

Effects of climate change on yield potential of wheat and maize crops in the European Union

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Abstract

Yields of winter wheat, silage maize and grain maize in the main arable areas of the European Union (E.U.) were calculated with a simulation model, WOFOST, using historical weather data and average soil characteristics. The sensitivity of the model to individual weather variables was determined. Subsequent analyses were made using climate change scenarios with and without the direct effects of increased atmospheric CO₂. The impact of crop management in a changed climate was also assessed. The various climate change scenarios used appear to yield considerably different changes in yield, both for each location and for the E.U. as a whole.

1. Introduction

Any changes in climate which may result from increasing concentration of greenhouse gases in the atmosphere could have dramatic consequences for the agricultural yield potential. In this study that formed a part of the E.U. funded EPOCH project, the effects of climate change on the yields of winterwheat, silage maize and grain maize were analysed. In the EPOCH project as a whole the effects of climate change on agriculture and horticulture in the E.U. have been investigated by scientists from nine research institutes in the E.U. The main tasks in this project were: 1. construction of scenarios of climate change; 2. broadscale analysis of the effects of climate change on selected crops; 3. site-specific analysis of the effects of climate change on crop phenology and yields with crop growth simulation models; 4. experimental investigation of the effects of CO₂ enrichment and temperature on crop growth.

2. Model and input data

A dynamic crop growth model, WOFOST, developed for calculating agricultural yield potential [1] was used. In the model, crop growth is simulated from sowing to maturity on the basis of physiological processes as determined by the crop's response to environmental conditions. The simulation is carried in time steps of one day. The major processes considered are CO₂ assimilation, respiration, partitioning of assimilates to various plant organs, transpiration and phenological development. Two levels of crop yield are calculated: the water limited yield which can be realized in situations where the supply of plant nutrients and crop management are optimum and secondly the potential yield which can be realized if also the water supply is optimum.

In order to apply the model data that specify crop growth and phenological development are required including information on properties that determine assimilation and respiration processes and response to moisture stress, partitioning of assimilates to plant organs, life span of leaves and death rates of plant organs. This information is

derived from the literature and field experiments. Calculations of crop growth were made for historical sets of daily weather data from 20 meteorological stations. For each of the stations that are representative of the main arable land areas in all E.U. countries, the weather data set covered generally the period 1966-1985. In order to calculate the soil water balance, the soil's physical characteristics such as effective soil depth, soil moisture characteristics and hydraulic conductivity must be known. For each meteorological station the main soil types that occur on arable land areas within a radius of 100 to 150 km around the station, were obtained from the soil map of the European Communities. By interpreting the information per soil type quantitative terms for use in the simulation model could be obtained.

3. Scenario data

In order to calculate crop growth in future the historical weather data were changed on the basis of climate change scenarios. Two different types of scenarios have been applied. Firstly, the composite time-dependent scenarios that were based on the average standardized output of seven equilibrium GCM's. This output resulted in a regional pattern of climate change. By using estimates of global mean warming for the various IPCC emission scenarios (in this study scenario A (i.e. business-as-usual emission scenario) for the years 2010, 2030 and 2050 and scenario A High (high estimate of climate change for scenario A) for year 2050 [2]) which were calculated with a simple climate model, the GCM-derived regional patterns could be scaled up to obtain the time-dependent changes in climate [3]. Secondly, the individual scenarios that were based on output from three equilibrium 2*CO₂ GCM's, i.e. GFDL, GISS and UKMO-L models.

4. Results

Variables that determine crop yield directly, are atmospheric CO₂ concentration, solar radiation and temperature and those that affect the water balance and hence the degree of drought stress are rainfall, windspeed, vapour pressure and again the other three variables. These variables were adjusted separately, in a stepwise manner, in order to gauge the sensitivity of crop yields to changing values of each. This sensitivity analysis was carried out for winter wheat on three locations, i.e. Kinloss, Orleans and Brindisi that cover the main differences in climate in the E.U. (Table 1).

Table 1

Sensitivity of potential (POT) and water-limited (WAT) grain yields of winterwheat in Kinloss, U.K., Orleans, France and Brindisi, Italy to increasing values for atmospheric CO₂ concentration (C), temperature (T), rainfall (R), solar radiation (S), windspeed (W) and vapour pressure (V)¹ (Source= [4]).

	C	T	R	S	W	V
POT	++	--,0 ²	0	+,++	0	0
WAT	++	--,+ ³	++	-	--	++

¹ 0, +, ++ : no, moderate, strong increase in grain yield;

-, -- : moderate, strong decrease in grain yield.

² Temperature effect varies from about zero in Kinloss to strongly negative in Brindisi.

³ Temperature effect varies from strongly and moderately negative in Kinloss and Orleans, respectively to moderately positive in Brindisi.

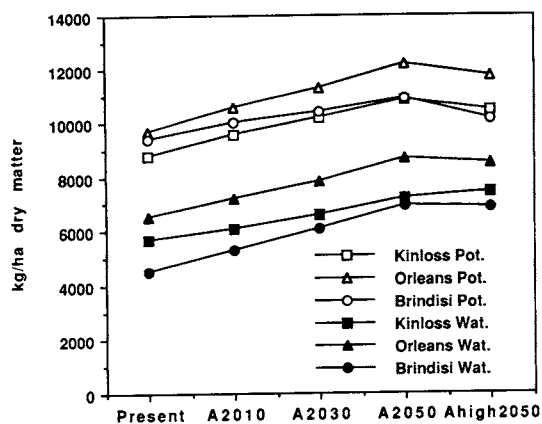


Figure 1. Average potential (Pot.) and water limited (Wat.) grain yields of winter wheat cultivated at current and at future climate conditions (based on composite scenarios A and A High) in Kinloss, U.K., Orleans, France and Brindisi, Italy, taking into account the direct effect of increasing atmospheric CO_2 in future (Source= [4]).

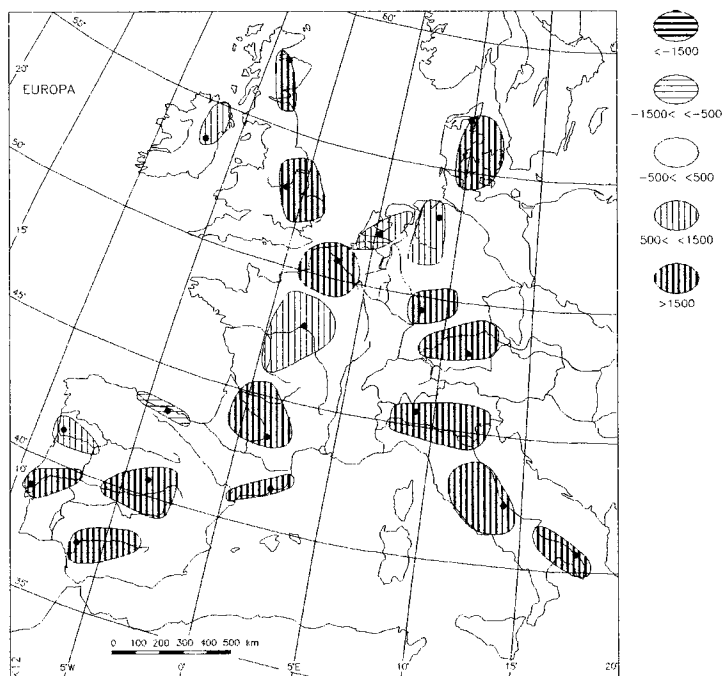


Figure 2. Changes in water limited grain yield (kg ha^{-1} dry matter) of winter wheat in the main arable land areas in the E.U. if the weather is changed on the basis of the GISS equilibrium $2 \times \text{CO}_2$ scenario and the direct effect of increased CO_2 is taken into account (Source= [4]).

Potential and water limited grain yields of winter wheat were calculated for historical weather data that were changed on the basis of composite scenarios A and A High (Fig. 1), taking also into account the direct effect of increasing atmospheric CO₂ concentration. Both potential and water-limited yield levels appear to increase greatly over time, mainly as a result of increasing CO₂. For scenario A High that gives the largest increase in temperature, the yield increase is somewhat less than that for scenario A for the same year.

If water limited grain yields were calculated for the individual scenarios and the direct effect of increased CO₂ (from 353 to 560 ppm) was taken into account, the GISS scenario gave major yield increases for most locations in the E.U., mainly as a result of CO₂ enrichment (Fig. 2). The GFDL scenario on the other hand, gave yield decreases for the western part of the E.U. (Fig. 3).

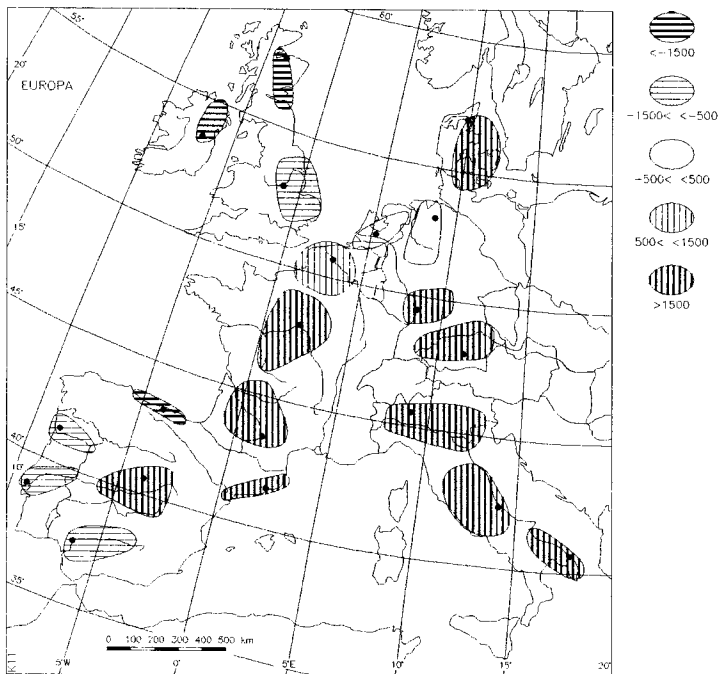


Figure 3. Changes in water limited grain yield (kg ha⁻¹ dry matter) of winter wheat in the main arable land areas in the E.U. if the weather is changed on the basis of the GFDL equilibrium 2*CO₂ scenario and the direct effect of increased CO₂ is taken into account (Source= [4]).

If climate changes, present crop management may be inadequate for the new climate conditions. A number of management responses and their potential usefulness in adapting to the adverse effects of climate change were evaluated. Firstly, yields were calculated for crop varieties that differ with respect to their temperature sum requirements for phenological development. Secondly, amounts of irrigation water required to attain the potential yield level were determined (Table 2). They increase with climate change but decrease if also the direct effect of increased atmospheric CO₂ is taken into account. Finally, the impact of changes in sowing date on the yield level of for example silage maize

were determined (Fig. 4). In a changed climate the optimum day for sowing appears to move to an earlier date.

Table 2

Required amounts of irrigation water (mm) for attaining the potential yield level of grain maize on three locations in the E.U., both for historical climate and for scenario climate with and without direct CO₂ effect (Source= [5]).

Location	Hist. climate	Scen. A 2050	Scen. A 2050 + CO ₂
Brindisi, Italy	382	400	326
Mannheim, Germany	92	109	66
Orleans, France	157	211	147

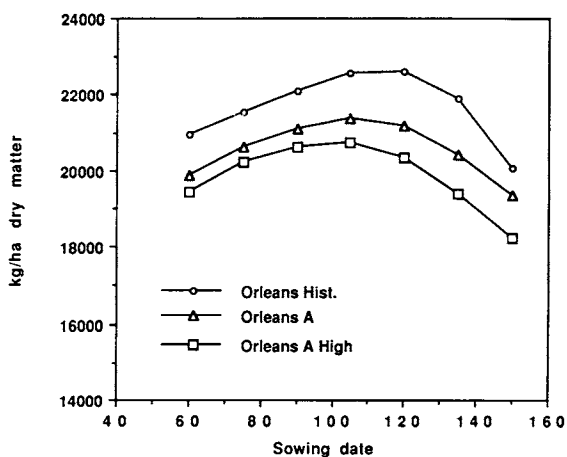


Figure 4. Sensitivity to changes in sowing date of the average potential total yield of silage maize cultivated in Orleans, France. Yields have been established for historical weather data (Hist.) and for composite scenarios A and A High for the year 2050 (A and A High) (Source= [6]).

5. Conclusions

- Various climate change scenarios appear to yield considerable different changes in yield both for each location and for the E.U. as a whole;
- The direct effect of increasing atmospheric CO₂ on wheat grain yield appears to be much greater than the effect of climate change;
- The average water limited grain yield of winter wheat in the E.U. increases by 1000, 1300 and 2300 kg ha⁻¹ dry matter for the UKMO-L, GFDL and GISS scenarios respectively (based on calculated yield changes and the present area distribution in the E.U.) if the direct effect of increased CO₂ is taken into account;
- The average potential grain yield of maize in the E.U. decreases by 2000, 2800 and 2800 kg ha⁻¹ dry matter for the GISS, GFDL and UKMO-L scenarios respectively;

- The average water limited total yield of silage maize in the E.U. decreases by 600, 2500 and 6300 kg ha⁻¹ dry matter for the GISS, UKMO-L and GFDL scenarios respectively if the direct effect of increased CO₂ is taken into account.

For more information on this study it is referred to [4], [5] and [6]. Complete reports on this study can be obtained from the first author. Results from the EPOCH project are given in a special issue of the European Journal of Agronomy (1993-2(4)).

6. References

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