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J. Goudriaan, H. van Keulen and H.H. van Laar (editors)

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The impact of changes in weather and CO_2 concentration on spring wheat yields in western Europe

S. Nonhebel
Department of Theoretical Production Ecology, Wageningen Agricultural University, P.O. Box 430, 6700 AK Wageningen, The Netherlands

An increase in atmospheric CO_2-concentration can affect agricultural productivity in two ways. First, a higher CO_2-concentration in itself has a stimulating effect on photosynthesis (Cure & Acock,1986; Strain & Cure,1985) and on water use efficiency of crops (Gifford, 1979; Sionit et al., 1980). Second, being a greenhouse gas increasing CO_2 can induce climatic change. Estimates based on general circulation models predict a rise in global temperature of 2.5 - 5.5 °C, when CO_2 concentration has reached the 700 μmol mol^{-1} level (Wilson & Mitchell, 1987).

A simulation model was constructed to estimate the impact of a rise in temperature and in atmospheric CO_2-concentration on spring wheat yields in The Netherlands and in southern France. The model used is based on SUCROS87 (Spitters et al., 1989). To simulate the impact of higher CO_2-levels on water use efficiency of the crop a soil water balance was included (van Keulen & Seligman, 1987) and transpiration was simulated according to the big-leaf model (Monteith, 1965). The impact of the atmospheric CO_2-concentration on assimilation rate was described in accordance with Goudriaan et al. (1985). The simulation of development rate between crop emergence and heading in the original model was replaced by the Miglietta routine (Miglietta, 1989, 1990a, b), as this routine gave a better description of phenology of wheat cultivars in various climates than the original routine.

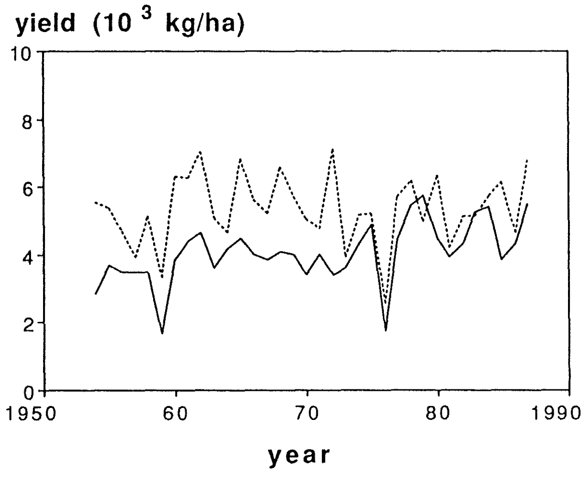

Figure 1. Spring wheat yield in field experiments (solid line) and simulated yield (broken line) in The Netherlands (see text).

The model simulates water-limited crop production, and impact of weeds, pests, diseases or nutrient stress on crop production is not taken into account. Daily weather data from Wageningen and Toulouse were used to simulate crop yield in The Netherlands and southern France, respectively.

The present annual variability in weather and crop yields was used to validate the simulation results. Simulation runs were made with weather data from Wageningen from 1954 till 1987 and results were compared with yields in field experiments in those years (Figure 1). Until 1974 the simulated yields were much higher than field production. In 1974, the use of pesticides was introduced in this field experiment and so was an additional nitrogen application. Since then, field production has approached the potential level. Simulation results present a satisfactory picture of the observed inter-annual variability.

The model is very sensitive to the origin of weather data used as input data. It was shown that in The Netherlands weather data of a central weather station could not be used to simulate accurately crop production along the coast.

The impact of temperature rise on crop yield was simulated by increasing the present temperature by 2 °C. Due to the higher temperature, development rate of the crop is accelerated and the growing period shortened. In both regions, in high yielding years the temperature rise resulted in a decline in yield (1000 - 2000 kg ha^{-1}) due to this shorter growing period (Figures 2A and B). A shift in sowing date or the use of other varieties did not eliminate these yield reductions. In low yielding years (water shortage!) yields were not affected, the shorter growing season of the crop reduced the water requirements and counteracted the effects of water shortage.

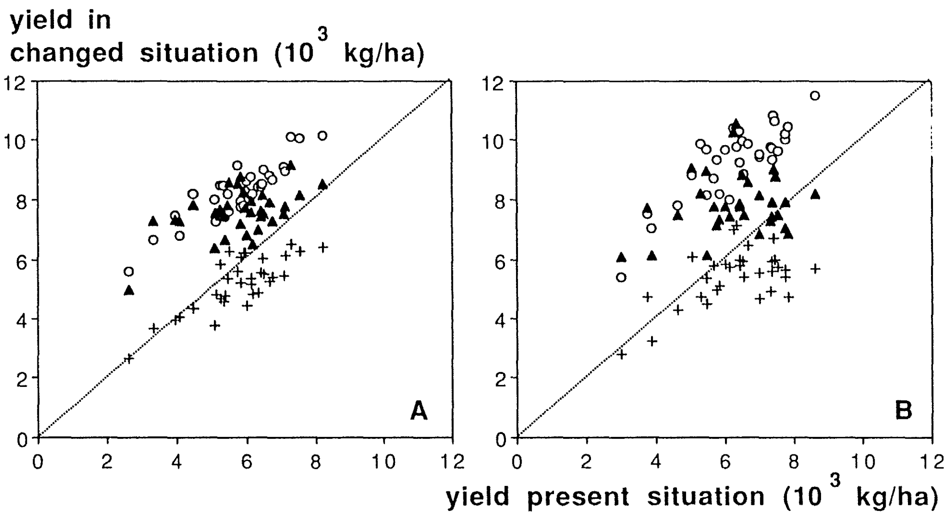

Figure 2. Impact of changes in climate and CO_2 concentration on water-limited yield in (A) Wageningen and (B) Toulouse. (Temperature + 2 °C (+); 2 x CO_2 (o); 2 x CO_2 and temperature + 2 °C (▲)).

Doubling the atmospheric CO_2-concentration from 350 to 700 μmol mol^{-1} resulted in a simulated yield increase of 3000 kg ha^{-1} (Figures 2A and B). Higher CO_2-concentration resulted in improved growth during the vegetative period which was beneficial to final yield.

Combination of both temperature increase and CO_2 concentration rise, resulted in an increase in yield of about 1000 kg ha^{-1} in high yielding years in The Netherlands (Figure 2A), while in southern France the positive effect of the higher CO_2-levels could not counteract the effect of a temperature rise (Figure 2B). In years with water stress the yield increase was large due to the effect of higher CO_2-concentration on water use efficiency of the crop: in both regions a yield increase of 2000 - 3000 kg ha^{-1} was obtained.

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