IDŐJÁRÁS

QUARTERLY JOURNAL
OF THE HUNGARIAN METEOROLOGICAL SERVICE

Special Issue: Recent Challenges in Agrometeorology in Hungary

Guest Editors: **Angéla Anda** and **Sándor Szalai**

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VOL. 116 * NO. 3 * JULY – SEPTEMBER 2012

IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service

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Recent Challenges in Agrometeorology in Hungary

Climate of Hungary is favorable for agricultural production. Any kind of agricultural productions (intensive, extensive, ecological, horticulture, etc.) needs detailed climatological, meteorological, especially agrometeorological information. Hungary had a high level agrometeorology, both theoretically and experimentally, before the change around 1990. In the first half of 90s, the strong decrease in the agriculture affected the development of the agrometeorology as well. Experimental poligons and departments were closed and experts left the branch. Recognizing the changing internal and external conditions, agriculture has an upwings in Hungary recently, both small and medium enterprises and large companies. Unfortunately, the lost expertise, information, and data bases cannot be reproduced as fast, as the production increases and it would be required. Feeling the demands of the users, the Meteorological Scientific Committee of the Hungarian Academy of Sciences (MSC HAS) decided to dedicate the annually organized Meteorological Scientific Days to agrometeorology in 2011. The disantageous situation of agrometeorology urged the organisers to invite more than usual foreigner lecturer to the connected conference. During the organizational work, a good picture has been evolved on the status of the present agrometeorology in Hungary. Benefits and gaps were detected the research level at individual topics according to the international results became more clear. The picture has positive features: many results have been archived despite of the individual, project-by-project development. Experts and/or research groups follow the main international directions on their field of interest. From the other side, there are many gaps, and some investigations are far from the international level, mostly because of the low level of resources both personally and financially. This volume contents only a small part of the presentations, but could give a first guess on some developments in the country. Many lessons have been learned. First, despite of the mosaic development of the discipline, a lot of results have been archived. This is because of the external requests, the needs of users for agrometeorological information. This leads to the second point: agrometeorology needs more support, not only from the users, but on state level, where higher level coordination is possible, and this necessity is the third lesson. Unfortunately, neither of the research groups have enough resources for a continuously high-level, wide range research production. This would be possible only by more stable supporting systems and better organization structures.

We strongly believe, that by the common efforts of the stakeholder groups, especially the groups of scientific and policy decision makers will lead the development of the Hungarian agrometeorology to get international position similarly to the past, and this publication is a small, but substantial step in this direction.

Angéla Anda and *Sándor Szalai*
Guest Editors

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Quarterly Journal of the Hungarian Meteorological Service
Vol. 116, No. 3, July–September 2012, pp. 173-194

Evaluating the performance of stochastic distribution models for European beech at low-elevation xeric limits

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(Manuscript received in final form April 10, 2012)

Abstract—Projection for future climate conditions is an increasingly popular application of distribution modeling. However, good performance of a model under current climate does not guarantee similar performance under future climate, particularly where prediction is outside the range of environmental conditions on which the original model was set up. The objective of this study was to model the habitat suitability for beech forests during three terms (2025, 2050, and 2100) in the 21st century in Hungary using species distribution models (SDMs).

Six out of the eight methods were unsuited for predicting climate change effects on the future distribution of beech. This underlines that predictions for conservation and management issues should be based on multimodel assessments. Spatial inconsistency appeared mainly in regions, where beech is situated close to its distributional range limit (xeric limit). This suggests that the basic theoretical assumption of species distribution models may not hold at the trailing edge.

Key-words: beech, Hungary, climate change, xeric limit, Ellenberg's climate quotient

1. Introduction

Fagus sylvatica L. is one of the dominant tree species in central European temperate forests with high physiological tolerance and competitiveness

(*Ellenberg et al.*, 1992). Drought sensitivity is assumed to be a key factor limiting growth and distribution of beech close to its lower distributional limit (xeric limit) (*Mátyás et al.*, 2009) in southern and south-eastern Europe (*Backes* and *Leuschner,* 2000).

Several studies suggested a decline in beech regeneration (*Rennenberg et al.,* 2004*; Penuelas et al.*, 2007) or extensive beech dieback (*Berki et al.,* 2009*; Czúcz et al.,* 2010*; Kramer et al.,* 2010*; Lindner et al.,* 2010) under increasingly adverse climatic conditions (*Gálos et al.,* 2007). Consequently, modeling the vitality response of beech to predicted changes of climate is a critical issue (*Franke* and *Köstner,* 2007; *Mátyás,* 2009).

For management and conservation issues (*Hannah et al.*, 2002), species distribution models (SDMs) have been extensively used. SDMs derive the species' environmental envelope from the observed conditions at the localities where it is currently known to occur. They can be evaluated for their ability to predict current distributions, but it is not tested whether models that are successful in predicting current distributions are equally powerful in predicting distributions under different climates. Studies comparing modeling algorithms are now common (*Segurado* and *Araujo,* 2004; *Elith et al.*, 2006; *Tsoar et al.*, 2007), but *Thuiller et al.* (2004) have pointed out the problem of strong variation between SDM predictions for future distributions. SDMs are 'statistical' models without specific ecological knowledge, they do not describe 'cause and effect' between model parameters and response (*Guisan* and *Zimmermann,* 2000; *Pearson* and *Dawson,* 2003; *Kearney* and *Porter,* 2004).

In this study, we compared and evaluated the results of eight SDMs for beech (*Fagus sylvatica* L.). Beech is considered a climate sensitive species, which is uniquely vulnerable in south-eastern Europe and, therefore, well suited for modeling. Another advantage is that compared to other tree species in Hungary, its populations are in a relatively undisturbed condition as they were rarely regenerated artificially, and the species' reproductive material was not subject to commercial relocations (*Mátyás et al.*, 2010). Modeling focused on its distribution in Hungary, since here the retreat of the species is imminent. This ecologically and climatically specific area has been largely neglected by European studies (*Jump et al.*, 2009; *Lindner et al.*, 2010; *Mátyás*, 2010).

We address the following questions:

1. Which SDM can best describe the present distribution of beech in Hungary?
2. What are the projections for the potential future distribution of beech using SDMs?

To answer the research questions we modeled the current and potential future distribution of beech in Hungary using SDMs, and compared the performance of the different methods.

2. *Material and methods*

There are many environmental niche modeling packages available; for example, MaxEnt (*Phillips et al.,* 2006), GARP (*Stockwell* and *Peters,* 1999), ModEco (*Guo* and *Liu,* 2010), BIOMOD (*Thuiller et al.,* 2009), and Openmodeller (*Munoz et al.,* 2009).

The primary reason to choose ModEco (*Guo* and *Liu,* 2010) was that it contains models for dealing with presence-only and presence/absence data. Additional advantages of ModEco are tools for feature analysis, and model performance evaluation, as well as an accuracy assessment tool. As ModEco incorporates several modeling methods, the training, analyses, and assessments can be carried out on the same platform supporting consistent comparisons.

A disadvantage of the platform is that a trained model needs new environmental surfaces for climate change predictions, which slows down the process (*Fig. 1*).

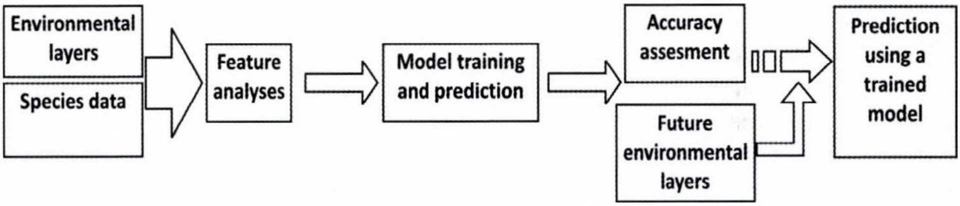

Fig. 1. General workflow of the modeling process.

2.1. *Environmental variables*

96 different environmental predictor surface maps were used as input, all with a spatial resolution of 0.0083 (appr. 1×1 km). Environmental variables were selected according to their relevance to tree survival and growth. Climatic variables were taken as surrogates for variables having more direct physiological roles in limiting the ability of plants to survive.

Although the main environmental data used were climate data, soil and geomorphological factors were also included. Soil texture and moisture regimes are indirect variables considered as surrogates for soil type, with direct impacts on nutrient and water availability for plant growth (*Austin* and *Smith, 1989*). Geomorphological factors were used as surrogates for sites in non-zonal positions.

2.2. *Soil data*

Three soil variables (soil texture, soil moisture regime, and genetic soil type – *AGROTOPO*, 2002) and three topographical factors (mean altitude, slope, and dominant orientation) were applied.

2.3. Climatic data

The dataset included monthly maximum, minimum, and mean temperatures, and monthly precipitation (48 variables in total); and a set of 19 climate-derived variables obtained from the "worldclim" database (*Hijmans et al.*, 2005).

2.4. Bioclimatic indices

12 bioclimatic factors (23 variables in total) computed from minimum and maximum monthly averaged temperatures and monthly precipitations were used (*Table 1.*). These bioclimatic predictors are: thermicity index (*Rivas-Martínez*, 1996), ombrothermic indices (*Rivas-Martínez,* 1990), de Martonne aridity index (*de Martonne,* 1942), Ellenberg quotients (*Ellenberg,* 1986; *Ellenberg*, 1996), monthly potential evapotranspiration (*Thornthwaite,* 1948), Box moisture index of precipitation/evapotranspiration (*Box,* 1981), continentality indices (*Gorczinski*, 1920; *Emberger*, 1930), forest aridity index (*Führer*, 2010; *Führer et al.*, 2011), and beech tolerance index (*Berki et. al,* 2009).

2.5. Species data

Species data for the habitat modeling were derived from the Hungarian Forest Inventory database provided by the Central Agricultural Office. The database incorporates every forest subcompartment containing beech. (A tree species is registered in a forest subcompartment, if the mixture ratio of the given tree species exceeds the 5% threshold limit.) These subcompartments were considered in the model as "true - presence" observation points (in total 11,332 subcompartments). For the presence-absence methods, "pseudo-absence" points were created randomly throughout the country with a buffer zone of 1000 m around the presence points. The size of the buffer zone was determined according to the spatial resolution of the environmental layers. The amount of pseudo-absence points was equal to the number of the presence points. As the environmental data were given in a 1×1 km grid, distribution maps were also converted to a raster format with the same resolution.

At this point it should be emphasized, that forests in Hungary are managed forest, and therefore, the presence/absence of beech is human influenced.

2.6. Future climate

The downscaled "Climate Limited Area Modeling" (CLM) regional climate model was applied for simulation of future vitality condition of beech using the A1B scenario (mean of two runs) with a grid size of 0.2 for the period 2000–2100 (*Keuler et al.*, 2009). Downscaling to regional level requires some assumptions, e.g., GCM biases are small at boundary locations or regional dynamics are non-linear and add uncertainty or biases or both due to detailed parameterizations (*Wu et al.,* 2005)).

CLM model data were corrected using the delta change approach (*Hay et al.*, 2000), based on the mean deviation of the observed and simulated variables between 1960 and 2000 for each grid box. Corrected long-term averages from monthly air temperature and precipitation were derived by kriging interpolation considering the elevation for the periods 2011–2040, 2036–2065, and 2066–2095.

Table 1. Bioclimatic variables

Bioclimatic predictors	Formula or reference
Beech tolerance index (BTI)	$= (0.2P_3+0.5P_4+P_5+P_6+P_7+0.8P_8) / T_{6\text{–}8}$
Box moisture index (BMI)	$= \mathrm{P/PET}$
Continentality index (CONTINENTY)	$= \mathrm{T_{max}-T_{min}}$
De Martonne aridity index (DMI)	$= [(P/T+10)+12p/(t+10)]/2$
Ellenberg index (EQ)	$= (T_{max}/P)1000$
Forest Aridity Index (FAI)	$= 100(\mathrm{T_{7\text{–}8}})/(\mathrm{P_{5\text{–}7}+P_{7\text{–}8}})$
Gorczinski's continentality index (GCT)	$= ((1.7\,A)/(\sin L)) - 20.4$
Modified Ellenberg index (EQm)	$= (T_{max}/P_{veg})\ 1000$
Ombrothermic index (Io)	$= (P_p/T_p)10$
Ombrothermic index of the summer quarter (Iosq)	$= (\mathrm{P_{6\text{–}8}/T_{6\text{–}8}})/10$
Thermicity index (It)	$= (T + m + M)10$
Thornthwaite's formula (PET)	$= 16 N_m \left(\frac{10\bar{T}_i}{I}\right)^a, \quad I = \sum i_m = \sum \left(\frac{\bar{T}_i}{5}\right)^{1.5}$ $\mathrm{a} = 6.7*10^{-7}*I^3 - 7.7*10^{-5}*I^2 + 1.8*10^{-2}*I + 0.49$

T_{max}: mean temperature of the hottest month [°C]
T_{min}: mean temperature of the coldest month [°C]
P: annual precipitation [mm]
T: mean annual temperature [°C]
P_i: precipitation sum of the given month [mm]
P_{ii}: precipitation sum of the given months [mm]
T_{ii}: mean temperature of the given months [°C]
p: precipitation of the driest month [mm]
t: mean temperature of the driest month [°C]
PET: annual accumulated potential evapotranspiration calculated by the Thornthwaite equation [mm]
A: mean annual air temperature amplitude [°C]
L: latitude of the site [absolute value]
P_{veg}: precipitation sum of the vegetation period [mm]
P_p: Yearly Positive Precipitation [mm] (total average precipitation of those months whose average temperature is higher than 0°C)
T_p: Yearly Positive Temperature [°C] (sum of the monthly average temperature of those months whose average temperature is higher than 0°C)
m: average minimum temperature of the coldest month of the year [°C]
M: average maximum temperature of the coldest month of the year [°C]
N_m: monthly adjustment factor related to hours of daylight [–]
I: heat index for the year [–]

2.7. Modeling algorithms

We evaluated and compared the following eight methods: "presence-only" methods such as BioClim (*Nix*, 1986; *Busby*, 1991), Domain (*Carpenter et al.*, 1993), and one-class support vector machine (SVM) (*Vapnik*, 1995); „presence-absence" classification methods such as generalized linear model (GLM), artificial neural network using back-propagation algorithm (BP-ANN, *Maravelias et al.*, 2003), maximum likelihood classification (*Richards* and *Jia,* 1999), maximum entropy (MAXENT, *Phillips et al.*, 2006), and classification tree (CTree, *Breiman et al.*, 1984).

2.8. Accuracy assessment

Cross-validation accuracy, area under the receiver operator curve (AUC), receiver operating characteristic (ROC), error matrix and maximum kappa values were used to assess the accuracy of presence/absence-based models (*Wiley et al.*, 2003; *Elith et al.*, 2006). For presence-only models, the above mentioned measures are not applicable, therefore, the true positive rate (TPR) vs. the factional prediction area (FPA) as a proxy for true positive rate vs. false positive rate, and the area under TPR vs. FPA were used (*Guo et al.*, 2005; *Phillips et al.*, 2006).

2.9. Factor analyses

Factor importance analysis was carried out to examine the contributions of different environmental factors (with-only and without a specific environmental factor) to the overall classification accuracy of SDMs, based on the kappa values (*Forman*, 2003). This importance analysis is designed to evaluate the change of classification accuracy of the model (*Phillips*, 2006).

Some models (i.e., Maximum likelihood, Domain) are sensitive to the number of the predictors therefore, the reduction of environmental factors was essential in some cases. Redundant environmental layers were identified via pairwise correlations. Variables with a correlation higher than 0.8 were considered redundant. Between any two redundant variables, those related to climate extremes were preferred.

3. *Results*

3.1. Performance of presence-only methods

3.1.1. Potential current distribution

Presence-only methods showed marked variation in modeling success. Although *TPR* was very similar, the predicted area varied a lot among the models. Using the accuracy measures of presence-only data, the one-class SVM performed better (*TPR*: 0.794) for predicting current distribution than BioClim and Domain, but the predicted area was also greater. If we also consider the specifically generated pseudo-absence points during the assessment and penalize the false negative predictions by using the *ROC* score (true positive rate vs. true negative rate), Domain showed the best performance (*Table 2*).

Table 2. Parameters and statistical performance of presence-only methods for predicting potential current distribution of beech in Hungary

Models	**Parameters**	**Number of layers**	**True positive rate (TPR)**	**Predicted area**	***TPR* vs. predicted area**	***ROC***
BioClim	percentile: 96%	88	0.708	1.004	0.8924	0.898
Domain	similarity: 0.995	64	0.765	0.987	0.7264	**0.933**
One-class SVM	Nu:0.064 Gamma: 27.6	65	**0.794**	**1.318**	**0.9046**	0.909

There were significant regional differences between the modeled potential and the actual distribution. While BioClim, the simplest climate envelope model, predicted in total almost the observed suitable area, there still were regional biases. BioClim notably overpredicted in the Southwest (Zala county, south from Szombathely) and Northeast (Cserhát, north from the Mátra Mountains), but also a smaller patch north form the lake Balaton (Balaton-felvidék) was predicted as suitable for beech. BioClim systematically excluded the marginal sites (Mátra, Bükk, Zemplén, Kőszeg, Sopron, and Börzsöny Mountains, Mura Valley) and also failed in the Őrség and Aggtelek Karst. One-class SVM performed regionally similarly to BioClim, only the magnitude of the overprediction was greater. Domain predicted very precisely the current distribution of beech, almost all observation point were enclosed in the potential area (*Fig. 2–3*).

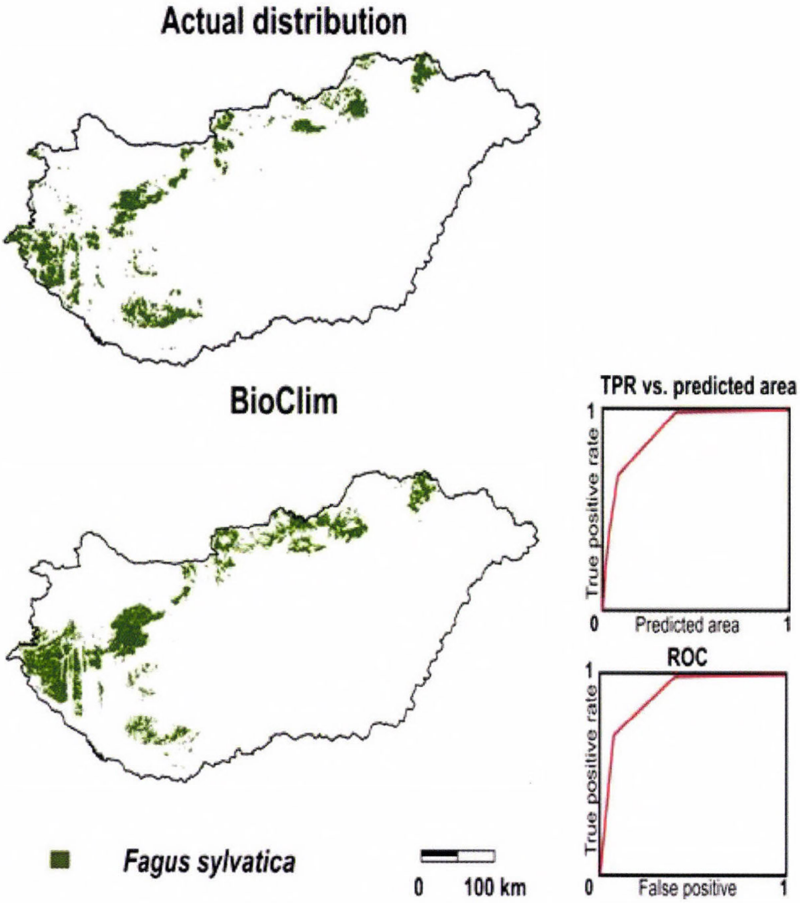

Fig. 2. Actual distribution and potential current distribution modeled by BioClim and the related operating curves. Green color represents observed localities of beech in the first map and areas modeled as suitable in the potential maps.

3.1.2. Future distribution

While the presence-only methods performed fairly well describing the current distribution of beech, all three methods were unsuited for predicting climate change impacts. BioClim and Domain removed all beech even for the near future (2011–2040), while one-class SVM predicted potential occurrence only for regions under sub-Mediterranean and subcontinental influences.

Prediction with Domain and BioClim was only possible when the number of the environmental predictors was strongly reduced.

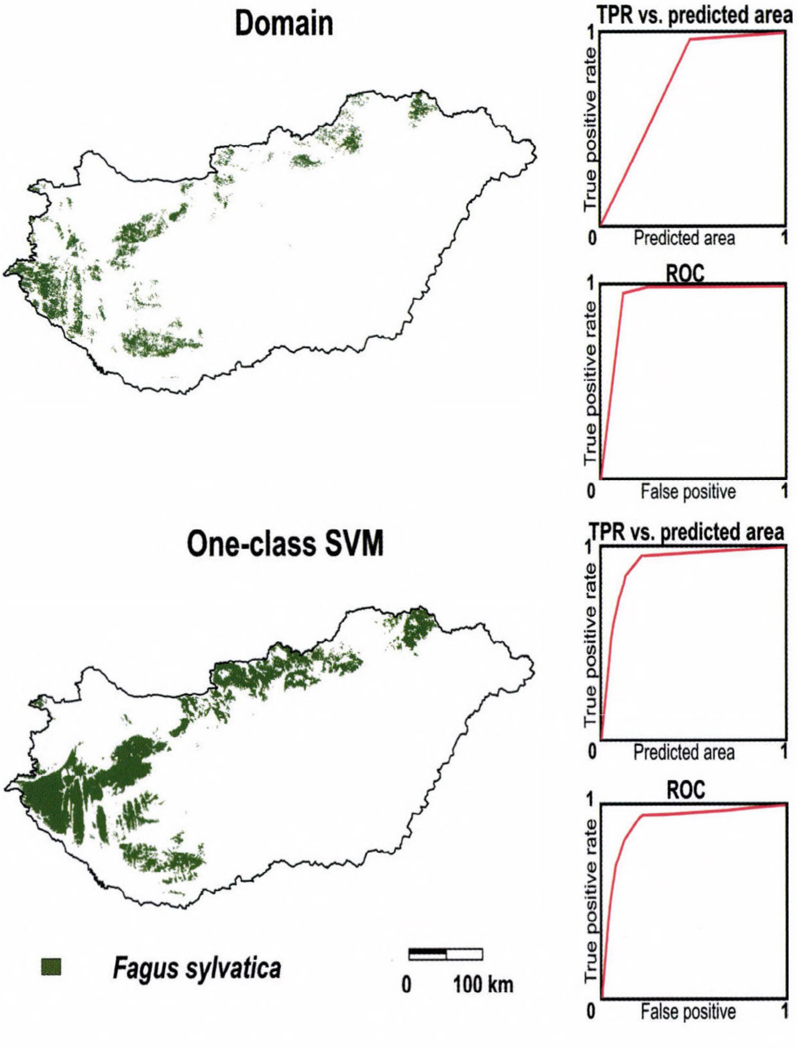

Fig. 3. Potential current distribution modeled by Domain and one-class SVM and the related operating curves. Green color represents areas modeled as suitable for beech.

3.2. Performance of presence/absence classification methods

3.2.1. Potential current distribution

Presence/absence classification methods outperformed presence-only models, the TPR and also the kappa score was higher in all cases (*Table 3*).

Table 3. Parameters and statistical performance of presence/absence models

Model	**Parameters**	**True positive rate (*TPR*)**	**Predicted area**	**Kappa index**
Artificial neural network with backpropagation (BP-ANN)	Momentum: 0.3 Learning rate: 0.1	0.9425	1.2096	**0.8336**
Classification tree (CTree)	Number of trails: 10 Window size: 20 Pruning confidence level: 0.25	0.9493	1.3196	**0.8431**
General linear model (GLM)	Link function type: LOGIT Threshold: 0.426	0.9592	1.6237	0.8174
Maximum entropy (MAXENT)	Omission rate: 0.05	0.9395	1.4362	0.8145
Maximum likelihood (MLC)	No parameter required	0.9415	1.5205	0.8076

MAXENT, MLC, and GLM performed relatively poorly, only GLM had high TPR (0.959), which was due to its strong overprediction of the species area (1.623). CTree and BP-ANN methods performed significantly better than the other models. The high *TPR*, the smaller predicted potential area, and the high kappa score indicated that these models are able to capture non-linear responses and can handle interactions between the variables.

Visually, the CTree model created a more dispersed potential area, while the BP-ANN model produced a less fragmented distribution with more distinct boundaries (*Fig. 4*).

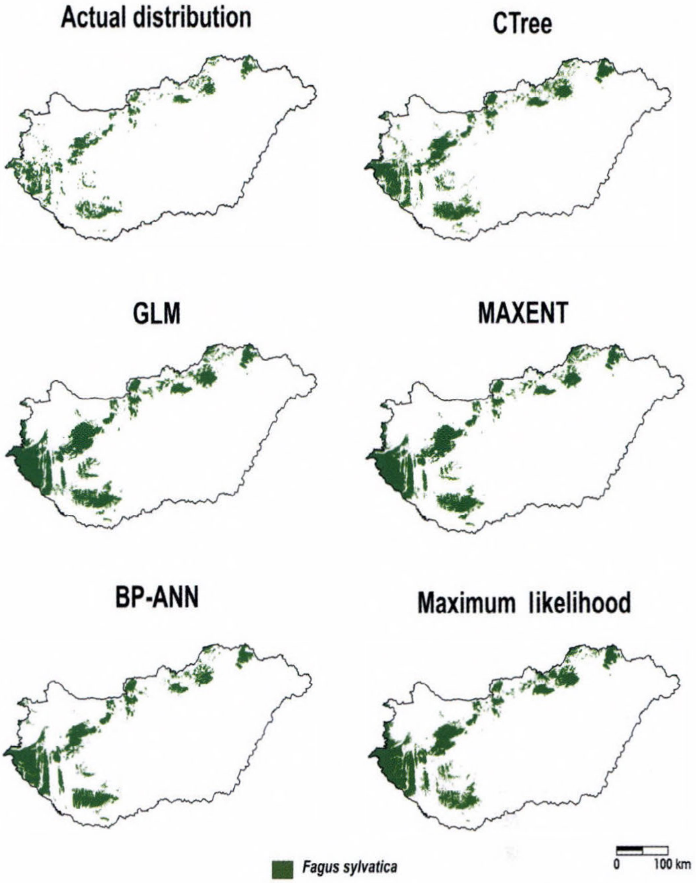

Fig. 4. Actual distribution and potential current distribution modeled by BP-ANN, CTree, GLM, MAXENT, and Maximum likelihood methods. Green color represents observed localities of beech in the top left map and areas modeled as suitable in the potential maps.

3.2.2. Future distribution

The Maximum likelihood method predicted complete extinction of beech for the whole country for the period 2011–2040. GLM overpredicted the distribution of beech in the near future, and marked regions as potential area, which are already out of the current distribution range. MAXENT predicted a considerable dieback even for the near future removing more than 91.6% of the current stands.

BP-ANN predicted almost no reduction in the potential area for the period 2011–2040 and a very slight (8.0%) for 2036–2065. A considerable shrinkage (56.8%) of the potential area was predicted only to the end of this century, which results that 45.2% of the current stands will be out of the potential area. Regionally, the most serious decrease was predicted for the sub-Mediterranean region in the Southwest.

CTree predicted a more pronounced shrinkage in all regions of Hungary by losing 37.3%, 67.5%, and 74.7%, respectively (*Fig. 5*).

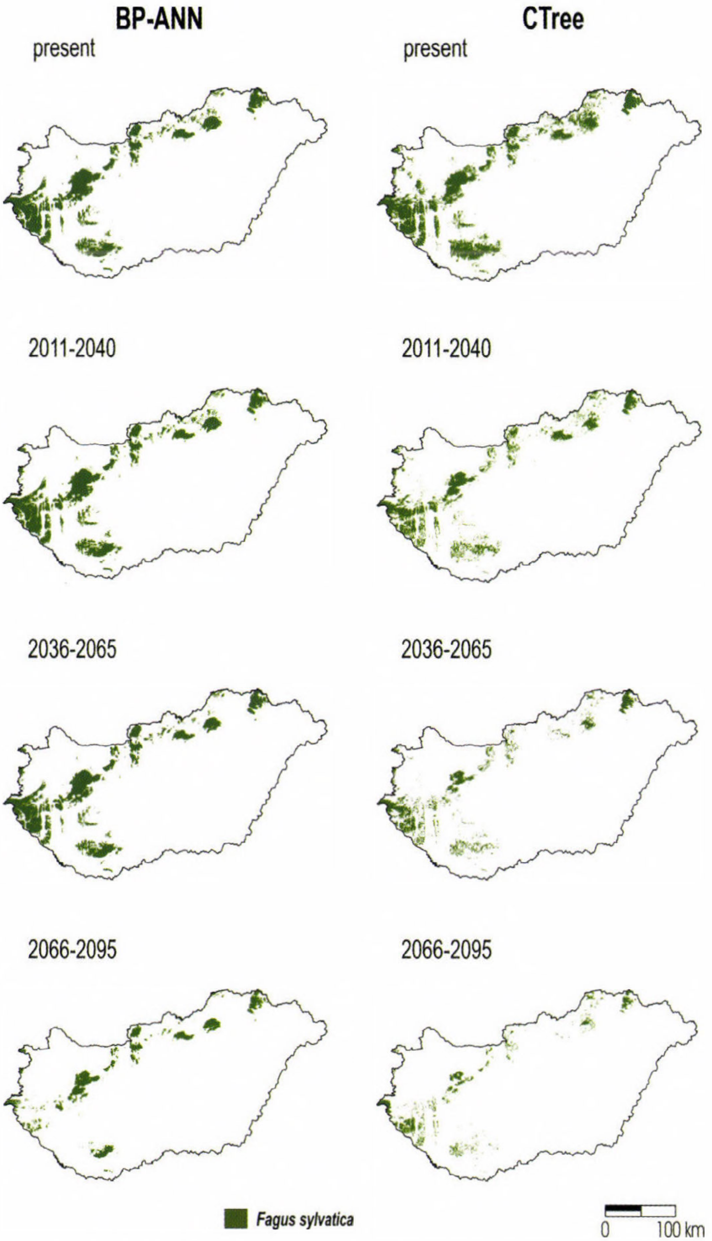

Fig. 5. Potential distribution modeled by BP-ANN and CTree for present and future conditions (2011–2040, 2036–2065, and 2066–2095, respectively). Green color represents areas modeled as suitable for beech during the given periods.

3.3. Factor importance analysis

Factor importance analysis is algorithm-sensitive, but among the environmental variables, the maximum temperature of May and the modified Ellenberg quotient appeared repeatedly as the most influential predictor. In addition, maximum temperatures of summer and precipitation of late summer played a significant role in determining the presence of beech (*Table 4*).

A climate quotient to characterize the humidity conditions of beech and oak forests was first suggested by *Ellenberg* (1986). He defined the climate quotient *EQ* as the quotient of the mean air temperature of the long-term hottest month per year and the annual precipitation sum. Later this quotient was changed to include a definition of the forest's growing period *(EQm)*, taking into account only the precipitation of the growing season (*Ellenberg, 1996*). This climate quotient has been successfully applied to separate areas dominated by beech from areas of boreal or thermophilic species (*Schlüter, 1968; Hofmann, 1968; Jensen et al., 2004; Czúcz et al., 2010*). *EQ* has been also used to evaluate sites of mixed beech-oak stands for studies of carbon and water relations (*Franke* and *Köstner, 2007*).

Table 4. The overall classification accuracy of the models and the most predictive five factors with their related kappa values resulting from the factor importance analyses. The repeatedly occurring predictors are in bold

	Models							
Rank	**BioClim**		**One-Class SVM**		**CTree**		**GLM**	
	Predictor	**kappa**	**Predictor**	**kappa**	**Predictor**	**kappa**	**Predictor**	**kappa**
	overall	0.611	overall	0.788	overall	0.843	overall	0.817
1.	**EQm**	0.570	**EQm**	0.533	**Tmax_05**	0.717	**Tmax_05**	0.708
2.	**Tmax_05**	0.565	Prec_09	0.511	Tmax_06	0.707	Tmax_06	0.697
3.	BMI	0.555	**Tmax_05**	0.491	Tmax_08	0.704	Tmax_07	0.673
4.	Prec_09	0.544	Tmax_08	0.544	Tmax_04	0.704	**EQm**	0.670
5.	IO	0.534	Prec_08	0.451	**EQm**	0.673	Tmean_05	0.664

4. Discussion

Overall, the BP-ANN method showed the highest model performance, whereas similarity- and ordination-based models (DOMAIN, BioClim, one-class SVM) showed the lowest performances by predicting the potential future distribution of beech. While some authors (e.g., *Mastrorillo et al.,* 1997; *Pearson et al.,* 2002) also consider BP-ANN to be advantageous to model species occurrences, these observations are not supported by other studies, where BP-ANN showed overall performances comparable to GLM (*Manel et al.,* 1999). Other studies also showed that similarity and ordination-based methods perform less well than advanced techniques, namely CTree and BP-ANN (*Elith* and *Burgman,* 2002). Since these studies did not always use the same parameterization, they are, however, not fully comparable.

4.1. Actual and potential current distribution

BioClim treats the environmental data values at the locations of species occurrence as multiple one-tailed percentile distributions. It creates hyperboxes to include a given percentile for each variable so that, for example, the fifth percentile is treated the same as the 95th percentile. This results in an approach in which locations with extreme conditions (wettest – driest, hottest – coldest, etc.) are considered as outliers. This is the reason, why BioClim obviously failed at the top of the mountains in the Northwest (coldest sites of Börzsöny, Mátra, Bükk, and Zemplén Mountains) and at low elevation sites in Zala (Mura Valley).

Domain is a similarity based model, which uses the Gower distance method to classify the suitability of any new sites. The more variables are incorporated, the more accurate is the similarity assessment of a new site. The calculation was very time consuming, but resulted in a very precise prediction with a high accuracy rate.

BioClim uses only hyperboxes to contain the presence data. Thus this model is often unsuitable for other forms of data that have irregular distributions in feature space. Therefore, one-class SVM was also applied. One-class SVMs seek to find an optimal hypersphere which contains all or most of the training points, at the same time tightly constraining the presence data in feature space. Originally, SVMs are designed for 2-class problems (separating two types of data) and optimized for working with low number of predictors. The relatively high number of the environmental variables produced a very complex distribution pattern which resulted in greater overprediction.

Although CTree has clear advantages over classic climate envelope methods, certain disadvantages emerged. CTree appeared to be very sensitive to the number of predictors. Even small changes produced highly divergent results. The dispersed potential map of CTree could be a sign of overfitting, which means, that the model is too specific (unbalance of specificity and sensitivity).

Except Domain, all models predicted larger potential area than the current distribution. The systematic overprediction of the models might be explained mainly by the following factors:

Human interaction: After the post-glacial recolonization, a general reduction of the distribution of tree species occurred as a result of deforestation and land use change. Due to the low-altitude occurrence of beech in the Southwest, beech forests were often transformed through human land use (plough-land, populated places). In the mountainous areas, human impact on beech forests has been traditionally low (cold and moist areas are unsuitable for agriculture), however, the low-elevation beech forests were often converted into oak forests (pasture).

Lack of soil data: Beech can be found on a wide scale of soil types from acidic to calcareous. However, beech is not able to tolerate quick changes of dry and wet soil conditions. Although, soil data were considered in the study, fine-scale soil information for forests was not available. Therefore, some models (BioClim, one-class SVM, GLM) assessed the macroclimate as suitable for beech in the west part Hungary. Nevertheless, its occurrence is often hindered by reduced aeration or unfavorable physical and textural characteristics of the soil.

Competition and other biotic interactions: Competition is an important mechanism that is absent from SDMs. Competitive tree species as predictors were not included in this work. Even if applying occurrence data of competitive species could enhance model performance by predicting current potential distribution, such reliable information is not available for the future (future distribution of competitors). We hypothesized that the occurrence of competitive tree species could be surrogated by applying a wide range of environmental predictors during the modeling.

Beside competition, other biotic interactions should be also considered, such as facilitation, pollination, herbivory, or symbiosis. However, databases for these factors do not exist.

Extreme events: Most SDMs are calibrated under the assumption that range margins are formulated by climatic means. The association of range margin and climatic mean may not hold when climatic extremes occur with a skewed frequency distribution, thus, predictions based on climatic means alone could overestimate ranges. The inclusion of real extreme measures could be especially important along the trailing edge (xeric limit) of the distribution (*Zimmermann et al.,* 2009).

4.2. Future potential distribution

The mathematical properties of the models can help to explain the differences in their predictive performance. The most important reason for the underprediction of BioClim is that the model is very sensitive to the occurrence of variables that are outside of what was observed as the current climate, even if this is not truly a limiting factor (*Tsoar et al.,* 2007). In Domain, all occurrence points are treated separately and, unlike in the other models, there is no generalization (creation of response functions). Domain is, therefore, very sensitive to the occurrence of new combinations of the environmental predictors, and this negatively affects its predictive ability. One-class SVMs are able to represent very irregular data distribution shapes without making assumption on the probability density of the data (*Tax* and *Duin,* 2002), which allowed better performance during prediction.

Presence-absence classification models seemed to be able to predict species distributions better under current and novel combinations of climate than presence-only methods. GLM performed relatively poorly due to the lack of flexibility (*Austin,* 2002). MAXENT uses an exponential model for probabilities, and gave very large predicted values for environmental conditions outside the range present in the training set (*Phillips et al.,* 2006). CTree provided the best statistical performance describing the current distribution among all models, although the predictions for the future showed regional inconsistency, especially in the Southwest and Northeast. The relatively good predictive performance of CTree could be explained by the ability of finding interactions and hierarchical relations among environmental variables (*Hastie* and *Tibshirani,* 1990; *Austin,* 2002).

BP-ANN significantly outperformed CTree in the domain of predicting the future potential distribution of beech. Although BP-ANN performed slightly poorer than CTree by predicting the current potential distribution, the predictions for the future were more realistic without regional inconsistency. The larger predicted area and the distinct boundaries in the future potential maps of BP-ANN indicated that the generalization ability of BP-ANN was clearly superior to that of CTree. One possible explanation for the difference in the predictive performance is that complex features that are constructed allow non axis-parallel and nonlinear decision boundaries.

The results of this investigation provide clear support to the preference for neural networks in at least this type of bio-informatics problems.

4.3. Regional differences

Model accuracy can be measured not only on the country scale (overall model performance), but also at a finer (regional) scale. Accuracy measures like *TPR*, *AUC*, Kappa values and predicted area can be assessed also across different forest regions. The regional analyses of the model performance enable the assessment of SDMs under different climatical/ecological conditions.

Hungary stretches across three climate regions. Southwest Hungary is under strong Mediterranean influence, northwest Hungary is subatlantic, while the north-eastern part is more continental. The soil and hydrological conditions that sustain the forest vary greatly. As a result, Hungary features 6 main forest regions and 54 forest regions, each supporting characteristic tree species and forest types.

The breakdown of the accuracy measures for forest regions indicated that false negative rates (overprediction) of the BP-ANN and CTree model were higher in Mecsek Mountains, Göcsej Hills, Őrség, east Zala Hills, Marcali Ridge, and west Zselic than the overall false negative rate by predicting the current potential distribution (*Fig. 6*). Beech in the above mentioned forest regions reaches its lower xeric distribution limit (trailing edge). The Mecsek Mountains, east Zala Hills and west Zselic were already affected with large-scale beech decline after 2003,(*Lakatos* and *Molnár*, 2009).

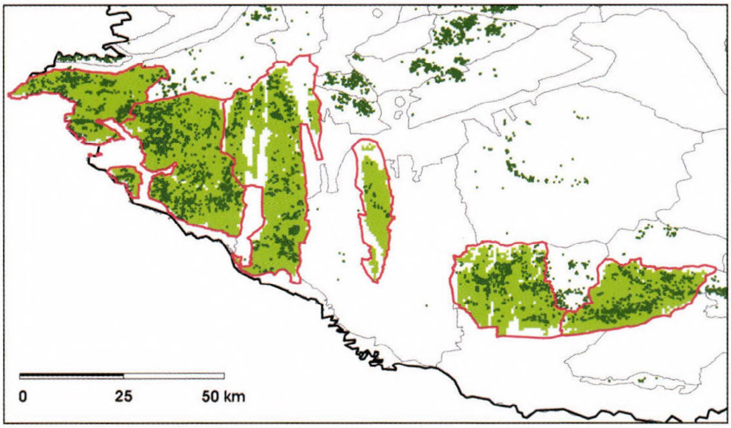

Fig. 6. Beech dominated forest regions (indicated with red contours) in southwest Hungary with high false negative values (overprediction) during the simulations under current climate conditions with the BP-ANN model. The potential area predicted by the BP-ANN method is colored with light green, observed localities with beech occurrence are indicated with dark green.

False negatives typically are due to the violation of the fundamental equilibrium assumption of static models (*Guisan* and *Zimmermann,* 2000). Accordingly, in the present study they suggest that beech at its trailing edge is not in equilibrium with the climate characterized by long-term means.

After the extreme dry and hot 2003, widespread beech decline was observed in several forest regions where beech reaches its lower distributional limit. This suggests that range margins of beech in Hungary are formulated by short-term dry periods – rather than by long-term climatic means.

4.4. Correlates of beech distribution

Beech trees show a rapid increase of radial increment from mid-May to July as soon as leaf expansion starts. Until the end of June 30–70% of annual growth is achieved (*Lebaube et al.,* 2000, *Bouriaud et al.,* 2003). In conclusion, beech appears particularly sensitive to weather conditions at the beginning of the growing season.

The factor importance analysis ranked the maximum temperature of spring and early summer and the modified Ellenberg quotient among the most influential factors. Our results, underlining the importance of May-June weather conditions in the presence of beech, are coherent with results obtained from dendrochronological analyses (*Lebourgeois et al.,* 2005; *Di Filippo et al.,* 2007).

Using climatic predictors, only the current distribution of beech could be easily predicted under optimal conditions, but models failed in the Southwest and Northeast. Including soil data and continentality indices improved model performance in these regions. This suggests that soil conditions could play an important role in determining the presence of beech at the edge of its distribution range.

An example of better prediction accuracy improved by the addition of soil parameters can be seen in *Fig. 7*.

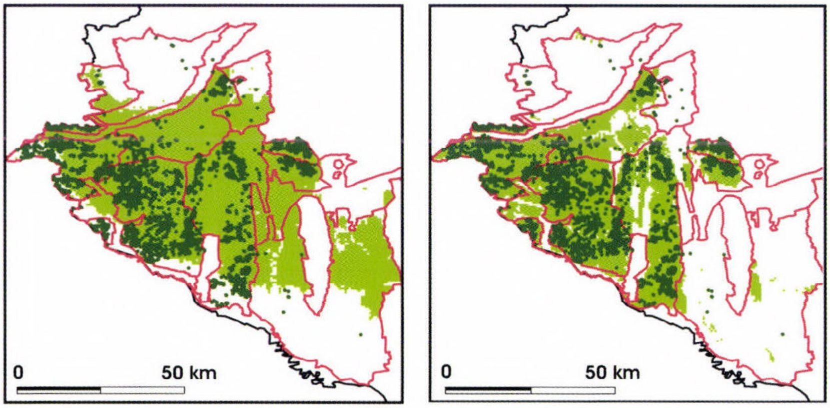

Fig. 7. Predicted potential distribution of beech by the BP-ANN method in southwest Hungary using climate predictors only (left) and using climate, soil, and geomorphological predictors (right). Forest regions are indicated with red.

5. Conclusions

The aim of this study was to test the performance of species distribution models predicting the potential future distribution of beech (*Fagus sylvatica* L.) near to the xeric limit in Hungary. To achieve this aim eight different stochastic algorithms were compared and evaluated.

Most of the species distribution models performed fair or good description of the current distribution of beech, but machine learning methods like classification trees and artificial neural networks with backpropagation algorithm, generally outperformed the established ones. Six out of the eight methods were unsuited for predicting climate change effects on the future distribution of beech. This confirms that a good model performance in predicting the current distribution does not guarantee success in predicting distribution under different climates. The relative failure of some methods underlines that predictions for conservation and management issues should be based on multimodel assessments.

Even machine learning methods like artificial neural networks with backpropagation algorithm failed in regions where beech reaches its distributional limit. The results of the present study suggest that:

- beech in Hungary at its trailing edge (xeric limit) is not in equilibrium with the climate and
- range margins of beech in Hungary are formulated by short-term dry periods rather than long-term climatic means.

The factor importance analysis of the species distribution models ranked the maximum temperature of May and the modified Ellenberg quotient repeatedly as the most influential predictors. In addition, maximum temperatures of summer and precipitation of late summer played a significant role in determining the presence of beech. The ranking suggests that the distribution of beech in Hungary is determined mainly by the maximum temperatures during springtime and it is secondly related to precipitation.

Acknowledgments—This research was funded by the Austrian-Hungarian Transboundary Cooperation 2007-2013 ("FaKlim" project - L00044) and by National Research and Development Agency ("TALENTUM" project - TÁMOP 4.2.2.B-10/1-2010-0018).

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IDŐJÁRÁS
Quarterly Journal of the Hungarian Meteorological Service
Vol. 116, No. 3, July–September 2012, pp. 195-209

Application of phenological observations in agrometeorological models and climate change research

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(Manuscript received in final form April 24, 2012)

Abstract—This paper intends to give a brief overview on the different approaches existing in plant phenological studies. The history of plant phenological observations in Europe and Hungary shows that the aim of the observations turned from the pure scientific interest to the application in agricultural practice, and recently, to climatic studies. Modeling of phenological development is demonstrated via examples for wheat and maize. The analysis of historical data has got new horizons by the international efforts done by COST Actions. New perspectives in observations of vegetation are remote sensing data. Vegetation indices like normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI) are also used for tracking the seasonal development of plants, and they give opportunity to analyze the year by year change.

Key-words: phenology, observational network, climate change, NDVI, EVI.

1. Introduction

Vegetation dynamics like growth, reproduction, and winter rest, competition for nutrients, water, and light are strongly influenced and determined by climate variables. Even in case of unchanged climate we can find big differences year by year in the start of life period simply as a result of different weather situation. A change in climate will result in a change of these dynamics. Phenology is the study of the timing of recurrent biological processes such as budburst, flowering, flight activity of insect, bird nesting, fruit ripening, and leaf fall. That is the scientific discipline, which is able to link vegetation dynamics with climate variables. The identified and recorded events are the so-called phenophases.

Phenological observations have long history, but the aim of observations has changed from scientific interest to practical applications, from local to global characterization of climate and biosphere interactions. The methodology of the observation could be different according to the relevant aims. It is important to know the time of the phenological phases for organizing agricultural works as well as the plant protection. Time by time organizing observational networks on national and international levels has got remarkable attentiveness, nevertheless, long-term data series are rather rare. Computerized crop simulation models contain phenological submodels since the potential biomass production is affected by the actual phenological phases. Examples of phenological models are presented for maize and wheat phenological development. Recently, in climate change studies phenology became interesting again, and great efforts have been done to collect old data series from large geographical area. The new possibilities for monitoring the vegetation on large spatial and temporal scale are remote sensing. Using vegetation indices like normalized difference vegetation index (NDVI) or enhanced vegetation index (EVI) makes possible to track phenological development of the vegetation on the scale of "landscape phenology" which differs from the traditional morphological characterization of individual plants.

2. Brief history of plant phenological observations

The scientific father of observations of periodical phenomena of plants and animals was *Carl Linné* (1707–1778). Besides his taxonomical works, he observed and recorded the timing of occurrence of birds, flowering of plants, and gave a calendar of nature for Scandinavia.

In the middle of the nineteenth century, two remarkable scientists in Belgium continued a long debate about the aims and methods of observations of periodical phenomena. *Demarrée* and *Rutishauser* (2011) give a detailed description of the correspondence between *Adolphe Quetelet* (1796–1874) and *Charles Morren* (1807–1858). *Quetelet* was physicist and astronomer. He was the founder of the Royal Observatory of Brussels and served as the Permanent Secretary of the Academy of Sciences, Brussels. He initiated a program of systematic observations of periodical phenomena of the vegetation and animal kingdoms in 1841. *Morren* was a professor of botany at the University of Liège and fellow of the Academy of Sciences, Brussels. According to *Quetelet*'s view, only few plants and animals should be observed but at the same time, on a large geographical area. This is very similar to the methods of meteorological observations. *Morren* argued this "too simple" approach and suggested recording the date of occurrence of phenological events. Finally, the discipline of phenology derives from *Morren*'s theory: the goal which proposes the association of the observation of the periodical phenomena is to know "the manifestation of life ruled by the time." (*Morren*, 1843).

In Hungary, *Pál Kitaibel* (1757–1817) was the first natural scientist who systematically observed flowering time of plants and explained the differences with climatic reasons. He intended to map flowering times of several agricultural plants; therefore, a circular letter was issued to collect data. Unfortunately, only few response arrived, and therefore, the mapping was not successful (*Both*, 2009).

The relationship of plant phenology and climate was obvious from the beginning; therefore, the observational program of National Meteorological Institutes organized in the middle of the nineteenth century contained also plant phenological observations. Meteorological yearbooks between the years 1871 and 1885 published by the Royal Hungarian Institute for Meteorology and Geomagnetism contain records from 57 locations for 200 plants (not all the plants from each location). Later, in 1910, the Hungarian Geographical Society and in 1934, the Research Institute for Forestry organized observational networks for plant phenological observations.

Organizing and especially maintaining an observational network is not an easy task. There is a need for competent observers and persistent work.

In 1935, the decision of the Agricultural Meteorological Committee of the International Meteorological Organization stated that the same species of plants should be observed in phenological studies everywhere, and that the different stages of development (phitophasis) should be determined uniformly. As *Réthly* (1936) wrote: systematic phenological observations have been carried on for a long time in Hungary by the State Foresters, and have provided much valuable data. The author therefore requests the Hungarian foresters to work according to the above lines in the future.

The collected observations were non-systematic either in space or time. *Dunay* (1984) gave a detailed description on the history of the time by time reorganization of phenological observation network in the Hungarian Meteorological Service. The next starting date of a phenological network maintained by the Meteorological Institute is 1951. The institute prepared the "Guidelines for phenological observations". The guidelines described the phases of 75 growing wild plants. The pictures of the guidelines were drawn by *Ms. Vera Csapody*, the famous Hungarian artist and botanist.

The newly established network mainly focused on plants growing wildly. The observation posts of the network were the precipitation stations of the institute. The agricultural plants were observed in 13 places in the agricultural research institutes and in species trial stations. The network was renewed in 1961, when new posts were organized instead of the closed stations. Using the gained experience, a detailed phenological observation program was worked out, and a new guideline, "Guideline for phenological observation of cultivated plants" was issued. The reorganized network had 80 observation stations. The number of observed cultivated plants was 34. Among others, many cereals, rough fodder, cereal fodder, industrial crops, vegetables, and fruits were monitored. Each station observed those species which had importance in their region. Some of the stations observed the phenological phases of cultivated plants; other stations had to monitor fruits or vegetables. The observation program was not restricted to the phenophases only, but it was extended to recording of the agricultural works, the general condition of the plants, and any damage.

The set of the observed growing wild plants were revised, and according to the international practice, the program was renewed again with 36 species. The network monitored 10 treespecies, 10 shrubs, and 16 grass species. Increasing the number of the stations, the phenological network consisted of 120 wildly growing and 80 cultivated plants observations. The Agrometeorological Division submitted a reconstruction plan in 1975 to add plus 33 natural and 236 cultivated plants stations to the network. Within the network, a rapid reporting smaller network was planned with only 30 stations. Taking into consideration the operative demand, a crucial change was carried out in the organization and data transfer system of the network. Instead of professional staff members of the standard meteorological network, the specialists of the MEM-NAK, the Hungarian Plant Protection and Agrochemistry Organization of the Ministry of Agriculture, were recruited into the phenological observation network. Much less mistake was found in the professional agronomist's observations. The base of the data transfer was the national telex system. In the 80s it was the most rapid and effective tool in the telecommunication. Unfortunately, the observation of natural vegetation was minimized, but the observation of few "signaling plant" was maintained. Few of them was a good sign of the start of the spring, others have got some economic importance. The new network started its work in 1983 cooperating with the MEM-NAK. This network continued its activity until 2000 when the OMSZ, the Hungarian Meteorological Service closed it because of financial reasons.

According to the international networks, the International Phenological Gardens (IPG) are a European and individual network within the Phenology Study Group of the International Society of Biometeorology. The network was founded in 1957 by *F. Schnelle* and *E. Volkert.* The current network ranges across 28 latitudes from Scandinavia to Macedonia and across 37 longitudes from Ireland to Finland in the north and from Portugal to Macedonia in the south. It consists of 89 gardens in 19 European countries. The philosophy of this network is quite different than the Hungarian's one. In all gardens, genetically identical trees and shrubs are planted in order to make large-scale comparisons among the timing of different developmental stages of plants. Recently, the coordination of this network belongs to the Humbolt University of Berlin (*Chmielewski*, 1996).

Among the most important and recent phenological activities at international level, there is the youngest phenological network of the United States. After two years of preparatory period, in 2007 it started its activities based mainly on volunteer observers (*Betancourt et al.*, 2007).

3. Phenological research work

The use of phenological observations is manifold. For scientific investigations, for planning and consulting tasks as well as in daily practice, phenological data are required. Examples for the application of phenological data are investigations of the impact of climate changes on plants, calibration of remotely sensed data, use of these data in yield-, growth-, or hydrological models, determination of regions with high frost-risks for fruit-tree growing, and the monitoring of environmental changes. Since the end of the 1980s, the demand for phenological observations increased substantially. Mainly, the rise in air temperature in the previous decades and the clear phenological response by plants led to this increased interest in phenological data.

3.1. Phenology in crop models

The ability to estimate the time required for a crop to pass through its various stages of development to maturity is useful in at least one other important way - it assists greatly in estimating crop yield. The history of phenological modeling goes back at least as far as 1735. It was then that *Reaumur* (1735) suggested that the time required for plants to complete a phase of their development could be more accurately estimated from temperature sums than from calendar days. Although there are many variations of the original concept, most methods of estimating phenological development still use this relatively simple approach.

Phenological modeling inevitably involves mathematical equations that express the rate of change in life stage as a function of environmental variables, such as temperature, humidity, photoperiod, and radiation. These equations are usually the product of regression analyses of experimental data (*Shaykewich*, 1995).

The models can be different according to:

- the phenophases taken into consideration,
- environmental variables (temperature, day-length, vernalization, etc.),
- the form of functions describing the effect of the environmental variables (linear, non-linear),
- the structure of the model (additive, multiplicative).

The models are always plant specific. They contain several plant specific parameters which can be different even for the different varieties.

Example 1: In the CERES-Maize model (*Jones* and *Kiniry*, 1986), phenological development is calculated as a function of growing degree days or daily thermal time (*DTT*) with a base temperature of 8 °C. The maize phenological phases used in the model are described in *Table 1*. The model assumes that the rate of development increases linearly above the base temperature up to 34 °C and then decreases linearly to zero as temperature increases from 34 to 44 °C. Similarly, rates of leaf initiation and leaf-tip appearance are assumed to change linearly in these two ranges of temperature. Photoperiodic induction is assumed to decrease with increasing photoperiod for photoperiods longer than12.5 hours. The number of days of tassel initiation delay for each hour increase in photoperiod is assumed to be a constant for any given photoperiod-sensitive cultivar. The total number of leaves is determined from the number of leaf primordia initiated between seedling emergence and tassel initiation. Date of tassel initiation is determined using both *DTT* with a base temperature of 8 °C and photoperiod. Silking or end of leaf growth is determined from total leaf number and the rate of leaf-tip appearance.

Table 1. Phenological phases used in CERES-Maize model.
(Source: *Jones* and *Kiniry*, 1986)

Phase No.	Description
1.	Seedling emergence to end of juvenile phase
2.	End of juvenile phase to tassel initiation (photoperiod-sensitive phase)
3.	Tassel initiation to silking
4.	Silking to beginning of effective grain-filling period (lag phase)
5.	Effective grain-filling period
6.	End of effective grain-filling period to physiological maturity (black layer)
7.	Before sowing (fallow)
8.	Sowing to germination
9.	Germination to seedling emergence

Example 2: Wheat phenological model of *Wang* and *Engel* (1998) is a multiplicative non-linear model. The first step in using the WE model is to calculate the daily rate of plant development (*r*). There are two main developmental stages: vegetative phase from emergence until anthesis and reproductive phase from anthesis until physiological maturity. The developmental stage (*DS*) is then calculated by accumulating the daily development rate values (i.e., at a 1 day time step, $DS=\Sigma r$). Other developmental stages in the vegetative phase are 0.4 at spikelet initiation, 0.8 at late booting, and 0.88 at awns first visible.

The model equationfor the vegetative phase is

$$r = R_{max,v} f(T) f(P) f(V), \tag{1}$$

while for the reproductive phase it is

$$r = R_{max,r} f(T), \tag{2}$$

where r is the daily development rate (per day), $R_{max,v}$ and $R_{max,r}$ are the maximum development rate (per day) in the vegetative and reproductive phases, and $f(T)$, $f(P)$, and $f(V)$ are temperature, photoperiod, and vernalization response functions, varying from 0 to 1.

The temperature response function is

$$f(T) = \frac{2(T - T_{min})^{\alpha}(T_{opt} - T_{min})^{\alpha} - (T - T_{min})^{2\alpha}}{(T_{opt} - T_{min})^{2\alpha}}, \tag{3}$$

$$\alpha = \frac{ln 2}{ln\left[(T_{max} - T_{min})/(T_{opt} - T_{min})\right]}, \tag{4}$$

where T_{min}, T_{opt}, and T_{max} are the cardinal temperatures for development (minimum, optimum, and maximum), and T is the mean daily temperature calculated from the 24 h temperature.

For the vegetative phase, T_{min}, T_{opt}, and T_{max} were 0 °C, 24 °C, and 35 °C, and for the reproductive phase they were 8 °C, 29 °C, and 40 °C, respectively (*Xue et al.*, 2004).

The photoperiod response function is

$$f(P) = 1 - e^{-\omega(P - P_c)}, \tag{5}$$

where P is the actual photoperiod (h), P_{c} the critical photoperiod (h) below which no development occurs, and ω is a cultivar specific photoperiod sensitivity coefficient [h^{-1} g]. Values of P_{c} and of ω are variety specific.

The vernalization response function:

$$f(V) = min\{1;\ max[0;\ (V_n - V_{nb})/(V_{nd} - V_{nb})]\}, \tag{6}$$

where V_n is the effective vernalization days, V_{nd} is the number of effective vernalization days for the plant to be fully vernalized, and V_{nb} is the minimum effective vernalization days, i.e. development begins only after a minimum value of V_{nb} has been reached (*Weir et al.*, 1984).

The functions max and min in Eq. (6) represent the maximum and minimum values in a string of numbers, respectively. The effective vernalization days, V_n, is calculated from sowing as

$$V_n = \sum fv_n(T), \tag{7}$$

where $fv_n(T)$ is the daily vernalization rate (per day), calculated using Eqs. (3) and (4) with the cardinal temperatures for vernalization ($T_{\mathrm{min},vn}$, $T_{\mathrm{opt},vn}$, and $T_{\mathrm{max},vn}$) being −1.3, 4.9, and 15.7 °C (*Porter* and *Gawith*, 1999). Both V_{nb} and V_{nd} are cultivar dependent.

These types of plant phenological models are always plant specific. Parameterization of the model is possible on experimental plots or in growth chambers. Whenever you want to develop phenological model for a native plant (especially for trees and shrubs), you should use long-time data series and the physiological parameters should be estimated on statistical ways.

3.2. Phenology in climate change studies

In the 1990s, the interest in phenological research and thus, the demand for phenological observations has increased substantially. Mainly, rising air temperatures in recent decades and the clear phenological response of plants and animals to this increase have caused the growing interest. Many studies have shown that the timing of life cycle events is able to provide a good indicator for climate change impacts (*Schwartz,* 1994; *Menzel et al.*, 2006; *Chmielewski* and *Rötzer,* 2001, 2002). The timing of phenological phases depends on numerous environmental conditions: temperature, precipitation, soil type, soil moisture, and insolation. However, in mid- and high latitudes, with vegetation-rest (dormancy) in winter and active growing period in summer, air temperature has the greatest influence on phenology (*Fitter et al.*, 1995; *Sparks et al.*, 2000; *Chmielewski et al.*, 2005). A comprehensive understanding of species phenological responses to global warming will require observations that are both long-term and spatially extensive. Long-term data series deriving from the same place are rare. One of these rarities is the data series of cherry tree flowering in Kyoto, Japan (*Aono* and *Kazui*, 2008), in which the first records came from the ninth centuries. In England, phenological events of various plants and animals observed since the 18th century have been reported as Marsham's phenological data series (*Margary*, 1926). In Geneva, Switzerland, the leafing date of the chestnut tree has been observed since 1808, and these records have been used to show climatic warming since the early 19th century (*Defila* and *Clot*, 2001). In

Hungary, there is unique series of St. George Day's wine shoot book in Kőszeg, in which every year since 1740 wine shoot captures notes and drawings are included. The work is still continuing, so more than 205 years of data series available (*Kiss*, 2009; *Kiss et al.*, 2011).

Monitoring phenological phases is carried out in many European countries. Each country has its own database, in some cases still on paper, mostly on databank-systems, going back to the 1950s in many cases.

After a period of reduction of the density of phenological networks and even cancelling all national observations in some countries in the 1980s, new interest in phenology grew in the following decade due to the new interest in climate change issues. In 2004, a new COST (European Cooperation in the Field of Scientific and Technical Research) Action was launched on European level. The basic idea of the Action was as a starting point to build a reference data set of selected species and phases that have been observed in European countries over a common reference period of at least one decade but preferably longer, using the BBCH code which was applied on phenophases observed in different countries by the German Weather Service. The project ended in 2009. According to the final report of COST 725 (*Koch et al.*, 2009) using 125,000 observational series of 542 plant and 19 animal species in 21 European countries for the period 1971–2000, the aggregation of the time series revealed a strong signal across Europe of changing spring and summer phenology: spring and summer exhibited a clear advance by 2.5 days/decade in Europe. Mean autumn trends were close to zero, but suggested more of a delay when the average trend per country was examined (1.3 days/decade). The patterns of observed changes in spring (leafing, flowering, and animal phases) were spatially consistent and matched measured national warming across 19 European countries; thus, the phenological evidence quantitatively mirrors a regional climate warming. The COST 725 results assessed the possible lack of evidence at a continental scale as 20%, since about 80% of spring/summer phases were found to be advancing.

In the IPCC AR4 WG II report (*Parry et al.*, 2007), the COST 725 study is one of the major contributions for the assessment of observed changes and responses in natural and managed systems. As a continuation, the chair of COST 725 submitted a 5 years project proposal PEP 725 (Pan European Phenological database), which was accepted by EUMETNET and launched in 2010. COST 725/PEP 725 is also being one of the leading partners of the new GEO-task: Global Phenology Data. Together with the USA National Phenology Network and the University of Milwaukee, COST 725/PEP 725 will coordinate the collection of in-situ phenology observations and expand existing observing networks, identify and generate satellite-derived phenological/temporal metrics, and test models for describing the phenological characteristics of natural and modified ecosystems. Changes in vegetation phenology impact biodiversity, net primary productivity, species distribution, albedo, biomass, and ultimately, the global climate.

4. Phenology from the space

The guides for plant phenological observations give detailed descriptions about morphology of different phenophases concerning to individual plants. This method is applicable in phenological gardens, where plants are the same or planted in the same place year by year, and they are monitored day by day. If a larger area of plant stands should be characterized by the phenological stages, difficulties arise because of the variability of individuals. In this case the percentage of plants having that specific phase should be estimated. This is a significant source of bias.

Remote sensing phenology, the use of satellites to track phenological events can complement ground observation networks. Satellites provide a unique perspective of the planet and allow for regular, even daily, monitoring of the entire global land surface.

Because the most frequently used satellite sensors for monitoring phenological events have relatively large "footprints" on the land surface, they gather data about entire ecosystems or regions rather than individual species. Remote sensing phenology can reveal broad-scale phenological trends that would be difficult, if not impossible, to detect from the ground. Moreover, because data collection by satellite sensors can be standardized, the data are reliably objective. Obviously, remote sensing data are not the traditional phenological phases but they are reflectance (ρ) in different spectral channels. The status of the vegetation is in close connection with its reflectance, especially in the near infrared and red spectra; therefore, the normalized difference vegetation index, (NDVI) has often used to characterize the vegetation status (*Reed et al.*, 1994):

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}. \tag{8}$$

Analyzing the seasonal curve of NDVI, the time of onset and the end of the vegetation season can be taken when NDVI reaches a threshold value (0.3) (*White et al.*, 2009; *Botta et al.*, 2000; *Jolly et al.*, 2005).

A bit more sophisticated the enhancedvegetation index (EVI) has an advantage over NDVI, because EVI includes a blue band, which allows residual atmospheric contamination and weight to be taken into account, compensating for the variable soil background reflectance (*Liu* and *Huete*, 1995; *Huete et al.*, 2002; *Churkina et al.*, 2005).

$$EVI = G \times \frac{\rho_{nir}/\rho_{red} - 1}{\rho_{nir}/\rho_{red} + \left(C_1 - C_2 \times \rho_{blue}/\rho_{red}\right) + L/\rho_{red}}, \tag{9}$$

where L is a soil adjustment factor, and C_1 and C_2 are coefficients used to correct aerosol scattering in the red band by the use of the blue band. ρ_{blue}, ρ_{red}, and ρ_{nir} represent reflectance at the blue (0.45–0.52μm), red (0.6–0.7μm), and near-infrared (NIR) wavelengths (0.7–1.1μm), respectively. In general, G=2.5, C_1=6.0, C_2=7.5, and L=1.

Temporal variation in EVI data are modeled using piecewise sigmoidal models. Each growth cycle is modeled using two sigmoidal functions: one for the growth phase, one for the senescence phase. To identify phenological transition dates, the rate of change in the curvature of the fitted logistic models is used. Specifically, transition dates correspond to the times at which the rate of change in curvature in the EVI data exhibits local minima or maxima. For each growth cycle, four phenological transition dates are recorded based on the approach described above. The corresponding phenological transition dates are defined as the onset of greenness increase, the onset of greenness maximum, the onset of greenness decrease, and the onset of greenness minimum.

Both NDVI and EVI data are available from MODIS placed at Terra and Aqua satellites. Data are provided by NASA Land Processes Distributed Active Archive Center (*NASA LP DAAC,* 2011). Our future plan is analyzing EVI data for different regions of Hungary for the last ten years. The EVI data on June 26, 2011 is shown in *Fig. 1* for Hungary. For a selected area of 5 × 5 km around Szenna (46°18.47'N, 17°43.95'E), time series from April to August, 2011 of EVI is presented in *Fig. 2.* The average seasonal curve for one pixel selected from the area mentioned above using data from 2003–2011 is shown in *Fig. 3.*

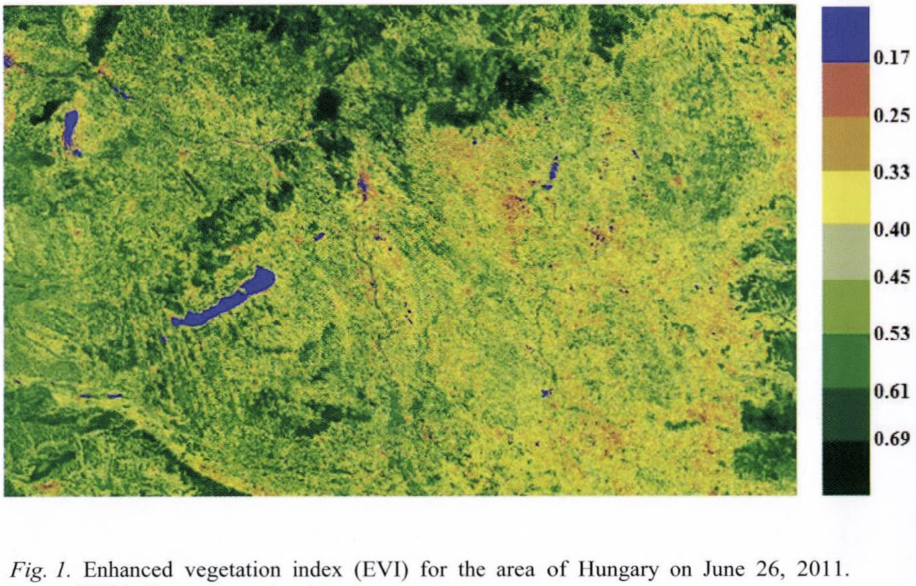

Fig. 1. Enhanced vegetation index (EVI) for the area of Hungary on June 26, 2011. Larger EVI indicates more developed vegetation.

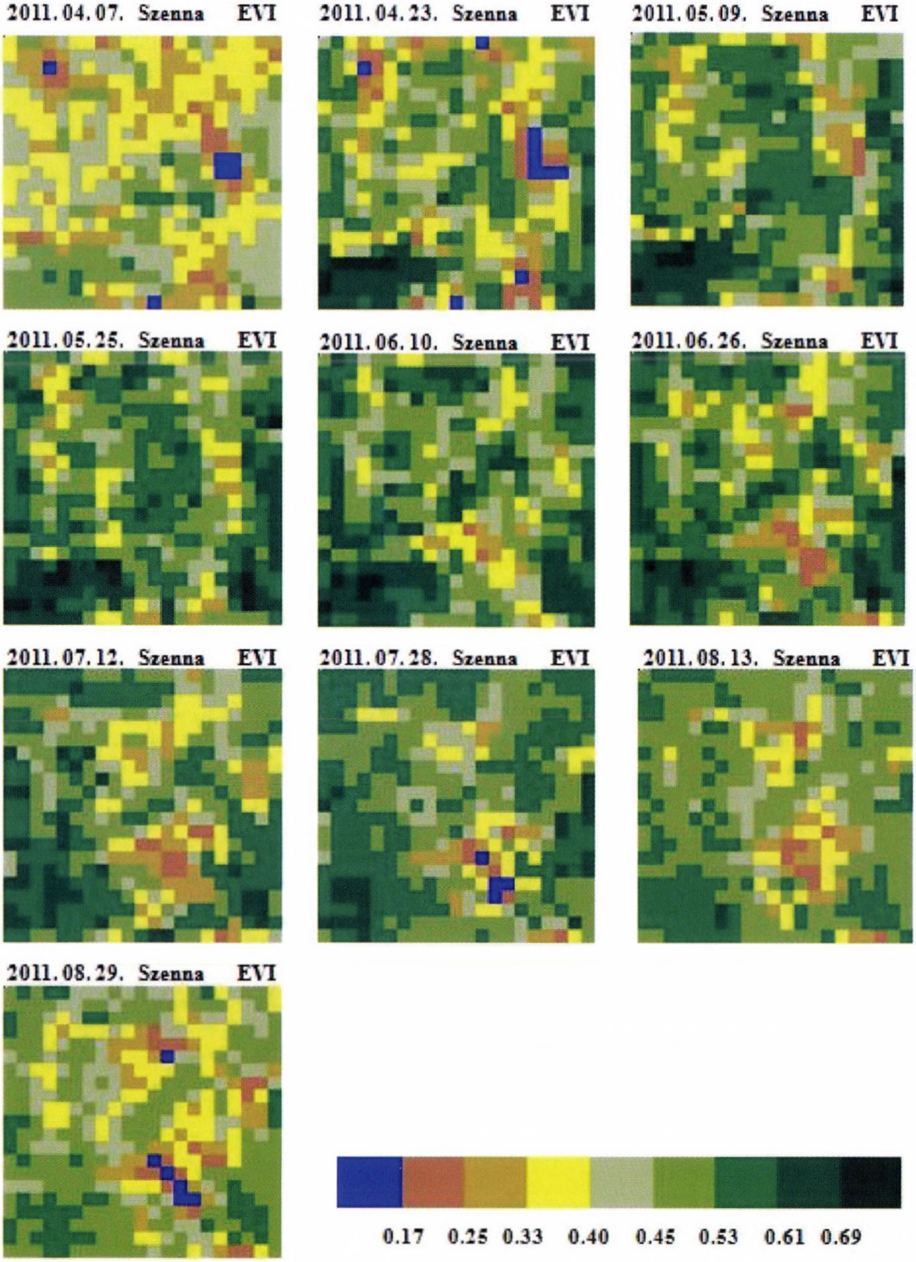

Fig. 2. Seasonal development of vegetation in a selected area according to EVI. The site of observations is a 5 km x 5 km area around Szenna (46°18.47'N, 17°43.95'E) between April and August, 2011.

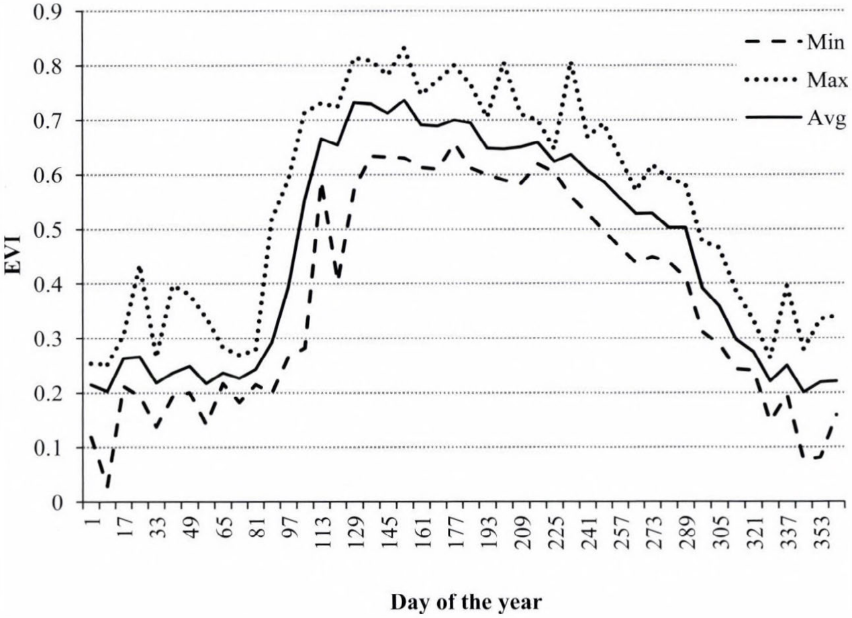

Fig. 3. Seasonal curve of EVI averaged for the years 2003–2011 for a selected pixel.

5. Conclusion

In the last two decades, climate change became a prevailing scientific paradigm, therefore, relating areas like phenology has been refocused. Searching for old phenological records, developing phenological models and new observation techniques applicable to track responses of vegetation to changing environment, and revealing interrelationships between biosphere and atmosphere are interesting tasks. New projects have been launched worldwide both on national and international levels to study plant and animal phenology. Reorganization of observation networks and collecting data is a big deal again. Remote sensing techniques offer new opportunities for comprehensive evaluation of processes taking place in biosphere.

Acknowledgement—The research project is supported by OTKA 81972.

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IDŐJÁRÁS
Quarterly Journal of the Hungarian Meteorological Service
Vol. 116, No. 3, July–September 2012, pp. 211-220

Impact of precipitation on yield quantity and quality of wheat and maize crops

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(Manuscript received in final form April 26, 2012)

Abstract—Yield samples of winter wheat *Triticum aestivum* L. and maize *Zea mays* L. taken from consecutive series of crop years at the Nagygombos experimental field of the Szent István University have been evaluated. Impact of precipitation on yield quantity and quality was studied. In case of wheat protein, wet gluten, farinographic value, and Hagberg sedimentation, while in case of maize, protein, starch, oil, and fibre content were examined.

Yield performance of wheat and maize varieties has been highly variable regarding crop years. Wheat was less affected by precipitation in general, however, extremely high precipitation as well as drought caused yield depression. Water demand of yield formation was in accordance with that of C3 – C4 physiological patterns. Yield quality was highly influenced by different crop years. In case of wheat, wet gluten content proved to be a most stable characteristic. Protein, farinographic values, and Hagberg sedimentation figures were more variable in relation with the precipitation of crop years. Yield quantity of maize crop proved to be more variable than quality parameters. Protein values were smaller, and starch values higher in rainy years. Other parameters, like oil and fibre have shown no consequent changes that could be related to the amount of annual precipitation.

Key-words: Precipitation impacts, grain crops, yield, grain quality.

1. Introduction

Water availability profoundly influences all physiological processes of plant life. Water transport of individual plants as well as water budget of the crop site determine growth and development, and finally, quality.

Crop water use, consumptive use, and evapotranspiration are terms used interchangeably to describe the water consumed by a crop. This water is mainly used for physiological processes; a negligible amount is retained by the crop for growth. Water requirements for crops depend mainly on environmental conditions. Plants use water for cooling purposes, and the driving force of this process is prevailing weather conditions. Different crops have different water use requirements, under the same weather conditions (*Várallyay,* 2008; *Pepó,* 2010). Crops will transpire water at the maximum rate when the soil water is at field capacity. When soil moisture decreases, crops have to exert greater forces (energy) to extract water from the soil. Usually, the transpiration rate does not decrease significantly until the soil moisture falls below 50 percent of available water capacity.

Information regarding seasonal crop water requirements are crucial for planning crop species planting especially during drought years. For example, in Hungary, the seasonal water use of maize crop is 550 mm, while wheat crops use some 400. These water requirements are net crop water use or the amount a crop will use (not counting water losses such as deep percolation and runoff) in an average year, given soil moisture levels do not fall below critical levels. Under ideal conditions, this net water requirement is reduced by the effective rain (*Muchová* and *Fazekašová,* 2010; *Führer et al.,* 2011; *Pásztorová et al.,* 2011).

Availability of water is a major stress in relation with yield quality and quantity performance of winter wheat. Cereals represent a most plausible source of human alimentation in the world. Wheat provides a basic staple for mankind. This crop is one of the most important cereals in Hungary with a high economic value. Utility, market, and alimentation values of the crop are highly affected by climatic conditions, annual weather performances, as well as soil moisture conditions (*Ács et al.*, 2008; *Koltai et al.*, 2008; *Skalová et al*, 2008; *Várallyay,* 2008). The aim of wheat production is twofold; to provide quantity and quality. Milling and baking quality of wheat is mainly determined by the genetic basis, however, it can be influenced by management techniques (*Pollhamer,* 1981; *Nagy* and *Jan*, 2006; *Varga et al.*, 2007; *Vida et al.,* 1996). The aim of this study was to determine the role of water availability impacts on wheat quantity and quality. Since main quality indicators – protein, farinographic value, gluten content, Hagberg falling number for wheat, as well as protein, starch, oil, and fibre for maize – have a rather diverse manifestation, there is a need to gain more information concerning the behavior of them.

2. *Materials and methods*

In long term field trials, a wide range of high milling and baking quality winter wheat *Triticum aestivum* L. varieties were examined under identical agronomic conditions during a 15 years period in the experimental years of 1996–2010, and high starch maize (*Zea mays* L.) hybrids were tested in a 9 years period of 2002–2010. The small plot trials were run at the Nagygombos experimental field of the Szent István University, Crop Production Institute, Hungary. Soil type of the experimental field is chernozem (calciustoll). Annual precipitation of the experimental site belongs to the 550–600 mm belt of the northern edges of the Great Plain in a 40 years average, 1961–2000 (*Fig. 1*), while the average depth of groundwater varies between 2 to 3 meters (*Fig. 2*).

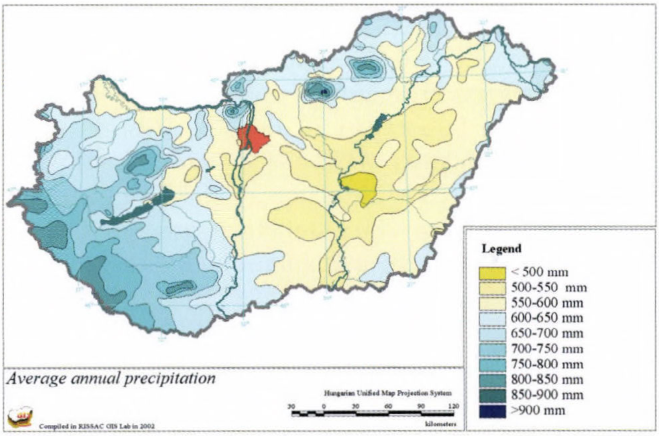

Fig. 1. Spatial distribution of average annual precipitation in Hungary (Source: RISSAC, 2002).

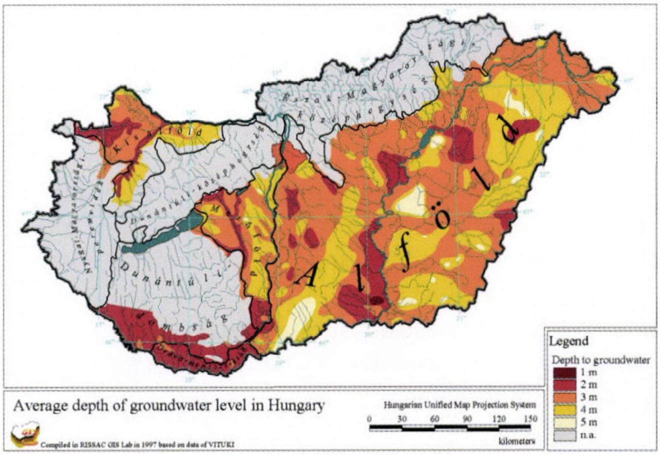

Fig. 2. Average depth of groundwater level in Hungary (Source: RISSAC, 1997).

Experiments were conducted in split-plot design with four replications. The size of each plot was 10 m^2. Plots were sown and harvested by plot machines (standard Wintersteiger cereal and maize specific experimental plot machinery series). Various identical agronomic treatments were applied to plots. Plant protection and plant nutrition applications were done in single and combined treatments. All plots were sown with identical series of wheat varieties and maize hybrids for studying their performance in relation with agronomic impacts. Regarding water availability impacts, experimental mean values of respective treatments and homogenized bulk yield samples were used only. Precipitation records have been evaluated in relation with yield quantity and quality. Wheat grain quality parameters like protein, farinographic value, wet gluten content, and Hagberg falling number results were processed, as well as maize quality parameters: protein, starch, oil, and fibre content. According to the specific harvest conditions of 1999 and 2010 crop years, Hagberg figures were not applicable. In case of maize trials, oil values have been analyzed from 2006 only. Quality characteristics were processed at the Research Laboratory of the SIU Crop Production Institute, according to Hungarian standards (*MSZ 6383,* 1998). Grain yield samples and quality figures were correlated with water availability parameters. Analyses were done by Microsoft Office 2003 statistical programmes with respect to the methodology of phenotypic crop adaptation (*Eberhart* and *Russell,* 1966; *Finlay* and *Wilkinson,* 1963; *Hohls,* 1995).

3. Results and discussion

Annual amounts of precipitation and winter wheat yields have been examined in a 15 years time range, while that of maize in a 9 years period at the Nagygombos experimental field of the Szent István University, Gödöllő. *Tables 1* and *2* illustrate the annual changes of yield and precipitation mean values. Yields have been correlated with water availability.

Yield figures were in accordance with annual precipitation patterns with an exception of some years when the distribution was irregular, eg., in 1999, when 837 mm rainfall, one of the highests in the period examined was recorded, however, a severely drought spring was followed by an extreme moist summer obstructing yield formation and ripening, as well as harvest. Also, the year 2010 with the ever highest annual precipitation, 847 mm measured at the experimetal site resulted in poor yield performance for both wheat and maize crops due long periods of water logging. Apart from these two years, annual precipitation was in accordance with the water consumption of the respective crop species and their C3 and C4 physiological patterns.

Table 1. Annual precipitation, yield and quality figures of a winter wheat trial (Nagygombos, 1996–2010)

Year	Precipitation, [mm]*	Yield [tha^{-1}]	Protein, [%]	Farinographic value	Wet gluten [%]	Hagberg Falling No
1996	544	4.08	15.8	89.7	37.8	339
1997	407	2.88	13.2	50.4	30.5	213
1998	725	6.21	11.5	70.7	27.4	278
1999	837	2.87	14.3	47.4	32.2	–
2000	344	3.32	11.6	44.4	28.3	188
2001	706	5.28	12.0	51.6	27.5	295
2002	426	4.34	17.2	62.4	38.4	362
2003	442	3.47	17.6	63.3	36.8	370
2004	463	6.06	15.3	58.8	29.9	296
2005	705	5.72	14.3	50.9	30.1	282
2006	593	7.11	15.4	54.8	33.7	346
2007	545	5.21	18.1	62.6	38.8	420
2008	612	7.82	13.2	54.1	28.8	349
2009	623	6.55	12.2	58.3	32.7	293
2010	847	3.87	14.5	–	32.3	–

*Source: OMSZ

Table 2. Annual precipitation, yield, and quality figures of a maize trial (Nagygombos, 2002–2010)

Year	Precipitation* [mm]	Yield [tha^{-1}]	Protein, [%]	Starch [%]	Oil [%]	Fibre [%]
2002	426	5.44	9.2	63.5	–	4.4
2003	442	4.12	7.63	72.2	–	4.35
2004	463	5.60	8.43	68.8	–	4.87
2005	705	5.22	7.1	74.5	–	3.96
2006	593	7.40	6.7	74.1	4.6	3.84
2007	545	8.24	8.5	65.8	4.7	5.8
2008	612	6.28	7.9	64.3	4.6	3.4
2009	623	7.34	6.8	63.3	4.2	2.1
2010	847	4.09	8.2	70.5	4.4	–

*Source: OMSZ

Quality manifestation of winter wheat yields have been impacted by annual precipitation in general in accordance with previous reports (*Klupács et al.*, 2010; *Pepó,* 2010). *Table 1* provides a summary of changes in yield quality characteristics. Apart from grain yields, protein, farinographic value, wet gluten, and Hagberg falling number records have also been evaluated all along the experiment. Yield figures were in accordance with annual amounts of precipitation with two exceptions regarding the 1999 and 2010 crop years.

Wet gluten content of grain samples proved to be a most stable quality characteristic. Annual changes of protein figures were significant. Farninographic values and Hagberg falling number figures were affected by precipitation. In some dry years like 2002 and 2003, baking quality was far better than in moist years, however, it was escorted by low yield figures as well. The manifestation of the Hagberg falling number was due to the rain conditions of the harvest and post-harvest periods. Re-moistening of ripen dry grain may result in alterations of the α-amylase activity, thus, it may have an impact on rheological characteristics of dough.

Results of maize experiments are summarized in *Table 2*. Yield quantity of maize crop proved to be more variable than quality parameters. Protein values were smaller, and starch values higher in rainy years. Oil values have shown no major changes. Fibre content values in certain crop years were randomly changing, however, no systematic trends could be observed.

4. Conclusions

Water availability can be considered as a basic factor related to yield quality and quantity performance of grain crops. In an agronomic long term trial run at the Szent István University's Nagygombos experimental site, the impact of water availability on wheat and maize crops have been evaluated. Correlation tables are presented in *Tables 3* and *4*. Various crop years have had different impacts on crop yield quantity. Yield figures were not in correlation with annual precipitation in general. However, with an exception of two years of extremely high precipitation, yield figures were in accordance with that the annual precipitation. Moisture availability had diverse influence on quality manifestation. High precipitation has often resulted in poorer quality, especially gluten and Hagberg values have been affected by that. Protein and gluten values proved to be the most stable quality characteristics in this study. Drought stress reducing the amount of yield has induced quality improvement in a few cases. Maize yields were more variable than that of wheat. Maize quality parameters proved to be more stable than yield figures except for fibre content values (*Fig. 3*). In *Fig. 3*, maize yields and quality parameters are displayed on a 9 years basis, while wheat yields and quality parameters are displayed on a 15 years basis. Both yields are clustered into three groups representing dry (<500 mm), normal (500–700 mm), and moist (>700 mm) crop years, and the range of stability is expressed in % of respective X value deviations.

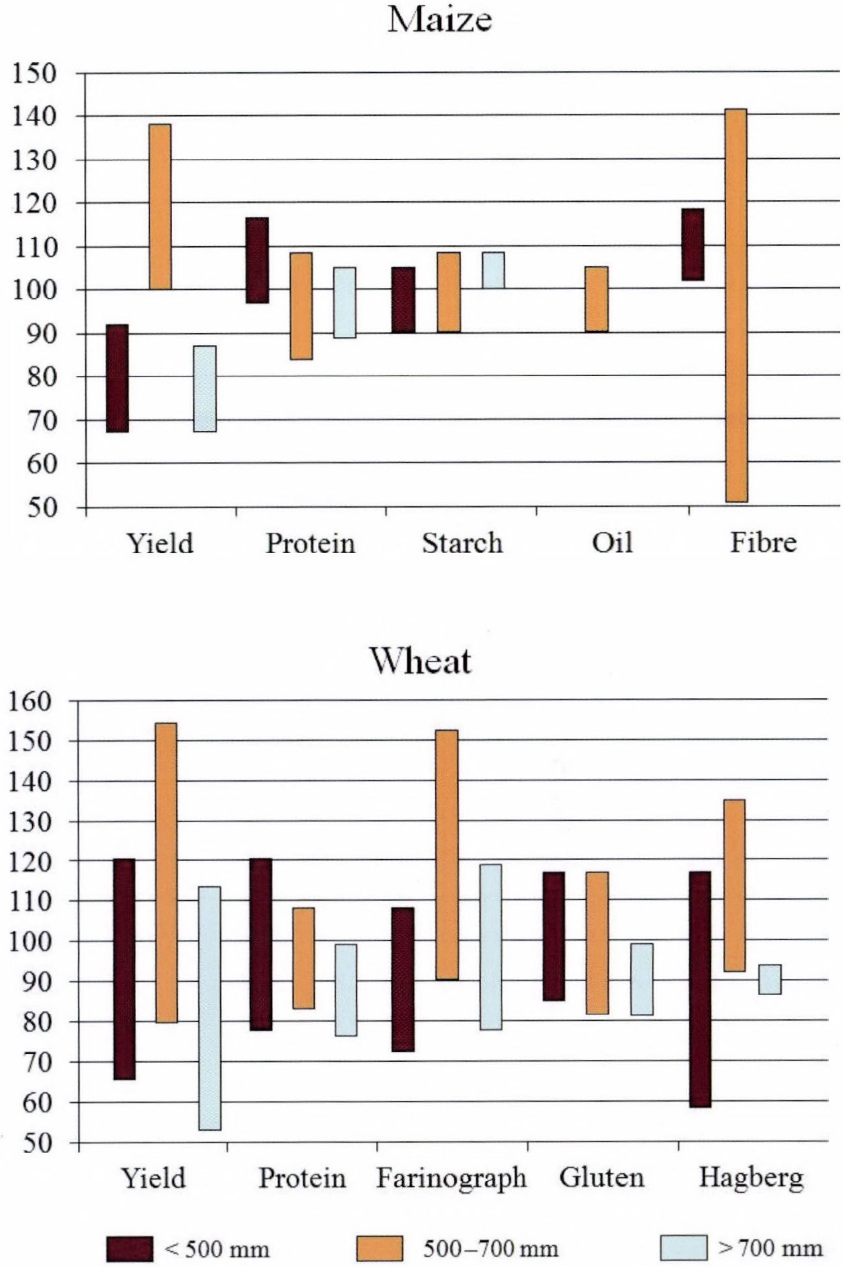

Fig. 3. Stability of yields and quality parameters of maize and wheat crops. (Nagygombos, 2002–2010; 1996–2010)

Table 3. Correlation figures of winter wheat trial. (Nagygombos, 1996–2010)

Correlation r value	**Year**	**Precipitation [mm]**	**Yield [tha^{-1}]**	**Protein [%]**	**Farinographic value**	**Wet gluten [%]**	**Hagberg Falling No**
Year	1	0.254	0.526	0.168	–0.268	0.084	0.449
Precipitation [mm]	0.254	1	0.180	–0.244	–0.044	–0.249	0.178
Yield [tha^{-1}]	0.526	0.180	1	–0.165	0.058	–0.246	0.308
Protein [%]	0.168	–0.244	–0.165	1	0.359	0.874	0.778
Farinographic value	–0.268	–0.044	0.058	0.359	1	0.513	0.453
Wet gluten [%]	0.084	–0.249	–0.246	0.875	0.513	1	0.716
Hagberg Falling No	0.449	0.178	0.308	0.778	0.453	0.716	1

Regression coefficient	**Year**	**Precipitation [mm]**	**Yield [tha^{-1}]**	**Protein [%]**	**Farinographic value**	**Wet gluten [%]**	**Hagberg Falling No**
Year	1	0.007	1.493	0.348	–0.098	0.095	0.029
Precipitation [mm]	8.807	1	17.69	–17.50	–0.547	–9.710	0.348
Yield [tha^{-1}]	0.185	0.002	1	–0.121	0.008	–0.097	0.007
Protein [%]	0.081	–0.003	–0.227	1	0.070	0.475	0.028
Farinographic value	–0.733	–0.004	0.415	1.833	1	1.425	0.081
Wet gluten [%]	0.075	–0.006	–0.619	1.610	0.185	1	0.048
Hagberg Falling No	6.786	0.091	12.82	21.28	2.530	10.65	1

There have been two parameters in this study with less chance to observe; once the soil impacts on water availability, since the trials were designed in a *ceteris paribus* agronomic layout. The other is the varietal differences between wheat cultivars and maize hybrids. These fields are to be evaluated in further studies.

Table 4. Correlation figures of maize trial (Nagygombos, 2002–2010)

Correlation r value	**Year**	**Precipitation [mm]**	**Yield $[tha^{-1}]$**	**Protein [%]**	**Starch [%]**	**Oil [%]**	**Fibre [%]**
Year	1	0.795	0.270	–0.331	–0.166	–0.712	–0.489
Precipitation [mm]	0.795	1	–0.131	–0.355	0.269	–0.448	–0.478
Yield $[tha^{-1}]$	0.270	–0.131	1	–0.223	–0.363	0.316	–0.024
Protein [%]	–0.331	–0.355	–0.223	1	–0.463	0.456	0.644
Starch [%]	–0.166	0.269	–0.363	–0.463	1	0.263	0.169
Oil [%]	–0.711	–0.448	0.316	0.456	0.263	1	0.858
Fibre [%]	–0.489	–0.478	–0.024	0.645	0.169	0.856	1

Regression coefficient	**Year**	**Precipitation [mm]**	**Yield $[tha^{-1}]$**	**Protein [%]**	**Starch [%]**	**Oil [%]**	**Fibre [%]**
Year	1	0.016	0.505	–1.072	–0.101	–5.625	–1.107
Precipitation [mm]	39.42	1	-12.13	-56.84	8.117	-263.1	-44.07
Yield $[tha^{-1}]$	0.144	-0.001	1	–0.385	–0.118	2.531	–0.031
Protein [%]	-0.103	-0.002	–0.129	1	-0.087	1.875	0.532
Starch [%]	-0.273	0.009	–1.117	–2.461	1	6.000	0.742
Oil [%]	-0.090	-0.001	0.039	0.111	0.012	1	0.124
Fibre [%]	-0.216	-0.006	–0.019	0.782	0.039	5.936	1

Acknowledgements—Authors are indebted regarding support received from NKTH and from the HAS.

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IDŐJÁRÁS
Quarterly Journal of the Hungarian Meteorological Service
Vol. 116, No. 3, July–September 2012, pp. 221–236

Impact of atmospheric black carbon on some members of the heat and water balances

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(Manuscript received in final form February 10, 2012)

Abstract—Impact of atmospheric black carbon (BC) on albedo, evapotranspiration, and growing characters of field grown maize was investigated at Keszthely, Hungary, over the 2010–2011 growing seasons. Chemically "pure" black carbon was used in weekly pollution (3 g m^{-2}). Low doses simulated the effect of particulates derived from vehicle exhaust and abrasion of tyres. Albedo of crop stand (0.3 ha/treatment) was measured with CMA-11-type pyranometers every 6 seconds. Maize grown in Thornthwaite-type compensation evapotranspirometers was included in the study. Dry matter yield of maize cob was determined in the end of the growing season.

Surprisingly, BC did not influence significantly the phenological phases and length of the crop year. Due to wet weather in 2010, seasonal water loss of BC treated maize increased only with 4%. Amount of seasonal total evapotranspiration of polluted crops was about threefold higher in dry 2011. The mean albedo of polluted canopy declined in both seasons. The surplus energy retention of BC polluted crops increased the canopy surface temperature of about 0.5–1.5 °C in midday hours, independently of the studied year. Significant yield loss in BC polluted maize stands was observed only in rainfed canopy. The production loss of dusted maize amounted 8.7% and 19.8%, in 2010 and 2011, respectively. Extra water of evapotranspirometers prevented yield drop-out of soot polluted plants. In arid years, BC had more severe impacts on maize characteristics and yield.

Key-words: black carbon, albedo, evapotranspiration, canopy temperature, dry matter, yield, maize

1. Introduction

Size and composition of atmospheric particulate matters (PM) are greatly variable. The class of particles having grain size of 2.5–10 μm is the coarse fraction. They are emitted to the air directly mainly from natural sources (earth crust, volcano eruption, deflation, erosion, etc). The fine fraction comprises particles below 2.5 μm. Fine fraction is forming by chemical and physical processes in the atmosphere. In the air of Budapest, the number of fine particles is higher (100,000/ml) than that of the coarse class (below 100/ml) after *Salma* and *Ocskay* (2006). The black carbon content is only about a few percent in the coarse fraction, while it may reach the 20% in the fine one. Diesel-exhaust particle may be elemental carbon up to 20–40% (*Balmes,* 2010). Soot has also been derived from incomplete burning (fossil fuels, biomass, etc.) as well as from industrial processes. Vehicle tyres are also sources of black carbon.

In EU standard, we are allowed to exceed the daily suspended particulate matter limitation of 50 μg/m^3 30 times per year (WHO, 2000; *Krzyzanowski et al.*, 2005). Unfortunately, already in the course of February, we often overstep this threshold at Hungary (examples are the years 2009 and 2010). This is due to the aged carriage park and the weather conditions in Hungarian winter.

Global scale influence of black carbon (BC), changing the radiative properties of the atmosphere (nucleation of clouds) and cryosphere (melting of ice cover) was published among others by IPCC (2007) or *Giere* and *Querol* (2010). The effect of soot on human health (*Behndig et al.*, 2011) and on some soil properties (*Hammes et al.*, 2008; *Nguyen et al.*, 2009; *Lorenz et al.*, 2010) are also well investigated. Studies on health impacts of particulates show an increased number of hospital admissions from chronic obstructive pulmonary disease, asthma, and other respiratory diseases (*Postma et al.*, 2011).

The importance of albedo modifications are widely studied in different observation levels. The local level contains relationship between crop life (physiological processes) and solar radiation. *Betts et al.* (2007) published that the global surface temperature change owing to vegetation changes is mainly due to the surface albedo changes. Land-use change in the past, involving variation from natural vegetation of relatively low albedo to arable crop growing with higher albedo has suppressed surface temperatures (*Monteith* and *Unsworth*, 1990). In an arable region of small size, *Matthews et al.* (2003) determined a 0.17°C cooling in response to 0.03–0.09 increase in albedo. In field level, *Ridgwell et al.* (2009) simulated more intense, 1 °C cooling in summertime surface temperature when increasing the albedo with 0.04.

Due to difference in crop stand morphology, significant variability exists not only between crop species, but among varieties of the same plant. The maximum of albedo modification due to crop varieties may reach the value of 0.04 (*Hatfield* and *Carlson*, 1979; *Febrero et al.*, 1998). One of the possible reasons of albedo variability within crop species may be the existence of wax or other leaf structural differences. Not only the crop species but the density of maize may impact the albedo. In thin maize stands (40,000 ha^{-1}), the decrease in albedo was significant, sometimes being as high as 8–10% when compared to dense canopy (100,000 ha^{-1}) with the same species (*Anda* and *Loke*, 2005).

Until now it remains unknown, how and to what extent the soot deposition effects the crop life. The aim of our investigation is to discuss the relationship between maize physiological properties and soot deriving from vehicle exhaust and tyres. A reproducible field trial was conducted, that is not extended in pollution studies even now. Despite that two decades have been passing, we still aimed the "stage of reproducible exposure experiment" that has not yet advanced (*Olszyk et al.*, 1989) in contaminated crops grown in the open air.

2. *Material and methods*

Field experiment was conducted to study the impact of black carbon on some maize crop characteristics and canopy microclimate. The place of the study was the Agrometeorological Research Station of Keszthely (46°45'N, 17°14'E, 102 m above sea level), during the vegetation periods of 2010 and 2011. The prevailing genetic soil type is the Ramann type brown forest soil with a mean bulk density of 1.46 $Mg\,m^{-3}$ in the top 1 m of the profile. The available water capacity is 150 $mm\,m^{-1}$. A Swiss-bred maize hybrid, Sperlona (FAO 340), was sown in the field using a plant density of 70,000 plants per hectare. A part of the crops was grown under rainfed conditions, while the others in growing chambers of Thornthwaite-type compensation evapotranspirometers (ET). This latter part of the experiment supplied a treatment of "ad libitum" watering level. The size of the evapotranspirometer's growing chamber was 2×2 m in area, and 1 m in depth. They were filled with a soil monolith from the surrounding field, layered as in the natural state. Dimension of field plots differed from ET chambers, due to the needs of radiation (albedo) measurements. The area of rainfed plots reached 0.3 ha.

Except of unlimited watering of evapotranspirometers, the usual agronomic procedures (plant protection, weed control) recommended for the place by the local staff of the University of Agricultural Sciences, Keszthely, were applied.

The black carbon applied by the Hankook Tyre Company (Dunaújváros, Hungary) to improve the wear resistance of tyres was used as contaminant. More than half of the soot grains are below 18.8 μm, and 90% of the total soot quantity is below 50.6 μm (*Fig. 1*). The black carbon is chemically "pure", i.e., it is free of other contaminants (heavy metals, etc.), so the reproducibility of the experiment is not problematic, unlike that of tests on other atmospheric air pollutants. Relatively small doses were applied (3 $g\,m^{-2}$), but they were repeated at weekly intervals. Due to lack of local information, in determination of applied dose, the extreme amounts of dust sediments published to vegetation surface during the growing season (*Prusty et al.*, 2005; *Freer-Smith et al.*, 2005), and the soot content of local road dust (*Salma* and *Ocskay*, 2006) were taken into account. The published road dust depositions included the background pollution. A motorized sprayer of SP 415 type was used to pollute the crops. The instrument acted as a pulverizer (dry application of BC).

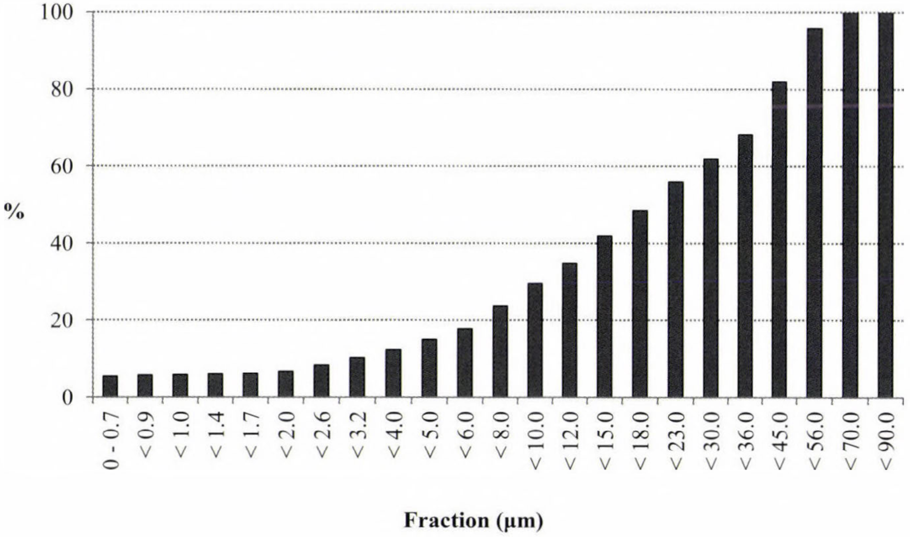


Fig. 1. Cumulative curve of the size distribution of black carbon.

Pyranometers of the CMA-11 type (Kipp & Zonen, Vaisala) were installed on columns of adjustable height in the centre of the 0.3 ha plots designated for albedo measurements. The height of the sensors was raised each week as the plants grew, so that they were always at least 1.5 m above the canopy. Data were collected using a Logbox SD (Kipp & Zonen, Vaisala) datalogger in the form of 10-minute means of samples taken every 6 seconds. Either these 10-minute means or the hourly or daily means calculated from them were used for the analysis.

Canopy temperature was measured by infrared thermometer of RAYNGER II. RTL type (Raytek., Santa Cruz, Calif. USA) with 2 ° field of view and an 8–14 μm waveband filter. For sample takings, the thermometer was hand-held about 1 m above the canopy at an oblique angle three, four or five times per reading at midday (from 12:00 to 3:00 p.m.). After canopy closure, temperature readings were taken daily in clear-sky and calm weather conditions. The emissivity was set to 0.96.

The grain yield was measured in plants from the 10 m^2 at the center area of each plot. In case of ET, the whole growing area of the chambers (4 m^2) was included in yield analysis. The samples were oven dried at 60 °C to a constant weight for 5–7 days and then weighed.

Meteorological data were obtained from the local QLC-50 automatic climate station.

Due to the fixed nature of evapotranspirometers, the experiment was laid out in a block design with four replications, while the dry plots were arranged in a randomized complete block design. The non-irrigated plots, also used for solar radiation measurements, had an area of 0.3 ha. Data analysis was performed using the STATA 5.0 computer package (STATA 5.0, 1996). The t-test was used to determine significant differences between the dry matter yields of polluted and control plants and of rainfed and ET-grown plants. In time series analysis, two-tailed t-test was applied. The significant level was settled to 5% ($P<0.05$).

3. *Results and discussions*

3.1. Crop and weather characteristics in the seasons

In 2010, the seasonal and monthly mean temperatures were in good correspondence with the long-term mean with the exception of July. In July, mean air temperature was 1.8 °C higher than the 1901–2000 average. Mean air temperature was 1.1 °C higher than the climatic norm in the season of 2011. The only exceptional month in 2011 was also July, when the air temperature was close to the average. The growing season of 2010 was substantially wetter than the mean, having 38% higher rainfall sum than the average over many years (*Fig. 2*). May, August, and September received more than double amount of rainfall. In July, however, the precipitation dropped off the long-term mean, the air temperature was high. Oppositely to the previous summer, the growing season of 2011 was extremely dry (the driest season from the beginning of weather observations at Keszthely). The amount of rainfall hardly exceeded the half of the long-term average (51%).

In spite of the variable weather of the two studied summers, the black carbon did not influence either the duration of the vegetation period or the length of phenological phases irrespective to water supplies.

Like a tendency, a moderate increase in the final height of dusted crops (about 20–40 cm) was measured independently on water level or season. This positive modification might be attributed to warming effect of black carbon, mainly during the cooler periods of the crop year, at the beginning of the growing season. In spring, higher air temperature may increase the intensity of photosynthesis producing more photosynthate used in the course of crop growing. The warming impact of soot was detected in the surface temperature of polluted crops.

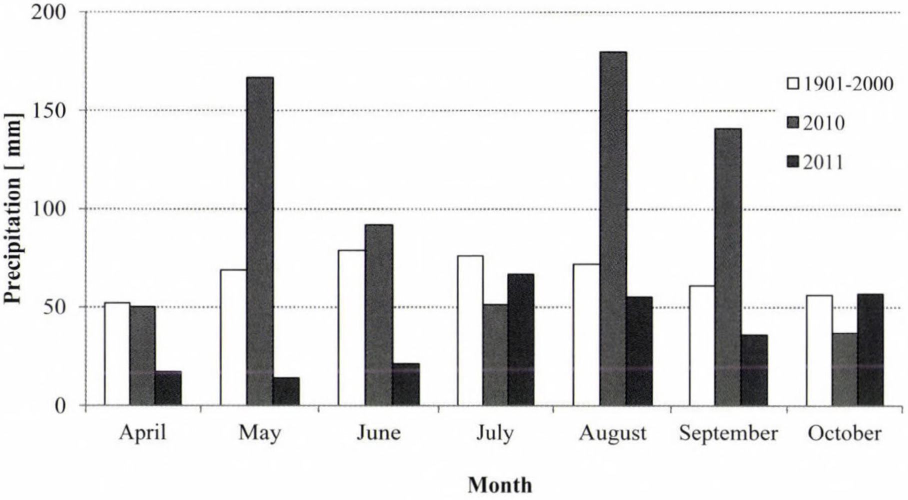
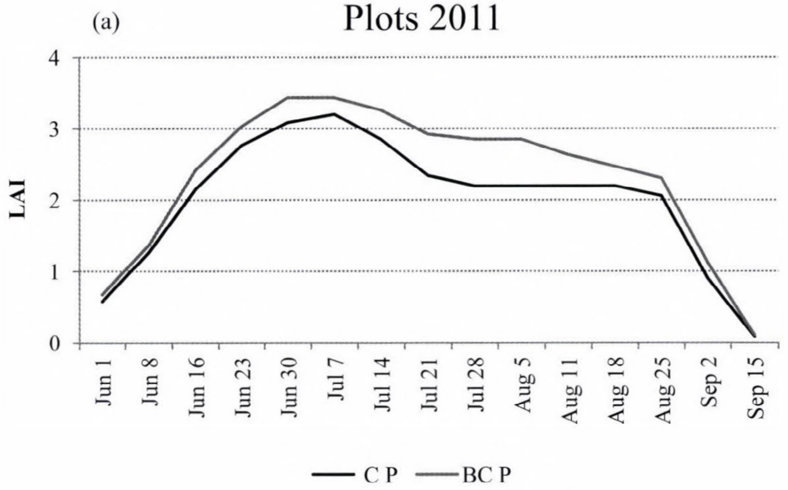


Fig. 2. Monthly sums of precipitation at Keszthely. The values were compared to the climate norm (1901–2000).

The excessive rainfall in 2010 approximated the assimilatory surface sizes of different treatments. Irrespectively to the extra water supply, the seasonal mean of leaf area index (LAI) in the plots was close to that of measured in the ET chamber (data not shown). In 2011, the warmer spring and early summer moderately increased the size of LAI comparing to the results of the previous year (*Figs. 3a* and *b*). Later on, drought of 2011 generated an intense leaf shriveling, and finally the yearly mean assimilatory surfaces were similar in the two studied seasons. Deviations in seasonal mean value of LAI between the two studied years were below 5% with the exception of non-irrigated control (6.8%).

In the wet summer of 2010, the yearly mean LAI of polluted maize remained unchanged. The black carbon was only drawn out the leaf withering in ET chambers. In polluted ET the green leaves lasted a week longer. The drying off of polluted crops in ET began a week later that increased the withering of dusted maize. It was excluded from the length of the growing season as it acted after full ripe of maize. In 2011, the seasonal mean LAI of polluted crops increased with 14.8 (P<0.05) and 11.4% (P<0.05) in non-irrigated control and ET, respectively. In rainy weather the rain might wash out the pollutant from the leaf surface on a larger extent. At about 15–20% of the dust has been removed by rain in our observation. The washing out was also modeled in laboratory, before conducting the field trial.

One of the most important plant characteristics is the season long-integrator, the yield. We expressed it in terms of ear dry matter (DM) production. The [illegible]essive water supply in ET could not amount the grain DM production [illegible]robably due to rainy summer in 2010. In the next season, the “ad libitum watering” of ET significantly rose the maize yield with 13% comparing to the production of non-irrigated control plots ($P<0.01$). This is in accordance with earlier local investigations (*Anda*, 2001).



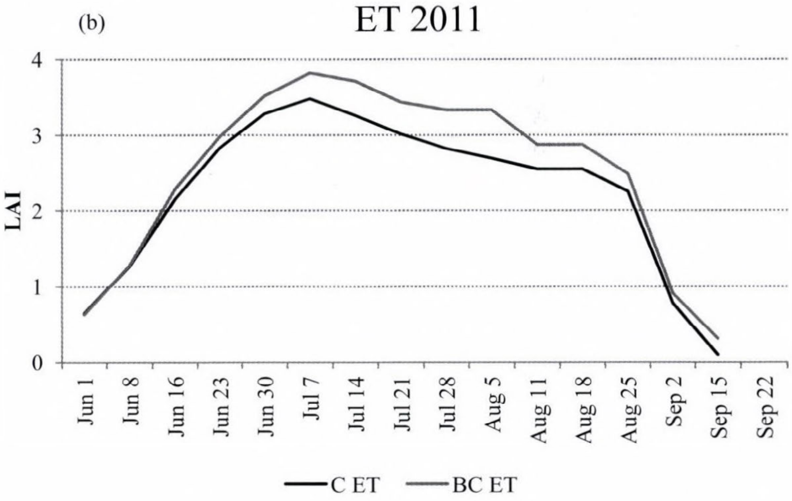


Fig. 3(a) and (b). Seasonal variation in weekly LAI of plots (P) and ET growing chambers (ET). C and BC stands for control and polluted treatments, respectively.

The black carbon pollution significantly declined the grain DM of maize grown in the rainfed plots. The yield loss was close to 9% ($P<0.05$) in 2010, while yield depression doubled ($P<0.05$) during the dry 2011. The same was not observed in dusted ET. A moderate, but not significant deterioration of DM production, including the grain DM of maize grown in the ET chambers was obtained. Finally, the surplus water of ET chambers reduced the yield loss of polluted grain maize irrespectively of variable weather conditions of the two seasons.

3.2. A few members of the heat and water balances

3.2.1 Reflection coefficient, the albedo (a)

Incoming solar radiation is partly reflected from the canopy, partly transmitted to the crop stand, and partly absorbed by the crops. The fraction of incoming short wave solar radiation that is reflected from the surface is called albedo. The albedo is the measure of lost radiation energy from the canopy surface.

In earlier studies, the mean albedo of maize is placed somewhere between 0.18 and 0.22 (*Davies* and *Idso*, 1979; *Hatfield* and *Carlson*, 1979; *Oke*, 1987; *Campbell* and *Norman*, 1998). In the two seasons investigation, after canopy closure, the mean albedo was 0.17 in the control canopy. The highest daily mean values of 0.21 and 0.20 (2010 and 2011) were measured in July, while the minimum albedo (0.11) was found in the end of September, when the crops were completely dried. The black carbon significantly decreased the seasonal mean albedo with about 0.03.

The size of albedo depends on surface characteristics – mainly the color and roughness – and on sun elevation. The black carbon makes the crop color darker declining the size of its albedo. Averaged over the whole measuring period, the mean albedo of polluted maize was 17.5% and 21.7% lower ($P<0.05$) in 2010 and 2011, respectively, than the albedo of control maize *(Fig. 4)*. Soot pollution resulted in a decline in the albedo leaded to higher energy retention of polluted crops. This amount of energy might be high enough to modify the physiological processes as well as crop microclimate.

Over the observations, the greatest deviation in daily mean albedo found for the wax ripe period was 30% in the polluted crop stand. At the beginning of the vegetative period, mainly until canopy closure, alteration in mean albedo of polluted crops fell well below 10%.

Shape of albedo's diurnal variation followed the regular one; while the greatest values were measured at low solar angles (afternoon hours), the minimum albedo was obtained at high elevation (*Fig. 5*). Irrespectively of treatment, the variability of albedo is more pronounced for the morning and afternoon hours. The sample day of *Fig. 5* contains twenty-minute averages of albedo for July 21, 2010. This day was extremely hot with extra strong insolation and high temperatures. The variability in the shape of albedo's curve was the most compensated in the course of cloudless days. These observations were also valid for the season of 2011.

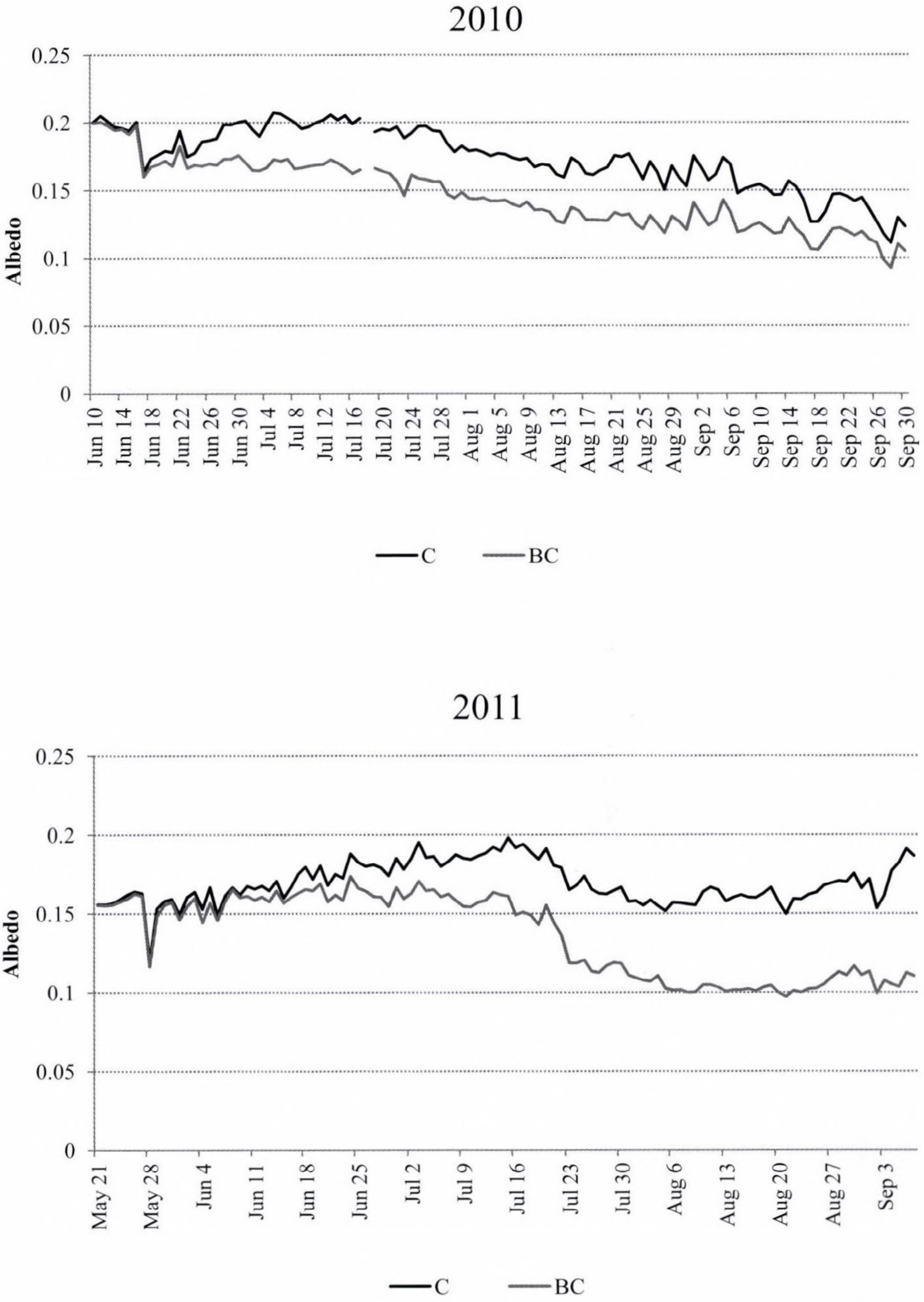


Fig. 4. Daily means of albedo during 2010 and 2011. C and BC denotes control and polluted crop stands, respectively.

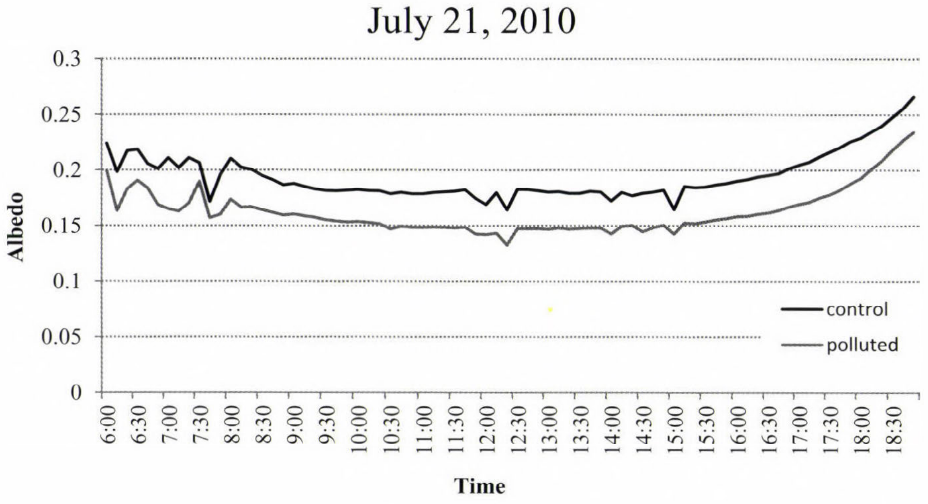


Fig. 5. Diurnal variation in the albedo of maize. Black and grey lines represent the albedo of control and polluted crops, respectively.

Irrespectively to studied summer, daily variation in the albedo's difference due to pollution remained the same as in the control at about in the half of the sample days. In the other half of the days, more pronounced soot impact on albedo was found at low solar elevation reaching values of 0.05–0.09 (*Fig. 6*). Equalized differences can be clearly detected at high insolation.

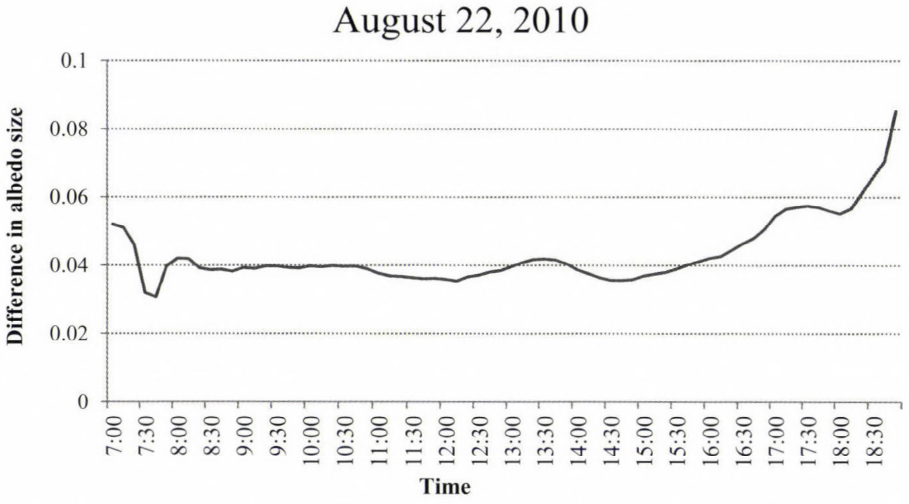


Fig. 6. Differences (contol data - polluted data) in the twenty-minute mean of albedo on August 22, 2010.

3.2.2. Maize evapotranspiration

For maize in ET, the seasonal totals of evapotranspiration were 403.7 and 572.1 mm in 2010 and 2011, respectively. Increment in water loss of the arid season was 34.5% ($P<0.01$). Soot pollution also rose the evapotranspiration of maize. In the wet season of 2010, only slight difference was observed (3.9%). The impact of black carbon increased by 9.6% during the arid 2011. Analyzing the evapotranspiration on daily basis showed that differences between treatments were consistent in time with and without pollution. The top water uses were 7.0 and 7.9 mm day^{-1} in control and polluted maize, respectively on July 19, 2010. The maximum water losses were 8.8 and 10 mm day^{-1} in the middle of July, 2011.

Variability in evapotranspiration is influenced by atmospheric and plant (biological) factors. The solar radiation and transpiration surface size (LAI) are the most important governor factors of plant water losses. Analyzing the evapotranspiration relationships, radiation properties were characterized by albedo, crop features were taken into account by transpiration surface size in the polluted and control treatments separately (*Figs. 7* and *8*). Data collected after canopy closure was included in the study, since information from the early vegetative period deteriorated the relationship between the variables. The number of observation pairs was 81. The observed relationship agreed well in both seasons, this is why the data of 2010 are presented only.

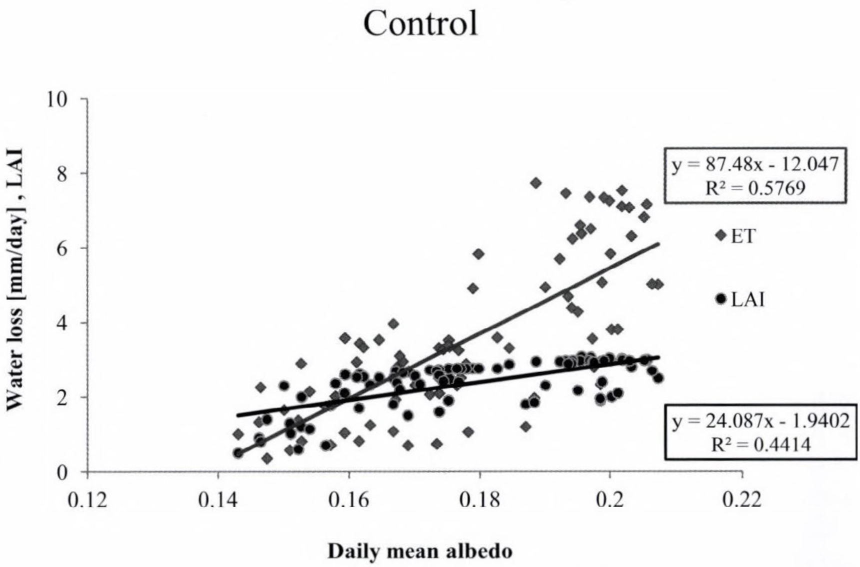


Fig. 7. Impact of albedo on evapotranspiration and leaf area index in control canopy. The number of measurements was 81.

Linear relationship exists between daily mean albedo and evapotranspiration of both treatments. Low water losses were measured in the end of the season when albedo also declined. After canopy closure (the end of June), growth in albedo results almost the same increment in crop water losses, irrespectively to the soot pollution. The reason of this surprising relationship is probably due to the drying off of leaves during the last third of the vegetation period. Withering opens the canopy, declines both transpiration and albedo. There was hardly enough difference in line interception between control and polluted treatments.

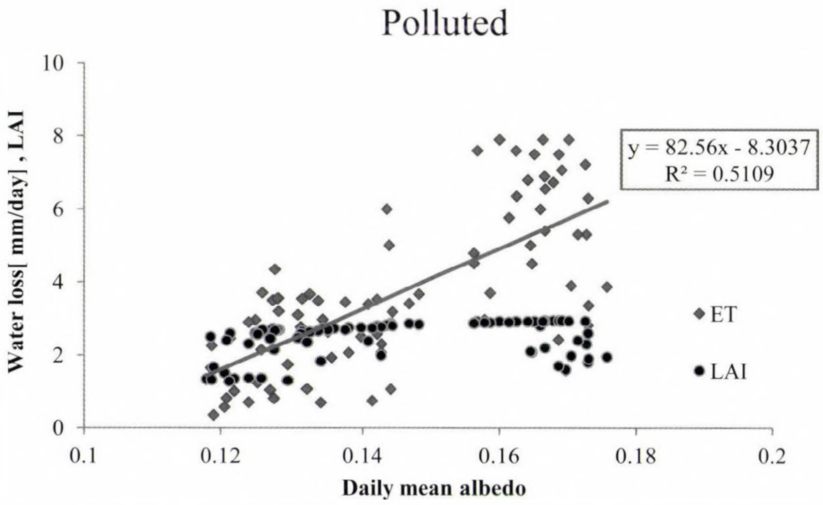


Fig. 8. Impact of albedo on evapotranspiration and leaf area index in polluted canopy. The number of measurements was 81.

The albedo-LAI relation was weaker than the albedo-water loss relation both treatments. In the control maize, linear relationship in albedo and evapotranspiration surface size may be acceptable, but not in case of polluted crops. Albedo of maize with BC was independent of the transpiration surface size after canopy closure. *Oguntunde* and *van de Giesen* (2004) found closer connection between albedo and LAI (correlation coefficient 0.970) in maize for the whole vegetation period. Only the linear shape of relationship agreed with earlier results (albedo data of open canopy are excluded from the study).

For a long while we know that temperature determines the plant growth and particularly development rates. *Warrington* and *Kanemasu* (1983) published that leaf initiation, leaf appearance and elongation are strongly related to temperature in maize. From the thermal time concept, strong correlation is assumed between air and crop temperatures (*Jackson*, 1982). Canopy temperature gave the best results in growth predictions when compared to soil and air temperatures (*Jamieson et al.*, 1995). In spite of the arising error, when extreme humidity and cloudiness mask canopy temperature differences with respect to the temperature differences in the air, the surface temperature is widely applied also in semi-humid regions (*Bajwa* and *Vories*, 2007).

The direction of change in canopy surface temperature resulted from black carbon pollution was irrespective to water supply. The size of change in non-irrigated crops exceeded the temperatures of crops grown in ET. As a rule, difference in crop temperatures between control and polluted plants in ET dropped at about half of those measured in the non-irrigated control plots. As the direction of soot impact on canopy surface temperature was independent of the seasons, detailed discussion is given for 2010 only. In 2011, the size of seasonal mean temperature change in ET resulted from pollution was almost the same as measured in the earlier season. In non-irrigated polluted control plots, more intense crop temperature modification was observed, and the increment in the seasonal mean of polluted maize reached the 1.6 °C (data not shown).

Altogether, 13 days were suitable for canopy temperature measurements in the wet growing season of 2010. We could only take one and two samples in June and August, respectively. In July, when monthly mean temperature was 1.8 °C higher than the climate norm, the crop temperatures were also extremely high, similarly to the larger part of the season in 2011. In spite of the extra water supply in ET, crop temperatures exceeded 31–32 °C three times during July. (The number of these occasions was the same in rainfed plots.) High crop temperatures in 2010, exceeding air temperatures, could not have been the result of water deficiency, but can be attributed to the influence of heat stress. The precipitation might be quite sufficient to supply the maize water need even in the rainfed plots. Finally, soot increased with 0.97 °C the seasonal mean of crop temperature observed at solar noon. Due to the same crop temperature change in ET and control treatments, the impact of BC measured in control is presented (*Fig. 9*). The same data for 2011 was 1.6 °C.

4. Conclusions

With the exception of leaf withering, maize polluted with low doses of BC (3 g m^{-2} $week^{-1}$) produced similar development (length and appearance of phenological phases). The polluted crops retained their green leaves a week longer in wet 2010. Like a tendency, the final crop height increased with 0.2–0.4 m in both seasons. It is important to mention, that this increment was not proved statistically.

The albedo of a crop stand is a key regulator in atmospheric circulation and plays an important role in mechanistic accounting of many ecological processes (*Oguntunde* and *van de Giesen*, 2004). The authors found that the albedo is avaluable input in agricultural practice as well as in different types of modeling (crop production models, eco-hydrological models, regional weather and climate models). Soot pollution significantly declined the mean albedo with about 0.03 after canopy closure. This value meant 17.5% and 21.8% higher energy retention of polluted crops in 2010 and 2011, respectively. A portion of the higher energy retention increased the midday canopy temperatures of dusted maize irrespectively to the season characteristics. In a global climate model, decreasing cropland albedo by 0.04 drives a more than 1 °C warming in summertime surface air temperatures in a wide latitudinal band spanning North America and Eurasia (*Betts et al.*, 2007). These findings are close to our field observations. *Ridgwell et al.* (2009) published more moderate temperature variations; albedo increments of 0.04 and 0.08 produced only 0.11 °C and 0.21 °C surface cooling, respectively.

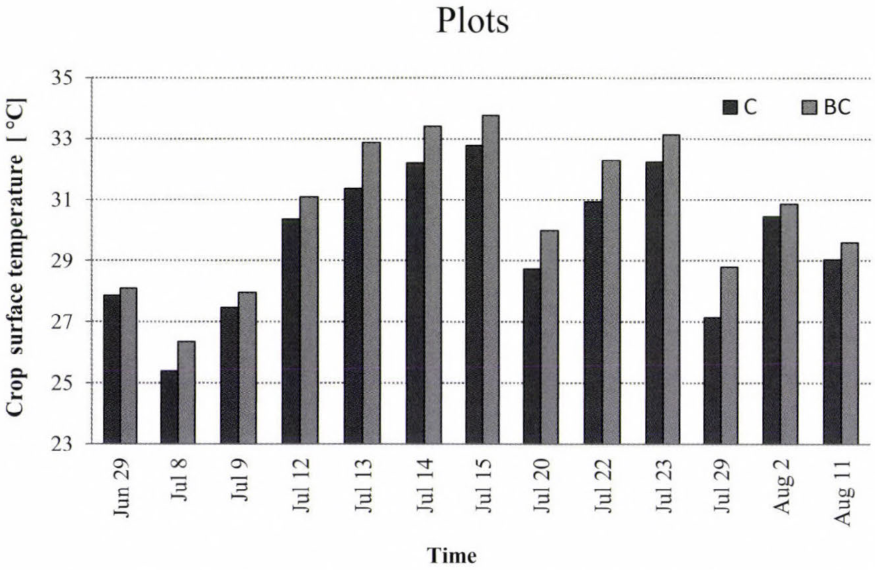


Fig. 9. Canopy surface temperatures measured at solar noon on clear-sky conditions during 2010.

The impact of BC on maize seasonal water loss was reasonable over the wet growing season of 2010. This might have been due to ample precipitation of the summer. Oppositely to 2010, the growth in seasonal water loss of polluted maize increased until 11% in the arid 2011. The physiologically desired crop temperature in ET was achieved with more intense transpiration during 2011 than in 2010.

After canopy closure, a linear relationship exists between daily water loss and albedo even in BC polluted crops. Linear connection between LAI and albedo is acceptable only in case of control maize. In polluted maize stand, the change in albedo seems to be independent on green leaf area size in maize after canopy closure.

Reasonable yield decline was measured in polluted maize plots irrespectively of season's weather. In polluted rainfed plots, the drop-out of DM grain yields were 9% and 20% in the two consecutive seasons. Irrespectively to the weather, the extra water supply in ET decreased the yield loss of polluted maize. The irrigation may be the proper tool to cope the negative impacts of atmospheric origin black carbon pollution.

Acknowledgement—The financial and infrastructural support of the State of Hungary and the European Union in the frame of the TÁMOP-4.2.2/B-10/1-2010-0025 project is gratefully acknowledged.

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