Effects of global warming on Crop Production in South Africa

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Introduction

It is now widely acknowledged that the increase of atmospheric greenhouse gases, notably carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), will produce climatic changes of global extent during the 21st century. Indeed, on the basis of current predictions, concentrations of CO_2, which is by far the most important of these gases, will double within the next 50-75 years[1]. The unprecedented extent and rapidity of these changes is best measured against CO_2 fluctuations between the last interglacial (some 127 000 years BP) when values were around 280 ppm, the Last Glacial Maximum (about 18 000 years BP) when they dropped to around 180 ppm, and the pre-industrial Holocene, ending some 190 years ago, when they again averaged close to 270 ppm[2]; by comparison present values are on the threshold of 350 ppm. The expected changes will therefore be more rapid, by about an order of magnitude, than any experienced since the appearance of *Homo sapiens sapiens* in the prehistoric record. The objectives of this paper are to assess the possible effects of these changes on agricultural crop production in South Africa, using as a basis for this assessment the output from available climate models and knowledge of the climate requirements of the major crops grown in South Africa.

Possible Climatic Effects of Co_2 Increase

The climatic effects of this unparalleled increase in CO_2 have been the subject of keen debate for nearly a decade, and a number of models based on general circulation within the atmosphere have been devised in an attempt to quantify likely changes. Five recent models have resulted in plausible scenarios based on a doubling of the global carbon dioxide content of the atmosphere: the National Centre for Atmospheric Research (NCAR) Community climate model[3], the Geophysical Fluid Dynamics Laboratory (GFDL) model[4] (also known as the National Oceanic and Atmospheric Administration (NOAA) model), the United Kingdom Meteorological Office (UKMO) model[5], and the Goddard Institute for Space Studies (GISS) model[6]. A new version of the NCAR model, finalised in 1989,[7] couples a 9-level atmosphere to a 4-layer dynamic ocean. The salient features of these models, their outputs for southern Africa and their limitations are summarised by Tyson[8, 9]; since the output from these models must necessarily form the basis for any worthwhile assessments relative to crop production in southern Africa they are discussed further below.

All five models predict increases in temperature over southern Africa; these are highest in the UKMO model, which suggests that both summer and winter temperatures will everywhere rise by some 4°C, with increases of up to 6°C occurring over the western areas. The GISS model predicts also that temperatures will rise by more than 4°C. The GFDL and NCAR models, on the other hand, suggest an increase of only 2—4°C, and in the latest interactive version of the NCAR model this is reduced to 1—2°C.

Possible changes in precipitation with doubling of CO_2 are less well defined by the models, largely because of their present poor horizontal resolution and their consequent inability to take into account topographic and other regional affects. In comparison with temperature, rainfall predictions must therefore be treated with even greater caution. In general, the UKMO and NCAR models predict a slight increase in summer rainfall over the northern part of the subcontinent, with a concomitant decrease of the southern and south western areas. The winter patterns in both models show drier conditions in the south western winter rainfall belt; over much of the rest of southern Africa the UKMO model suggests that conditions will be somewhat wetter, while the NCAR model restricts this increase to the eastern areas.

Palaeoclimatic analogues hold the potential to mitigate some of the uncertainties inherent in these early scenarios. On the evidence of the stable isotope content of speleothems[10] and artesian groundwater[11] in the southern Cape, mean temperatures there were between 5° and 6°C lower between 17 000 and 21 000 years ago than at present. In contrast, the mean temperature during the Holocene Maximum, some 5 000—8 000 years ago, was up to 3°C higher than at present[11]. ^{13}C values measured in a stalagmite from the Cango cave suggest that, prior to about 14 000 years BP during the last Glacial Period the temperature during the rainy season in the southern Cape was low in comparison with that during the Holocene; this argues for a possible shift from a winter rainfall regime towards a great preponderance of summer rainfall as the temperature increased[12]. Furthermore, a synthesis of all available palaeoclimatic evidence from sites in southern Africa which have been relatively confidently dated indicates that, during the temperature maximum between 5 000 and 8 000 years ago, the south western Cape and the Karoo became somewhat drier while the northern part of the subcontinent, including the Kalahari and the eastern regions, were, on the whole, slightly wetter[10]. Despite obvious differences between the factors which produced the Holocene altithermal and thode which could give rise to projected greenhouse warming, these findings support model predictions which associate temperature increase with overall desiccation in the Karoo and winter rainfall regions accompanied by a greater preponderance of summer precipitation in the latter; they support, too, a modest increase in precipitation in the summer rainfall areas to the north.

From the agricultural viewpoint the distribution of drought cycles is as important for crop production as the overall amount and seasonality of the rainfall. Tyson[9] observes that global warming may alter the quasi 18-year oscillation in summer rainfall which has, for a considerable time, characterised the climate of southern Africa. Its effects on the continued occurrence of El Nino — Southern Oscillation (ENSO) phenomena, also evidently of considerable antiquity and of major importance in constraining the occurrence of drought cycles in the southern hemisphere, are likewise problematical, but their continued existence seems likely[13]. There is, however, a growing consensus that extreme events will occur more frequently in the mid-latitudes, at least locally and temporarily, owing to increased temperature contrasts between land and sea; it seems probable that this could be manifested in an increase in the frequency of both flood and drought events[13, 14]. The distribution and effects of such events are presently beyond the predictive capabilities of the general circulation models.

Despite these limitations, the GFDL and NCAR models have been used to simulate annual change in soil moisture index [$I_m = 100\ (P/PE) — 1$] for selected areas, including southern Africa[15]. With a doubling of atmospheric CO_2 the GFDL model registered a mean decrease of 19% in comparison with a decrease of 11% for the GISS model. By way of comparison, in winter rainfall areas broadly comparable with the south western Cape, with a 2—4°C temperature rise accompanied by a 20% decrease in rainfall, reductions in winter soil moisture of 11—25% have been estimated in two separate studies[16—18]. These results are dependent on predictions of precipitation, and they should be applied with extreme caution in regional crop models for the reasons given previously. However, since they are, at present the best estimates available, and since the data on which they are based derive some support from the palaeoclimatic evidence, there is justification in their use to develop preliminary scenarios.

At present none of the GCMs consider local contributions of change in climate. Another issue which is not addressed by the models is the temporal variability of climate, both seasonally within one year and between years. Another deficiency of these models is the way in which they have been used to simulate climatic change due to doubling of CO_2; the model is run at the normal level for a number of years until the climate stabilises and then the CO_2 is doubled and the model run until it again stabilises. This does not accord with reality, since the CO_2 level is gradually increasing all the time. These models have, therefore, in very few cases been used to simulate the changes as they will actually occur. In the remainder of the paper we refer to actual case studies in other parts of the world and how these can be applied to the South African situation, what lessons can be learned from them, and what should be done in the future to aid policy makers, farmers and the general public to adapt to possible climatic change.

Scenarios for the Rest of the World

Parry, Carter & Konijn[14] reported on the results of a worldwide project funded by the International Institute for Applied Systems Analysis (IIASA) and UNEP. The purpose of the study was twofold: first, to investigate the effects of climatic change and variability on agriculture; second, to evaluate the alternative responses to these effects. To address these objectives within a manageable research context, the project focused on a number of regional case studies. These fall into two groups: studies in cool temperate and cold regions (where low temperatures place a major limitation on agriculture) and in semi-arid regions (where deficiency of moisture is a dominant constraint). The methodology followed was a partially integrated approach and three elements highlight the integrated approach. First, the assessment of effects of climatic variations on agriculture was conducted using a hierarchy of models; at the top of the hierarchy were models or scenarios of climatic variation (e.g. a single anomalous weather year, an extreme weather decade and the GISS GCM 2 x CO_2 scenario), these were used as inputs to biophysical models of first-order relationships (e.g. agroclimatic indices, empirical-statistical models and deterministic crop simulation models), the output of which in turn were used as input for higher-order models (e.g. farm simulation models, input-output models, employment models, food supply models and land allocation models). Secondly, the effects of climatic variations were analysed in terms of their interactions with other physical systems (e.g. changes in soil structure, soil nutrients, soil erosion, pests and diseases). Third, the project considered two types of response to climate impacts; adjustments at the enterprise level and policy responses at the regional, national and international level.

Since South Africa has climates which belong in both the above categories, it would be worthwhile to look briefly at their findings for both groups:

(a) Cool temperate and cold regions: The estimated temperature increases in middle and high latitudes would result in a longer growing season, which could be exploited by planting late-maturing cultivars. This would lead to increased yields if farming practices were suitably adapted.

   Climatic change can be expected to bring about spatial shifts in crop potential. The extent of these shifts has yet to be investigated fully.

(b) Semi-arid regions: Little is known about likely changes in average annual receipts of rainfall at low latitudes and almost nothing about likely changes in rainfall patterns and duration. If large-scale shifts of rainfall patterns were to occur, two broad responses are possible:

   (i) extensive spatial shifts of farming activities, and

   (ii) large-scale inter-temporal or inter-regional transfers of water.

From the above it is obvious that there should be an adaptive capability from national level policy to on-farm decision making. In the semi-arid areas it is also evident that any drought amelioration policy would go a long way towards accommodating any changes that may occur in climate due to the greenhouse effect.

A number of studies have considered the effect of the doubling of CO_2 on expected grain yields on the North American continent (Rosenzweig, 1989[19], Achutuni & Decker, 1989[20], Liverman, Terjung, Hayes & Mearns, 1986[21], Smit *et al* 1989[22] and Wilks, 1988[23]). In the following paragraph we attempt to summarise the salient features of these studies:

> Rosenzweig, 1989[19] used the Ceres-Wheat and -Maize models to simulate the effects of changed climate on grain yields. To derive plausible climate scenarios she used output from both the GISS and GFDL models to calculate average monthly changes in temperature, precipitation and solar radiation. Observed daily climate variables were then multiplied by the appropriate monthly ratios calculated. This meant that no changes in climate variability were considered. She found that climatic change alone tended to depress yield, but that CO_2 enrichment compensated for this loss at most locations used in this study. Using a statistical model for maize yield estimation Achutuni & Decker, 1989[20] reached much the same conclusion. They calculated that in Missouri CO_2 enrichment could compensate for yield reductions caused by temperature change of up to +2°C. Liverman *et al*, 1986[21] constructed 124 different scenarios of climatic change from a change in temperature of −5 to +5°C, in solar radiation of +50% to −50% and in precipitation of +50% to −50% for four stations in a transect from Austin, Texas to Grande

Prairie, Alberta. They did not, however, consider the effect of CO_2 enrichment. Smit *et al*, 1988[22] limited their study to the province of Ontario in Canada. They used the output from the GISS model, in conjunction with rather elaborate calculations, to produce the daily data from the mean outputs for grid cells of approximately 4° latitude by 5° longitude. The crops used were maize, barley, soybeans and grass hay. They found that in Northern Ontario, where at present maize production is not feasible, modest to excellent yields could be expected, depending on soil type.

Yields of barley would tend to increase in some areas and decrease in others. Soybean yields would decrease in most areas except Northern Ontario, where new opportunities would be created for the crop. With hay the impacts would be much smaller than for other crops. The authors stressed that their findings were preliminary and should be viewed with caution due to uncertainties regarding future climatic trends and the shortcomings of the output from GCMs. It also appears that the impacts are likely to vary from region to region, from soil to soil and from crop to crop.

Wilks, 1988[23] used output from the Oregon State University (OSU) GCM to predict climate change due to CO_2 doubling and calculated the effects on maize and wheat yields in Kansas, Iowa and the Dakotas using CORNF and TAMW crop yield models. Elaborate calculations were used to derive the needed daily climate data from the output of the OSU GCM. Shifts in yields of wheat and maize were indicated, but no account was taken of the effects of CO_2 enrichment on yields. The most important points made by Wilks are that agricultural practices have historically exhibited considerable adaptability and continue to do so, and it is therefore reasonable to assume that practices will be nearly fully adapted to prevailing climatic conditions at any stage of warming, although an increasing rate of change will make reaction more difficult.

In this review mention has been made of the effect of CO_2 enrichment on crop yields. Cure & Acock, 1986[24] published a literature survey on this subject; the overall yield increases estimated for some crops are as follows for carbon dioxide doubling:

Wheat	35% ± 15%
Barley	70%
Rice	15% ± 3%
Maize	29% ± 64%
Soybean	29% ± 8%
Cotton	209%
Potato	51% ± 111%
Sweet Potato	83% ± 12*

Pittock & Nix, 1986[25] developed a climate change scenario and calculated resulting primary biomass production in Australia using the so-called "Miami model" for annual net primary productivity. The following scenario was postulated:

(a) Mean annual temperature was increased by 0,1°C above current values for every degree of latitude from the equator southwards.

(b) Summer (November — April) half-year precipitation was increased by 40%.

(c) Winter (May — October) half-year precipitation was decreased by 20%.

Results from the Miami model showed that about half of Australia might experience productivity increases in excess of 20%. A small area in the extreme south-west of Australia shows limited potential decrease in productivity. This method does not include the effects of CO_2 enrichment as described above. The authors also point out that an increase in net primary productivity leading to an average annual increase of only 1% in the total carbon stored in the vegetation would be of the same order as the annual release of carbon due to combustion of fossil fuel. This implies that CO_2-induced climatic change, as well as increased biospheric productivity due directly to higher ambient CO_2 concentrations, could considerably slow the actual increase in atmospheric CO_2 concentrations.

A wholly divergent view on the greenhouse effect was put forward by Sherwood Idso[26] in 1987. He calculated that, with measured increases of CO_2, the northern third of the globe should have warmed by about 5,7 K from 1880 to 1980; actual values have been only 0,5 K or less, thus "disproving" the greenhouse model, or at least reducing its worst effects. Another sobering article has very recently appeared from the pen of Bill Reifsnyder[27] where he describes ten fallacies which seems to be prevalent. It is a worthwhile and thought-provoking article which is worth any serious scholar's while to read, especially if he is interested in the issues which we are currently addressing. The ten fallacies he discusses are:

(1) models are better than data;
(2) government imprimatur equals scientific validation;
(3) climate change will appear as a discontinuity;
(4) climate variability increases with climatic change;
(5) the warming trend over the past 100 years is clear evidence that CO_2 warming is upon us;
(6) record high temperatures indicate CO_2 warming; record low temperatures indicate the approach of an ice age;
(7) indirect climatic effects of CO_2 are more important than direct effects;
(8) farmers should use predictions of climate warming for planning purposes even though modellers cannot predict next year's climate;
(9) forests are especially vulnerable to climatic warming because trees live a long time;
(10) deforestation equals desertification.

It is evident that at present there are severe limitations to any attempt to predict future climatic scenarios and to assess the impacts thereof on agricultural production. In the first instance the GCMs are at present very imprecise in the future climate scenarios being predicted. Different models yield different answers and due to restrictions in computer hardware the outputs of these models are on a very coarse grid which precludes the determination of regional differences. Further they give no idea of temporal variations, both within season and year-to-year fluctuations. Since most deterministic crop growth models need daily data, this makes their use extremely difficult and those researchers that made use of these models had to make many assumptions to generate daily data. Furthermore it would also need the inclusion of a technology trend to ascertain yield levels in the future, since a study of past yields show that ever-increasing yields have been accomplished by farmers using the constantly improving technology as far as new hybrids and other cultivation practices are concerned. These are at present unknown factors which make predictions extremely difficult.

The Southern African Outlook

Taking into consideration what has thus far been achieved and the uncertainties regarding future climatic change, it is a brave person indeed who will venture to make any prediction of the effects of global warming on crop production in Southern Africa. The following should be seen as speculations based on results from other parts of the world and taking into account the uncertainties which accompany any scenario of future climate. Selected single crops and some groups of crops are discussed. It should be emphasised that, in view of the uncertainty of current climatic predictions, no attempt has been made to run comprehensive crop yield models for individual crops nor to consider the effects of biological feedbacks into the atmosphere.

(a) **Maize:** This is the most important crop in the RSA as far as area planted and gross income are concerned. In most years there is an over-production and at current international price levels the surplus has to be exported at a loss. Maize farmers are being guided to plant a smaller area by converting their marginal soils to permanent pasture. The best guestimate for the future would be that this crop would be phased out on all marginal soils in time. The potential for dryland maize production would, in all probability be reduced somewhat by moisture stress, although in cooler areas with sufficient rain its potential might be increased, especially if the direct effect of CO_2 enrichment is taken into account. If the dryland production of maize were to decrease, it might become a more prominent crop under irrigation, depending upon the price structure that is prevalent at that time.

(b) **Wheat:** If the scenario sketched for the winter rainfall area does materialise, it could have a serious effect on wheat production in this part of the country. Traditionally production has just managed to keep up with consumption, except over the last few seasons when surpluses have been achieved. Wheat is already an important crop under irrigation and could become more so under a warmer climate and with the phasing out of production in the winter rainfall area; such a shift would demand increased efficiency in the use of water since supplies of irrigation water could become more limited. De Jager & Singels[28] used the PUTU model to calculate wheat yields for different scenarios of future temperature and rainfall. The worst scenario of 3,5°C warming showed a yield decrease of about 30%, but this could be nullified, in part by the enrichment of CO_2. It is possible that, in the summer rainfall area, wheat yields may not be much influenced by the greenhouse effect.

(c) **Deciduous Fruit:** A change in the temperature regime of the south-western Cape could have a dramatic influence on the types and cultivars of deciduous fruit being planted, e.g. apples require a certain amount of cold during the winter to break their rest; they also like cool summers, while pears prefer hot summers and cold winters. It is unlikely that deciduous fruit production would be abandoned as a result of global warming, and if sufficient irrigation water is available, production should not be seriously affected. Depending on the new temperature regime, the traditional, deciduous fruit growing areas might also increasingly plant table or wine grapes, or even subtropical crops. It has recently been announced that mango growing is to be commenced on a limited scale in this area.

(d) **Grapes:** A change in temperature regime would lead to a shift in the cultivars being planted of table, wine and raisin grapes. It might also lead to a fall in the quality of dry red wines and a greater emphasis on dry whites and red and white sweet wines. On the other hand grapes might replace much of the deciduous fruit in some areas. Since grapes are among the best utilisers of water, a drier climate might also favour such changes.

(e) **Subtropical and Tropical Crops:** South Africa is at present marginal for the production of many subtropical crops. A temperature increase might favour the production of these crops and could reduce South African dependence on imports to satisfy local needs; in some cases it might even be possible to export these products. There are many crops which fall into this category such as tea, coffee, macadamia nuts, avocados, mangoes, bananas, pecan nuts, papya, pepper, ginger, paprika, etc.

(f) **Citrus:** The need would again be to adapt the type of citrus to be grown in a particular area as the temperature regime changes, e.g. to plant Valencia instead of Navel oranges or grapefruit instead of naartjies. Citrus might also replace some of the deciduous fruit in areas where the latter is traditionally grown.

(g) **Sugar cane:** A hotter climate would shorten the growth cycle of sugar cane. Under dryland conditions decreased soil moisture might adversely affect yield, but irrigated yields should increase. Sugar cane is at present overproduced insofar as the local market is concerned and with low world prices local consumers subsidise exports. The production of ethyl alcohol for fuel from sugar cane might alleviate this problem.

(h) **Cotton:** A hotter climate would also encourage the production of cotton in areas where the growing season is at present too short and temperatures marginal. As a result cotton could also become a major crop in the Orange River irrigation scheme, especially in the area between the PK le Roux Dam and Douglas.

It may, in general, be stated that greenhouse warming will in all probability increase the frost-free growing season and this could be of benefit to irrigation farmers in the Orange River and other large schemes, where it might be possible to grow two crops per annum (for example, wheat and groundnuts).

The crux of the matter is that we should be aware that changes might and probably will occur, and that we should be prepared for these changes when they happen. The saying that we must adapt or die is very true for South African agriculture if we are to survive economically in the future. Research into the modelling of climatic change should be actively encouraged. In particular, there is an urgent need for the resolution and quality of output of current General Circulation Models to be improved for southern Africa, preferably through the use of nesting techniques (i.e. the formulation of more detailed regional models within the broader global constraints imposed by the General Circulation Models). Modelling of crop yields for different scenarios should also be encouraged (the studies of the North American Great Plains[21] and Ontario[22] are amongst the best to date). For many crops these models are simply not available and it is therefore imperative that the research effort into modelling of crop yield using meteorological, crop and edaphic information should be increased dramatically.

In view of the serious adverse effects which an overall decrease in soil moisture, accompanied by a concomitant reduction in rainfall reliability, is likely to have on the production of crops under rainfed conditions throughout most of southern Africa, the conclusion is inescapable that global warming during the 21st century will demand the more efficient use of irrigation to ensure adequate levels of food production. In particular, the use of more efficient overhead systems (and of microjet and drip irrigation where applicable) will help to maximise available water resources. Economics will also play a major role in irrigation farming insofar as crop and irrigation equipment selection is concerned. There will be a need, too, to confine irrigation to soils with a reasonably high moisture retaining capacity. It must be borne in mind, however, that water resources are likely also to diminish; evapotranspiration rates have been found to increase generally by 3-4% for every 1°C temperature rise[29]; with no change in rainfall an increase of 4°C would result in a decrease in runoff of about 25%[29]. Where an actual decrease in precipitation is possible (as in the winter rainfall region of the south-western Cape) these effects are likely to be considerably greater. For example in the winter rainfall area of the Sacramento River Basin of California, Gleick[16, 17] estimated that, with an increase in mean annual temperature of 4°C together with an increase in summer rainfall of 20%, summer runoff would decrease by nearly 50%. These results are borne out by the work of Nathan *et al*[15] in a catchment within the winter rainfall belt of southern Australia, where, on the basis of a likely 20% decrease in winter precipitation and a 10% increase in evaporation, an 18% decrease in reliable reservoir draft was predicted. And Sadler *et al*[31] estimate that similar changes in the winter rainfall region of western Australia will decrease the amount of groundwater available for extraction by more than 20%. It is clear, therefore, that while greater reliance will have to be placed on irrigated crop production, the local water resources available for this purpose are likely to be diminished. These problems will demand the formulation of a comprehensive strategy among the nations of southern Africa for both the optimum use of regional water resources and for the selection of agricultural areas and the crops to be grown within them.

Conclusion

In conclusion it is evident that at present we only have a very imperfect appreciation of the likely extent of greenhouse warming and associated changes in climatic regimes. It is clear that we will have to adapt and that improved efficiency in all aspects of farming will be demanded by changing conditions. All of those concerned with agricultural policy should be aware of the possibility of these changes, from ministries of agriculture to researchers, extension officers and finally to farmers, for whom the need to adapt will be greatest. As has been emphasised previously, research must continue to provide the best estimates of these changes and their likely impacts on agriculture. Improved monitoring of climatic and vegetative parameters (e.g. by using satellite remote sensing) will reduce the reaction time as well as provide direction for the appropriate response. Rational land use planning will become even more important than at present for the maintenance of agricultural productivity.

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