TEMPERATURE CONDITIONS IN THE MICROCLIMATE OF A RICE CROP

by

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Summary: Research workers on the Chair of Climatology of the József Attila University at Szeged undertook in July and August 1971, under Prof. R. WAGNER, microclimatological investigations in a rice crop on the site of the Research Institute for Irrigation at Szarvas.

Measurements were carried out on four rice crops subjected to various treatments, on a free water surface and on a dry area.

From these measurements it is found that, during the earlier phases of development of the rice plant, the rice crop is not yet influencing the temperature conditions of the microclimatic space. During the later phenological phases, the vegetative organs are enriched and the effective surface is transferred to a higher level. In a depth of 10 cm in the flooding water and in the soil below it, temperature variation is modified, the amplitudes are decreased and significant deviations are experienced as compared to data from the free water surface and from the free dry surface.

In processing the data, we used the method of approximation by trigonometrical polynomials. In addition of the investigation of various crops, trigonometrical polynomials of temperature are well exhibiting the modifications in temperature which are typical for a rice crop in three phenophases.

Zusammenfassung: *(Temperaturverhältnisse im Mikroklimaraum der Reispflanze).* Von den Mitarbeitern des Lehrstuhls für Klimatologie an der József Attila Universität zu Szeged wurden in den Monaten Juli und August 1971 unter der Leitung von Prof. RICHARD WAGNER mikroklimatische Untersuchungen in einem Reisbestande auf dem Gebiete der Forschungsanstalt für Berieselung in Szarvas unternommen.

Messungen wurden an vier verschieden behandelten Reisbeständen, sowie an einer freien Wasserfläche und auf einem trockenen Gelände durchgeführt.

Aus den Messungen geht es hervor, dass in den früheren Stadien der Entwicklung der Reispflanze durch den Pflanzenbestand noch keine Einwirkung auf die Temperaturverhältnisse des mikroklimatischen Raumes ausgeübt wird. In den späteren Phenophasen tritt die Anreicherung der vegetativen Teile ein und damit wird die wirksame Oberfläche auf ein höheres Niveau verschoben. In einer Tiefe von 10 cm im Bedeckungswasser und im Boden unterhalb des Wassers wird der Temperaturgang verändert, die Amplituden werden verkleinert und bedeutende Abweichungen treten in Erscheinung gegenüber den entsprechenden Werten des freien Wassers und des freien Geländes.

Bei der Verarbeitung der Angaben wurde das Verfahren einer Annäherung durch trigonometrische Polynomen verwendet. Neben einer Untersuchung der verschiedenen Bestände zeigen die trigonometrischen Polynome der Temperatur in einem unbeeinflussten Gebiete die für einen Reisbestand charakteristischen Temperaturveränderungen in drei Phenophasen.

Investigation of the climate of rice fields appears to be a rather important task both abroad and in Hungary. The dominant part of research work is done in connection to the study of the biological properties of the rice plant, however, the particular microclimatological and climatological properties of the surface covered by a shallow water layer are presenting an independent goal of investigation. In recent years, literature is reporting on a still increasing number of hothouse experiments and field experiments which are comprehensively elucidating the meteorological factors and are analyzing the dependence of some or other biological index on weather conditions. M. DZAPBASBAEV (1969 a) has pointed out that the determination of indices in the field of agricultural meteorology and the study of their influence on crop development is a task of prominent theoretical and practical importance. According to his opinion, conclusions regarding rice crops may be obtained only by a detailed analyzis of the climatical conditions. Accordingly, current investigations have the scope of detecting the relations existing between climatical elements and the quality and quantity of rice crops. D. DRAGANOV—J. CHILIKOV—G. STARIDOLSKIJ (1969) have investigated the influence of temperature, atmospheric humidity and evaporation from the surface on the maturation of rice. They found that, in the course of maturation, the humidity content of the grain is decreasing to 27 or 25%. The influences of temperature and precipitation on the crop yield are different ones. Monthly mean temperatures of the growing period, the number of insolation hours and the temperature sums of the various phenophases are exhibiting a positive correlation to the crop yield, whereas the annual amount of precipitation is exhibiting a negative correlation to it. (I. BÁRÁNY, 1971, G. V. NALIVKO—E. P. ALESIN, 1971).

N. P. KRASNOOK—V. PTASKIN—J. A. VISNAKOVA (1971) as well as M. DZAPBASBAEV (1969 a) found that maturation takes place more slowly at lower temperatures and more rapidly at higher temperatures.

VAMADEVAN (1971) investigated variations of water depth and those of the meteorological elements, and reached the conclusion, that in the case of a shallow water layer the crop is more sensitive to the variations of meteorological elements.

In connection to low temperatures at night, P. C. OWEN (1969) found that this occurence is impeding flowering. M. DZAPBASBAEV (1969 b) investigated comprehensively the conditions of rice growth in a continental climate. In addition to the measurement of indices in agricultural climatology, he is drawing on the basis of microclimatological observations some conclusions concerning the crop climate of rice. He is discussing, for an area in Kazachstane, the energy balance of rice fields and the diurnal variations of air temperature and atmospheric humidity. The instruments and methods used in this investigation are similar ones to those used in our own work, and investigations were made according to the phases of plant development. The cited Author makes statements on the day-time and night-time stratification of the crop temperatures during the various phenological phases, and he is determining the location and occurrence of the various inversions and isothermal layers.

R. WAGNER (1957, 1965, 1966) investigated from several points of view the microclimatical conditions of rice and, respectively, the effect of water flooding on the microclimate of a rice crop. He found that in a rice crop (similarly as in the case of other flooded crops) the thickness of the water layer is exerting an influence, under identical weather conditions, on the thermal balance of the soil and on the plant crop, and, on the other hand, the plant crop is influencing the thermal conditions of the water layer. With increasing crop density, the temperature difference existing between the root zone and the leaf zone is increased.

In the present paper (on the basis of microclimatological research work done by the Climatological Institute of the József Attila University of Szeged under Prof. R. WAGNER) the temperature conditions of the microclimatological space of a rice crop is analyzed for several phenological phases by utilizing the extreme values and hourly mean values of temperature.

Measuring Methods and Instruments

The measurements were executed on the experimental site of the Irrigation Research Institute at Szarvas, during the period July 1st to August 31th.

Microclimatological stations were erected in five differently treated rice crops, (namely: lately seeded; copiously fertilized; unfertilized; provocated and fertilized; and provocated without fertilizer), as well as in free water and on dry land.

The main point of view in the proper choice of the places of the microclimatological stations was to be able to registrate with microclimatological measurements the alterating effects of fertilizer treatments on the vegetation and the effects of conditions established for provocation of rice disease caused by Piricularia.

Evaluation of the data was made according to phenological phases. In July and August, we were able to observe the termination of the phenological phase called growing thick, the development of stems and the first phase of the period of the development of panicles, flowering and maturation.

In the variously treated crops (according to observations made by Mrs I. Simon the duration of the phenophases investigated was as follows (Table 1).

Table I

Observing station	Growing thick	Development of stems	Development of panicles flowering and maturation
1. Lately seeded crop	10th July to 31st August	1st to 10th August	From 11th August
3. Copiously fertilized	18th June to 21st July	22nd July to 1st August	From 2nd August
4. Unfertilized	20th June to 19th July	20th to 31st July	From 1st August
5. Provocated and fertilized	9th July to 23rd July	24th July to 1st August	From 2nd August
6. Provocated and unfertilized	10th June to 19th July	20th to 27th July	From 28th July

Data from station 2 (free water) and from station 7 (dry area) and, in the case of processing macroclimatological data, those from station 3 were used for determining phenophases.

Station 4 was used as a checking for station 3 and station 6 was used as a checking for station 5.

Flooding of station 1 was only since middle August a uniform one, and, as a consequence, the data from this station may be compared only in the following time to those of the other stations. On every station, measurements of air temperatures, water temperatures and soil temperatures were carried out.

Air temperature has been measured at the 10 cm and 200 cm levels above the actual water surface and, in addition, at the "panicle level". The altitude of the panicle level varied in the course of plant development. At the panicle level, and, respectively, beneath this level, are located the most closed sections of the leaf zone, and this level is a radiation-absorbing and radiation-transforming active surface being the warmest, or, respectively, coldest level in the crop. During the period before the development of panicles, the panicle level is defined as the most closed region of the leaf zone.

Water temperature measurements were taken 1 cm below the water surface, at middle depth of the flooding water, and at the bottom. Water thermometers were screened against direct solar radiation.

Soil temperatures were measured in the soil below the water layer and in dry soil at the depths of 2, 5, 10 and 20 cm.

In each of these three media (i.e. air, water and soil) temperatures were measured by using platinum resistance thermometers.

In addition, measurements were executed on the following meteorological elements: atmospheric humidity, by using Assmann's psychrometer; duration of insolation, by using a Campbell—Stokes instrument; global radiation, by using Robitzsch's instrument; radiation balance, by using the balance-meter of Schultze; and wind velocity, by using a revolving-cup anemometer.

Instrumental measurements were supplemented by visual observation concerning nebulosity, cloud types and other meteorological factors.

Hourly measurements were taken by day and by night on a round-the-clock basis.

At the research site, also a climatological station has been erected equipped with direct-reading instruments, a recording thermometer and a pluviometer. On the climatological station, observations were executed only at the standard climatological hours.

Macrosynoptical Situation during the Observation Period

During the last days of June, an irruption of cold air-masses from the NW was experienced in Central Europe. As a consequence, the daily mean temperature at Budapest was 7,5 centigrades below normal. On the research site, daily mean temperature was equal to 14,3 °C. During the first half of July, warmer air-masses have been advected to the continent, a slow increase in temperature was experienced and the daily mean temperatures reached on July 6th the normal value. Subsiding air-masses in a high-pressure system extending from Central Europe to the Black Sea brought during the period 6th to 12th July for the greater part of Europe a clear and dry weather.

Only on July 13th, some cooler air-masses arrived to the Carpathian Basin and in the afternoon, country-wide showers and thunderstorms occurred. At the research site, during several days various amounts of precipitation were observed and the mean temperature varied between the limits of 16 and 23 degrees centigrade. On July 25th, a slow increase in temperature began with decreasing nebulosity and increasing insolation. On the 29th July, a convergence zone over Central Europe and the Balkan Peninsula created favourable conditions for the formation of showers and thunderstorms. Up to the end of the month, rather week showers and thunderstorms occurred in the whole area of the country, followed by a warm spell with logical thunderstorms.

On the 4th and 5th August, the invasion of cooler air-masses of oceanic origin caused a decrease in temperature. Following this, a rapid rise of temperature occurred and the maximum temperature of the two-month period was reached (33,8 degrees centrigrade).

In the period between the 8th and the 17th August, the arrival of several cold fronts caused again a weather situation characterized by transient nebulosity and variable daily mean temperatures. On the 18th August, the cooler air-masses stopped their movement over the Black Sea area, the invasion of further cold air-masses ceased and subsidence caused a spell of dry and clear weather. Up to the end of the month, further three dry cold fronts of oceanic origin occurred, impeding a more intensive rise in temperature.

The monthly mean temperature of July 1971 was by 1,3 degrees centigrade

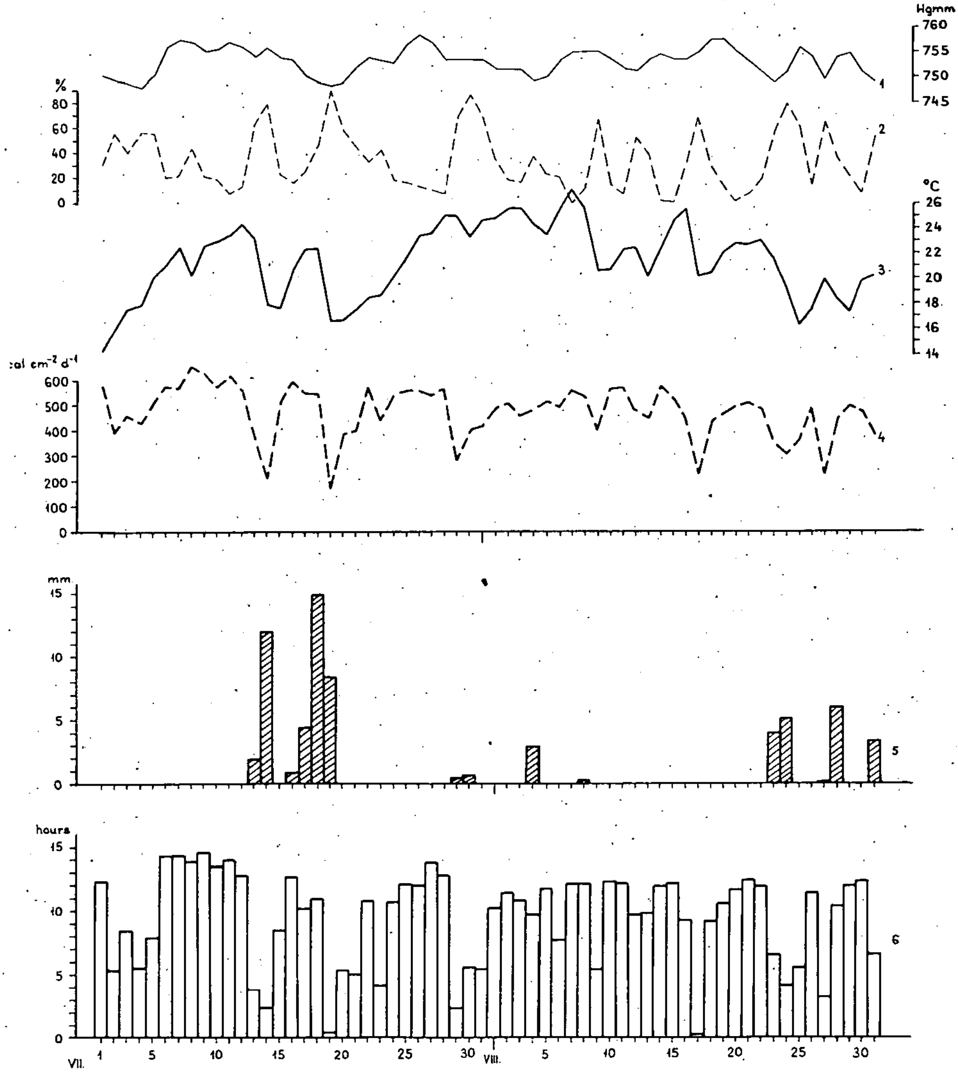

Fig. 1. Variation of meteorological elements at the research site in Szarvas, July—August 1971
1 = atmospheric pressure, including correction for the dilatation of the mercury column
2 = nebulosity
3 = daily mean temperature
4 = global radiation
5 = precipitation amount
6 = number of insolation hours

lower and that of August 1971 was by 0,8 degree higher as compared to the fifty-year normal values of the meteorological station Szarvas-Bikazug. Precipitation amount in July was about normal, in August, however, it was by 50 per cent lower than normal.

Figure 1 is yielding detailed information on the variation of meteorological elements at the research site during the two months in question (the value of atmospheric pressure, corrected of course for thermal dilatation of the mercury column, was taken from the meteorological station Szeged-University).

Both in July and in August, nebulosity was rather variable. Taking three classes of nebulosity (i.e.: between 0 and 30%, "fair"; between 31 and 60%, "cloudy", and between 61 and 100%, "overcast" days), we had, in July, 45,2% fair days, 35,4% cloudy days and 19,4% overcast days. In August 56,1% fair days, 25,0% cloudy days and 18,9% overcast days occurred.

During the rainy and overcast periods, the amount of total radiation was lower than the following value:

$$300 \text{ cal/cm}^2 \cdot \text{day}$$

Sustainedly high values of the diurnal mean temperature occurred mainly in the third ten-day period of July and in the first ten-day period of August. The absolute maximum of temperature (33,7 degrees centigrade) were reached in the second period, on the 7th August.

Radiation Conditions

The study of the radiation conditions at the research site is contributing to a clear understanding of the temperature conditions prevailing in the microclimatical space of a rice crop. Under the immediate influence of radiation, the surface, the surface-near air layer and the water layer are exhibiting a peculiar diurnal temperature variation, and these factors are, accordingly, controlling the temperature conditions in the lower water layer and in the soil beneath the water.

An analysis of radiation data is supporting the investigation of crop microclimates conducted on the basis of extreme values and hourly mean values.

Within the research site, radiation-balance-meters were located on the dry area (station 7) at the 200 cm level, while in the crop they were placed at the panicle level.

The total (short-wave and long-wave) radiation balance on station 7 is shown for the various phenological phases on Figure 2 (the phenological phases are corresponding to these observed on station 3, the values given are the hourly means of the corresponding phenological phase).

During the phenological phases of growing thick and of stem development the energy intake of the surface is greatest between 11 and 12 a.m. During the phase of panicle development and flowering, however, the highest energy intake is encountered between 10 and 11 a.m. The maximum value of the radiation balance is reached during the phenophase of stem development at noon, its value is approximately the following:

$$50 \text{ cal/cm}^2 \cdot \text{hour}$$

The sum of the global radiation ($I+H$, I being the direct and H the scattered radiation) and the Gegenstrahlung (G) is in a rice crop not the same as on a dry

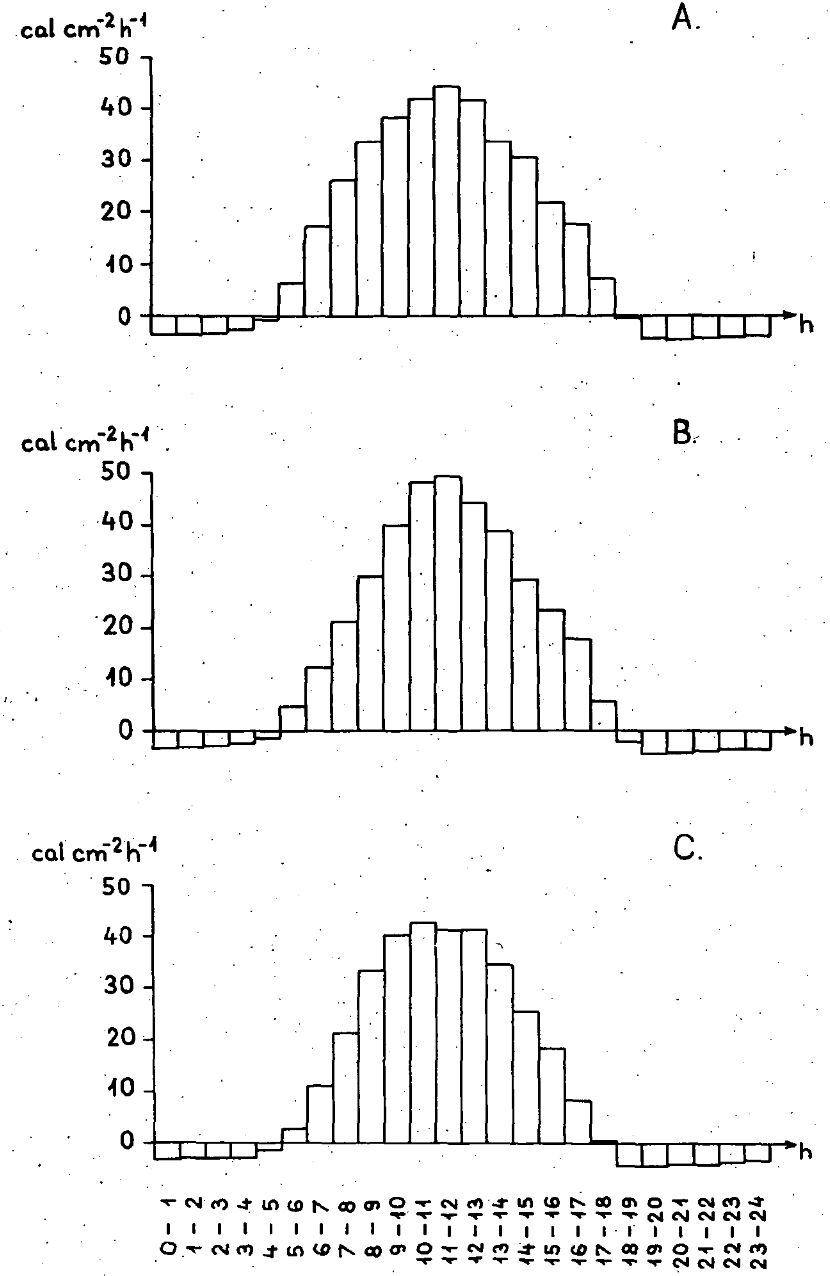

Fig. 2. Radiation balance for the various phenological phases on a dry area
A = phenological phase of growing thick
B = stem development
C = panicle development, flowering, maturation

area (it would perhaps be more correct to call this value “total radiation arriving downwards” and, because the instrument was placed at the “panicle level”, the radiation balance is influenced also by long-wave radiation from leaves and other plant organs which are located over the instrument), that is, in our case the so-called Gegenstrahlung is not exclusively consisting of radiation emitted by the atmosphere (Table 2). From these data it appears that the sum

$$I+H+G$$

is at night higher and at day-time lower than on a free area. Accordingly, at the panicle level, the contrasts between day and night are less sharp than on a free area.

Therefore, it may be stated that with the development of the plants the difference between the rice crop and the free area in the total energy intake on the active surface (that is, on the soil and on the panicle level, respectively) is increasing.

Table 2

Values of (I+H+G) measured in a rice crop, expressed as percentages of the corresponding values measured on a dry area.

F.F. = phenophase

A = growing thick

B = development of stems

C = development of panicles

F.F time	0–1	1—2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16—17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
A)	102,8	103,2	103,2	101,2	101,1	93,6	88,8	89,5	88,3	94,3	95,5	95,1	93,7	89,2	85,5	87,0	83,5	87,6	95,3	101,5	101,2	100,3	100,6	101,2
B)	106,3	105,7	106,9	106,6	104,0	91,0	81,4	77,7	76,0	72,9	79,7	83,8	76,0	72,2	76,6	73,9	77,1	88,3	101,8	108,0	107,1	106,9	108,0	106,9
C)	108,5	108,6	108,9	109,7	105,2	91,4	78,6	72,3	68,6	65,2	66,2	66,1	66,0	66,2	69,3	72,3	78,7	93,4	109,6	110,4	110,5	111,0	109,8	109,1

Investigation of Crop Temperatures According to Phenological Phases

Extreme Values of Air Temperature

R. Wagner's (1965, 1966) and M. Dzapbasbaev's (1969 b) earlier statements (according to which, on rice fields, the amplitudes of temperature variations are lower than on dry areas) are supported by an investigation of the values of air temperatures. This statement is valid for the whole of the microclimatic area of the rice crop.

In a rice crop, diurnal temperature maxima are lower and the minima are, under the influence of the crop and of the water layer, higher than on a free area.

Taking the maxima, minima and amplitudes of the climatological station on the experimental site (middle values for the corresponding phenophases) to be 100%, and comparing them to the corresponding data of the four rice crops that were seeded at the same time (again middle values for the phenophases), we are obtaining results that are in agreement with the above statements (Table 3).

Table 3

Station	Pheno-phase	Macrostation (100%)			10 cm			Panicle level			200 cm		
		max. °C	min. °C	ampl.	max. %	min. %	ampl. %	max. %	min. %	ampl. %	max. %	min. %	ampl. %
7.	A)	24,8	14,3	10,5	112,1	85,3	148,6	110,5	88,1	140,9	102,4	90,2	119,0
7.	B)	27,8	16,9	10,9	112,2	85,2	154,1	111,2	87,6	147,7	103,2	89,3	124,8
7.	C)	27,6	15,9	12,2	114,5	86,8	145,8	113,4	88,1	141,8	104,7	91,2	118,0
2.	A)	24,8	14,3	10,5	105,2	94,4	120,0	104,8	91,6	122,9	103,2	92,3	118,1
2.	B)	27,8	16,9	10,9	102,2	90,5	120,2	102,2	88,8	122,9	100,7	88,8	119,3
2.	C)	27,6	15,9	12,2	105,1	95,0	113,9	104,7	93,1	115,6	103,3	87,4	119,7
3.	A)	24,8	14,3	10,5	103,2	99,3	108,5	106,0	91,6	125,7	102,0	94,4	112,4
3.	B)	27,8	16,9	10,9	95,3	95,2	95,4	100,4	88,7	118,3	98,6	89,3	112,8
3.	C)	27,6	15,4	12,2	89,4	109,0	64,7	103,3	92,8	116,3	100,0	96,7	104,1
4.	A)	25,2	14,4	10,8	107,1	95,8	122,2	106,7	95,1	122,2	102,7	94,4	113,9
4.	B)	26,5	16,1	10,4	102,3	93,1	116,3	103,0	90,1	123,1	98,1	89,4	111,5
4.	C)	27,6	15,5	12,1	103,3	103,2	103,3	103,9	96,1	114,0	101,1	96,7	106,6
5.	A)	24,7	14,3	10,4	104,9	102,1	108,6	104,5	87,4	127,8	100,4	90,9	113,4
5.	B)	28,8	17,6	11,2	93,1	98,9	83,9	102,4	88,1	125,0	98,6	90,3	111,6
5.	C)	27,6	15,4	12,2	93,5	108,4	74,6	104,0	90,3	121,3	100,0	92,8	109,0
6.	A)	25,2	14,4	10,8	103,5	93,5	117,5	101,1	90,2	115,7	98,8	91,5	108,3
6.	B)	24,9	14,5	10,4	105,6	93,7	122,1	106,0	88,2	130,7	98,7	88,2	113,4
6.	C)	27,9	16,0	11,9	97,8	105,6	87,3	102,5	90,0	119,3	97,8	91,2	106,7

Maxima for the dry area and the free water are exceeding, in each phenophase, the maxima of the climatological station. The difference is decreasing with increasing height. At the 10 cm level and at the panicle level this difference is greater for the dry area and smaller for the free water surface.

The minima, however, are lower both over the dry area and over the free water surface than at the macroclimatological station. As a result, the diurnal amplitude of temperature variation is on the dry area by 40 to 50% higher and over the free water surface by 15 to 25% higher than on the climatological station.

Within the crops, a different situation is encountered. At station 3 (strongly fertilized crop) and on station 5 (provocated and fertilized crop) on the 10 cm level, in consequence of the richer vegetation, the maximum is, during the phenophases of stem development and of panicle development, flowering and maturation, essentially lower than on the dry area or over the free water surface. During the phenophase of growing thick, maxima are nearly identical one to the other.

At station 4 and at station 6 (unfertilized and, respectively, provocated and unfertilized crops) the difference on the 10 cm level is unimportant for each phenological phase. The minima, however, are lower on the dry area than within the crop. At station 3 (copiously fertilized crop) and at station 5 (provocated and fertilized crop) the amplitudes are, beginning with the stem development, lower than on the dry area and over the free water surface. The greatest difference in this respect is experienced at the time of panicle development, flowering and maturation, which could be attributed to a decrease in the nocturnal cooling caused by the more closed crop.

At the panicle level, maxima are in each crop higher and minima are lower than those observed at the macroclimatological station. Compared to the dry area within the crop maxima are lower and minima are higher. Compared to the free water surface, this difference is of course smaller. Within the crops, the panicle level is becoming the active surface, minima are at this level the lowest ones. The amplitude of the diurnal temperature variation is at the panicle level higher than on the 10 cm and 200 cm levels. In the more strongly fertilized crops this phenomenon is observed already during the phenophase of growing thick. In the crops which received less fertilizer, the amplitude of temperature is highest at the time of stem development, which is equally a consequence of the differences in the closing of the crops.

At the 200 cm level, the difference against the macroclimatological station is a lower one, the amplitudes are here smaller.

To sum up, we may state that the extreme values of air temperatures are deviating, under the influence of the flooding water and of the crop from those observed at a dry area or over a free water surface. The more strongly manured crops are developing more abundant vegetative parts, and, as a consequence, at the 10 cm level, a higher shadowing occurs which is leading, together with the influence of water, to a decrease in the amplitudes. On the other hand, at the panicle level, under the influence of direct irradiation, the amplitudes are larger. At the time of growing thick, in the lower levels, maxima are higher and minima are lower. During the later periods of plant development, the active surface is transferred toward the higher levels of the crop and, at this time, it is at this level where are experiencedhigher maximum and lower minimum values, leading to a larger value of the temperature amplitude.

Investigation of the Diurnal Temperature Variation by Using Trigonometric Polynomials

For the various crops, the analysis of the vertical distribution of temperature will be carried out by using hourly mean values for the phenophases.

The majority of the continuous meteorological elements, and thus temperature as well, is exhibiting a diurnal variation of the periodical type. Accordingly, we are using for the processing of data, the method of an approximation by trigonometric polynomials (an approach which has been described by K. JORDAN in 1949 using an example of climatological data).

The type of the approximating function is as follows:

$$f(x) = u_0+u_1 \sin (U_1+15x)+u_2 \sin (U_2+30x)$$

where

$$u_0=\frac{1}{24}\sum_{i=1}^{24} y_i$$

(y_i being the temperature value measured at the i-eth hour);

u_1 and u_2 are the coefficients of the trigonometric functions;

x is the time of measurement;

U_1 and U_2 are transformation parameters of the function.

By using the hourly mean temperatures of the phenophases for the following levels:

in the air at the 10 cm level, at the panicle level and the 200 cm level;

in the water at the depth of 1 cm below the surface, at the middle depth of the water layer, and at the water bottom;

and *in the soil* under the water at the depths of 2, 5, 10 and 20 cm,

we are computing on the basis of the hourly mean values of the phenophases the values $f(x)$ and we are drawing a smoothed curve. In every case, we are showing the curves for the stations 3 to 6 for the various phenological phases. Thus, we are able to reach conclusions concerning the differences in temperature distribution caused through the various conditions prevailing in the respective crops for a given phenophase or, respectively, among the phenophases. (The calculations were executed on the computer of the Cybernetical Laboratory of the József Attila University at Szeged.)

Every trigonometric polynomial is representing a given type of temperature behaviour, from which one is able to read, on the one hand, the characteristical points (such as maximum, minimum, the intersection point of the curve with the axis, as well as the amplitudes) and, on the other hand, the phase-shift of the characteristical points occurring at the various stations. In the course of evaluation, instead of the absolute magnitudes of temperature, the trends were taken into consideration.

In the diurnal variation of *air temperature* there is, during the phenological phase of *growing thick*, only a difference of 1,0 or at most 1,5 degree centigrade among the various crops, a difference which may be attributed to the differences in the dates of the beginnings of sprouting and growing thick. The phenophase of growing thick begins in the provocated crops by about 10 days earlier. This is leading, under the influence of the macrosynoptical situation, to important differences in temperature, and, as a consequence a comparison can be made, in this case, only within one and the same crop, in a vertical direction. At night, the largest difference between the 10 cm level and the panicle level is found in the provocated and fertilized crop. Only a smaller difference is found between the temperatures at the correspondent levels in the unfertilized and in the copiously fertilized crops. This may be explained by the earlier vegetation development of the provocated crop and, respectively, by the more rapid development of the copiously fertilized crop. At the 10 cm level, because of the development of the leaves, and under the influence of the moderating effect of these, the nocturnal decrease of temperature

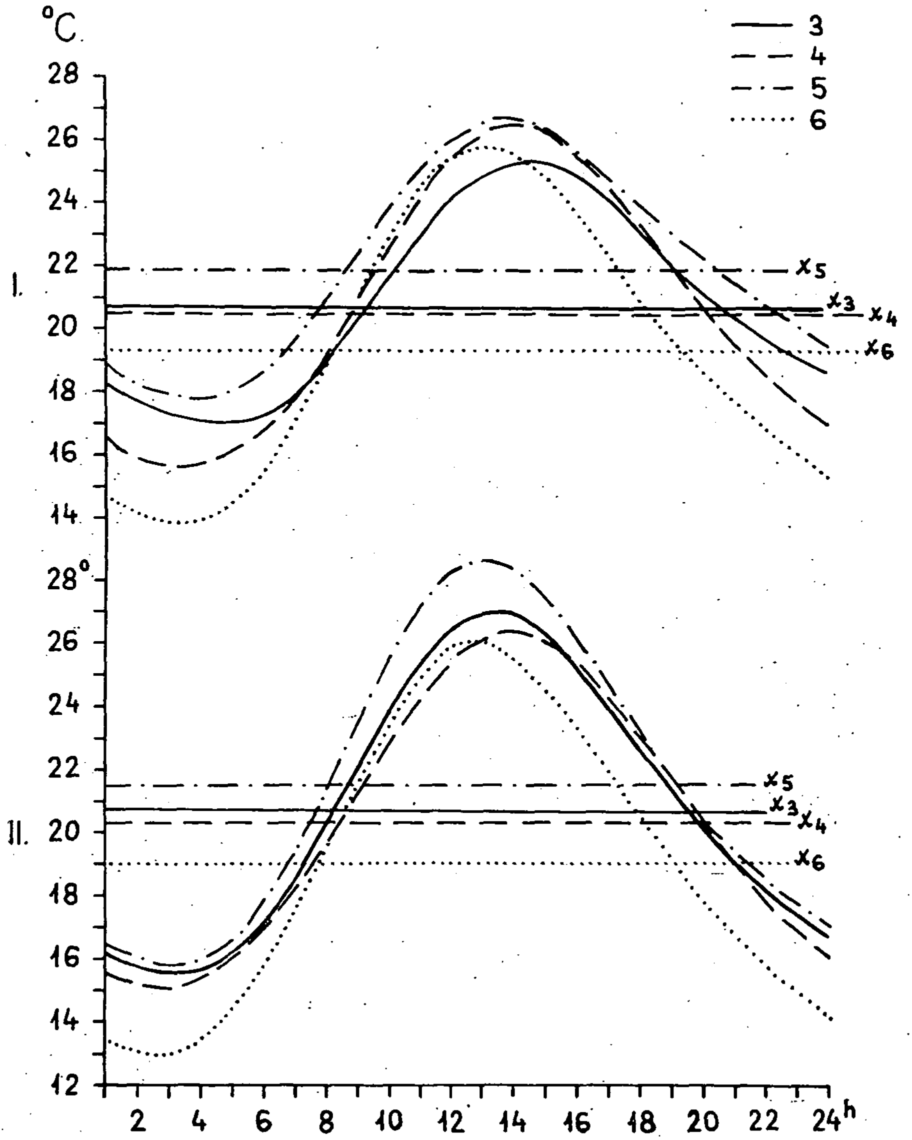

Fig. 3. Trigonometric polynomials for the phenological phase of stem development
I = 10 cm level
II = panicle level
3 = copiously fertilized crop
4 = unfertilized crop
5 = provocated and fertilized crop
6 = provocated unfertilized crop

is weaker then at the panicle level. At the 200 cm level, temperatures are of course lower than at the levels discussed previously, and the shape of the curve is nearly identical for the various crops. The maxima are occurring within one and the same crop at the 10 cm level and at the panicle level simultaneously about 01 p.m., with the exception of the unfertilized crop, where the maximum is occurring about 02 p.m. Already during the phenophase of growing thick it can be demonstrated that the amplitude of the polynomial is possessing its highest value at the panicle level, as a consequence of the circumstance that, at the 10 cm level, the nocturnal decrease of temperature is impeded by the presence of the developing foliage and, at the same time, it is not yet seriously hindering the strong day-time irradiation. At the panicle level, however, the nocturnal temperature fall is already stronger at the surface of the existing foliage than at the 10 cm level, and it is approximating also at day-time the corresponding values of the 10 cm level.

During the phenological phase of *stem development*, when the shift of the vegetation period is comporting only some days, the trigonometric polynomials of hourly mean values are suitable for the comparison of the various crops (Fig. 3).

It is a conspicuous fact that in the case of the fertilized and of the provocated and fertilized crops the minima are higher ones than in the other two crops. In the maxima, a certain phase shift is observed. At the 10 cm level, the maximum is found earliest in the unfertilized crop (at noon), then follow, an hour later, the provocated and fertilized and the unfertilized crops, and latest occurs the maximum in the copiously fertilized crop (at 02 p.m.). Amplitudes are lower than at the panicle level. They are lowest in the unfertilized crop, in which the day-time rise and the nocturnal fall of temperature are more moderate. In the provocated and unfertilized crop (in which the vegetative parts are less dense ones) a stronger nocturnal temperature fall is occurring and this is increasing the value of the amplitude. At the panicle level, the nocturnal decrease of temperature is strongest in the unfertilized crop, in the remaining three crops it is weaker. At day-time, the panicle level of the provocated and fertilized crop is the warmest, followed by the copiously fertilized crop (in both cases, the vegetative parts are well developed). In the maxima of the unfertilized and of the provocated and fertilized crops there is a phase shift of one hour. At the 200 cm level, already the macroclimatical influences are prevailing and, consequently, the differences are unimportant ones.

During the phase of panicle development, flowering and partly of that of maturation, the vegetative parts are fully developed. A difference among the various crops is found only at the 10 cm level (Fig. 4). The panicle level is representing already in each of the four crops an active surface, the difference among the various crops is, at this level, a negligible one. At the 200 cm level, the trigonometric polynomials are entirely coinciding.

During the various periods of plant development, the variations of temperature are the strongest at the *panicle level* (Fig. 5).

During the phenological phase of growing thick, at each hour of the day, the highest temperatures are encountered still in the unfertilized crop, however, at the time of stem development, the temperature is higher in the provocated and fertilized and in the copiously fertilized crops. During stem development, temperatures in the period between 04 p.m. and 08 p.m. are nearly the same in all three of the crops mentioned. In the provocated unfertilized crops, air temperatures are only in the morning hours reaching, or, respectively, exceeding those in the unfertilized crop. During the phenophase of panicle development, flowering and maturation, already

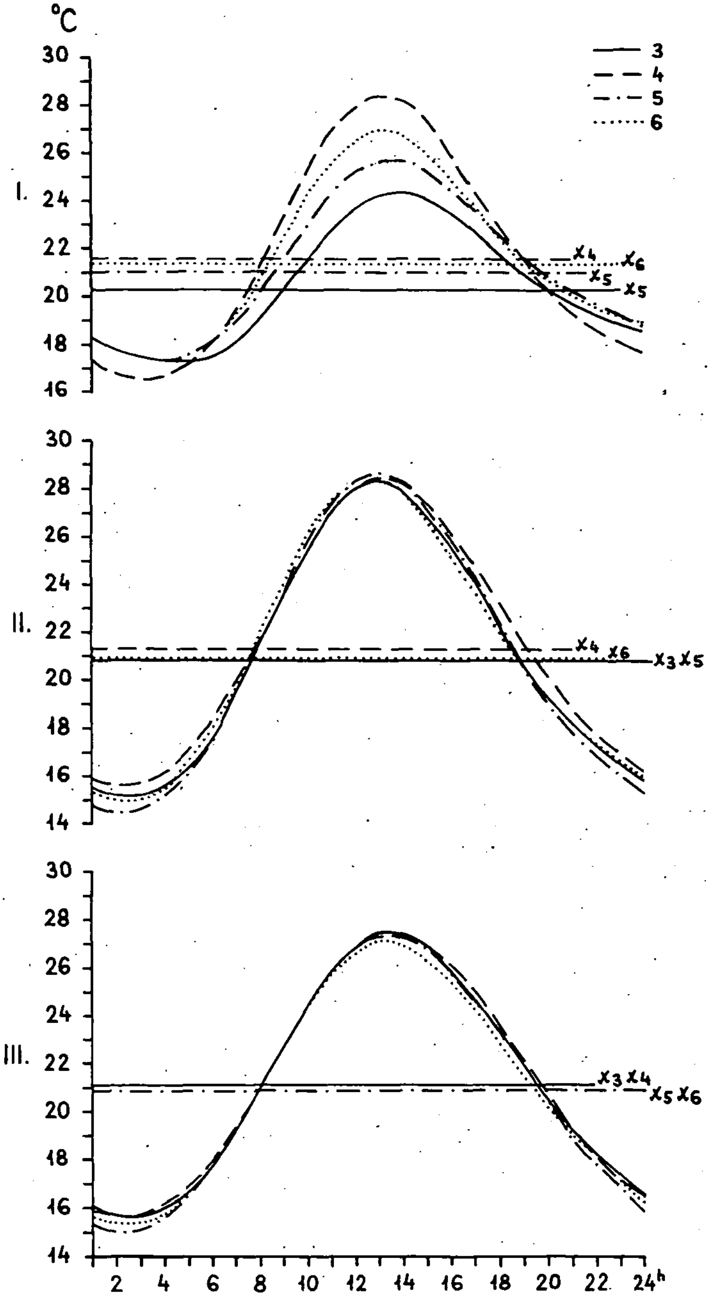

Fig. 4. Trigonometric polynomials of air temperature for the phenological phase of panicle development flowering and maturation

3 = copiously fertilized crop
4 = unfertilized crop
5 = provocated and fertilized crop
6 = provocated unfertilized crop

I = 10 cm level
II = panicle level
III = 200 cm level

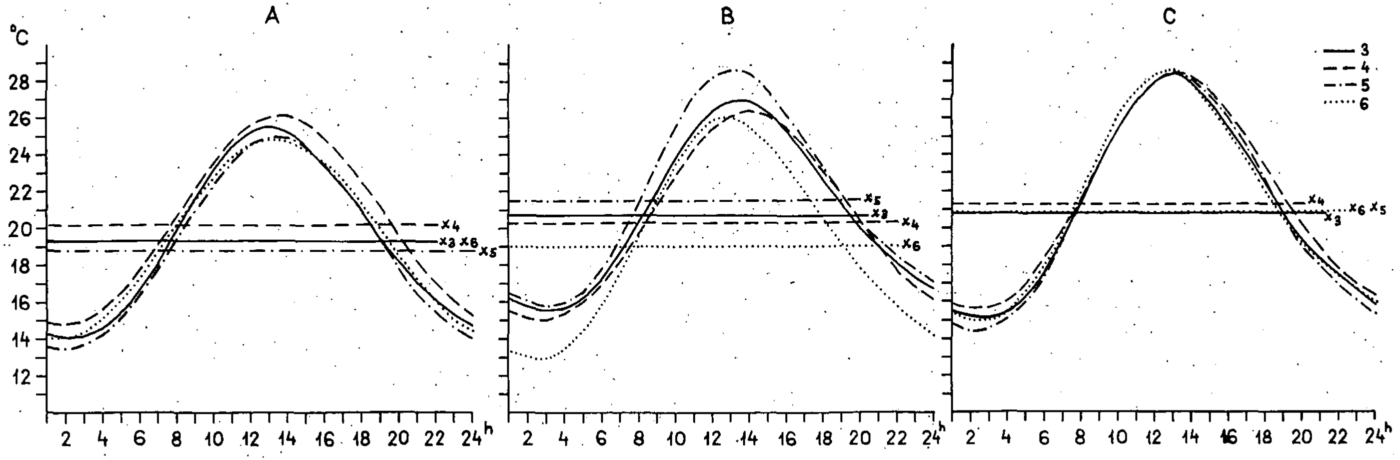

Fig. 5. Trigonometric polynomials of air temperature at the panicle level for various phenological phases.

A = phenological phase of growing thick
B = stem development
C = panicle development, flowering and maturation
3 = copiously fertilized crop
4 = unfertilized crop
5 = provocated and fertilized crop
6 = provocated unfertilized crop

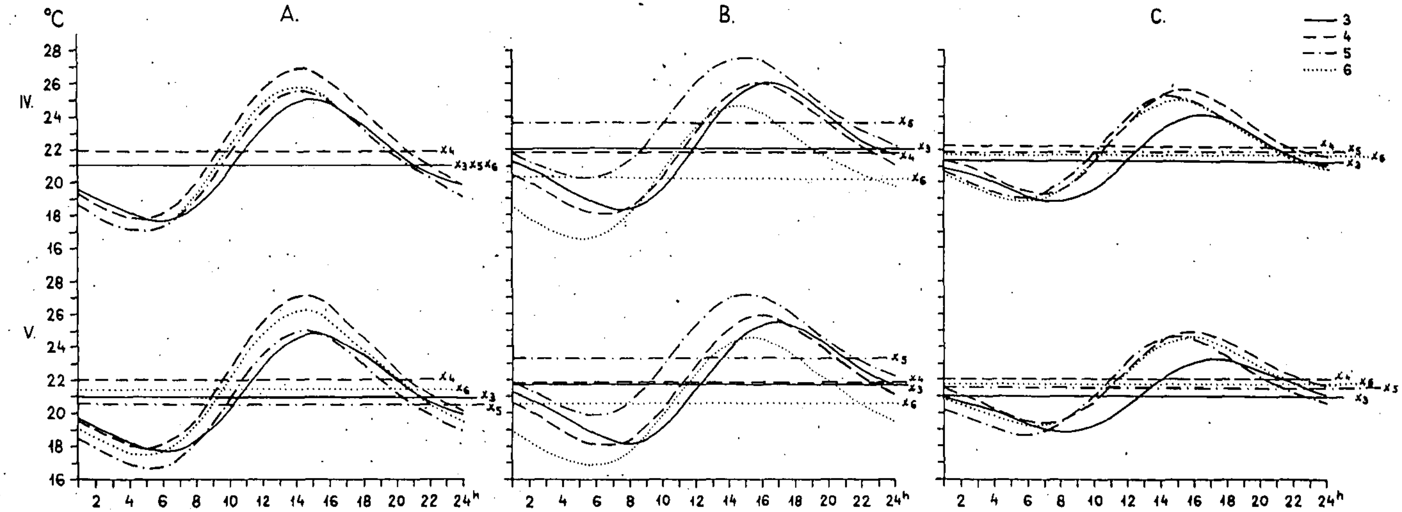

Fig. 6. Trigonometric polynomials of water temperature.
IV = at a depth of 1 cm below the water surface
V = at the middle depth of the water layer
3 = copiously fertilized crop
4 = unfertilized crop
5 = provocated and fertilized crop
6 = provocated unfertilized crop

in each of the four crops, nearly the same degrees of temperature increase and decrease are occurring.

Diurnal variations of *water temperature* are nearly the same beneath the surface and at middle depth (Fig. 6). Differences are again the consequences of differences occurring in the respective macrosynoptical situations. Within a given phase of development, however, the trigonometric polynomials are yielding an explanation concerning the plant development.

During the phenological phase of stem development, the water temperature was generally lowest in the provocated unfertilized crop. During the same phanological phase, however, the provocated and fertilized crop was the warmest one. The maxima occurred in both crops between 02 and 03 p.m. The minima are occurring between 05 and 06 a.m. In the non-provocated crops, there is a phase shift as compared to these crops. Both maxima and minima are occurring later. The latest occurrence of both the maxima and the minima is found in the copiously fertilized crops, which may be attributed to the shadowing effect of this crop. During the phenophase of panicle development, flowering and maturation, the strongly fertilized crop is exhibiting conditions which are different of those of the remaining crops. This is caused by the shadow effect of the rich vegetation. Amplitudes are during this phenophase in all the crops lower ones than those of the earlier periods.

On the water bottom, the moderating influence of the soil and of the whole water layer is already strongly prevailing, and the differences within the crops are lower ones.

The temperature of the water surface is influenced by two factors: on the one hand, by crop density or, respectively, its variation, and on the other hand, by the amount of flooding water. There is an interdependence between water temperature and soil temperature, which, in addition, in influenced by heat conduction from the lower soil strata. The amplitudes are here (as it is clearly shown on the figure) lower than in the case of air temperature.

The *temperature of the soil under the water* is controlled by the thickness of the flooding water layer, by the roots and by the heat stream in the soil. The amplitudes decrease with increasing depth. By reviewing the thermal polynomials for the phenological phase of panicle development, flowring and maturation (Fig. 7) it may be stated that in the more copiously fertilized crops, day-time temperatures are lower, which is a consequence of the density of vegetation, and, respectively, of its shadowing effect. This influence is more strongly expressed at the 2 cm and 5 cm levels. At night, again the soil of the two fertilized crops is colder. The amplitudes are decreasing with increasing depth, and the phase shifts of maxima and minima are well shown in the deeper layers. At the phases of growing thick and of stem development, the differences are consequences of the differences in the macrosynoptical situations.

The investigation of the temperatures of each of the three media (air, water, soil) is yielding data for the temperature variations during the various phenological phases. However, it must be taken into account that, during the particular phenological phases of the various crops, different weather conditions prevailed.

To sum up we are reviewing the behaviour of the polynomials of the unfertilized rice crop for each of the three phenological phases and for the whole microclimatological space of the rice crop (Fig. 8). On this figure, the diurnal temperature variation characteristic for flooded crops is well appearing for the three different media. In the air, at the 10 cm level and at the panicle level, there is, at the time of growing thick, an isothermal layer, which is caused by the underdeveloped state of the vegetative parts. During the phenological phase of stem development, there is, at night, between the two levels in question, already appearing a difference in the diurnal temperature variation, in that, at the panicle level, the nocturnal fall of temperature becomes stronger, while, at the 10 cm level, the influence of the radiation emission from the foliage is prevailing. This difference is somewhat increased during the

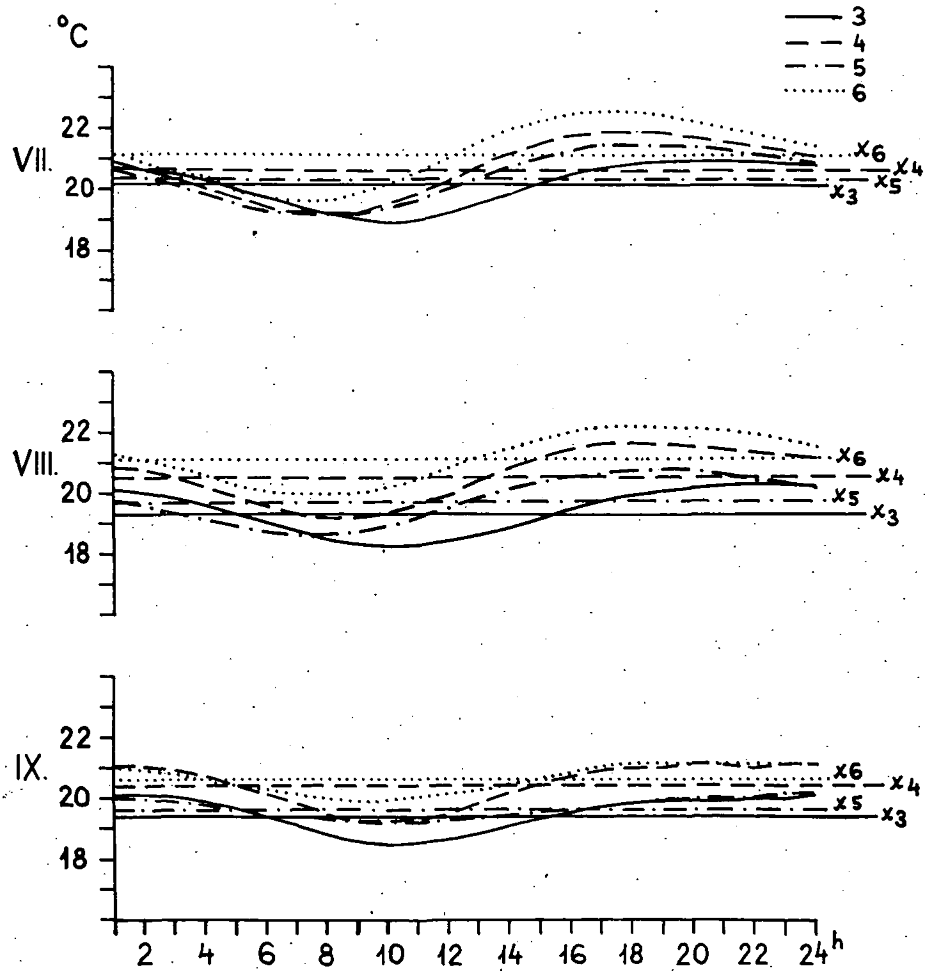

Fig. 7. Trigonometric polynomials for the temperature of the soil under the water
VII=at a depth of 2 cm
VIII=at a depth of 5 cm
IX=at a depth of 10 cm
3=copiously fertilized crop
4=unfertilized crop
5=provocated and fertilized crop
6=provocated unfertilized crop

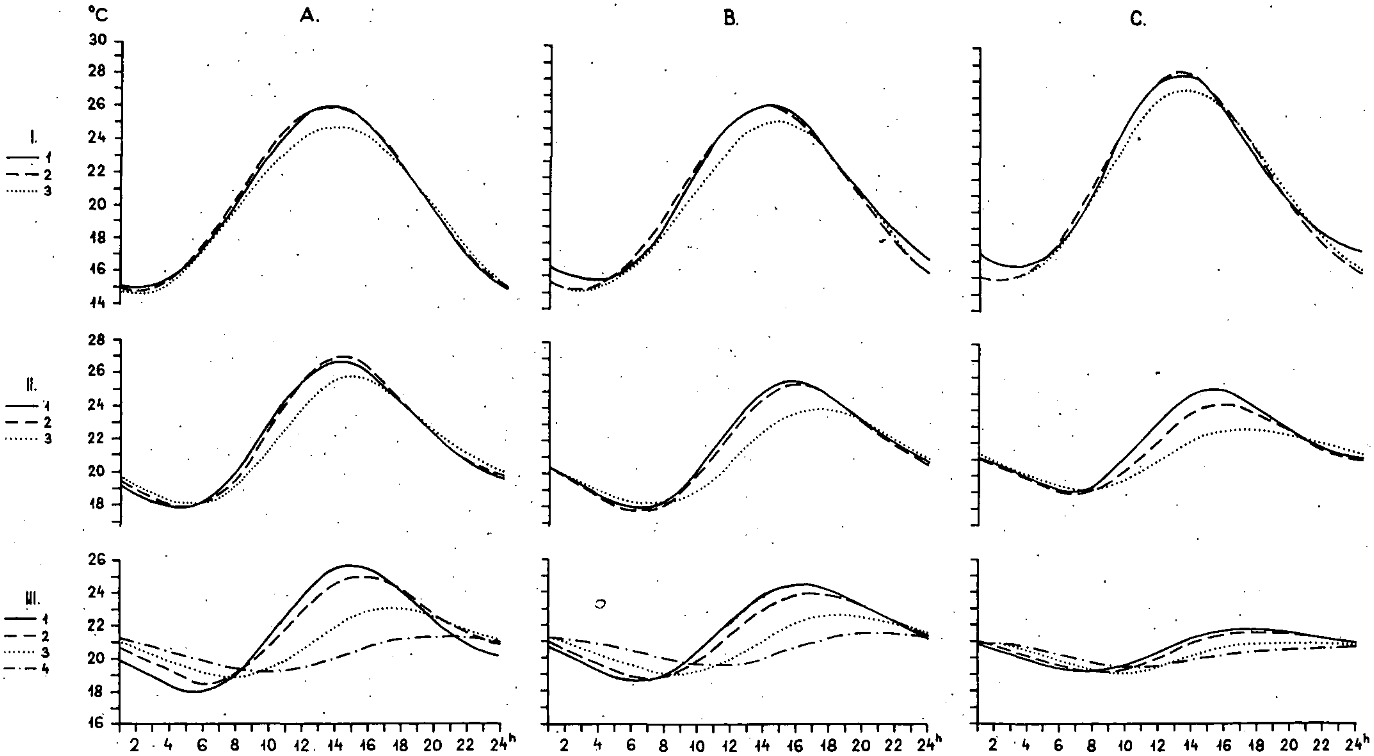

Fig. 8. Temperature polynomials for the microclimatic space in the case of a unfertilized rice crop, according to phenophases
A = phenological phase of growing thick
B = stem development
C = panicle development, flowering, maturation
I = air temperature: 1 = 10 cm level, 2 = panicle level, 3 = 200 cm level
II = water temperature: 1 = at a depth of 1 cm below the water surface, 2 = at the middle of the water layer, 3 = water bottom
III = soil temperature: 1 = 2 cm level, 2 = 5 cm level, 3 = 10 cm level, 4 = 20 cm level.

phenological phase of panicle development, flowering and maturation. Amplitudes at the 10 cm level and at the panicle level are highest during this phenological phase. At the level of 200 cm, temperature is, at day-time, lower than at the 10 cm level and at the panicle level, and, at night, we have there the same temperature as at the panicle level. The amplitude is also at the 200 cm level largest during the phenological phase in question, which is a consequence of the synoptical situation. Within the flooding water, amplitudes are lower than those of air temperature, and this statement is valid for the later phenological phases as well. At the water bottom a strong phase shift is already encountered, which is exhibiting a similarity to the variation of soil temperature at the depth of 2 cm. At a water depth of 1 cm and at the middle of the water layer, there exists in the two earlier phenological phases (i.e. growing thick and stem development) an isothermal layer, while during the phenological phase of panicle development, flowering and maturation there appears already a thermal stratification which is a consequence of the complete plant development. In the soil beneath the water, the temperature variation is different according to the various phenological phases, under an indirect influence of the crop and under the direct influence of the flooding water. During the phenological period of growing thick, we are still encountering a strong thermal stratification; as the influence of the crop is not prevailing in the water layer, minima and maxima are occurring at an early time. During the phenological period of stem development, minima and maxima are occurring at a later time, which is an indication of the increaingsinfluence of crop development on the flooding water. During the phenological period of panicle development, flowering and maturation, the differences among various layers is essentially smaller, a phenomenon which may be explained by the complete development of the crop. As a consequence of the circumstances mentioned above, amplitudes are decreasing in the course of the later phenological phases.

In the figure, for the various phenological phases, the peculiarities of the diurnal temperature variation may be well followed in a vertical direction through the various media. It may be stated, that the amplitudes decrease with increasing depth most strongly during the phenological phase of panicle development, flowering and maturation, under the influence of the developed crop. During the phenological periods of growing thick and stem development, the influence of the crop is not yet exerting itself to a large extent in the soil (there is still a significant thermal stratification), whereas, during the phenological phase of flowring and maturation, the soil is entirely experiencing the influences of the crop and of the flooding water.

Conclusions

On the basis of the present investigation of rice crops, it may be stated that, during the various phases of plant development, there are differences both in the diurnal temperature variation and in the field of extreme values and amplitudes.

In air, at the 10 cm level, in the course of the development of the crops, the amplitudes are decreasing because of the increase in the shadowing effect. At the panicle level, however (as this level becomes the active surface), the amplitudes are gradually increasing. The temperature maximum also is transferred to this level. Diurnal temperature variation is exhibiting its largest changes at the panicle level.

Within the flooding water, during the earlier phenological phases, there exist still two isothermal layers, namely one beneath the water surface and the other at the middle of the water layer. However, at the time of panicle development and maturation, already a thermal stratification is encountered.

The diurnal variation of the soil temperature is strongly influenced, in addition to the effect of the heat stream from below, by the thermal balance of the rice crop and by that of the flooding water.

In greater depths, the amplitudes are most strongly decreased during the phenological phase of panicle development and flowering.

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