that we, in turn, use to drive models of the impacts on human systems (e.g. of heat waves, or human discomfort) and on natural systems (e.g. yields of crops).

**Uncertainties Inherent in GCMs** [Further Reading: Schulze et al., 2014]
The uncertainties which are inherent in GCMs have been well documented, and these uncertainties result in certain limitations, with GCMs less capable of simulating second order atmospheric processes such as rainfall, compared to those related to first order atmospheric processes, such as
temperature. We have to appreciate these limitations of GCMs, and in regard to the agriculture sector they include:

- Failure to simulate individual convective (thunderstorm) rainfall events, owing to the coarse spatial resolutions of the GCMs, and the smaller spatial and temporal nature of convective rainfall, which poses problems over most of southern Africa summer rainfall region, where convective rainfall is a dominant form of rainfall and crucial to agricultural production;
- Difficulty in simulating the intensity, frequency and distribution of extreme rainfall events and hence the damage they could do to the farming sector, including flooding;
- Tending to simulate too many light rainfall events (< 2 mm/day) which affect plant diseases and do not enhance soil water content, and generally too few heavy rainfall events (> 10 mm/day) which produce soil moisture for the plant, whilst maintaining a fairly realistic longer term averages of rainfall; and
- Poorly representing major drivers of year-to-year climate variability, such as the El Niño phenomenon, which can severely impact on seasonal crop yields.

Addressing Shortcomings of GCMs for Applications in this Handbook

These factors tend to reduce the accuracy of rainfall output from GCMs. Therefore, there remain limits surrounding the usability of direct GCM output in detailed agricultural and hydrological studies, where precipitation, temperature and potential evaporation at the local scale are primary inputs into hydrological models.

To try and overcome these shortcomings, the ratio approach has often been adopted in this Handbook, by determining the ratio of change between (say) crop yields from future climate scenarios to present climate scenarios from GCMs on the assumption that some inherent errors in the GCMs will be at least partially self-cancelling.

Even so, outputs from GCMs remain the basis for climate change impact assessments. However, as has already been alluded to, a significant discontinuity exists between the output from GCMs (generated around a grid point every 100 km, i.e. with spatial resolutions generally around 10 000 km²) and the resolution at which local decisions are sought and local adaptation options need to be considered (generally every 3 to 10 km, i.e. with a spatial resolution of 10-100 km²). It is due to this discrepancy that GCM output needs to be translated from the coarse to more local scales by the process of regional climate downscaling which, in the case of GCMs used in this Handbook, includes correcting both temperature and rainfall values for local topographic influences, as described in detail in Schulze et al. (2014).

Additionally, since individual GCMs do not give identical values of temperature and rainfall, neither for their present climate scenarios nor for their projected future climates, outputs from a suite of GCMs are used. Averages of the GCM results are then mapped, assuming that an average is likely to give a fairer representation than any individual GCM. Using a suite of models also allows the differences among the GCMs to be quantified, thereby allowing an assessment of the confidence of outputs to be made.

Further Reading


Climate Change Scenarios Used in this Study

Introduction

Outputs from a range of sets of GCMs were used in various sections of this Handbook, and on many of the maps the multiple GCMs used are listed. All the GCMs used were accredited by the South African Long Term Adaptation Scenarios initiative of the Department of Environmental Affairs.

The GCMs Used

The first suite of climate change scenarios used were those downscaled / distributed by the

- Climate Systems Analysis Group (CSAG) of the University of Cape Town and derived from global scenarios produced by five IPCC AR4 approved GCMs, all statistically downscaled to over 2 000 climate stations in South Africa and then further bias corrected for the 5 838 Quinaries covering...
South Africa by techniques described in Schulze et al. (2010), all for the A2 “business as usual” future scenarios, and all of which were applied in the IPCC’s Fourth Assessment Report, viz.
- CGCM3.1(T47)
- CNRM-CM3
- ECHAM/MPI-OM
- GISS-ER and
- IPSL-CM4
in each case with daily values of rainfall, maximum and minimum temperatures provided (from which were computed daily values of solar radiation, maximum and minimum relative humidity and reference potential evaporation by methods given in Schulze, 2008) for three 20 year time periods, viz. for
- the present (1971-1990)
- the intermediate future (2046-2065) and
- the more distant future (2081-2100).

A second suite of climate change scenarios came from the
• CSIR, from whom 6 dynamically downscaled GCMs were obtained (Engelbrecht, 2012; pers com), each with daily values of rainfall and maximum / minimum temperatures from 1961-2100, generated by IPCC AR4 coupled climate models for the A2 “business as usual” emissions scenario, and bias corrected for local temperature and rainfall patterns by techniques described in Schulze et al. (2014) viz.
  - CCAM-CSIROmk3.5 Commonwealth Scientific & Industrial Research Organisation Mk3
  - CCAM-GFDLcm2.0 Geophysical Fluid Dynamics Lab Coupled Model Version 2.0
  - CCAM-GFDLcm2.1 Geophysical Fluid Dynamics Lab Coupled Model Version 2.1
  - CCAM-MIROC Model for Interdisciplinary Research on Climate Medium Res
  - CCAM-ECHAM5 Max Planck Institute for Meteorology Ocean Coupled Model Ver 5
  - CCAM-UKHADcm3 UK Meteorological Office Coupled Model Version 3.

The third suite of climate change scenarios were again provided by the
• Climate Systems Analysis Group (CSAG) of the University of Cape Town, again for the three 20 year periods of the present, the intermediate future and the more distant future, but in this instance for 10 GCMs in each case for both the B1 (more benign) as well as for the A2 (business as usual) emissions scenarios and, in addition to daily rainfall and temperatures, also GCM values of daily solar radiation, all downscaled for solar radiation and temperature (as well as temperature derived variables) directly to the centroids of the 5 838 Quinaries covering South Africa, but with rainfall only to the middle Quinary of Quaternary catchments, viz.
  - CCMA_CGCM3_1
  - CNRM_CM3
  - CSIRO_MK_3_5
  - GFDL_CM2_0
  - GFDL_CM2_1
  - GISS_MODEL_E_R
  - IPSL_CM4
  - MIUB_ECHO_G
  - MPI_ECHAM5
  - MRI_CGCM2_3_2

The fourth suite of climate scenarios used were from the
• World Climate Research Programme sponsored Coordinated Regional Climate Downscaling Experiment CORDEX, in each case with daily rainfall and maximum / minimum temperature (with derived daily values of solar radiation, relative humidity and potential evaporation as described in various chapters in Schulze, 2008) for the 30 year periods 1976-2005 (with historical climate) and for 2016-2045 (assuming the business as usual Representative Concentration Pathway 8.5), downscaled to the 5 838 Quinaries and then bias corrected for local topography by methods described in Schulze et al. (2014), viz.
  - CCCma-CanESM2_historical_RCA5_1976
  - CCCma-CanESM2_rcp85_RCA5_2016
  - CNRM-CERFACS-CNRM-CM5_historical_RCA5_1976
  - CNRM-CERFACS-CNRM-CM5_rcp85_RCA5_2016
  - ICHEC-EC-EARTH_historical_RCA5_1976
  - ICHEC-EC-EARTH_rcp85_RCA5_2016
  - MIROC-ESM_historical_RCA5_1976
  - MIROC-ESM_rcp85_RCA5_2016
  - MPI-ESM-LR_historical_RCA5_1976
  - MPI-ESM-LR_rcp85_RCA5_2016
  - MRI-CGCM3.0_historical_RCA5_1976
  - MRI-CGCM3.0_rcp85_RCA5_2016
  - UKCA_uk_historical_RCA5_1976
  - UKCA_uk_rcp85_RCA5_2016
  - CNRM_CERFACS_CNRM_CM5_historical_RCA5_2016
  - CNRM_CERFACS_CNRM_CM5_rcp85_RCA5_2016
  - CSIRO_MK3.5_historical_RCA5_2016
  - CSIRO_MK3.5_rcp85_RCA5_2016

84
Further Reading

Simulation Models: Crop Yield Models
What are Crop Yield Models?
In order to mimic potential impacts of climate change on crop yields, simulation models need to be employed. Crop simulation models are computer programs that describe plant-environment interactions in quantitative terms. Computer models in general are a mathematical representation of a real-world system. Thus, a crop simulation model attempts to simulate the way in which a crop responds to its environment. In reality, it is impossible to include all the interactions in the environment in a computer model. In most cases a computer model is a simplification of a real-world system and may include many assumptions.

In this Handbook both simple and more complex crop yield models were used.

On Issues of Model Complexity in Crop Yield Models and the Approaches Adopted in this Study
Different levels of complexity of crop yield models exist, ranging from relatively simple climate and soils threshold based unidirectional response models, to daily time step soil water budget and phenology driven yield functions of intermediate complexity, to the more complex daily time step physiology and genetics derived growth and yield models (Table A5.1).

Table A5.1 Attributes of biomass/crop yield models of different complexity (After Schulze et al., 1995)

<table>
<thead>
<tr>
<th>LEVELS OF COMPLEXITY OF CROP YIELD MODELS</th>
<th>SIMPLE</th>
<th>INTERMEDIATE</th>
<th>COMPLEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL STRUCTURE</td>
<td>Experience and rate based climatic threshold yield functions</td>
<td>Phenoology driven soil water deficit yield functions</td>
<td>Genetics, physiology, phenology and management based growth, development and yield functions</td>
</tr>
<tr>
<td>MODEL TIME STEP</td>
<td>Monthly / annual</td>
<td>Daily</td>
<td>Daily</td>
</tr>
<tr>
<td>CLIMATE VARIABLES</td>
<td>Rainfall, Temperature, - maximum, - minimum</td>
<td>Rainfall, Temperature, - maximum, - minimum, Reference potential evaporation, CO₂ transpiration feedback</td>
<td>Rainfall, Temperature, - maximum, - minimum, Solar radiation, Reference potential evaporation, CO₂ transpiration feedback</td>
</tr>
<tr>
<td>SOIL VARIABLES</td>
<td>Single horizon, Texture class, Normative weighting (Deep → shallow) (Clay → sand)</td>
<td>1 - 2 horizons, Horizon thicknesses, Retention constants, Drainage/ permeability</td>
<td>Multiple horizons, Horizon thick- nesses, Retention constants, Drainage / permeability, Soil physics, Soil chemistry - pH, C, N Previous crop residue - O, C:N, root, depth</td>
</tr>
</tbody>
</table>
In both past and current studies in South Africa on agricultural responses to climate change, and in this Handbook, all three levels of model have been, and are being, used, depending on
• the level at which modellers of respective crops have conceptualised climate change effects into their models, on
• data availability, and on
• the process uncertainties which still exist, especially in regard to the CO₂ “fertilization” feed-forward in photosynthesis and the transpiration feed-back resulting from an increase in stomatal control under enhanced CO₂ conditions.

The Smith Rule Based Suite of Models: Application of a Simple Crop Yield Model
Smith (2006 and previous versions) developed a suite of rule based models to estimate yields over South Africa for a range of crops according to
• climatic criteria, using climate variables with limits for each specific crop, optionally adjusted first for
• different levels of management and, secondly, for
• soils characteristics.

The climatic criteria in the Smith models consist of the product of
• the growing season accumulated rainfall,
• an effective rainfall fraction for the growing season, which depends on classes of rainfall amounts within crop specified limits, and
• a dry matter yield index for that crop, which is a function of classes of growing season heat units between crop related upper and lower limits.

The Smith models have in the past been used in sensitivity analyses of climate change. More recently the Smith suite of rule based models has been used with the South African Quinary Catchments Database for climate change impact studies (Schulze, 2010). By way of example, the algorithm developed of the Smith model for dryland winter wheat yield is given in Box A5.1.

The DSSAT Crop Systems Model: Application of a Complex Crop Yield Model
DSSAT was originally developed by an international network of scientists, cooperating in the International Benchmark Sites Network for Agrotechnology Transfer project. Updated releases of DSSAT followed (e.g. Hoogenboom et al., 1994; Jones et al., 1998), with Version 4.5 was released in 2011.

<table>
<thead>
<tr>
<th>MANAGEMENT OPTIONS</th>
<th>Normative Weighting (Excellent → poor)</th>
<th>Plant date</th>
<th>Cultivar attributes</th>
<th>Tillage options</th>
<th>Plant date</th>
<th>Cultivar attributes</th>
<th>Plant density/row spacing</th>
<th>N-fertilization</th>
<th>Tillage options</th>
</tr>
</thead>
</table>

Box A5.1 Estimation of Dryland Winter Wheat Yield, Based on Smith’s Climatic Criteria

Using Smith’s (2006) climatic criteria only, without cognisance of the soil properties or level of management, dryland winter wheat yield with a planting date in May was calculated as

$$Y_{wd} = 0.0075 \cdot P_{ems} \cdot D_{wd}$$

where
- $Y_{wd} = \text{dryland winter wheat yield (t/ha/season)}$
- $P_{ems} = \text{effective rainfall for May to September}$
- $D_{wd} = \text{dryland wheat heat unit factor}$
- $ASM = \text{antecedent soil moisture}$
- $P_{ms} = \text{accumulated rainfall (mm) for May to September (inclusive) for } P_{ms} < 850 \text{ mm}$
- $H_{wi} = \text{accumulated heat units (base 4.4 °C) in degree days for the period May to September.}$

Note that this model does not include a CO₂ fertilization effect.
In this study the DSSAT v4.5 Crop Systems Model (CSM) was used. Potential dry matter production is calculated as a function of radiation, leaf area index and reduction factors for temperature and moisture stress. Phenological stages are simulated based on growing degree days, and leaf and stem growth are calculated depending on phenological stages. Available photosynthetic rate is initially partitioned to leaves and stems, and later for ear and grain growth. Any remaining photosynthetic rate is allocated to root growth. However, if photosynthetic available for root growth is below a minimum threshold, then the grain, leaves and stem allocations are reduced and the minimum level of root growth occurs. Separate routines calculate the water balance, which includes runoff, infiltration, saturated and unsaturated water flow and drainage. Mineral nitrogen dynamics and nitrogen availability for crop uptake are also calculated. The model provides information on above-ground dry matter, on grain dry matter and nitrogen content, as well as providing summaries of the water balance and soil mineral nitrogen. In DSSAT v4.5, the atmospheric CO₂ concentration can be specified as a user defined static value or a measured value. The advantages of using the CSM to simulate the effects of climate change are as follows:

- The model structure allows for genetic, physiology, phenology and management based growth development and yield functions, where the growth degree day concept is able to capture the effect of temperature and increased plant growth due to CO₂ fertilization.
- The model uses a daily time step which allows for extremes, especially as a result of climate, to terminate growth.
- The climate variables are represented by daily rainfall, minimum and maximum temperature, solar radiation and these are used to calculate reference potential evaporation and the CO₂ transpiration feedback. These are the most important input variables that are expected to change under future climate.
- The soil variables such as multiple soil horizons, differences in horizon thicknesses, water holding capacity, drainage and permeability together with previous crop residue and rooting depth dictate, in conjunction with the rainfall from the climate variables, the plant variable water and the potential water stress under present and projected future climates.
- The management options such as planting date, cultivar attributes, planting density, row spacing, nitrogen fertilization and tillage options permit the manipulation of the timing of onset of certain reproductive phases in relation to climatic events. This can be an important factor when adaptation measures to mitigate the effect of climate change.

**APSIM, the Agricultural Production Systems Simulator: Application of a Further Complex Crop Yield Model**

The Agricultural Production Systems Simulator (APSIM) modelling framework was developed by the Agricultural Production Systems Research Unit in Australia (McCown et al., 1995) to simulate biophysical processes in agricultural systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk. It is structured around plant, soil and management modules including a diverse range of crops, pastures and trees, soil processes including water balance, N and P transformations, soil pH, erosion and a full range of management controls. APSIM resulted from a need for tools that provided accurate predictions of crop production in relation to climate, genotype, soil and management factors while addressing long-term resource management issues. In the APSIM model high order processes such as crop production and the soil water balance are represented as modules which relate to each other only through a central control unit, which is referred to as the program engine. Thermal time is used in the model to drive phenological development and canopy expansion (Keating et al., 1999).

**The AQUACROP Model**

The AQUACROP model was used to estimate the attainable yield of selected biofuel feedstocks, in relation to their seasonal water use. Crop simulations were undertaken for three strategic biofuel feedstocks, viz. soybean, grain sorghum and sugarcane. AQUACROP was developed by the Food and Agricultural Organisation (FAO) and designed to simulate yield response of a range of crops to water availability. The model is particularly suited to conditions where water is a key limiting factor in crop production.

AQUACROP is a water productivity model that simulates biomass production based on the amount of water transpired by the green canopy cover. Canopy cover development (biomass production) is based on thermal time. Temperature governs thermal time as well as pollination success. In addition,
low temperatures limit biomass production. Water stress affects the transpiration rate via the crop water productivity parameter, which is a measure of water use efficiency. However, like most crop models, AQUACROP does not account for the effects of pests and diseases on crop response. The model requires daily rainfall, minimum and maximum temperature as well as reference crop evaporation as climatic input data.

The model is also well suited for the analysis of climate change impacts on crop productivity, water requirements and water consumption. The model allows for the assessment of crop responses under different climate change scenarios in terms of altered water and temperature regimes as well as elevated CO$_2$ concentration in the atmosphere.

In regard to model calibration, the AQUACROP model (version 4.0) has already been parameterised for a number of crops, of which sugarcane, sugarbeet, grain sorghum, soybean and sunflower are considered suitable feedstocks for biofuel production. Where possible, the model was further calibrated for selected feedstocks to better represent local growing conditions in South Africa. This is discussed further in each Chapter for a specific crop.

The model assesses attainable yield, which refers to the utilisable portion of the biomass that contains sugar (i.e. stem or tuber), starch (i.e. grain) or vegetable oil (i.e. seed). The yield is expressed as mass of dry matter per unit area, i.e. dry kg per hectare or kg/ha.

For national level simulations, the AQUACROP model was linked to the Quinary Catchments database that exists for South Africa, Lesotho and Swaziland. This historical climate database consists of 50 years (1950-1999) of daily climate data (rainfall, maximum and minimum temperature as well as reference crop evaporation) for each of the 5 838 Quinary Catchments. The climate database also contains 20 years of projected climate data for two periods, namely present (1971-1990) and intermediate future (2046-2065). The climate projects were derived from four global climate models (GCMs).

The Quinary Catchments soils database contains soil water retention parameters and soil thickness for two horizons, and the values are deemed to be representative of each entire Quinary. However, AQUACROP also requires saturated hydraulic conductivity which was derived using a pedo-transfer function for each Quinary.

The model was run to determine the attainable yield, water use efficiency and growing season length for a single season. The process was then repeated to obtain simulated data for the following season. The crop yield, water use efficiency and length of growing season for each consecutive season was then analysed to calculate the mean statistic.

This procedure was then repeated for each of the 5 838 Quinary Catchments and again for each selected feedstock. Owing to the large number of model runs, the plug-in$^1$ version of the AQUACROP model was used. The methodology was fully automated to reduce its computational complexity, thus minimising the time required to complete a national run.

Further Reading


$^1$ http://www.fao.org/nr/water/docs/AquaCropPluginV40.doc
Simulation Models: The ACRU Agro-Hydrological Model [Further Reading: Schulze, 1995]

Background 1: The Use of Models to Evaluate Agro-Hydrological Responses
Long term observations of hydrological responses such as stormflow or baseflow or sediment yield, as well as of transpiration from plants or evaporative losses from the soil surface, at the scales of homogeneous response areas cannot be made for all feasible combinations of climate, soils, land uses and their different management regimes for reasons of logistics, time and cost. In order to mimic such responses, an appropriately structured and conceptualised agro-hydrological simulation model has to be used. Such a model is thus viewed as a tool for transferring knowledge (i.e. observation > analysis > information > prediction) from a selected study area where observations are made (e.g. a research plot or catchment) to other unmonitored areas (e.g. farm or Quinary Catchment) where the information is required and agro-hydrological decisions may have to be made. The model does this by simplifying a complex terrestrial system by way of a sequence of equations and pathways which describe the atmosphere-soil-plant-water continuum on the landscape component of the area (or catchment) and the flows and storages in the channel component of the catchment.

Background 2: From Model Input to Model Output
Such an agro-hydrological model requires input of known, or measurable, or derivable factors made up of data and information on, inter alia,
- climate (e.g. daily rainfall, maximum and minimum temperature, potential evaporation),
- physiography (e.g. altitude, its range within a catchment, slope gradients),
- soils (e.g. thicknesses of the various soil horizons, as well as soil water retention at critical soil water contents and saturated drainage rates from the respective horizons, and/or the inherent erodibility of the soil),
- land uses (e.g. natural vegetation and crop types, levels of management, planting dates, growth rates, above- as well as surface and below-ground vegetation attributes at different growth stages during the year and for different management strategies / scenarios),
- soil water budgeting threshold and rates (e.g. onset of plant stress, degrees of stress, capillary movement),
- runoff producing mechanisms (e.g. stormflow generation, recharge and resultant baseflow rates, as well as flows from impervious areas),
- irrigation practices (e.g. crop type, above-and-below-ground attributes at different growth stages, modes of scheduling and their controls, source of water, application efficiencies) and, where relevant, information on
- dams (e.g. inflows, full supply capacities, surface areas, evaporation rates, releases, abstractions and inter-basin transfers), or
- other abstractions (e.g. domestic, livestock by amount, season and source of water).

This information is transformed in the model by considering
- the climate, soil, vegetative, hydrological and management subsystems
- how they interact with one another
- what thresholds are required for responses to take place
- how the various responses are lagged at different rates and
- whether there are feedforwards and feedbacks which allow the system to respond in a positive or reverse direction.

The model then produces output of the unmeasured variable to be assessed, such as
- streamflow (i.e. the so-called “blue water” flows), from different pervious and impervious parts of the catchment, including stormflows and baseflows being modelled explicitly and on a daily basis, and hence high and low flows,
- evaporation (i.e. the so-called “green water” flows) from different parts of the catchment, and made up of productive transpiration through the plant plus the non-productive evaporation from the soil surface,
• crop yield (e.g. per season, annum or growth cycle; dryland or irrigated; and where relevant, with economic analysis),
• irrigation water requirements (gross or net requirements; associated crop yields; deep percolation and stormflow from irrigated areas; water use efficiencies under different modes of scheduling water for irrigation; analysis of incremental benefit of applying irrigation vs dryland farming),
• peak discharge, and
• sediment yield from different parts of the catchment and computed on an event-by-event basis for the pertinent hydrological, soil, slope, plant cover and management conditions, with all of the above output available as a
• risk analysis (month-by-month / annual statistics for median / mean conditions and for, say, driest / wettest years in 10 or 20 years; flow variability or extreme value analysis).

The ACRU agro-hydrological modelling system (Schulze, 1995 and continual updates includes the facilities to simulate the agro-hydrological responses described above and was selected as a suitable model for this Handbook.

**Concepts of the ACRU Model**

ACRU is a daily time step, physical-conceptual and multi-purpose model (Figure A5.4).

![ACRU Model Diagram](image)

**Figure A5.4** ACRU: Concepts of the modelling system (Schulze, 1995)

It contains options to output, inter alia, daily values of stormflows, baseflows, total streamflow, transpiration, soil water evaporation, peak discharge, sediment yields, recharge to groundwater, reservoir status, irrigation water supply and demand as well as seasonal crop yields at a specific location / catchment. The model revolves around multi-layer soil water budgeting (Figure A5.5) and is structured to be sensitive to changes in land uses and management. Individual processes and equations are not given here, but can be read up in Schulze (1995)

**Further Reading**

Figure A5.5  ACRU: Model structure (Schulze, 1995)
Appendix 2: On Clarification of Terms and Concepts Used Frequently in this Handbook

R.E. Schulze

Weather and Climate Related

- Weather
- Hazard
- Climate
- Climate System
- Climate Variability
- Forecasts
- Extreme Weather Events
- El Niño-Southern Oscillation (ENSO)

Climate Change Related

- Anthropogenic Emissions
- Greenhouse Gases (GHGs)
- Greenhouse Effect
- Climate Change
- Emission / Climate Scenarios
- Simple Incremental Scenarios
- Climate Projections
- Business as Usual (BAU) Projections
- Climate Predictions
- GCMs
- Downscaling
- Uncertainty
- Ensemble of Models / Multiple Models
- Confidence

Vulnerability, Impacts and Adaptation Related

- Risk
- Risk Mitigation
- Vulnerability
- Exposure
- Climate Change Impacts
- Sensitivity
- Tipping Point
- Resilience
- Coping
- Coping Capacity
- Adaptation
- Adaptation Assessment
- Adaptive Capacity
- Adaptation Constraint
- Adaptation Deficit
- Adaptation Limit
- Adaptive Management
- Adaptation Opportunity
- Adaptation Options
- Adaptive Policy
- Community-Based Adaptation
- Co-Benefits
- Mainstreaming Climate Change
- No Regret Principle
- Precautionary Principle
- Mitigation
Many relatively specialised terms are used in the field of climate change studies, and different user communities often interpret terms and concepts related to climate change differently. This Chapter therefore serves to clarify some key terms in the context that they are used in this Handbook. Where possible the terms have been simplified from their formal definitions and sometimes explanatory notes have been added. The reader will find that the terms are often partially overlapping and not entirely independent of one another. The terms have been gleaned from multiple sources, notably from IPCC (Intergovernmental Panel on Climate Change) documentation.

Weather and Climate Related

Weather
Weather is the sum total of prevailing atmospheric variables (e.g. temperature, humidity, wind) at a given place and at any instant (now) or brief period of time (this morning). Weather is an everyday experience – one talks of “today’s weather”.

Hazard
A hazard is the potential occurrence of a natural or human-induced physical event (e.g. a flood producing rainfall) or trend, or a physical impact, that may cause damage and loss to property, infrastructure (e.g. farm roads), livelihoods (loss of jobs), service provision and environmental resources, and at times even loss of life, injury or other health impacts (e.g. from heat waves), as well as. In this Handbook, the term hazard usually refers to weather or climate-related physical events or trends or their physical impacts. A hazard has a magnitude (how much rainfall in total), an intensity (how many mm/hour), a duration (e.g. falling over 2 days), has a probability of occurrence (on average once every 5 years) and takes place within a specified location.

Climate
Climate, in a narrow sense, is usually defined as the “average weather”, or more rigorously in a wider sense, as the state of the climate system including the statistical description in terms of the mean (e.g. what is the average rainfall) and variability of relevant quantities (e.g. in mm) over a period of time ranging from months to years to decades and centuries. These quantities are most often surface variables such as temperature, precipitation, relative humidity and wind. The conventional period to define climate is 30 years.

Climate System
The climate system is the highly complex system consisting of the following major components, viz. the atmosphere, the hydrosphere (water), the lithosphere (geology and soils) and the biosphere (vegetation), and the interactions among them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations, and anthropogenic (i.e. human) forcings such as the changing composition of the atmosphere and land use change.

Climate Variability
Climate variability (CV) refers to any variations (deviation) from the long-term expected value (the mean) and other statistics (such as the occurrence of extremes) of the climate on all time and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system, i.e. internal variability, or to variations in natural or human-induced
(anthropogenic) external forcing, i.e. external variability. Internal variability is an entirely natural phenomenon, is reversible and non-permanent. An example would be the droughts in southern Africa associated with the El Niño. CV has time scales from
- diurnal (within the course of a day, e.g. time of occurrence of convective thunderstorms), to
- daily (i.e. variations from one day to the next), to
- intra-seasonal (e.g. monthly CVs), to
- inter-annual (e.g. year-to-year variability), and
- decadal (e.g. consecutive wet years or dry years).

**Forecasts**
Forecasts focus on individual events (e.g. a cold front is being forecast) where the physical processes (i.e. what causes the front) or statistical inter-linkages are relatively well understood to the extent that, depending on the nature of the event being forecast, it is possible to provide information about its timing (when will the front arrive), location (where) and magnitude (how much rain is forecast). Forecasts facilitate short term planning to the farmer and are thus able to reduce sources of uncertainty and hence diminish risk.

**Extreme Weather Events**
An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as, or rarer than, the 10th percentile (i.e. statistically the lowest in 10 years) or the 90th percentile (e.g. the statistically highest in 10 years) of a probability density function (i.e. a statistic used to calculate extremes) estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense (i.e. what is rare in the semi-arid Karoo may not be rare along the coast of KwaZulu-Natal). When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g. drought or heavy rainfall over a season).

**El Niño-Southern Oscillation (ENSO)**
El Niño, in its original sense, is a warm water current that periodically (approximately every 2-7 years) flows along the coast of Ecuador and Peru, disrupting the local fishery. This oceanic event is associated with a fluctuation of the surface pressure pattern within the tropics and circulation in the Indian and Pacific Oceans, and is called the Southern Oscillation. This coupled atmosphere-ocean phenomenon is collectively known as El Niño-Southern Oscillation. During an El Niño event, the prevailing trade winds weaken and the equatorial countercurrent strengthens, causing warm surface waters in the Indonesian area to flow eastward to overlie the cold waters of the Peru ocean current. This event has great impact on the wind, sea surface temperature and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and, through what are known as teleconnections, in many other parts of the world, including southern Africa, where it is associated with drought conditions. The opposite of an El Niño event is called La Niña, associated in southern Africa with periods of above average rainfall.

**Climate Change Related**

**Anthropogenic Emissions**
Anthropogenic emissions are those of greenhouse gases (GHGs) and aerosols resulting from human activities. These activities include the burning of fossil fuels, deforestation, land use changes, livestock production, fertilization, waste management and industrial processes.

**Greenhouse Gases (GHGs)**
Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth’s surface, the atmosphere itself and clouds. This property causes the greenhouse effect. Water vapor (H₂O), carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), and ozone (O₃) are the primary greenhouse gases in the Earth’s atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances.
**Greenhouse Effect**
The Greenhouse effect is the infrared radiative effect of all infrared-absorbing constituents in the atmosphere. Greenhouse gases, clouds, and (to a small extent) aerosols absorb terrestrial radiation (i.e. the longwave radiation) emitted by the Earth’s surface and elsewhere in the atmosphere. These substances emit infrared radiation in all directions, but, everything else being equal, the net amount emitted to space is normally less than would have been emitted in the absence of these absorbers because of the decline of temperature with altitude in the troposphere and the consequent weakening of emission. An increase in the concentration of greenhouse gases increases the magnitude of this effect; the difference is sometimes called the enhanced greenhouse effect. The change in a greenhouse gas concentration because of anthropogenic emissions contributes to an instantaneous radiative forcing. Surface temperature and troposphere warm in response to this forcing, gradually restoring the radiative balance at the top of the atmosphere.

**Climate Change**
Climate change, broadly speaking, refers to any change in climate over time, whether due to natural variability or as a result of human activity. A more comprehensive definition is that climate change is a statistically significant change of climate which is attributed directly or indirectly to human activities that have altered the composition of the global atmosphere, and which is in addition to natural climate variability observed over comparable time periods. Human activities include the burning of fossil fuels (oil, coal, natural gas), unsustainable land use systems and clearing of forests, resulting in increasing the concentration of the greenhouse gases (GHGs such as CO$_2$, CH$_4$, N$_2$O, water vapour and chlorofluorocarbons, CFCs) in the atmosphere. These gases act to trap the energy from the sun resulting in global warming. Note that

- Climate change is considered to be irreversible and permanent, where a trend over time (either positive or negative) of means and deviations from the mean as well as other higher order statistics (e.g. changes in extremes) is superimposed over naturally occurring variability; that
- The time scale of climate change is decades to centuries, and that
- The trend is more likely to occur in steps than linearly over time.

**Emission / Climate Scenarios**
An emission scenario is a plausible representation of the future development of emissions of (mainly) greenhouse gases over decades, based on a coherent and internally consistent set of “what if” assumptions about driving forces into the future – driving forces such as population growth, increased energy demand, socio-economic development, politics, land use and technological change, and their key interactions and relationships. Concentration scenarios, derived from emission scenarios, are used as input to climate models, or GCMs, to compute climate projections. In this Handbook many of the scenarios are from the so-called SRES scenarios of the “Special Report on Emission Scenarios” from the year 2000; others are from the new emission scenarios for climate change, termed the four Representative Concentration Pathways or RCPs, which were developed for, but independently of, the present 2013 IPCC assessment. Note that scenarios are neither predictions nor forecasts, but are useful to provide a view of the implications of developments and actions.

**Simple Incremental Scenarios**
Another type of scenarios can take the form of simple incremental scenarios, which in effect are a type of sensitivity analyses of plausible changes in climate such as

- increases in temperature by +1°C, or +2°C, or +3°C, or
- changes in precipitation by -10%, or -20%, or +10%, or +20%, or
- enhancements of atmospheric CO$_2$ concentrations to 1.5 times pre-industrial revolution values, or to an effective doubling of CO$_2$, or to specific concentrations (in ppmv),
- with changes made by small, but realistic (i.e. plausible), increments from a baseline, and
- changes made initially to single variables and later to multiple variables, and with the usefulness of such sensitivity analysis being that one can
  - gauge likely impacts,
  - determine critical thresholds of change (when does the system “flip”?),
  - determine when change becomes significant,
  - determine where change is significant, and
  - determine which driver is more significant than others, thereby determining the sensitivity of the “exposure unit” (e.g. of rainfall).
Climate Projections

Climate projections are simulated projections of the responses of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, which are based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised, and are therefore subject to substantial uncertainty.

- Climate projections are usually based on simulations by Global Climate Models, also known as General Circulation Models (GCMs).
- Projections are not predictions in the sense that the quality of a projection, and therefore the likelihood that it will occur, cannot be firmly determined.

Business as Usual (BAU) Projections

‘Business as usual projections’ are based on the assumption that operating practices and policies remain as they are at present. Although baseline scenarios could incorporate some specific features of BAU scenarios (e.g. a ban on a specific technology), BAU scenarios imply that no practices or policies other than the current ones are in place.

Climate Predictions

A climate prediction or climate forecast is the result of an attempt to produce (starting from a particular state of the climate system) an estimate of the actual evolution of the climate in the future, for example, at seasonal, inter-annual, or decadal time scales. Since the future evolution of the climate system may be highly sensitive to initial conditions, such predictions are usually probabilistic in nature. The predictability of a phenomenon can be defined as the degree to which its evolution can be deduced from the known initial conditions and the known evolution of factors that affect the phenomenon. It thus depends significantly upon the spatial and temporal scales of the phenomenon. Predictions are based on statistical theory, which uses the historical records to estimate the probability of occurrence of events. Predictions are therefore based on average probabilities and give no indication of when a particular event may occur.

GCMs

The climate system can be represented by models of varying complexity; that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parameterizations are involved. These models are termed GCMs, i.e. General Circulation Models or Global Climate Models. They are numerical (i.e. quantitative) representations of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes. These complex mathematical models represent the general circulation of the earth's atmosphere and / or oceans. There are both atmospheric GCMs (AGCMs) and oceanic GCMs (OGCMs). An AGCM and an OGCM can be coupled together to form an atmosphere-ocean coupled general circulation model (CGCM or AOGCM). With the addition of other components (such as a sea ice model or a model for evapotranspiration over land), the AOGCM becomes the basis for a full climate model. Coupled ocean-atmosphere models represent the pinnacle of climate modelling and as such, can provide plausible simulations of both the present climate and the climatological seasonal cycle over broad continental scales for most variables of interest for climate change. There is an evolution towards more complex models with interactive chemistry and biology. Climate models are applied as a research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal, and inter-annual climate predictions. According to the Intergovernmental Panel on Climate Change (IPCC) there is considerable confidence that climate models can provide credible quantitative estimates of future climate change, particularly at larger spatial scales.

Downscaling

Downscaling is a method that derives local- to regional-scale (10 to 100 km) information from larger-scale models such as GCMs. Two main methods of downscaling exist: dynamical downscaling and empirical / statistical downscaling. The dynamical method uses the output of regional climate models, of global models with variable spatial resolution, or high-resolution global models. The empirical / statistical methods develop statistical relationships that link the large-scale atmospheric variables with local / regional climate variables. In all cases, the quality of the driving model remains an important limitation on the quality of the downscaled information. In this Handbook examples of both statistical and dynamic downscaling are used.
Uncertainty

Uncertainty is a state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g. a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts).

In regard to climate scenarios, it is largely the uncertainty surrounding the assumptions made in emissions scenarios which determines the range of uncertainties from outputs of GCMs. These are based on one of several emissions scenarios or representative concentration pathways (see also the section on GCMs), bearing in mind that
- uncertainties exist within each of the scenarios, with each having their own explicit assumptions on greenhouse gas emissions dependent on technology, politics, economics and type of development, and associated probabilities, that
- no one scenario is “a more likely future”, or a “best guess”, that
- uncertainties occur due to differences between GCMs, each of which represents certain processes differently and not perfectly, with no GCM being the “best”, and
- “best” in agriculture (or any other sector) not necessarily being the “best” in terms of (say) hydrology, and that
- uncertainties associated with changes in precipitation (the main “driver” of agricultural potential) are greater than uncertainties in temperature, that
- uncertainty is greater in regard to the magnitudes of change (i.e. how big the change will be) than the direction of change (e.g. whether rainfall will increase or decrease), and
- they are greater for changes in variability and extremes than for means, while
- uncertainties associated with downscaling from global to agriculturally relevant local scales, be it by empirical / statistical techniques or by dynamic methods, remain a source of concern.
- It is because of the above uncertainties that users should apply multiple GCM scenarios in impact assessments, where these multiple scenarios span a range of possible future climates, rather than designing and applying a single “best-guess” scenario.

Ensemble of Models / Multiple Models

An ensemble is a collection of model simulations characterizing a climate prediction or projection. Differences in initial conditions and model formulation result in different evolutions of the modelled system and may give information on uncertainty associated with model error and error in initial conditions in the case of climate forecasts and on uncertainty associated with model error and with internally generated climate variability in the case of climate projections. In this Handbook the averages of GCM derived results which have been mapped have been termed “Outputs from Multiple Models”.

Confidence

Confidence, in the context of climate change studies, is the validity of a finding based on the type, amount, quality, and consistency of evidence (e.g. mechanistic understanding, theory, data, models, expert judgment) and on the degree of agreement. Confidence is usually expressed qualitatively.

Vulnerability, Impacts and Adaptation Related

Risk

Risk is the potential for consequences where something of human value (e.g. food supply; but including humans themselves) is at stake and where the outcome is uncertain. Risk is often represented as the probability of occurrence of hazardous events (e.g. a devastating drought) or trends (e.g. global warming over time) multiplied by the consequences (e.g. economic; food famine) if these events occur. This Handbook assesses climate-related risks.

Risk Mitigation

Risk mitigation considers setting up alternative measures to reduce the impacts of a hazard by minimising its destructive and disruptive effects, thereby lessening the scale of the disaster. It attempts to find practical and workable strategies and solutions for minimising risk at scales ranging from international, to national to local.
**Vulnerability** [Note that broad definitions only are given here as the entire Chapter 2 is devoted to this theme]

Vulnerability to climate change is the degree to which geophysical systems (e.g. the hydrological cycle; the landscape), biological systems (e.g. the crop) and socio-economic systems (e.g. the farming community) are susceptible to, and unable to cope with, adverse impacts of climate change, including climate variability and extremes. It is a measure of a system’s (e.g. that of agriculture) susceptibility to the type (e.g. less rainfall), the magnitude (e.g. by how much) and the rate (how quickly will it set in) of climate change, and it therefore depends on what the system (e.g. again, the agriculture sector) is exposed to (e.g. soil water stress), what it is sensitive to (e.g. too many consecutive days of stress), and whether it has the capacity to adapt to climate change (e.g. by conservation tillage). In a simpler definition, vulnerability is the characteristic of a person, or group, or component, of a natural system in terms of its capacity to resist and/or recover from and/or anticipate and/or cope with, the impacts of an adverse event.

**Exposure**

Exposure is the extent (i.e. the nature and degree) to which a climate-sensitive sector (e.g. farming) is in contact with/exposed to significant climatic variations (e.g. of rainfall).

**Climate Change Impacts**

Climate change impacts are the consequences of climate change on any natural and human system and, depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts, where

- **Potential Impacts** imply all impacts that may occur given a projected change in climate, without considering adaptation, while
- **Residual Impacts** are the impacts of climate change that would occur after adaptation.

**Sensitivity**

Sensitivity is the degree to which a system (e.g. agricultural) or species (e.g. Zea mays, or maize) is affected, either adversely or beneficially, by climate-related stimuli. Climate-related stimuli encompass all the elements of climate change, including mean climate variability, and the frequency and magnitude of extremes. Effectively it is the magnitude of change in a response (e.g. crop yield) to a change in the driver of that response (e.g. rainfall). The effect may be

- **direct** (e.g. a change in rainfall implies a change in yield), or
- **indirect**, and the response to an event or exposure can be
  - **positive** (e.g. as rainfall increases, so does crop yield), or
  - **negative**, i.e. inverse (e.g. as the drought increases, so the crop yield will decrease).

**Tipping Point**

A tipping point is the level of change in system properties beyond which a system reorganizes, often abruptly, and does not return to the initial state even if the drivers of the change are abated.

**Resilience**

Resilience is the capacity of a social-ecological system to cope with a hazardous event or disturbance, responding or re-organizing in ways that maintain its essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation. A resilient system is synonymous with a region that is ecologically, economically and socially sustainable and has the ability of a social or ecological system to absorb disturbances (e.g. a drought) and recover from them while retaining the same basic structure and ways of functioning. Because the word “resilience” has been used in different ways, we need to be clear about its meaning.

- One interpretation has to do with the rate of return of a system to some equilibrium state after a small disturbance. This is what we term “engineering resilience”, or in ordinary English, the “bounce-back-ability”.
- In another definition resilience is the magnitude of disturbance that can be experienced before a system moves into a different state and different set of controls. This is termed “ecosystem resilience”.

Based on this interpretation resilience, when applied to ecosystems, or to integrated systems of people and natural resources (such as farming), has three defining characteristics:
• The amount of change the system can undergo and still retain the same controls on function and structure (still be in the same state - within the same domain of attraction); resilience therefore implying that there are thresholds which, when exceeded, result in a system being vulnerable;
• The degree to which the system is capable of self-organisation; and
• The ability to build and increase the capacity for learning and adaptation, including the capacity to adapt to stress and change.

Coping
Coping is the use of available skills, resources and opportunities to address, manage, and overcome adverse conditions, with the aim of achieving basic functioning of people, institutions, organizations, and systems in the short to medium term.

Coping Capacity
Coping capacity is the ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term.

Adaptation [Note that broad explanations and definitions only are given here as the entire ChapterA3 is devoted to this theme. There is a degree of repetition, however]
Adaptation to climate change refers to the actions of making adjustments / alterations of current human practices and capital to natural (e.g. agricultural) or human systems, or changes in decision environments, in response to actual or expected climatic stimuli (e.g. to increases in temperature) or their effects (i.e. impacts on crop yields), which could moderate (i.e. reduce) harm and which might therefore ultimately enhance resilience or reduce vulnerability to observed or expected changes in climate, or even exploit beneficial opportunities. In natural systems such as the agriculture sector, adaptation implies human interventions which may facilitate adjustment to expected climate and its effects. One can either
• adapt incrementally, i.e. step by step, or
• adapt transformationally, in which fundamental attributes of a system (e.g. farming with sugarcane) are changed in response to climate and its effects.

Various types of adaptation can be distinguished.
• Anticipatory Adaptation, i.e. adaptation that takes place before impacts of climate change are observed. It is also referred to as proactive adaptation.
• Autonomous Adaptation: Here adaptation does not constitute a conscious response to climatic stimuli, but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. It is also referred to as spontaneous adaptation.
• Planned Adaptation: This is adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.
• Private Adaptation: In this type, adaptation is initiated and implemented by individuals, households or private companies. Private adaptation is usually in the actor's (e.g. the individual farmer's) rational self-interest.
• Public Adaptation is adaptation that is initiated and implemented by governments at all levels. Public adaptation is usually directed at overall / collective needs.
• Reactive Adaptation: This is adaptation that takes place after impacts of climate change have been observed.

Adaptation includes responses in the decision environment, such as changes in social and institutional structures or altered technical options that can affect the potential or capacity for these actions to be realized.

From an agricultural perspective adaptation to climate change therefore refers to the adoption of appropriate coping strategies to minimise any negative effects of climate change. This includes a range of management related activities and practices such as timing of agricultural activities (e.g. of planting dates), annual cultivar choice assumptions and other farm-level choices.such as crop selection and breeding, animal selection and rainfall use efficiency.

The majority of climate change impact studies imply only changes to climate, but no change in agricultural technologies. Technology is, of course, a most important driver to adaptation, but one has
to concede that relationships determining technology development remain unclear and will require further research focus.

More detail on the various types and levels of adaptation as well as on differences between adaptive management and adaptive governance are given in Chapter A3.

**Adaptation Assessment**
An adaptation assessment is the practice of identifying options to adapt to climate change and evaluating the options in terms of criteria such as availability, benefits, costs, effectiveness, efficiency and feasibility.

**Adaptive Capacity** [Note that more detail on adaptive capacity is given in Chapter A3]
Adaptive capacity has been defined as the ability or potential of a system, or institutions, humans and other organisms, to respond successfully (i.e. adjust in both behaviour and in resources and technologies) to climate change (including climate variability and extremes), to moderate (i.e. reduce) potential damages (by changing ones exposure to or sensitivity to the specific element of climate change), to take advantage of opportunities, or to cope with the consequences of impacts (by recovering or maintaining welfare / system function in the face of climatic change) and to profit from new opportunities (assuming climate change affects agents differentially).

**Adaptation Constraint**
Adaptation constraints are the factors that make it more difficult to plan and implement adaptation actions or factors that restrict options.

**Adaptation Deficit**
The adaptation deficit is the gap between the current state of a system and a state that minimizes adverse impacts from existing climate conditions and variability, i.e. the adaptation we should have been doing anyway.

**Adaptation Limit**
The adaptation limit is the point at which one’s objectives (or the needs of, say, the agriculture sector) cannot be secured from risks which one cannot tolerate through adaptive actions.

**Adaptive Management**
Adaptive management is a process of iteratively (i.e. step by step) planning, implementing, and modifying strategies for managing resources in the face of uncertainty and change. Adaptive management involves adjusting approaches in response to observations of their effect and changes in the system brought on by resulting feedback effects and other variables.

**Adaptation Opportunity**
Adaptation opportunities are the factors that make it easier to plan and implement adaptation actions, that expand adaptation options, or that provide ancillary co-benefits.

**Adaptation Options**
Adaptive options are the array of strategies and measures that are available and appropriate for addressing adaptation needs. They include a wide range of actions that can be categorized as structural, institutional, or social.

**Adaptive Policy**
This is a kind of adaptation that can be applied by a set of policy actors to affect what kinds of decisions are made about social standards, infrastructure development and management practices, land and ecosystem planning and / or civic goals; and how those decisions are made.

**Community-Based Adaptation**
Community-based adaptation focuses attention on empowering and promoting the adaptive capacity of communities. It is an approach that takes context, culture, knowledge, agency, and preferences of communities as strengths.
Co-Benefits
Co-benefits are the positive effects that a policy or measure which is aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare. Co-benefits are often subject to uncertainty and depend on local circumstances and implementation practices. Co-benefits are also called ancillary benefits.

Mainstreaming Climate Change
- **Mainstreaming**, in the climate change context, refers to integration of climate change vulnerabilities or adaptation into some aspect of related government policy such as water management, disaster preparedness and emergency planning or land use planning.
- Actions that promote the mainstreaming of climate change adaptation include:
  - integration of climate information into environmental data sets,
  - preparing climate change related vulnerability or hazard assessments,
  - factoring climate change into broad development strategies, as well as into macro policies and / or sector policies,
  - institutional or organisational structures, or
  - development project design and implementation.
- By implementing mainstreaming initiatives, it is argued that adaptation to climate change will become part of, or will be consistent with, other well established programmes, particularly sustainable development planning, but that mainstreaming needs to encompass a broader set of measures to reduce vulnerability than has thus far been the case.
- Mainstreaming initiatives are classified in the development planning literature at various levels:
  - At the international level, mainstreaming of climate change can occur through policy formulation, project approval and country-level implementation of projects funded by international organisations.
  - At the regional level mainstreaming assesses the likely impacts of climate change on key economic sectors such as water, agriculture or human health, while
  - At the community level responses may also be defined.

No Regret Principle
No regret measures are those whose benefits equal or exceed their cost to society. They are sometimes known as “measures worth doing anyway”.

Precautionary Principle
The precautionary principle recognises that the absence of full scientific certainty shall not be used as a reason to postpone decisions when faced with the threat of serious or irreversible harm.

Mitigation
Mitigation is largely concerned with innovative ways of eliminating or reducing the risks and hazards associated with greenhouse gas emissions (mainly of fossil fuel related activities, methane and nitrous oxide) by avoiding, reducing or minimising sources of pollution that can have a deleterious effect on levels of GHGs and hence global warming and climate change.

Agriculture Related

Carbon dioxide (CO₂) Fertilization
The enhancement of the growth of plants as a result of increased atmospheric carbon dioxide (CO₂) concentration.

Food System
A food system includes the suite of activities and actors in the food chain (i.e. producing, processing and packaging, storing and transporting, trading and retailing, and preparing and consuming food); and the outcome of these activities relating to the three components underpinning food security (viz. access to food, utilization of food, and food availability), all of which need to be stable over time. Food security is therefore underpinned by food systems, and is an emergent property of the behavior of the whole food system. Food insecurity arises when any aspect of the food system is stressed.

Crop Modelling
Crop models are essentially collections of mathematical equations that represent the various processes occurring within the plant and the interactions between the plant and its environment.
Owing to the complexity of biological and environmental systems it is impossible to fully represent the system in mathematical terms. Agronomic models thus condense current knowledge and assumptions regarding these processes and interactions to seek a simplified representation of reality. Crop modelling is now considered a natural component of the toolbox of crop science – a view that has emerged only in the past 35 or so years.

**C3 and C4 plants**
The different methods plants use to convert carbon dioxide from air into organic compounds through the process of photosynthesis. All plants use C3 processes; some plants, such as buffel grass and many other warm climate grasses, also use C4 processes. C4 plants have an advantage in a warmer climate due to their higher CO₂ assimilation rates at higher temperatures and higher photosynthetic optima than their C3 counterparts.

**Drought**
A drought is a period of abnormally dry weather long enough to cause a serious agricultural or hydrological imbalance. Drought is a relative term; therefore any discussion in terms of rainfall deficit must refer to the particular Rainfall-related activity that is under discussion. For example, a shortage of rainfall during the growing season impinges on crop production or ecosystem function in general (due to soil moisture drought, also termed agricultural drought), and during the runoff and percolation season primarily affects water supplies (hydrological drought). Storage changes in soil moisture and groundwater are also affected by increases in actual evapotranspiration in addition to reductions in precipitation. A period with an abnormal precipitation deficit is defined as a meteorological drought. A mega-drought is a very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more.

**Terms in General Usage**

**Anthropogenic**
Resulting from, or produced by, human activities.

**Stakeholders**
These include all individuals and / or groups who are affected by, or can affect, a given operation (e.g. a farming operation). Stakeholders can be individuals (the farmer), interest groups (the co-op) or corporate organisations (e.g. the supermarket group which sells the farming products).

**Participation**
The process through which stakeholders influence and share control over development initiatives and decisions and resources affecting them. It can improve the quality, effectiveness and sustainability of projects and strengthen ownership and commitment of government and stakeholders.

**Capacity Building**
*Capacity building* is a co-ordinated process of deliberate interventions by insiders and / or outsiders of a given society leading to skill upgrading, both general and specific, procedural improvements, and organisational strengthening. Capacity building refers to investment in people, institutions, and practices that will, together, enable countries in the region to achieve their development objective. Capacity is effectively built when these activities are sustained and enhanced with decreasing levels of donor-aid dependence accompanied by increasing levels of societal goal achievement.

**Empowerment**
*Empowerment* is the expansion of assets and capabilities of poor people to participate in, negotiate with, influence, control, and hold accountable institutions that affect their lives. In its broadest sense, empowerment is the expansion of freedom of choice and action. It is a participatory process, which places or transfers decision-making responsibility and the resources to act into the hands of those who will benefit. This can include:

- capacity building for stakeholder organisations;
- strengthening legal status of stakeholder organisations;
- stakeholder authority to manage funds, hire and fire workers, supervise work, procure materials;
- stakeholder authority to certify satisfactory completion of project and establish monitoring and evaluation indicators; and
- support for new and spontaneous initiatives by stakeholders.