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„THESES OF DOCTORAL (PhD) DISSERTATION"

AGROMETEOROLOGICAL ASPECTS OF HUNGARIAN RICE GROWING

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1. THE AIMS OF THE RESEARCH

Growing of rice (*Oryza sativa* L.) has a near 100-year-long tradition in Hungary. The rice production area reached its maximum of 50 000 ha in the middle of 1950's following a very steep increase. After that time the sowing area decreased gradually - with fluctuations - to the today's 2000-2500 ha. The economic-political reasons played an important role in these huge changes. However, the climatic risks of Hungarian rice growing and its changing estimation have also played an important role in these changes.

In the field of Hungarian crop production the rice is unique, because Hungarian rice fields are at the northern border of European rice growing areas. The temperature often becomes the main yield limiting factor, because of this marginal location according to the law of ecological minimum. This phenomenon can be especially well expressed if high level agrotechnology is applied when the other yield-factors are near optimal (weeds, water and nutrient supply, crop protection). Therefore, a small improvement in utilization of climatic conditions and in reducing unfavourable effects of weather can result in significant increase of rice yield.

The aim of my research is to study various agrometeorological aspects of Hungarian rice production. The temperature (its temporal and spatial characteristics in rice canopies and its effect on rice) is the main field of my study, because of its overriding importance. The main theme and the main questions of my study were the following:

- How does the weather (temperature) influence the developement rate (the length of the phenophases) of rice?
- What are the main meteorological elements and time periods (month, decade) determining rice yield?
- Were there any changes in the thermal characteristics of the vegetation period of rice in the last 32 years, which may be considered in agronomical recommendations?
- What differences exist between the thermal characteristics of flooding water and air in flooded and non-flooded rice canopy?
- How to reduce the risk of cold stress by modifying the level of flooding water?
- How to minimize the climatic risk of rice growing by optimal timing of sensitive phenological phases (sowing time, cultivars)?

These topics were choosen to have numerous connecting points and to create a complex unit. Above all the last topic is based on the others and synthetizes a lot of partial results.

Our aim was to offer useful, new or newish information or methods for the stakeholders of rice cultivation even if they are only partial results.

2. BACKGROUND

In Hungary the research rice began with the domestication experiments. Already at that time one of the main questions was the suitability of climate for rice production. However, the problem was discussed from the viewpoint of cultivars and agrotechnology. Researches focusing on the agrometeorology of rice were carried out only from the 1950's to the 1970's.

The conclusions on temperature requirement of germination and emergence as well as on optimal sowing time are also valid and used today (SZELÉNYI and FRANK, 1940; É. KISS and HADNAGY, 1965; LAJTOS, 1967; SIMONNÉ, 1979), but their actualisation is neccessery especially because of the new cultivars. Additionally there is a lack of information about the detailed temperature-emergence time (or rate) relationship.

The thermal time requirement from sowing to flowering and/or maturity was calculated mainly for the varieties, which have not been produced yet (É. KISS, 1980; SIMONNÉ, 1983).

The effect of meteorological elements on yield was estimated from data averaged for months or phenological stages (mainly from temperature, radiation, precipitation data or derived indices). The relationships found varied according to the years involved into the examinations (SZÁSZ, 1961; DUNAY, 1974; É. KISS, 1980).

The potential rice production areas in Hungary were indicated and classified on the basis of climatic data (monthly mean temperature, heat units, relative sunshine duration, etc.) (OBERMAYER and SOMORJAI, 1937; BACSÓ, 1963; DUNAY, 1974; SIMONNÉ, 1983). However, the detailed statistical examinations have been only partly carried out from the point of view of rice growing.

The microclimate of rice was studied by several researchers mainly empirically (BERÉNYI, 1951; WAGNER, 1957; BERÉNYI, 1958; PETRASOVITS, 1958; WAGNER, 1966).

Despite the improvement of scientitic methods and tools there was only a limited number of research dealing with agrometeorology of rice in the last 20-30 years in Hungary. On the contrary, international scientific activity has become more intensive recently. My examinations have been based on the results which are valid in climatic conditions similar to the Hungarian ones (for example cold stress in Japan and South-Australia). In some research the geographic location has no importance (methods). Similar examinations of other crops could also be adapted for rice.

3. MATERIALS AND METHODS

The materials and methods of my research were very different, because of complex structure of my work.

A separate experiment was carried out to **study the emergence of rice**. The emergence time of five Hungarian cultivars (Augusta, Bioryza, Dáma, Ringola, Risabell) was measured at different constant temperature values (in growth chamber), using optimal water supply and sowing depth of 2 cm. The parameters of the thermal time model were estimated by linear regression (base temperature: x-intercept of the best fit line, thermal time requirement: from the slope of the regression line). The model verification was carried out with independent data got from our field experiment (nine different sowing dates) and pot experiments (three, near constant temperatures).

The **microclimate studies** of rice fields were based also almost exclusively on own measurements. The measurements were conducted in representative flooded and non-flooded rice canopy in the vegetation (mainly reproductive) period of rice using 23 thermologgers (sensors). In 2005 the measuring program was limited, but in 2006 it was enlarged. Temperature data were logged in every 5, 10 or 20 minutes in the soil, water and air, respectively.

Most of our studies on microclimate were of empirical, describing character. In general the examinations were carried out with relatively simple methods (calculations of extreem and average values, correlation- and regression analyses) using Microsoft Excel software, but based on a huge database.

A new dynamic-empirical **model** was developed **to describe water temperature** (daily maximum and minimum). Our model has a physical background, and it uses natural time steps for calculations of changes. The changes are calculated based on empirical relationships. It improves the value of the model that only „normal", easy to get meteorological data are needed as input values. The parameterization and verification were done using measurement data of 2006 and 2005 (independent data set), respectively.

The **termal effect on flowering time** was examined based on a 9-year-long phenological data set of experiments of Irrigation Research Institute. Own experiments were not carried out for that purpose, because at least such a long period is neccessary for getting statistically reliable results. As a new method in Hungarian rice research, bilinear models (three different functions) have been created to estimate time from sowing to flowering. The parameters of the models were determined by minimizing the coefficient of variation (CV) using Microsoft Excel program. As a kind of sensitivity-analyses of parameters a new, graphical method was developed.

The **analysis of the weather-yield relationship** needed a longer time series data (average rice yield in Bekes County from statistical records, meteorological data of Hungarian Meteorological Service, Szarvas Agrometeorological Observatory, 26 years). The main methods used were correlation analyses, multiple linear regression (Systat 9) and verification.

The daily temperature data from Szarvas (Hungarian Meteorological Service: 1976-2000, Tessedik Samuel College: 2001-2007) gave the possibility to **calculate growing degree days and cooling degree days**, to **indicate climatic trends** and to make **statistical analysis of critical periods** and **risk analysis with different sowing dates**. The risk analysis was the most complex task, and it also needed the use of our thermal time models.

The bilinear thermal time models of flowering time and the dynamic-empirical model of water temperature – our most sophisticated tools – also have an own methodological value.

4. RESULTS

4.1. Effect of temperature on the phenological development of rice

- The median emergence time (E_{50}) of the five Hungarian rice cultivars gradually decreased in the interval between 14 and 34°C. The average emergence time is 23.9 days (unfavourable) at 14°C and 13.4 days (acceptable) at 16°C (Table 1). That means an increase of 2°C causes „qualitative” change in emergence characteristics. Comparing the rice cultivars in that temperature interval provides the most useful information from practical point of view. The E_{50} values have significant, but small (less than 1°C) differences between 26 and 34°C. This interval is ideal for the emergence, the rice needs only 3.3 to 4.4 days to emerge.

Table 1. Time from sowing to median (50%) emergence at different temperature values as an average of five cultivars

Temperature (°C)	Average E_{50} (days)
14	23,9 j
16	13,4 i
18	10,6 h
20	7,3 g
22	6,6 f
24	5,1 e
26	4,4 d
28	4,3 d
30	3,7 c
32	3,5 b
34	3,3 a

Means within a column followed by the same letter are not significantly different based on Tukey test at P = 0.05.

- A close relationship was found between temperature and development rate. The linear thermal time model is able for an accurate prediction (R^2= 0.98-0.99) of the emergence time. The base temperature varies between 9.8 (Bioryza) and 10.9°C (Risabell) while the thermal time requirement is between 69 and 88°Cday (Table 2). The base temperature of cultivars does not differ significantly from each other and is a little bit lower than 12°C (generally accepted for all cultivars and phenophases). Taking the heterogenety of the soil temperature into consideration the model parameters can be simplified (base temperature = 10°C, thermal time requirement = 70°Cday).

Table 2. Base temperature (Tb) and thermal time requirement (TU) of five rice cultivars

Cultivar	Tb (°C)	TU (°Cday)
Augusta	10,1	70
Bioryza	9,8	88
Dáma	10,6	73
Ringola	10,9	70
Risabell	10,8	69

- The flowering time of an early flowering rice cultivar was successfully described with three different bilinear thermal time models. Functions representing the different bilinear methods with optimal parameters can be seen in Fig. 1. All of these methods predict the length of the phenophase more accurate than the linear thermal time model. It is so, because above a certain temperature the rate of emergence does not increase, but can decrease as a function of temperature. The optimal temperature of flowering (got as a model parameter) is relatively low (23.5-24.1°C). Therefore, further research to study unfavourable effect of high temperature is needed in the future.

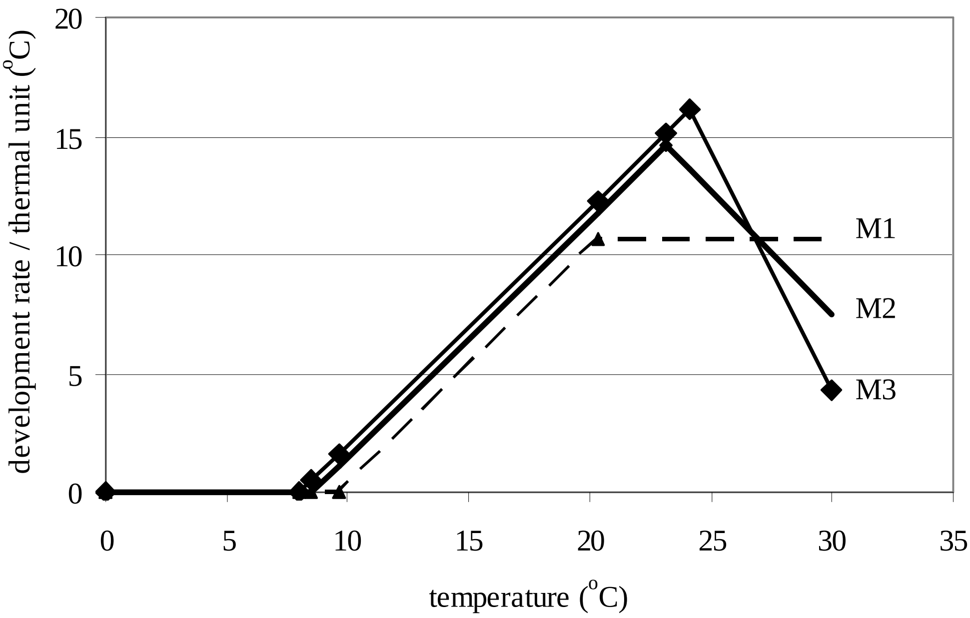

Figure 1. Thermal units to sum as a function of temperature for our three bilinear models

The base temperature values in models (8.0-9.6°C) are lower then generally admitted by Hungarian rice researchers and growers (12°C). This result hints to possibilities of various interpretations of base temperature.

▪ The construction of bilinear models shows a proper way how to create a sophisticated thermal time model valid for various species, cultivar, phenophase and ecological circumstances from phenological data. The model parameters can be calculated by minimizing the coefficients of variations of thermal time. To collect phenological data from own experiments or crop production can be useful for that purpose.

Our new graphical method is a very simple, new method to study how sensitive the bilinear models are for uncertainity of parameter values. The example of a model version shows the distribution of CV values of thermal time as a function of base and optimum temperatures (Fig. 2). With the help of the figure relatively stable parameter values can be choosen, even if uncertainity in phenological data exists.

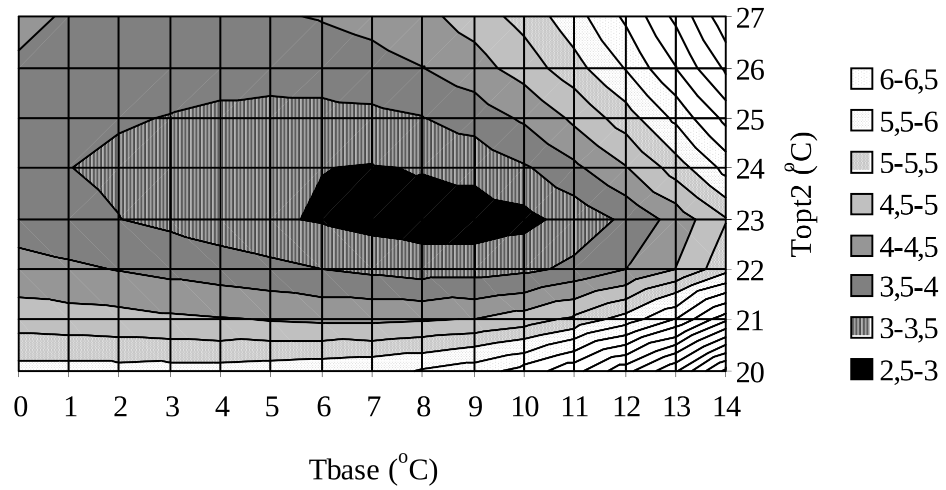

Figure 2. Coefficient of variations of the thermal time as a function of base and optimal temperatures (method 2)

4.2. Agrometeorological study of critical development stages of rice

The temperature in the first decade of April is warm enough in some years to urge rice growers to make the sowing. To sow so early can cause problems, because there is a high probability that the weather changes to cool (especially in the middle of April), and the emergence time will be unfavourably long. After 20 April there is not a significant break in warming process in the average of many years (Fig. 3).

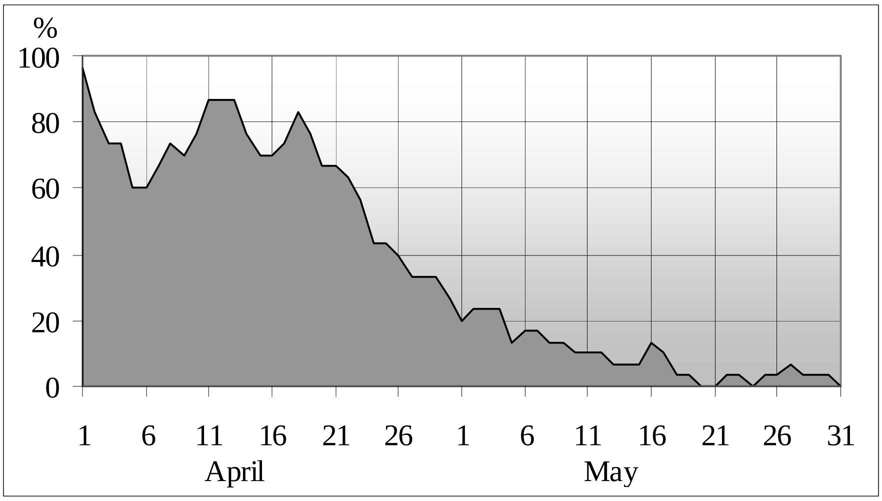

Figure 3. Probability (%) of the lower than 12°C 5-day-average temperature in Szarvas

The risk of unfavourably long emergence time was determined in case of various sowing dates using our linear thermal time model. This quantitative information is new for Hungarian rice growers (Table 3).

Table 3. Number of cases during 32 years (1976-2007) when the emergence time (ET) exceeded 3 weeks and 1 month, in case of different sowing dates

	1 April	10 April	15 April	20 April	25 April	30 April
ET ≥21 days	30	22	16	11	5	3
ET ≥30 days	14	8	6	2	1	0

According to these results the earliest sowing date recommended is usually 20 April. Sowing can be done maximum one week earlier if soil temperature is at least 15°C and a persisting warm weather period is forcasted. To sow the rice earlier is not advised (independently from the actual soil- and air temperatures), because it has a too big climatological risk. The probability of emergence time longer than 3 weeks is above 50%.

- Regarding the sterile-type cold stress, the probability of unfavourably cool periods (5-day-average of minimum temperature values < 14°C) is the lowest at the end of July and at the beginning of August. The most sensitive phenological phases are recommended to be timed to this period with appropriate sowing time and cultivar to minimize risk of panicle sterility (Fig. 4.).

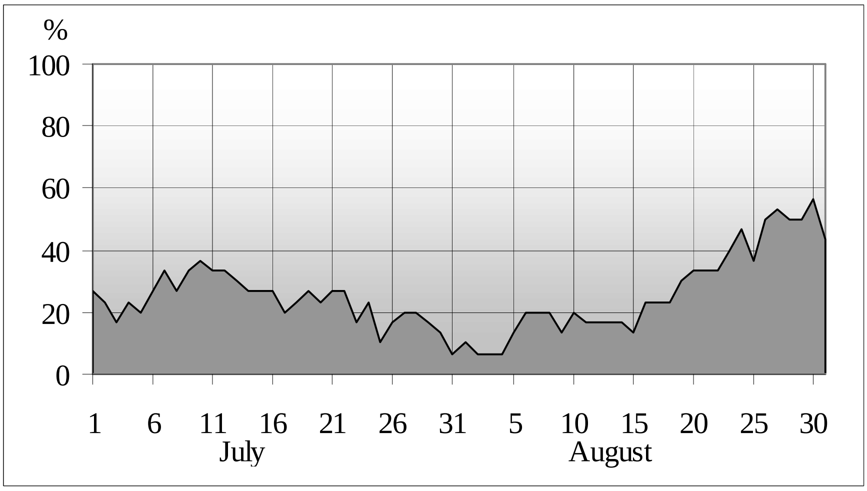

Figure 4. Probability (%) of 5-day-average of lower than 14°C minimum temperatures in Szarvas

By the use of our bilinear model it was found that the flowering time of early flowering rice varieties is not later than the first decade of August (44% in the 1st decade of August, 56% in July) if sown in the middle of May. That is within the optimal interval. Varieties with a 10-15 days later flowering time can be affected by an increased level of cold stress.

Sowing of early varieties is not advised as early as 20 April, because in that case the flowering time would be before the most risky period (the beginning of July instead of the end of July). If rice can be sown early, it is advised to use longer maturity cultivars.

- Regarding the maturity, the probability of unfavourably cool periods (5-day-average of maximum temperature values < 20°C) increases nearly linearly from the end of August (0%) till 20th of October (100%) (Fig. 5).

The sowing of rice can be only slightly delayed, because it has to reach the maturity before 10 October. Based on our calculations it can be stated that rice will not ripe in time in one of 5 years (20%) if early flowering rice cultivars are sown on 25 May (cv. with rapid water loss at maturity, maturity type I., TU=500°C d) and 20 May (cv. with slower water loss at maturity, maturity type II., TU=560°C d) (Table 4). This level of risk is acceptable, because the troublesome cases can be handeled with some extra costs. For the late maturity type cultivars the latest advised sowing dates are the 10th of May (maturity type I:) and the 5th of May (maturity type II.).

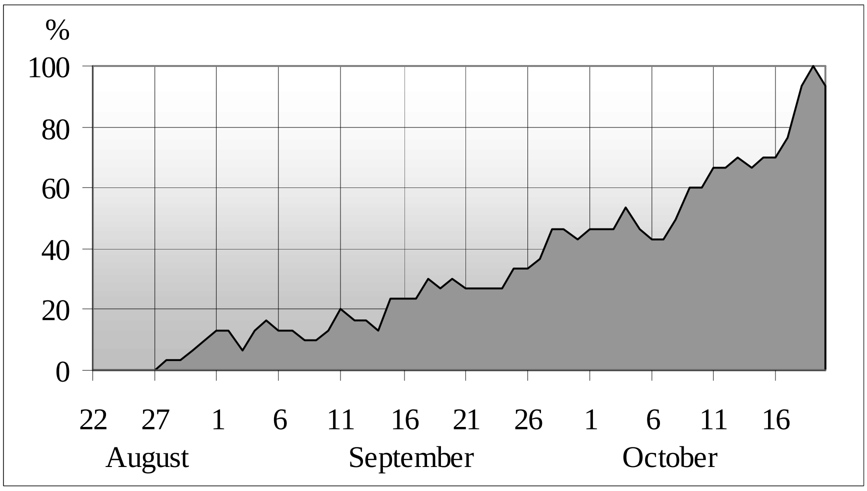

Figure 5. Probability (%) of 5-day-average of lower than 20°C maximum temperatures in Szarvas

Table 4. Relative probability (%) of unfavourably late maturity time (rice does not ripe before 10 October) in case of various sowing dates, based on a 32-year-long period (1976-2007)

	1 May	5 May	10 May	15 May	20 May	25 May
Early flowering, maturity type I.	0	3	6	6	6	16
Early flowering, maturity type II.	6	6	6	6	22	28
Late flowering, maturity type I.	6	6	12	31	43	59
Late flowering, maturity type II.	12	19	31	43	66	81

The adviced dates refer to direct sowing (into the soil) and full maturity. If sown into water, on soil surface or using soaked seeds, the sowing time can be shifted a few days later. However, in case of late sowings the early varieties should be preferred.

4.3. The effect of weather on rice yield

The relationship between the meteorological elements and rice yield is valid always only for the studied area. This is shown by an example of northern island of Japan, where the yield is by 1 to 2 t/ha higher than in Hungary where there is less sunshine and generally lower temperatures. This hints to hidden extra possibilities of Hungarian rice production, too (Fig. 6).

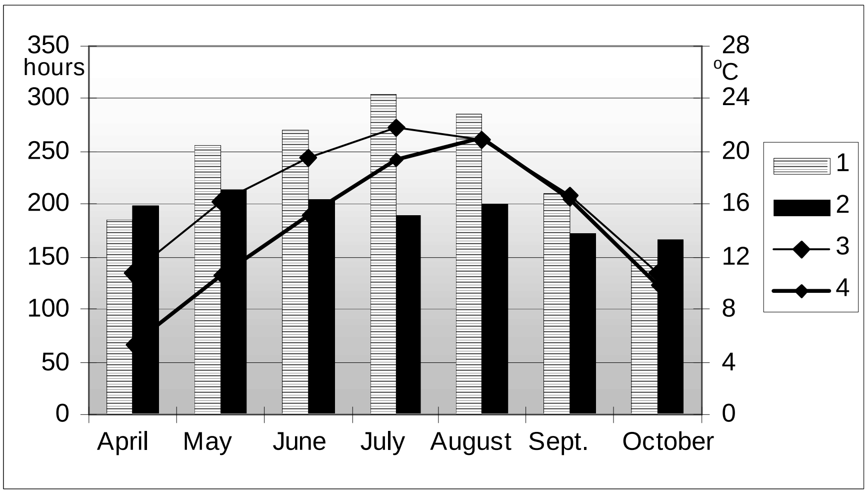

Figure 6. Monthly averages of sunshine duration in Szarvas (1) and Sapporo (2), monthly means of air temperature in Szarvas (3) and Sapporo (4).

- The average rice yield of Bekes County was estimated with monthly mean air temperature and sunshine duration using multiple linear regression. The standard error was 0.5 to 0.6 t/ha according to the number of parameters (months) (Fig. 7).

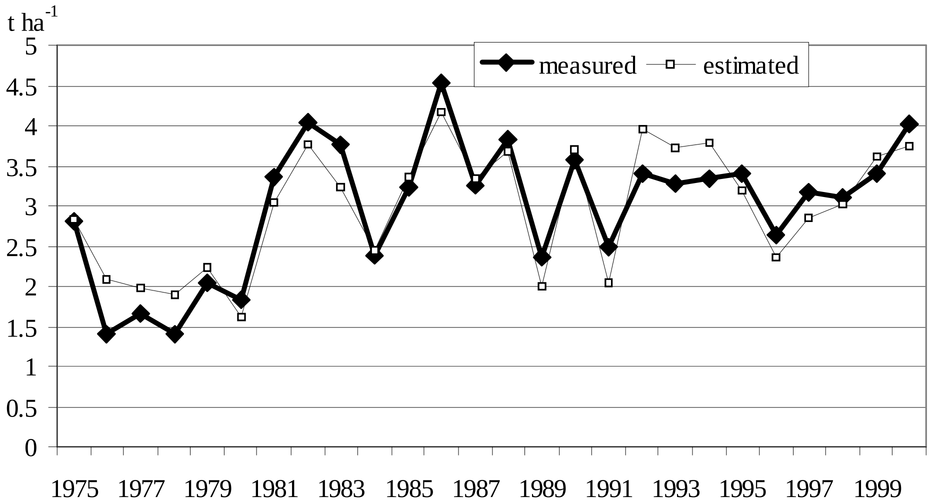

Figure 7. Measured and estimated (by regression) rice yield in Bekes County

- Partly differently from the earlier results it was found that the monthly averages of air temperature and duration of sunshine have similar importance in determining the yield of rice. There is a closer correlation of yield of rice to the maximum temperature than to the minimum temperature. Yield is affected mostly by the weather of August, followed by the weather of May and July (Table 5). Differently from the previous researches it was found that the weather of emergence period was more important and the weather of July less important. The yield loss is caused more by pests connected to cool, cloudy and foggy weather in August than by low temperature in the early reproductive stage of rice. That has been explained by the higher correlation values of August than those of July.

Table 5. Correlation between meteorological elements and rice yield of Bekes County

	April	May	June	July	August	September
Precipitation	-0.04	-0.32	-0.16	0.05	-0.14	0.03
Sunshine duration	0.57^{xx}	0.54^{xx}	0.23	0.51^{xx}	0.64^{xxx}	0.39^{x}
Temperature	0.30	0.49^{x}	0.23	0.39^{x}	0.63^{xxx}	0.32
Maximum temperature	0.24	0.40^{x}	0.18	0.36	0.51^{xx}	0.14
Minimum temperature	0.32	0.52^{xx}	0.30	0.41^{x}	0.62^{xxx}	0.41^{x}

Significance: ^{x}: P=5%, ^{xx}: P=1%, ^{xxx}: P=0.1%

- The calculations based on the 10-day-average temperatures resulted in detailed information about the effect of temperature on yield of rice. The periods with significant effects of temperature are: middle of August (highest significance), end of April, middle and end of May as well as end of July (Fig. 8).

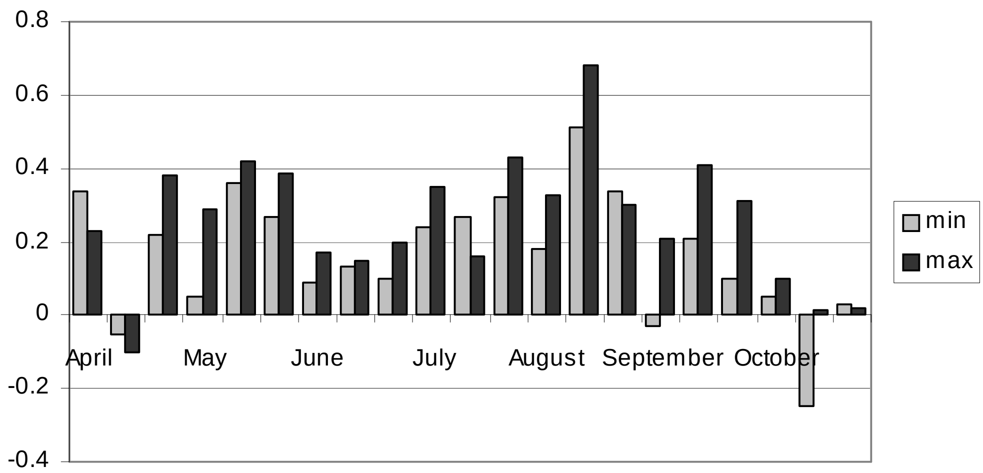

Figure 8. Correlation between yield of rice and 10-day-average of minimum and of maximum temperature during the vegetation period (1976-2000)

The yield correlates more with cooling degree days than with the temperature (minimum, maximum or average) only in August. This is true only if cooling degree days are calculated starting from a high temperature. That means the irreversible effect of short-time cool periods could not be shown. The results hint that the effect of high temperatures must be filtered from monthly data.

- The temperature trends observed in the last 32 years hint that the warming in spring and the cooling in autumn happens more and more rapidly giving a sharper beginning and end for the vegetation period. Parallel to it, the vegetation period becomes warmer than before, resulting in more favourable circumstances for emergence and less probability of sterile type cold-stress (Fig. 9).

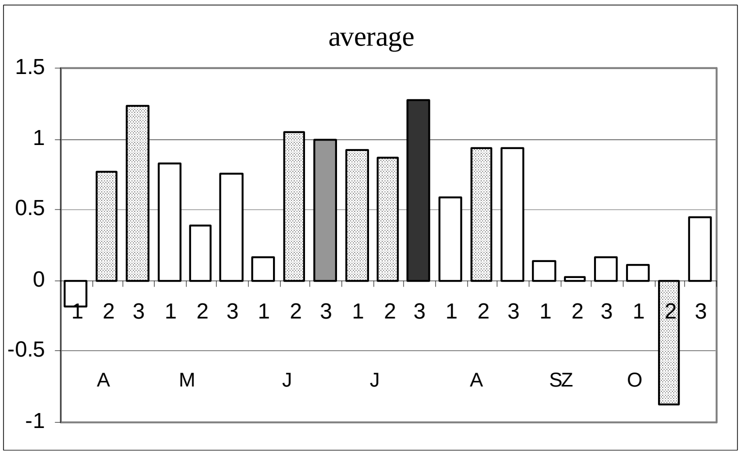

Figure 9. Changes (linear trend in °C/10 years) of 10-day-average temperatures in Szarvas between 1976 and 2007. The colour of the columns represents the level of significance. White: not significant, dotted: P=5%, gray: P=1%, black: P=0.1%.

According to this tendency, the early (from15 to 25 April) and late (till 25 May) sowing dates, and the production of cultivars with longer vegetation period may become more acceptable.

4.4. Microclimate of rice

- During the coolest period of the nights the flooding water has a 5°C advantage compared to the air, and it can protect the cold-sensitive developing panicle under the water level. The daily control of the height of panicle is advised. In some cases (sensitive period of rice, large temperature drop is forecasted) the appropriate increase of water level is also advised to reduce panicle sterility. A few centimetres increase sometimes can mean an extra protection of 2-5°C. For practical purposes additional information would be very important concerning the exact effects of various (duration, level) temperature drops on yield of Hungarian rice cultivars. This information would help to estimate the advance of microclimatical modification.

- A model has been constructed to predict the daily maximum and minimum of temperatures in flooding water of rice. The model uses standard meteorological data as input parameter, which are:
  - Daily maximum and minimum of air temperature (Version 1);
  - Daily maximum and minimum of air temperature, daily sum of global radiation, daily average of relative air humidity, daily average of windspeed (Version 2).

The root mean square error (RMSE) in predicting daily extremes of water temperature was 0.78-1.31 and 0.43-1.20°C in case of versions 1 and 2, respectively. These errors are proper for practical purposes, especially if compared to differences of water and air temperatures (Fig. 10).

Both versions of the model can be built in weather-rice models (simulation model, cold stress model), but this is beyond the topic of our research. The simple version is an effective tool for rice growers to calculate water temperature for the next 5-10 days using data of weather forecasts. This new information can help the planning of water management, i.e. it can hint to the advantages of modifying the water level.

- The air in flooded and non-flooded rice canopies is characterised by different temperature conditions at nighttime. A difference of 1 to 3 (4)°C developes between air temperature in the canopies of flooded and non-flooded rice as a function of water temperature and weather parameters. Our empirical model is utilizable to predict the difference with a standard error less than 0.5°C (Fig. 11).

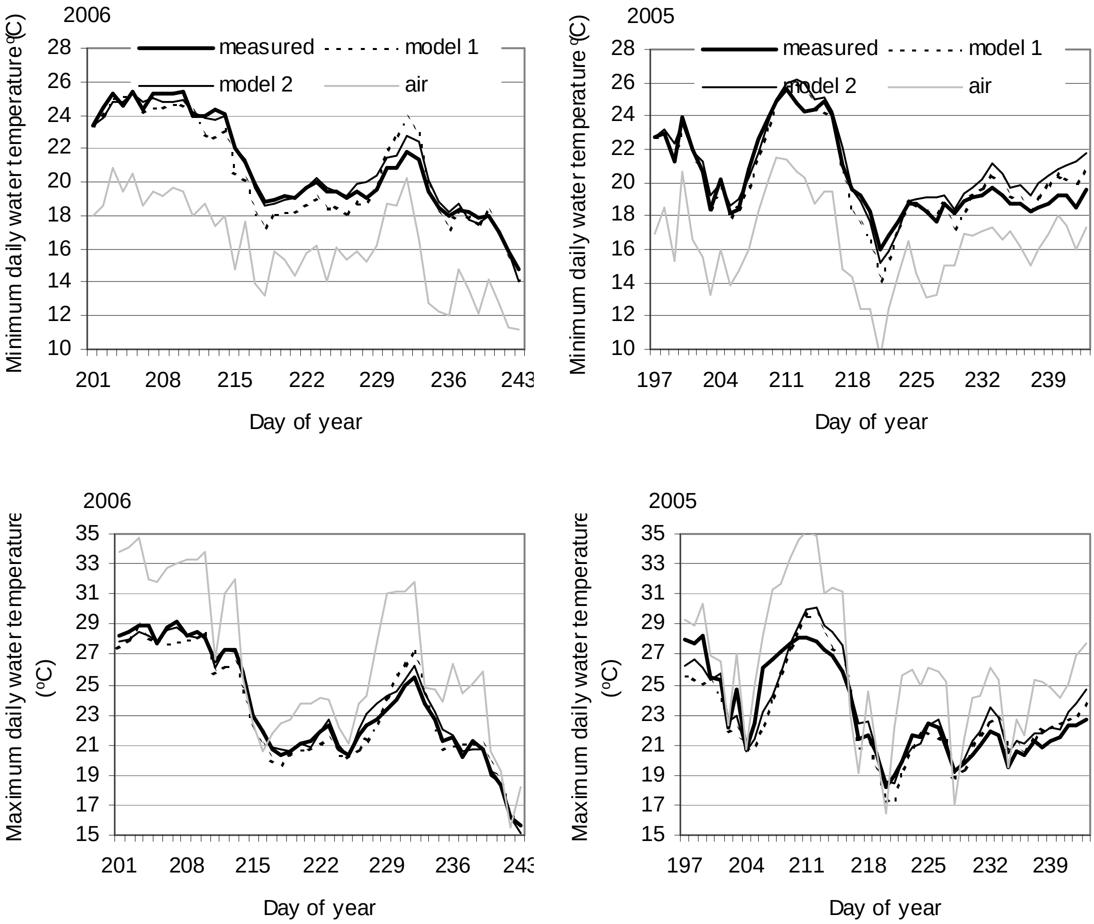

Figure 10. Prediction of Model version 1 (dotted line) and Model version 2 (normal line) compared to measured water (dark line) and air temperature (light line) in 2006 (calibration) and 2005 (validation)

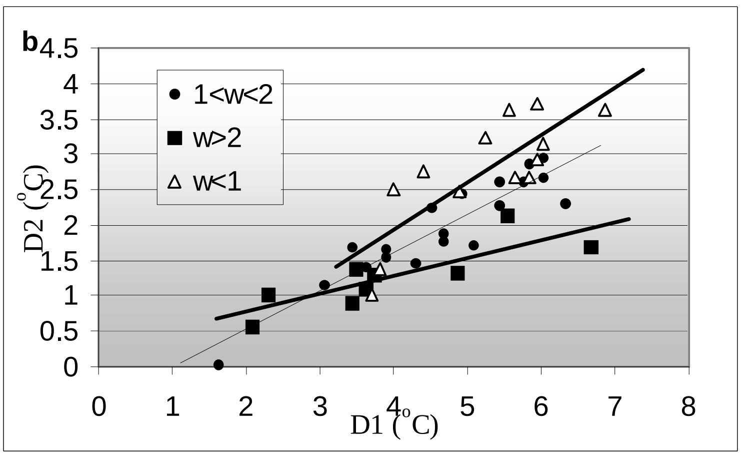

Figure 11. Relationship between the difference of minimum temperature of water and air at 2 m height (D1) and the difference of minimum temperature of air in flooded and non-flooded rice canopies separated according to average wind speed

- Our examinations resulted in detailed information about the nighttime course and the vertical profiles of temperature in non-flooded canopy. The canopy of non-flooded rice can be much cooler than air at 2m already in the evening hours. The temperature difference can reach 6 to 9°C in cloudless, calm evenings. The difference decreases gradually during the night, but it persists (Table 6).

Table 6. Typical differences between temperatures measured in weather shelter at 2 meters height and temperatures of the coldest level of rice canopy: (1) cloudless, calm night, intensive long wave outgoing radiation, (2) moderate long wave outgoing radiation

	19 hours	**20 hours**	**21 hours**	**22 hours**	**23 hours**	**0 hour**	**1 hour**	**2 hours**	**3 hours**	**4 hours**	**5 hours**	**min**
1	6-9	5-7	4-6	3.5-5.5	3-5.5	3-5	2.5-5	2.5-4.5	2-4	2-3.5	1-2.5	2-2.5
2	3-7	3-5	2-4	2-3	2-3	2-3	1.5-2.5	1.5-2.5	1.5-2	1-2	0.5-1	1.5-2

The risk of panicle sterility caused by low temperature is probably higher in non-flooded rice than in flooded rice, because the night temperatures are significantly lower in the non-flooded canopy. The cold tolerance of Hungarian rice cultivars is relatively high. Therefore sterily type cold stress becomes usually not the main yield-limiting factor. The agrotechnical problems often lead to such a huge yield loss that the effect of cold stress can not be observed (also in case if it exists). However, the importance of temperature will increase in the future at a higher level of agrotechnology.

5. NEW SCIENTIFIC RESULTS

1. The relationship between the temperature and the emergence of five Hungarian rice cultivars (optimal water supply, sowing depth of 2 cm) was explored in details. The parameters (base temperature, thermal time requirement) of a thermal time model suitable for calculation of emergence time was determined.

2. Construction and parameterization of bilinear thermal time models which describe the length of the emergence-flowering phenophase of an early maturity rice cultivar (Ringola)

were carried out. The base temperature of rice was statistically interpreted and calculated differently from the usual calculation described in the Hungarian literature.

3. The analyses of weather-yield relationship resulted in parameters and time periods different from the previous results. The studies carried out according to 10-day-averages supplied additional details about the effect of temperature on yield. The examination with cooling degree days did not show the irreversible effect of short time temperature drops. The results hint that the eliminating of too warm days (max> 30°C) from data set can improve the prediction of yield.

4. Complex risk-analyses of (1) unfavourably long emergence time, (2) irreversible panicle-sterility caused by cold stress and (3) delay in ripening were conducted. Daily temperature data of Szarvas in the period of 1976-2007, various sowing dates and cultivars were applied. The previous recommendations concerning the sowing dates were slightly modified.

5. Detailed examination of nighttime temperature conditions in non-flooded rice canopy (vertical profile, course of temperature) was carried out according to weather types. The nighttime extra heat in the air of the canopy caused by flooding water was analysed and modelled using water temperature and standard meteorological data (temperature at 2 m height in weather shelter, wind speed).

6. The temperature of flooding water and air was compared by the analyses of daily minimum, maximum and average temperatures. Two versions of a dynamic-empirical water temperature model were constructed. Both models are suitable for the predicting of daily minimum and maximum water temperature using standard meteorological data as input variables.

7. The flooding water can reduce the harmful effect of unfavourable meteorological conditions lasting relatively short time (a few days).

6. PRACTICAL UTILITY OF THE RESULTS

The limits and possibilities of Hungarian rice production are mainly determined by the climate, especially by the temperature. There is an especially high importance of agrometeorological examinations because of the thermal marginality of rice fields (northernmost fields in Europe). The weather conditions can not be improved, only the microclimate can be a little bit modified. However, according to our results it is possible to utilize the climatic potential better and to limit the unfavourable effects of weather.

Reliable and long-term weather forecasts do not exist, so the uncertainity can not be neglected. However, the statistical probability of favourable and unfavourable weather can be determined for different parts of the vegetation period.

Proper choosing of sowing date can be an effective tool without extra costs. Our research resulted in quantitative information about the climatic risk during the sensitive phenological stages of rice in case of different sowing dates. This information helps the growers to maximize the yield, i.e. to minimize the risk that unfavourable weather conditions meet the sensitive phenological stages with appropriate sowing time. The complex risk analysis is especially important when early and late sowing is planned (or is only possible).

The suggested optimal sowing intervals for different maturity time cultivars are good guidelines. Additionally, the actual weather and the weather forecasts (1 week) can also be considered with the help of our thermal time models (emergence time). This can give extra information to choose the best/earliest/latest time of sowing.

The rice is the only crop where an effective tool exists for modification of the microclimate in the canopy, and it is the flooding water. On the contrary the flooding water is not used for this purpose directly, because of the high expenses of water supply. However, in planning the water management (timing, water level) it is worth to consider the thermal effect of the water as well. Without (or with a little) extra costs the harmful effects of cool weather can be reduced in some cases. To do this our microclimate research gives the neccessary base in form of quantitative information about direct and indirect effects of flooding water.

The knowledge of general thermal characteristics is important, but our models (about water temperature and cooling of canopies) estimate the thermal conditions more accurately from the actual and forecasted meteorological data. The model calculations are relatively simple. The identification of microclimatic effects on rice yield (Hungarian cultivars) would increase the value of our results.

The importance of weather related to yield was determined in 10-day-intervals. The results hint to the critical periods of the rice vegetation period in Hungary. The effects of the possible climate change can be evaluated based on our results (especially, if more detailed data will be available about the manifestation of climate change in Hungary).

The breeding is also an important area where the results of our examinations can be put into the practice. The critical temperature values for emergence demonstrate the criteria for selection and evaluation of cultivars. The detailed climatic statistics focussing on the demands of rice is important for the breeders, too. It would be a meaningful practical result if the more sophisticated bilinear thermal time models (and the way of parameterization) were used instead of simple linear methods.

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