Climate change and winter wheat: possible impacts and responses

PhD theses

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Corvinus University of Budapest, Department of Mathematics and Informatics
2008

Doctoral School: **CORVINUS UNIVERSITY OF BUDAPEST**
Landscape-Architecture and Decision Support Systems

Field: **Interdisciplinary Agricultural Sciences**

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The applicant met the requirement of the PhD regulations of the Corvinus University of Budapest and the theses are accepted for the defence process.

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INTRODUCTION AND AIMS

It is evident that climate is changing nowadays. In Hungary, results show that we must count with an increasing temperature and a decreasing precipitation. The possible future climate – as it is predicted by the scenarios – would be similar to the present climate of South-Southeast Europe. Rising temperatures may allow earlier sowing dates, enhance crop growth and increase potential crop yield. On the other hand, rising temperatures increase the water demand of crops. In addition, extreme weather events such as droughts and floods have increased, which implicates many serious problems in agriculture. Climate and its change determine agricultural production basically. Information about weather and predicting the potential climate change is of great importance all over the world. 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. The results have to be spread and applied. There are important questions about effects on the plant phenology, yield and the adaptation strategies for avoiding the damages.

In this work we have analysed the climate change impacts on winter wheat, because it is one of the most cultivated plant in Hungary. The aim of the research was to learn the possible changes and their effects to the plant phenology and yield as much as possible based on comparative statistical analyses and crop modelling results. For the simulation we used the 4M model which is based on CERES model, adapted to Hungarian circumstances by applying the results of Hungarian scientists.

We planed to:

- study if the production risk between 1951 and 1990 has increased independently to the rate of risk aversion of the decision maker, and whether the situation became worse after that period of time. We have also analysed how the rate of increase has changed in the observed regions;
- analyse statistically whether the climate needs of winter wheat will be satisfied or not in its important growing periods and how does the frequency of extreme weather events of its development change comparing the data of different climate scenarios for the middle of the century and the observations of their reference period;
- examine how the lengths and the starting points of the growing periods of the plant change using the method of modelling. For this purpose, as a path-finder, we applied the 4M model breaking a new ground for its using in other national climate change impact research;
- give predictions for winter wheat production running the simulations for climate change scenarios;
- compare the simulation results for different sowing dates in order to find an adaptation strategy to the changing conditions.

We tried to present the results by pointing at the adaptation possibilities, because living under changing climate conditions we need to have tools to describe and predict the impacts. Considering the possible changes we have to answer many questions in order to prepare for the future. We intend to underline that studies about different circumstances in agriculture are very much needed for understanding the advantage and disadvantage of the change. We are convinced that interdisciplinary and collaborative research projects are required also in Hungary in order to help us prepare for the future. Our approach was planned to be a slice of a huge national project.

MATERIALS AND METHODS

Climate needs of winter wheat and its phases of development

The effects of climate have considerable impact on winter wheat yield; its variability is increasing with the variability of meteorological parameters, especially with shortage of precipitation. Climate change impact can be very different in different phenological phases of the plant. With appropriate agrotechnical interventions we can control and avoid the negative effects of the meteorological circumstances. The most important periods of plant development were defined according to Zoltán Varga-Haszonits: we analyzed the *sowing-emergence* phenological phase, the *stem elongation – spikelet initiation* period and *the anthesis-grain filling* phenological phase.

The grains need to have wet soil after sowing, so it is very important to analyse precipitation availability in November, but also in spring when winter wheat starts growing, because then it needs wet soil again. 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 shortage of precipitation can be seen in leaf development. The other problem is that too wet soil and high evapotranspiration produce lower yield. In this period precipitation is of higher importance than temperature. The third period for which we made calculations is the anthesis-grain filling phenological phase. In this period the plant develops its generative organs. With lower amount of precipitation the plant may produces infertile florets or the florets may not develop as required, so the winter wheat production becomes smaller. Analysing if the temperature requirement is fulfilled gives us also valuable information. It is very important especially in the stem elongation – spikelet initiation period, when the plant is producing the most of its organic substances and also in the anthesis-grain filling phenological phase, in which period the plant develops its generative organs. It is important to examine the tendency of temperature values in May, when increasing temperature is good for the plant and also in June, when it is harmful for it. The climate scenarios show great variability in the frequency of the extreme temperature values, so besides studying the changes in average we decided to count the number of extreme values in order to predict the possible effects on the length of the of the growing periods.

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.

Climate description of the research location

Production risk analyses have four locations, which are far from each other and different in meteorological circumstances: Győr-Moson-Sopron county is in the west with more precipitation, Bács-Kiskun and Fejér county describing the regions from the middle of the county and Hajdú-Bihar county which represents the warmer and drier East-Hungarian agricultural regions. The case studies for climate change impact analyses are presented for Debrecen region, comparing the results for different climate change scenarios downscaled to Debrecen and historical data for their reference period (1961-90). We examined the predicted changes for the vegetation period and the yearly accumulated precipitation amount to highlight the trends of climate change. Our case study showed that the sum of the temperature averages increases by time in the past and the scenarios predict even more drastic increase. We compared the sums of precipitation for the growing season of winter wheat, too. We can see a slow decrease of the accumulated precipitation amounts for this period (October-July); the scenarios predict slightly smaller values in the future. This might be good for winter wheat, because its yield grows with less precipitation in some periods of growing. But analyzing the observed and the future weather using climate scenarios we see 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 wheat.

Data and data management software

Weather data

Climate scenarios can be defined as relevant and adequate patterns of the climate characteristics in the future. During our research we applied the principles defined by IPCC (Intergovernmental Panel on Climate Change) and we used some of the most widely accepted scenarios presented in international reports. Our work is based on Global Climate Models downscaled to Debrecen. We used the climate models of two meteorological institutes:

- Scenarios GFDL2535 and GFDL5564 have been created by Geophysical Fluid Dynamics Laboratory (USA) with consideration of CO2 increase in atmosphere. The only difference between the two scenarios is, that the latest has a finer resolution;
- UKHI (high-resolution equilibrium climate change experiment), UKLO (low-resolution equilibrium climate change experiment) and UKTR3140 (high-resolution transient climate change experiment) are three very different scenarios worked out by United Kingdom Meteorological Office (UKMO);
- Scenario BASE which is the base of the UKTR scenario, with the parameters of present days.

For comparison we applied the daily meteorological data from the monitoring database of OMSZ (*Hungarian Meteorological Service*) for the reference period of the climate scenarios, namely the time interval 1961-90.

The KKT Climate Research Database Management Software and the production data

In order to collect, organize, manage and search databases for climate change research in a handsome and friendly way a special data management system was needed. An indicator-search software KKT has been developed at Corvinus University of Budapest, Department of Mathematics and Informatics. Frequency calculations were made with the help of this program and by MS Excel using the daily precipitation, minimum and maximum temperature data forecasted by climate scenarios. Using the KKT Software we can calculate the number of the years when the needs of the plant are satisfied (or when not) and it can give us information about climate change indices, as well. These results can give us information for predicting extreme conditions. The system allows researchers from various disciplines to set up special databases for specific studies as well as having the capacity to filter and aggregate data from different perspectives.

Beside the meteorological databases we used, it contains the crop production data we used for risk analyses. The production data are from the Agricultural and Environmental Statistics Department of the Hungarian Central Statistical Office (KSH) for all counties, for the time interval 1922-2005.

The ROPstat statistical software package

For statistical evaluation of the results we have used the ROPstat Package, the comparison results are given on significance level of 95%.

The applied methods

A new stochastic efficiency method for detection of the production risk

For analysing the production risk the data of the Hungarian regional yearly crop results of winter wheat were applied. The yield data were fitted by nonlinear regression. Then they were corrected by *MS Excel®* with the help of *Phillips*-method in order to make them comparable. The subjective expectation, as well as the subjective standard deviation (E_s, D_s) were calculated based on experts' estimations. The corrected data were defined by $y_i^{korr} = f(x_{akt}) + \varepsilon_i$, where ε_i denotes the residuals of the regression, while $f(x_{akt})$ denotes the value of the regression function at the right endpoint of the regression domain.

The values y_i^{korr} can be weighted by p_i the following way: based on experts' estimation the probability of the occurrence of the year i is calculated. It is obvious that $\sum_i p_i = 1$. Because of the shortage of information we used the same p_i for each year in this work. Denote by E_t and D_t the expectation and the standard deviation of y_i^{korr}, respectively. The current data can be gained as follows:

$$Y_i + \frac{y_i^{korr} - E_t}{D_t} \cdot D_s$$

It is evident that $E(Y_i) = E_s$ and $D(Y_i) = D_s$. The subjective distribution functions were calculated based on experts' estimations.

As the exact personal risk aversion was not known, we used the widely applied negative exponential utility function $U : w \mapsto U(w) = 1 - \exp(-cw)$. The most important property of this function is that its absolute risk aversion r_a is constant while its relative risk aversion r_r is linearly dependent of wealth w

$$r_a(w) = c \qquad\qquad r_r(w) = cw.$$

Three efficiency criteria were considered, namely: the stochastic dominance based on the subjective distribution functions, the $E,V-$efficiency and the criterion based on the utility function. However, the results have not fulfilled all of our expectations. The risk increase was finally proved by a recently simplified variant of the general stochastic dominance criterion.

Modelling by the 4M crop model package

Models have played an important role in scientific research for a long time. The crop models simulate the soil-plant-atmosphere system with the help of computers. They can be useful tools in solving agricultural and environmental protection related problems, so therefore effective tools also for investigation the future circumstances without the need of having expensive and long experiments. In our crop model research we used the 4M model, which has been developed by the Hungarian Agricultural Model Designer Group. It is a daily-step, deterministic model that simulates the water and nutrient balance of the soil, the soil - plant interactions and the plant development and growth. It contains several models to describe the physiological interactions of soil - plant systems and offers a possibility of building up different system models for the specific purposes of the users. The CERES model was chosen to be a starting point and the 4M was adapted to Hungarian conditions using the results of Hungarian scientists and Hungarian soil data. The simulations were performed for meteorological data given by climate scenarios and the historical data of their reference period, as weather inputs. For this purpose, we focused on breaking a new ground for using it in case of winter wheat and as a path-finder to help the application of the 4M model in other national climate change impact research project. In this effort we were supported with the help of the model developer Nándor Fodor, who has been improving the model parallel with our work. We used this model for analysing the changes due to climate change in the phenology and the yield of the plant. We applied it in searching for adaptation strategy, as well.

First we have compared the simulation results of the reference period 1961-90 and the historical production data. We can conclude that the model predictions are very close to real data. In the case studies we compared the simulation results of the UKTR3140 scenario with the simulation results of the historical data of reference period 1961-90, both for Debrecen with the soil type meadow-chernozem that is characteristic of this region. The land use type was crop rotation wheat-corn-wheat-…, with yearly change of the types Mv-Irma and Dekalb 471. The agrotechnical setting was the usual with fertilising before sowing and in spring for winter wheat and in autumn and spring for corn. The sowing date was set of October 20th for winter wheat and April 25th for corn. The analyses of the length of the phenological phases were based on the periods defined by the 4M models. The results were collected in MS Excel sheets, analysed by a statistical program package and presented on diagrams.

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 and even to carry out economical analyses, so they are very adequate tools in climate change research.

RESULTS

The first step of our research was to examine the production data of winter wheat by analysing how the production risk has changed with time. The next step was to study the climatic needs of the plant through the most important periods of its development.

Risk analysis

First we have studied the winter wheat production data for four selected counties. The observed time interval was 1951-2005, which was split into five twenty-year intervals for the later analysis (1951-70, 1961-80, 1971-90, 1981-2000 and 1986-2005).

Observing the graphs of winter wheat yield we can recognize that beside the yield loss caused by the Hungarian political situation at the end of the eighties, the deviation of the yield started to become greater yet at the beginning of the eighties. On the basis of experts' estimations we calculated the comparative yield data. First the subjective distribution functions are defined for the four counties and for the five times twenty years. The most evident risk increase of wheat production was in the last two time intervals in all the four observed counties. The subjective distribution functions are shifted left for these time intervals almost pointwise. The same can be proved with the E,V-efficiency method (while the expectation was decreasing, the deviation was increasing). In every case we got that the situations become worse with time, though we get no ordering for the first three time intervals for any of the observed counties. The disadvantage of the method based on utility criterion is, however, that it can make an order for fixed absolute risk aversion, only. For more information we should call for the more general stochastic efficiency criterion.

Comparing the first three (1951-70, 1961-80, 1971-90) and last two (1981-2000, 1986-2005) time intervals, applying the stochastic efficiency criterion we proved that the risk of wheat production has increased in all the four counties. The order can be seen also in comparing the first three time intervals for Hajdú-Bihar and Bács-Kiskun county, independently from the rate of absolute risk aversion r_a. The rate of increase became greater in Bács-Kiskun and Fejér county. In the Debrecen region, moreover, the increase is quite high and occurred even faster.

Climate needs of winter wheat through its phenological phases

Climate change might be good for the plant, because it can easily stand hot and dry conditions, moreover, in some phases of development the precipitation can be even harmful for it. Quite high risk increase of wheat production was detected in Hajdú-Bihar county which capital is Debrecen. Moreover, the risk increase was here even faster than in other observed counties, especially after 1990, so the risk increase in wheat production gave us many questions, as well. We wanted to see what we might expect in crop production by analyzing the precipitation and temperature needs of winter wheat. By comparing the results of the same six climate scenarios and their reference period (1961-90 time interval), we examined, whether the needs of winter wheat would be satisfied or not. We wanted to see what climate scenarios predict for the most important growing periods of winter wheat.

The periods we analyzed are the sowing-emergence phenological phase, the stem elongation – spikelet initiation period and the anthesis-grain filling phenological phase. With the help of the Klíma KKT software we reveal how the appearance of extreme values of the outlined indicators has been changing with time. It is no doubt that the anomalies of the indicators have been becoming more and more frequent. Moreover, based on the most widely accepted GCM scenarios we pointed out that such kind of extremes are expected to become further more frequent in the next 30-50 years. We saw that increasing frequency of extreme weather events is probable, though the future is very unpredictable.

The precipitation requirement in *sowing-emergence* phenological phase will be fulfilled according to the results of almost all of the climate scenarios. This phenological phase lasts usually 12-15 days, but can be shorter than a week when it is warmer than $14\,^0C$. Our results show, that this will happen quite often in this period. This period can last longer than 20 days with temperatures lower than $7\,^0C$, which might occur fewer times in the future. The temperature requirement in the sowing-emergence period, the experienced 9-12,5 ^0C will be fulfilled according to the results of almost all of the climate scenarios except two, which predict warmer circumstances.

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 average temperature in this phenological phase used to be 13-17 ^0C in the past. 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. The precipitation need of the plant is 75-160 mm. With lower amounts it may produces infertile florets or the florets may not develop as required, so the winter wheat production becomes smaller. In this period we can be quite satisfied with the forecasted values we got. The temperature need is 18-20 ^0C , with temperatures lower than 16 ^0C this period lasts longer than 45 days, with temperatures higher than 20 ^0C it can be shorter than 40 days. The scenarios do not show extreme temperatures too many times, so this period is in favour of the plant.

We present the results also by giving the needed amounts of precipitation and the predicted average values with their variability measures. The averages show us the same conclusions as above, but the measures of variability are unfortunately too high. This means that the standard deviations are high and the future is very unpredictable.

The quality factors

. It is very important to learn about factors that influence the wheat yield, as much as possible. However, it is also very important to examine the quality factors as well. One of these indicators is the optimal number of spikelets. Their development is the best if the average temperature is around 15 ^oC in the second half of March and in the first half of April. We have counted the number of the days with 14-16 ^oC average temperature in this period. We can conclude that climate change might be in favour of the plant in this sense. The quality of the grain depends on its gluten and starch content. The gluten content of wheat grain is a determinative quality factor especially in baking industry. It depends on the enzyme activity of the plant which is influenced by the temperature. The optimal temperature for the enzyme activity is 17-23 °C**.** We have also counted the number of days with optimal temperature for the enzyme activity. Results show that 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.

Modelling case studies

We decided to analyze the future winter wheat production using a crop model and the same climate scenarios. 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. We continued our research by using the model 4M.

Phenological phases of winter wheat

Considering the the extreme temperature values influencing the length of the periods of growing, we were interested in how the starting points of the growing periods of the plants can be shifted in order to make it of benefit to the production. For that purpose we used the simulation method based on the 4M model. In summary it can be said that phenological phases of winter wheat shortened and happened earlier as a result of temperature increase, especially in the first period of growing. Harvesting is predicted to be eight days earlier (in average) in the future which means about one day in ten years. We got the results by comparing the historical data and the UKTR scenario. Modelling can help us finding a good strategy in preparing for the future.

Searching for an adaptation strategy

In order to simulate the yield, first we compared the model results of winter wheat yield and the real data for period 1961-90. We can conclude that the model operates with small variation and the predicted yield is close to the measured ones. We used the model for finding an adaptation strategy for increasing the yield with changing the sowing date. The shortening of the growing periods in the future is very probable. So we were interested whether we can decrease the production risk or increase the yield or not with changing the sowing date. Comparing the results for the period 1961-90 and simulated values for the UKTR climate scenario we can say again, that climate change might be good in cereal production of Hungary. The simulation result for the climate scenario gives about 18% of 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. 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 one and two weeks earlier and later dates. The 4M model was run for the same weather data as before, for the same location, but with these input sowing dates.

Considering the uncertainty from our previous results, 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 have also analyzed the grain development and grain mass. 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. The production results are very promising. Analyzing the results we can see not only the shifting of the period of grain development, but also that climate change may have a good influence on grain mass of the plant. The average production is predicted to be higher in the future than before, the same holds for the maximum production in the two weeks earlier case. But the coefficient of variation is unfortunately also higher than before, which means increasing risk and uncertainty. In summary we can say that the two weeks earlier sowing might be a good adaptation strategy. This strategy is good for the plant because the growing period could avoid the most unfavourable drought condition; enhancement of ripening is more probable.

The list of the new results

Living under changing climate conditions we decided to analyse the changing phenology and production of winter wheat. For the comparison we used six of the most accepted climate scenarios and the historical meteorological data of their reference period. The location of our case studies was Debrecen, which is of great importance in Hungarian agricultural production.

- Using the production data of 1951-2005 we have proved with a general stochastic dominance criterion that the risk of winter wheat production in four Hungarian counties has increased independently to the risk aversion of the decision maker.
- We have shown that the quality of winter wheat might be better in the near future.

- In search of the reasons, we analyzed the temperature and precipitation needs of the plant in each phenological phase. We have shown that climate needs of winter wheat will be fulfilled, but with increasing uncertainty in production.
- Based on the modelling results we can conclude that the starting points of the phenological phases are expected to shift to earlier dates, especially in the first period of growing. Harvesting is predicted to be a day per ten years earlier in the future.
- The predicted yield with the 4M model is very close to the real data. The simulation using the UKTR scenario for Debrecen predict about 18% of yield increase for 2031-40 compared to 1961-90, but with increasing variance.
- Searching for adaptation strategy we found that the simulation results are very promising in case of the two weeks earlier sowing date. The average yield increase is close to 6% for the two weeks earlier sowing date.

In summary we can say that modelling can be well applied in planning adaptation strategies. This means that we can decrease the uncertainty the change could bring and we can concentrate on how to benefit from climate change.

CONCLUSIONS AND SUGGESTIONS

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, in damage prevention of given regions. In the aspect of efficient plant growing it is very important to raise the harmony of biological, ecological and agrotechnical factors. To achieve this, scientists can choose from different possibilities:

- simulating the environment, analyzing the processes of the ecological systems (experiments in greenhouses, with guaranteed ideal circumstances);
- searching for analogues in the past using the comparison of the historical data and the predictions for future;
- comparison analyses of the climatic needs;
- mathematical modelling (simulation, risk analyses, etc.);
- experts evaluations which are based on observations, experience and statistical analyses.

We examined the effects of climate change on winter wheat, which is one of the most important plants in Hungary; we traced the possible changes of production risk, expected yield and phenology. From the possibilities mentioned above we used all, except the first (for which we didn't have opportunity). The increase of the production risk proves the fact, that the climate has already been changing (we can already experience the effects). The predicted meteorological parameters do not change much in the near future – as it do up to the end of the century – but they can have serious impacts on the agriculture. The more frequent the extreme weather events are, the more we can be convinced of uncertainty. There are lots of questions about the change itself and also on the possible impacts. For planning the response strategies we need wide range multidisciplinary approaches and collaborative research work on both national and international level.

What can we do? It is necessary to analyze more factors, their effects and their combined influence at the same time. Using informatics and electronics agricultural production can be controlled through a complex system, which integrates biological, technological and ecological factors. Beside the statistical analyses of the observed and predicted meteorological parameters, other methods have to be involved, as well. One of these methods is simulation modelling. Applying crop models we can do many virtual experiments on very low cost and in very short time. They are able to operate with meteorological parameters of climate scenarios, too.

Though we can hear mostly about the negative effects of climate change, it may bring also positive effects. Analyzing the quality factors of grains and the climatic circumstances of anthesis we give examples of its positive influence. The level of the effects could be expressed by words *sensitivity* and *vulnerability*. Sensitivity is the degree to which a system would be affected by a particular change in climate or climate-related variable. (E.g. a change in agricultural crop yield in response to a change in the mean, range or variability of temperature.) Different systems may differ in their sensitivity to climate change, resulting different levels of impact. Vulnerability defines the extent to which a system is unable to cope with adverse effects of climate change, including climate variability and extremes. It depends not only on the sensitivity of a system but also on its adaptive capacity. *Adaptive capacity* is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, as well as to take advantage of opportunities, or cope with the consequences. Adaptive capacity can be an inherent property of the system, i.e. it can be a spontaneous or autonomous response. Alternatively, adaptive capacity may depend upon policy, planning and design decisions carried out in response to, or in anticipation of, changes in climatic conditions. This means that not only the plants can cope with the changing conditions (which might be a very long procedure), but we can help in introducing optimal interventions. Working out adaptation and response strategies gets much interest nowadays, because of more frequent extreme weather events. After having learnt the probable future frequencies of the temperature limit which influences the length of the phenological phases, we can do further investigations, more precise plant and location specific calculations in order to elicite the production risk.

Crop development and the degree of how crops stand the winter depend very much on the right timing of sowing. It can guarantee better adaptation of the plant to the changing condition. Early sowing has other advantages, as well. If the plant is strong enough before the beginning of winter, it can better benefit the winter precipitation, so its development is supported more in spring. Besides that, meteorological circumstances are much better on the field in early autumn.

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. 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.

As modelling is very appropriate for climate change impact studies, it can help us in analyzing the changing harvest index, but also in estimating the present and future characteristics of the investigated system. Designing simulations, virtual experiments are very useful in practical applications, because the model can be used to prepare agro-technological advisory systems for farmers including fertilization, irrigation, etc. 4M model has a modul which can carry out economical analyses, as well. It has also a possibility of analyzing the impact of different CO2 levels. The results can help the scientists in improving new, drough resistant, better quality and more successfully adaptable species, which can benefit from increasing carbon-dioxide. We have to make an effort in improving varieties which are not very sensitive to the shortage of their needs and the variability of the growing season circumstances even if the production is lower than it can potentially be expected. This way of thinking could give a chance of decreasing the production risk and reducing the damages.

Models play an important role in scientific research. Applying crop models we can simulate plant development with the help of computers. Besides research, models are effective tools in education for learning how to solve agricultural and environmental protection related problems. Students at the Corvinus University of Budapest are lucky to learn about modelling, designing 'zero-cost' virtual agricultural experiments and enjoy the challenge of enhancement to gain the system oriented complex thinking. The practical applications of modelling and introducing the 4M package are in the frame of the lectures of decision support and technical advisory system at the Department of Mathematics and Informatics.

Living under changing climate conditions we have to answer many questions. Our duty in the future is to find out the possible ways how the positive effects of climate change can be utilized and, at the same time, how the negative effects can be prevented, avoided or reduced. Risk caused by climate change should also be managed with coordinated adaptive strategies. Researches on impacts and adaptation possibilities have to support the decision makers in policy as well as in agriculture with information and plans. There is a wide scientific consensus that if these changes continue, significant damage of global ecosystems, food production and economies will ensue, so further interdisciplinary, collaborative research projects are very much needed all over the world.

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