The Effect of Climate Change on Agricultural and Horticultural Potential in Europe

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J. Wolf, M.A. Semenov, J.R. Porter, F. Couvreur & J. Tranchefort :

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ENVIRONMENTAL CHANGE UNIT
University of Oxford
1a Mansfield Road
Oxford OX1 3TB, UK

8 Comparison of results from different models for calculating winter wheat production

J. Wolf[1], M.A. Semenov[2], J.R. Porter[2], F. Couvreur[3] and J. Tranchefort[3]

[1] *Department of Theoretical Production Ecology, Wageningen Agricultural University, 6700 AK Wageningen, the Netherlands*

[2] *Department of Agricultural Sciences, University of Bristol, Long Ashton Research Station, Long Ashton, Bristol BS18 9AF, UK*

[3] *Institut Technique des Céréales et des Fourrages (ITCF), Boigneville 91720, France*

Summary

- The effects of climate change on winter wheat production in different countries of the EC were calculated with three models. Two are crop growth simulation models, ie. AFRCWHEAT2 and WOFOST, and the third is a statistical agroclimatic model, which is used in France for regional production forecasting. Comparison of the results from AFRCWHEAT2 and WOFOST was carried out for two locations in the UK for composite and individual GCMs scenarios with direct effects of CO_2. Comparison of the results from WOFOST and the statistical model were made for two locations in France for the same scenarios but without the direct effects of CO_2.
- There are differences between the two simulation models AFRCWHEAT2 and WOFOST. The CO_2 sensitivity of WOFOST is higher than that of AFRCWHEAT2. The temperature sensitivity is the same for both models as long as water supply is not limiting. The large soil water supply in AFRCWHEAT2 for the UK makes its results only comparable to potential production from WOFOST. WOFOST used for the UK has a smaller initial soil water supply which caused reductions in grain production with even small decreases in rainfall. The radiation sensitivity is about the same for both models if water supply is not limiting. The main changes in grain production due to climate change are determined by the increase in atmospheric CO_2 concentration and by the rise in temperature. Both models, AFRCWHEAT2 and WOFOST, calculated an increase in grain production for composite time-dependent scenarios, but WOFOST calculated a larger increase for potential and water-limited production. For individual GCM scenarios, the average grain yield calculated by AFRCWHEAT2 and WOFOST varied compared to the baseline production, but the variation from WOFOST are much larger. The effects of climate change on the coefficient of variations (CVs) of grain production of both models are different, particularly if the water-limited production from WOFOST is considered. WOFOST is more sensitive to precipitation than AFRCWHEAT and the CV is determined mainly by this risk for water shortage.
- There are large differences between the statistical model and the simulation model. An increase in the amount of rainfall caused a small decrease in grain production according to the statistical model but a large production increase according to WOFOST. A rise in temperature resulted according to the statistical model in large to very large production decreases except for the area with mountain influence where production increased, and according to WOFOST also in large production decreases. Climate change on the basis of the composite scenarios causes a small decrease in grain production according to WOFOST and a small increase or small decrease depending on the location according to the statistical model. For individual GCM scenarios the statistical model calculated large to very large decreases in grain production or large production increases depending on the location. Large decreases in potential grain production are calculated with WOFOST for all scenarios at both locations and small increases to large decreases in water-limited production.

8.1 Introduction

The effects of climate change on winter wheat production in different countries of the EC were calculated with three models. Two of them are crop growth simulation models, ie. AFRCWHEAT2 (Semenov *et al.*, Chapter 6) and WOFOST (Wolf, Chapter 5) that apply knowledge about crop characteristics and their interaction with the environment, and calculate maximum production at optimum land and crop management for the specified crop, soil and climatic conditions. The third one is a statistical agroclimatic model which is used in France for regional production forecasting (Couvreur *et al.*, Chapter 7). It is based on the hypothesis that interannual production variation is caused partly by the weather differences between years and partly by gradual improvement of crop varieties and management. This management improvement is estimated through linear adjustment from long-term regional production data. Deviations between the theoretical production obtained with this method and the observed regional production data are caused mainly by weather differences and hence can be expressed as functions of weather variables. These functions are applied for calculating the effect of climate change on wheat production.

Results from the models depend not only on the model structure as indicated above, but also on the data used to characterise the soil, crop and weather. There are large differences between the statistical and the simulation models, but also between the crop growth simulation models (eg. crop physiological development, soil water balance, etc.). Even if the models behaved in the same way but the input data that determine the water supply, the drought sensitivity or the growth period of the crop were different, then the calculated results would be different. Hence it is only possible to do a limited inter-model comparison. First, the sensitivity of each model to weather variables is analysed. This information is then used to understand differences in results for the climate change scenarios.

Comparison of the results from AFRCWHEAT2 and WOFOST was performed for two locations in the UK for composite and individual GCM scenarios with direct effects of CO_2 (Table 8.1). These were Edinburgh (site 1) in Scotland and Sutton Bonington (site 2) in England for AFRCWHEAT2, and Kinloss (site 1) in Scotland and Nottingham (site 2) in England for WOFOST. Despite differences between these locations, particularly Kinloss and Edinburgh, results are generally comparable.

Comparison of the results from WOFOST and the statistical agroclimatic model were made for two locations in France for scenarios without the direct effects of CO_2 (Table 8.1). These were Orleans (site 3) in central France, Toulouse (site 4) in southern France for WOFOST; and *département* 45 Loiret (site 3) in central France, *département* 31 Haute-Garonne (site 4a) and *département* 47 Lot-et-Garonne (site 4b) in southern France for the statistical model (Couvreur *et al.*, Chapter 7). To compare results from the models, output for locations nearby, eg. Orleans and *département* 45 Loiret, was used.

8.2 Comparison of results from the AFRCWHEAT2 and WOFOST models

Calculations using WOFOST were done both with and without a water balance, yielding water-limited and potential production, respectively. AFRCWHEAT2 was used only with a water balance but, for situations in the UK, little effect of water shortage was found, due to the relatively large estimate of soil water supply compared to the one used in WOFOST. Thus AFRCWHEAT2 results are most comparable with the potential production given by WOFOST.

8.2.1 Baseline climate

The average grain production calculated with WOFOST for sites 1 and 2 was 8.7 and 9.0 t/ha (potential production), respectively and calculated with AFRCWHEAT2 was 8.8 and 8.6 t/ha, respectively. Thus the production levels are about the same. The coefficient of variation (CV) of grain production is 0.07 to 0.09 according to WOFOST and 0.13 to 0.14 according to AFRCWHEAT2. The latter model takes account of the water balance, and a limited degree of drought in the summer probably caused the higher CV. If WOFOST is run with a water balance, mean grain production decreases to 5.7 t/ha for site 1 and 7.5 t/ha for site 2 and the CV increases to 0.42 for site 1 and 0.28 for site 2, both results being due to the much lower estimate of the soil water supply than the one used in

Table 8.1 Sites for model comparison.

Crop models	Site 1	Site 2	Site 3	Site 4
AFRCWHEAT2	Edinburgh	Sutton Bonington		
WOFOST	Kinloss	Nottingham	Orleans	Toulouse
STATISTICAL			*département* 45 Loiret	*département* 31 Haute-Garonne (4a) *département* 47 Lot-et-Garonne (4b)

AFRCWHEAT2. The CV of grain production at the Broadbalk long-term continuous wheat experiment at Rothamsted was 0.17 (Semenov and Porter, Chapter 6), which means that WOFOST overestimated variation in grain production for conditions in the UK if soil characteristics at Rothamsted can be assumed representative for sites 1 and 2.

8.2.2 Sensitivity analyses

The sensitivity of AFRCWHEAT2 was analysed for weather data from Rothamsted, England, comparable to Nottingham. Sensitivity analysis for WOFOST was done for Kinloss and Orleans, the first with lower temperatures and less radiation during the growing season and the second with higher temperatures and more radiation when compared to Rothamsted. Because of soil and climatic differences between sites the model sensitivity to particular variables may be different, but some limited comparisons are possible. The weather variables for which the models' sensitivity can be compared are atmospheric CO_2, temperature, rainfall and radiation.

If the atmospheric CO_2 concentration rises from 353 ppm to 550 ppm, AFRCWHEAT2 calculates an increase in grain production of 22%, while WOFOST calculates an increase in potential production of 21% for Kinloss and 30% for Orleans and in water-limited production of 32% for Kinloss and 38% for Orleans (Figure 8.1). In WOFOST an increase in atmospheric CO_2 results in lower water loss by transpiration (earlier closure of stomata) and hence in a larger relative increase in water-limited production than that for potential production. As production in Kinloss is limited by low temperatures it is not meaningful to make a comparison of CO_2 response with Rothamsted. Temperature is not limiting in either Rothamsted or Orleans and therefore a comparison of CO_2 response is possible. By comparing results from AFRCWHEAT2 at Rothamsted with potential production from WOFOST at Orleans it can be concluded that the CO_2 sensitivity of WOFOST is about 1.4 times that of AFRCWHEAT2.

Sensitivity to temperature of results from AFRCWHEAT2 is close to that of potential production from WOFOST and their change in production as a result of a rise in temperature appears to be about the same (Figure 8.2). The decrease of water-limited production from WOFOST is relatively large, up to 32%, with an increase in temperature of 4°C.

The WOFOST model is much more sensitive to rainfall than AFRCWHEAT2 (Figure 8.3 a,b), which probably explains the main differences in results from the two models for the scenario analyses. One of the reasons for the low sensitivity of AFRCWHEAT2 to precipitation is that AFRCWHEAT2 assumes a large amount of initial available soil water for the UK. This limits the effect of the amount of rainfall on both the average production and its CV. On the other hand WOFOST seems to be very sensitive to water supply, which causes a large CV for grain production in Kinloss.

The response of grain production to changes in radiation calculated by WOFOST (potential production) and AFRCWHEAT2 appears to be about the same. Grain production increases with increasing radiation in both cases (Figure 8.4). Water-limited production from WOFOST takes into account the fact that the water supply may become more limiting with increased radiation. This is due to increased water loss by soil evaporation and crop transpiration and leads to a decrease in grain production.

Figure 8.1 Response of grain production of AFRCWHEAT2 and potential grain production of WOFOST to different ambient CO_2 concentrations at different sites (Rothamsted for AFRCWHEAT2, Kinloss (site 1) and Orleans (site 3) for WOFOST).

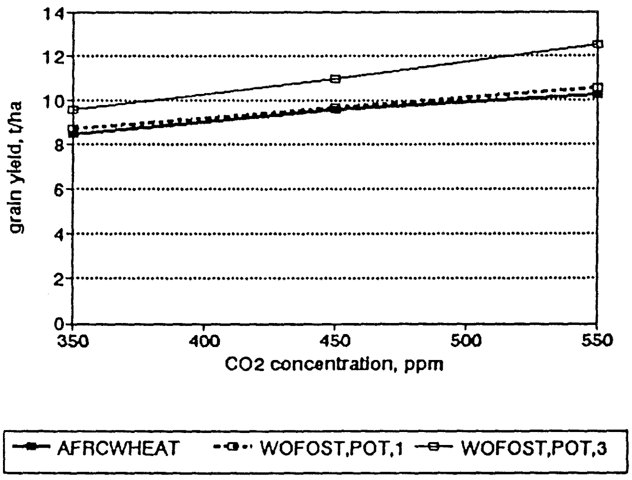


Figure 8.2 Response of AFRCWHEAT2 (grain production, Rothamsted) and WOFOST (potential and water-limited production, site 1) to changes in temperature.

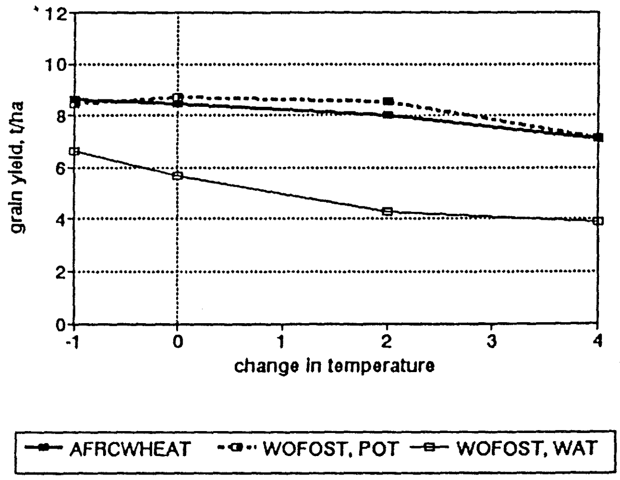


Figure 8.3 Response of AFRCWHEAT2 (grain production, Rothamsted) and WOFOST (potential and water-limited production, site 1) to changes in the amount of precipitation: (a) grain production; (b) CV.

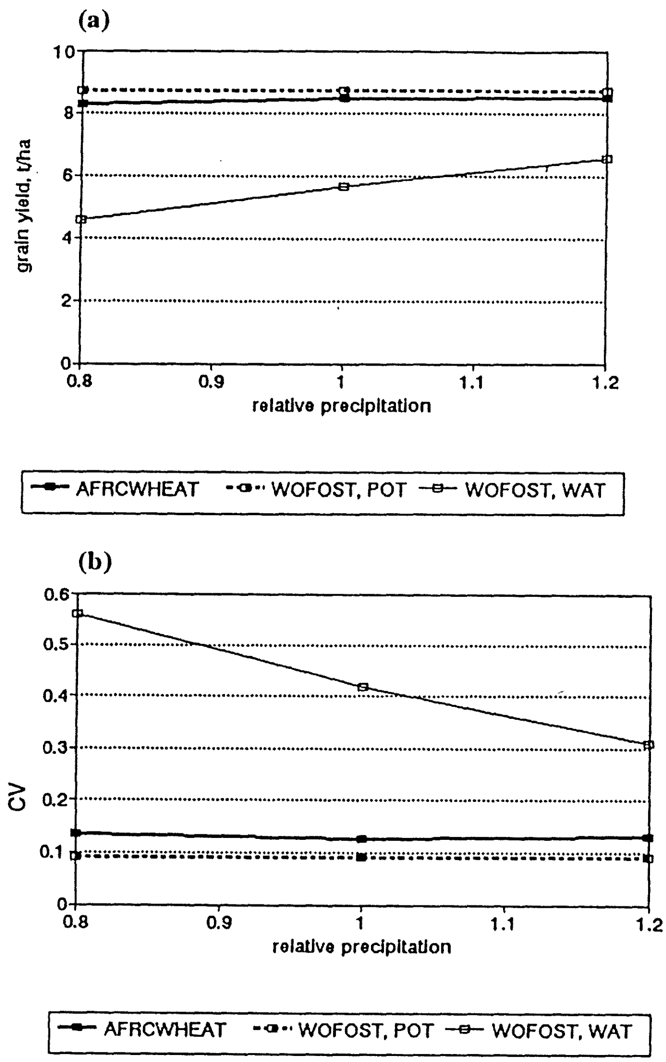
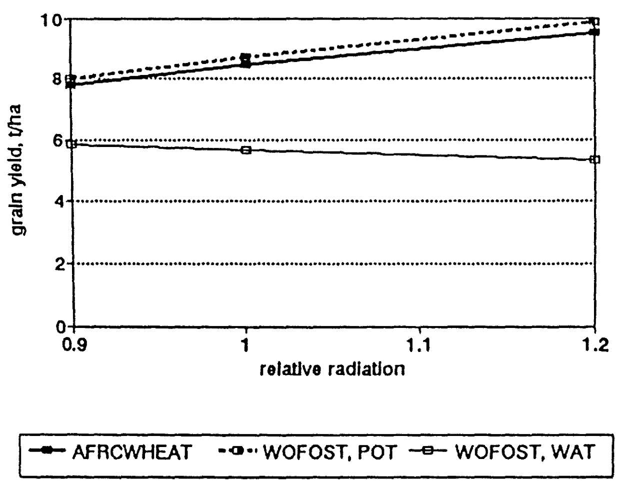


Figure 8.4 Response of AFRCWHEAT2 (grain production, Rothamsted) and WOFOST (potential and water-limited production, site 1) to changes in radiation.



8.2.3 Scenario analyses

Comparisons were made for composite scenarios A 2010, A 2030 and A 2050 and individual GCM scenarios with the direct effects of CO_2 on crop growth.

Both models, AFRCWHEAT2 and WOFOST, calculate an increase in grain production for the composite time-dependent scenarios, but WOFOST calculates a larger increase for potential and water-limited production (Figures 8.5a and 8.6a). The main changes in grain production due to climate change are determined by the increase in atmospheric CO_2 concentration and the rise in temperature. For scenario A 2050 atmospheric CO_2 is set at 539 ppm and the average global rise in temperature is 1.7°C. From the sensitivity analysis the effects of changing temperature and CO_2 for AFRCWHEAT2 result in an increase in production to 1.14 times the baseline production, which agrees well for site 2 and is slightly too large for site 1, probably because low temperatures in Scotland set a limit to the production increase. For WOFOST the effects of changing temperature and CO_2 result in an increase in production of 1.26 times the baseline production, which agrees well for both the two locations in the UK.

For individual GCM scenarios, the average grain production calculated by AFRCWHEAT2 and WOFOST varied compared to the baseline production, but the variations from WOFOST are much larger (production for GISS scenario is 2.5 larger than that for the GFDL scenario at site 1, Figure 8.5a). Differences between the models can be explained by the fact that the sensitivity of WOFOST to increasing CO_2 is stronger and that production from WOFOST was reduced strongly by a decrease in solar radiation in spring.

Differences in the CV of grain production between the two models are sometimes large (Figures 8.5b and 8.6b). CVs of grain production, according to AFRCWHEAT2, varied near the CV for the baseline climate (small increase for composite scenarios and increase or decrease for individual GCM scenarios). CVs of potential grain production calculated by WOFOST were between 0.07 and 0.1 for both baseline climate and composite scenarios and increased for individual GCMs scenarios to about 0.15 (except 0.32 for the GFDL scenario at site 1). CVs of water-limited grain production from WOFOST decreased for all composite and individual GCM scenarios. The CV of water-limited grain production for the GISS scenario decreased even by factor 3 compared with that for the baseline climate at site 1.

The CV is determined mainly by the risk for water shortage and hence by the amount of rainfall and maximum soil water supply, and increases with increasing risk of drought. As AFRCWHEAT2 assumes a

Figure 8.5 Simulation results for composite and individual GCM scenarios with direct effect of CO_2 from AFRCWHEAT2 (grain production) and WOFOST (potential and water-limited production) at site 1 in the UK (see text): (a) grain production, (b) CV.

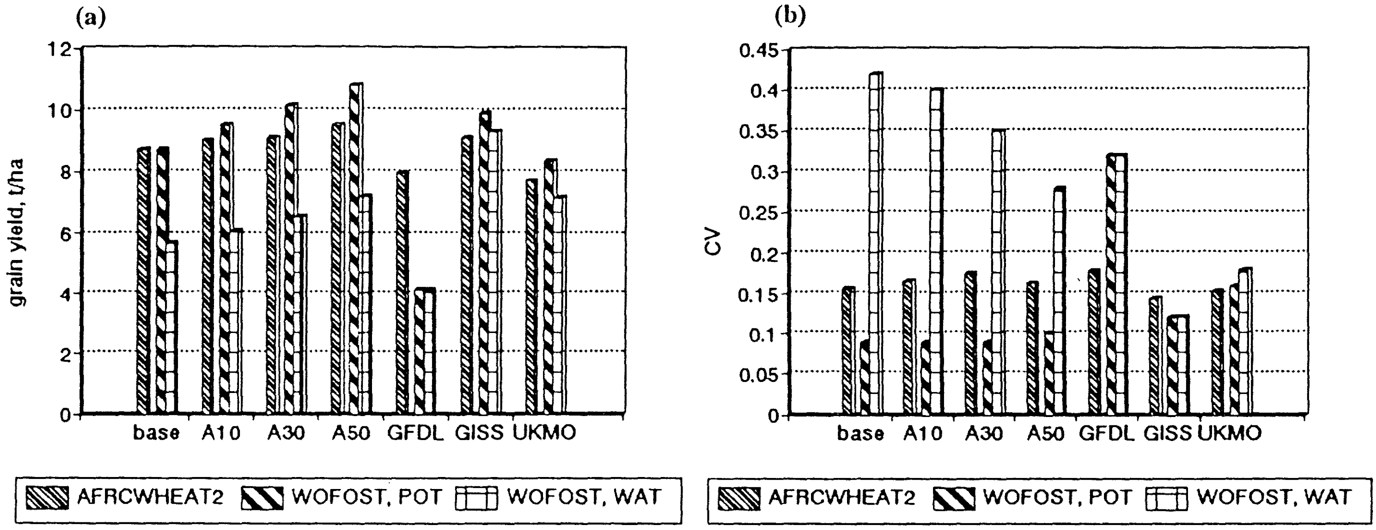
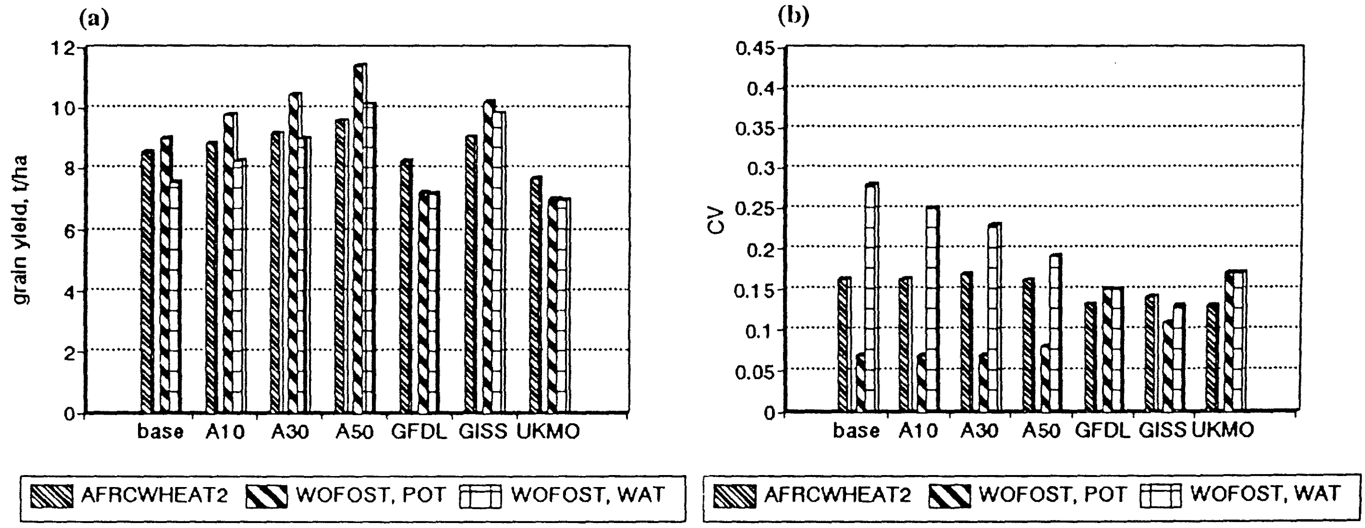


Figure 8.6 Simulation results for composite and individual GCM scenarios with direct effect of CO_2 from AFRCWHEAT2 (grain production) and WOFOST (potential and water-limited production) at site2 in the UK (see text): (a) grain production, (b) CV.



much larger amount of initial soil water for locations in the UK than WOFOST, it calculates a lower CV than that of water-limited production from WOFOST, but a little higher than that of potential production. In addition, advancement of the period of grain filling due to a rise in temperature as determined by climate change, may result in other weather conditions at the end of the growth cycle. This effect of the time shift on the CV of grain production is sometimes found to be much larger than the scenario effect and depends strongly on the weather data-base that is used in both simulation models.

8.3 Comparison of results from statistical and WOFOST models

In comparing the results of the statistical model with those of a simulation model the following should be taken into account:

- the results from WOFOST and the statistical model were compared for scenarios without the direct effects of CO_2;
- the absolute results of both models cannot be compared. Average production data per region from the statistical model are determined not only by crop potential, weather and soil water supply, as applies to

production calculated with crop growth simulation models. They are also limited by suboptimal nutrient supply, losses from weed competition, pests and diseases and during harvest, suboptimal natural and artificial drainage, timing of field operations, etc.;

- the standard deviation of differences between variations of productions observed and simulated as calculated with the statistical model, cannot be compared in absolute figures with standard deviation of grain productions from simulation models, because they have a different meaning.

8.3.1 Sensitivity analyses

The sensitivity of average actual grain production to changes in rainfall, temperature, radiation and potential evapotranspiration were determined with the statistical model for a large number of *départements*. Results for *département* Loiret, near Orleans, are used for comparison with results for Orleans from WOFOST (site 3). Results for the *départements* Haute-Garonne (site 4a) and Lot-et-Garonne (site 4b) can be compared with results for Toulouse (site 4) from the WOFOST model. The Haute-Garonne *département* partly comprises a highland area and is influenced by the mountains of the Pyrenees, which affects the results from the statistical model.

An increase in the amount of rainfall from 0.9 to 1.1 times the baseline amount resulted, according to the statistical model, in a decrease in average grain production of about 3% for all *départements*. If the temperature rose by 3°C, this resulted in a change in production of about –39% for site 3, of +10% for site 4a and of –12% for site 4b. Although too many factors are involved in farm practice to allow complete explanation of these sensitivities, the following might apply. An increase in rainfall, particularly if it occurs at the end of grain filling, might result in lower production due to larger losses from ripening diseases. More rainfall may also correspond with less radiation and hence lower production. Higher temperature results in higher production in relatively cool areas (site 4a), due to an earlier growing season that is not shortened and suffers less from damage by frost and possibly drought at the end of grain filling. In relatively warm areas (site nos. 3 and 4b) a higher temperature results in a shortened growing season and hence lower grain production.

WOFOST calculates for a change in the amount of rainfall from 0.9 to 1.1 times the baseline amount for site 3, an increase in water-limited grain production of 16% and for a temperature rise of 3°C a decrease in potential and water-limited grain productions of 17% and 21%, respectively. More rainfall results in less water shortage during grain filling and thus higher grain production. Higher temperatures result in a shorter period of grain filling and thus lower grain production. As an explanation of these differences in sensitivity, it should be noted that effects of diseases, frosts etc. are not included in WOFOST, regional average data cannot be compared well with results calculated with WOFOST for one location, and the winter wheat crop may be less sensitive to drought than assumed in WOFOST.

8.3.2 Scenario analyses

A comparison was carried out for the same composite and individual GCM scenarios, but the direct effect of increasing atmospheric CO_2 on crop growth was not taken into account.

Average relative changes in grain production for the statistical model and WOFOST are shown in Figure 8.7 for site 3 and Figure 8.8 for site 4. Climate change on the basis of the composite scenarios causes a small

Figure 8.7 Results for composite and individual GCM scenarios without direct effect of CO_2 from ITCF statistical model (grain production) and WOFOST (water-limited production) for site 3 in France (see text).

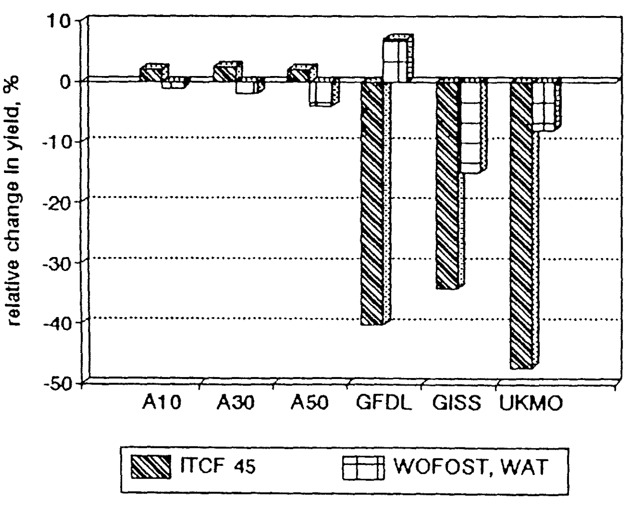
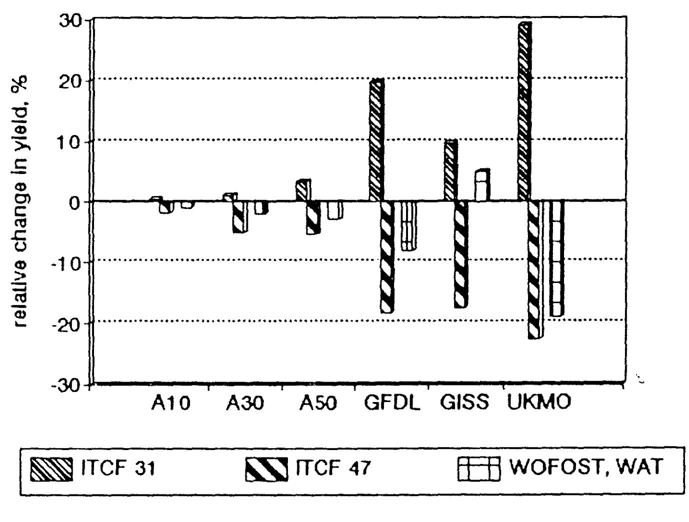


Figure 8.8 Results for composite and individual GCM scenarios without direct effect of CO_2 for ITCF statistical model (grain production, site nos. 4a and 4b) and WOFOST (water-limited production, site 4) in France (see text).



decrease in grain production according to WOFOST, and a small increase or small decrease depending on the *département*, according to the statistical model.

For individual GCM scenarios the statistical model calculated large to very large decreases in grain production for site nos. 3 and 4b and large production increases for the area with mountain influence (site 4a). Large decreases in potential grain production are calculated with WOFOST for all scenarios at site nos. 3 and 4, as are small increases to large decreases in water-limited production. Comparison of standard deviations from the statistical model and WOFOST does not make sense, as mentioned above, and hence is not carried out.

8.4 Conclusions

There are large differences (in structure and output) between the statistical model and the simulation models but also between the two simulation models AFRCWHEAT2 and WOFOST. Therefore it is only possible to carry out a limited comparison.

The main changes in grain production due to climate change are determined by the increase in atmospheric CO_2 concentration and by the rise in temperature, and can be roughly explained on the basis of sensitivity analysis. The CO_2 sensitivity of WOFOST is higher than that of AFRCWHEAT2. The temperature sensitivity is the same for both models as long as water supply is not limiting. For locations in the UK, AFRCWHEAT2 assumes a large initial soil water supply. As a consequence, a reduction in grain production occurs only if rainfall is reduced to 50% or less. WOFOST used for the UK has a smaller initial soil water supply,which caused reductions in grain production with even small decreases in rainfall. Results from AFRCWHEAT2 are therefore only comparable to those from WOFOST for potential production conditions. The radiation sensitivity is about the same for both models if water supply is not limiting. The effects of climate change on the CVs of grain yield of both models are different, particularly for water-limited production conditions.

An increase in the amount of rainfall caused a small decrease in grain production according to the statistical model but a large production increase according to WOFOST. A rise in temperature resulted in large to very large production decreases according to the statistical model, except for the area with mountain influence where production increased, and also according to WOFOST in large production decreases. Climate change on the basis of the composite scenarios caused a small decrease in grain production according to WOFOST, and a small increase or small decrease, depending on the *département*, according to the statistical model. For individual GCM scenarios the statistical model calculated large to very large decreases in grain production or large production increases, depending on the *département*. Large decreases in potential grain production were calculated with WOFOST for all scenarios at both locations, and small increases to large decreases in water-limited production.

It is evident that significant differences in model output can arise not just from the choice of climate scenarios, but also from the choice of crop models and their data base. Because of these differences the results from the crop model analyses must be treated as inconclusive. Given the uncertainties that appear from this limited number of comparisons, it is evident that future analyses need to incorporate more critical applications of crop models. It would be desirable for different crop models to be used at a range of common sites to give a more coherent picture of where differences and similarities in response occur throughout Europe. Moreover, a reliable data base on soil characteristics, weather variables and crop characteristics throughout Europe is required.