Climate change impacts in agriculture and possible responses

Dr. Éva Erdélyi [1], Dr. Márta Gaál [1], Dr. Levente Horváth [2]
[1] Corvinus University of Budapest, Department of Mathematics and Informatics
[2] 'Adaptation to Climate Change' Research Group of the Hungarian Academy of Sciences
H-1118 Budapest, Villanyi út 29-43., eva.erdelyi@uni-corvinus.hu

ABSTRACT

It is evident that climate change is one of the most serious problems we face in the 21st century. Considering the possible changes we have to answer many questions in order to prepare for the future. Using geographical analogues it is shown that the possible future climate in Hungary would be similar to the present climate of South-Southeast Europe. In the case of crops phenophases could become shorter. We traced the possible changes of production risk, expected yield and phenology of maize and winter wheat. In our research we have used six climate scenarios and the historical meteorological data of their reference period. We have proved that the risk of maize and winter wheat production has increased. We examined the frequencies of extreme temperature values during the growing season, as well. We have shown that the quality of winter wheat might be better in the near future and that with appropriate adaptation strategy we can benefit from climate change. Next we analyzed how the yield and the length of the phenological phases of the plants are expected to change. Modeling is a useful tool for investigation of the future circumstances without having expensive and long experiments. The simulations were run by the 4M crop model. It can be stated that, as a result of temperature increase, the starting points of the phenological phases are expected to shift a day earlier in ten years, on average. We have also used the model for finding an adaptive strategy for increasing the yield with changing the sowing date. The results are very promising in case of the two weeks earlier sowing date, which may suggest new prospects in land use, too. Studies about climate change impacts in agriculture are needed very much in order to find adaptive response strategies.

Keywords: Adaptation, climate change, impact, maize, modeling, winter wheat, Hungary

1. INTRODUCTION

Climate change is one of the most serious problems we face in the 21st century. Considering the possible changes we have to answer many questions in order to prepare for the future. Climate change related problems bring together very different, specific scientific communities such as meteorologists, modelers, agriculture engineers, soil scientists, urban and rural planners, water managers. The combined effects of warmer temperatures and reduced mean summer precipitation would enhance the occurrence of heat waves and the risk of drought. Using geographical analogues it is shown that the possible future climate in Hungary - predicted by the

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scenarios - would be similar to the present climate of South-Southeast Europe (Horváth, 2007). With the method of spatial climatic analogy (Horvath, 2009) analogue areas the present climate of which is similar to the one of the studied areas in the future can be identified, or the future climate of which is expected to be similar to the one of the studied area at present. It is found, that the ‘climatic shift’ is expected to be 250-450 km in the next decades, and 450-650 km up to the middle of the century. Considering the possible changes we have to rise to the challenge in order to prepare for the future. Modeling the future climate helps in finding out the possible impacts of climate change on agriculture production in many studies all over the world (Barrow and Hulme, 1996, Semenov et al., 1996). We examined the effects of climate change on maize and winter wheat, which are the most important plants in Hungary; we traced the possible changes of production risk, expected yield and phenology.

First, with a new stochastic dominance criterion, we have proved that the risk of maize and winter wheat production in four Hungarian counties has increased independently to the risk aversion of the decision maker (Ladányi and Erdélyi, 2005, Erdélyi, 2007). In search of the reasons, we analyzed the temperature and precipitation needs of the plants in each phenological phase. We examined using the Klíma-KKT software (Szenteleki et al., 2007) the frequencies of extreme temperature values during the growing season. For the comparison we used six climate scenarios (BASE, GFDL2535, GFDL5564, UKHI, UKLO, UKTR) with daily data, downscaled to Hungary and the historical meteorological data of their reference period 1961-1990. The location of our case studies was Debrecen, which is of big importance in agricultural production. We have analyzed the climate demands of the plant from both quantity and quality aspects, as well (Erdélyi, 2007).

Increased mean annual temperatures in our region, if limited to two or three degrees, can be generally expected to extend growing season. In case of crops, where phenological phases depend on an accumulated heat unit, the phenophases could become shorter. In this paper first we present the prospective climatic characterization of the location of our case studies and investigate the effects of climate change on the growing period of corn and winter wheat, as the two most cultivated plants in Hungary. Next we have analyzed how the yield and the length of the phenological phases of the plant are expected to change and trace the possible response strategies by the method of modeling, applying climate scenarios as weather inputs. We show that the quality of winter wheat might be better in the near future and that with appropriate adaptation strategy we can benefit from climate change. Debrecen, the basic point of our calculations is an important centre of agricultural production in Hungary, so our intension is to interpret the results in this aspect.

2. MATERIALS AND METHODS

2.1 Meteorological data

Climate scenarios can be defined as relevant and adequate pictures of how the climate may look like in the future. The simulations were performed for the daily average temperature and precipitation amount based on climate scenarios. During our research, we applied the principles defined by IPCC (Intergovernmental Panel on Climate Change) and we used scenarios presented in international reports (IPCC, 2001), such as:

1) Scenario BASE which is the base of climate scenarios with the parameters of 1961-90;

2) Scenarios created by Geophysical Fluid Dynamics Laboratory (USA), GFDL2534 (generated for 2025-34) and GFDL5564 (generated for (2055-2064);
3) UKHI and UKLO (high and low-resolution equilibrium supposing doubled CO_2 concentration) and UKTR (high-resolution transient climate change experiment, generated for 2031-40) worked out by United Kingdom Meteorological Office (UKMO).

In this work General Circulation Models outputs were downscaled to Debrecen, the basic object of our calculations. Scenarios UKHI and UKLO show the most drastic change very similar to the newest scenarios in Prudence database (IPCC, 2007) developed for studies about the end of this century (Diós et al., 2008), which models predict average warming of at least 6°C.

Table 1. Examples of temperature and precipitation changes indicated by different scenarios

	Changes in temperature (compared to 1961-1990, ^{o}C)					Changes in precipitation (compared to 1961-1990, %)				
	yearly	winter	spring	summer	Autumn	**yearly**	winter	spring	summer	autumn
GFDL 2534	**0,8**	0,0	0,6	1,2	1,4	**-7**	20	14	-30	-18
GFDL 5564	**2,3**	1,8	2,1	1,6	3,5	**0**	12	18	-6	-21
UKTR	**1,8**	2,5	0,8	1,3	2,6	**-12**	23	7	-31	-32

It should be noted that Debrecen - the location of our case studies - is in a favourable situation, as in the middle and south part of the country the increase of the temperature and heat units would be greater, while the precipitation would increase in smaller extent, or even decrease.

2.2 Climate description of the research location

To highlight the trends of climate change in the observed region we present the monthly average temperature and precipitation changes indicated for it in Table 2 and Table 3, comparing the data of the UKTR and GFDL scenarios and their reference period 1961-90.

Table 2. Temperature changes indicated by different scenarios, monthly average data, Debrecen

Temperature (°C)	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1961-1990	**-2,6**	**0,2**	**5,1**	**10,7**	**15,8**	**18,7**	**20,3**	**19,6**	**15,8**	**10,3**	**4,5**	**-0,2**
UKTR	1,3	4,3	5,6	12,4	16,1	19,6	21,3	21,6	18,7	12,8	6,9	-0,8
GFD5564	0,3	0,7	7,7	13,2	17,0	20,3	21,9	21,3	20,4	12,8	7,8	1,8
GFDL2534	-0,8	-0,6	6,4	11,4	15,7	19,7	21,7	20,8	17,9	12,5	4,5	-1,1

Table 3. Precipitation changes indicated by different scenarios, monthly average data, Debrecen

Precipitation (mm)	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1961-1990	**37**	**30**	**34**	**42**	**59**	**80**	**65**	**61**	**38**	**31**	**45**	**44**
UKTR	53	27	32	48	64	50	50	42	19	27	31	57
GFD5564	47	30	34	65	60	67	78	49	26	37	27	47
GFDL2534	52	27	51	55	48	55	46	44	32	28	33	54

To find the analogues of the observed region (similarity › 90%), monthly data of precipitation sums and temperature averages were used with the method of spatial climatic analogy (SCA) (Horváth, 2007). The darker areas represent the more similar climatic characterization (Figure 1).

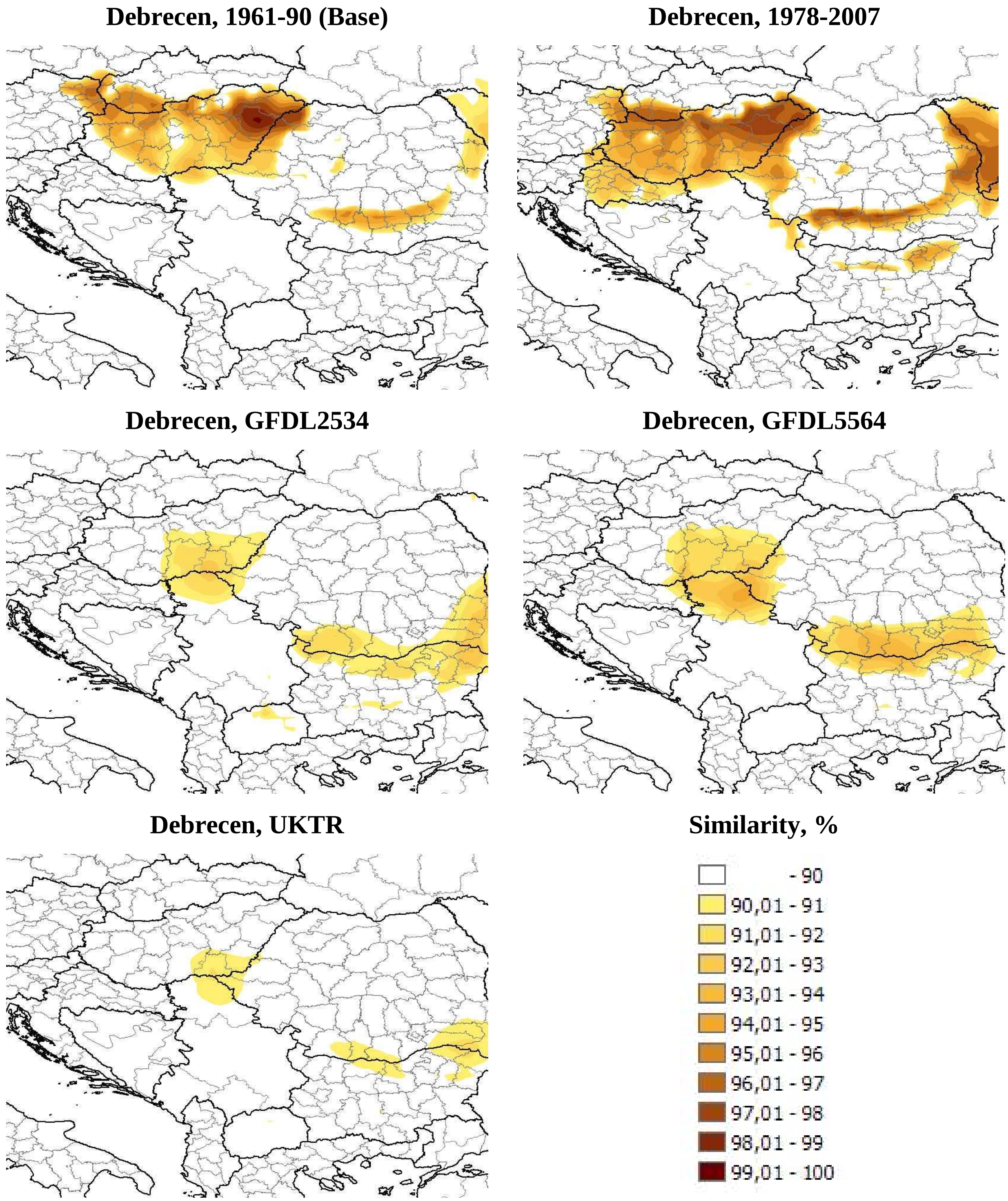

Figure 1. Similar regions to Debrecen, results of the SCA method for different climate scenarios

2.3 Modeling, the 4M crop model

Modeling is a useful tool for investigation of the future circumstances without having expensive and long experiments (Rajkai et al., 2004). In our crop model research we used the 4M model, which has been developed by the Hungarian Agricultural Model Designer Group (Fodor et al., 2002 and Fodor, 2006). It contains several models to describe the physiological interactions of soil - plant systems and offers a possibility of building up different system models in it for the specific purposes of the users need. The CERES model was chosen to be a starting point and was adapted to Hungarian conditions. The simulations were performed for meteorological data predicted on the basis of climate scenarios, as weather inputs. We have analyzed the crops phenological phases using the intervals defined by the 4M model. Models are very applicable for the description of changes in the future, for giving hints in improving new plant varieties, which are resistant to probable changes.

3. RESULTS OF OUR CASE STUDIES

3.1 Shifting of the phenological phases, simulation

Analyzing the observed and the future weather using climate scenarios we have seen a great variability in the amount of the precipitation. This means that the increase of the frequencies of extreme weather events such as droughts and floods is more probable. This is the reason why we intended to learn, what climate scenarios predict for the most important growing periods of crops. In summary, it can be said that for both, maize and winter wheat the phenological phases might shorten and happen earlier in the future as a result of temperature increase.

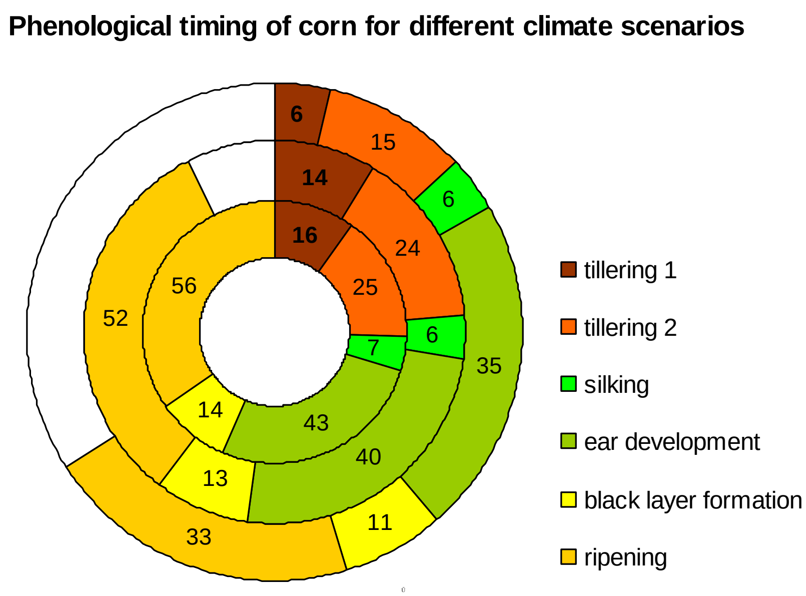

Figure 2. Duration of the phenological phases of corn given in days for different climate scenarios (inner: baseline scenario for 1961-90, middle: scenario UKTR for 2031-40, outer: scenario simulating circumstances for the end of the century)

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We have simulated how the length and the starting dates of phenological phases of the two most important field crops in Hungary - maize and winter wheat - change if different scenarios are used. Simulation results for corn show shortening of the growing period for all the used scenarios, significant difference was observed for the GFDL5564, UKHI and UKLO scenario compared to the BASE. For statistical evaluation of the results we have used the ROPstat Package, the comparison results are given on significance level of 95%. The shifting can be clearly seen for a given example on Figure 2.

We analysed the effects of changing climate on the growing periods of winter wheat, as well. We used the simulation method based on the 4M model again. We used the data for Debrecen for the reference period of the climate scenarios, 1961-1990 and the estimations of the same climate scenarios as above. We present the results by comparing the historical data and the UKTR scenario for the starting dates of the phenological phases of winter wheat in Figure 3. The starting points of the phenological phases shifted to earlier dates, especially in the first period of the growing season. Harvesting is predicted to be eight days earlier (in average) in the future which means about one day in 10 years.

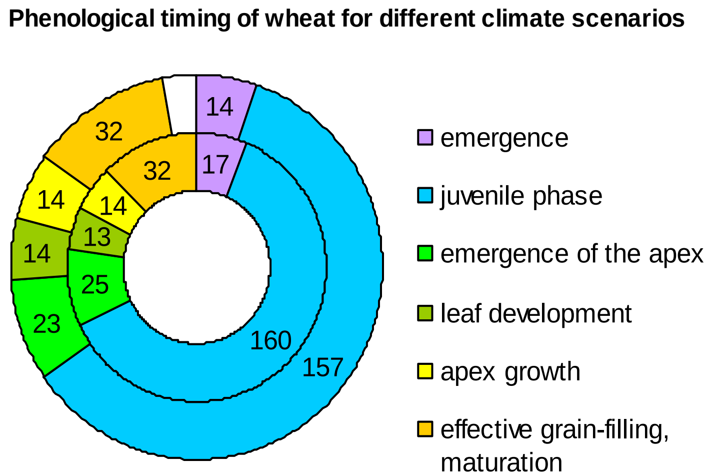

Figure 3. Duration of the phenological phases of winter wheat given in days; scenario UKTR for 2031-40 (outer) and its Baseline scenario for 1961-90 (inner)

We have also analyzed the grain development (the last two phenological phases) and grain mass. Analyzing the results we can see not only the shifting of the period of grain development, but also that climate change has a good influence on grain mass of the plant: besides the shifting of the grain development period for eight days earlier date we detected that the average production is predicted to be higher in the future than before. We present the results on Figure 4. In order to check the reliability of the used crop model we have compared the simulated yield results of the reference period 1961-90 and the historical production data (Table 4). We can conclude that the model operates with small variation and the predicted yield is close to the measured one. The UKTR scenario shows increasing grain mass quantity, but higher variation.

Using the historical production data of 1951-2005 we have previously proved with a general stochastic dominance criterion that the risk of maize and winter wheat production in Hungary has increased independently to the risk aversion of the decision maker (Ladányi and Erdélyi, 2005; Erdélyi, 2007).

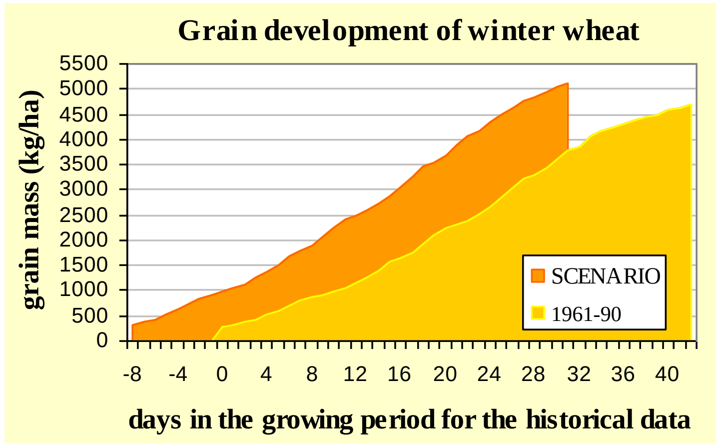

Figure 4. Comparison of the period of grain development and grain mass of winter wheat for the reference period and the UKTR climate scenario

Table 4. Comparing the observed and simulated grain mass of winter wheat, Debrecen region

	grain mass (kg/ha) observed			grain mass (kg/ha) predicted		
	average	st.dev.	CV	average	st.dev.	CV
1961-90	4282,1	1337,92	0,312	4565,21	510,62	0,11
UKTR3140	-	-	-	5164,73	825,71	0,21

In the given case study we compared the simulation results of the UKTR3140 scenario with the simulation results of the historical data of reference period 1961-90. Seeing the predicted values for the two time periods we can conclude, that climate change might be good in winter wheat production of Hungary. The simulation result for the climate scenario gives about 13% of winter wheat yield increase compared to the simulated value with the input of the historical data. Even on the basis of small standard deviation and coefficient of variation (CV) values, we can conclude that the results are very promising. The application of 4M crop-model is justified in many national climate change impact research projects (Fodor and Kovács, 2005).

3.2 Quality factors of winter wheat

Varieties used nowadays are very sensitive to the meteorological parameters. It is very important to learn about factors that influence the yield, as much as possible. However, it is also very important to examine the quality factors as well. The quality of the grain depends on the number of spikelets. Their optimal development is the best if the average temperature is around 15 ^{o}C in the second half of March and in the first half of April. All of the climate scenarios show better results compared to their reference period. Results can be seen in Table 5. Another quality factor is the gluten and starch content of grains. We have checked if the values of meteorological parameters for this factor will be satisfied or not. The optimal temperature for the enzyme activity is 17-23°C in the spikelet initiation, anthesis period for gluten content.

Table 5: Frequency of 14-16 ^{o}C daily average temperature in Debrecen, from middle of March to middle of April

	number of years in 31 years	number of days		
		total	average	max. number in one year
BASE	18	40	1.29	5
UKHI	31	180	5.8	16
UKLO	30	153	4.94	11
UKTR	27	81	2.61	8
GF2534	19	48	1.55	6
GF5564	27	112	3.61	10

It is also very important to have enough precipitation in April-May for good starch content. The climate scenarios are given for different time intervals as independent patterns and not as time series, so for comparison we have used distribution functions and the first order stochastic dominance criterion.

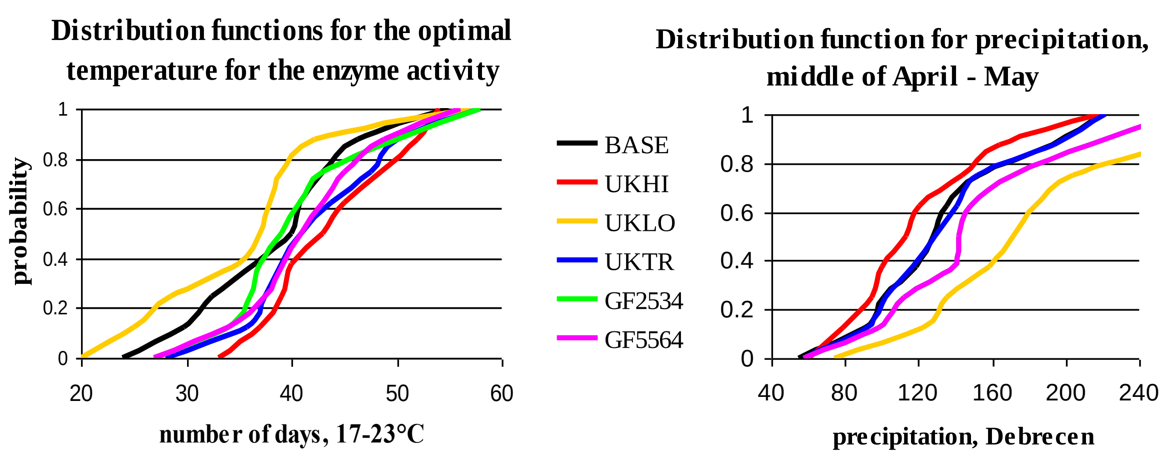

Figure 5 Examples of winter wheat quality factors, comparison of climate scenarios

Based on the results on Figure 5 we can conclude that climate change might be in favour of the plant in this sense. Only one of the equilibrium scenarios is showing worse circumstances in each case. Thinking of the quality factors in the future we can be optimistic, but we should not forget the increasing frequency of extreme events which make the development of the plant before this period very unpredictable.

3.3 Analyzing climate needs and production

The effects of climate have considerable impact on crops yield; its variability is increasing with the variability of meteorological parameters, especially with shortage of precipitation. We decided to do some further research in analysing the reasons and the prospective yield. The production risk has increased especially in the observed region. Comparing the first three (1951-70, 1961-80, 1971-90) and last two (1981-2000, 1986-2005) time intervals it can be seen on

Figure 6 that the expectation of winter wheat yield became decreasing while the deviation was increasing at the beginning of the eighties. The same was detected for maize yield, as well.

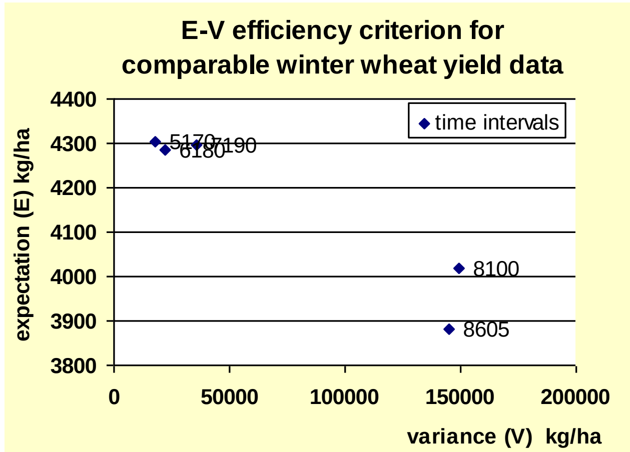

Figure 6. *E,V*-efficiency method for wheat yield in Debrecen region, comparing time intervals

We have also compared the simulated average maize yield for different climate scenarios (Table 6). It can be seen that the two equilibrium scenarios predict very different quantities, UKHI much lower yield, UKHI predicting no change, for these scenarios predicting for the thirties we can expect lower yield, but increasing yield for GFDL5564, in average. The standard deviations are around the same (not very low value), so the coefficients of variation are not changing much. These results with their variability need further investigations.

Table 6. Comparing the estimated maize yield for different climate scenarios (kg/ha)

SCENARIO	**BASE**	UKHI	UKLO	UKTR3140	GFDL2534	GFDL5564
average maize yield	**9429.65**	5831.87	9806.97	7101.35	7941.55	10600.19
st.deviation	**2877.95**	2048.57	2497.38	2372.81	2557.62	2887.04
CV	**0.31**	0.35	0.25	0.33	0.32	0.27

Analysing how the production risk has changed with time we decided to search for the reasons. Climate change impact can be very different in different phenological phases of the plant. We studied the climatic needs of winter wheat and the harmful extreme values of the meteorological parameters through the most important periods of its development. We made calculations for the sowing-emergence phenological phase, the stem elongation – spikelet initiation period and the anthesis-grain filling phase. The climate scenarios show great variability in the frequency of the extreme temperature values, so besides studying the changes in average we have counted the number of extreme values, too. The comparison results based on the temperature data and the plants need through the periods of its growing, supports the simulation results that the starting dates of the periods of growing are expected to shift to earlier dates. The precipitation requirement in sowing-emergence phenological phase will be fulfilled according to the results of almost all of the climate scenarios. Winter wheat is very sensitive to meteorological

circumstances when it is producing the most of its organic substances, in the stem elongation – spikelet initiation period. The climate scenarios show great variability in the frequency of the extreme values, but future does not show significant change in the average. We have detected a little higher temperature in May, which is good for the plant and also in June, when it is harmful for it. In this period precipitation is of higher importance than temperature. The forecasted precipitation values are not very good for any of the climate scenarios we used. The third period for which we made calculations is the anthesis-grain filling phenological phase, when the plant develops its generative organs. In this period we can be quite satisfied with the forecasted values we got. The scenarios do not show extreme temperatures too many times, so this period is in favour of the plant. In the case of corn plant we can also conclude that the average values are not changing very much, but the deviation of the values is pretty high. It is no doubt that the anomalies have been becoming more and more frequent, the future is very unpredictable.
In regions where temperatures are near the optimum, under current climatic conditions, such as those prevalent in Hungary, increases in temperature and less precipitation would probably lead to decreased yields. With appropriate agrotechnical interventions we can control and avoid the negative effects of the meteorological circumstances and benefit from the positive effects.

3.4 Modeling, searching for adaptation strategies

Thinking of sustainability we face several decision problems in agriculture: analysing the impacts of change and finding the possible adaptation response are needed to be investigated. Considering the uncertainty, we have to concentrate on searching for prevention strategies in order to avoid the negative effects of the extreme weather events and strategies for improving the production, if possible. We decided to analyze the future crop production using a crop model, different agrotechnical circumstances and the same climate scenarios.
As we have seen that the shortening of the periods of growing in the future is very probable, we were interested whether changing the sowing date can decrease the production risk, increase the yield (or not) in the future. In the case of corn the simulations were run for the 25th of April and four other dates: one and two weeks earlier and one and two weeks later. We examined by comparing the results, how the lengths and the starting points of the growing periods of the plant change and whether the changing conditions decrease the yield or not. Results show, that the ripening day of the plant has shifted with the shifting of the sowing date. In case of the one week earlier sowing the ripening date was simulated to be 4 days earlier, in case of the two week earlier sowing for almost two weeks and in the one and two weeks later case for 5-6 days in average. For the earlier sowing dates the variability has increased, especially for the two weeks case, but for the later sowing dates not. The probability of increasing biomass and grain mass quantity of maize is high for the two weeks earlier sowing date, which could mean that for decreasing the production risk and uncertainty the two weeks earlier sowing might be a good adaptation strategy. This strategy is good for the plant because its growing period could avoid the most unfavourable drought condition, enhance its ripening is more probable.
In case of winter wheat we defined the basic sowing date in the simulation process for the 20th of October, and also have examined the simulation results for the one and two weeks earlier and later dates. The results are very promising for the two weeks earlier sowing date for both biomass and grain mass quantity, again. For winter wheat the shifting in sowing dates can be hardly seen at the end of the growing period. The more significant influence on the ripening date

has the two weeks earlier sowing, which has the highest variability, as well. The result we got by the simulation for biomass and grain mass averages, has not change significantly, but in some cases we got very high maximum values for the estimated yield. The duration of the grain ripening is significantly shifting with the sowing dates in case of winter wheat, especially for the two weeks earlier case, where the simulation shows the shortest grain development duration (significantly the same for each sowing date in case of maize).
The model can be also used to trace when the plant is suffering from precipitation shortage in its development and to see whether it is worth irrigating or not. Comparing runs without treatment and runs with irrigation, it was found that maize biomass and grain levels increased significantly for all scenarios. (Erdélyi et al, 2009).
Studying the changes of the length of the phenological phases can help us in the further research of climate change impacts. We can use the new starting dates for an alternative approach of climate needs of the plant; we can check whether they are satisfied in the most important growing periods or not.

4. CONCLUSION

Climate change has already considerable impacts on the environment, human health and society. Climate change affects agriculture in many direct and indirect ways. Considering the possible changes we have to answer many questions in order to prepare for the future. The key challenge is how the basic research results and progresses can be linked to each other in different fields. The results of spatial climatic analogy research are also usable in agriculture, spatial planning, environment and conservation; they are helpful for policymakers and they open a new window to the analysis of climate change effects. The conclusion about effects of climate change leads to find adaptation strategies, to open new land use possibilities which can support mitigation. The adaptation means changing support systems, crop patterns, and climate change policies.
The calendar of the nature, together with the development process of plants is changing. The starting dates of the phenological phases of plants are valuable indicators of climate change, because they are sensitive to temperature and easy to observe. Results indicate that short-term adaptation of agriculture may include changes in crop varieties or sowing dates, may be applying irrigation. If sowing dates would not change then simulation modeling show that the phenological phases might be shorter and occur earlier as a result of warming temperature. The application of regional climate models has been becoming more and more often focused. It may be the basis of action plans of the response, prevention and adaptation strategies of given regions. Applying crop models we can do many virtual experiments on very low cost and in very short time. The results can help the scientists in improving new, drought resistant, better quality and more successfully adaptable species, which can benefit from increasing carbon-dioxide. Because of the high variability of the meteorological parameters and more frequent extreme values, we have to make an effort in improving varieties which are not very sensitive to the shortage of their needs.
We intend to point out, that studies about different circumstances in agriculture and interdisciplinary, collaborative research projects are very much needed. Models can help us in designing experiments and estimating the present and future characteristics of the investigated system, to prepare agro-technological advising for plant growers, so they are very adequate tools in climate change research. But later – in the second half of the century – we could have

problems with the interpretation, as the heat unit values are going out of the normal scope, will be almost double for maize and 50% more for winter wheat. It is problematic also in simulation modelling, as we can get easily false results. In modelling work it is necessary to use daily data, but also reliable meteorological data (Fodor and Kovács, 2005) for reliable results. Hungary is situated in the Carpathian basin with special sensitivity to climate change (Bartholy et al., 2007). That's why, regional climate models from the newer global models, generating meteorological data for the end of the century are still under adaptation (Horányi, 2006) and impossible to use. With this paper we would like to call the attention to the importance of creating well-designed descriptive-forecasting systems, as well as defining the optimal preparing and response strategies to the conditions in change. Simulations give us a great opportunity in planning adaptation strategies in order to decrease the uncertainty the change could bring and also to concentrate on how to benefit from climate change. Using informatics and electronics agricultural production can be controlled through a complex system, which integrates biological, technological and ecological factors.

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