Second Congress

of the

European Society for Agronomy

Warwick University 23-28 August 1992

Proceedings

Edited by Alan Scaife

S. Nonhebel :

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(156-165).

Proc. 2nd ESA congress, Warwick Univ. 1992.

USE OF WEATHER DATA IN CROP GROWTH SIMULATION MODELS

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

Abstract

Most crop growth models require daily weather data as input values. These data are not easy to obtain and therefore in many studies daily data are generated, or average values are used as input data for these models. In crop growth models often non-linear relations occur, through which the simulation result with average data can be different from the average result with daily data. In this study the effects of using average weather data on simulated yield was investigated with a spring wheat crop growth model. This was done with weather data from sites in two different climates: a temperate maritime, a mediterranean climate.

For both sites the variability of the weather during the growing season was quantified. The sites hardly differed in this variability. The explanation of this result was found in the fact that crops are grown during seasons in which rain falls. The existence of dry and wet days results in a day to day variation in weather.

For both sites an overestimation of the simulated potential yield of 5-15 % was found as a result of the use of average weather data. For water limited production the use of average data resulted in overestimation of the yield in the wet conditions and underestimation of yield in dry conditions. Thus, when average values are used as input in simulation models developed for daily data, for most locations in the world deviations in simulated yield can occur.

Introduction

During the last decades the quantitative approach of crop growth has taken a high flight, resulting in the development of crop growth simulation models by various research groups in the world (Whisler et al., 1986). These models simulate crop growth and development under given circumstances and vary in background and structure. Crop growth is strongly influenced by weather conditions. Essential effects of weather conditions on crop growth processes are therefore described in crop growth simulation models and weather data are important input data. Presently for major crops like wheat, maize etc. well developed crop growth simulation models exist (Ritchie et al., 1984; Jones et al., 1986; van Keulen et al., 1987; Spitters et al., 1989). In general these models operate with a time step of one day and require daily weather data as input. Daily data are not commonly available, therefore monthly averages are frequently used as input for crop growth models or daily data are generated from average values. An important advantage of average data is that the data sets are less voluminous and by that easier to handle.

Weather-crop growth relations are often non linear, so that the simulation result with average input data can deviate from average result of simulation with daily data. The use of crop growth simulation models is likely to increase in the future, it is therefore important to understand the consequences of the use these average data for simulation results.

In this paper the effects of use of averaged weather data as input in a simulation model developed for daily data is studied. The model used is a spring wheat crop growth model based on SUCROS87 (Spitters et al., 1989) a detailed description of the model is given in Nonhebel (1992a). The model simulates potential production (limited by crop characteristics, temperature and radiation but without any stress from water or nutrient shortages or pests, diseases and weeds) and water limited production in which growth is also limited by water shortage (de Wit et al., 1982). In Nonhebel (1992,b,c,d) it is shown that the sensitivity of this model to changes in weather variables is not the same for both production levels. Therefore the effects of using average weather data for both the potential and the water limited production were studied. It is likely that the effect will differ between various climates. When weather is constant the average will not deviate from the daily value and simulation result will not be affected, when large variation in weather exists deviation from the average value will be large and deviation is simulation result may occur.

Therefore the effects of using average data were studied for two sites in different climates: Wageningen in the Netherlands (temperate maritime climate, annual precipitation 700 mm, homogeneously distributed over the year) and Migda in Israel (mediterranean climate, annual precipitation 50-450 mm, mainly in December and January).

Methods

Daily weather data were available from Wageningen 1954-1987 ~~and from Migda 1962-1983. The sets contained daily data on:~~ on minimum temperature (°C), maximum temperature (°C), total global radiation (MJ m^{-2}), precipitation (mm), vapour pressure (mb) and wind speed (m s^{-1}). From these daily data sets, sets with average data over 10 days and one month were derived. Finally monthly values were averaged over the years available (climatic averages).

Table 1. The size of the data sets for Wageningen.

data set	number of data	composed of
daily data	74460	= 34 years * 365 days *6 variables
10 day averages	7344	= 34 years * 36*10 days *6 variables
monthly averages	2448	= 34 years * 12 months *6 variables
climate	72	= 12 months *6 variables

When averages were used the average value was expected to occur in the middle of the interval (for monthly averages: 15th of the each month) and on days in between the value was obtained by linear interpolation. This method implies that there is precipitation every day. This contrasts with the actual situation in which there are dry and wet days.

To quantify the variability in weather at the two sites, the average deviation (av dev) from the daily values was calculated for each weather variable for each averaging interval according to:

$$\text{av dev}=\sqrt{\frac{\sum_{i=1}^{n}(x_{di}-x_{ai})^2}{n}}$$

in which x_{di} is the value in the original daily data set for day i, x_{ai} is the value for day i derived from a set with average data. This was done over all years available.
Since the simulation result is only affected by the

variability during the growing season (the model only runs from sowing till maturing of the crop), average deviations were only calculated for the 180 days after start of the simulation on the two sites. So for Wageningen n equals 34 (years)*180 (days)= 6120.

Table 2. Average deviation from the daily value for six weather variables (minimum temperature (Tmin), maximum temperature (Tmax), global radiation (Rad), precipitation (Rain), vapour pressure (Vap), wind speed (Wind)), when averages over several intervals are used.

site	interval	Tmin ^oC	Tmax ^oC	Rad MJ m^{-2}	Rain mm	Vap mb	Wind ms^{-1}
Wageningen	10 days	2.7	3.0	4.8	4.2	2.0	1.3
Wageningen	months	3.1	3.6	5.3	4.4	2.3	1.4
Wageningen	climate	3.4	4.0	5.6	4.5	2.5	1.5
Migda	10 days	2.3	3.3	3.6	5.5	2.4	0.7
Migda	months	2.6	3.8	3.8	5.7	2.5	0.8
Migda	climate	2.8	4.1	4.3	5.8	2.7	0.8

The initial conditions at the start of the simulation for the two locations were made in accordance with present agricultural practices for rainfed spring wheat. For Wageningen this implied that the crop was sown on March 11th with the soil profile at field capacity. For Migda, sowing was set on November 1st and the soil at wilting point. For the water limited production soil characteristics from a hypothetical soil with a low available water holding capacity (comparable with a sandy soil) were used, this was done to achieve large differences in potential and water limited production.
For each production level, on each site, 4 simulation runs were made: using the set with 1) daily data, 2) 10 day averages 3) monthly averages and 4) climatic averages.

Results and discussion

When precipitation is left out of consideration, weather in

the mediterranean is intuitively far more constant than the weather in the temperate maritime climates. This impression is not in accordance with the deviations shown in table 2: hardly any difference was found in average deviation between the two sites. However, it should be realised that in table 2 the deviation during the growing season is given. The growing season in Israel takes place in the winter period and in The Netherlands in the summer season. Based on table 2 it can be concluded that weather in the summer in the Netherlands is as variable as the weather in the Israeli winter.
In general crops are grown in the season in which rain falls. Due to the existence of dry and rainy days in these seasons large variation in radiation occurs on successive days (clouds!) and on most locations also in temperature. So in most growing seasons deviation in simulated yields as result of the use of averages can be expected.
Since on both sites large variability in weather existed it is not surprising that the use of averages influenced the simulation results everywhere. The effect of using averages as input depended on the length of the averaged interval and the production level.

Potential production.

In general extremes in weather during the growing season (e.g. high or low temperatures) have a negative effect on crop growth. When averages are used these extremes are lost, through which average weather is more optimal for crop growth than daily weather. The loss of extremes is the explanation for the higher simulated yield when averages are used. The use of averages over one month resulted in overestimation of the yield by 1 ton ha^{-1} in Wageningen and 0.6 ton ha^{-1} in Migda (figures 1a,2a), the inter annual variation in yield was remained. Hardly any difference was found in simulated yield with 10 day or monthly averages. Use of climatic averages led in Wageningen to a higher yield than average yield with monthly data but in Israel to a lower yield (table 3).
So when one is interested in simulated yield in one particular year (for instance in combination with a field experiment) average data should be avoided since deviation in yield up to 25 % can occur.

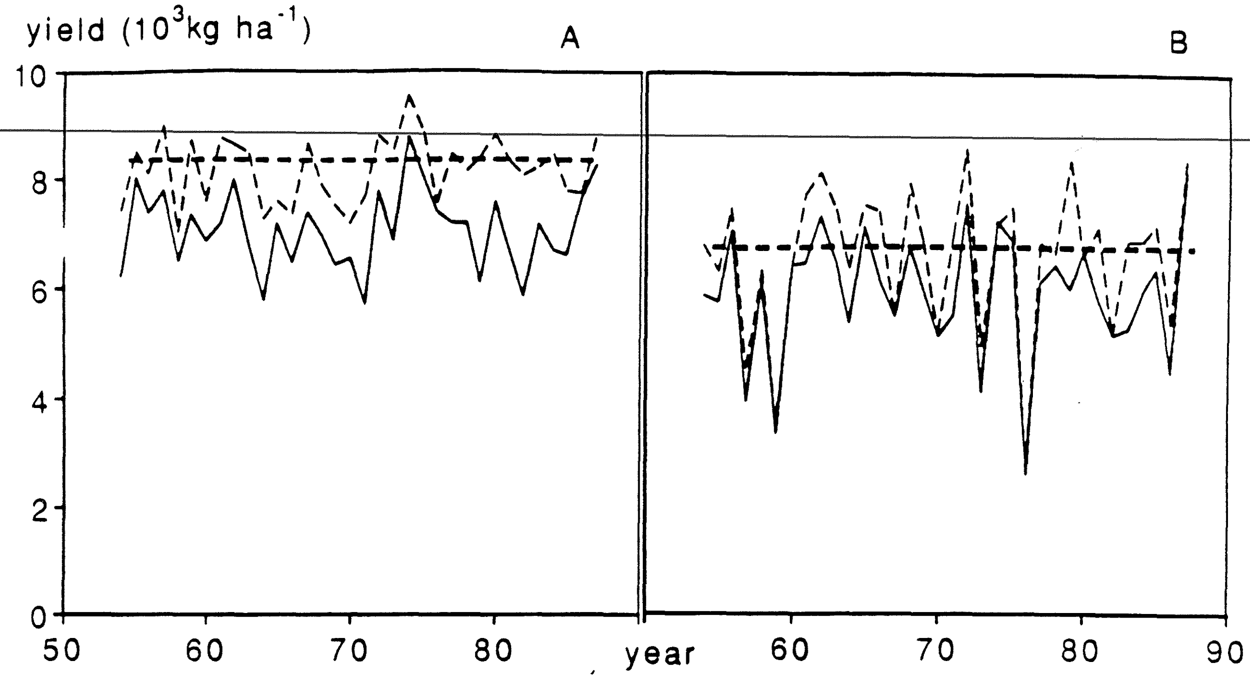

Figure 1 Effect of using daily and average weather data as input on simulated potential (A) and water limited production (B) in Wageningen, using daily data (——), average data over one month (- - -) and the result with climatic averages (▬ ▬).

When the model is used to obtain an indication of potential production possibilities in a region, climatic averages can be used as input, although it should be kept in mind that the simulated yield is higher than the averaged yield with daily data. However, a study on the production possibilities in a region usually involves comparison with possibilities in other regions. In such a study use of averages can be misleading. As to be seen in table 3 the difference in average yield between the two sites is not similar for daily values and climate averages. The difference in average potential yield between Wageningen and Migda based on daily values is 1.7 ton ha^{-1}, based on climatic averages it is 0.5 ton ha^{-1}.
When also inter annual variability of the yield is a point of interest monthly averages should be used instead of climatic averages. The inter annual variation and yield level can deviate from the values calculated with daily data (table 3) The use of averages over shorter periods than one month (10

days) did not improve the simulation results neither in average yield level nor in annual variability. So the larger efforts and expenses coupled with handling and obtaining 3 times as many data are not worth the trouble.

Water limited production

Distribution of the precipitation has a large effect on the amount of water available to the plant. One large shower will saturate the profile while many small showers will only moisten the top layer. Water in the top layer of the soil is subject to evaporation. Use of average precipitation (=small amount of rain every day) implies that evaporation losses from the top soil layer will increase. When water is limiting crop growth increased evaporation will lead to a yield decline. This effect is to be seen in the dry years in the Netherlands and in all years in Migda. Under wet conditions averaging precipitation had no effect on water shortage since even when evaporation losses increased still enough water was available for growth. In these cases the effects were the same as for the potential situation: averaging weather data led to overestimation of the yield. In seasons in which only a small number of days with water shortage exists these effects level out. On the dry days growth is underestimated and on wet days it is overestimated, resulting in only a very small deviation from the simulated yield with daily data.
So the use of average values in the water limited situation has an effect on the variability of the yields (table 3). In regions in which dry and wet years occur the variability increases since use of averages over short periods results in overestimation of the yield in wet years and underestimation in dry years. In regions in which yield is mainly determined by the amount of water available, use of averages results in decline of the variability, since even relative wet years become dry due to the increase of the evaporation losses (Migda, 1974, 1980).
In Israel another process was affected by precipitation. In the model the crop starts to growth as soon as water is available. In 1966 first winter rains only occurred at the end of December. Monthly averages of precipitation implied that the 1st of December was already a wet day, so with the monthly averages the growing season started nearly one month earlier,

resulting in yield increase in that particular season (figure 2b, harvest in 1967!).

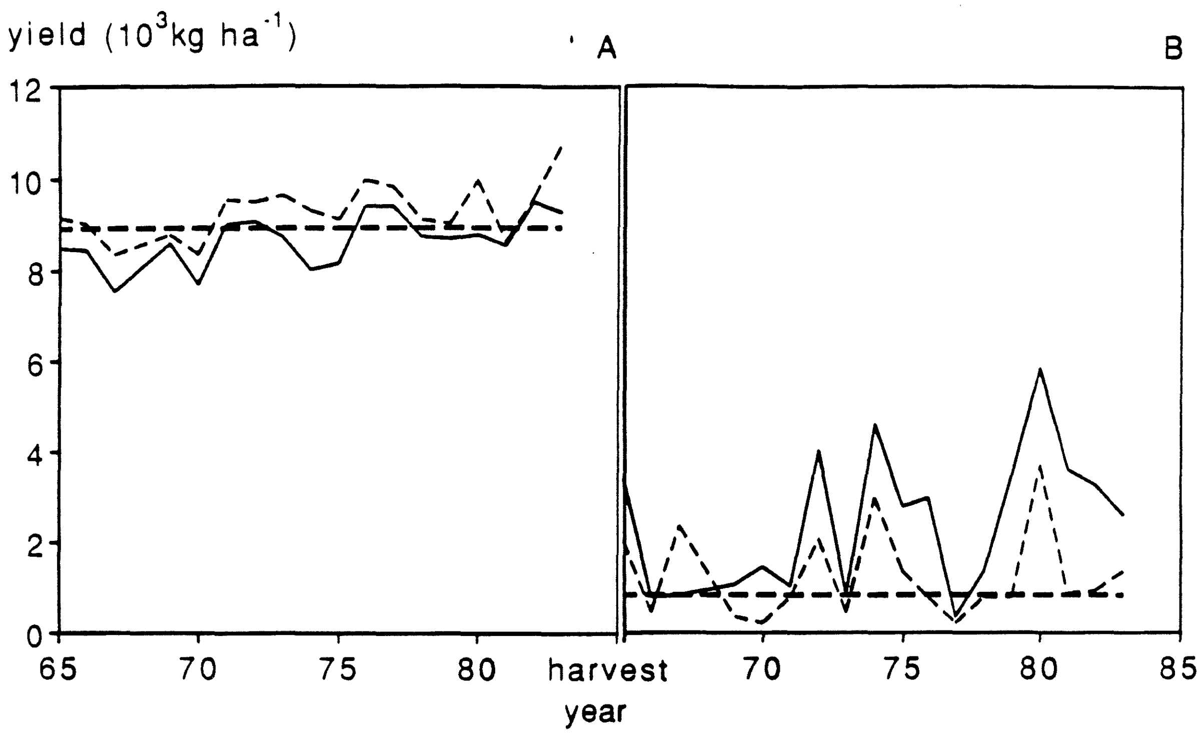

Figure 2 Effect of using daily and average weather data as input on simulated potential (A) and water limited production (B) in Migda, using daily data (——), average data over one month (- - -) and the result with climatic averages (▬ ▬).

The importance of rainfall distribution on the amount of water available for uptake by the roots is recognized by many authors. Therefore often rainfall generators are used when only average values are available (van Keulen et al., 1987; van Lanen et al., 1992). These routines simulate a rainfall pattern, through which wet and dry days are created (Geng et al.,1986). Such a simulated rainfall distribution will reduce the evaporation losses and it is likely that simulation results will improve in arid conditions.

Table 3 The average simulated potential and water-limited yield in ton ha^{-1} and (standard deviation), using daily values, averages over 10 days, monthly averages as input. And the simulation result using climatic averages based on monthly data as input.

	day	10 days	month	climate
potential				
Wageningen	7.0 (0.7)	8.0 (0.6)	8.1 (0.6)	8.4
Migda	8.7 (0.6)	9.2 (0.5)	9.3 (0.6)	8.9
water limited				
Wageningen	5.9 (1.2)	6.4 (1.5)	6.6 (1.3)	6.8
Migda	2.6 (1.8)	1.6 (1.5)	1.3 (1.1)	0.8

Concluding remarks

The use of average weather data for simulation of potential production results in overestimation of the yield. When one is only interested in an indication of the average potential yield in a region average data can be used. The effects of the use of averages for simulation of water limited production depend on climate type and water availability, both over and underestimation of the yield can occur. Use of averages for this production level should therefore be avoided.

In this paper the consequences of the use of average weather data on simulation results are calculated for only one model. Since the effect of using average values depends on the relations incorporated in the model, the results found in here can not be extrapolated to other models. However, variation in weather can be expected for most growing seasons on earth. So for most locations use of average weather data in simulation models developed for daily data is not without risk.

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