THE AGRO-ECOLOGICAL POTENTIAL OF HUNGARY AND ITS PROSPECTIVE DEVELOPMENT DUE TO CLIMATE CHANGE

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Abstract The climate change is one of the most relevant challenges that agriculture is facing in Hungary and all over the World. It is very difficult to express the agriculture related effects of the climate change in numbers and figures, since the atmosphere-soil-plant system is very complex. A crop simulation model was used for exploring the prospective effects of climate change on the agro-ecological potential of Hungary. The model was linked to a detailed meteorological and soil database of Hungary to provide the required input data. Simulations first employing measured meteorological data then combining them with a climate change scenario were used to determine the present and the prospective agro-ecological potential of Hungary. The simulation results indicate that the Hungarian agriculture can not avoid the effects of climate change, and unfortunately the majority of these effects would be negative. The yields of the spring crops will prospectively decrease while higher yields might be expected for the autumn crops. The amount of N-based green house gases emitted from the soil will prospectively increase because of the changes in the annual distribution of precipitation. On the basis of the simulation results the role of the autumn crops is likely to become more significant in Hungary. Another alternative for the Hungarian agriculture is to find new crops maybe species of Mediterranean origin that could be profitably grown here.
Keywords: *crop model, crop production, GHGs, nitrate leaching*

Introduction

The Carpathian basin is an important area of crop production in Europe. Around 10 million tonnes yields of different crops are produced here for eight countries, not counting the exports. The majority of the agricultural land in the basin belongs to Hungary. Unfortunately the animal husbandry gradually fell into the background in the past decades, yet concerning its plant production, Hungary is among the best on the world regarding the average yields of her main crops. This result could be primarily owed to the outstanding natural endowments of the country: the majority of soils naturally have high water storing capacity and high nutrient content (Kovács et al., 2005) and the climate is favourable to many agricultural crops. Considering the performance of crops production in Hungary it is not a negligible factor that farmers are supported by such advisory systems as the RISSAC-RIA cost-effective and environmentally friendly fertilizer recommendation system (Csathó et al., 1998) that was awarded with the Hungarian Innovation Grand Prize in 2008.

One of the most important questions that the Hungarian agriculture faces is whether this performance could be maintained in the future. More and more observations prove that the Middle-European climate is changing faster than in any other period in the past. Even the most cautious climate change scenarios predict more than 1 °C temperature increase (the average of different scenarios is 3 °C) combined with a decrease of precipitation by the end of this century. Using the method of spatial analogies (Adams

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et al., 1998) it is quite easy to find those parts of Europe whose present climate is similar to the future climate of the Carpathian basin. The analogous locations of the Carpathian basin for 2030, 2060 and 2090 could be found in Northern Bulgaria, Northern Greece and Northern Africa (Horváth, 2008). Since agriculture is very much dependent on the climate it is no small wonder that the pattern of agricultural land use is quite different for the present Carpathian basin and for its future analogue, Northern Greece. Winter wheat, maize, sunflower and rape are the basic crops of agriculture in Hungary. Around 85% of the agricultural land is covered with these crops. Will the present way of agriculture sustainable in the future or we need new, feasible but also profitable alternatives for sustainable agriculture in Hungary? Should the present pattern of land use be modified due to climate change and economic changes? There are two main conceptions about the future of the agriculture in Hungary:

- The food production and the processing industry are based mostly on the above mentioned four crops. Despite of the changes the climatic conditions for producing the present basic crops will be given, or even if the conditions became marginal it would be too difficult to change the whole system.
- Approaching the end of this century the climate of this area will become more and more Mediterranean which may open the door for many crops which can not be grown profitably here at present, while the conditions might become marginal for some of the currently dominant crops. For example cotton is grown at 15 % of the agricultural land in Northern Greece. The increase of the fossil fuel prices has turned the attention of many to energy crops. The share of energy consumption of biomass origin has shown a continuously growing figure in the near past. These are only two simple examples that might cause bigger changes in land use in the future in Hungary as well as in the Carpathian basin.

The agriculture related effects of climate change in Hungary would prospectively be mainly negative (Erdélyi, 2009). The climate change scenarios predict several degree increase of temperature by the end of the century combined with a 10% decrease of precipitation for the crucial summer period (Pongrácz et al., 2006). Along with this the probability of extreme weather events such as frost during autumn and spring is expected to increase (Mika et al., 2008). The lack of precipitation during summer, prospectively result in an increase of yield loss and crop fluctuation. New pests, weeds, plant diseases might appear on the scene and the death rate of pests is expected to decrease due to the milder winters. The increase of winter precipitation amount and the more intense rainstorms increase the risk of soil erosion.

It is very difficult to express the agriculture related effects of the climate change in numbers and figures, since the atmosphere-soil-plant system is very complex. On one hectare agricultural land 4 TJ solar radiation and 5-6000 tonnes of precipitation reach the soil surface within a year, and from the several 10 kgs of sown seeds over 20 tonnes of biomass develops. In the meanwhile innumerable faster and slower, important and less important processes take place that more or less influence each other. The crop simulation models were created to give an approximate description of this complex system.

The primary purpose of crop simulation models is to describe the processes of the very complex atmosphere–soil–plant system, including human activities, using mathematical tools (functions, differential equations, etc.) and to simulate them with the help of computers. The ultimate aim of using these models, however, is to answer such production and environment related questions that otherwise could only be answered by carrying out expensive and time-consuming experiments. The main advantage of the simulation models is that they are capable of exactly describing the processes within, and interactions between complex systems. As a matter of course the precondition of using models is that they have to be calibrated and validated using quality experimental data.

Many aspects of the potential effects due to the climate change in Hungary were investigated by several researchers (Ladányi and Hufnagel, 2006; Sipkay et al., 2008; Boksai and Erdélyi, 2009; Diós et al., 2009; Ladányi and Horváth, 2010). The main objective of this study is to enlarge the scope of the previous studies (Harnos, 1996; Kovács et al., 1998; Harnos, 2000) by exploring and estimating the prospective effects of climate change on the agro-ecological potential of Hungary in more detail, more accurately using more sophisticated instruments.

Materials and methods

Meteorological, soil and plant data used in the study

A database of the Hungarian Meteorological Service for the 2002-2006 period including daily maximum temperature, daily minimum temperature and daily precipitation covering the area of Hungary with an 1/6 degree resolution grid was used in the present study (*Fig. 1*).

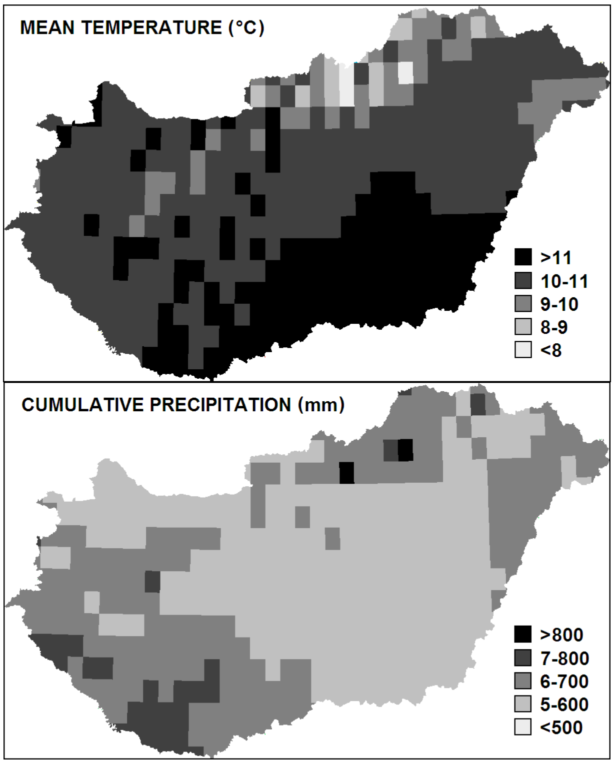

Figure 1. *The spatial distribution of average annual cumulative precipitation and mean temperature in Hungary, 2002-2006 (source: Hungarian Meteorological Service)*

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The database contains the data of 466 rectangles that are considered meteorologically homogenous. Despite of its shortness, the 2002-2006 period seems to be representative for Hungary regarding the average annual cumulative precipitation and the mean temperature as well as the distribution of the individual years within the period (*Table 1*). There is an average year, two years that are slightly under and above the average and two years that are considerably under and above the average regarding both investigated meteorological parameters. The national average of the annual precipitation totals is practically equal for the 2002-2006 period and the 1961-1990 reference period (*Table 1*). Extrapolating the linear temperature growth rate (0,76 ± 0,28 °C/100 year (α=0,05)) that was established based on the 1901-2004 period (Szalai *et al.*, 2005) the average temperature of the 2002-2006 period should be 10,25 ± 0,15 °C that is lower than the observed by a couple of tenth degrees (*Table 1*).

Table 1. *Some of the characteristic figures of the 2002-2006 period, compared to the 1961-1990 reference period for Hungary*

Year / period	(Average) annual cumulative precipitation, mm	Mean temperature, °C
2002	552	11.5
2003	469	10.6
2004	693	10.4
2005	737	10
2006	585	10.8
2002-2006	607	10.66
1961-1990	612	9.96

It could be attributed to the fact that this period was warmer than the average thus it can not be considered to be representative, or it could be ascribed to the direct manifestation of the climate change (local warming) and the linear trend of the temperature growth simply underestimate the actual growth rate at end of the 1901-2004 period. We make the latter likely since for the next 100 years even the most cautious climate change scenarios predict more than 1 °C temperature increase (Bartholy et al., 2006) that indicates that the increase of the average temperature is different from the linear, it is more like exponential. On the basis of all this we used the working hypothesis that the 2002-2006 period was representative for the present climate of Hungary.

The database of the Hungarian soils was created in the Research Institute of Soil Science and Agricultural Chemistry in the early 1990s (Várallyay et al., 1994). It is presented on *Fig. 2* in a form of a map just to demonstrate the diversity and the mosaic character of the Hungarian soils. The database categorizes the Hungarian soils into 22 soil types and characterise each of these types with a representative soil profile. The soil-physical and soil-chemical parameters as well as the water and nutrient balance characteristics of the profiles were measured in situ and were included in the database. This database was used in the study.

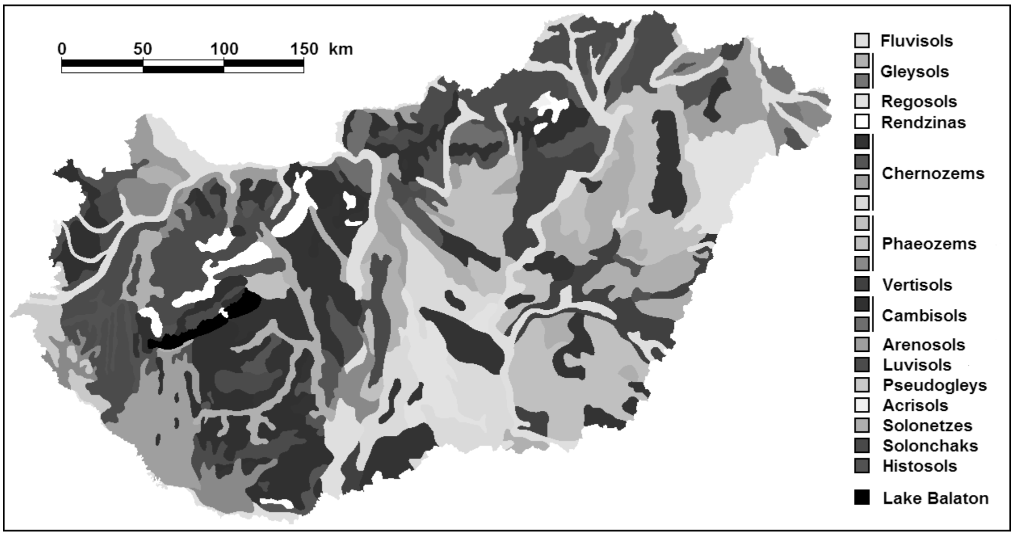

Figure 2. *FAO soil map of Hungary (source: Research Institute for Soil Science and Agricultural Chemistry, Hungary)*

The maximum yields of winter wheat, maize and sunflower in Hungary on a county level were extracted from the yearbooks of the Central Statistical Office for the 1982-2006 period (*Fig. 3*). It is obvious that even the yield of the best county in the best year can not be considered to be equal to the potential yield because none of the counties can be considered to be homogenous from pedological and meteorological point of view, to say nothing of the fact that many of the farmers can not afford to provide the ideal agricultural conditions for plant growth. Since the effect of climate change was the focus of this study it was practical to use the maxima of the yearly maximum yield levels as conditionally potential yields for each crop. Conditionally potential yield is defined as the maximum reachable yield level among the present climatic, pedological and agricultural circumstances.

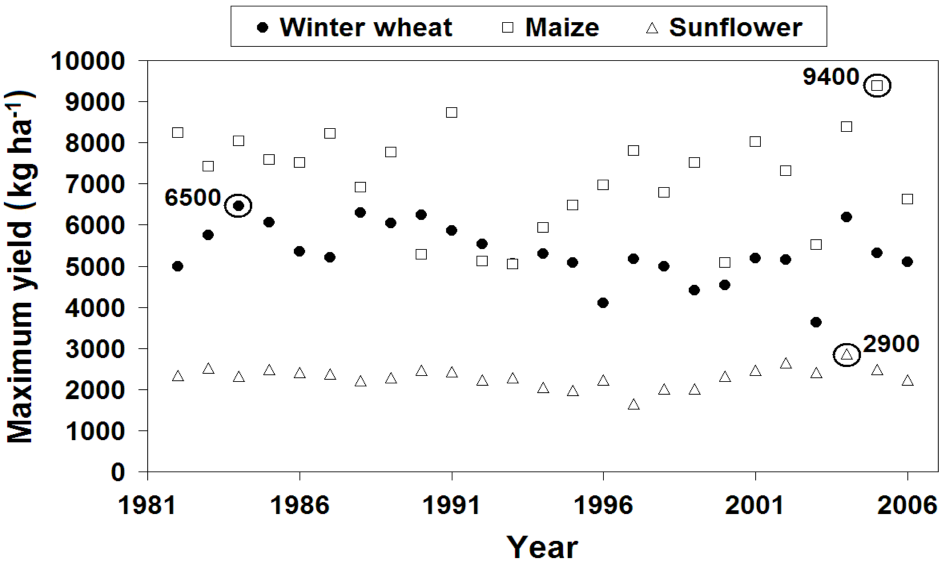

Figure 3. *Maximum yields of the three main crops of Hungary and their maxima in the period of 1982-2006, on a county level (source: Central Statistical Office, Hungary)*

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Methods and tools used in the study

The collected data were fed into the 4M crop simulation model (Fodor et al., 2002; Fodor and Kovács, 2003) so that some indices of the agro-ecological potential of Hungary and its prospective development due to climate change could be quantified. 4M is a CERES (Ritchie et al., 1998) clone. The source code of the CERES model (Ritchie et al., 1994) was used as a starting point for developing 4M. Several studies have proved CERES to be an effective crop model (Kovács et al., 1995; Jamieson et al., 1998). The entire FORTRAN code of CERES was rewritten in Delphi and a user-friendly interface was also developed for the model to ease handling input and output data. 4M inherited all the capabilities of CERES but was developed with several new subroutines and modules in the past years (Fodor, 2006; Fodor et al., 2009).

4M is a daily-step, deterministic (not stochastic) model whose functioning (computation) is determined by the numerical characteristics (parameters) of the atmosphere–soil–plants system. Besides the data that describe the physical, chemical and biological profile of the system, it is also necessary to set its initial, boundary and constraint conditions in the input file of the model. The parameters regulate the functions and equations of the model: the development and growth of plants or the heat, water and nutrient balance of the soil. The initial conditions are the measured system variables at the beginning of the simulation run such as the water or nutrient content of the soil. The boundary conditions are primarily the daily meteorological data such as the global radiation, temperature and precipitation. The constraint conditions cover the numerical expressions of the human activities such as data about planting, harvest, fertilization or irrigation.

Without going into details the outlined functioning of 4M is the following. The model calculates (simulates) the plant growth and development determined by the meteorological, soil and agro-technical conditions given by the input data. It calculates how the plant goes through the different phenological stages, the amount of the new matter produced by the plant via photosynthesis, the partition of the assimilates among the organs, the leaf growth depending on the amount of new matter that arrives into the leaves, and finally the yield. Meanwhile the model also calculates the amount of water and nutrients extracted from the soil by the plant and as a result of this how the soil dries out and becomes poorer in nutrients. If the water and/or the nutrient content of the soil decrease under a predefined limit the plant growth slows down and in serious shortage the plant even dies. In parallel with these the simulation of the processes independent of plant growth also takes place. The model calculates how the precipitation infiltrates into the soil, the amount of nitrate that percolates down under the root zone and the amount of the NO_x gases released from the soil due to denitrification: the former can contaminate the drinking water reservoirs by reaching the water table, while the latter are greenhouse gases.

Since all the required meteorological and soil data were available only the plant parameters were needed to be set. The plant parameters of the model were calibrated so that the simulated yields would be equal to the determined conditionally potential yields (*Fig. 3*) for each investigated crop switching off the effect of any kind of stress factor in the model. In other words we adjusted the crops specific input parameters till the simulated and observed conditionally potential yields were practically the same.

Only the most basic agro-technical applications were taken into account during the simulations (*Table 2*). The amount of fertilizer required by the plants was calculated by

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using the Cost-Saving and Environmentally Friendly Fertilizer Recommendation System of the RISSAC and RIA institutes (Csathó et al., 1998).

After feeding all the input data into the 4M model the 2002-2006 period was simulated for every meteorologically and pedologically different cell of Hungary as if winter wheat, maize or sunflower was grown on that area. This meant 1311 simulation runs for each crops, since the intersect of the maps of *Fig. 1* and *Fig. 2*, the 466 meteorologically distinguished cells and the 18 distinguished soil groups resulted in this many combinations for Hungary. It has to be noted that four of the 22 FAO soil groups that is presented in Hungary were excluded from the study since on these areas (e.g. Gleysols) there is no reason for the existence of simulating crop production not even from theoretical point of view. These soils add up to an insignificant proportion of the country area and are denoted with black colour on the result maps.

Table 2. *Characteristics of the agro-technical applications that were taken into account during the simulations.*

Crop	Planting date (day/month)	Harvest date (day/month)	Fertilization date (day/month)	N dose [kg ha^{-1}]
Winter wheat	10/10	10/07	25/09+05/03	30+60
Maize	25/04	30/09	05/04	100
Sunflower	15/04	20/09	05/04	50

The calculated 5 year average yields, denitrification and nitrate leaching were recorded in every simulation and were represented on maps. Three categories were displayed on each map: under the average, average and above the average areas. The lower and upper limits of the average category were determined by extracting and adding the standard deviation from and to the 5 year country average. Since the simulated denitrification values showed a quite skewed distribution, the median was used instead of the arithmetic mean in this case. Using the simulation results an estimation could be given for the agro-ecological potential of Hungary taking the most important limiting factors such as the climate and the soil into account.

The prospective development in the next hundred years of the above determined potentials due to the climate change was also investigated. The 4M model enables the user to systematically alter the original weather data that is representing the present climate, according to a scenario taking the effect of climate change into account during the simulations. A scenario can be visualized as a table that sets the amount and the mathematical operation for the change of the meteorological data (*Table 3*).

Table 3. *The prospective scale of climate change by 2100 in Hungary*

Parameter	Mathematical operation	Winter	Spring	Summer	Autumn
Temperature (°C)	Add	3.2	2.3	2.8	2.7
Precipitation (mm)	Multiply	1.11	1.04	0.91	0.99
CO_2 (mg kg^{-1})	Fix value	557			

The actual values in the scenario (*Table 3*) were set based upon the studies of Hungarian climate change researchers (Pongrácz et al., 2006; Haszpra, 2008) and

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represent the simple arithmetic mean of several existing prognoses for each meteorological variable.

The effect of the predicted increase of the possibility of frosts during spring and autumn (Mika et al., 2008) as well as the prognosticated increase of rainstorm events during summer (Bartholy et al., 2006) was ignored in the simulations. It was also postulated that there will be no significant changes in the soil conditions as well as in the plant production. It has to be noted the probable achievements of plant breeders in improving more drought resistant cultivars was not taken into account either. This was beyond the scope of this study. However the meteorological data of the 2002-2006 period was used in the study, on the maps presenting the results, for the shake of simplicity, year 2000 and 2100 were indicated denoting that the specific results related to the present or the future climatic conditions.

Results

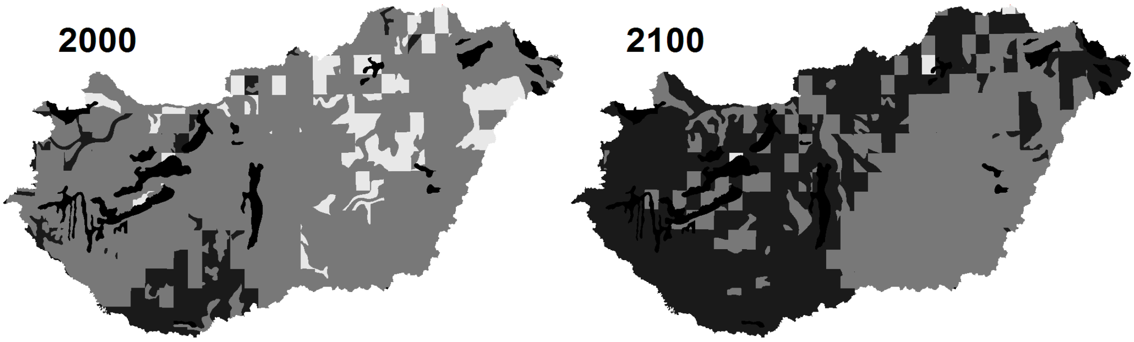
Being a countrywide investigation, the amount of NO_x gases that is emitted from the agricultural areas of Hungary (approx. 45 000 km^2) could be estimated. An average of 1 650 000 kg of N based greenhouse gases of agricultural origin are emitted to the atmosphere in Hungary in a year and this figure is expected to slightly increase by the end of this century independently of the kind of the produced crops (*Fig. 5*).

It is fully visible on the yield maps (*Fig. 4a* and *Fig. 4b*) that both the climatic and the soil conditions are responsible for the development of the winter wheat and maize yields: the mosaic-like pattern coming from both the climate and soil database (*Fig. 1* and *Fig. 2*) is identifiable on the corresponding maps. This characteristic prospectively will not change due to the climate change. On the sunflower yield maps, however, only the pattern of the meteorological cells (*Fig. 1*) appears indicating that the yield development of this crop is determined by the climate in the first place, which can be explained with the greater water demand of the sunflower. Based on the simulation results the sunflower will be an explicit ‘loser’ due to the climate change: the expected yields are shifted from the ‘above average’ category to the ‘average’ while the average yields are shifted to the ‘below average’ category (*Fig. 4c*).

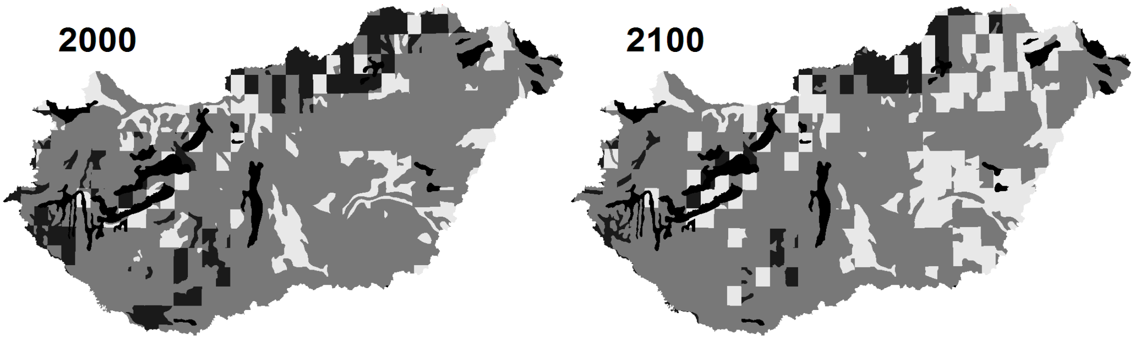
It is not so obvious to see the prospective effect of climate change for maize, though an 6-7% decrease of the average yield is expected on country level. There could be smaller areas at the central and the north-western parts of Hungary where an increase of the maize yields could be expected while an explicit decrease of yields could be expected at the eastern territories of the country (*Fig. 4b*). In case of both crops the dryer and hotter summers resulting in greater water and heat stresses could be hold responsible for the yield loss. This negative effect could not be counterbalanced by the increased CO_2 promoted photosynthesis.

The probable reaction of winter wheat is just contrary to that of the sunflower. The present ‘below average’ yields practically disappear due to the climate change while higher than the present average yields could be expected at the majority of the country area by the end of this century (*Fig. 4a*). It is probably due to the increased precipitation amount during the winter period (*Table 3*) which creates more advantageous conditions for the development in spring. The less summer precipitation does not really decrease the yield since the growing season of the winter wheat ends at the end of June or at the beginning of July even today and the shortening of the growing seasons is also expected (Erdélyi, 2008) due to the climate change.

(a) winter wheat



(b) maize



(c) sunflower

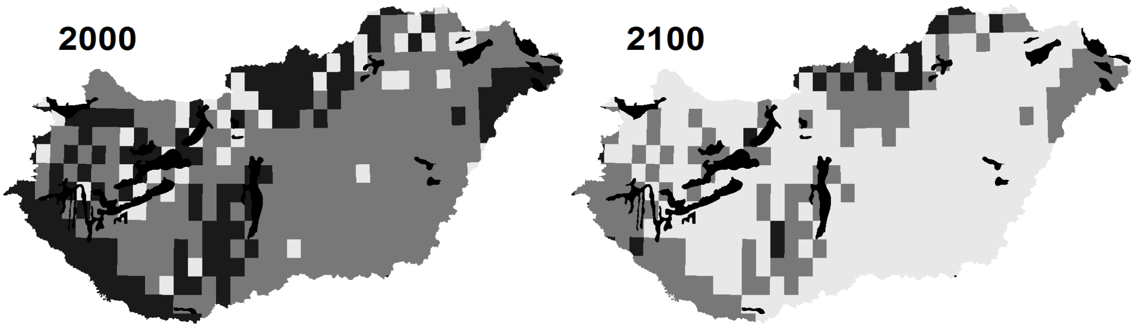


Figure 4. *The spatial distribution of the present (2000) and the expected future (2100) yields in Hungary for the three main crops. The grey colour denotes the present average yields (winter wheat: 3300-4300 kg ha^{-1}, maize: 4500-6500 kg ha^{-1}, sunflower: 2500-3000 kg ha^{-1}), while light and dark grey represent the 'below average' and the 'above average' yields respectively*

It is distinctly visible on the maps presenting the denitrification (NO_x emission) rates (*Fig. 5*) that the soils having high clay content at the eastern part of Hungary produce 'above average' NO_x emission rates in the first place. The quantity of this is expected to increase due to the climate change especially in the case of growing maize and sunflower. The increase of precipitation amounts in the winter-spring period might be responsible for this when the soil is not or scarcely covered with crops thus the plant water uptake is negligible that results in higher soil water content and an increase of denitrification rates. This phenomenon is not so stressed in case of growing winter wheat since its growing season includes the whole winter-spring period.

A similar trend can be seen on the nitrate leaching maps (*Fig. 6*) due to the climate change. The risk of nitrate leaching is expected to rise as a consequence of the increasing precipitation amounts during the winter and spring quarters (*Table 3*). Another factor that might contribute to the probable nitrate leaching increase is that the plants prospectively won't take up as much nitrogen as today as they develop lower yields. Since possible changes in fertilization practices were not taken into account in the simulations more and more nitrogen could be remained in the sol during the consecutive growing seasons further increasing the risk of nitrate leaching. This tendency can be observed in the case of winter wheat only to a small degree. Wheat takes up water as well as nitrogen during winter and spring that might be an explanation for this.

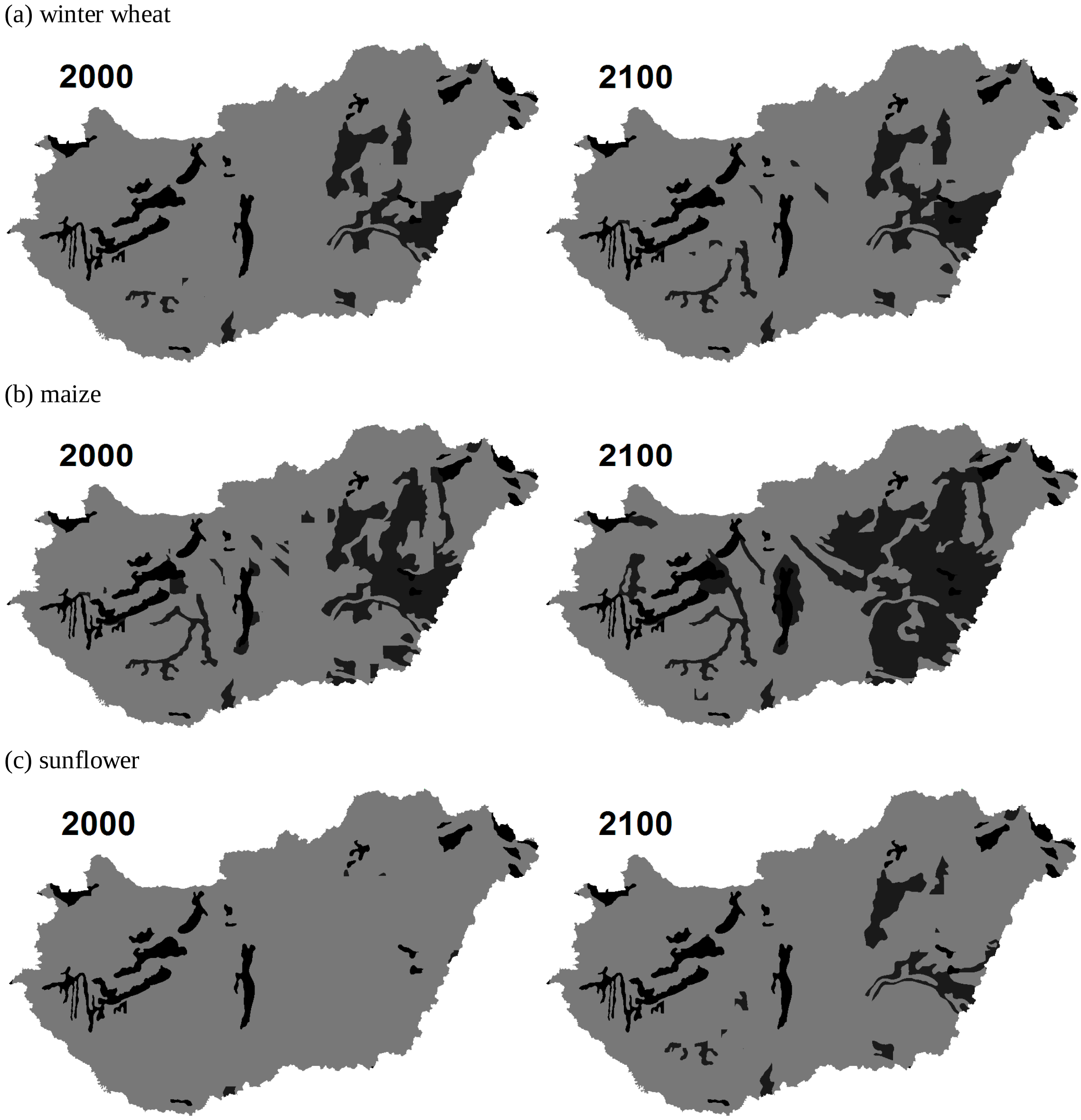


Figure 5. *The spatial distribution of the present (2000) and the expected future (2100) NO_x emission in Hungary growing winter wheat (a), maize (b) and sunflower (c). The grey colour denotes the present average emission rates (0-2000 kg km^{-2} y^{-1}), while dark grey represents the 'above average' emission rates*

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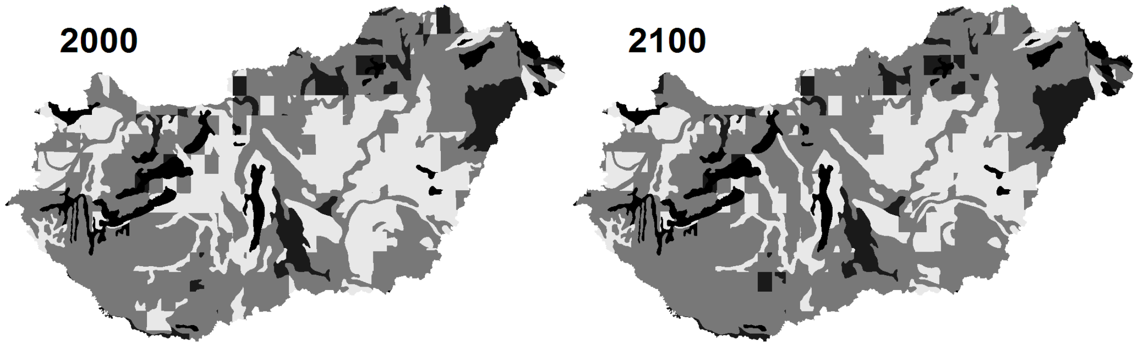
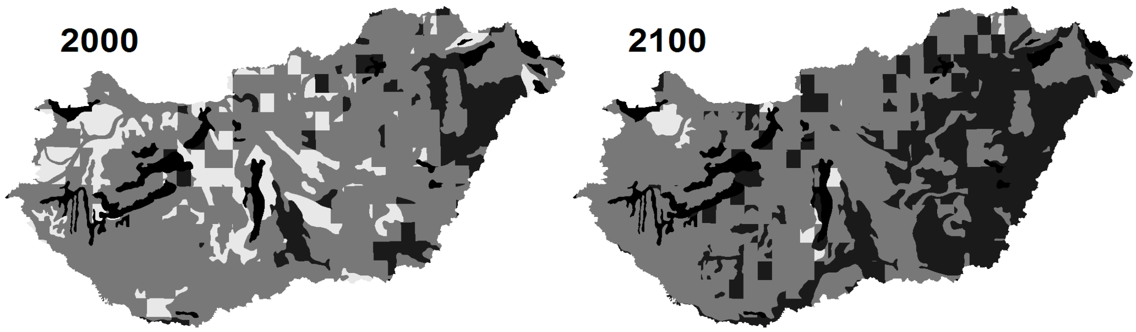
(a) winter wheat



(b) maize



(c) sunflower

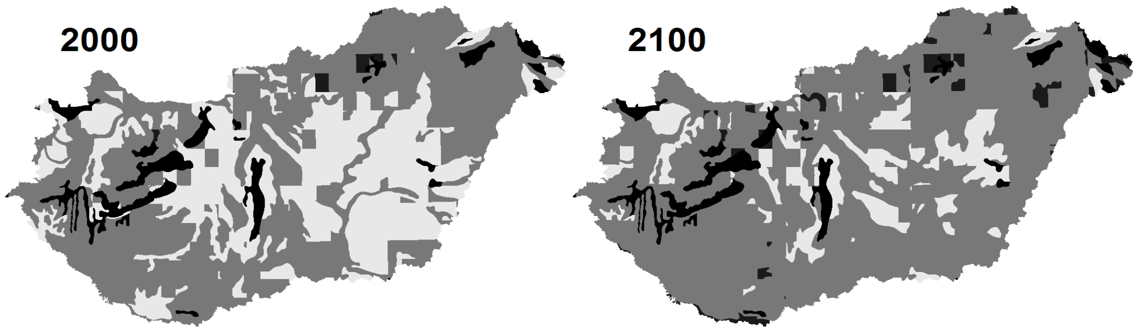


Figure 6. *The spatial distribution of the present (2000) and the expected future (2100) nitrate leaching rates in Hungary growing winter wheat (a), maize (b) and sunflower (c). The grey colour denotes the present average nitrate leaching rates (1000-3000 kg km^{-2} y^{-1}), while light and dark grey represent the 'below average' and the 'above average' leaching rates respectively*

Summary and conclusions

The 4M crop simulation model was used to quantify some indices of the agro-ecological potential of Hungary and its prospective development due to climate change. The simulation results indicate that the Hungarian agriculture can not avoid the effects of climate change, and unfortunately the majority of these effects would be negative. The yields of the spring crops (maize, sunflower, etc.) will prospectively decrease while higher yields might be expected for the autumn crops like winter wheat. The selection of the suitable variety to sow might become particularly important. The need for drought resistant varieties – especially for sunflower - might be the most important

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challenge for plant breeders hoping that this race would be won by the man and not by the nature. The feasibility of irrigation should be investigated from economic and as a matter of course from environmental protection point of view, since yield loss of spring crops could be attributed to the dryer summers in the first place. The amount of N-based green house gases emitted from the soil will prospectively increase because of the changes in the annual distribution of precipitation. The growing of spring crops might imply an additional environmental protection risk due to the prospectively increasing nitrate leaching rates. This effect might be mitigated by rational and properly timed fertilization. Considering the prospectively growing yields and the decreasing environmental protection risks the role of the autumn crops is likely to become more significant in Hungary. Another alternative for the Hungarian agriculture is to start testing and - in case of getting positive results - start growing alternative crops such as energy crops like robinia (*Robinia pseudoacacia*), poplar (*Populus*), etc. or crops native or successfully grown at Mediterranean areas such as fenugreek (*Trigonella foenum-graecum L.*), lady's thistle (*Silybum marianum (L.) Gaernt.*) or cotton (*Gossypium*).

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