Analytical Studies on the Planning of Time-Scheduled Rice Cultivation

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crop has increased due to increased frequency of unusual meteorological conditions occurring in recent years. To obtain stable cropping of rice from year to year, it is necessary to establish time-scheduled cultural plans by taking the fluctuation of meteorological condition into consideration[5]. The present study was carried out to formulate technical indices to be used for planning the time-scheduled cultural systems corresponding to meteorological fluctuations, by quantifying relationships between meteorological fluctuations and growth and yield of rice crop[4].

Technical indices related to grain ripening

1) Temperature index for the percentage of ripened grains

From experimental data of varietal comparison tests conducted in various districts of Hokkaido for 5 years, the following equation was obtained between the percentage of sterility (Y) and the integrated value (X) of mean daily temperature during a period of 30 days, starting from 24 days prior to heading.

$$Y = C + \frac{X}{a + bX}$$

In case of Kitahikari, a=−168.85, b=0.315, and C=−3.188. It implies that to have the percentage sterility lower than 20%, mean temperature higher than 20.7°C is required. Similarly, Kitaake and Matsumae require mean temperature higher than 19.1 and 20.0°C, respectively. Therefore, these temperatures can be used as the temperature time.

2) Temperature index for 1,000-kernel-weight

A correlation diagram prepared from the above-mentioned data between 1,000-kernel-weight and integrated mean daily temperature during a period of 40 days after heading showed the following relation.

When 1,000-kernel-weight less than its mean value by quartile deviation (standard deviation ×0.6745) is taken as the lowest allowable limit for the lowering of kernel weight, the integrated value of temperature corresponding to that limit of 1,000-kernel-weight was 740°C for Kitahikari, and 747°C for Matsumae. These values can be used as the temperature indices to determine the late limit of the heading date.

3) Temperature index for ripening of rice grains

In case of Kitakogane in Sapporo, when the integrated value of mean daily temperature (T) minus 5°C reached 619, the time of maturity comes, irrespective of different years and different dates of transplanting. Therefore, the value of $\Sigma(T-5)=619$ can serve as the temperature index to estimate the time of maturity. The temperature index was $\Sigma(T-7)=571$ for Shiokari, and $\Sigma(T-13)=312$ for Kitahikari. These values were applicable to the ordinary growth of rice crop with about 40,000 spikelets/m^2. When the number of spikelets/m^2 of Shiokari was 17,000, 23,000, 29,000 or 35,000, $\Sigma(T-4)=672$, $\Sigma(T-4)=677$, $\Sigma(T-5)=647$, or $\Sigma(T-7)=565$ must be used, respectively. This result shows that the larger the vegetative growth of rice crop, the higher daily mean temperature, and hence higher integrated temperature are needed for grain ripening of rice.

4) The quantity of ripened grains (grain yield) in relation to meteorological factors

The following equations were obtained from the experiment conducted in various years and with different transplanting dates in Sapporo.

$$y = -8.0105 + 0.27597x - 0.34723x^2 + 7.70096t - 2.07795t^2 + 1.08913x \cdot t + 0.03972x \cdot s$$
$$R = 0.781^{***}$$
$$y = -56.777 + 2.117x - 0.399x^2 + 28.666r - 3.673r^2 + 0.271x \cdot r$$
$$R = 0.812^{***}$$

where, y: grain yield (kg/0.1 a), x: the number of spikelets per $m^2/10,000$, t: 10^{-1} value of mean daily temperature during a period of 40 days, starting from 10 days prior to heading, s: average hour of daily sunshine during that period, and r: 10^{-1} value of $Cal/cm^2/day$ during the same period.

These relationships are shown in Fig. 1.

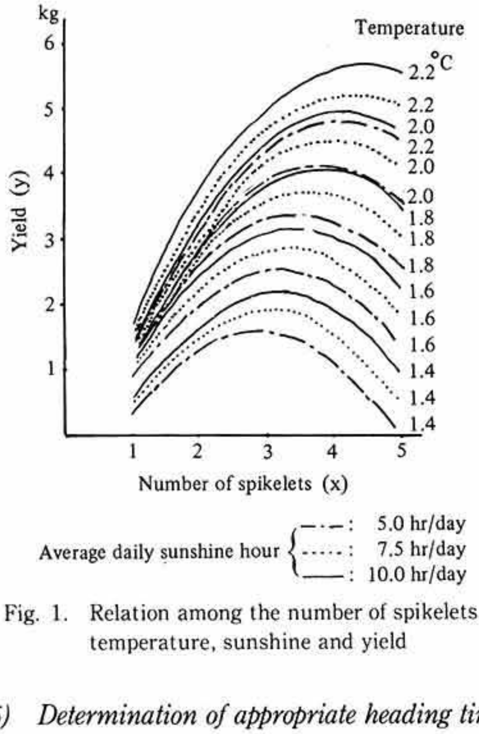

Fig. 1. Relation among the number of spikelets, temperature, sunshine and yield

5) Determination of appropriate heading time

The results of analysis shown in the foregoing sections were applied to meteorological factors of normal or fluctuated years in Sapporo to find out the allowable range of heading time.

Firstly, to get allowable kernel weight given in 2), the late limit of heading time for Kitahikari and Matsumae must be August 20, and August 19, respectively. On the other hand, the late limit of heading time which enables full ripening of grains by October 7, i.e., the first frost day of usual years in Sapporo, can be obtained from the temperature index shown in 3). It is August 17 in case of 44,000 spikelets/m^2 and August 21 in case of 23,000 spikelets/m^2 of Shiokari, with the average of August 19. Furthermore, as shown in 4), yield reduction occurs when heading time delays. Particularly the delay of heading time after August 19 causes remarkable yield reduction. From these facts, it is reasonable to conclude that the late limit of heading time in ordinary years in Sapporo is August 19.

Secondly, according to the equation given in 4), the highest yield is shown for the heading date of July 20. However, the yield in this case was calculated on the basis of the meteorological values only during the ripening period. On the other hand, we must pay attention to the fact that the earlier the heading time the more frequent is the low-temperature damage of young panicles during the young panicle development stage. The early limit of heading time which can give a temperature condition enabling to assure the ripening percentage (of Kitahikari) higher than 80% in ordinary years in Sapporo was estimated at July 26, based on the equation in 1).

When the mean temperature during a period of 30 days starting from 24 days prior to heading was higher than 21.5°C, any damage to ripening was not found in all varieties, and when the mean temperature of 40 days after heading was over 20.0°C, the percentage of perfect rice grains was over 80%. The heading dates which can give both temperature conditions mentioned above are regarded as the beginning of safe heading time, and the end of safe heading time, respectively. In ordinary years of Sapporo, the former is August 2, and the latter August 10. The period between these two dates can be a safer heading period.

Table 1. Effective aero-heat unit in degrees for leaf emergence*

		Temperature range represented by average temperature (T)											
		11	13	15	17	19	21	23	25	27	29	31	33
Days required for growth increment of 0.2 leaf	D		3.73	1.65	1.16	0.94	0.81	0.73	0.68	0.63	0.60	0.58	0.56
	T·D		48.5	24.8	19.7	17.9	17.0	16.8	17.0	17.0	17.4	18.0	18.5
Proportional coeff. of effective aero-heat unit	α		0.346	0.678	0.851	0.940	0.978	1.000	0.988	0.987	0.965	0.934	0.909
Effective aero-heat unit in degrees	$\alpha \cdot T$		4.5	10.2	14.5	17.9	20.5	23.0	24.7	26.7	28.0	29.0	30.0
Effective aero-heat unit in degrees	θ**		5.0	10.0	15.0	18.0	21.0	23.0	25.0	27.0	28.0	29.0	30.0

* Average of Kitakogane, Kitahikari and Matsumae.
** $\theta=\alpha \cdot T$ but fractions of 0.5 and over were counted as 1, and the rest disregarded.

Planning of cropping period with appropriate heading time

To bring about heading at the appropriate time, the cropping period has to be planned. For that purpose, temperature indices which can express the rate (speed) of growth of rice crops growing at the temperature changing daily in various ways must be established.

1) Growth rate and effective temperature

Rice plants at the 6-leaf-stage were brought into a phytotron, and the following equation was obtained as an experimental result:

$$D=\frac{T}{2.834T-29.622}$$ (average of Kitakogane, Kitahikari, and Matsumae)

where, T: air temperature
D: no. of days required for a growth inclement of 0.2 leaf

On the assumption that the same growth rate may be achieved when the value of integrated temperature, i.e., $T \times D$, is the same, the following equation can exist:

$$T_1 \cdot D_1 = T_2 \cdot D_2 = \cdots = T_n \cdot D_n$$

However, as given in Table 1, the proportional coefficient between temperature and growth rate (as indicated by rate of leafing) showed different values at different temperature levels. Then, the above equation has to be improved as follows:

$$\alpha_1 \cdot T_1 \cdot D_1 = \alpha_2 \cdot T_2 \cdot D_2 = \cdots = \alpha_n \cdot T_n \cdot D_n$$

where, α is the proportional coefficient at each temperature, and hence $\alpha \cdot T$ is regarded as effective temperature (θ).

Thus, at the temperature below 11°C, $\theta=0$. At 21—27°C, θ was the same as Centigrade degrees, and at higher temperature θ was lower than that.

2) Integrated effective temperature

Daily temperature changing continuously under the natural condition was divided at intervals of 2°C into a number of temperature strata (T_i),

Table 2. Accumulated aero-heat unit in effective degrees

	Range °C	D	θ	$\Sigma\theta$ ($\theta \times D$)
1	0.1~ 2.0	0	0	0
3	2.1~ 4.0	0.10	0	0
5	4.1~ 6.0	0.32	0	0
7	6.1~ 8.0	1.75	0	0
9	8.1~10.0	2.59	0	0
11	10.1~12.0	6.45	0	0
13	12.1~14.0	8.46	5	42.30
15	14.1~16.0	13.89	10	138.90
17	16.1~18.0	13.28	15	199.20
19	18.1~20.0	12.47	18	224.46
21	20.1~22.0	9.81	21	206.01
23	22.1~24.0	5.86	23	134.78
25	24.1~26.0	4.42	25	110.50
27	26.1~28.0	1.61	27	43.47
29	28.1~30.0	0.63	28	17.64
31	30.1~32.0	0.36	29	10.44
33	32.1~34.0	0	30	0
Total		82.00		1,127.70

82 days required from transplanting to heading.

Table 3. $\Sigma\theta$ required from transplanting to heading

Variety	Young seedling	Middle-age seedling
Kiyokaze	984	929
Kitakogane	1009	954
Narukaze	1076	1021
Shiokari	1085	1030
Kitahikari	1128	1073
Himehonami	1149	1094
Yuukara	1190	1135
Matsumae	1178	1123
Tomoemasari	1239	1184

and their duration (D_i)[2,3]. By using θ_i instead of T_i, the effective integrated temperature ($\Sigma\theta$) was obtained as $\Sigma(\theta_1 \times \text{sum of } D_1)$ (Table 2). This $\Sigma\theta$ showed small variation* against differences in meteorological conditions, and was recognized to be an excellent index which can express the progress of growth such as heading and others (Table 3).

3) *Planning of cultivation schedule for heading at appropriate time*

By using the effective integrated temperature, the combination of various cultural factors such as varieties which can attain heading during the safe heading time, the sort of seedlings to be planted and the transplanting time (early limit of transplanting is the time when mean temperature of 5 days after transplanting is 11.5°C for young seedlings, and 12°C for middle-aged seedlings raised in mat, while the late limit is May 25 for young seedlings and May 31 for seedlings raised in mat) is shown in Fig. 2. By using this chart, selection of varieties to be grown, methods of seedling raising, and transplanting time, namely, the planning of the cultural schedule, can be done in advance in response to meteorological forecast.

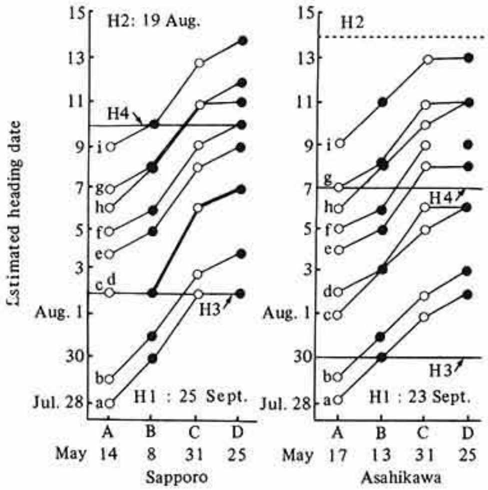

Fig. 2. Early or late limit of transplanting time for young or middle age seedlings, and estimated heading date for each case
A: Early limit of middle-age seedling transplanting
B: Early limit of young seedling transplanting
C: Late limit of middle-age seedling transplanting
D: Late limit of young seedling transplanting
H1: Early limit of heading
H2: Late limit of heading
H3: Initiation of safety heading time
H4: End of safety heading time
Varieties
a: Kiyokaze b: Kitakogane
c: Narukaze d: Shiokari
e: Kitahikari f: Himehonami
g: Yuukara h: Matsumae
i: Tomoemasari

Rooting of seedlings as influenced by water temperature

Even if the transplanting time is determined aiming at the heading at right time, it can not be overlooked that seedling rooting is influenced markedly by water temperature. From the study on the relationship between daily water temperature and seedling establishment (as expressed by a growth increment of 0.5 leaf), conducted with the use of effective integrated water temperature (obtained by the same way as adopted for effective integrated temperature described above), it was found that the effective integrated water temperature, $\Sigma\theta_w$ is a useful temperature index for seedling rooting. $\Sigma\theta_w$ was 60 for young seedlings, 62 for middle-aged seedlings in mat, and 84 for seedlings in frame. It was made clear that when

* The variation of $\Sigma\theta$ was ca. 1/2–1/3 that of integrated (accumulated) temperature so far employed.

mean water temperature is 16—18°C, small diurnal fluctuation is better for rooting than big one, even when mean water temperature is the same. On the contrary, at the mean water temperature of 12—13°C, the reverse is true.

Furthermore, the number of days required for seedling establishment at the early limit of transplanting time at different locations in Hokkaido was estimated by using $\Sigma\theta_w$. The result showed that it was about 6 days for all kinds of seedlings.

Quality of sound seedlings and growth condition

In addition to water temperature, the quality of seedlings also determines the rate of seedling establishment. Rice seedlings raised under different conditions, such as different seed-rates and various environment, were transplanted and grown for 3 weeks at low temperature (12°C). Effect of each characteristic of the seedlings on seedling growth after transplanting (in terms of dry weight (g) of leaves and stems) was examined by multivariate analysis. The result showed that the number of leaves and the ratio of top dry weight/plant length of the seedlings before transplanting exerted a great effect on seedling establishment and growth. The effect of the former accounts for 31%, and that of the latter 27%. Contents of nitrogen, starch, and phosphoric acid in the seedlings gave only small effects. Therefore, as shown in the following equation, the large number of leaves (X_1) and high ratio of top dry weight/plant length (X_2) can be used as indices for sound seedlings.

$$\hat{Y} = 60.597 + 22.115X_1 + 25.214X_2$$
$$R = 0.8098^{***}$$

Then, to know how to raise sound seeldings with good quality, different conditions of nursery beds were prepared by combining different bed areas allocated/seedling ($X\,cm^2$) with different amount of bed soil allocated/seedling ($Y\,ml$). The number of leaves (L) and top dry weight (Wg) of seedlings grown for 35 days on these nursery beds were examined, and the following equations were obtained:

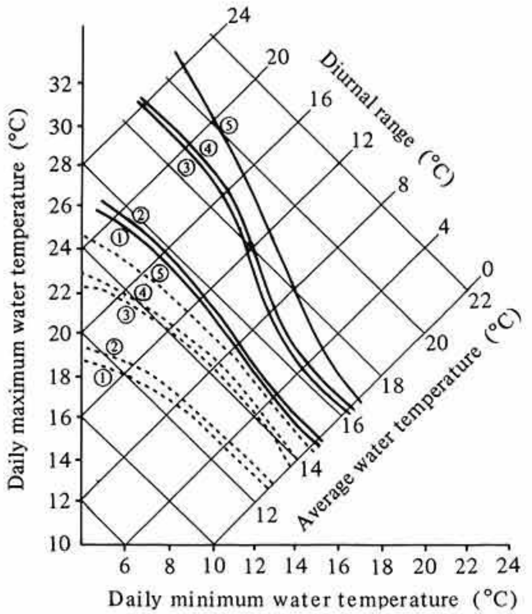

Fig. 3. Water temperature condition and seedling establishment

Variety: Yuunami

····· 10 days taken for establishment

—— 6 days taken for establishment

① Young seedling

② Middle-age mat seedling

③ Ordinary seedling

④ Katawaku seedling

⑤ Mature seedling

$$L = 2.425 + 0.169X - 0.045X^2 + 0.270Y - 0.047Y^2 + 0.098XY$$
$$R^2 = 0.815$$
$$W = 1.186 + 0.188X - 0.066X^2 + 0.497Y - 0.093Y^2 + 0.209XY$$
$$R^2 = 0.960$$

These equations clearly indicate that, to increase the number of leaves and top dry weight, the following consideration has to be taken. When seed rate is more than 75 g, the amount of bed soil/seedling must be increased, while when seed rate is less than 60 g, bed area/seedling has to be increased.

Furthermore, a comprehensive guideline for raising sound seedlings with good quality is demonstrated in Fig. 4, which was produced on the basis of equations showing the relationship between various nursery conditions and seedling quality.

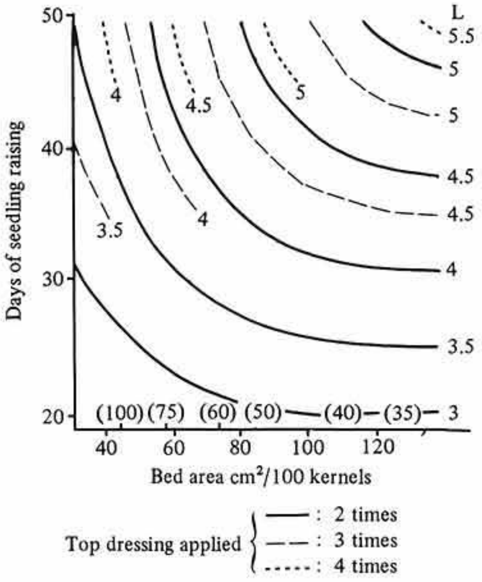

Fig. 4. Environment for seedling raising and leaf number
Figures in the parentheses indicate seedling rates (g/box).

Technical index for presoaking and hastening germination

Growth uniformity of seedlings is an important prerequisite for mechanical transplanting. To know the appropriate method of presoaking for obtaining uniform germination, presoaking treatment at different water temperature (T) and for a different soaking period was applied to seeds of Ishikari, and incubated at 32°C for 24 hr to hasten germination. After the incubation, the number of seeds which germinated to the so-called pigeon-breast stage* was counted. In case of $\Sigma(T-12) > 10°C$, over-sprouted seeds increased more than 20%, while in case of $\Sigma(T-5) < 20°C$ ungerminated seeds accounted for more than 20%. Therefore, from the relation between integrated water temperature (excepting the above two cases) and percentage of seeds at the pigeon-breast stage, an appropriate soaking condition for getting high percentage of pigeon-breast germination was clarified (Fig. 5).

Using seeds of Tomoyutaka, effect of oxygen

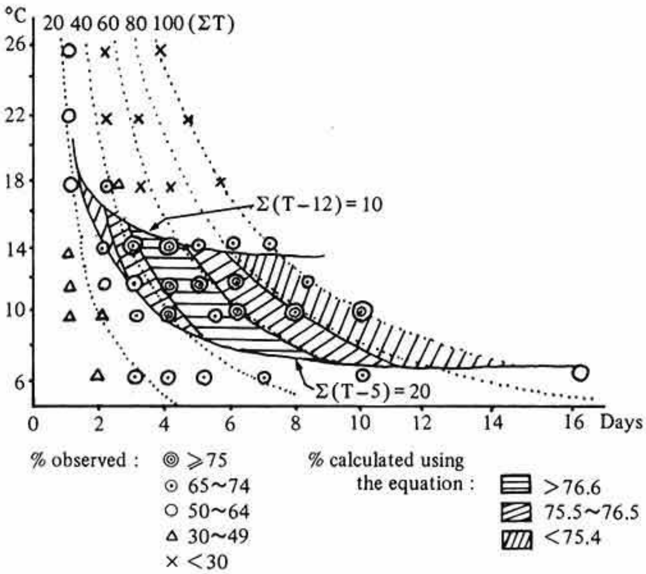

Fig. 5. Duration and water temperature of seed presoaking and percentage of pigeon-breast germination

* Emerged plumule looks like pigeon-breast. Plumule length was 1.2 mm at this stage.

supply during the presoaking (X_1) or during the incubation (X_2) on the pigeon-breast germination (Y) was examined. The result was shown by the following equation:

$$Y=4.344-2.476X_1+23.939X_2-1.172X_1 \cdot X_2$$

where X_1 and X_2 show mg of dissolved O_2/100 g of dry paddy.

The equation shows that high percentage of pigeon-breast germination can be obtained by supplying enough oxygen during the incubation, because oxygen available during presoaking is limited.

Conclusion

To assure high and stable productivity of rice crop, it is essential to grasp dynamically the response of plant growth and development to cultivation, and to attempt the wise utilization of meteorological factors. As to the improvement of cultural technique, for example, examination and evaluation of its effect must always be done in relation to meteorological conditions. This is particularly important when abnormal climate frequently occurs. The author hopes that the information given in this paper may be utilized for the improvement of rice cropping in cold regions elsewhere.

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