Paddy Rice Ripening and Temperature

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Among many weather factors which may have some effects on the growth of rice plant in this country situated in a high latitude region with sufficient rainfall, temperature has the most important influence.

Especially, in the cooler region as the Tōhoku district, this influence is very great at the ripening stage of rice plant. Though the temperature itself is not effective energy for the growth of rice plant, it cooperates with the light to a certain extent and reveals some important rôles on the plant physiology, that is, the production, translocation and accumulation of the assimilation outcomes, and so in the cooler district, it can wield a dominant influence to the growth rate of rice grain.

I wish to describe in this report my experimental results on the effect of temperature upon rice ripening after the heading stage, referring to those knowledges already known.

Thermal condition and rice ripening

The growth of rice grain weight is obstructed by low temperature and this obstruction is recognizable, experimentally, nearly below 20°C (constant).

On the other hand, the higher temperature brings several injurious influences to the plant, that is, early decrepitude of plant tissue, excessive consumption by high respiration and nutritive obstruction caused by the appearance of injurious substances in culture soil.

After all, it is regarded that the optimum temperature for rice plant growth is 21°C (constant continuously) during 25 days after heading time[4]. But it is recognized that the optimum temperature in daytime is different from that at night, and also it goes down as time goes by, that is, during 15 days after heading, the optimum temperature is 29°C in the daytime and 19°C at night, and during subsequent 15 days it is 26°C in the daytime and 16°C at night[4].

The causes of these phenomena are possibly due to the balance of the degree of cellular activity for the ripening and its durability[1].

Meanwhile, it is known that to get complete ripening in the cooler district, the mean value of daily maximum and minimum temperatures, during 40 days after heading, must be above 22°C[10], and for effective ripening, it is necessary that the accumulated daily thermal mean value, during 15 days after heading, should reach 350°C[13]. Based upon these experimental results, the reasonable stable cropping season is determined referring to the average year weather indices.

But in recent years, the thicken growth of rice plants is more often sought to get the augmentation of crop. As the result, the relation between ripening and weather is becoming more important. Therefore, the experimental researches are now being carried out not only to analyze and attempt to avoid the delay of ripening caused by low temperature, but also to investigate the more favorable weather for ripening and to make an active use of the regional weather. And then it is becoming very important to manifest quantitatively the relation between natural weather and ripening amount.

Correlative formula between the natural weather at the ripening stage and the ripening amount

A correlation between the crop yield (y) and the weather factors (t & s) has been proposed in a formula as follows by Murata and Hanyu et al.

$$y=s\{a-b(t-c)^2\} \quad (a, b, c=\text{constants})$$

In this formula, y was calculated from the paddy crop per 10 are at prefectural level by Murata, or from the experimental results of nationwide investigation on the agro-climatological efficacy upon paddy crop by Hanyu, and the weather factors (t=average temperature, s=duration of sunshine) were calculated from the data during August and September by Murata or from the data during 40 days after heading by Hanyu.

The optimum temperature produced from this formula by the value of c were 21.5 and 21.4 respectively. This formula is based upon miscellaneous examples that contain multiple biological factors besides the two weather factors mentioned above.

We have also got a similar correlative formula, practicable for any year, district and season, between the crop yield and the values of weather factors during 40 days after heading from the results of experiments carried out by the cooperation of six prefectures in the Tôhoku district with the same varieties of rice plant and the same artificial culture bed.

The optimum temperature calculated in this formula was 21.8°C. In this formula, if we change s to s' (the value of sunshine duration additionally weighed as time goes by) considering the progressive decay in biological function of rice plant, the compatibility of the formula gets much higher (the optimum temperature in this case was 21.30°C)[7].

$$s' : \sum_{n=1}^{40} s_n\left(\frac{40-n}{40}\right)$$

n: days passed after heading, s_n: sunshine duration at n th day.

As to the correlative formula between the weather and the ripening amount, we can find some others; for example, those that calculated by Munakata[6] or by Kawahara[3], containing the factors of plant itself. And they showed that the light factor reveals a positive relation and the optimum temperature during 40 days after heading exists in 20–22°C.

Ripening and effective thermal index

Excessive temperature, too high or too low for plant growth, cannot be available. As the consequent of this fact, the concept of temperature in effective degrees was devised, and its accumulated value has been used as an index of growth progress.

This is the accumulated effective thermal index that is calculated by deducting a certain constant degree from daily average temperature and accumulating the remainders.

For example, Yamazaki has deducted 8°C from daily average temperature during the ripening stage and he concluded that the accumulated effective thermal index needed for rice grain maturation was always nearly constant in any year, with any variety of rice plant[12].

We have also calculated this index needed to attain a certain ratio of number of green kernelled rice (15%) after heading, and recognized that its seasonal deviation stay at the least when 4–8°C were deducted from daily average temperature and that the deducted temperature shifts to the higher side according to the increase in the number of spikelets per unit area[5].

The exponential indices of temperature efficiency, an application of the chemical reaction principle of Van Hoff and Arrhenius, may be available to analyze the increase of growth rate accelerated by the temperature elevation between the effective thermal stage and the optimum.

Yamasaki has reported that he deducted $2^{\frac{t-4.5°C}{10}}$ instead of 8°C described above and found the more compatibility for rice grain growth[11]. But in these treatments exist some unsuitable points, that is, it is not available when the daily average temperature is lower than that of the deducted temperature, and the efficiency of higher thermal stage temperature might be overestimated than that of the optimum. Moreover, these calculations were carried out with the maximum, minimum and average values, so, the real working function of each thermal stage temperature and their working hours were not adequately estimated.

At lower temperature condition, it is necessary to have higher accumulated daily average temperature efficiency than that of optimum temperature condition to obtain the same amount of growth. This fact means that the proportional coefficient between temperature and growth rate is variable by the thermal stage temperature. We have investigated from this point the ripening reaction to temperature and have obtained the following results[8].

1) Accumulated effective thermal index and basic pattern

If growth during unit hour is controlled by the fixed proportion (effective thermal index) of each thermal stage, growth under natural variable temperature conditions would be described as a function of product of the hours in each thermal stage temperature and the effective thermal index.

It is possible to consider that there must be many (basic) patterns of the correspondence of each thermal stage and effective thermal index, and supposing that each pattern might be manifested by an unimodal quadratic curve as indicated hereunder, there could be established 100–200 patterns in the calculation of 2°C intervals in the extent of normal temperature. (Fig. 1)

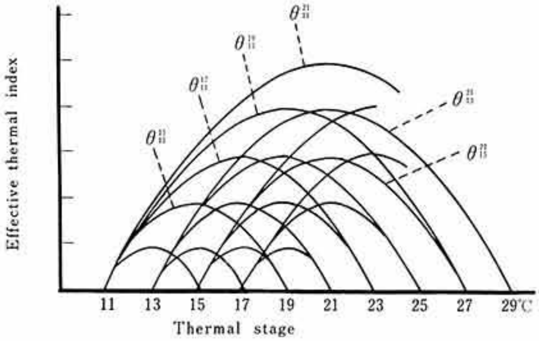

Fig. 1. Basic pattern in respect of the correspondence between each thermal stage and the effective thermal index

In the case of $i \leqq P$, $\theta_P^Q = 0$

In the case of $P \leqq i \leqq 2Q-P$,

$$\theta_P^Q = -\frac{1}{Q-P}(i-P)(i-2Q+P)$$

In the case of $i \geqq 2Q-P$, $\theta_P^Q = 0$

i : any value of thermal stage

P : value of ineffective low thermal stage

Q : value of optimum thermal stage

$2Q-P$: value of ineffective high thermal stage

θ_P^Q: effective thermal index

$P, Q, i = 1, 3, 5, \cdots$

In this case, the accumulated effective thermal index was calculated from the sum of product of the effective thermal index in each thermal stage of every basic pattern and the hours of each thermal stage temperature during that period.

2) Effective hours of every thermal stage temperature

Supposing that the temperature change of a day can be manifested in a sine curve in which the maximum value is the highest temperature and the minimum value is the lowest of that day respectively, the effective hours (x_i) of the thermal stage temperature

Table 1. Variation between the planting seasons in respect of the accumulation in each item required to attain to each definitive value in grain weight

Year		1970			1971		
Ripening stage (grain wt.)		~⅓	⅓~⅔	⅔~	~⅓	⅓~⅔	⅔~
Accumulated effective thermal index	Basic pattern	θ_{11}^{33}	θ_{15}^{23}	θ_{13}^{25}	θ_{11}^{35}	θ_{15}^{23}	θ_{13}^{17}
	average	252±10	51±7		258±10	48±4	
	CV %	3.9	13.5	$\gamma=0.761$	3.7	7.9	$\gamma=0.913$
Daily mean temperature accumulation °C	average	357±18	241±64		354±21	199±42	
	CV %	5.0	26.4	$\gamma=0.698$	6.0	21.0	$\gamma=0.867$
No. of days	average	15.8±2.4	12.1±5.9		15.9±2.5	10.4±3.4	
	CV %	15.1	48.8	$\gamma=0.330$	15.6	33.0	$\gamma=0.879$

between $y_{i-1} \sim y_i$ (atmospheric temperature) in a day could be written as follows: $i=1, 2, 3$)

$$x_i=\frac{1}{24\pi}\left[\left[H\left[\sin^{-1}\left\{\frac{2(y_i-B)}{A-B}-1\right\}-\sin^{-1}\left\{\frac{2(y_{i-1}-B)}{A-B}-1\right\}\right]+(24-H)\left[\sin^{-1}\left\{\frac{2(y_i-B')}{A-B'}-1\right\}-\sin^{-1}\left\{\frac{2(y_{i-1}-B')}{A-B'}-1\right\}\right]\right]\right]$$

$H=9.7756-10^{-4}\times 1.7765(x-178.24)^2$

- A: the maximum temperature of a day
- B: the minimum temperature of a day
- B': the minimum temperature of the next day
- H: hours from the time of minimum temperature to that of the maximum
- x: number of days reckoned from the 1st day of January

The compatibility of this calculation value to the measured practical value was tested during both months in June and September, and its practicability was confirmed[11].

3) Ripening progress and the changes of accumulated effective thermal index and basic pattern

We have set up 9 weather conditions and divided the ripening stage into three terms; that is, the earlier term (a term from heading to the time when the grain weight attained to 1/3 of its definitive value under normal condition), the middle term (similarly 1/3–2/3) and the latter term (similarly 2/3–), and then calculated the accumulated effective thermal index of every basic pattern needed for each term described above and detected the basic pattern that could possess the minimum value of variation between 9 weather conditions described above.

The results are shown in Table 1. It could be recognized that the optimum thermal stage shifts to the lower side according to the progress of ripening and the range of effective thermal stage gets more limited.

It is possible, throughout various thermal conditions, to presume the full grown stage of rice grain by the necessary value for accumulated effective thermal index of corresponding basic pattern and its accuracy is 4-2 times as high as that of the number of days or accumulated average temperature after heading.

These values have been calculated with some suppositions and so the effectiveness of every thermal stage must be examined furthermore considering the factors of the light or of the rice plant itself.

It may be one way to get rid of the ancient agriculture which has been based upon inherited experiences that in order to get better crops, we make use of a practically high compatible rule gotten from some hypotheses set up with knowledges already known.

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