http://dx.doi.org/10.7896/j.1614 Studies in Agricultural Economics 118 (2016) 85-90

FOGARASI József*‡1, KEMÉNY Gábor*2, MOLNÁR András*3, KEMÉNYNÉ HORVÁTH Zsuzsanna*4, ZUBOR-NEMES Anna* and KISS Andrea*

Modelling climate effects on Hungarian winter wheat and maize yields

Hungarian cereal production is situated in the zone of Europe which is most vulnerable to the effects of changes in climatic conditions. The objectives of this paper are to present the calibration and validation of the 4M crop simulation model using farm-level observed representative values, and to estimate the potential yields of winter wheat and maize production for the next three decades. Analysing the differences between the estimated and observed yields, we identified as key influencing factors the heterogeneity of technologies and of land quality. A trend of slightly decreasing yields is projected for the next three decades for both cereals. The precise impact of environmental change on crop yields will depend on which climate scenario occurs.

Keywords: crop simulation, climate change, yields

* Agrárgazdasági Kutató Intézet, Zsil utca 3-5, 1093 Budapest, Hungary. Corresponding author: fogarasi.jozsef@aki.gov.hu
‡ Also Partiumi Keresztény Egyetem, Oradea, Romania and Dunaújvárosi Egyetem, Dunaújváros, Hungary

Introduction

Agriculture is sensitive to changing temperature and precipitation patterns as well as to frequencies of extreme weather events. A growing number of studies have dealt with the impact of climate change on agricultural production and the farming sector (e.g. Mendelsohn *et al*., 1994; Chang, 2002; Seo and Mendelsohn, 2008; van der Werf, 2008; Wang *et al*., 2009; Di Falco *et al*., 2011; Chang *et al*., 2012; Kaminski *et al*., 2013; Nelson *et al*., 2014, Mitter *et al*., 2015). The effects of climate change on agricultural production would highly depend upon the geographical location of the crop and animal production, with farms in some regions benefiting (Ghaffari *et al*., 2002) and farms in other regions suffering adverse effects under new climatic conditions (Jones and Thorton, 2003; Key and Sneeringer, 2014).

Modelling supply and market price adjustments of the European Union (EU) agricultural sector as well as technical adaptation to climate change, Shrestha *et al*. (2013) estimated an increase in yields and production volume. In general, there are relatively small effects at the EU aggregate level and stronger impacts at regional level with some stronger effects prevailing in the Central and Northern EU and higher impacts in Southern Europe. The most negative effects of climate change in Europe were found to occur in the continental climate in the Pannonian environmental zone, which includes Bulgaria, Hungary, Romania and Serbia (Olsen *et al*., 2011).

A growing number of recent studies provide evidence of climate change in Hungary (Spinoni *et al*., 2013) and on the likely effects of climate change on Hungarian agriculture (Fodor and Pásztor, 2010; Fodor *et al*., 2014; Gaál *et al*., 2014; Kemeny *et al*., 2014). These studies focus on biophysical and environmental consequences of climate change, and there are no empirical investigations on economic impacts of climate change on Hungarian agricultural production.

The objectives of this paper are, firstly, to estimate the impacts of climate change on yields in the Hungarian cereal sector using the 4M crop simulation model and, secondly, to assess the possibilities for technological adaptation with regression analysis. The 4M model has been applied in previous studies focusing on soil and weather influence (Máthé-Gáspár *et al*., 2005), and on the effects of climate change on crop yields in Hungary (Fodor and Pásztor, 2010; Fodor *et al*., 2014). However, these studies are based mainly on experimental and non-representative farm-level data, whereas in this study we apply the model to representative Hungarian Farm Accountancy Data Network (FADN) data.

Methodology

Here we present the crop simulation and regression analysis models with the implementation settings and describe the data of the case study application.

Crop simulation model and implementation

The simulation of the effects of climate change on cereals yields is performed by using the 4M deterministic crop model. This mathematical programming crop model is adjusted to the Hungarian agro-technical and environmental conditions from the CERES model (Fodor *et al*., 2002; Fodor, 2006). 4M is a daily-step deterministic model using input parameters of the atmosphere, soil and plant system. These input parameters are processed by the functions and equations of the model simulating the development and growth of plants and the heat, water and nutrient balance of the soil. The boundary conditions are primarily the daily meteorological data such as radiation, temperature and precipitation. The constraint conditions are the numerical expressions of human activities such as planting, harvesting, fertilisation and irrigation. In addition to plant development and growth, the model calculates the water, heat and nitrogen flows as well as the nitrogen transformation process of the soil.

The meteorological data include daily maximum and minimum temperatures and daily precipitation covering the area of Hungary with a one-sixth degree resolution grid, and were provided by the Hungarian Meteorological Service. The

[1] http://orcid.org/0000-0001-7989-8375
[2] http://orcid.org/0000-0002-1849-5991
[3] http://orcid.org/0000-0002-7010-7917
[4] http://orcid.org/0000-0003-2918-4977

Meteorological Interpolation based on Surface Homogenised Data Basis (MISH) interpolation technique (Szentimrey *et al.*, 2005) was used for producing the grid of meteorological data from the local observations (Szépszó and Horányi, 2008; Szépszó *et al.*, 2011; Szépszó *et al.*, 2013). The soil use data are from the Hungarian Soil Information and Monitoring System (SIMS) covering clay, sand and organic matter soil types. The land use information was collected from the National Land Cover Database and was used to calculate agricultural areas within the meteorological cells used for simulation. The plant data, such as the phenological characteristics and stages, maximum root depth, light use efficiency and specific nitrogen content were determined from the relevant scientific literature (Fodor *et al.*, 2014). Agro-technical data such as planting date, plant density and fertiliser applications were provided according to the usual Hungarian agro-technology of each plant (Fodor *et al.*, 2014).

The calibration and validation of the crop simulation model

The calibration and validation of the 4M model was performed using actual crop fertilisation data as well as the observed yields for winter wheat and maize from the Hungarian FADN database for the period 2001-2012. The survey comprises detailed farm-level information on cost accounting, farming system and structural aspects.

The differences between the yields obtained from simulation and observed inputs were tested using equation (1):

$$Y_i = c + \beta_1 Y_{e,i} + \beta_2 dY_{e,i} + \beta_3 TC_i + \beta_4 LQ_i + e_i \qquad (1)$$

where Y_i denotes the observed yield of every *i* farms, *c* is the constant term, $Y_{e,i}$ represents the simulated yields of the different farms by the 4M model, $dY_{e,i}$ is the difference of estimated yields of every farms from the average, TC_i and LQ_i denote deflated total costs and land quality of every farms obtained from Hungarian FADN survey data, e_i is the error term, and β are the parameters of the regression. The data used for the regression analysis are given in Table 1.

The effects of climate change on cereal yields

After validation of the model using observed Hungarian FADN data, the projections of the yields until 2050 were calculated based on the data of the farms selected for calibration and validation. The simulated yield values were adjusted using the parameters of the regression analysis.

The forecast of climate change is performed by the Hungarian Meteorological Service (*Országos Meteorológiai Szolgálat*, OMSZ) employing three regional climatic models from the ESSEMBLES project (van der Linden and Mitchell, 2009). The ALADIN, RACMO and REGCM models simulate different climate scenarios for the Carpathian Basin and Central and Eastern European regions respectively. These models are based on 50 km, 25 km and 10 km grids for the period 1951-2100, applying the newest emission scenarios. The model results are validated with observed data from the periods 1961-1990 and 1971-2000 and the projections are made for the periods 2021-2050 and 2050-2100 (Szépszó *et al.*, 2013). The interpretation of climate simulation models results should be made taking into account the uncertainty due to the estimation of physical processes and human activities. The application of these three regional climatic models offers the opportunity of addressing these uncertainties, but for a more complete estimation the regional simulation results of the ENSEMBLES project with 25 km grid density were applied (van der Linden and Mitchell, 2009).

Table 1: Description of the data used for the regression analysis.

Parameter	Winter wheat	Maize
Number of farms	1,002	1,075
Number of observations	7,811	7,675
Average observed yield, t/ha^{-1} (Y_i)	4.16	6.48
Average estimated yield, t/ha^{-1} ($Y_{e,i}$)	4.21	6.50
Average total production costs, HUF/ha^{-1} (TC_i)	78,677	103,700
Average utilised agricultural area, ha	21.70	21.60

Source: own calculations based primarily on Hungarian FADN data

Results

The differences between observed yields and the yields estimated with the 4M model indicated the need for calibration and validation. After adaptation to the changed environmental conditions, the model was used for the projection of winter wheat and maize yields.

Calibration and validation

In comparison to the observed yields, the winter wheat and maize yields calculated by the 4M model were lower in the years with favourable climatic conditions for cereal production, and higher in the years with unfavourable climatic conditions. To improve the comparability of the simulated yields with the observed yields, only those farms with the smallest differences between observed and estimated yields were retained in the sample. Based on five-year farm-level data sets during the period 2001-2012, 1,002 winter wheat and 1,075 and maize producing farms were chosen. The 4M model was validated for these selected sample farms, the causes of differences between observed and estimated yields were investigated using regression analysis, and this validated crop simulation model was used to estimate the potential yields in the selected farms.

The regression analysis was based on estimated yield per hectare, difference of estimated yield per hectare, deflated total production costs per hectare and land quality parameters, and we found that main error source of the 4M model (the difference between observed and estimated yields) can be attributed primarily to heterogeneity of production technologies and the quality of land (Table 2).

In the calibration process, water stress and dry matter values were modified (Table 3). The calibration resulted in slightly higher coefficients of determination (R^2), but a more efficient indicator of calibration is the coefficient of variation of root mean square error – CV(RMSE). As a result of calibration we obtain values for CV(RMSE) that are closer to the critical value 40, when the estimated yields with the

Table 2: Regression analysis results of the selected sample of farms.

Parameter	Winter wheat	Maize
Estimated yield per hectare ($Y_{e,i}$)	0.284***	0.215***
Difference of estimated yields per hectare ($dY_{e,i}$)	0.045***	0.284***
Total production costs per hectare (TC_i)	0.305***	0.332***
Land quality (LQ_i)	0.183***	0.127***
Constant (c)	1.678***	1.534***
Adjusted R square	0.279	0.448

***/**/*: statistically significant, respectively at the 1%, 5%, and 10% levels
Source: own calculations based primarily on Hungarian FADN data

calibrated simulation model can be accepted. Validation of our calibrated 4M model indicated that we improved the estimation characteristics of the model, which can therefore be used for yield forecasts.

Climate effects on expected crop yields

The forecasted yields of winter wheat and maize as a consequence of changes in the climatic conditions without more efficient risk mitigation follow a slightly decreasing

Table 3: Calibration and validation results of 4M crop simulation model.

Calibration		Calibration values		Calibration/validation equation			Error indicators		
		Water stress	Dry matter	Slope	Constant	R square	Mean difference	RMSE	CV (RMSE)
Winter wheat	Initial	1.0	0.0022	0.5132	1.9952	0.1268	-0.0243	1.8322	44.1677
	Calibrated	1.6	0.0021	0.4660	2.3001	0.1465	0.0848	1.5953	38.4551
	Validated	1.6	0.0021	0.4767	2.1753	0.1486	-0.0173	1.5936	38.0350
Maize	Initial	1.0	0.0027	0.7456	0.6342	0.3112	-1.0030	2.9280	45.4956
	Calibrated	1.7	0.0029	0.7638	1.4661	0.3203	-0.0543	2.7494	42.7185
	Validated	1.7	0.0029	0.7401	1.4895	0.2969	-0.1776	2.8418	44.3074

Source: own calculations (4M model)

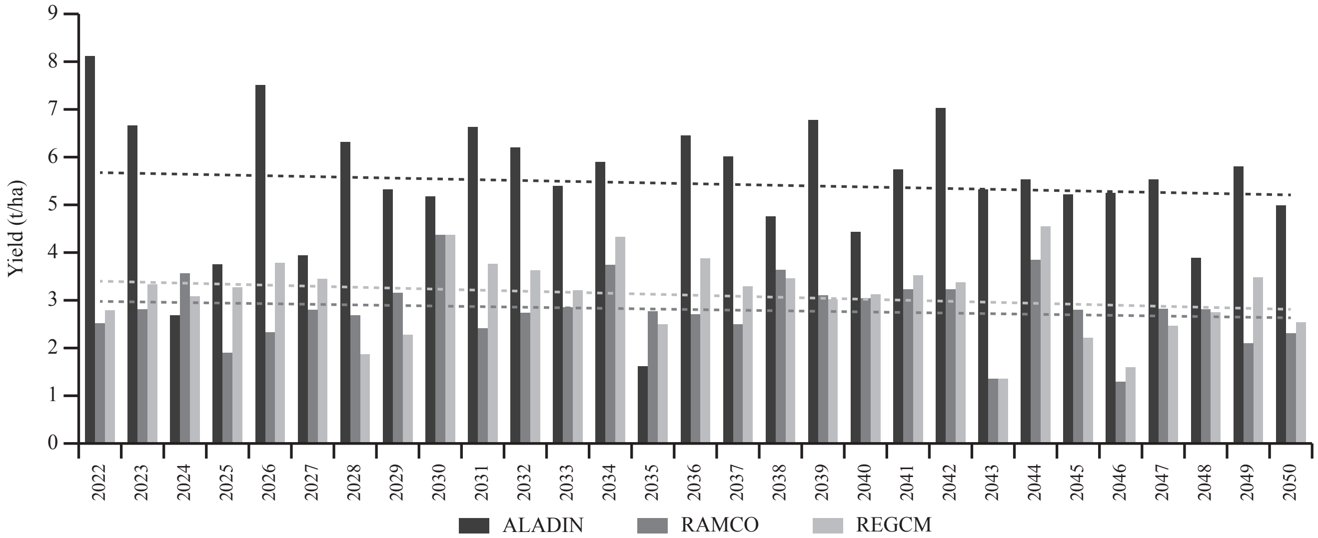

Figure 1: Winter wheat yield estimations according to three climate scenarios, 2022-2050.
Source: own calculations (4M model)

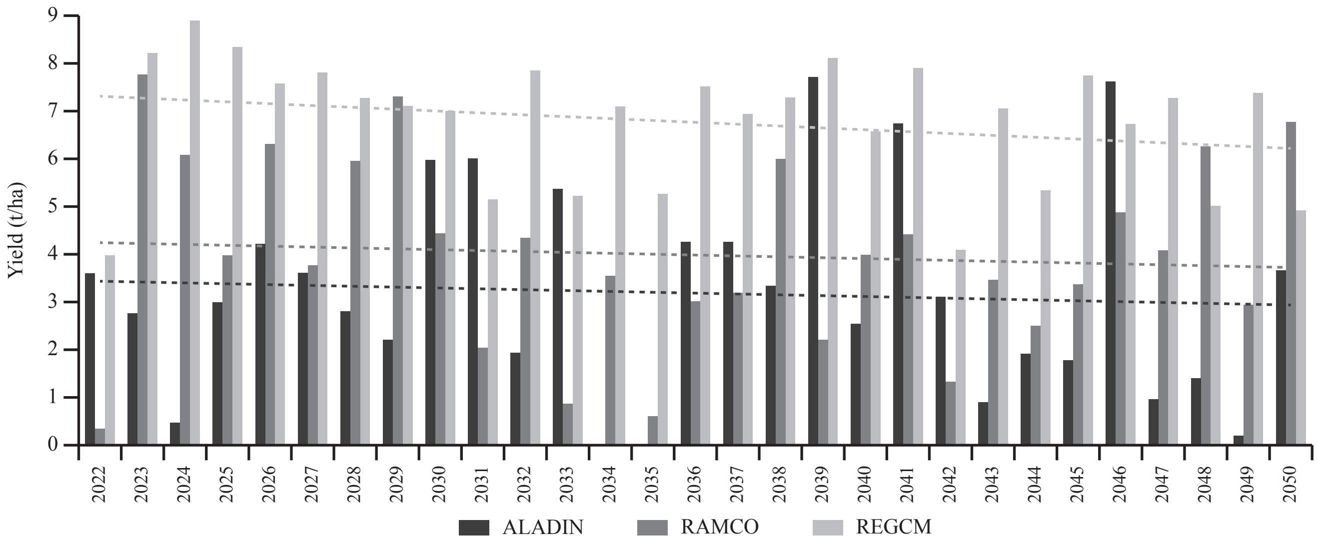

Figure 2: Maize yield estimations according to three climate scenarios, 2022-2050.
Source: own calculations (4M model)

trend in the coming decades (Figures 1 and 2). The average forecasted yields vary according to the climate scenario: for winter wheat and maize the estimated yields are close to current yields when the ALADIN and REGCM climate scenarios are considered, respectively. The predicted yields of winter wheat are sharply lower under the RACMO and REGCM climate scenarios while for maize production this trend is predicted under the ALADIN and RACMO climate scenarios. No climate scenario is favourable for both crops.

Considering farmers' resilience and adaptation to the changing climate conditions, we adjusted the yield projections obtained with the 4M model with the parameters of the regression analysis (Figures 3 and 4). After adjusting the technology, the favourable climate scenarios for winter wheat and maize result in lower yields and the unfavourable climate scenarios result in higher yields. In both cases the 'volatility' of yearly average yields is reduced as a result of farmers' risk mitigation arrangements.

Discussion

This paper investigates the impact of changes in climatic conditions on Hungarian winter wheat and maize yields using the linear programming 4M model and regression analysis to highlight the necessity of adaptation in private and public decisions (Antle and Capalbo, 2010). Previous studies (e.g. Fodor *et al.*, 2014) indicated that the 4M model provides realistic estimations for Hungarian crop yields. Other crop production optimisation models display similar performance at larger spatial scales (Moriondo *et al.*, 2011; Liu *et al.*, 2013).

Before calibration and validation, the simulated yields were systematically underestimated, but with the calibration and validation of the 4M model based on a Hungarian FADN representative sample of farms resulted in improved performance indicators (Table 2), the model is able to reproduce better the trend of observed yields variations. The regression parameters of the calibrated and validated 4M simulation

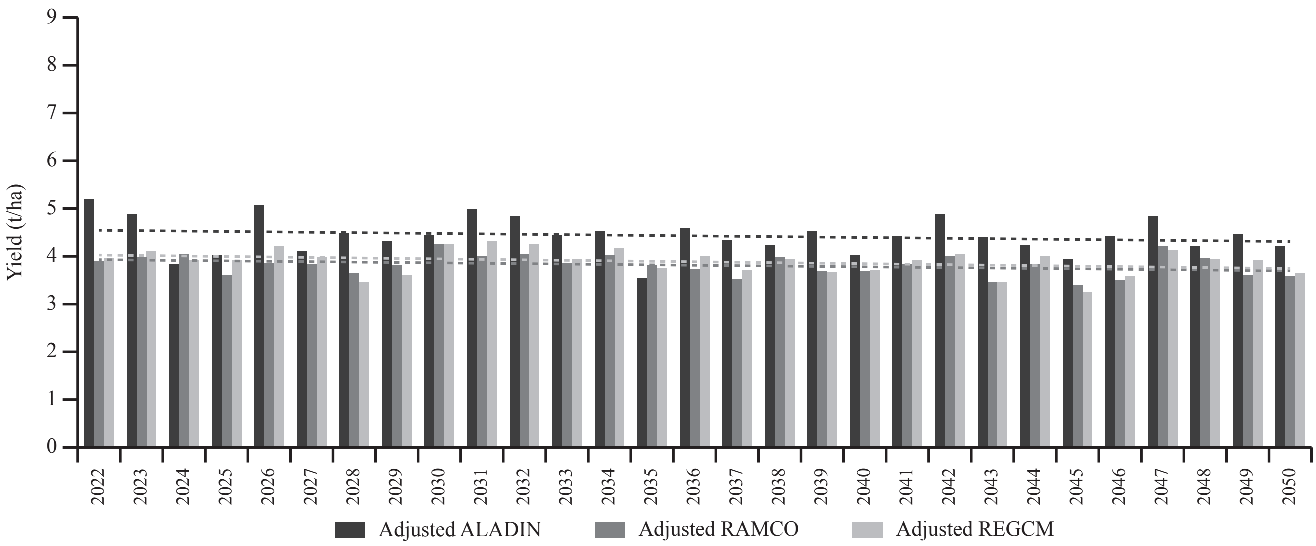

Figure 3: Adjusted winter wheat yields estimation according to three climate scenarios, 2022-2050.
Source: own calculations (4M model)

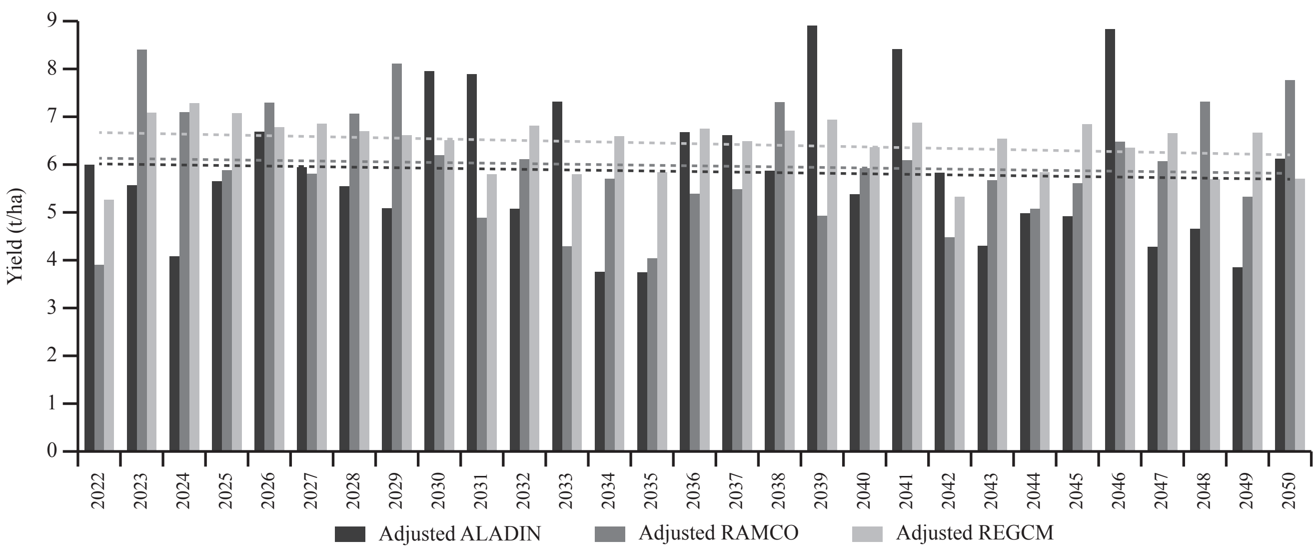

Figure 4: Adjusted maize yields estimations according to three climate scenarios, 2022-2050.
Source: own calculations (4M model)

results and the observed values indicate that the main factors causing the differences in the simulated and observed yields are the heterogeneity of production technology and land quality.

A slightly decreasing trend in the yields of both analysed crops is estimated for the next three decades due to the changes in climatic conditions. This trend for Hungarian crop production was also reported by Neményi (2015); his research shows that a sharp decrease in yields is expected in the second half of this century. This suggests that further investigations are needed to assess the capacity of Hungarian crop producers to adapt to the variations of climatic conditions that consider longer projections than those presented in this paper, changing sowing dates (Dobor *et al.*, 2016), and evaluation of different private and public adaptation measures.

References

Antle, J.M. and Capalbo, S.M. (2010): Adaptation of agricultural and food systems to climate change: an economic and policy perspective. Applied Economic Perspectives and Policies **32** (3), 386-417. http://dx.doi.org/10.1093/aepp/ppq015

Chang, C. (2002): The potential impact of climate change on Taiwan's agriculture. Agricultural Economics **27** (1), 51-64. http://dx.doi.org/10.1111/j.1574-0862.2002.tb00104.x

Chang, C., Chen, C. and McCarl, B. (2012): Evaluating the economic impacts of crop yield change and sea level rise induced by climate change on Taiwan's agricultural sector. Agricultural Economics **43** (2), 205-214. http://dx.doi.org/10.1111/j.1574-0862.2011.00577.x

Di Falco, S., Veronesi, M. and Yesuf, M. (2011): Does Adaptation to Climate Change Provide Food Security? A Micro-Perspective from Ethiopia. American Journal of Agricultural Economics **93** (3), 829-846. http://dx.doi.org/10.1093/ajae/aar006

Dobor, L., Barcza, Z., Hlásny, T., Árendás, T., Spitkó, T. and Fodor, N. (2016): Crop planting date matters: Estimation methods and effect on future yields. Agricultural and Forest Meteorology **223**, 103-115. http://dx.doi.org/10.1016/j.agrformet.2016.03.023

Fodor, N. (2006): 4M – Software for Modelling and Analysing Cropping Systems. Journal of Universal Computer Science **12** (9), 1196-1207.

Fodor, N., Máthé-Gáspár, G., Pokovai, K. and Kovács, G.J. (2002): 4M: Software package for modelling cropping systems. European Journal of Agronomy **18**, 389-393. http://dx.doi.org/10.1016/S1161-0301(02)00126-0

Fodor, N. and Pásztor, L. (2010): The agro-ecological potential of Hungary and its prospective development due to climate change. Applied Ecology and Environmental Research **8**, 177-190.

Fodor, N., Pásztor, L. and Németh, T. (2014): Coupling the 4M crop model with national geo-databases for assessing the effects of climate change on agroecological characteristics of Hungary. International Journal of Digital Earth **7** (5), 391-410. http://dx.doi.org/10.1080/17538947.2012.689998

Gaál, M., Quiroga, S. and Fernandez-Haddad, Z. (2014): Potential impacts of climate change on agricultural land use suitability of the Hungarian counties. Review of Environmental Change **14**, 597-610. http://dx.doi.org/10.1007/s10113-013-0518-3

Ghaffari, A., Cook, H.F. and Lee, H.C. (2002): Climate change and winter wheat management: A modelling scenario for south eastern England. Climatic Change **55**, 509-533. http://dx.doi.org/10.1023/A:1020784311916

Jones, P.G. and Thorton, P.K. (2003): The potential impacts of climate change on maize production in Africa and Latin America in 2055. Global Environmental Change **13**, 51-59. http://dx.doi.org/10.1016/S0959-3780(02)00090-0

Kaminski, J., Kan, I. and Fleischer, A. (2013): A Structural Land-Use Analysis of Agricultural Adaptation to Climate Change: A Proactive Approach. American Journal of Agricultural Economics **95** (1), 70-93. http://dx.doi.org/10.1093/ajae/aas075

Kemény, G., Kiss, A., Fogarasi, J. and Nemes, A. (2014): Verwendungsmöglichkeiten eines Pflanzenwachstumsmodells auf betrieblicher Ebene [Uses of a plant growth model at the enterprise level], in proceedings of the 24th Annual Meeting of the Austrian Society of Agricultural Economics, Wien, Austria, 25-26 September 2014.

Key, N. and Sneeringer, S. (2014): Potential effects of climate change on the productivity of U.S. dairies. American Journal of Agricultural Economics **96** (4), 1136-1156. http://dx.doi.org/10.1093/ajae/aau002

Liu, Z., Hubbard, K.G., Lin, X. and Yand, X. (2013): Negative effects of climate warming on maize yield are reversed by the changing of sowing date and cultivar selection in Northeast China. Global Change Biology **19** (11), 3481-3492. http://dx.doi.org/10.1111/gcb.12324

Máthé-Gáspár, G., Fodor, N., Pokovai, K. and Kovács, H.J. (2005): Crop modelling as a tool to separate the influence of the soil and weather on crop yields. Physics and Chemistry of the Earth **30**, 165-169. http://dx.doi.org/10.1016/j.pce.2004.08.024

Mendelsohn, R., Nordhous, W. and Shaw, D. (1994): The Impact of Global Warming on Agriculture: A Ricardian Analysis. American Economic Review **84**, 753-771.

Mitter, C., Heumesser, C. and Schmid, E. (2015): Spatial modelling of robust crop production portfolios to assess agricultural vulnerability and adaptation to climate change. Land use Policy **46**, 75-90. http://dx.doi.org/10.1016/j.landusepol.2015.01.010

Moriondo, M., Giannakopoulos, C. and Bindi, M. (2011): Climate change impact assessment: the role of climate extremes in crop yield simulation. Climatic Change **104** (3), 679-701. http://dx.doi.org/10.1007/s10584-010-9871-0

Nelson, G.C., van der Mensbrugghe, D., Ahammad, H., Blanc, E., Calvin, K., Hasegawa, T., Havlik, P., Heyhoe, E., Kyle, P., Lotze-Campen, H., von Lampe, M., Mason d'Croz, D., van Meijl, H., Muller, C., Reilly, J., Robertson, R., Sands, R.D., Schmitz, C., Tabeau, A., Takahashi, K., Valin, H. and Willenbockel, D. (2014): Agriculture and climate change in global scenarios: why don't the models agree. Agricultural Economics **45**, 85-101. http://dx.doi.org/10.1111/agec.12091

Neményi, M. (2015): Klímaváltozás hatása a szántóföldi növénytermesztésre [The effects of climate change on crop production]. [www document] http://www.agrarklima.nyme.hu/fileadmin/Image_Archive/gi/agroklima/zaro/13.pdf (accessed 12 June 2016).

Olsen, J.E, Trnka, M., Kersebaum, K.C., Skjelvag, A.O., Seguin, B., Peltonen-Sainio, P., Rossi, R., Kozyra, J. and Micale, F. (2011): Impacts and adaptation of European crop production systems to climate change. European Journal of Agronomy **34**, 96-112. http://dx.doi.org/10.1016/j.eja.2010.11.003

Seo, N. and Mendelsohn, R. (2008): Measuring impacts and adaptations to climate change: a structural Ricardian model of African livestock management. Agricultural Economics **38** (2), 151-165. http://dx.doi.org/10.1111/j.1574-0862.2007.00289.x

Shrestha, S., Ciaian, P., Himics, M. and van Doorslaer, B. (2013): Impacts of climate change on EU agriculture. Review of Agricultural and Applied Economics **14** (2), 24-39. http://dx.doi.org/10.15414/raae.2013.16.02.24-39

Spinoni, J., Antofie, T., Barbosa, P., Bihari, Z., Lakatos, M., Szalai, S., Szentimrey, T. and Vogt, J. (2013): An overview of drought events in the Carpathian Region in 1961-2010. Advances in

Science and Research **10**, 21-32. http://dx.doi.org/10.5194/asr-10-21-2013

Szentimrey, T., Bihari, Z. and Szalai, S. (2005): Meteorological Interpolation based on Surface Homogenized Data Basis (MISH). European Geosciences Union, General Assembly 2005, Vienna, Austria, 24-29 April 2005.

Szépszó, G. and Horányi, A. (2008): Transient simulation of the REMO regional climate model and its evaluation over Hungary. Időjárás **112**, 203-232.

Szépszó, G., Horányi, A. and Lakatos, M. (2011): A Magyarországon megfigyelt éghajlati tendenciák, valamint a jövőben várható változások és bizonytalanságaik elemzése [Analysis of Hungarian observed weather trends and their future changes and uncertainties] [www document]. http://owww.met.hu/klimavaltozas/kerdoiv/melleklet_2_szakmai.pdf (accessed 18 June 2015).

Szépszó, G., Horányi, A., Szűcs, M. and Bölöni, G. (2013): A numerikus időjárási modellek felépítése: tér- és időskála, adatasszimiláció, diszkretizáció, parametrizációk, valószínűségi előrejelzések, éghajlati modellezés [Setting up numeric weather models: space and time scale, data assimilation, discretisation, parametrisation, projections, weather modelling] [www document]. http://nimbus.elte.hu/~numelo/Doc/jegyzetek/NumerikusModellezes.pdf (accessed 10 April 2015).

van der Linden, P. and Mitchell, J.F.B. (eds) (2009): ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Exeter, UK: Met Office Hadley Centre.

van der Werf, E. (2008). Production functions for climate policy modelling: An empirical analysis. Energy Economics **30** (6), 2964-2979. http://dx.doi.org/10.1016/j.eneco.2008.05.008

Wang, J., Mendelsohn, R., Dinar, A., Huang, J., Rozelle, S. and Zhang, L. (2009): The impact of climate change on China's agriculture. Agricultural Economics **40** (3), 323-337. http://dx.doi.org/10.1111/j.1574-0862.2009.00379.x