Estimation of the Effect of Global Warming on Yields and Environment of Arable Crops in Hungary

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Introduction

Justification

The importance of production is expected to grow again in the foreseeable future jointly with the environmental concern caused by the increasing pollution of soils, groundwater and atmosphere. One of Hungary's most important national resources is its fertile soil. Our responsibility is, on the one hand, to make use of it effectively for the good of the people and, on the other hand, to save it from degradation for the following generations.

The climatic conditions of Hungary, however, are less favourable, with special regard to the amount and distribution of rain. Under this semi-arid climate drought frequently causes significant yield losses. Among these marginal weather conditions, any further changes can be critical for production in a given year.

Climate change studies showed that the variability of Hungarian weather is going to increase due to global warming (SZÁSZ et al., 1994). The expectable reaction of soils – namely moisture regime and degradation processes – were dealt with in detail by VÁRALLYAY (1990a,b,c, 1992, 1998). The sensitivity of cropping systems can be estimated by the reaction of yields and nitrate leaching to the factors in plot experiments (NAGY, 1995, 1996a,b; NÉMETH 1995, 1996; NÉMETH et al., 1989).

Construction of future regional climate scenarios

There are two logical approaches to gain regional climate scenarios:

a) The climatological approach considers scenarios as conditional forecasts for tendencies of likely external forcing with the time resolution allowed by methodological constrains.

b) According to the climate impact approach, a regional scenario should give coherent ensemble of climate parameters in any possible future state with practically useful time resolution.

The solution can be a conceptual combination of the two approaches, namely the regional scenario can be constructed according to the climatological approach, first, with maximum methodically possible resolution in time (seasonal and monthly) and scientific methods of downscaling in time have to be developed, as it has already been done for the space problem.

Downscaling in space from General Circulation Models (GCMs) can be carried out by the method of slices (MIKA, 1993, 1994) based on the relationships between regional climatic elements and two hemispherical temperature characteristics. This is the first step. It contains the expected changes in mean seasonal (quarter of years) values of temperature, radiation and precipitation. Downscaling in time can be approached by assessing detailed statistical characteristics for the future condition. The third step is the simulation of daily sequences of weather elements by a stochastic weather generator (RACSKÓ et al., 1991).

As an alternative, earlier authors calculated change factors between present and future values for the climatic elements (BACSI & HUNKÁR, 1994; SMITH & TIRPAK, 1989).

Crop model applications

The selected model was CERES-maize (JONES & KINIRY, 1986; RITCHIE, 1991, 1993; RITCHIE & NESMITH, 1991). Before the present forecast study started a large number of simulation experiments had been carried out for locations where long-term experiments have been carried out in Hungary (KOVÁCS et al., 1995; KOVÁCS, 1997; PETŐ et al., 1994; KOVÁCS & DUNKEL, 1998; KOVÁCS & NAGY, 1997). At the experimental sites several types of observations and measurements secured the necessary data for model inputs, i. e. soil characteristics (like soil texture, hydrophysical properties, humus content, pH, nutrient concentrations), meteorological data (such as daily global radiation, maximum and minimum air temperature and precipitation) and plant genetic information. The results of simulation studies showed good agreements between the measured yields and the forecasts for different years.

Concept of the study

Long-term forecast of maize yields and environmental changes (such as stress factors, drainage, nitrate leaching, denitrification) are calculated for two different times in the future (10 to 20 years from now and 30 to 50 years from now) based on the following assumptions:

1. The expectable climatic changes for a region can be derived from the statistical relationship of general circulation model outputs and the regional weather scenario (MIKA, 1993, 1994). Parameters can be gained for weather

generators that correspond to an observed colder and warmer historical series of years, respectively.

2. Using the above parameters weather forecasts can be generated (DOBI 1997a; RACSKÓ et al., 1991; DOBI et al., 1995, 1996) for the present time (as „cold climatic analogue" series of years) and for future times („warm climatic analogue" series).

3. Crop models – once they are adopted to the Hungarian conditions – can be used to reasonably estimate the yields and yield components of the main Hungarian arable crops.

4. In addition to yield forecasts, several outputs of the models can be used to characterize the changes of the ecological system: drainage, nitrate leaching, denitrification, evapotranspiration, drought effects at different stages of plant development, etc.

Material and Methods

Downscaling in space from GCMs, for the present study, was done by the method of slices (MIKA, 1993, 1994) based on the relationships between regional climatic elements and two hemispherical temperature characteristics. Downscaling in time was approached by assessing detailed statistical characteristics for the future condition. A close statistical relationship was found between two characteristics of the northern hemisphere (i. e. mean temperature and the contrast of continental and oceanic air temperature) and the changes in instrumentally measured local climate elements in time. The examined period was 1881 to 1980. The time steps were the four seasons of the year, but not exactly the astronomical ones. In this study three regions of Hungary met the conditions: Szeged, Kecskemét and Szombathely, out of which Szeged region is dealt with in the Results and discussion. The daily sequences of weather elements were calculated by a stochastic weather generator (RACSKÓ et al., 1991). The method is described in detail by KOVÁCS & DUNKEL (1998).

As it was mentioned, CERES Maize and Wheat crop models were adapted to Hungarian conditions. Simulations gave good agreements with the measured yearly yields in 20-year continuous experiments. In the present study the crop yields were collected from agricultural and food industry statistical yearbooks (1980-1985) for Csongrád county (where Szeged is located) to check the possibility of forecasting yield changes for a county from a single meteorological station.

Then weather forecasts of 60 years were generated for each of the four treatments: cold and warm climatic analogues for the shorter (10 to 20 years) and the longer (30 to 50 years) forecast (DOBI, 1997b). Both production and environmental results were then analyzed using those runs. The two series of runs representing the present climatic analogues for the two different time legs differ from each other as the bases are different. The years between 1976 and 1980 as compared to 1991-1995 were used as cold and warm analogues, respectively for the longer forecast, representing a 0.75 °C rise on global scale (corresponding to a 30 to 50 years time from today). On the other hand, the years between 1961 and 1980 in comparison with 1981-1996 were used as cold and warm analogues, respectively for the shorter forecast, representing a 0.30 °C rise on global scale (corresponding to about a 10 to 20 years time from today).

Runs were executed with and without CO_2 changes. Climate change will not occur without CO_2 changes, but the simulation may help us in distinguishing between the direct effect of CO_2 changes and the effect of other climate elements.

Soil parameters were not changed in this study. A clayey soil was selected with the following average values for the profile LL= 0.23, DUL= 0.36, and SAT= 0.46. The initial value for SW= 0.27, SNO3= 2.00, SNH4= 2.00.

Plant genetic parameters were kept stabile during the runs; the values were: 110, 0.5, 630, 600, 8.0 for maize variables P1, P2, P5, G2, G3, respectively and 6.0, 4.0 3.8, 1.8, 4.0, 2.2 for wheat variables P1V, P1D, P5, G1, G2, G3 respectively. (For more information see JONES & KINIRY (1986) and KOVÁCS (1995).)

Results and Discussion

Simulation of the yearly variation of yields for a county, based on the data of a single meteorological station

Figure 1 shows the continuous increase in yield between 1960 and 1980 as a result of the development of agricultural technology (artificial fertilizers, genetic potential, machinery). However, the stability of expectable yield decreased in

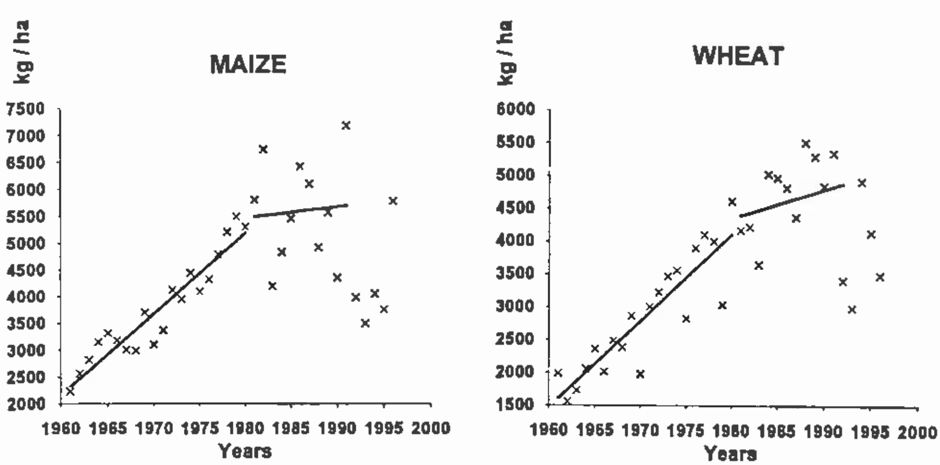

Figure 1
Maize and wheat yields in Csongrád county, 1961-1996

the 80's when yields reached an equilibrium. There was a drop in the average yields in the 90's, due to re-privatization and lack of capital of the farmers. Data were collected to test the model for yearly variability due to the different weather conditions. These data cannot be used as they are, only in a standardized format to eliminate the effect of agricultural technology development. Maize and wheat yield were standardized as 5.0 and 4.0 tonnes per hectare per year, respectively. In the simulation 100 kg per ha per year nitrogen fertilizer was used.

Figure 2 compares the good and bad production years as they were modelled and measured for the 20 years following 1960. It shows that in most years there is an agreement between modelled and measured data in the direction from the averages, but the predicted yields have much higher amplitude. This can be explained by the fact that measured yields represent averages of thousands of fields, while the prediction was based on the weather of only one meteoro-

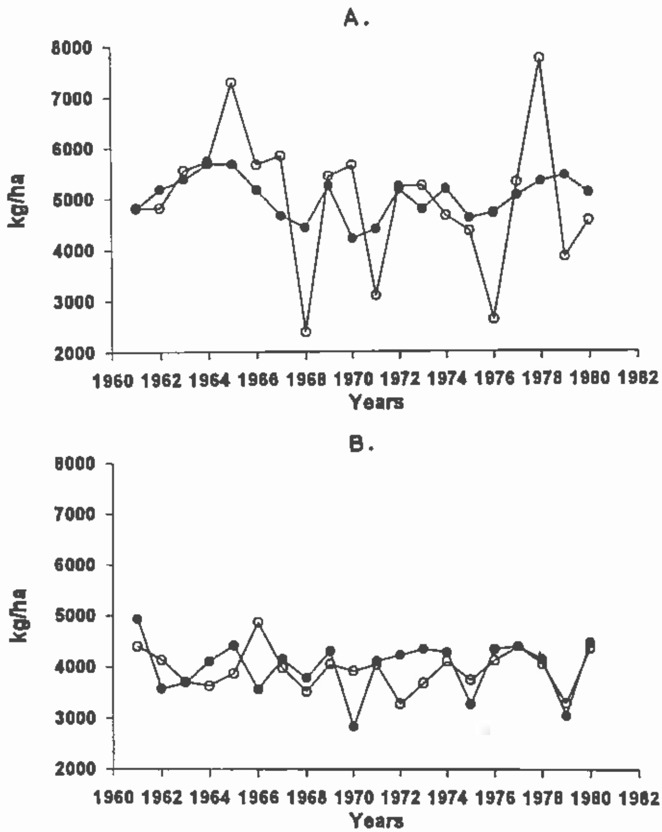

Figure 2
Good and bad production years as observed (•) and modelled (o)
A. Maize. B. Wheat

logical station. If local yields would be plotted against simulation, the amplitudes would be more similar. For the territorial extension of the model several weather data sets are required, especially about rain, and soil parameters have to be used according to the scale of the map used for the purpose of application.

Yield response to expected climate changes

Figure 3 shows the simulated response of maize and wheat yields in approx. 15 and 40 years time from now in south-east Hungary under a global warming of 0.30 °C (corresponding to an expected change up to 2008–2018) and 0.75 °C

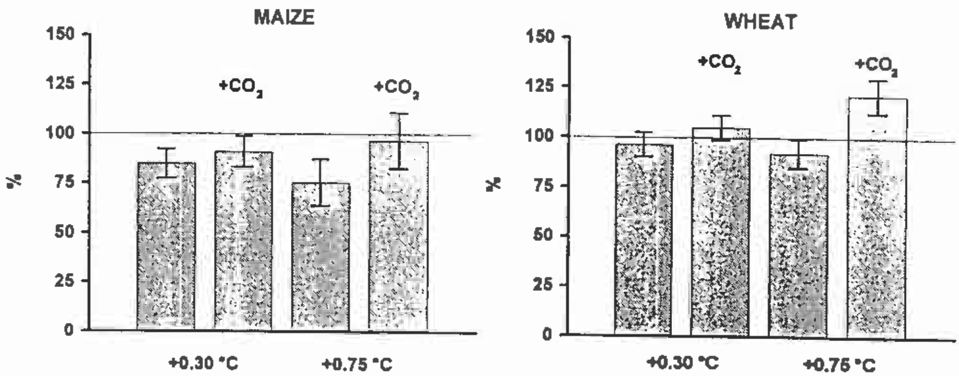

Figure 3
Response of maize and wheat yield to global warming of 0.30 °C and 0.75 °C (corresponding to an expected change up to 2008-2018 and approx. 2040, resp.) 100% = yield at present. +CO_2: direct effect of atmospheric change in CO_2 on photosynthesis

(corresponding to an expected change till approx. 2040). The bars represent the standard deviation of 60 years of runs for each column. +CO_2 expresses that the computation considered the direct effect of the atmospheric change in CO_2 on photosynthesis. The line at 100% shows the basis of the comparison, that is the present yield.

As it can be seen, the forecast for maize yield is worse than for wheat yield at both time legs, which is a consequence of the different shares of seasons these crops have. Winter wheat is not exposed to summer droughts, like maize is. The expected change in weather is: milder winter and more extreme summer, meaning a higher risk of drought during summer months. This is proven later by the drought stress study.

In the long run none of our main crops are seriously endangered by the climate change, if the direct effect of CO_2 is considered. Even a favourable influence can be expected for wheat production. Though in case of both crops only the direct effect of CO_2 is positive. Without taking CO_2 changes into consideration, a slight loss of yield is expected, especially in case of maize.

Table 1 shows the forecast for the duration of plant development stages of maize for 0.75 °C global warming (40 year forecast) and for 0.30 °C global warming (15 year forecast). It should be noted that runs did not consider CO_2 changes. It can be seen that the overall duration is shortened by 6 days in the shorter time leg and 12 days on the longer one. Most changes occur in the duration of grain filling, which causes significant yield decrease. The effect of the shorter life span may lead to a positive consequence in energy consumption by the drier harvested grains, but this was not part of the study.

Table 1

Forecast for the duration of plant development stages of maize for 0.75 °C and 0.30 °C global warming (40 and 15 year forecasts, respectively)

Plant development stages	Duration of stages (days)			
	Present 0.75 °C	Future 0.75 °C	Present 0.30 °C	Future 0.30 °C
Germination to Emergence	12	11	12	10
Emergence to End Juvenile	12	12	13	12
End Juvenile to Floral Initiation	6	6	6	6
Floral Initiation to Silking	40	38	40	40
Silking to Begin Grain filling	13	12	13	13
Begin to End Grain filling	31	24	29	26
End Grain filling to Maturity	3	2	2	2
Germination to Maturity	117	105	115	109
Decrease	0	12	0	6
Estimated yields (kg/ha)	4601	3416	5036	4271

Figure 4 demonstrates the effect of global warming on water deficit stress on maize (Figure 4A) and wheat (Figure 4B). CSD1 and CSD2 express water stress in phenological phases. CSD1 influences photosynthesis, which is less sensitive. CSD2 influences the longitudinal growth, that is more sensitive to drought. The latter is revealed in the figures: value 0 means no stress, 1 means maximum possible stress. The stress increases for maize, especially later in the season, while it does not increase much for wheat.

Changes with an environmental significance

Three environmentally important characteristics were studied: denitrification, drainage and NO_3-N leaching. In the present paper only the longer time leg is discussed, that is a change that can be expected 40 years from now.

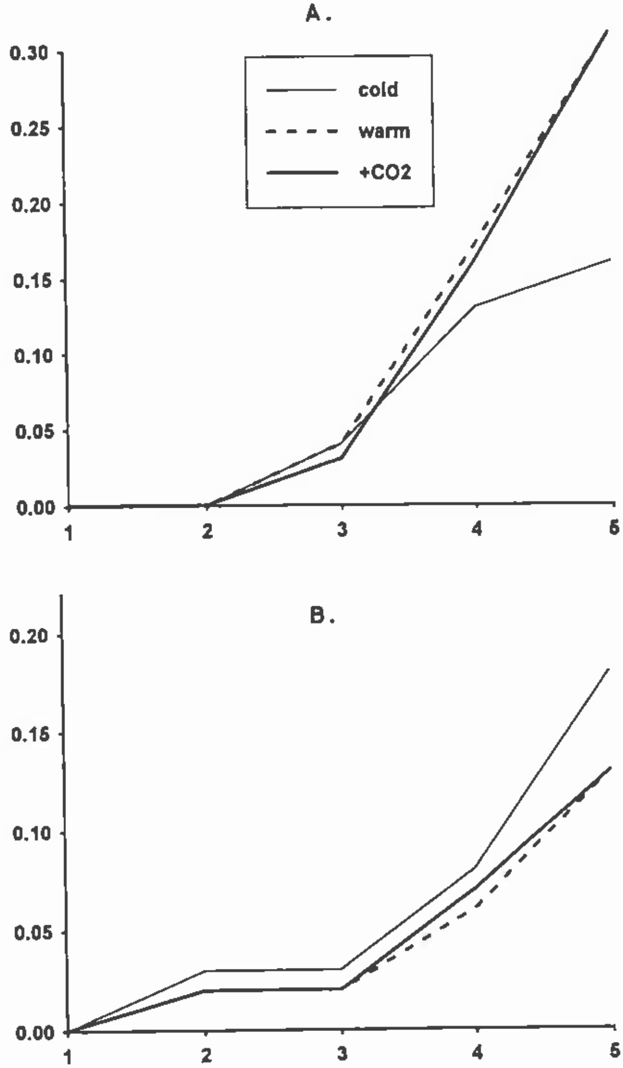

Figure 4

Effect of global warming (0.75 °C) on water stress of maize (A) and wheat (B) at different phenological stages: 1. Emergence to end of juvenile; 2. End of juvenile to tassel initiation; 3. Tassel initiation to silking; 4. Silking to beginning of grain filling; 5. Beginning of grain filling to maturity

Table 2 shows the forecast of denitrification. At present 10 kg nitrogen loss is estimated yearly from one hectare of Hungarian arable land according to the CERES model. It varies year by year, that is why 10 years is taken in the table. The total amount of denitrification will decrease by 20% according to this forecast. Selecting an arbitrary limit, the years with denitrification were separated from years (practically) without denitrification and comparisons were made to learn the expectable tendency. As it is shown, the frequency is not going to change, but the extreme years may increase with a factor of 1.6.

Table 2

Denitrification influenced by global warming of 0.75 °C (approx. 40 years change)

Denitrification	At present	Global warming of 0.75 °C
Mean of 10 years (kg N/ha/year)	101	82
Frequency of „Denitrification year" in 10 years	7.8	7.7
Extra amount over 30 kg/ha/year in 10 years	0.5	0.8

According to Table 3, drainage has a tendency of decrease in the long run. This is true for the total amount, frequency of occurrence of drainage years and the extreme drainage years as well.

Table 3

Drainage influenced by global warming of 0.75 °C (approx. 40 years change)

Drainage	At present	Global warming of 0.75 °C
Means of 10 years, mm/year	111	62
Frequency of „Drainage year" in 10 years	2.3	1.5
Extra amount over 30 mm/year in 10 years	1.3	1.0

As indicated in Table 4, the total amount of leached nitrogen is going to decrease by 40% according to the projection of the CERES model. This is evident if we take into consideration the decrease in drainage (see above). The same can be stated about the frequency of occurrence of N leaching years and the extreme N leaching years as well.

Table 4

Nitrate-N leaching influenced by global warming of 0.75 °C (approx. 40 years change)

Nitrate-N leaching	At present	Global warming of 0.75 °C
Means of 10 years, kg NO_3-N /ha/year	108	56
Frequency of „Leaching year" in 10 years	2.3	1.5
Extra amount over 30 kg/ha/year in 10 years	0.7	0.5

Conclusions

For territorial extension of the model several weather data sets are required, especially about rain, and soil parameters have to be used according to the scale of the map used for the purpose of application.

In Hungary the two major arable crops are not expected to loose yields in the long run on the average.

Maize is more exposed to unfavourable years due to droughts, but if the projected climate consequences of global warming occur, the direct effect of CO_2 will balance the drought effect on the average of years.

Wheat crop has a chance of gaining from the effect of expected global warming.

Environmental hazards – like nitrate-N leaching and pollution by NO_x-gases – are also expected to ease due to the less projected water drainage from the soils and less favourable conditions for denitrification.

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