

Possible impacts of climate change on the productivity and carbon balance of Hungarian croplands

Theses of the PhD dissertation

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1. Introduction and objectives

Food security could be seriously affected by climate change since crop production is strongly related to the meteorological conditions. State-of-the-art climate models provide information on the possible future realization of the different meteorological parameters thus these projections can be used for further impact studies including the simulation of the possible changes in crop production.

According to the climate models temperature is expected to increase, while summer precipitation is expected to decrease in Hungary in the future. Moreover, the frequency of extreme meteorological events is expected to increase. These changes could potentially affect the agricultural productivity and carbon balance in Hungary (where the latter means the role of croplands in the carbon cycle of the land-surface system).

The main aim of this study was to estimate the possible effects of climate change on maize and winter wheat, which are the two main crop types of the country. A multi-model ensemble simulation system was created by using two plant models and several climate model results, which could provide robust estimation on the expected changes of crop production and carbon balance.

2. Materials and methods

Two models with different logic – the biogeochemical Biome-BGCMuSo and the 4M crop model – were used in this study. In order to provide the needed input meteorological data for the models, a new, open access climate database was created called

FORESEE, which covers the 1951-2100 time period with daily time steps. The FORESEE contains observation-based data for the past, and ten different, bias-corrected regional climate model results for the future. A cumulative distribution function fitting method was used for the temperature and precipitation correction. The correction of the precipitation frequency was also executed. The target area of the database is Central Europe, with a horizontal resolution of $1/6 \times 1/6$ degree. The Hungarian grid points of the FORESEE grid were used for the crop modeling study.

Additionally, climate-dependent planting date estimation methods were created and validated for Hungary, since the timing of planting is also a crucial input for the models. The planting dates were estimated for the future based on the existing meteorological and soil conditions for every grid point. Besides the business-as-usual fertilizing practices that are characteristic for Hungary, four alternative management scenarios were created and tested for maize and winter wheat. Since maize is expected to be strongly exposed to drought conditions in the summer, three irrigation scenarios were introduced in order to estimate their possible effects on crop yields.

The models were calibrated with the GLUE method, which is based on large number of Monte Carlo simulations. Within GLUE first the unknown or uncertain ecophysiological parameters were randomized between predefined intervals, then a large number of simulations were done (10-20000). The results of the simulations were compared with measurements (in this case to yield observations

published by the Hungarian Central Statistical Office) and the parameter sets that gave the best results were selected. The uncertainty related to the parameter estimation was also quantified by the GLUE method.

After the model validation, simulations were performed on every Hungarian grid point, for the two crop types by using 10 climate projections and different management scenarios with both models for the period 1986-2100. In order to handle the bias of the models, the expected yield changes were estimated by comparing the model results for the future (2014-2100) to the model results for the past (1986-2013). The trends of the expected changes were calculated and significances were determined using different levels (T-test). The uncertainty of the model simulations was estimated and the two model results were compared.

3. Results

The results of my doctoral thesis could be summarized by the following points:

1. A new gridded meteorological database (FORESEE) was created for Central Europe, which covers a 150-years period with daily time step. FORESEE contains observations for the past and 10 bias-corrected regional climate model results for the future. FORESEE was disseminated for the scientific community through its website, where a GIS-based data retrieval option was also implemented.

2. Published, climate-dependent planting date estimation methods were tested and validated for maize and winter wheat for Hungary based on observations. The estimation methods gave unacceptable results. Novel methods were introduced, which are using air temperature but are also taking into account the soil conditions. The new methods gave more accurate results for Hungary.
3. The two plant models were calibrated for maize and winter wheat by using the GLUE method. The quality of the simulations improved after calibration where observed yields for the 1986-2013 period were used for evaluation of model performance. 4M explains 62% of the variability of the observations in case of maize (with a 0.12 t ha^{-1} bias) and 49% in case of winter wheat (with a 0.06 t ha^{-1} bias). The results of the Biome-BGCMuSo explain 10% of the observed variability for maize and 50% for winter wheat. In this case the bias is 0.47 t ha^{-1} for maize and -0.73 t ha^{-1} for winter wheat. The simulated carbon fluxes were validated for the Hegyhátsál experimental site against the eddy-covariance measurement results, where the calibrated model showed more accurate results.
4. The 4M model results projected 0.15 t ha^{-1} yield decrease per decade for maize assuming the business-as-usual management scenario, while for winter wheat an increase of 0.07 t ha^{-1} per decade is expected. Based on the same management settings Biome-BGCMuSo projected yield decrease of $0.06 \text{ t ha}^{-1} \text{ decade}^{-1}$

for maize and an increase of $0.05 \text{ t ha}^{-1} \text{ decade}^{-1}$ for winter wheat (the values refer to the multi-climate model mean).

5. The results of 4M and Biome-BGCMuSo models were compared. The two models were consistent in the followings:
 - a. Both models agreed in the sign of the expected changes for the given crops.
 - b. Both models projected significant yield increase for winter wheat with the same order of magnitude decadal trend.
 - c. The variability of the projected yield which is caused by the climate-model selection is greater in case of maize than in case of winter wheat.
 - d. The irrigation scenarios for maize, which uses a smaller amount (20mm) of water more frequently and which assumes a greater amount (40mm) less often, show very similar results considering the crop yield.
 - e. In case of maize the introduction of irrigation shows larger yield increase than the more intensive fertilization.
 - f. Winter wheat is less sensitive to the amount of applied fertilization than maize.
 - g. The uncertainty of the model results is greater in case of maize than winter wheat.
6. The two plant models showed differences in the followings:
 - a. 4M shows larger expected changes than Biome-BGCMuSo and higher sensitivity to the management settings.
 - b. In case of maize 4M projects a significant decreasing trend ($p < 0.001$), while Biome-BGCMuSo shows no significant

trend even if $p < 0.01$. This results could be explained by the structural differences of the models

7. Based on the multi-multi-model mean (average of climate models and average of the two plant models) the expected yield decrease for Hungary in case of maize is $0.43 \pm 0.58 \text{ t ha}^{-1}$ for 2021-2050 and $0.96 \pm 0.5 \text{ t ha}^{-1}$ for 2071-2100 relative to the period 1986-2013. The yield of winter wheat is expected to increase by $0.20 \pm 0.12 \text{ t ha}^{-1}$ for 2021-2050 and $0.51 \pm 0.19 \text{ t ha}^{-1}$ for 2071-2100¹.
8. The gradual transition towards the irrigated (I30) and the combined scenario (I30+F3, where both irrigation and fertilization amount increasing were executed) were studied for maize. Both cases show a possible significant ($p < 0.001$) increasing yield trend, which is 0.09 t ha^{-1} per decade for I30 and 1.7 t ha^{-1} per decade for I30+F3 considering the 2014-2100 period.
9. On a county average the decrease of gross primary production (GPP) and total ecosystem respiration (Reco) are projected for the future. In contrast, net ecosystem exchange (NEE) does not show any significant expected trend, thus no changes are expected in the amount of carbon taken from the atmosphere year by year.

¹ The \pm values show the standard deviation caused by the 10 climate model results.

4. Conclusions

A unique multi-climate model and multi-plant model simulation system was created to quantify the uncertainty and study the robustness of possible future yield simulations for Hungary. The results suggested that both models have advantages and disadvantages, thus a joint development of the models are recommended. This study is the first when croplands were simulated with Biome-BGCMuSo in a country scale. We propose that after a few structural changes taken from the 4M model could substantially improve the quality of cropland related simulations with Biome-BGCMuSo.

Publications related to the topic of the thesis

Peer-reviewed papers:

- Dobor, L., Barcza, Z., Hlásny, T., Árendás, T., Spitkó, T., Fodor, N., 2016. Crop planting date matters: estimation methods and effect on future yields. *Agricultural and Forest Meteorology* **223**: 103-115. doi:10.1016/j.agrformet.2016.03.023 [IF: 3.762]
- Horemans, J.A., Bosela, M., Dobor, L., Barna, M., Bahyl, J., Deckmyn, G., Fabrika, M., Sedmak, R., Ceulemans, R. 2016. Variance decomposition of stem biomass increment predictions for European beech: contribution of selected sources of uncertainty. *Forest Ecology and Management* **361**:46-55. doi:10.1016/j.foreco.2015.10.048 [IF: 2.660]
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- Dobor, L., Barcza, Z., Fodor, N., Hidy, D., Horváth, F., Tóth, E., Gelybó, Gy., Farkas, Cs., 2014. Preparation for estimating climate change effects on agriculture in Central Europe: creation of climatic database and model selection. *Spitzenforscherwerkstatt – Environmental Science Summit*. Garmsich Partenkirchen, Germany, 14-16 July 2014.
- Dobor, L., Barcza, Z., Hidy, D., Horváth, F., Ittzés, P., Gelybó, Gy., Suyker, A.E., Verma, S.B., 2014. Statistical calibration of the Biome-BGC MuSo biogeochemical model for croplands. *Science and Solutions for a Sustainable Environment Conference*. Dublin, Ireland, 11-12 December 2014.
- Dobor, L., Barcza, Z., Hidy, D., Fodor, N., Horváth, F., Tóth, E., Gelybó, Gy., Farkas, Cs., 2014. Modeling water and carbon balance of managed agricultural lands in Hungary. *4th iLEAPS Science Conference: Terrestrial ecosystems, atmosphere, and people in the Earth system*. Nanjing, China, 12-16 May 2014.
- Dobor, L., 2013. Climate change related impact study in Hungary using a large ensemble of climate projections. *TTORCH Summer School: Challenges in measurements of greenhouse gases and their interpretation*. Hyytiälä, Finland, 30 September - 11 October 2013.
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- Dobor, L., Barcza, Z., Havasi, Á., Fodor, N., 2012. Preparation of high resolution climate scenarios for agricultural impact analysis in Hungary. *European Geosciences Union, General Assembly 2012*. Vienna, Austria, 22-27 April 2012.
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