A CLIMATE PROFILE INDICATOR BASED COMPARATIVE ANALYSIS OF CLIMATE CHANGE SCENARIOS WITH REGARD TO MAIZE (ZEA MAYS L.) CULTURES

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Abstract. Using ecological data compiled from scientific literature on pest, pathogen and weed species characteristic in maize cultures in Hungary, we defined monthly climate profile indicators and applied them to complete a comparative analysis of the historical and modelled climate change scenario meteorological data of the city of Debrecen. Our results call attention to a drastic decline of the competitive ability of maize as compared to several C_4 and especially C_3 plants. According to the stricter scenarios, the frequency of potential pest and pathogen damage emergency situations will grow significantly by the end of the century.
Keywords: *climate changes, agriculture, seasonality, new method*

Introduction

Climate change of our planet has by now become an unquestionable fact accepted by all scientists. The general concepts regarding this change roughly coincide, though this is not true when taking smaller details – that might be of extreme importance for agricultural research – into account [16]. Recent research results let us conclude that climate change might have a significant effect on the yield of wheat, barley, rye, potato and maize, and the borderlines of their area of cultivation might shift 100-150 kilometres to the north [10]. The possible mass occurrence of new aggressive pest, pathogen and weed species in our country might also create a problem for plant protection [17].

Maize is one of our most important fodder-plants and Hungary has close on the largest total cultivating area in Europe. Maize is used in many ways, thus being of outstanding economic importance. In Hungary the conditions of maize cultivation are – except for the dry years – quite favourable in most cultural regions and complex cultivating technologies are available. It also might gain a significant role in the line of new environment-friendly alternative sources of energy. For these reasons, it is important to examine the influence of meteorological factors on maize ecosystems and this examination should include as many climate change scenarios and as long a time series as possible.

Materials and Methods

We may study the impact of climate change on maize ecosystems and the consequent changes of the risk of potential plant protection emergency situations using various alternative research methods, each characterised by different limitations. **Modelling by species** is an unsuitable method, as only the modelling of maize – though it is quite well known and some maize-simulation model types already exist – is a great enough challenge for scientists. **A statistical analysis of the past data** of pests would equally not provide true results, as the 50s, 60s and 70s were characterised by an excessive use of chemicals, while protection later on was rather based on prognostics.

In the course of our research we compiled from Hungarian scientific literature the pest, pathogen and segetal weed species potentially occurring in Hungarian maize ecosystems and also surveyed their ecological needs. Using these we created monthly **climate profile indicators** to be able to make a comparative analysis of the relative frequencies of potential plant protection emergency situations. We introduced the concept of climate profile indicator based on our methodological research. In our study we completed a comparative analysis of the historical and modelled scenario meteorological data of Debrecen, based on monthly climate profile indicators.

Data concerning pest, pathogen and weed species of maize ecosystems were collected from as many Hungarian sources as possible [1, 3, 5, 7, 8, 11, 12, 13, 14, 18, 19, 20, 21,25, 26]. The abovementioned works are characterised by different structures, some of them list pest species, micro organisms or weeds by taxonomic order, others group them by host plants. But they all have one thing in common: they all provide more or less detailed descriptions of the biological and ecological needs of the given harmful creatures.

These descriptions of the climatic needs of harmful creatures have rarely yielded exact numbers, instead they report on the warm or cold, wet or dry circumstances favourable for their occurrence or reproduction in the given month or season. While converting these descriptions into numerical data, we took the many years' mean meteorological data of the base period of the description as a reference. We tried to primarily rely upon data from Hungarian scientific literature, but in some of the cases, for the refinement of data we also took statements of the international literature into consideration. Unfortunately, data concerning the climatic needs taken from international scientific literature are not always applicable for the area of the Carpathian-basin, due to their different ecological and biogeographical characteristics.

The monthly mean temperature and precipitation values concerning the present climate of Debrecen were taken from the monitoring network database of the Hungarian Meteorological Service (OMSZ). A series of data were at our disposal complete from 1952 to 1992.

The change of climate is studied by scientists using climate models. International simulation experiments using these models result in **climate scenarios**. A scenario is a consistent and realistic description of a possible future state of the world. It is not a prediction, but rather an alternative picture of future climate. Scenarios are the final results of 3D numerical General Circulation Models (GCM). They are usually created as a solution of Navier-Stokes partial differential equation systems defined for the cells of a vertically 10-20 times multilayered 250-600 km grid, considering the laws of energy and mass conservation. The solution of these complicated and robust systems of differential equations is only possible with the help of high capacity computers, so only larger institutes are capable of running these models.

Although the starting parameters are the same, it is interesting that the different runs of the models produce different results [2]. Because of this, we examined in our study runs of the United Kingdom Met Office Hadley Centre and also those of the American Geophysical Fluid Dynamics Laboratory. The scenario called BASE is the run of the Hadley Centre simulated with current conditions, forming the base for further scenarios. We also used data series of the recently created new model runs, representing the latest results of Central European climate modelling. Thus, to analyse the climate of Debrecen, we used UKHI (1990) and UKLO (1987) balanced, UKTR (1992) transient, as well as HCA2 and HCB2 scenarios of the HadCH3 (1998) climate change model created by the **United Kingdom Met Office** (UKMO) **Hadley Centre** (England), MPA2 scenario by the **Max Planck Institute für Meteorologie** (MPI-M, Germany), and GFDL2534 (1991) (=GF2), GFDL5564 (1991) (=GF5) and Base scenarios of the **Geophysical Fluid Dynamics Laboratory** (GFDL, USA).

For the definition and evaluation of monthly climate profile indicators we used **KKT,** a software and database created by [22]. The software works with special data handling functions, thus being perfectly suitable for the handling of a great mass of data.

We introduced the concept of climate profile indicator based on our methodological research. By climate profile indicator we mean the seasonal pattern of the climatic needs of a certain species. Climate profile indicators may be of different temporal resolutions. During this work, we only applied monthly climate profile indicators, assigning monthly precipitation and temperature need values to the 12 months of the year.

Based on literature data we used KKT to generate 55 monthly climate profile indicators and named them after their serial number. Each monthly climate profile saved in the computer can be considered as an individual indicator that could be used to classify both real historical and official climate scenario meteorological data.

The climate profile is consisted of 3 – minimum, mean and maximum – temperature – and one precipitation data. For every month we defined the lower and higher limit of the 4 meteorological parameters mentioned above, meaning 96 data, 8 parameters for each 12 months.

After the selection of the appropriate meteorological database uploaded in the software, we may apply further limitations concerning the annual (year to year) and seasonal (month to month) period of investigation. The historical meteorological data set of Debrecen has been incomplete since 1993, so we restricted the evaluation of monthly profiles for the period between 1951 and 1992. *(Fig. 1.)*

Having selected the preferred profile from the previously defined indicators, we could start with the evaluation of climate profile indicators. **Our question was in how many years do the defined climate profiles come true regarding historical meteorological data of the 1951-1992 period and 31 years of applied scenario data.** With the help of the software for each parameter we received a result, namely, an answer to the question whether the defined monthly conditions did or did not come true in the given year. *(Fig. 2.)*

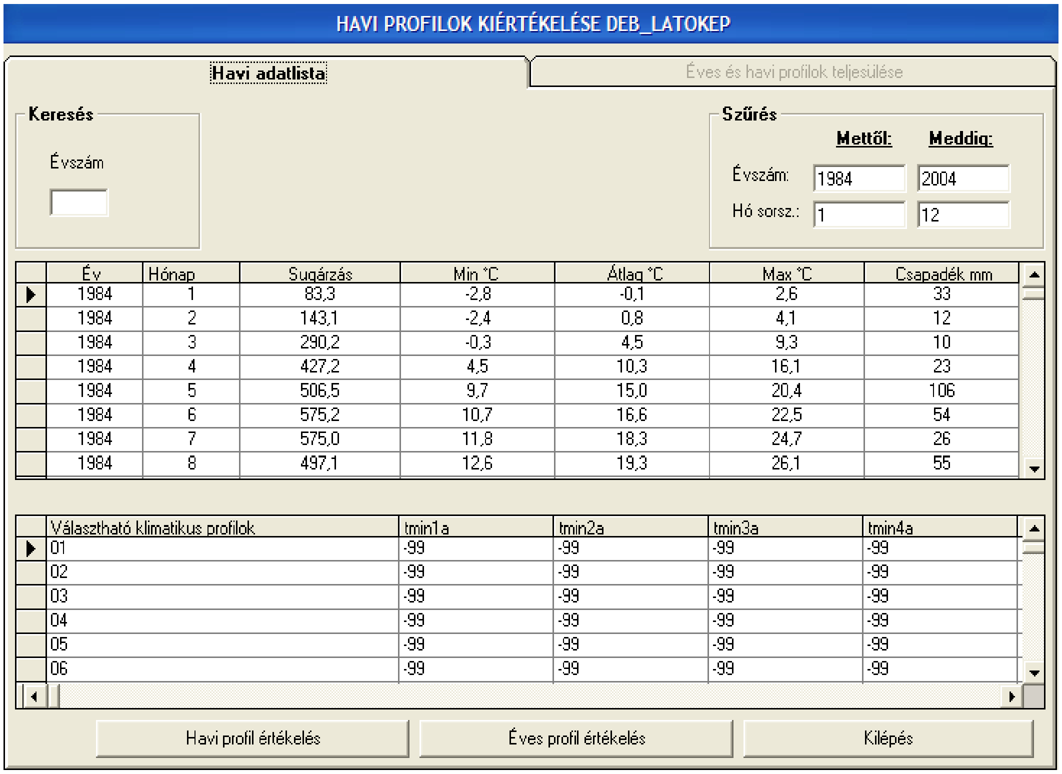

***Figure 1.** Monthy data list of DEB_LATOKEP used for the evaluation of monthly climate profile indicators*

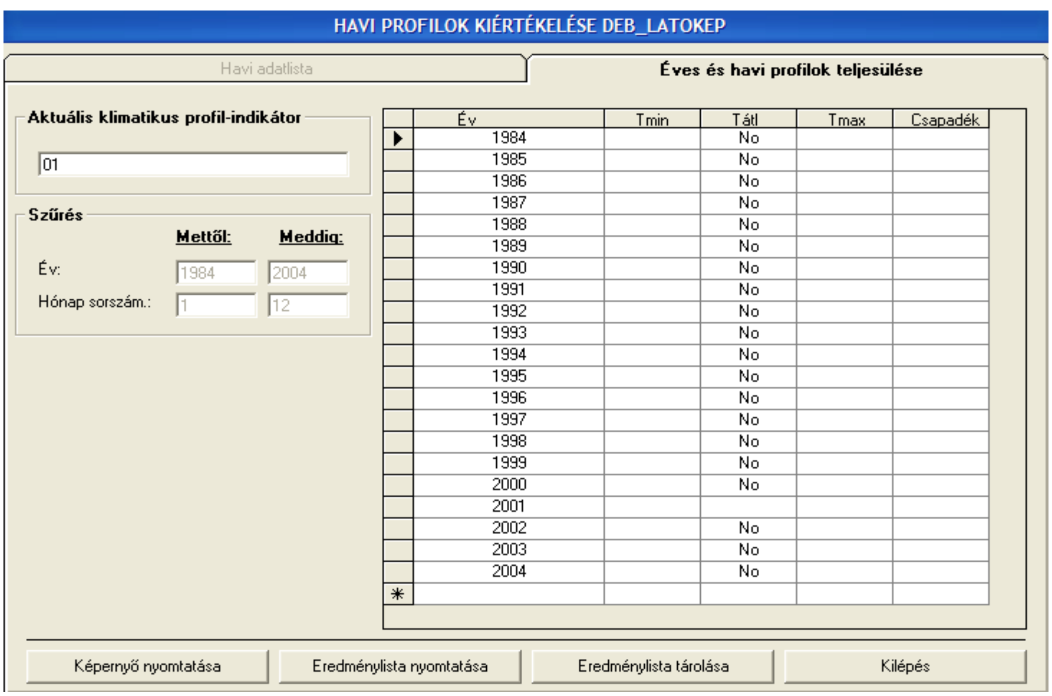

***Figure 2.** The database of the annual evaluation of monthly climate profile indicators*

Table 1. *Relative frequencies of monthly climate profile indicators concerning historical and modelled scenario data of Debrecen*

	Látókép	Base	GF2	GF5	UKHI	UKLO	UKTR	HCA2	HCB2	MPA2
1	5	3	19	68	100	100	26	94	71	84
2	0	0	6	32	97	100	0	94	71	84
3	0	0	0	6	3	26	3	6	13	19
4	0	0	3	13	48	16	3	26	16	13
5	0	0	0	6	3	0	0	6	3	3
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	3	3	3
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	3	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	5	3	3	3	3	6	6	3	3	6
18	0	0	0	3	0	3	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	14	0	6	0	0	0	0	3	10	3
21	0	0	6	32	97	100	94	94	84	90
22	0	3	3	19	42	10	6	29	19	13
23	10	10	10	0	0	0	6	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	84	97	0	13	0	6
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	71	90	84	84	71	87	87	45	58	87
30	5	3	3	0	0	0	3	0	0	0
31	0	0	0	0	0	0	0	0	0	0
32	0	0	0	3	55	16	3	81	77	45
33	0	0	0	0	6	10	3	16	23	10
34	5	16	23	39	65	29	32	55	45	32
35	0	0	0	3	35	3	0	48	39	26
36	0	0	0	3	35	0	0	29	32	16
37	0	0	0	0	16	29	0	13	0	0
38	0	0	0	0	0	0	0	0	0	0
39	0	0	6	3	42	13	13	65	65	35
40	0	0	0	0	0	0	0	0	0	0
41	14	10	45	58	97	100	32	100	100	100
42	10	3	26	45	97	100	26	100	100	100
43	5	13	61	74	97	100	71	97	94	100
44	5	6	45	90	94	100	61	100	94	97
45	0	0	0	0	16	29	0	13	0	0
46	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	6	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0
51	24	13	48	68	100	100	45	100	100	100
52	10	3	32	23	71	35	32	97	97	68
53	0	0	0	3	0	3	0	0	0	0
54	5	13	3	16	0	13	3	0	0	3
55	0	3	3	6	0	13	3	3	13	13

After the yearly evaluation of the monthly climate profile indicators with the KKT software we summarized the results in an Excel table. At first, we recorded in a table the number of fulfilments of all monthly climate profile indicators in the examined years, for all scenarios. Afterwards, we calculated the relative frequencies of these indicators. The obtained table of results *(Table 1.)* we compared with multivariate pattern analytic methods, both from the aspect of objects and variables, using the statistical software package Past (PAST – PAlaeontological STatistics, ver. 1.79, [9]. We analysed the columns (objects, i.e. climatic data series) and rows (variables, i.e. indicators) of the table by hierarchical cluster analysis – a method of classification – and by non-metric multi dimensional scaling (NMDS) – a method of ordination. We verified the results by graphically projecting the classifications and ordinations onto each other, then, based on verified cluster orders, we applied a two-way clustering for the re-arrangement of tables.

Results and Discussion

Definition of Monthly Climate Profile Indicators

As a result of synthesizing literature data, we created a classified numerical database, introducing 55 monthly climate profile indicators *(Table 5.).* including information on 91 species. Besides maize, the species under examination included 23 zoological pests *(Table 2.),* 12 pathogenic micro-organisms *(Table 3.)* and 55 weed species *(Table 4.)* typically occurring in maize cultures. The tables list the species in taxonomic order.

Table 5. lists the 55 monthly climate profile indicators, the red numbers showing temperature and the blue ones precipitation values. Relation marks indicate if the given indicators demand of temperature or precipitation is higher or lower. The values were established as follows: if we found in literature that e.g. a warm and dry spring was favourable for a given creature, then we recorded the mean temperature and precipitation values with the appropriate relation marks for all the spring months. The profiles of weed species were created after their growth form, this way the 55 species were divided into groups, containing different numbers of weeds.

Table 2. *Most important zoological pests of maize in Hungary and their indicators (ISN: serial number of climate profile indicators)*

SCIENTIFIC NAME	ISN	HUNGARIAN NAME
Ditylenchus dipsaci	18	Szár-fonálféreg
Melanogryllus desertus	35	Fekete tücsök
Gryllotalpa gryllotalpa	35	Lótücsök
Dociostaurus maroccanus	32	Marokkói sáska
Tetraneura ulmi	34	Kukorica-gyökértetű
Rhopalosiphum maidis	5	Zöld kukorica -levéltetű
Rhopalosiphum padi	5	Zselnicemeggy-levéltetű
Schizaphis graminum	5	Zöld gabona-levéltetű
Aphis fabae	6	Fekete répa-levéltetű
Myzus persicae	5	Zöld őszibarack-levéltetű
Zabrus tenebrioides	54	Gabonafutrinka
Opatrum sabulosum	20	Sároshátú gyászbogár
Amphimallon solstitalis	41	Közönséges júniusi cserebogár
Melolontha melolontha	22	Májusi cserebogár
Melolontha hippocastani	22	Erdei cserebogár
Anoxia pilosa	22	Pusztai cserebogár
Polyphilla fullo	54	Kalló cserebogár
Diabrotica virgifera virgifera	39	Amerikai kukoricabogár
Psalidium maxillosum	3	Fekete barkó
Tanymecus dilaticollis	17	Kukoricabarkó
Ostrinia nubilalis	33	Kukoricamoly
Autographa gamma	36	Gamma-bagolylepke
Heliothis maritima	36	Somkóró-bagolylepke
Helicoverpa armigera	36	Gyapottok-bagolylepke
Mamestra brassicae	36	Káposzta-bagolylepke
Scotia segetum	36	Vetési-bagolylepke
Oscinella frit	23	Fritlégy

Table 3. *The most important pathogenic micro-organisms of maize in Hungary and their indicators (ISN: serial number of climate profile indicators)*

SCIENTIFIC NAME	ISN	HUNGARIAN NAME
Maize dwarf mosaic potyvirus	5	Kukorica csíkos mozaik
Sclerophora macrospora	30	Kukoricaperonoszpóra
Ustilago maydis	47	Golyvásüszög
Sorosporium holci-sorghi	51	Rostosüszög
Puccinia sorghi	4	Kukoricarozsda
Phyllosticta maydis/Mycosphaerella maydis	40	Sárga levélfoltosság
Rhizoctonia bataticola	52	Kukorica szürke szárkorhadása
Kabatiella zeae	53	Kabatiellás szemfoltosság
Nigrospora oryzae/Khuskia oryzae	55	Nigrospórás szárazkorhadás
Fusarium graminearum	24	Kukorica fuzáriózása
Helminthosporium turcicum	48	Kukorica helmintospóriumos levélfoltossága

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Table 4. *The most important segetal weeds occurring in maize cultures in Hungary and their indicators (ISN: serial number of climate profile indicators)*

SCIENTIFIC NAME	ISN	HUNGARIAN NAME
Equisetum arvense	19	Mezei zsurló
Portulaca oleracea	28	Kövér porcsin
Atriplex patula	46	Terebélyes laboda
Atriplex tatarica	13	Tatár laboda
Chenopodium album	15	Fehér libaparéj
Chenopodium hybridum	15	Pokolvar libaparéj
Chenopodium polyspermum	15	Hegyes levelű libatop
Amaranthus albus	14	Fehér disznóparéj
Amaranthus blitoides	46	Henye disznóparéj
Amaranthus clorostachys	25	Karcsú disznóparéj
Amaranthus retroflexus	25	Szőrös disznóparéj
Bilderdykia convolvulus	11	Ugari szulákpohánka
Polygonum lapathifolium	15	Lapulevelű keserűfű
Polygonum persicaria	15	Baracklevelű keserűfű
Cannabis sativa	2	Kender
Lathyrus tuberosus	21	Mogyorós lednek
Mercurialis annua	43	Egynyári szélfű
Capsella bursa-pastoris	10	Pásztortáska
Diplotaxis muralis	46	Fali kányazsázsa
Raphanus raphanistrum	8	Repcsényretek
Sinapis arvensis	9	Vadrepce
Reseda lutea	42	Vadrezeda
Abutilon theophrasti	45	Selyemmályva
Hibiscus trionum	28	Varjúmák
Anagallis arvensis	15	Mezei tikszem
Convolvulus arvensis	31	Apró szulák
Datura stramonium	43	Csattanó maszlag
Heliotropium europaeum	49	Parlagi kunkor
Symphytum officinale	19	Fekete nadálytő
Plantago major	19	Nagy útifű
Ajuga chamaepitys	11	Kalinca ínfű
Stachys annua	15	Tarlóvirág
Ambrosia elatior	13	Parlagfű
Cirsium arvense	50	Mezei aszat
Galinsoga parviflora	11	Kicsiny gombvirág
Matricaria inodora	16	Ebszékfű
Xanthium italicum	12	Olasz szerbtövis
Sonchus arvensis	44	Mezei csorbóka
Sonchus asper	44	Szúrós csorbóka
Elymus repens	1	Tarackbúza
Phragmites communis	19	Nád
Cynodon dactylon	7	Csillagpázsit
Eragrostis spp.	37	Tőtippan fajok
Digitaria sanguinalis	38	Pirok ujjasmuhar
Echinochloa crus-galli	37	Közönséges kakaslábfű
Panicum miliaceum	1	Termesztett köles
Setaria glauca	27	Fakó muhar
Setaria media	46	Tyúkhúr
Setaria verticillata	45	Ragadós muhar
Setaria viridis	26	Zöld muhar
Sorghum halapense	1	Fenyércirok

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Table 5. *Monthly climate profile indicators (Budapest, 2008) (red: temperature data, blue: amount of precipitation)*

	March	April	May	June	July	August	September	October	November
1	6<	11<	16<						
2	6<	11<	16<	19<	21<	20<			
3	6<	11<	16<						
4	6<	11<	16<						
5	6< <31	11<	16<	19<					
6	6<	11<	16<	19<	21<	20<	16< 42<		
7	6<	11<	16<	19<	21<	20<	16< <42		
8	8-14	8-14	8-14						
9	8-14	8-14	8-14	8-14	8-14	8-14	8-14 42<		
10	10<	10<	10<	10<	10<	10<	10< 42<		
11	18<	18<	18<	18<	18<	18<	18<		
12	18<	18<	18<	18<	18<	18<	18<	18<	
13	18<	18<	18<	18<	18<	18<	18<	18<	18<
14	18<	18<	18<	18<	18<	18<	18< 42<		
15	18<	18<	18<	18<	18<	18<	18< 42<		
16	18<	18<	18<	18<	18<	18<	18<	18<	18<
17			16<						
18						58<			
19						58<	42<		
20						<58	<42		
21		11<	16<	19<	21<	20<	16<		
22		11<	16<	19<					
23		<11	<16						
24		<11	<16			58<	42<		
25		18<	18<	18<	18<	18<	18<		
26		18<	18<	18<	18<	18<	18< 42<	18<	
27		18<	18<	18<	18<	18<	18< 42<	18<	
28		18<	18<	18<	18<	18<	18< 42<		
29			5<	10<	10< 5<	10< 5<	8<	5<	
30			<16	<19					
31			16< 59<	19<	21<	20<	16< 42<		
32			16<	19<	21<	20<			
33			16< 59<	19<	21<	20<	16< <42		
34			16<				16< <42		
35			16<	19<	21<	20<	16< <42		
36			16<	19<	21<	20<	16< <42	11<	
37			18<	18<	18<	18<	18<	18<	
38			25<			58<	42<		
39				19<	21<	20<	16< <42		
40						58<	42<		
41				19<	21<				
42				19<	21<	20<			
43				18<	18<	18<	16<	11<	
44				18<	18<	18<	18<		
45				18<	18<	18<	18<	18<	
46				18<	18<	18<	18<	18<	18<
47				19<	21<	20<			
48				19<	21<	20<	16< 42<	11<	
49				19<	21<	20<	16< 42<		
50						58	42 <		
51					21<	20<			
52					21<	20<			
53					21<	20<	16< 42<		
54						58<			
55							16< 42<	11<	

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A Comparative Analysis of the Historical and Modelled Meteorological Data of Debrecen

We used the statistical software package PAST for the analysis of the relative frequency table *(Table 1.)* regarding the monthly climate profile indicators for the historical and modelled scenario data of Debrecen.

The dendrogram *(Fig. 3 a)* shows the classification of the monthly climate profile indicators. We can see that the indicators (1, 2, 21, 29, 41, 42, 43, 44, 51) preferring warm springs or/and summers without any precipitation demands (e.g. *Datura stramonium, Sonchus species, Sorosporium holci-sorghi, Reseda lutea, Elymus repens, Lathyrus tuberosus, Zea mays*) belong to one big group which is closely related to the indicators (32, 34, 39, 52) demanding hot dry summers (e.g..: *Dociostaurus maroccanus, Tetraneura ulmi, Diabrotica virgifera virgifera, Rhizoctonia bataticola*). Indicators (4, 22, 25, 35, 36) demanding warm and dry spring or/and summer (e.g.: *Helicoverpa armigera, Gryllotalpa gryllotalpa, Melolontha species, Puccinia sorghi, Amaranthus species*) are linked to the group of indicators demanding warmth and various amounts of precipitation in the spring and summer (e.g. *Nigrospora oryzae, Kabatiella zeae, Ustilago maydis, Abutilon theophrasti, Ostrinia nubilalis, Tanymecus dilaticollis, Ditylenchus dipsaci*). The lower part of figure *(Fig. 3 b)* shows the position of indicators after the dimension reduction by NMDS, the elements of the groups are exactly the same as those of the groups produced by cluster analysis in higher dimensions of space.

After the results of the monthly climate profile indicator based evaluation of the model runs for the scenarios of Debrecen and the classification and ordination of data we found that data may be divided into two larger groups *(Fig. 4 a).* The first group includes the historical data of Debrecen (Látókép), the Base scenario fitted on past data and the scenarios GF2, GF5 and UKTR calculating with a moderate change of climate. The second group is formed by balanced models (UKHI, UKLO) and the scenarios originating from the PRUDENCE project (HCA2, HCB2, MPA2), both calculating with a significant change of climate. Inside the two larger groups well identifiable sub-groups can be recognized. In the first group the data series Látókép and Base are much similar, being closer to each other than to any other scenarios. This fact supports the reliability of the models applied. Inside the group scenarios calculating with a more significant climate change, regional data series of the PRUDENCE project (HCA2, HCB2, MPA2) are separated from the older balanced models (UKHI, UKLO). Ordination *(Fig. 4 b)* also shows us the model runs calculating with more and more serious changes of climate getting further and further away from the data of the historical base period. The picture may be considered as a proof for the applied monthly climate profile indicators being suitable for the efficient evaluation of information lying inside model runs.

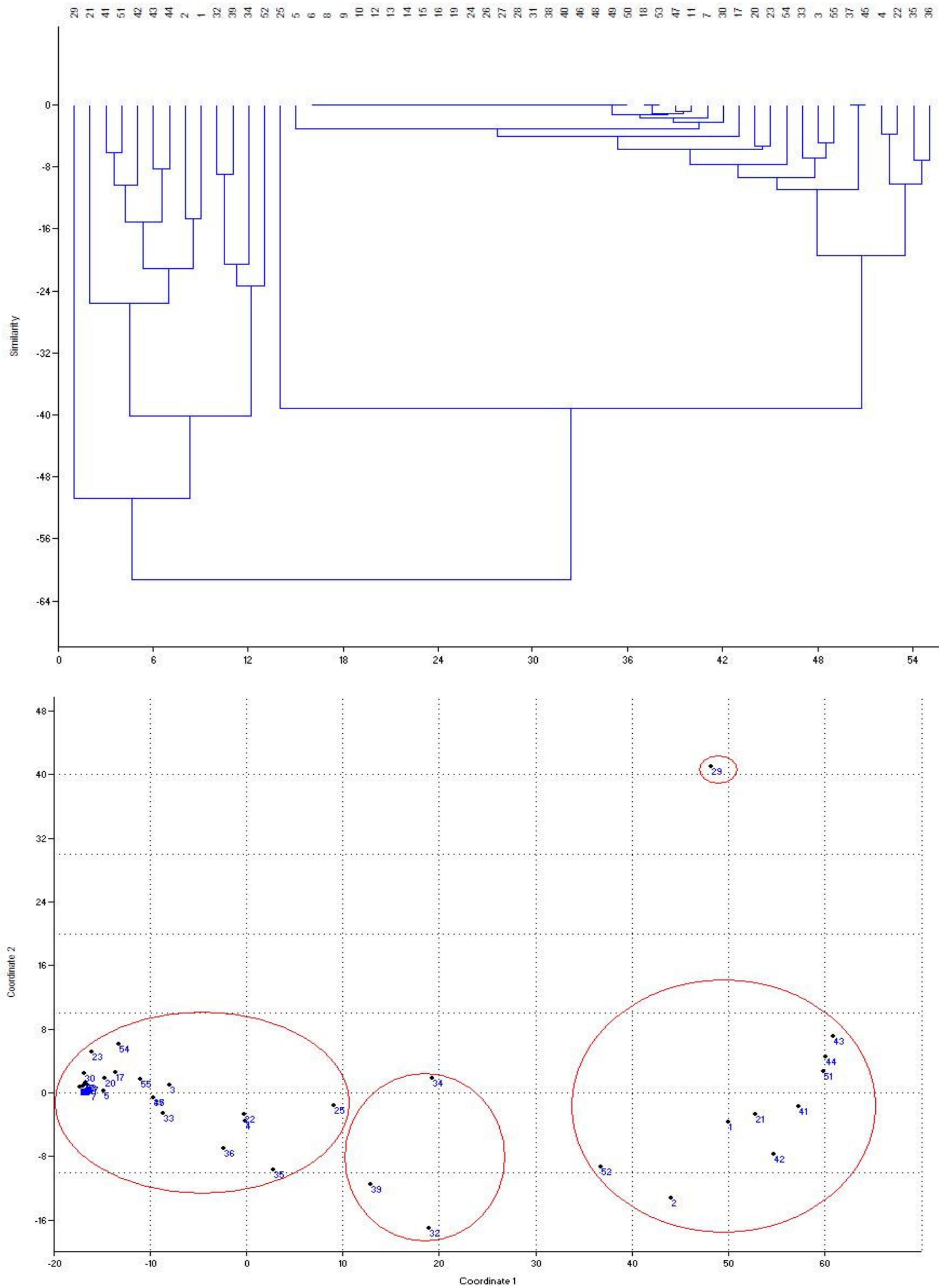

Figure 3. a, *Classification of monthly climate profile indicators based on historical and modelled scenario meteorological data of Debrecen, by cluster analysis* ***b,*** *Ordination of monthly climate profile indicators including the projection of groups created by cluster analysis, based on historical and modelled scenario meteorological data of Debrecen, by NMDS*

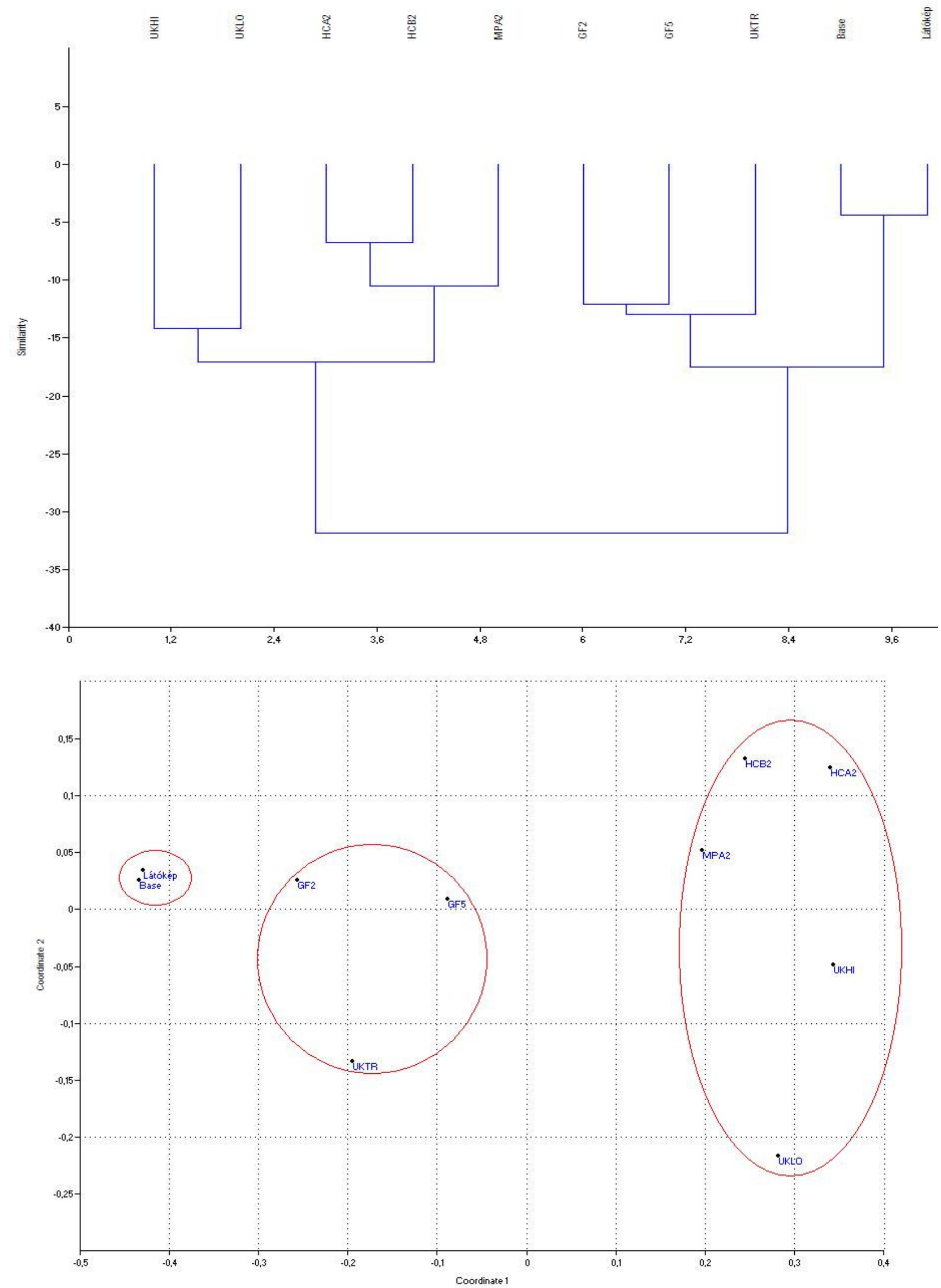

Figure 4. a, *Classification of monthly climate profile indicators based on historical and modelled scenario meteorological data of Debrecen, by hierarchic cluster analysis* ***b,*** *Ordination of monthly climate profile indicators including the projection of groups created by classification, based on historical and modelled scenario meteorological data of Debrecen, by NMDS*

Fig. 5 and *Table 6*. shows a two-way cluster analysis of the monthly climate profile indicators and the meteorological data of scenarios for Debrecen. Rows were created by a classification of monthly climate profile indicators, as columns by one of the data of the Debrecen scenarios. Indicators containing only 0 values and thus no information were excluded from the analysis. We found Base scenario being much similar to the historical meteorological data of Látókép. This proves, that Base scenario simulated using present conditions may form a suitable basis for the other scenarios.

The relative frequency of all indicators falls between 0-24% for Base and Látókép data. In the case of GF2, GF5 and UKTR scenarios, indicators with warm spring and/or summer temperature and no precipitation demands (e.g. *Datura stramonium, Sonchus fajok, Sorosporium holci-sorghi, Reseda lutea, Elymus repens, Lathyrus tuberosus)* had a relative frequency of 19-94%. Indicators needing warm and dry summers (e.g. *Dociostaurus maroccanus, Tetraneura ulmi, Diabrotica virgifera virgifera, Rhizoctonia bataticola*) came up with a relative frequency of 0-39% at these scenarios, and those needing warm and dry spring and/or summer (e.g. *Helicoverpa armigera, Gryllotalpa gryllotalpa, Amaranthus species, Melolontha species, Puccinia sorghi*) with a relative frequency of 0-19%.

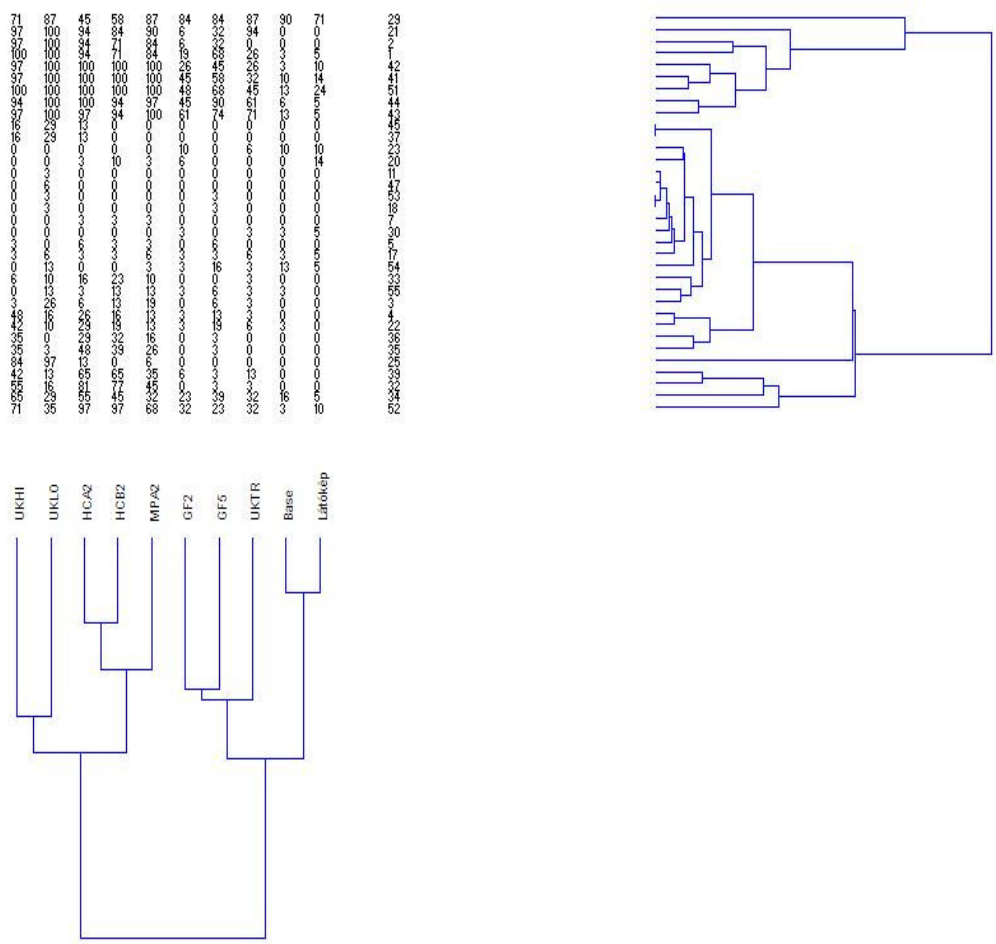

Figure 5. *Two-way cluster classification of monthly climate profile indicators and the historical and modelled scenario meteorological data of Debrecen*

Table 6. *The result of two-way classification of monthly climate profile indicators and the historical and scenario meteorological data of Debrecen, including the monthly climate profile indicators*

	UKHI	UKLO	HCA2	HCB2	MPA2	GF2	GF5	UKTR	Base	Latókép	március	április	május	június	július	augusztus	szeptember	október
29	71	87	45	58	87	84	84	87	90	71			5<	10<	10< 5<	10< 5<	8< <100	5< <100
21	97	100	94	84	90	6	32	94	0	0		11<	16<	19<	21<	20<	16<	
2	97	100	94	71	84	6	32	0	0	0	6<	11<	16<	19<	21<	20<		
1	100	100	94	71	84	19	68	26	3	5	6<	11<	16<					
42	97	100	100	100	100	26	45	26	3	10				19<	21<	20<		
41	97	100	100	100	100	45	58	32	10	14				19<	21<			
51	100	100	100	100	100	48	68	45	13	24					21<	20<		
44	94	100	100	94	97	45	90	61	6	5				18<	18<	18<	18<	
43	97	100	97	94	100	61	74	71	13	5				18<	18<	18<	16<	11<
45	16	29	13	0	0	0	0	0	0	0				18<	18<	18<	18<	18<
37	16	29	13	0	0	0	0	0	0	0			18<	18<	18<	18<	18<	18<
23	0	0	0	0	0	10	0	6	10	10		<11 44<	<16 59<					
20	0	0	3	10	3	6	0	0	0	14	<31	<44	<59	<72	<60	<58	<42	
11	0	3	0	0	0	0	0	0	0	0	18<	18<	18<	18<	18<	18<	18<	
47	0	6	0	0	0	0	0	0	0	0				19< 72<	21< 60<	20< 58<		
53	0	3	0	0	0	0	3	0	0	0					21< 60<	20< 58<	16< 42<	
18	0	3	0	0	0	0	3	0	0	0	31<	44<	59<	72<	60<	58<		
7	0	0	3	3	3	0	0	0	0	0	6< <31	11< <44	16< <59	19< <72	21< <60	20< <58	16< <42	
30	0	0	0	0	0	3	0	3	3	5			<16 59<	<19 72<				
5	3	0	6	3	3	0	6	0	0	0	6< <31	11< <44	16< <59	19< <72				
17	3	6	3	3	6	3	3	6	3	5	<31	<44	16< 59<					
54	0	13	0	0	3	3	16	3	13	5					60<	58<		
33	6	10	16	23	10	0	0	3	0	0			16< 59<	19< <72	21< <60	20< <58	16< <42	
55	0	13	3	13	13	3	6	3	3	0							16< 42<	11< 43<
3	3	26	6	13	19	0	6	3	0	0	6< 31<	11< 44<	16< 59<					
4	48	16	26	16	13	3	13	3	0	0	6< 31<	11< <44	16< <59					
22	42	10	29	19	13	3	19	6	3	0		11< <44	16< <59	19< <72				
36	35	0	29	32	16	0	3	0	0	0			16< <59	19< <72	21< <60	20< <58	16< <42	11< <43
35	35	3	48	39	26	0	3	0	0	0			16< <59	19< <72	21< <60	20< <58	16< <42	
25	84	97	13	0	6	0	0	0	0	0		18<	18<	18<	18<	18<	18<	
39	42	13	65	65	35	6	3	13	0	0				19< <72	21< <60	20< <58	16< <42	
32	55	16	81	77	45	0	3	3	0	0			16<	19< <72	21< <60	20< <58		
34	65	29	55	45	32	23	39	32	16	5			16< <59				16< <42	
52	71	35	97	97	68	32	23	32	3	10					21< <60	20< <58		

In the case of scenarios UKHI, UKLO, HCA2, HCB2, MPA2, indicators with warm spring and/or summer but no precipitation demands (pl.: *Datura stramonium, Sonchus species, Sorosporium holci-sorghi, Reseda lutea, Elymus repens, Lathyrus tuberosus*) occured with a relative frequency of 32-100%. Indicators needing warm and dry spring and/or summer (e.g. *Helicoverpa armigera, Melanogryllus desertus, Amaranthus species, Melolontha species, Puccinia sorghi*) showed a relative frequency of 13-48%. Maize (*Zea mays*) indicated a relative frequency of 45-90% for historical and modelled scenarios.

Based on literature, C_3 plants are much more sensitive to a higher CO2 concentration than C_4 plants (Fuhrer, 2003). According to our own studies, the monthly climate profile indicator of C_4 maize was the only one indicating a significant decline of its high present relative frequency with climate change, although the interpretation of decline is more difficult than that of growth, as here we can not consider the possibility of the phenological acclimatization of maize or the adaptation effect of breeding. Still, the results indicate the rise of the risk of abiotic damages (direct climatic effect) of maize. On the other hand, in the case of more C_3 and C_4 weed species, the relative frequency of the years suitable for their monthly climate profile indicators is significantly rising, from the current low value to even 90-100%. As literature information, the result also calls our attention to the drastic decline of the competitive abilities of maize, as compared to numerous C_4 and especially C_3 plants. Of C_3 plants the weed species *Elymus repens, Abutilon theophrasti, Datura stamonium* (represented by indicators 1, 43, 45) should be mentioned, along with C_4 *Sorghum halapense, Amaranthus retroflexus, Echinochloa crus-galli* (1, 25, 37). Of these species *Elymus repens, Datura stramonium, Sorghum halapense, Amaranthus retroflexus, Echinochloa crus-galli* have already been considered as the most important weeds of maize cultures in the past [3].

Being one of the most important pests of maize, the development of the larvae of the European Corn Borer (*Ostrinia nubilalis*) depends on heat units, growing faster in higher temperature [24]. According to our study the frequency of potential damage emergency situations of *Ostrinia nubilalis* will be significant by the end of the century, primarily regarding scenarios calculating with a stronger change of climate (UKLO, UKHI, HCA2, HCB2, MPA2). Occurring in Hungary in 1995, the successful European acclimatization of *Diabrotica virgifera virgifera* is due to the dry and arid climatic conditions of Central Europe [15]. Based on scenario data, the risk of potential damages caused by this species will be considerably high. Scarce-Bordered Straw (*Helicoverpa armigera,* indicator 36) has been a regular - and in dry years serious - agricultural pest in Hungary since 1993 [23]. According to the scenarios counting with a stronger change, the risk of potential damage of this species will also grow significantly.

In view of pathogen micro-organisms, autumnal, winter and spring low temperatures may be considered as limiting factors, as in the summer, precipitation is the most important [4, 6]. According to our study, the risk of potential damage emergency situation of *Maize dwarf mosaic potyvirus*, *Puccinia sorghi*, *Sorosporium holci-sorghi*, *Rhizoctonia bataticola* and *Nigrospora oryzae* (indicators 4, 5, 51, 52, 55) will grow significantly. In case of *Sorosporium holci-sorghi* this growth might reach 100% by the end of the century.

We must emphasize that though our indicators represent the best information sources available, the interpretation of the results requires certain awareness, considering the unsatisfactory literature data and the way of turning them into numerical data. We also have to keep in mind that our study calculated only with temperature and precipitation data, leaving CO2 concentration – obviously changing with climate change – and radiation out of consideration. Our presumption that the behaviour of pathogen, pest and weed species will be constant regarding climate is also a simplification, not counting with the physiological, phonological, biochemical and onto-genetic acclimatization, or adaptation at the population genetic level. As a consequence, in the comparative analysis of historical and scenario climates using profile indicators only the rise of relative frequencies is of professional importance. Namely, in this case, the rise means the rise of the frequency of potential damage situations even if we do not consider the adaptive ability of the plant. On the other hand, the stagnancy or decrease of this value does not mean that the risk of emergency in question may not grow.

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