Modelling the impact of climate on the financial vulnerability of farms – a Hoedspruit irrigation farm case study

ABSTRACT ID: 2535940

May 2014

Authors

HJ Oosthuizen - PhD student at the Department of Agricultural Economics, University of Stellenbosch, South Africa
DB Louw - PhD, Lecturer extraordinary at the Department of Agricultural Economics, University of Stellenbosch, South Africa
RE Schulze - PhD, Centre for Water Resources Research, University of KwaZulu-Natal, South Africa
P Johnston - PhD, Climate Systems Analysis Group, Department of Environmental and Geographical Science, University of Cape Town, South Africa
JP Lombard - PhD, Senior Lecturer, Department of Agricultural Economics, University of Stellenbosch, South Africa
GR Backeberg - PhD, Director: Water Utilisation in South Africa, Water Research Commission (WRC), Pretoria, South Africa

Contact information of corresponding author

HJ Oosthuizen - PhD student, Department of Agricultural Economics, University of Stellenbosch, South Africa

E-mail: hamman@oabs.co.za

PO Box 7324, George, 6531

Tel: +27 82 783 6192

Fax: +27 44 871 0182

Type of presentation

Oral

Abstract selected for which theme/track:

- 21/05/2014 / Strategies for Adapting the Agricultural Landscape to Changes in Water Availability and Climate

Modelling the impact of climate on the financial vulnerability of farms – a Hoedspruit irrigation farm case study[1]

HJ Oosthuizen[2], DB Louw[3], R Schulze[4], P Johnston[5], JP Lombard[6], GR Backeberg[7]

May 2014

ABSTRACT

Numerous studies indicate that the agricultural sector is physically and economically vulnerable to climate change. With regard to determining possible impacts of projected future climates on the financial vulnerability of commercial citrus and mango farmers in the Hoedspruit area of South Africa, a case study methodology was applied. The integrated modelling framework consists of four modules, namely: climate change impact modelling, dynamic linear programming (DLP) modelling, modelling interphases and financial vulnerability assessment modelling. Empirically downscaled climate data from five global climate models (GCMs) served as base for the integrated modelling. A unique modelling technique (critical crop climate threshold modelling) was developed and applied to model the impact of climate change on yield and quality of agricultural produce. Climate change impact modelling also takes into account the projected changes in irrigation water availability and crop irrigation needs as a result of projected climate change. The results show that from a financial point of view a decrease in profitability can be expected. The erection of shade netting as an adaptation strategy will reduce financial vulnerability to climate change in the Hoedspruit area. The research also highlights the need for effective management of irrigation systems, moisture conservation and cultivar development to increase natural heat resistance.

KEYWORDS

Climate change, adaptation strategies, integrated modelling, financial vulnerability assessment.

INTRODUCTION

The agricultural sector is physically and economically vulnerable to climate change (Kaiser et al., 1993; Darwin et al., 1995; IISD, 1997; IPCC, 2001; Mukheibir et al., 2003; IFPRI, 2009).

[1] Research undertaken according to the terms of reference published under a directed call for proposals, funded and managed by the Water Research Commission (WRC) and co-funded by Department of Agriculture, Forestry and Fisheries (DAFF) (WRC, 2010).
[2] PhD student at the Department of Agricultural Economics, University of Stellenbosch, South Africa
[3] PhD, Lecturer extraordinary at the Department of Agricultural Economics, University of Stellenbosch, South Africa
[4] PhD, Emeritus Professor, Centre for Water Resources Research, University of KwaZulu-Natal, South Africa
[5] PhD, Climate Systems Analysis Group, Department of Environmental and Geographical Science, University of Cape Town, South Africa
[6] PhD, Senior Lecturer, Department of Agricultural Economics, University of Stellenbosch, South Africa
[7] PhD, Director: Water utilisation in South Africa, Water Research Commission (WRC), Pretoria, South Africa

There is limited research on climate change and related impacts on livelihood and the natural resources in some African countries (Environmental Alert, 2010; Louw et al., 2012). However, evidence from global climate models developed so far suggests that the agricultural sector in the Southern African region is highly sensitive to future climate shifts and increased climate variability (Gbetibouo et al., 2004). Therefore, Schulze (2011) suggests that because of the complexity of South Africa's physiography, climate and socio-economic milieu, detailed local scale analyses are needed to assess potential impacts of climate change.

There is a gap in the research with regard to integrated economic modelling at micro level. This includes the linkages between changing projected climates, changing yield and quality of produce, hydrology (availability of irrigation water), changing crop irrigation needs (with new projected climates), financial vulnerability and financial sustainability of farming systems. The Water Research Commission (WRC, 2010) therefore initiated a project on "Adaptive interventions in agriculture to reduce vulnerability of different farming systems to climate change in South Africa." The project addresses the knowledge gaps by making a contribution to integrated climate change modelling and this paper reports on research work done as part of the project.

METHODOLOGY

A case study methodology was applied. The case study was modelled in two phases:

- An Excel spread sheet was used to construct a model of the current situation to establish a base case (the household and farming system under current climate conditions).
- In the second phase, an integrated model was constructed for the case study and a base analysis was undertaken (under current climate conditions). The results were then compared with the Excel model to validate the integrated model.

The technical, production and financial input data were validated during a workshop with the producer and various experts from different institutions and agribusinesses. At the same workshop the critical climate thresholds for mangoes and citrus and possible climate change impact on production yield and quality were debated.

Basic description of the integrated model

In order to analyse financial vulnerability towards climate change, an integrated modelling approach was developed. Figure 1 is a diagrammatic illustration of the modelling framework which consists of four modules, namely:

- Climate change impact modelling – using downscaled data from five global climate models (GCMs) to determine the impact of changing climate on crop yield and quality, availability of irrigation water (determined by using the ACRU agrohydrological model) and changing irrigation water needs (using SAPWAT3 modelling).
- A DLP module to simulate the farming system for the case study.
- Modelling interphases – to feed output from the Crop Critical Climate Thresholds (CCCT) modelling, ACRU model and SAPWAT3 model into the DLP model.

- Financial vulnerability assessment module – the output of the DLP module is used as input to determine financial vulnerability of the farming system.

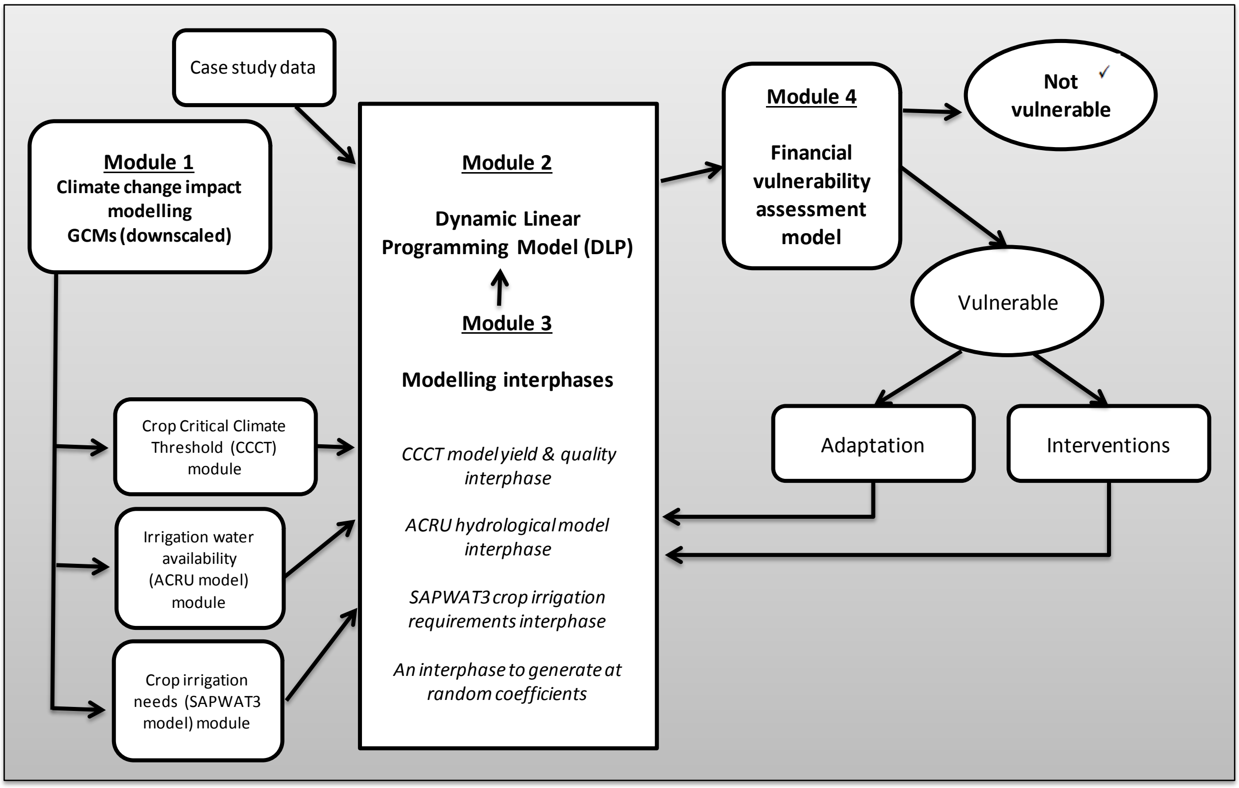

Figure 1: Diagrammatic illustration of the modelling framework

These modules will be discussed in more detail in the next four sections.

Climate change impact modelling – downscaled GCMs

Empirical downscaling makes use of the quantitative relationships between the state of the larger scale climatic environment and local variations sourced from historical data. By coupling specific local baseline climate data with GCM output, a valuable solution to overcoming the mismatch in scale between climate model projections and the unit under investigation is provided. Empirical downscaling can be applied to a grid or to a particular meteorological station. The latter sub-set of empirical downscaling is more common and is referred to as statistical empirical downscaling.

The Climate Systems Analysis Group (CSAG), based at the University of Cape Town, South Africa, operates the preeminent empirical downscaled model for Africa and provides meteorological station level responses to global climate forcings for a growing number of stations across the African continent.

Table 1 provides a condensed description of the information on GCMs, the global climate change scenarios which were empirically downscaled by CSAG to point climate station scale for application in this study. Five GCMs from various respected international organisations were used.

Table 1: Global climate model (GCM) description

Institute	GCM
Canadian Center for Climate Modelling and Analysis (CCCma), Canada ***Abbreviation: CCC***	**Name:** CGCM3.1(T47) **First published:** 2005 Website: http://www.cccma.bc.ec.gc.ca/models/cgcm3.shtml
Meteo-France / Centre National de Recherches Meteorologiques (CNRM), France ***Abbreviation: CRM***	**Name:** CNRM-CM3 **First published:** 2004 Website: http://www.cnrm.meteo.fr/scenario2004/indexenglish.html
Max Planck Institute for Meteorology (MPI-M), Germany ***Abbreviation: ECH***	**Name:** ECHAM5/MPI-OM **First published:** 2005 Website: http://www.mpimet.mpg.de/en/wissenschaft/modelle.html
NASA / Goddard Institute for Space Studies (GISS), USA ***Abbreviation: GISS***	**Name:** GISS-ER **First published:** 2004 Website: http://www.giss.nasa.gov/tools/modelE
Institut Pierre Simon Laplace (IPSL), France ***Abbreviation: IPS***	**Name:** IPSL-CM4 **First published:** 2005 Website: http://mc2.ipsl.jussieu.fr/simules.html

Whole farm dynamic linear programming approach

Dynamic linear programming (DLP) is one of the most practical agricultural economic tools to simulate farming systems and has been used by various South African researchers (Backeberg, 1984; Oosthuizen, 1995; Maré, 1995; Louw, 1996; Louw and Van Schalkwyk, 1997; Haile et al., 2003). DLP is a mathematical technique which may be employed by management to determine the optimal utilisation of limited resources. It comprises the formulation of a model, which is solved mathematically to provide an optimal answer (Redelinghuis et al., 1987). In order to analyse a problem using DLP, it has to be moulded into a particular structure that should at least contain the following components (see Figure 2):

- Objective – to obtain the best or optimal solution, i.e. maximizing cash-flow surplus
- Activities or decision variables that define the action
- Constraints or restrictions that limit the availability of resources

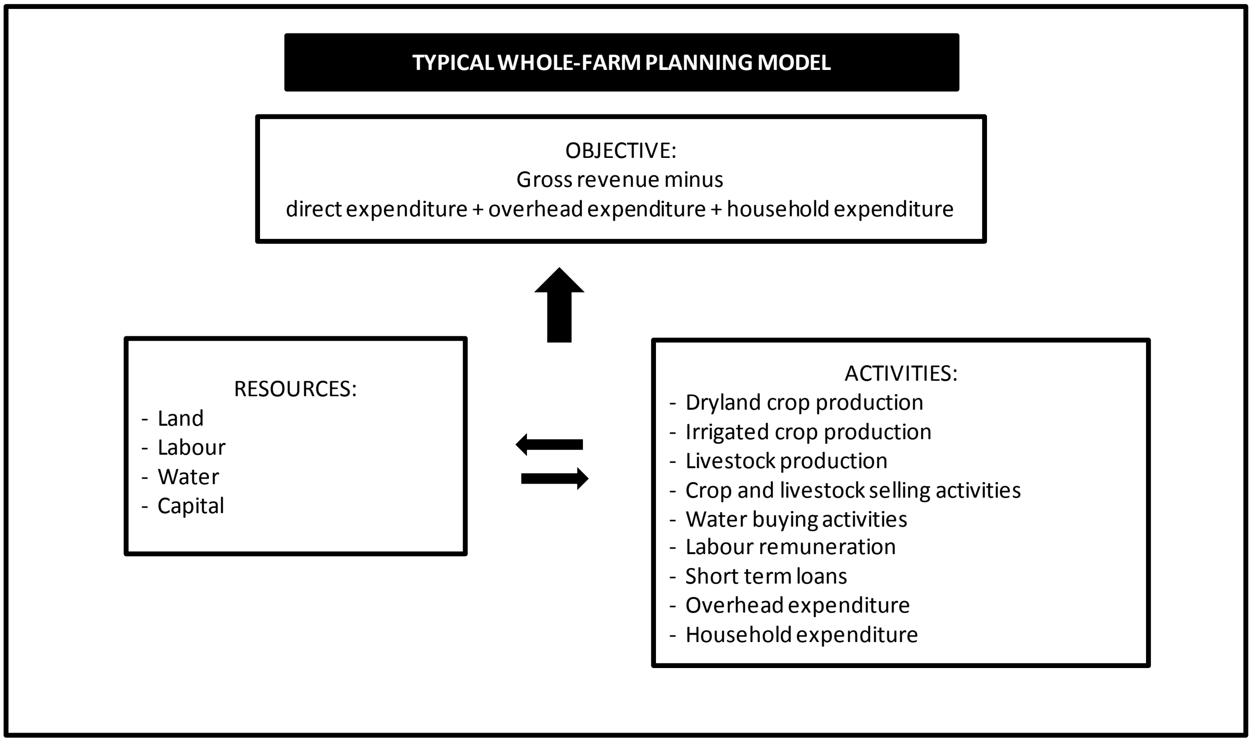

Figure 2: Conceptual linear programming modelling framework

The DLP model was developed in GAMS notation and solved with the CPLEX solver. For the sake of brevity the mathematical model is not described in detail in this paper. For illustration purposes Table 2 shows some sets and parameters of the model and their respective descriptions.

Table 2: DLP model - sets and parameters (for illustration purposes)

SET ELEMENT	DESCRIPTION
c	All enterprises
i_c	All crops
tc_i	All test crops
Mji_{tc}	Multi-year crops
Oji_{tc}	Single-year crops
l	Landtypes
j	Water users
b_j	Irrigation users
t	Typical users
tu_t	Test users
gsl	Growth stage / g01*g29 /
Th	Total time serie
ph_{th}	Planning horizon
Csc	Climate threshold condition / 1*19 /
Qsc	Quality condition / 1*10 /
PARAMETER ELEMENT	**DESCRIPTION**
$TRADJUST_{iph}$	Attach climate threshold breaches to yield adjustment of crops
$TEMPRAINSC_{iCsc}$	Scaling of yield for crops due to climate impact
$PQUALITYSC_{iCsc}$	Scaling of quality for crops due to climate impact
$PRICEADJUST_{iph}$	Attach climate threshold breaches to price adjustment of crops
$IRINT_{ih}$	Irrigation intensity possibilities for crops
$IRINTSC_{mh}$	Scaling of irrigation intensity possibilities per month
$IRINCSC_{ih}$	Scaling of the gross margin for crops due to irrigation intensity
WC_{igslm}	Irrigation requirements of crops per hectare per growthstage per month
$TOTWALLOC_{btph}$	Total annual water allocation over planning horizon
$TRYIELDCALC_{igsllPh}$	Calculates yield of crop per growthstage due to threshold breaches – Step 1
$YIELDCALC2_{igsllPh}$	Calculate yield of crop per growthstage due to threshold breaches – Step 2
$PRICESET_{iphCsc}$	Calculate price set due to climate threshold condition
$PRICEQUAL_{ilph}$	Calculate annual price of crops due to quality conciderations

The objective functions for the irrigation case study is calculated in two steps (b = region, tu = case study, ph = year).

Equation NDICALC*btuPh* calculates the net disposable income per case study farm (b,tu) and per year (ph)

Plus gross revenue from crop sales

Plus non-farm revenue (if applicable)

Minus direct allocatable production expenditure for crops

Minus overhead expenditure

Minus household expenditure

Plus loans (cash inflow)

Minus payback of loans (cash outflow)

Plus surplus (if any from the previous year) + interest on surplus

Plus the terminal values for long term crops

= EndB*btuPh*

Objective function Z (quantified in mathematical terms)

Z = Maximize sum (EndB*btuPh*)

The impact of climate change on farming system is calculated in four phases:

- Changes in yield (as per CCCT model)
- Changes in quality/price (as per CCCT model)
- Changes in availability of irrigation water (as per ACRU model)
- Changes in crops irrigation requirements (as per SAPWAT3 model)

The following formulae display the relative yield calculation in the DLP model:

PARAMETER TRCscCalc(i,ph,Csc) Calculate set

TRCscCalc(i,ph,Csc) = TRADJUST(i,ph) eq ORDCsc(Csc))

PARAMETER TRYIELDCALC(i,gsl,l,Ph) calculates yield of crops per growth stage due to threshold breaches – Step 1

TRYIELDCALC(i,gsl,l,Ph) = 1 - sum(Csc,TEMPRAINSC(i,Csc)

PARAMETER YIELDCALC2(i,gsl,l,Ph) calculates yield of crops per growth stage due to threshold breaches – Step 2

YIELDCALC2(i,gsl,l,Ph) = Rescrres(i,gsl,l,"yield") - ((TRYIELDCALC(i,gsl,l,Ph) x Rescrres(i,gsl,l,"yield")))

The following formulae display the calculation of climate change impact on quality/price:

PARAMETER Priceset(i,ph,Csc) Calculate set

Priceset(i,ph,Csc) = (PriceADJUST(i, ph) eq ORDCsc(Csc))

PARAMETER PriceQual(i,l,Ph) calculates annual price due to quality considerations

PriceQual(i,l,Ph) = sum(Csc,PQUALITYSC(i,Csc)$Priceset(i,ph,Csc)) x Rescroth(i,l,"Price")

To incorporate climate change impact modelling results in the DLP model requires several interphases in the modelling framework, to be discussed in the following sections.

Climate change modelling interphases

The development of interphases between the downscaled climate data sets which were applied in the CCCT, ACRU and SAPWAT3 models and the DLP model is of paramount importance. Not only do they enable a better understanding of the relative changes from the observed and projected climate, but they also make a substantial contribution towards the interpretation and the dissemination of the results. For the purpose of this project, four interphases were developed. They are:

- The CCCT yield and quality model – DLP model interphase
- The ACRU hydrological model - DLP model interphase
- The SAPWAT crop irrigation requirement – DLP model interphase
- An interphase to generate at random variation coefficients to be imposed on all the crops in the model where CCCT models are not available.

The following sections allows for a brief discussion of each of the interphases.

CCCT yield and quality model interphase

Crop models for annual crops are fairly straight forward: however, there is a considerable gap in the knowledge and the technology to simulate the response of perennial crops to climate change.

With this in mind, the researchers developed the crop critical climate threshold (CCCT) modelling technique, which is supported by expert group discussions. This modelling technique was validated in two case studies where the CCCT model results and APSIM crop model results correlated to such an extent that the researchers are confident that the CCCT modelling technique can be applied successfully in integrated climate change modelling. The model can be used for crops where more conventional and recognised models are not available or trustworthy.

The downscaled climate data sets for the various GCMs feed into the CCCT model. The basic output of the CCCT model is projected yield and quality (annually and per crop cycle) over the planning horizon for each GCM data set. In this project it is for-

- the present (observed) – 1971 to 1990, and
- the intermediate future – 2046 to 2065.

The output of the CCCT model (projected annual yield and quality) feeds into the DLP model.

The following section gives an overview of the different elements in the modelling process.

Similar to Hoffman's (2010) approach, the minimum and maximum climate thresholds (temperature and rainfall) for all the important crops were identified during a validation workshop and through expert group discussions.

These climate thresholds are used as input to the CCCT model, which is then run with different climate data sets. The model calculates the number of times that each critical threshold is breached. A factor (positive or negative) is assigned to each critical threshold, which implies that the crop yield/quality will be adjusted each time a threshold is breached.

Table 3 reflects the crop critical climate thresholds for citrus (grapefruit) in the Hoedspruit area as well as the expected impact on yield and/or quality.

Table 3: Example for Hoedspruit citrus (grapefruit) crop critical climate thresholds

Crop critical climate threshold	Yield penalty factor	Quality penalty factor
Temp >40,RH <30% for 2 days Sept	-0.40	0.00
Temp >35, RH <30% for 2 days Sept	-0.40	0.00
Temp >35, RH <20% for 2 days Sept	-0.40	0.00
Fruit drop (Nov/Dec) >7 days of T> 36 degrees, humidity <40 %	-0.30	-0.10
Grapefruit - 2 deg warmer in May - colour deteriorates	0.00	-0.04
During picking temp >36 degrees - increase rind problems	0.00	-0.01
>14 days continuous rain during picking (autumn) causes leaf wetness and overripe fruit	0.00	-0.10
Scaling dummy	0.00	0.05

The following procedures are then executed:

Step 1

The daily temperature and rainfall for each climate change scenario per planning horizon (present [1971 – 1990] and intermediate future [2046 – 2065]) as received from the climatologists is converted to a pivot table in Excel. This includes daily data for five downscaled climate models (GCMs). The data are then processed through a procedure where the threshold breaches for temperature and rainfall are identified.

The threshold breach results for a specific crop are summarised into one table (see Table 3 above and Table 4 below). The yield/quality is then penalised with a certain percentage according to the breaches of each threshold. In this specific model all the threshold breaches have a negative effect on the yield/quality. Owing to a lack of positive factors, a dummy scaling factor is used to normalise the data, without disturbing the trends. The combined effect of all the threshold breaches that occurred in that specific year is then calculated.

For yield calculation, the DLP model provides for 19 levels of impact ranging from -50% to plus 50% at intervals of 5% to 10% (which can easily be changed). During the procedure any number from 1 to 19 is allocated in the event that the climate condition exceeds the threshold. These are converted into tables for each crop (it can be any number) that is compatible with the GAMS program.

Similar to the yield calculation, the impact of climate change on quality is calculated. The DLP model provides for 10 levels of impact ranging from -40% to plus 50% of the base quality (price). The results are summarised in a table to be fed into the DLP model.

For illustration purposes, quality scaling as a result of climate change will be illustrated in the rest of this section. Table 4 presents the process to arrive at a quality scaling code due to temperature and rainfall threshold breaches. The procedure is as follows:

- For each year under consideration the quality deviation from the base quality (realistic price) is incorporated in the respective row e.g. for 2047 there is a 25% negative impact and a 5% positive impact (scaling dummy). The net effect is therefore -20% which results in a quality scaling Code 3 which GAMS will read as 80% x base quality. See Step 2.

Table 4: Allocation of quality deviation per code derived from Step 1

Climate impact quality scaling	Temp >40,RH <30% for 2 days Sept	Temp >35, RH <30% for 2 days Sept	Temp >35, RH <20% for 2 days Sept	Fruit drop (Nov/Dec) >7 days of T> 36 degrees, humidity <40 %	Grapefruit - 2 deg warmer in May - colour deteriorates	During picking temp >36 degrees - increase rind problems	>14 days continuous rain during picking (autumn) causes leaf wetness and overripe fruit	Scaling dummy	**Temp Yield Scaling factor**	**Rainfal Yield Scaling factor**	**Temp & Rain Yield Scaling factor**	**Climate model Quality scaling code**
2046					-0.04	-0.1875		0.05	**-0.1775**		**-0.1775**	**3**
2047					-0.04	-0.21		0.05	**-0.2**		**-0.2**	**3**
2048					-0.04	-0.1425		0.05	**-0.1325**		**-0.1325**	**4**
2049					-0.04	-0.1875		0.05	**-0.1775**		**-0.1775**	**3**
2050						-0.15		0.05	**-0.1**		**-0.1**	**4**
2051					-0.04	-0.1725		0.05	**-0.1625**		**-0.1625**	**3**
2052						-0.12		0.05	**-0.07**		**-0.07**	**4**
2053					-0.04	-0.21		0.05	**-0.2**		**-0.2**	**3**
2054					-0.04	-0.1725		0.05	**-0.1625**		**-0.1625**	**3**
2055					-0.04	-0.1875		0.05	**-0.1775**		**-0.1775**	**3**
2056					-0.04	-0.15		0.05	**-0.14**		**-0.14**	**4**
2057						-0.18		0.05	**-0.13**		**-0.13**	**4**
2058					-0.04	-0.165		0.05	**-0.155**		**-0.155**	**3**
2059					-0.04	-0.18		0.05	**-0.17**		**-0.17**	**3**
2060					-0.04	-0.1875		0.05	**-0.1775**		**-0.1775**	**3**
2061					-0.04	-0.21		0.05	**-0.2**		**-0.2**	**3**
2062					-0.04	-0.15		0.05	**-0.14**		**-0.14**	**4**
2063						-0.1425		0.05	**-0.0925**		**-0.0925**	**4**
2064					-0.04	-0.18		0.05	**-0.17**		**-0.17**	**3**
2065					-0.04	-0.165		0.05	**-0.155**		**-0.155**	**3**

The GAMS program now uses the scaling code number in Table 4 and applies the adjustment factor in Table 5 to determine with how much the model must increase/decrease the base quality (price). It should be clear that by following this procedure it is possible to trace back the specific reason why the experts were of the opinion that the quality will decrease in a specific year.

Step 2

In this step a scaling percentage is attached to the quality scaling codes which were calculated in Step 1. The quality code is adjusted by allocating a model code of 1 to 9 to the event (where 5 means no change and the others are four factors negative and four factors positive).

Table 5: Allocating a code to scale quality (price) of crops

Scaling code	1	2	3	4	5	6	7	8	9	10
ManTA	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
ManKent	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
ManSens	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
ManKeitt	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
CitPom	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
CitVal	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
CitLem	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
ManA	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5
CitA	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5

For example, if a Code 5 is allocated the GAMS model will establish that there is zero change in quality/price. A Code 4 will result in the model changing the quality of, for example, crop ManTA to 90% of base quality (price).

The procedure described here is a practical solution to estimate yield and quality variation based on critical climate thresholds for crops. It may not be the ideal methodology; however it can be very useful where crop models either do not exist, or where there is doubt about the reliability of the crop models or where crop models do not account for the quality of produce.

ACRU hydrological model interphase

The availability of irrigation water is a derivative of dam levels which are a function of, amongst others, rainfall and runoff patterns, which should be investigated to determine the impact of climate change on the financial vulnerability of irrigation farming systems.

The projected dam levels for the Blyde River Dam was calculated by the Centre for Water Resources Research, University of KwaZulu-Natal (UKZN). The present and intermediate climate data for downscaled GCMs were used in the ACRU model to project dam levels. The following paragraphs give a brief description of the background and methodology applied to arrive at the projected dam levels.

The erstwhile South African Department of Water Affairs and Forestry (DWAF; now DWA - the Department of Water Affairs) delineated the RSA, together with Swaziland and Lesotho, into 22 primary catchments, which in turn have been disaggregated into secondary, then tertiary and finally, into 1 946 interlinked and hydrologically cascading quaternary catchments (QCs) (Schulze et al., 2011).

The sub-delineation of quaternary into quinary catchments has resulted in 5 838 hydrologically interlinked and cascading quinaries covering the RSA, Lesotho and Swaziland. These have been demonstrated to be physiographically considerably more homogeneous than the quaternaries (Schulze and Horan, 2007; 2010) and on a national and smaller scale are considered to be relatively homogeneous hydrological (as well as agricultural) response zones.

Following the delineation of the Southern African countries of the RSA, Lesotho and Swaziland into hydrologically interlinked quinary catchments, the formerly used quaternary catchments database (QCB; e.g. Schulze et al., 2005) needed to be expanded to form a new database, viz. the Southern African Quinary Catchments Database (QnCDB) (Schulze et al., 2011).

The key climatic and catchment input into the QnCDB include (Schulze et al., 2011):

- Daily rainfall input per quinary catchment
- Daily temperature input per quinary catchment
- Estimations of daily values of reference crop evapotranspiration per quinary catchment
- Soils information
- Baseline land cover information

Applying die different downscaled GCMs data sets to the ACRU model enabled the researchers to project the daily and from those, monthly dam levels (for present and future climate scenarios) of the Blyde River Dam (Figure 3). The results show that the availability of irrigation water for this area will not be negatively influenced by climate change. Increased dam levels are projected for both average and median intermediate climate scenarios for the Blyde River Dam.

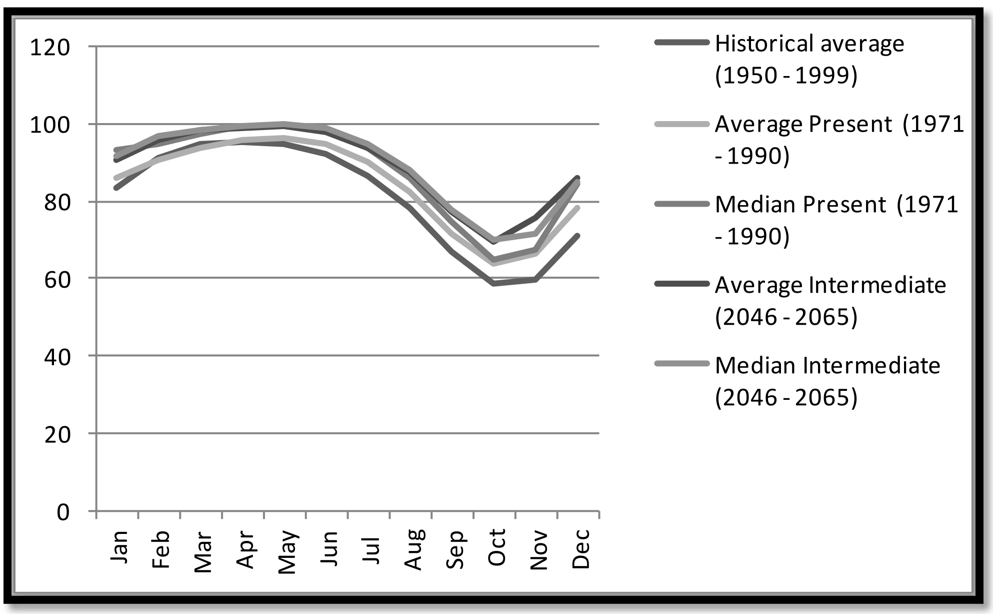

Figure 3: Simulated monthly damlevels for Blyde River Dam

The simulated hydrological data is introduced to the DLP model as constraints via the irrigation water availability interphase which include yearly and monthly constraints.

SAPWAT3 crop irrigation requirements interphase

The irrigation requirement of crops is dominated by weather, particularly in the yearly and seasonal variation in the evaporative demand of the atmosphere as well as precipitation. The SAPWAT3 model has included in its installed database comprehensive weather data which is immediately available to the user (Van Heerden et al., 2009):

- Firstly it includes the complete FAO Climwat weather data base encompassing not only South Africa, but many other countries in the world where there is irrigation development. Climwat comprises 3 262 weather stations from 144 countries, including South Africa, and contains long-term monthly average data for calculating Penman-Monteith ET0 values as well as rainfall.
- The second installed set of weather data in SAPWAT3 consists of data derived from over 2 100 weather stations in South Africa. This database was developed from the South African Atlas of Climatology and Agro Hydrology by the team from the School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal.
- SAPWAT3 also provides facilities for importing additional weather stations.

The model utilises the four stage crop development curve procedure based on relating crop evapotranspiration in each stage to the short grass (Penman-Monteith) reference evapotranspiration by applying a crop coefficient.

The SAPWAT 3 model was applied to determine changing crop irrigation requirements under present and future climate scenarios using downscaled climate data of the various GCMs used in this study.

Table 6 illustrates the monthly irrigation requirements for citrus for the different downscaled GCMs for the present and intermediate future. All the GCMs indicate an increase in demand for irrigation water, varying from 3% to 12% with an average projected increase of 8%.

Table 6: Crop irrigation requirements (per hectare) for citrus for present and intermediate future climates

Citrus	Present climate scenario															
Case study region	**Crop**		**Irri01**	**Irri02**	**Irri03**	**Irri04**	**Irri05**	**Irri06**	**Irri07**	**Irri08**	**Irri09**	**Irri10**	**Irri11**	**Irri12**	**Total**	
Hoedspruit_CCC_PR3	Citrus	No ground cover	105	90	105	100	82	54	97	99	110	114	96	110	**1,162**	
Hoedspruit_CRM_PR3	Citrus	No ground cover	64	44	64	84	88	62	105	111	111	98	70	74	**975**	
Hoedspruit_ECH_PR3	Citrus	No ground cover	100	78	83	75	85	58	96	103	109	112	102	74	**1,075**	
Hoedspruit_GISS_PR3	Citrus	No ground cover	101	92	99	86	82	49	89	95	94	83	90	88	**1,048**	
Hoedspruit_IPS_PR3	Citrus	No ground cover	89	84	92	90	79	58	108	105	107	107	99	84	**1,102**	
Average	Citrus	No ground cover	92	78	89	87	83	56	99	103	106	103	91	86	**1,072**	
Citrus	**Intermediate climate scenario**															
Case study region	**Crop**		**Irri01**	**Irri02**	**Irri03**	**Irri04**	**Irri05**	**Irri06**	**Irri07**	**Irri08**	**Irri09**	**Irri10**	**Irri11**	**Irri12**	**Total**	**% change**
Hoedspruit_CCC_INT	Citrus	No ground cover	105	100	114	100	96	63	102	98	127	122	104	108	**1,239**	7%
Hoedspruit_CRM_INT	Citrus	No ground cover	80	54	67	73	91	71	108	120	131	108	72	86	**1,061**	9%
Hoedspruit_ECH_INT	Citrus	No ground cover	102	85	81	75	91	70	105	114	122	113	98	113	**1,169**	9%
Hoedspruit_GISS_INT	Citrus	No ground cover	107	91	108	99	94	60	104	101	99	100	98	109	**1,170**	12%
Hoedspruit_IPS_INT	Citrus	No ground cover	83	83	102	90	90	63	96	111	103	121	103	90	**1,135**	3%
Average	Citrus	No ground cover	95	83	94	87	92	65	103	109	116	113	95	101	**1,155**	8%

The crop irrigation requirements data are introduced to the DLP model via the crop irrigation requirements interphase.

An interphase to generate at random variation coefficients

The model makes provision for smaller crops or crops where information on the thresholds is not available. It is possible to impose decreases or increases (yield and/or price) in random variation in GAMS through a very simple but useful function in the programme by simply changing the upper and lower variation boundaries.

Financial vulnerability assessment model

The financial model provides a set of criteria to determine financial vulnerability. These are:

- IRR (Internal Rate of Return)
- NPV (Net Present Value)
- Cash Flow Ratio
- Highest Debt : Asset Ratio (D:A ratio)
- Highest Debt

The definitions for the criteria are the following:

Internal rate of return (IRR)

The internal rate of return (IRR) is probably the most widely used sophisticated capital budgeting technique. The IRR is the compound annual rate of return that the firm will earn if it invests in the project and receives the given cash inflows (Gitman, 2009).

Net present value (NPV)

Because net present value (NPV) gives explicit consideration to the time value of money, it is considered a sophisticated capital budgeting technique (Gitman, 2009). NPV can be described as the "difference amount" between the sums of discounted: cash inflows and cash outflows. It compares the present value of money today to the present value of money in future, taking inflation, uncertainty and opportunity cost of capital into account.

Cash flow ratio (CFR)

A measure of how well cash flow out is covered by the cash flow in. The CFR can gauge a company's liquidity in the short term. Using cash flow as opposed to income is sometimes a better indication of liquidity simply because cash is how bills are normally paid (Absa, 2002).

Debt : Asset ratio

The debt position of a firm indicates the amount of other people's money (debt) being used to generate profits (Gitman, 2009). It is the total liabilities divided by total assets. If the ratio is less than 0.5, most of the company's assets are financed through equity. If the ratio is greater than 0.5, most of the company's assets are financed through debt.

Highest debt

Within the context of this study it is simply the highest debt over the 20-year planning horizon.

Modelling results

Table 7 contains the abbreviations for the different climate data that was applied to the integrated model.

Table 7: Climate data scenario abbreviations

Abbreviation	Description
Base run	Current average yields
CCC Present Static (1971 - 1990)	CCC Model - Present climate scenario, current crop pattern
CRM Present Static (1971 - 1990)	CRM Model - Present climate scenario, current crop pattern
ECH Present Static (1971 - 1990)	ECH Model - Present climate scenario, current crop pattern
GISS Present Static (1971 - 1990)	GISS Model - Present climate scenario, current crop pattern
IPS Present Static (1971 - 1990)	IPS Model - Present climate scenario, current crop pattern
CCC Intermediate Static (2046 - 2065)	CCC Model - Intermediate climate scenario, current crop pattern
CRM Intermediate Static (2046 - 2065)	CRM Model - Intermediate climate scenario, current crop pattern
ECH Intermediate Static (2046 - 2065)	ECH Model - Intermediate climate scenario, current crop pattern
GISS Intermediate Static (2046 - 2065)	GISS Model - Intermediate climate scenario, current crop pattern
IPS Intermediate Static (2046 - 2065)	IPS Model - Intermediate climate scenario, current crop pattern
CCC Intermediate Adapt Opt (2046 - 2065)	CCC Intermediate scenario - Optimise adaptation strategies
CRM Intermediate Adapt Opt (2046 - 2065)	CRM Intermediate scenario - Optimise adaptation strategies
ECH Intermediate Adapt Opt (2046 - 2065)	CRM Intermediate scenario - Optimise adaptation strategies
GISS Intermediate Adapt Opt (2046 - 2065)	GISS Intermediate scenario - Optimise adaptation strategies
IPS Intermediate Adapt Opt (2046 - 2065)	IPS Intermediate scenario - Optimise adaptation strategies

The scenarios can be divided into four broad categories namely:

- Base run (apply current average yields and prices and project over 20 year period – 15% variability in yield and price)
- Present climate scenario – CCCT modelling (apply crop critical climate thresholds and downscaled GCMs climate data sets to determine potential yield and quality of crops with current production pattern as input to the model)
- Intermediate climate scenario – CCCT modelling (apply crop critical climate thresholds and downscaled GCMs climate data sets to determine potential yield and quality of crops with current production pattern as input to the model).
- Intermediate climate scenario with adaptation – CCCT modelling (apply crop critical climate thresholds and downscaled GCMs climate data sets to determine potential yield and quality of crops including adaptation options as input to the model)

Adaptation strategies

An increase in average temperatures and seasonal rainfall shifts are the biggest threats that the Hoedspruit area faces. The following are problems associated with increased temperatures:

- Quality losses as a result of wind and sunburn (citrus and mangoes)
- Reduction in fruit set (citrus) as a result of sunburn
- Seedless cultivars are less tolerant to increased temperatures than seeded cultivars – the demand, however, is for seedless cultivars (citrus)

The only adaptation strategy that was identified to eliminate the threats associated with climate change and to be included in the integrated model is the installation of shade nets over citrus and mango production areas.

While water efficiency is a key concept to solve water shortage problems in semiarid areas, shading net structures in semi-arid and arid environments can be considered as an intermediate solution for increasing water use efficiency and reducing plant water stress. It offers many advantages and environmental benefits, and this is why crops, including citrus, are increasingly being grown under shading materials of various types. It was found that the use of the shading net reduces wind speed within the foliage and helps to decrease fruit dropping. The shade provided by the net does not affect yield and internal fruit quality (ratio of sugar to acid), but may increase the fruit's average weight and diameter (Abouatallah et al., 2012).

The Panel of Experts agreed that shade nets on citrus and mangoes can eliminate most threats associated with projected climate change and will have the following advantages:

- Improvement in fruit quality (citrus and mangoes) [less hail, wind and sun damage]
- Less stress on the tree (citrus and mangoes) [more consistent yields]
- More effective use of irrigation water (citrus and mangoes) [less evapotranspiration]

The following list of adaptation strategies was debated but not included in the integrated climate change model:

- Mulching cover to conserve soil moisture
- More effective management of irrigation systems
- Focus on cultivar development to increase natural heat resistance

Results of the integrated financial vulnerability modelling

The key financial modelling results are presented in Table 8. The average projected IRR for the present climate scenario is 16% compared to 1% for the intermediate climate scenario without adaptations and 7% for the intermediate future scenario if adaptation strategies are adopted.

The average projected NPV was calculated at R13.3 million for the present climate scenario, (R3.7 million) for the intermediate climate scenario without adaptations and R10.5 million if adaptations strategies are included in the modelling.

The average projected CFR for the present climate scenario was calculated at a healthy 126%, a negative CFR (89%) for the intermediate future climate scenario with production patterns and a fairly reasonable 115% if adaptation strategies are implemented.

A highest average D:A ratio of 47% is projected for the current climate scenario, and this falls within acceptable financing norms. The projection for both intermediate climate scenarios (with and without adaptations), however, do not meet the general acceptable financing norm of <50%.

In terms of highest debt, during the 20-year modelling period, the average was calculated at R3.7 million for the present climate scenario, R14 million for the intermediate climate scenario without adaptations and R28 million for the intermediate climate scenario if adaptations strategies are adopted.

Table 8: Key financial modelling results

	IRR	NPV	Cash flow ratio	Highest D:A Ratio	Highest debt
Base run	14%	11,699,862	127%	43%	(3,419,599)
CCC Present Static (1971 - 1990)	18%	14,765,968	128%	56%	(4,439,923)
CRM Present Static (1971 - 1990)	19%	14,576,767	122%	35%	(2,759,573)
ECH Present Static (1971 - 1990)	12%	8,961,991	119%	46%	(3,638,295)
GISS Present Static (1971 - 1990)	19%	17,828,480	135%	42%	(3,342,224)
IPS Present Static (1971 - 1990)	13%	10,654,980	125%	56%	(4,446,420)
CCC Intermediate Static (2046 - 2065)	2%	(2,338,374)	95%	125%	(9,945,383)
CRM Intermediate Static (2046 - 2065)	-2%	(6,122,120)	78%	315%	(25,068,543)
ECH Intermediate Static (2046 - 2065)	-1%	(5,359,147)	82%	255%	(20,314,210)
GISS Intermediate Static (2046 - 2065)	1%	(2,933,370)	92%	104%	(8,302,087)
IPS Intermediate Static (2046 - 2065)	2%	(1,985,007)	97%	80%	(6,378,299)
CCC Intermediate Adapt Opt (2046 - 2065)	2%	(2,335,238)	93%	126%	(11,021,540)
CRM Intermediate Adapt Opt (2046 - 2065)	-1%	(6,118,835)	76%	300%	(26,167,396)
ECH Intermediate Adapt Opt (2046 - 2065)	-1%	(5,309,892)	81%	241%	(21,017,467)
GISS Intermediate Adapt Opt (2046 - 2065)	1%	(2,898,311)	91%	104%	(9,021,487)
IPS Intermediate Adapt Opt (2046 - 2065)	2%	(1,792,508)	97%	80%	(6,948,781)
CCC Intermediate Adapt Opt No constraints(2046 - 2065)	7%	10,616,893	115%	177%	(28,995,741)
CRM Intermediate Adapt Opt No constraints (2046 - 2065)	7%	10,616,893	115%	177%	(28,995,741)
ECH Intermediate Adapt Opt No constraints (2046 - 2065)	7%	10,616,893	115%	177%	(28,995,741)
GISS Intermediate Adapt Opt No constraints (2046 - 2065)	7%	10,293,827	114%	175%	(28,350,214)
IPS Intermediate Adapt Opt No constraints (2046 - 2065)	7%	10,616,893	115%	177%	(28,995,741)

The results in Table 8 are based on a 20% start-up D:A ratio for the case study. A sensitivity analysis clearly showed that farmers with high debt ratios would be financially more vulnerable to climate change than those with low debt ratios.

CONCLUSIONS

The agricultural sector is vulnerable to climate change, both physically and economically, as concluded by various studies, both national and international. It is critical to determine the possible impacts of projected future climates on the financial vulnerability of different farming systems in South Africa and to evaluate suggested adaptation strategies. The case study represents an irrigation farm with citrus and mangoes in the Hoedspruit summer rainfall area of South Africa.

The integrated climate change modelling is based on five empirically downscaled GCM climate data sets for the present (1971 – 1990) and intermediate future (2046 – 2065). These climate sets served as base for the ACRU hydrological model (to determine the availability of irrigation water) and the SAPWAT3 model (to determine crop irrigation needs). The same climate sets were used to calculate the breaches of crop critical climate thresholds (CCCT modelling) and the impact thereof on crop yield and quality, as determined through expert group discussions.

In terms of climate change, seasonal shifts and an increase in average temperatures pose a threat to the farming community of the Hoedspruit area. Problems that may incur include, amongst others, quality losses, reduction in fruit set and an increase in irrigation water utilisation.

The results show that for the citrus and mango producing area of Hoedspruit, from a financial point of view, a decrease in profitability can be expected. Farmers with high debt ratios will be more financially vulnerable than those with low debt levels.

The modelling results indicate that shade nets as an adaptation strategy will contribute positively to profitability. The capital cost of these structures is, however, high and it may not be affordable to all farmers.

The research has also highlights the need for effective management of irrigation systems, moisture conservation and the development of cultivars that are naturally more heat resistant.

ACKNOWLEDGMENTS to the Water Research Commission (WRC) for initiating, managing and funding this research project under the directed call for proposals and to the Department of Agriculture, Forestry and Fisheries (DAFF) for co-funding the project.

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