DEBRECENI UNIVERSITY
Center for Agricultural Sciences
Faculty of Agriculture
Department of Land Use and Regional Development

INTERDISCIPLINARY AGRICULTURAL AND NATURAL SCIENCES PH.D. SCHOOL

Head of Ph.D. school:
Prof. Dr. János Nagy
Doctor of HAS

Supervisor:
Prof. Dr. János Nagy
Doctor of HAS

"Ph.D. THESIS "

EXAMINING DIFFERENT HEAT SUM CALCULATION METHODS IN MAIZE PRODUCTION

Prepared by:
Dénes Dorka
Ph.D. candidate

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1. INTRODUCTION

The agroecologic potential in Hungary allows efficient maize production. Maize production is essential in Hungary since it occupies the largest area among all the produced crops and as a result there are not many farms where it is not produced either for human or animal consumption. It growing area fluctuated between 20-35% in the past 50 years.

Its significance is due to the fact that it is utilised for *direct human consumption*, as raw material in the food industry as a result of its high energy content and good digestibility. On the other hand, its utilisation as *animal forage* also has great significance. The whole plant is utilised as silo or green forage worldwide. Its significance is further increased by its *widespread industrial processing* and utilisation.

As a result of the above mentioned facts, making production efficient is of decisive importance to farms. The precise knowledge of climatic requirements for maize essential for profitable maize production. When considering *climatic conditions*, we have take into account that various climatic elements have different effects on the yield of maize.

Regarding weather it can be concluded that maize can be mainly characterised by the following requirements: high amount of winter precipitation, which requires large water storages in the soil. Relatively high average temperature in April is required, which is a condition of early sowing and even, rapid germination. In May, high precipitation and relatively low temperatures and sunlight is favourable. In June, high sunlight length and temperature and relative low precipitation requirement is favourable. The optimal conditions of July and august are high precipitation, temperature and sunlight requirement. Warm, humid and wet weather favourably influences fertility and seed fixation. Optimal September is dry, and can be characterised by warm and sunny weather which promotes processes of assimilation, grain filling and ripening. Considering the above mentioned, it is clear that heat sum calculation plays an important role in maize production.

During the 20. century, heat sum calculations were widely used for determining plant development rate and yield quantity. However, calculations and actual yield quantities often differed from each other thus, the methods required continous development. Differences were due to both inaccurate calculations and both to different environmental conditions. Attention was mainly focused on making basis temperatures more accurate, which can be regarded as approximately zero for plant development or the upper threshold limit where development does not continue due to heat stress or where decaying starts. The global climate change that began during the 20-21. century, due to antropogen effects, has become more significant from the aspect of basis temperature and upper threshold temperatures as well as the formation of daily average temperature.

As a result, it is quite likely that climate borders will change in the future. The modeling of these processes will be of special significance from the aspect of future life conditions, opportunities and food provision of mankind since the cognition of harmful processes, extent and expected consequences can bring closer the solution and the possibility to live a more acceptable life on our planet.

The majority of prospects regarding climate change focus on the consequences inflicted by the warming atmosphere on the conditions of plant culture production. With the modification of general atmospheric circulation and the change in climate zones temperature and precipitation conditions also change. In specific areas we can expect increasing drought, and in other places wetter and more moderate climate. Therefore, the evaluation and analysis of future climate samples with General Circulation Model or GCM are becoming more significant.

Examinations and evaluations regarding these issues can be of great importance for Hungary as well since the Carpathian basin is located on the borders of wet oceanic, dry continental and meditarrenean, which is dry in the summer and wet in the winter, regions and this border zone can be especially sensitive to any small degree of climate change, since the change of climate zones can lead to the dominancy of one of the above mentioned climatic region.

The current nature of the topic and the outstanding influence on the Debrecen region is further emphasised by the fact that one out of the two specially sensitive regions of the country is the Great Plain while the other is the area of central and South Transdanubia.

At the same time, the spatial resolution of scenarios developed for the examination of global scale changes is not large enough and these only provide relatively obvious estimates regarding the changes of temperature conditions of our region from the climatic parameters. This fact greatly contributed to the fact that in this dissertation primarily temperature values are mentioned, though we clearly cannot draw a distinctive line between the formation of temperature and other climatic conditions.

2. RESEARCH OBJECTIVES

According to the previously mentioned, the objectives of my Ph.D. dissertation can be summarised as follows.

1. The review of main heat sum calculation methods and variations.

   Many types of heat sum calculation methods have evolved over time. The characterisation of various methods can happen in a number of ways depending on the approach by examiner and what the focus is directed on. In this dissertation, I have foused on 26 formulas beyond the basic formual. My objective was to characterise and group formulas as a result of data density examinations, or due to the evaluation of photoperiodic effects ensure examination according to hourly, special hourly and daily temperature values.

2. Comparing the accuracy and useof calculation methods by using actual measurement results.

   I targeted the use of data pairing according to the method accepted in professional literature. Namely, I aim to emphasise the relationships obtained by pairing the phenologic data of the examined growing site and the temperature data measured during the time of examination. Detecting correlation between phenologic data obtained at the Látókép Experimental Station of DU-CAS and the temperature data measured at the Kismacs Station of the Agrometeorological Center of DU-CAS. The distance between the two stations is 8 km, thus it meets requirements set by the professional literature for such measurements.

3. Heat sum calculation method optimised for domestic conditions, developing formula combination at the growing site of Hajdúság.

   Based on growing site and temperature data provided it was possible to develop an optimised formual combination. As a first step, through the cluster analysis of the 27 formulas, I wished to group the provided formulas according to calculated heat sum values. The essence of the method is to obtain a formula made up of more, different weighing factor elements, minimising the weaknesses in different temperature ranges of specific formulas.

4. Analysing the climate deformation effects of global climate change in the relation of Debrecen and its surroundings.

   This objective of the research can be achieved by using the current data sequence of Debrecen and its surroundings based on the algorithm system of the three climate scenarios. My objective is to depict the future for the specific growing periods based on scaled temperature data sequences, using heat sum calculation methods.

5. The effects of current temperature and temperatures formed according to global climate change prognosis on maize production.

   The future formation of the expected maize cultivation condition according to the changed temperature parameters based on professional publicationsand the calculated and analysed values. As an objective of the dissertation, I wish to introduce the future formation of Hungarian conditions in maize production. Though the various cultivation conditions (sunlight, temperature, precipitation, soil etc.) cannot be separated from each other, the prognosis can still provide assistance for future yield results considering the outstanding significance of temperature and its effect on yield.

3. MATERIALS AND METHOD

Antoine Ferchault de Reaumur (1683-1757) French physicist was to first to mention in 1735 that the length of specific phenophases in plant development are directly related to temperature and the length of various development phases can described through summarising daily average temperatures.

So the basic hypothesis is that all plants require a specific amount of heat to reach a given degree of development and stage of ripening. This enables us to use the cumulated heat sums as indicators in characterising plant development. Temperature can have various effects on physiological processes, both at the level of chemical reactions, phenomenon (diffusion, viscosity, translocation) as well as at the level of plant organs, plant and the entire plant production on photosynthesis, respiration, or rate of development.

Thus heat sum calculation is of primary importance in arable land plant cultivation.

3.1. GROWING SITE DATA

Samples were taken at the Látókép Experimental Station of DU. The three factorial (fertilisation, irrigation, genotype) experiment was launched in 1978 by Debrecen University, center of Agricultural Sciences in collaboration with KITE at Nádudvar at the Látókép Experimental Station of DU. The research work was supported by the National Scientific Research Fund from 1991. Within the framework of this, the productivity of 10 maize hybrids annually along with natural nutrient utilisation ability and fertiliser reaction was examined. The experiment is a four repetition, split-plot structure, the main plot (120m^2) was the fertiliser treatment and the subplots (15m^2) were the maize hybrids.

The Experimental Station can be found at Loess back of Hajdúság, on loess soil, deep humus layer lowland chernozem with lime deposits. Its physical soil type is medium bound clay. Groundwater is located at 5-8 m. The total nitrogen content of the soil is 0.15%, which is about medium supply level. The AL-soluble P_2O_5 content of the cultivated layer shows significant heterogeneity, the average value (133ppm) of the 0-20 cm soil layer can be considered medium, and according to AL-soluble K_2O content (240ppm) it can be classified as well supplied.

In the vegetative phase germination and the time of 50% female flowering was determined along with the time of black layer formation in the generative phase according to hybrids and treatments. Following the flowering in 1998 and 1999 weekly and in 1997 every three days destructive samples were taken.
At the times of sample takings, we measured the thousand grain weight of 50 grains in 4 repetitions in 4 cobs from the mid section. Determining dry matter was done by using drying cabinet at 60 ^{0}C, dried to constant weight.
We have analysed the water loss dynamics of hybrids in 90 kg N/ha fertiliser treatments. We examined the effects of fertilisation on the grain yield of maize at six levels of unfertilised treatments and five levels of fertiliser dosages, on Debrecen yield data. The fertiliser dosages were 1N: 0.75 P_2O_5: 0.88 K_2O constant ratio NPK dosages, where the basic dosage was 158 kg/ha until 1995, and 89 kg/ha dosages from 1996. The examined years were between 1994-1999.
We included those from the examind hybrids in the analysis, that had at least three years of yield data. In 1998 and 1999, we examined the effect of fertilisation on grain filling, grain number and water loss dynamics.

3.2. TEMPERATURE DATA

Data was collected using VAISALA HMP45D type analogue probes. The measurements were taken by platinum sensors (PT 100 IEC 751). The sensors are located at the tip of the probes and protected by membrane filters. Their measurement range is between -39,2 and 60°C. Their accuracy is ±0,2°C at 20°C-on. The signs from the sensors run into a PCLD770, 8 channel multiplex base, where 8 PCLD771 cards are located, one of which to measure temperature. During the measurement, this card induces a 1mA power and transmits to a platinum sensor where the sensor has a specific resistance at specific temperature 100 ohm at 0°C, and positive resistance at increasing temperatures. The sensor can be described with linear increasing resistance characteristics up to 150-200°C. The electric potential going through the sensor changes with the temperature of the sensor, which is redirected back to PCLD771 card through another circuit, where power amplifier is built in for a more accurate measurement.
The analogue measurement results are handled by a 12 bit accuracy (±1 bit at 0,015% evaluation) PCLD 812PG MULTILAB card and it is digitalised. The already digitalised temperature data is processed by the METEO program with a LINUX kernel. The

system that operates at 100kHz sample taking density, averages the data of every 6 seconds and saves them as data files every 15 minutes. The exterem temeparture values are saved in a different file which can be accessed and processed later as well.

3.3. CALCULATION METHODS

Many formulas were created during the continuous refinement of heat sum calculation methods. Later on the formulas and calculation methods became more refined, the range of those environmental parameters has widened that could be integrated into the formula combinations. The temperature range that could be actively utilised in plant development became known and separable along with the passive temperature range.

The aim of this dissertation is is to create such a formula combination which corrects the deficiencies of existing formulas and increases the reliability of the new formula by weighing it to different extents.

Calculation methods can be grouped into three large sets:

- formulas using temperature data
- formulas using temperature and photoperiodic data
- formulas using temperature, photoperiodic and solar radiation

In my dissertation I only used examples for the first two formula types considering that data deficiency. Then altogether 27 calculation methods were compared. I separated the heat sum calculation methods that use daily minimum and maximum temperatures and the hourly calculation methods. Then I also selected the special hourly resolution calculation methods, which deal separately with daily photoperiods.

The difference among the examined calculation methods are primarily the threshold temperatures in the various formulas (basis temparture, upper threshold temperature). Secondly, the different weighing of day times (eg. Ontario), or selecting the daily formation of temperatures to phases (eg. Ritchie). Thirdly, the use of different empiric values (eg. Stewart) connected to main phenophases (vegetative, generative phase).

3.4. THE ROLE OF DATA DENSITY DURING CALCULATIONS

During the processing of data sequences it is essential to know what data density provides the most suitable basis for comparing calculation methods.

Two significant aspects were to consider the temperature data during processing. On the one hand since tempearture unlike other physical phenomenon (eg. Percipitation, solar radiation) can be regarded as constant, the most typical feature of temperature entity is continouity, its measurement onyl depends on the density of sample taking and the provided technolgical background, so in theory it does not have an upper limit. On the other hand from the aspect of the cumulated data density, continuous data colelction does not make sense.

By selecting a month (June 1997) I chose the most appropriate data density and the easiest to manage heat sum calculation methods to evaluate the growing periods of 3 years (1997, 1998, 1999). I used the temperature data of three levels, one of which was a soil temperature data sequence (-2cm), and two were air temperature (0,5m; 2,0m).

I used cluster analysis to decide which data density is the most appropriate for the calculations. Cluster analysis is a multiple variable statistical method, where groups are formed based many classification variables. The objective is to organise the data sequence in such a way, that relationships are revealed. We aim to form such cgroups (clusters) where the elements are closely related and differ relatively well from the elements of the other clusters.

The variables in the analysis are data density techniques, the cases are the specific months. I have used the hierarchic agglomarative technique and within this the Ward-type method. For this method, the following euklides distance rate can be used:

$$[1] \qquad d_{ij} = \sum_{k=1}^{p} (x_{ik} - x_{jk})^2$$

d_{ij} the distance of i and j element
k running index
p number of dimensions
x_i, x_j elements with coordinates

I have carried out the analysis for all three levels (-2cm; 0,5m; 2,0m) separately and I have made the evaluations for the levels jointly as well.

I carried out the cluster analysis with different cluster element numbers and based on these I chose 15 minute daily average data density. This data density brought the most balanced results at all measurement levels. This data density has many advantages. It provides an ideal mean for suitable data separation and handling as well as for preventing possible errors, since it sets out minimum and maximum temperatures from each hour out of a separately calculated hourly average.

So if 1-2 sensor errors slip in during the hour and a few values are left out, averaging the remaining hourly values will still provide acceptable values for interpolating. Further advantage of these data sequences is that they can be used for formulas comparing special daytimes. Thus, the special and general formulas become comparable considering that correct comparison is essential for the use of similar background data sets.

4. RESULTS AND EVALUATIONS

4.1. REDUCING CALCULATION METHODS

From the provided formulas any can be used with any plant density and averaging method, excpet for the 4 special, hourly resolution since these are related to a specific time of day. The hourly data that I used enable the joint analysis of the 4 special formula.

Firstly, I did the comparison of total daily heat sum calculation methods and the special hourly calculation methods for 1997. Since the phenophases of the examined hybrids are not synchronised and the few days or weeks of deviations can be significant factors of uncertainty, therefore I chose the comparison of temperatures of the coldest and warmest months. My choice was also supported by the fact that in the case other comparative evaluations, monthly resolutions are used.

The comparisons of the total daily heat sums calculation method and the special hourly calculation method for June and October months of 1997 at 0.5 m level seemed reasonable. The selection of these two months was justified by the extreme values since these are the two months where the coldest and warmest days occur. Though July is hotter than June, the provided data are more unreliable since data deficiency for July of 1997 was greater than in June. Since there are no significant differences between the 2 months, I chose June.

The 0.5 m level is a result of compromise since almost no deficiencies were present in these datasets and the soil temperature at 2 cm only has an effect on the early stages of

plant development. For the same reason the 2.0 m level will provide false temperature data for a long period during development.
During the evaluations of algorithms, I rejected the modified Ontario heat sum calculation [15], since it produced vrey differing values compared to other formulas. For the month of June -3023.06°C, compared to the 300-800°C data of other formulas, while -2373.82°C for October, compared to 100-400°C of other formulas.
This formula was completely left out of the analysis since it would have distorted the other results significantly. Later on I used cluster and variance analysis for determining the number and type of the algorithms for all three years (1997, 1998, 1999). The two methods jointly enabled me to select the 9 calculation methods which provided the foundation for my further analysis. These methods also enabled me to decide which indicators are the most alike. When choosing the 9 indicators, I tried to select indicators from different groups, then I created a standard indicator on the basis of this, which best describes the data of the region.

4.2. VARIANCE ANALYSIS OF JUNE AND OCTOBER

The heat sums of 2 months (June, October 1997) are provided. I wanted to find out whether there were significant differences among the average values of specific indicators or do the deviations among or within an indicators. The evaluation showed that there were significant differences among the calculation methods.
Then, to make results more accurate I did the previously applied cluster evaluations as well, the results of which were almost identical. Based on the cluster analysis, I chose the identical ones, or the formulas that provided similar results through different methodology.
Then 1 pair of such formulas were chosen from all groups that were in the specific group for both June and October. Therefore, the following formulas were selected:

- Conventional average temperature, adjusted with basis temperature [1]
- Ontario heat sum calculation method [3]
- Stewart-type heat sum calculation method [4]
- Ritchie-type heat sum calculation method [5]
- Average temperature calculation method based on daily heat stress [9]
- Newman-type heat sum calculation method [16]

- Daytime average temperature hourly heat sum[25]
- Nighttime average temperature hourly heat sum [26]
- Daytime-nighttime average hourly heat sum [27]

4.3. DEVELOPMENT OF NEW FORMULA COMBINATION

During optimalisation, I selected 9 formulas by using variance analysis and cluster analysis. Minimalisation was done using the Microsoft Excel Solver programme. With solver optimisation, the basic concept was to find out to what extent do heat sum values, calculated in the growing seasons, fluctuate according to the specific methods. The main objective during optimalisation was to minimise fluctuation values.

As the first step, I took all the heat sum values received with the 9 selected formulas in the growing season for 0.5 m level. I grouped them separately according to calculation methods.

Then I took the deviation and average of these values. Then I got their relative deviation by dividing the previously calculated deviation with the average. I carried this out with all 9 methods, then I received the 9 relative deviation values.

Then I calculated the average of the 9 relative deviations and I set this as an objective cell in the case of Solver. As a limiting factor I set $0<X<1$ interval and as a basic weighting I assigned 1 for each formula.

Then, I divided each separately with the sums of values obtained during solver minimalisation, so their sums would be 1 which then provides the solution for weighing the 9 formulas when using them collectively.

Then I calculated with each of the 9 algorithms, selected with the cluster analysis, the heat sums for all three levels of the growing period in all three years (table 1).

Period	**Serial no. of the method**								
	1	**3**	**4**	**5**	**9**	**16**	**25**	**26**	**27**
'97., '98., '99.	0.11	0.06	0.14	0.13	0.08	0.13	0.06	0.09	0.19

Table 1: **The parameters of the new formula with the help of the Solver programme**

I developed the weighting formula combination based on the weighting factors calculated for the entire growing season:

[2] **[1] * 0,12 + [3] * 0,06 + [4] * 0,13 + [5] * 0,12 + [9] * 0,07 + [16] * 0,12 + [25] * 0,06 + [26] * 0,09 + [27] * 0,22**

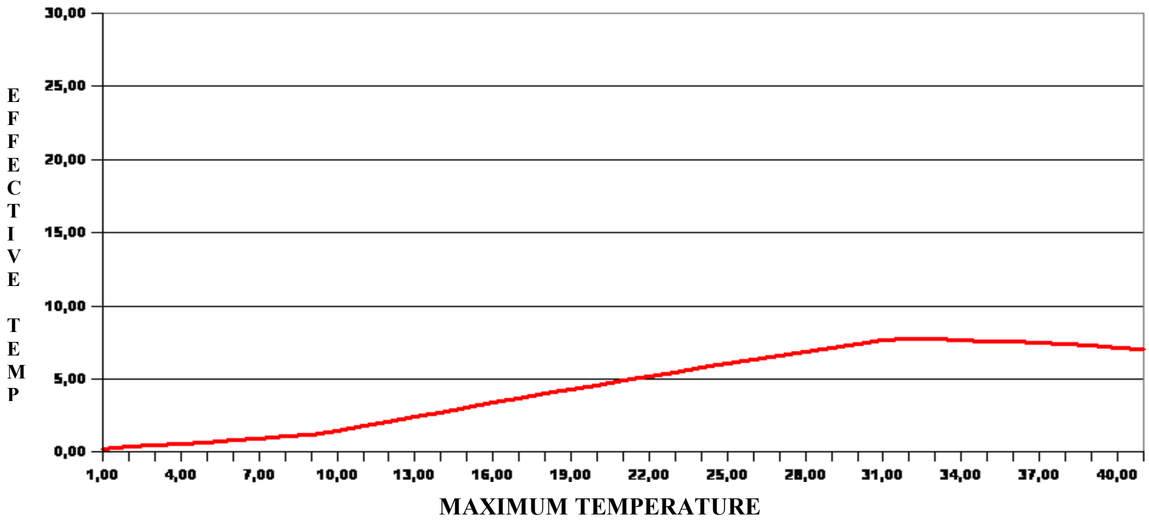

Figure 1: **General formation of the optimised formula combination**

The new formula combination aims to prevent weaknesses of the individual formulas in different climatic and phenophase conditions.

Figure 1. desribes well how the new algorithm evened out outstanding values. Its formation is closest to the Ritchie type calculation method, which is the most precise from all the formulas. The main difference between the two formulas is that he new formula is more sensitive to lower and higher temperatures.

4.4. DETAILED PHENOPHASE ANALYSIS

The reliability of the new algorithm combination was supported by detailed phenophase analysis.

The time of 50% female flowering were provided from all three years were provided for detailed examination, while more detailed observations were made only in 1997.

Thus I analysed the average leaf number changes of maize hybrids (table 2) in the examined year of 1997, based on temperature values measured at 0.5 m. By using the 9 heat sum calculation methods, selected previously with cluster analysis, I calculated the heat sums up to the sample taking days and by dividing it with the average leaf number produced up to that day I received the temperature values required for the total development of a leaf. Then dividing their averages with the calculated heat sum values I calculated the accuracy of leaf number measurements according to calculation methods.

1997	Measured average	[1]	[3]	[4]	[5]	[9]	[16]	[25]	[26]	[27]	Solver	Deviation
05.02.	sowing	-	-	-	-	-	-	-	-	-	-	-
05.12.	germination	-	-	-	-	-	-	-	-	-	-	-
05.30.	**3.56**	2.76	5.85	2.35	2.74	4.72	2.73	5.45	4.08	1.37	**3.03**	**0.53**
06.02.	**3.74**	2.86	6.18	2.45	2.83	4.99	2.83	5.76	4.31	1.46	**3.17**	**0.57**
06.05.	**4.11**	3.13	6.80	2.69	3.10	5.48	3.10	6.34	4.73	1.60	**3.49**	**0.62**
06.06.	**4.29**	3.27	7.11	2.81	3.24	5.72	3.24	6.61	4.94	1.67	**3.64**	**0.65**
06.09.	**4.89**	3.74	8.11	3.21	3.72	6.51	3.71	7.50	5.64	1.87	**4.15**	**0.74**
06.11.	**5.21**	4.01	8.63	3.42	3.98	6.92	3.98	7.98	5.99	1.99	**4.42**	**0.79**
06.13.	**5.76**	4.46	9.52	3.79	4.43	7.64	4.43	8.79	6.63	2.16	**4.89**	**0.87**
06.16.	**6.43**	5.02	10.63	4.24	4.99	8.51	4.98	9.75	7.41	2.34	**5.46**	**0.97**
06.18.	**6.87**	5.37	11.36	4.53	5.34	9.09	5.34	10.40	7.91	2.48	**5.83**	**1.04**
06.20.	**7.26**	5.68	12.03	4.79	5.65	9.60	5.65	10.97	8.36	2.61	**6.16**	**1.10**
06.24.	**8.11**	6.37	13.42	5.36	6.34	10.72	6.33	12.23	9.33	2.89	**6.88**	**1.23**
06.26.	**8.53**	6.68	14.10	5.63	6.65	11.27	6.64	12.89	9.79	3.11	**7.24**	**1.29**
06.30.	**9.41**	7.42	15.42	6.22	7.37	12.36	7.34	14.27	10.74	3.53	**8.01**	**1.40**
07.02.	**10.13**	7.99	16.61	6.70	7.94	13.31	7.91	15.36	11.56	3.80	**8.62**	**1.51**
07.04.	**10.69**	8.44	17.48	7.07	8.38	14.03	8.35	16.23	12.18	4.05	**9.10**	**1.59**
07.07.	**11.71**	9.24	19.19	7.75	9.19	15.39	9.16	17.74	13.37	4.37	**9.97**	**1.74**
07.09.	**12.63**	9.96	20.77	8.36	9.90	16.62	9.87	19.10	14.45	4.66	**10.74**	**1.89**
07.11.	**13.49**	10.63	22.22	8.93	10.57	17.76	10.53	20.39	15.43	4.96	**11.47**	**2.02**
07.14.	**14.76**	11.60	24.38	9.76	11.53	19.46	11.50	22.31	16.88	5.43	**12.54**	**2.22**
07.16.	**15.59**	12.23	25.78	10.32	12.16	20.56	12.12	23.57	17.82	5.75	**13.25**	**2.34**
07.18.	**16.37**	12.81	27.11	10.84	12.74	21.60	12.70	24.77	18.74	6.02	**13.91**	**2.46**
07.21.	**17.07**	13.31	28.35	11.34	13.24	22.57	13.20	25.82	19.60	6.22	**14.49**	**2.58**
07.22.	**17.10**	13.32	28.42	11.37	13.25	22.62	13.21	25.86	19.65	6.22	**14.51**	**2.59**

Table 2: **Measured and calculated leaf number values at 0.5m (1997)**

If we examine the results of formula combinations, optimised with the Solver programme, based on the differences between actual and calculated leaf number, it becomes clear that the weighted formula combination allows for a more precise prognosis than any other formula. It is also clear from the figure that the accuracy of the formula gradually decreases as the growing season progresses and deviations increase.

During the average 3 daily sample takings on all maize hybrids, the correlation between the observed average leaf numbers and the optimised formula combination can be regarded as high, at the same time it gradually decreases with the progress of physiological ripening (figure 2).

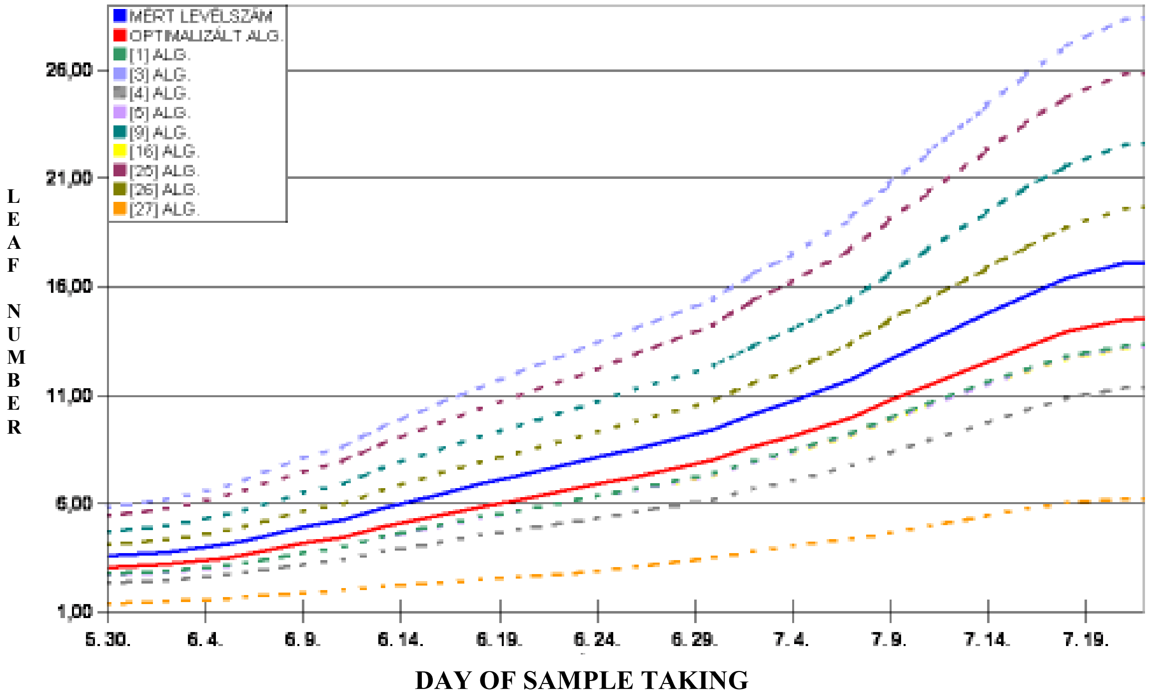

Figure 2: **Comparison of measured and calculated leaf degree values (1997)**

The precise leaf number evaluation of examined maize hybrids was carried out 37 times in 1997. Thus I analysed the average leaf number changes of maize hybrids in the examined year of 1997, based on temperature values measured at 0.5 m. By using the 9 heat sum calculation methods, selected previously with cluster analysis, I calculated the heat sums up to the sample taking days and by dividing it with the average leaf number produced up to that day I received the temperature values required for the total development of a leaf. Then dividing their averages with the calculated heat sum values I calculated the accuracy of leaf number measurements according to calculation methods.

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4.5. THE ROLE OF SOIL TEMPERATURE IN ONTOGENY

Soil temperature is significant already during sowing, especially during spring sowing and it can lead to significant differences in the case of values fluctuating around threshold temperatures during heat sum calculations. Soil temperature has insignificant impact in the first two weeks from sowing as far as the later ripening of maize is concerned, in the opposite case however, lower temperature values can significantly increase the time required for black layer formation.

As a result of the above mentioned, or if data set is provided for such an examination, I decided to carry out an analysis in this direction as well. As the first step, I compared the average temperatures of the three growing seasons at all three levels (-2cm, 0,5m, 2,0m). The phenophase measurements introducing the detailed development degrees (1997) and based on professional publications, I examined two cases, as I calculated with soil temperature data up to the 6 and 12 leaf status then compared the obtained values with the standardized measurement results.

Since the task here was not the comparison of calculation methods, but rather the calculation with temperatures of different levels, I only used average temperatures during the comparisons (table 3).

<table>
<tr><th rowspan="2">1997</th><th colspan="3">Soil</th><th rowspan="2">Combined</th></tr>
<tr><th>Normal</th><th>6 leaf</th><th>12 leaf</th></tr>
<tr><td>-2cm</td><td>3432.58</td><td>-</td><td>-</td><td rowspan="3">2922.82</td></tr>
<tr><td>0.5m</td><td>2980.87</td><td>2978.56</td><td>3083.15</td></tr>
<tr><td>2.0m</td><td>2869.60</td><td>2922.09</td><td>3006.13</td></tr>
<tr><td rowspan="2">Deviations</td><td>-</td><td>2.31</td><td>102.28</td><td>58.05</td></tr>
<tr><td>-</td><td>52.49</td><td>136.53</td><td>53.22</td></tr>
</table>

Table 3: **Average temperature heat sum deviations with level variations (°C)**

In conclusion it can be said that in order to obtain more accurate heat sum values, it is better to use more differentiated temperature data if provided, considering the differences that are not negligible.

4.6 THE CONSEQUENCES OF GLOBAL WARMING IN HUNGARIAN MAIZE PRODUCTION

Since global warming will have an impact on the Carpathian Basin as well, as a result, plant cultivation conditions will change, which is also important from an economic aspect.

This especially true with the frequent occurance of extreme climatic phenomenon, since the importance of threshold temperatures in heat sums used in algorithms also increases. At the same time we have to use caution with climatic trends, since the scenarios are often inaccurate due to the outdated nature of equipment at meteorological stations or change and inproper calibration.

Hungary is located on the borders of wet oceanic, dry continental and meditarrenean, which is dry in the summer and wet in the winter, regions and this border zone can be especially sensitive to any small degree of climate change, since the change of climate zones can lead to the dominancy of one of the above mentioned climatic region.

The situation is further aggraveted by the fact that the Great Plain, which is the main agricultural area of Hungary, is among the most sensitive regions in easter-central European region regarding global climate change. Based on international and domestic research, the intensification of greenhouse effects will result in more significant increases in temperature than the global average.

In my dissertation I processed the temperature datasets of 30 years for Debrecen and its surroundings by using the high resolution, so-called equilibrium climate model (UKHI) of the United Kingdom Meteorological Center (UKMO) and the small resolution equilibrium climate model (UKLO) and the high resolution, transient climate model (UKTR). Regarding the features of the UKMO models, they differ mainly in resolution and ocean modeling. Oceans have a significant impact in the structure of the model, since they cover 71% of the Earth's surface, thus it is an important criteria that their simulated structure should be close to reality within a specific model. The resolution of UKTR models reaches 300-1000 km and 20 parellel layers in the atmosphere and below the Earth's surface as well as below the ocean.

Using the the scaled, future daily minimum and maximum values for Debrecen and its surroundings I calculated the heat sums. During heat sum calculations, I used the methods applicable with daily data that I selected and grouped in previous chapters with cluster analysis. During the heat sum calculations, I left each temperature variable at the levels provided during heat sum calculations of specific past years.

In the intrest of exact comparison, I considered the values of the growing period of 1997, with a sowing time of May 2 and a black layer formation of October 3. This means a 154 day long growing period in all cases. When examining the values themselves or the trend lines we always have to consider that the values are for the growing period, so the data of winter or the colder months are not included. This is important since the future picture is distorted, in relation with other meteorologic parameters, and can influence the expected yield results.

I calculated heat sums by using the future daily minimum and maximum values scaled for Debrecen and its surroundings. The validation of temperature scenarios was based on recorded and historical data of Budapest dating back to 1785.

During the heat sum calculations, I used the methods suitable for use with daily resolution, selected through cluster analysis:

- Conventional average temperature, adjusted with basis temperature [1]
- Ontario heat sum calculation method [3]
- Stewart-type heat sum calculation method [4]
- Ritchie-type heat sum calculation method [5]
- Average temperature calculation method based on daily heat stress [9]
- Newman-type heat sum calculation method [16]

During the heat sum calculations, I left each temperature variable at the levels provided during heat sum calculations of specific past years (1997, 1998, 1999). This way, i calculated with 8°C basis temperature in all cases, 30°C of upper threshold temperature or in the case the Ontario method 4,4°C nighttime basis temperature and also 8°C daytime basis. In the case of the Newman formula, I also left the empiric values of 2.8°C, 16.6°C and 18.33°C. In all cases, I received much higher values with all the heat sum calculation methods, contrary to the fact that the 154 day period of evaluated periods is significantly short compared to the total length of a year and it only applies to the warmer period of the year and the global temperature increase will expectedly be due to moderate cold months as we can already experience.

Our climate will become drier and more exposed to sunlight, at least in the first couple of decades. On the contrary, if this continues at the current rate, then the temperature increase can be accompanied by precipitation surplus as well. For example a 0.5-1.5°C increase in temperature can make the climate of the Carpathian Basin drier, while annual precipitation can increase by even 40-400mm in the case of a 4-5°C annual increase in temperatures.

Based on the data sequences of the evaluated scenarios, more significant warming can be expected in Debrecen and its surroundings.

As a result, hybrids (mid and late ripening; FAO 4-500) with longer growing periods can be produced in Hungary, and longer frost free periods are partly responsible for this.

According to the transient GCM-model, a 10-15% increase in precipitation accompanied by a 3-4°C rise in temperatures would push agricultural zones to the north. If the temperature increase is not accompanied by precipitation increase, then the risk of maize production would increase further.

In Hungary, daily minimum and maximum data for Budapest has been available from 1785. The amount of precipitation has been tracked since 1845. During the analysis of historical data, a 2°C fluctuation can be detected in annual average temperatures between 1785 and 1985, with a 3-4°C fluctuation between winter and summer seasons. According to the provided data, cooling was typical in the beginning of 1800. The detailed analysis of winter (October-March) and summer (April-September) seasons indicates that decrease in temperatures, mainly characterised summer months, though towards the end of the century, winter seasons were also colder than normal.

From the mid 20. century, a slow increase in annual average temperatures can be observed. Based on historical data, we can find that the warmer years were 1951-52. considering the vegetative period, the warmest year was 1952, which was accompanied by significant drought in the whole country. Yields were 50% lower than the average then.

According to the scenarios, further increase in temperatures can be expected. UKTR prognosed that annual average temperatures can increase by even 3°C than current averages which is a significant difference. Drought will be more frequent which will also have an impact on yields.

Forecasts are predicting much higher heat sum values than the ones observed in the 1951-1990 period and since no increasing tendency can be expected for precipation, conditions will be unfavourable for maize, similarly to the year of 1952.

Two factors will play an important role. Very high summer temperature on one hand, acompanied by record number of extreme heat days (≥30°C), and drought on the other hand.

From the aspect of maize, the following 3 degrees will become more dominant in the future in the relation of drought-yield results:

- The *significant drought will be accompanied by remarkably decreasing winter precipitation,* and at least 30% less precipitation than the average of many years during the months of June-July.

- *Droughty summer months*, in any of the May, June-July months which will be accompanied by at least 30% less precipitation than the average of many years.

- *Less significant summer drought, average precipitation in the winter months,* at least 30% less precipitation in any of the May, June-July months than the average of many years.

The analysed data and the profesional publications in the field also indicate that thegreat degree of drought will cause significant yield losses everywhere in the country, even in the wetter Western Transdanubian areas, espcially in Hajdú-Bihar.

Moderate drought occurs in Hajdú-Bihar every four years. In 80% of the moderately droughty years, yield loss can be observed. The ratio of droughty years fluctuated between 9% (sever) and 17% (moderate) between 1951 and 1980, which is expected to increase. The most significant yield reducing factors for maize are: short vegetative period, which is determined by the length of frost free period and the ratio of heat days (≥30°C).

There is no significant difference regarding frost free days in the past 40 years in Debrecen. Between 1951 and 1990 the daily minimum temperatures formed between -10°C and 15°C in general.

Frost free periods generally start around the end of February and middle of March and last until November or the beginning of December. Between 1951-1993 the number of frost free days gradually decreased by 8-10 days, due to early frosts around the beginning of November.

Increasing tendency in heat days can be detected from 1975. In the 1990's, record number of heat days were recorded.

In conclusion it can be said that the dry characteristics of climate in the past 20-30 years became more robust, with frequent drought and yield decrease, which is expected to continue thus researchers are focusing on weather risks and extereme meteorologic events.

The following conclusions can be made from the comparative analysis:

- The increasing dominance of unfavourable years in the past 20 to 30 years can be significantly detected and according to scenarios, these will intensify, which will be accompanied by a 5-10% yield loss.
- The extreme increase of summer heat sums will be unfavourable from the aspect of maize production, which will be even higher than the maximum heat sums of the 1951-1990 period. This especially aggravate the conditions of maize production, as there will be no expected increase in precipitation.

The most obvious consequence of global climate change for Hungary will be the ***changeability of agricultural production***.

5. NEW SCIENTIFIC RESULTS

1. During the detailed analysis, classification and organisation of heat sum calculation methods adapted to Hungarian conditions I have found that there are 9 such calculation methods among the analysed 27 algorithms, which can be classified into the same clusters even based on different temperature values of the examined growing periods of June and October.

2. I found that the most suitable data density resolution for temperature sum calculations is the daily average of 15 minutes resolution. This was not only justified by the more balanced results experienced during calculations but also because of the multiple averaging method, with the possibility to bridge errors or smaller data deficiencies.

3. During the analysis and comparison of phenologic data of three years, I established a weighted formula which allows a more reliable temperature sum calculation than the previous formulas of professional publications. The formula, calibrated for 0.5m level, applies the following weight factors for the used basic formulas:

- Conventional average temperature, adjusted with basis temperature - 0.12
- Ontario heat sum calculation method - 0.06
- Stewart-type heat sum calculation method - 0.13
- Ritchie-type heat sum calculation method - 0.12
- Average temperature calculation method based on daily heat stress - 0.07
- Newman-type heat sum calculation method - 0.12
- Daytime average temperature hourly heat sum - 0.06
- Nighttime average temperature hourly heat sum - 0.09
- Daytime-nighttime average hourly heat sum - 0.22

4. Based on the measured and analysed temperature sum values, at various levels (-2cm, 0.5m, 2.0m), I found that taking soil temperature values into account is justified. According to the results, we could calculate with soil temperature values (-

2cm) until the 8 leaf stage of maize, with 0.5 m values until the 12 leaf stage then with the widely used 2.0 m values during the later phenophases.

5. I analysed the expected temperature conditions of maize production by using various resolution and methodology GCM-models, scaled for Debrecen and its surroundings, by using formulas selected through cluster analysis. During this I found that significant warming can be expected at Hajdúhát, and as a consequence, the opportunity to produce hybrids with longer growing periods (early and late ripening; FAO 4-500) will be possible. I have also concluded that the high degree of summer temperature sums will be unfavourable from the aspect of maize production, which can be explained by the increase in heat days.

6. PUBLICATIONS AND CONFERENCE POSTERS RELATED TO THE THESIS

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