CLIMATE CHANGE AND SUSTAINABLE PRECISION CROP PRODUCTION WITH REGARD TO MAIZE (ZEA MAYS L.)

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ABSTRACT

The paper is based on the European Regional Climate Models of Ensemble project and DSSAT – Ceres-Maize crop simulation model. The main goal of our paper was to predict maize *(Zea mays L.)* yield based on various climate models at management zones level and county level until 2100.

Another application was the use of crop simulation model in order to find responses to the climate change challenges. However, the change of yield in the next decades of the 21st century is predicted differently by the various climate change scenarios. Consequently, the responses should also be different: change of genotypes, and technologies (site-specific soil tillage, planting, nitrogen replenishment, variable rate irrigation) etc.

This study brings together the expected effect of climate change and fulfilling the requirements of sustainable crop production based on management zone and county level approach.

Keywords: DSSAT, regional climate models, maize yield forecast until 2100**,** response to the challenges, management zones level to county level

INTRODUCTION

The Millennium Project of UNU (United Nations University) collected the 15 most important global challenges, and the first of them is sustainability and climate change. One of the possible definitions of sustainability can be found in the Brundtland report: "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." From the agro-technological and social points of view the definition above should be supplemented with the expectation of maximum utilization of the fertility potential of arable lands. It is important to note that hunger kills more people every year than AIDS, malaria and TB together (FAO). Unfortunately most of the developing countries are unable to produce sufficient amounts of food, in spite of the fact that the potential for it exists. A new green revolution is needed where sustainable, environmental protective, nature friendly technologies receive priority. Finding an answer to the challenges is made more difficult by the fact that climate change has to be faced at the same time.

Morowitz (1968) citing Bridgeman wrote: “It springs to eye that the tendency of living organisms is to organize their surroundings, that is, to produce ‘order’ where formerly there was disorder.” Consequently, the following question arises: if all species in nature have the right to make order in their surroundings in order to get more energy or to increase their living conditions, then why can’t humans do it, too.

The answer is given by Margulis (1998) citing Lovelock: “No organism feeds on its own waste … One organism’s waste is another’s food. Failing to distinguish anyone’s food from someone else’s waste, the Gaian system recycles matter on the global level…The sum of planetary life, Gaia, displays a physiology that we recognize as environmental regulation.”

How can we achieve similar processes to the natural regulator ones in agroecology?

The answer to this question is given by one of the possible definitions of sustainable crop production: CO_2 neutral production technologies, nutrient replacement and plant protection without environment pollution: avoidance of ground and super terrestrial water nitrification, eutrophication and erosion, prevention of soil and air pollution, keeping the gradients (primarily the diversity gradient) between the natural and agro ecosystems over long time. If we fulfil the expectations of nature friendly agricultural production our activity will be sustainable and we can utilise the yield potential of our land (Neményi, 2012).

Consequently, the meaning of the terms ‘sustainable agricultural production’ and ‘natural regulations’ are very closely related. It is another question that the two terms will be realised in different ways. In our paper we would like to prove this hypothesis. The solution of the following tasks need a dynamic approach because of continuously changing conditions: micro evolutionary phenomena are occurring in the field and in the neighbour areas, and additionally the climate change should also be taken into account. The most important research topics are the following, inter alia:

1. *Contributing to the improvement of accuracy of nitrogen dynamics models.* The aim of such models is to describe soil conditions in which the speed of root penetration is larger than the nitrogen diffusion intensity. Therefore nitrogen leaching can be avoided or drastically reduced.
2. According to our experience, *by increasing the influencing parameters the accuracy of decision support models can be improved* in order to achieve sustainable technologies.
3. Permanently improving the detection and monitoring techniques aimed at recognizing the attacks of insects, weeds, microorganisms etc.; consequently, the amount of applied chemicals can be extremely reduced.
4. Investigation of climate change impact on sustainable crop production.

The above mentioned research fields are connected to each other for at least two reasons: 1. They all have to be solved in order to meet the challenges presented by the criteria of sustainability. 2. The solutions can be achieved only by applying precision crop production technologies in all cases. A precision crop production technology can be described by two main characteristics: 1. It has to be precise; e.g. in the case of chemical application +/- 1-2% accuracy should be realized. 2. The technology has to be site-specific. The goal is to achieve the +/- 2 cm accuracy at the level of all technological elements (planting, weed control, fertilizer, plant protection). The tendency nowadays is that site-specific treatment moves from the quasi -homogenous management zones level into the individual crop level; in other words, the management zones are decreasing to one individual plant (e.g. maize) or to small group of plants (e.g. cereals). This is the way to achieve real sustainable crop production.

Consequently, the definition of precision agriculture should be supplemented with the above mentioned tendency, namely the size of management zones are decreasing into individual crop level.

This article focuses on the investigation of the impact of climate change on sustainable crop production in the future (Topic number 4 mentioned above). At the same time we are also taking into consideration the relevant aspects of the other three topics as well.

MATERIALS AND METHODS

In research connected to climate change many authors emphasize the importance of the application of precision agriculture technologies at management zones level, moreover they also require the evaluation of the different levels: individual plant → field → land → region and global (Fischer et al., 2005, Fischer et al., 2006, Tian et al., 2012, Tian et al., 2013, Thorp et al., 2007). Therefore, the response of the physiological process of individual crops to micro-environmental changes and the adaptation of the crop community to regional and global climate changes can be exemplified. As we have mentioned earlier, in precision agriculture the management zones are becoming smaller and smaller, down to the individual plant level, firstly in the case of monograin seeding (e.g. maize), which means ~ 0.2 m^2 management zone size, and secondly with seed drillers (cereals) the size of the management zone can be the same, however the number of plants are three to five in this case. On the other hand, nearly all of the articles published in connection with evaluating the effect of climate change on agricultural production suggest the importance of topic first and second; or rather suggest using the results provided by decision support models (Fischer et al., 2005; Fischer et al., 2006; Thorp et al., 2007; Wang et al.; 2011).

The utilization of plant production potential based on energy balance calculations: net output-input ratio calculations

In this approach net energy function has to be defined, and based on these functions several input variations have to be given. In all variations the cumulative energy input has to be almost the same. It is important to note that the uncertainty level of the forms of the various energy inputs is different, for instance the same amount of energy can be put into the systems based on labour or machinery. At the same time the uncertainty level of manual work is much higher than that of up-to-date technology. For this reason the methods applied in our study are valid for those regions where the minimal expectations of PA exist. Therefore decreasing the damage caused by climatic changes in both developed and developing countries is possible by applying precision crop production technologies. The management zones of a given field are determined by means of applying artificial intelligence systems (fuzzy logic – Mike-Hegedűs, 2006), and the maximum of the net energy (E_{out}-E_{inp}) level is determined in these management zones, too (Fig 1.).

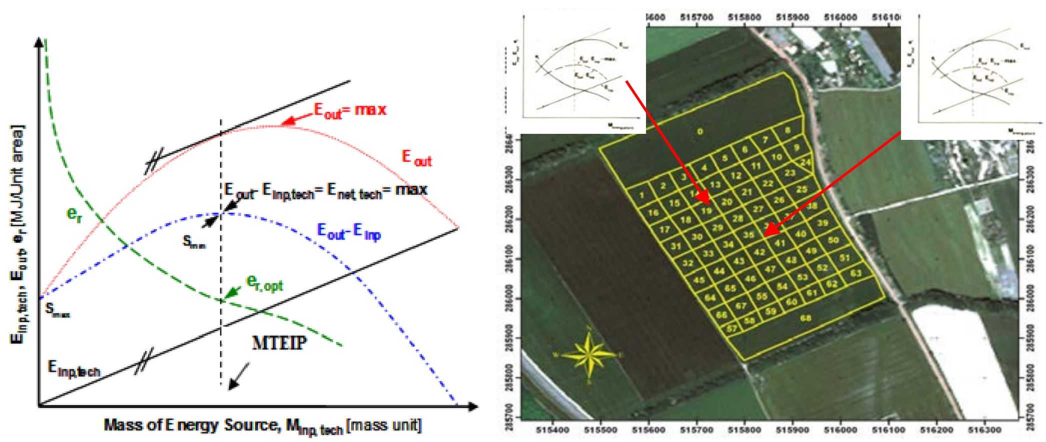


Figure 1a (left). Theoretical demonstration of Maximal Technological Energy Input (MTEIP) (Neményi and Milics, 2009; Neményi and Milics, 2010). Where: $E_{inp,techn}$ = technologic energy input; E_{out} = energy of produced biomass; e_r=E_{out} / $E_{inp,techn}$
Figure 1b (right). Calculation of the MTEIP of management zones.

The diagram shows the creation of net energy function (E_{inp}-E_{out}). At the maximum of this function can be found the maximum technological energy input (MTEIP).
Philosophical approaches: solar energy and utilization of water (irrigation) require different approaches.

Solar energy cannot be "over utilized", however the utilization of water resources is limited. There is an optimum in this case as well from energy point of view, namely where too much soil water is used for irrigation, consequently the ground water level is decreasing, therefore irrigation water for the plants needs more energy input. As a result energy input-output analysis can be applied in this case as well, since there is a maximum of input, which means a limit for possible irrigation.

Crop decision support simulation model

The application of the worldwide used DSSAT/Ceres-Maize (Tian et al., 2012; Thorp et al., 2007) in connection to precision agriculture appeared for the first time at the research management zone level in 2013 (Nyéki et al., 2013).

The current version of Decision Support System for Agrotechnology (DSSAT), ver. 4.5, the Ceres Maize model simulates the plant growth, biomass production, physiological processes, photosynthesis, respiration, leaf area index, root weight, etc (Hoogenboom et al. 2003; Hoogenboom et al., 2010). The DSSAT model inputs contain soil, experiment, management and phenological phase's database and daily meteorological, as well (Hoogenboom et al., 2003; Hoogenboom et al., 2010; Nyéki et al., 2013; Tian et al., 2012). The soil is includes the information's of the topsoil (0-30 cm). Each management zones in the database is linked to soil parameters, namely: colour, drainage rate, depth, bulk density, organic carbon, physical texture, clay fraction, soil pH, and other properties.

On the basis of the experiences with DSSAT the impact of climate change on maize yield (three soil types) was investigated until 2100.

The DSSAT can calculated rainfed and irrigated conditions at a field level. Based on the results of the model we can calculate the need for variable rate irrigation for the management zones. These calculations are valid for both requirements of sustainability being a field rainfed or irrigated. One of the main characteristics of the agro-ecological models is the ability to determine the fertility potential of a given land.

Climate data for modelling

The stochastic climate data for the investigation of the impacts of climate change in our region were downloaded from Ensembles site (ENSEMBLE PROJECT: An Integrated Project under the 6th Framework Programme of the EU). Some scenarios of Ensemble project are integrated into global climate models (Diffenbaugh and Field, 2013).

The Ensemble project was financed by EU between 2005 and 2009 in the FP6. The previous projects were Prudence and Cordex. The project had 69 partners, and was coordinated by the Hadley Centre at the Met Office in the UK. The project created a climate forecasting system (timescales: seasonal, decadal and longer) at a global, regional and local level. One of the most important objectives of the model was to make usable the results of "multi-model climate change global simulation" predictions for the broader user groups, enabling the researchers in the field of agriculture, water management, health, energy supply, food security etc. to integrate these data into their small scale databases used for their decision support systems.

The Ensembles project helps to fulfil the requirements of the Kyoto protocol, and makes recommendations for the IPCC Report (Third Assessment Report, 2001).

Some simulations have been extended beyond 2100 with constant use of the B1 and A1B scenarios, and additional simulations have been performed with 1% increase of CO^2 per year with stabilization at $2xCO^2$ and $4xCO^2$. For the yield predictions we used six Ensembles-based regional models (Table 1) because they provide data with high temporal resolution (daily) results. We used the following eight different meteorological parameters: daily maximum and minimum temperatures, wind speed, amount of precipitation, relative humidity, potential evaporation, sunshine duration and surface radiation.

Six validated regional climate models of the Ensembles Project (RT3 program) were integrated into the DSSAT model for the yield prediction, one of them provides database only until 2075, the others until 2100 (Fig. 2).

These models (C4I-HadCM3, DMI-ARPEGE, KNMI-ECHAM5, ETZH-HadCM3Q, MPI-ECHAM5, SMHI-BCM) have daily parameters in

25 km^2 resolution at A1B (this scenario assumes balance between the use of fossil fuels and renewable energy sources). At the same time the model assumes that the average global atmospheric CO^2 content will be doubled (the present level of carbon dioxide is 395 ppm and the simulation predicts 700 ppm by the end of this century). The above mentioned scenarios of A1B are used in IPCC Reports (e.g. IPCC Report, 2014), too.

Altogether about fifty additional soil and agrotechnological parameters were taken into consideration in the DSSAT model.

Matlab (Ver.: 7.14) with Mapping (Ver.: 3.5) and Statistic (Ver.: 8.0) Toolboxes were used to open and process the raw data downloaded from the project website (http://www.ensembles-eu.org/). The predicted climatic data were spatially investigated used coordinates of the experimental field.

Table 1. Basic characteristics of the regional climate models.

Model	Country	Institute	Spatial and *temporal* distribution (2000-2100 in data package of ten years)
C4I-HadCM3	Ireland	Community Climate Changes Consortium for Ireland	190*190**3600*
DMI-ARPEGE	Denmark	Danish Meteorological Institute	174*190**3652*
KNMI-ECHAM5	Netherlands	The Royal Netherlands Meteorological Institute	170*190**3652*
ETZH-HadCM3Q	Switzerland	Swiss Institute for Technology	170*190**3600*
MPI-ECHAM5	Germany	Max-Planck-Institute for Meteorology	170*190**3652*
SMHI-BCM	Sweden	Swedish Meteorological and Hydrologic Institute	170*190**3652*

Precision crop production

Precision crop production research activities were started during the mid-'90s at the Institute of Biosystems Engineering, Faculty of Agricultural and Food Sciences, University of West Hungary (Csiba et al, 2012; Nagy et al., 2013; Neményi et al.; 2003, Neményi et al., 2006a and 2006b). The research area is 15.3 ha which is divided into management zones (each unit is ~0.25 ha). The determination of the size of the treatment units is described by Mesterházi (2003) and Mike – Hegedűs (2006). The field includes three soil texture classes: loam, silt loam and sandy loam soils.

In the selected treatment units (management zones), soil physical parameters showed certain variability in the soil particle size. From West side to East side of the experimental field, clay content has decreased from 15.6% to 8%, the change of content of sand: 24.9% to 48.9%, SOM: 1.82 to 1.92. The other used soil parameters can be seen on Table 2.

Table 2. The average amount of by the model used parameters at three soil physical categories.

	Zala county			Mosonmagyaróvár		
	loam	sandy loam	silt loam	loam	sandy loam	silt loam
pH KCl	6.79	7.28	7.67	7.58	7.48	7.51
CaCO3	21	17.1	16	18.20	16.98	17.73
P2O5	220.1	219.24	235.45	223.67	220.50	245.50
K2O	287.45	300.28	350.1	294.67	314.50	387.25
Na	56	70	54.3	58.03	61.70	59.40
NO2-NO3-N	9.45	8.52	9.11	9.32	9.57	10.15

Mg	99	98.12	91.23	133.00	100.98	95.58
SO4	25.66	32	29.8	27.67	34.23	32.45
Cu	1.52	1.53	3.19	2.69	2.96	2.91
Mn	20.70	21.7	22.4	19.50	23.68	23.38
Zn	1.03	1.27	1.58	2.60	3.28	3.56
organic matter	1.47	1.08	2.04	1.70	1.60	1.73
clay content	18.01	14.6	22.42	15.6	15.6	23.9
silt content	42.17	29.62	63.7	38.8	30.8	66.3

Soil characteristics of 39 investigated points of Zala County was provided by the Hungarian Soil Information and Monitoring System (SIMS). It was developed by the Research Institute for Soil Science and Agricultural Chemistry (RISSAC) of the Hungarian Academy of Sciences in 1992. SIMS offers national level database; it is based on soil survey experiences, general and thematic maps and other soil data. The monitoring system harmonizes with the EU level soils database and the same framework was developed by the Soil Survey Program Plan in the USA in 1992 as well.

This system contains soil information, for example the quality of Hungarian soils, including the general soil characteristics, element content of soils and potentially toxic microelements. The database covers each county (19) with almost 1300 sampling points. They are situated in arable land, in forest and some are so-called special points, which focus on environmental problems. The soil sampling is carried out annually and in every 1, 3, 6 years depending on the characteristics of samples.

The instrumentation of PA technologies was the same as described in Nyéki et al. (2013).

RESULTS AND DISCUSSION

The climatic conditions of surroundings of Mosonmagyaróvár from a meteorological point of view represent the Hungarian average (Varga-Haszonits et al., 1999). The other investigated area is Zala County (Table 3). Soil textures which were used for the DSSAT calculations in both cases are almost the same: loam, sandy loam and silt loam soil physical types (Fig. 2). The experiences and calculations in Mosonmagyaróvár were carried out for the research field, for Zala county the averaged climate data of a middle grid (centre: N 46^{o}36'05.72", E 16^{o}56'38.88") was used.

Investigation of precision technologies of the field level (management zones) and the county level shows the relationship between the two levels. It represents the opportunity for building a hierarchical system from management zone (or individual crop level) to regional and, furthermore, global level.

Table 3. Average precipitation during 1951-2000, and 1971-2000 in Mosonmagyaróvár and Zalaegerszeg.

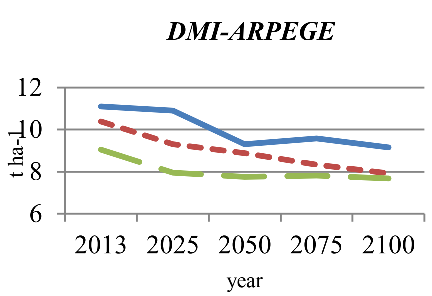
Station	Period		II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
Mosonmagyaróvár	1951-2000	33	33	35	43	54	66	71	57	46	43	53	44	**577**
Mosonmagyaróvár	1971-2000	34	30	33	42	55	63	63	54	52	40	49	42	**556**
Zalaegerszeg	1951-2000	32	32	40	53	70	87	84	74	64	55	64	46	**701**
Zalaegerszeg	1971-2000	29	29	38	52	68	82	80	73	65	56	61	45	**678**

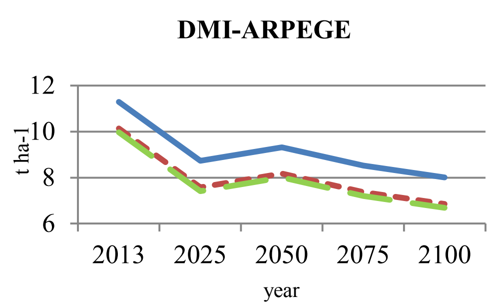
The Meteorological Station of the Faculty of Agricultural and Food Sciences, University of West Hungary provides weather data for crop modelling in Mosonmagyaróvár. It is situated 1.8 km from the research field. Zalaegerszeg is the county city (Table 3), located 15 km far from the investigated location.

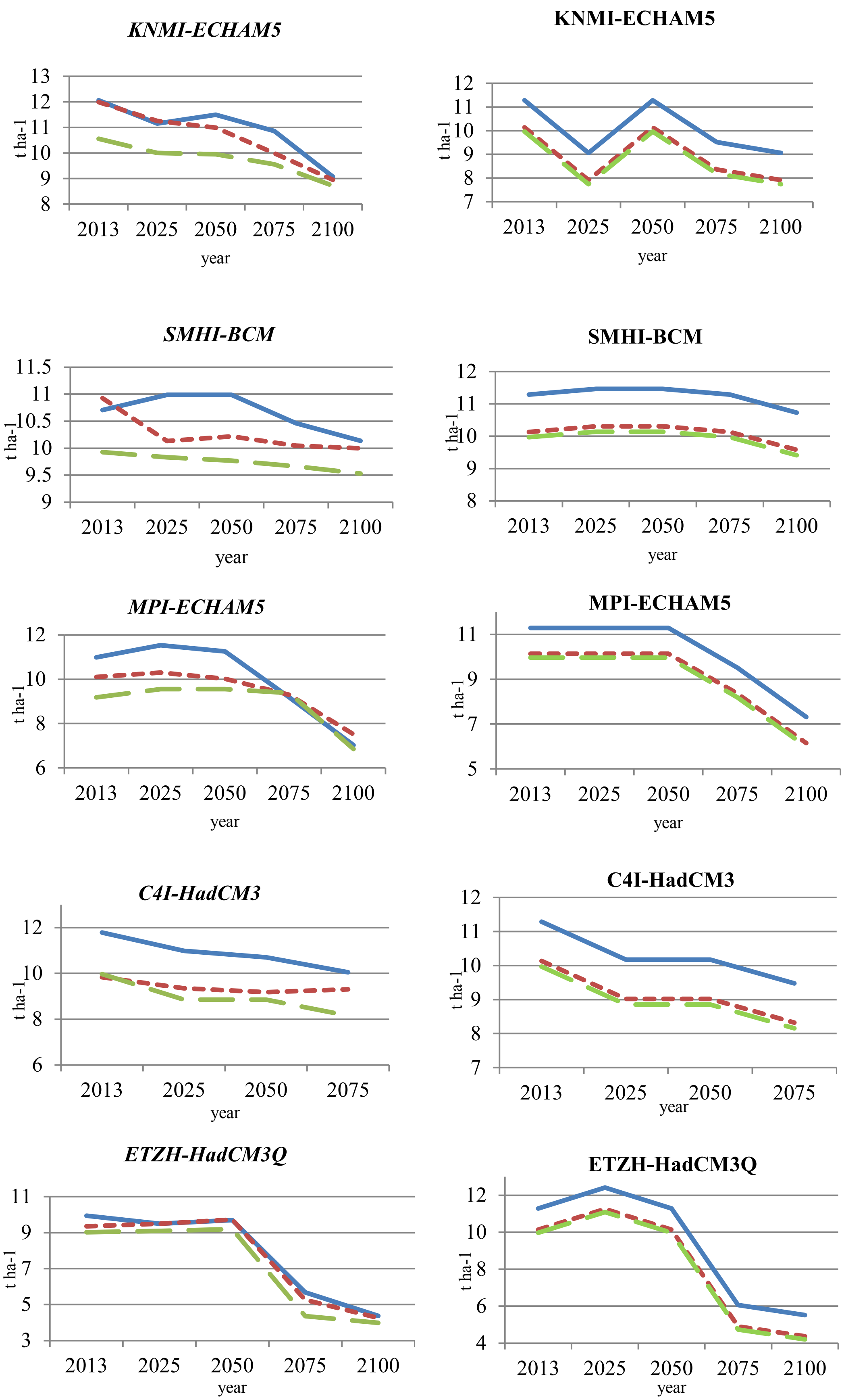
By the year 2100 four out of the five models have predicted annual precipitation between 400-750 mm in Mosonmagyaróvár and 550-800 mm in Zala County (Table 4). In the investigated location the average annual precipitation in the last ten years was 556 mm in Mosonmagyaróvár and in Zala County was ~ 678 mm, which is significantly lower than the predicted. These values prove the inaccuracy of climate models. Tab. 4 indicates the significant decreasing of precipitation in the vegetation period between 2075 and 2100 in Zala County. The only exception is DMI-ARPEGE model. This tendency appears moderately in the area of Mosonmagyaróvár. In both areas the predicted yield has to be carefully investigated where precipitation in the vegetation period is predicted below 200 mm.

Table 4. Amount of precipitation (mm) in Zala County and in Mosonmagyaróvár (2013-2100).

	Zala County					**Mosonmagyaróvár**				
	2013	**2025**	**2050**	**2075**	**2100**	**2013**	**2025**	**2050**	**2075**	**2100**
MPI-ECHAM5 annual	789	765	719	598	658	800	759	724	550	658
growing period	325	400	399	297	174	379	365	360	259	174
KNMI-ECHAM5 annual	790	660	899	800	699	800	653	891	800	740
growing period	295	240	467	311	199	379	182	397	259	184
SMHI-BCM annual	800	800	869	811	682	800	795	875	783	700
growing period	365	450	460	459	219	379	421	418	398	340
ETZH-HadCM3Q annual	800	886	688	448	420	800	886	688	448	420
growing period	379	220	290	280	100	379	450	397	126	100
DMI-ARPEGE annual	880	555	583	415	550	800	529	593	500	550
growing period	415	225	263	154	215	379	169	224	210	200







KNMI-ECHAM5
t ha-1
year
2013 2025 2050 2075 2100
KNMI-ECHAM5
SMHI-BCM
SMHI-BCM
MPI-ECHAM5
MPI-ECHAM5
C4I-HadCM3
C4I-HadCM3
ETZH-HadCM3Q
ETZH-HadCM3Q

Figure 2. Predicted maize yield by various models until 2100 in *Zala County (left)* and in Mosonmagyaróvár (right) in the three soil texture types: ——— loam, - - - sandy loam, ——— silt loam.

The Fig. 2 shows that the various climate models result different tendencies at the three soil texture types in Zala County. However in the case of the silt loam and sandy loam soils no differences can be found.

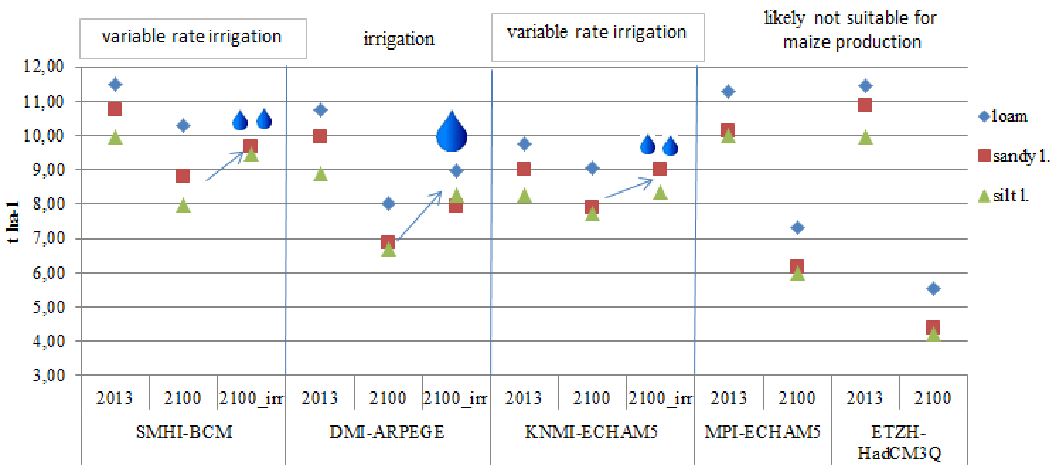


Figure 3. Predicted maize yield in Mosonmagyaróvár in 2100 with irrigation applications.

Concerning the yearly precipitation data, 35% yield decrease is predicted by MPI-ECHAM5 model and 52% in HadCM3Q, which most likely results in unfavourable conditions for maize production in 2100.

Concerning SMHI-BCM and KNMI-ECHAM5 models, if precision irrigation is applied – primarily in the case of sandy loam and silt loam soil types – the effect of climate change is moderated practically to zero, e.g. the expected yield remains at the same level.

In the case DMI-ARPEGE scenario should become practice, where decrease of yield is 25% only homogeneous irrigation can moderate the effect of the predicted climate change (Fig. 3).

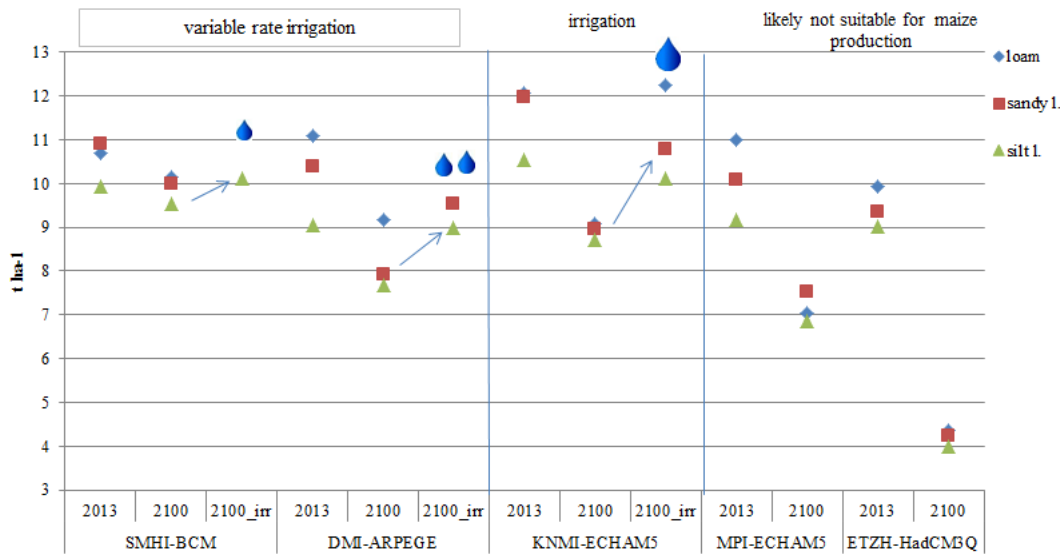


Figure 4. Predicted maize yield in Zala County in 2100 with irrigation applications.

In the case of Zala County (Fig. 4), if ETZH-HadCM3Q or MPI-ECHAM5 scenarios occur, most likely the climatic conditions will not be suitable for maize production. Should the SMHI-BCM and DMI-ARPEGE scenarios occur, Variable Rate Irrigation will be needed in silt loam and sandy loam management zones in order to keep the present stable corn yields that are currently achieved with natural rainfall. In Zala County in the case KNMI-ECHAM5 scenario occurs homogeneous irrigation is needed for the same yield level.

CONCLUSIONS

The fertility of production units can be categorized by applying energy input-output analysis. In our opinion, this fertility potential ranking could be more accurate than the earlier used evaluating (Fischer et al., 2006).

It seems clear that one of the important possibilities of reducing the effect of climate change on agriculture would be precision irrigation.

On the base of Figures 4 and 5 variable rate irrigation plans can be created.

However, the responses should also be differently: change of genotypes, and technologies (site-specific soil tillage, planting, nitrogen replenishment, irrigation, etc.).

It should be noted that the impact of climate change on maize production is in the investigated two conditions moderately different.

In our further project “Agricultural Climate 2” starting in October 2014 we will predict crop yields and agro-ecological potential in aspect of climate change for the whole country (~ 93.000 km2 - 19 county) with various soil texture.

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