PHYLOGENETIC DIFFERENTIATION OF THE CULTIVATED RICE PLANT.

III. The responses to day-length and temperature and the number of days of growth period.

by

H. Oka, Y. C. Lu, and K. H. Tsai

Introduction

The response to day-length of rice has been studied by a number of Japanese workers (1, 5, 6, 19, etc.), and it is well known that, while early varieties are not sensible, late varieties are generally short day-plants and do not emerge the ear when the day length exceeds a certain limit which is specific to the variety. In Formosa, Suenaga (17) and other workers (9, 10) have established that the native varieties of the first crop nature are insensible and those of the second crop nature are highly sensible. As to the tropical region, sensible varietes are known to predominate among those grown in the rainy season and by which a greater part of tropical rice production is maintained.

As to the response to temperature of the rice plant, on the other hand, our knowledge seems still insufficient for analysing its varietal variaton. Temperature exerts an important influence on various stages of development: Defining the response to temperature, in the same manner as the case of day-length, to be the degree of shortening of growth period by the rise of temperature, there may be still involved the following two kinds of events, i.e., first, as a general property of living things, the basic vegetative growth from germination until being capable of flower bud formation must be quickened by high temperature, and secondly, the stage of flower bud formation itself may be affected by the temperature. Intervarietal differences in the response to temperature have been pointed out by a number of workers (1, 7, 17, 13, etc.), but further studies seem to be necessary for understanding the response to temperature with reference to the above mentioned points. And, we have little knowledge as to how these physiological characters vary among the varieties of different latitudal regions.

In order to throw a light on these points, the writers investigated the responses to day-length and temperature of rice varieties by means of observing the change of the date of heading due to the difference in the date of seeding, and outlined the geographical variation of the responses in connection with the differentiation of "Continental and Insular" variety groups which was established in the preceding study (15).

This work was carried out in the Taiwan Provincial College of Agriculture from 1945 to 1949. The writers are indebted to the college authorities and the staffs of the laboratory for their kind support and laborous efforts. They wish also to thank Dr. Eikichi

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Materials and Methods

Varieties of various districts of Asia, 163 in total number, were used as the materials. These varieties are same to those used in the preceding works (15), and variety numbers are common to all papers by the writers.

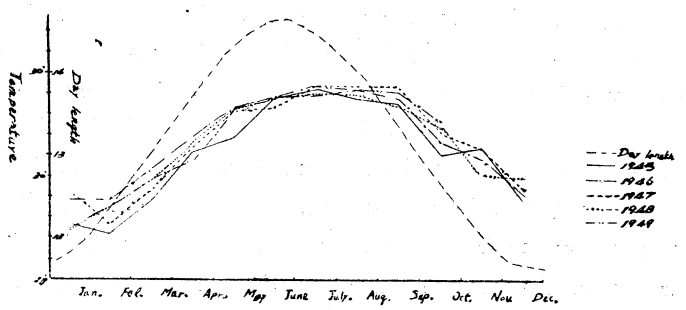
The response of varieties to day-length and temperature was observed from the change of growth period due to the seasonal change of day-length and temperature under the natural condition of field cultivation. Namely, the varieties were seeded repeatedly for a whole year at the intervals of 30 to 50 days, and on each variety the relation between the date of heading and the number of days of growth period (from water soaking of seed to heading) was investigated. The method of calculation will be mentioned later with observation results.

Such growing-season-experiments were repeated three times in 1945, 1946-47 and 1948-49 using same varieties. The dates of seeding were as follows. In 1945, Jan. 26, Mar. 1, Apr. 1, May 1, June 1, July 4 and Aug. 4; in 1946-47, Feb. 1, Mar. 18, May 3, June 13, July 20, Sep. 5, Oct. 5, Nov. 5, Dec. 14 and Feb. 1; in 1948-49, July 9, Oct. 22, Dec. 10, Feb. 1, Apr. 15, May 15, June 14, July 15 and Aug. 15.

Method of cultivation: Seed was germinated in a petri-dish at 30°C, and the seedlings cultured in pots up to the stage of having two to three leaves were transplanted in an experimental paddly field, spacing 25cm, and with single plant per clump. It was for the purpose of eliminating the errors due to the influence of nursery period that such young seedlings were transplanted, Soya been cake 100 g per m^2. was used as the fertilizer. In other points, cultivation method was substantially same to the usual system in Formosa. For finding the date of heading, the date of appearance of the first ear was regarded as the date of the given plant, and the dates of 5-10 plants were averaged.

Annual periodicity of day-length at Taichung city (24°N) and the temperature of monthly average in each year of the experiment are given in Fig. 1.

Fig. 1 Day-length and the temperature of monthly average at Taichung city.



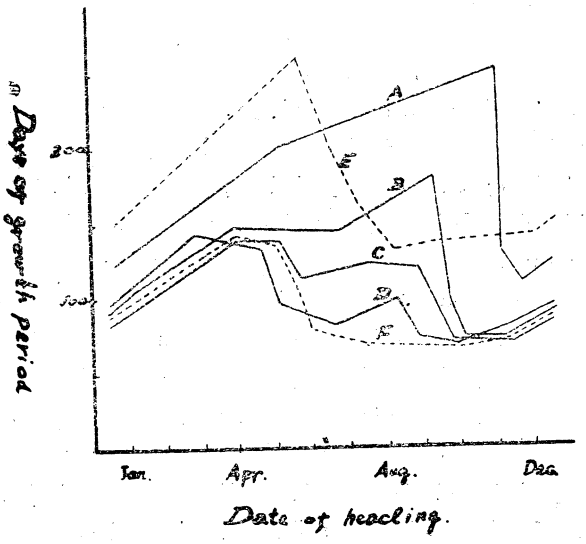
An Outline of the Seasonal Variation of Growth Period.

According to various previous studies on the photoperiodism of rice plant, it will be accepted as a rule that the capability of flower bud formation develops potentially after a certain period of vegetative growth, but if the outer conditions such as day-length and temperature were unfavorable, so-called "excessive vegetative growth" goes on until certain necessary conditons are given. Whereas, if the flower bud formation was once finished, heading seems to follow invariably after a definite time.

In almost all previous experiments on the season of growing, the effect of the time of seeding or transplanting has been dealt with in relation to the character in question. However, as discussed above, the number of days of growth period does not depend directly upon the date of seeding, but depends upon the conditions given during the growth period, especially upon those inducing flower bud formation. And the time of flower bud formation will be inferrable by subtracing a certain number of days from the date of heading. In the present study, therefore, the relation of the date of heading to the days of growth period was dealt with instead of the date of seeding.

Such a tendency was found generally that in spring(April and May) and in autumn (September to November), the later the date of heading was, the shorter became the growth period. Fig. 2 illustrates this tendency in several representative varieties. The ahortening of growth period will be seen in varieties A and B in autumn, in varieties E and F in spring, and in varieties C and D in both spring and autumn. Such a shortening of growth period will be, in the case of spring, due to the rise of temperature, and in the case of autumn, due to the shortening of day-length.

Fig. 2. There relation between the days of growth period and the date of heading in different varieties.



(Vide Table 1 as to the varieties A-F)

The line of variety A in Fig. 2 descends vertically at the beginning of November; in other words, when germinated between February and June, this variety shows the same date of heading. Such a variety as this will be the most sensible one. Varieties B, C and D, although similar in tendency with A, show no vertical portion in their lines, but show slopes which are different in angle among them. This angle of inclination will be a rough measure of the sensibility to day-length. Varieties E and F, which show the shortening of growth period only in spring, will be insensible to day-length.

Method to Measure the Sensibility to Day-length.

It is necessary for measuring the sensibility to day-length to observe the relation between the days of growth period and the day-length which has induced flower buds and has determined the days of growth period. The time of flower bud formation, which is necessary for finding the day-length in question, was assumed in the present work to be 30 days before the heading. Because, according to Akihama and Togawa(2), Ujihara (20) and others, flower buds become detectable microscopically at about 30 days before the heading. According to Fukke (5), further, it is necessary for delaying the natural date of heading artificially by long-day treatment to continue illumination up to a definite day that is 30-36 days before the natural heading. And the effect of short-day to quicken the heading disappears 24-30 days before the natural heading. Considering from these facts, the time of physiological differentiation of flower bud seems to agree well with the time of morphological differentiation, and the development of ear seems to be affected little by the day-length after the irreversible differenciation. As these informations have been gained under the condition of summer in Japan, it will be rational to assume the time of flower bud formation to be 30 days before the heading in a similar environment.

Fig. 3 illustrates the relation of day-length to the days of growth period in varieties A-F which have been presented in Fig. 2. In Fig. 3, the angle between the line showing growth period and the abscissa will show the rate of change of growth period for the change of an unit of day-length, and thus it will serve as an estimate of the sensibility to day-length. This angle varies in a same variety with the day-length and the maximum is realized at a certain day-length. This day-length will represent the "critical day-length", for the most radical change of growth period appears around it. The day-length corresponding to the mid-point of the segment showing the most steep inclination was used as the critical day-length.

In this case, the greatest angle of a variety, or the angle at the critical day-length, will represent the sensibility to day-length of the given variety.. Tangent of this angle is the change of growth period divided by the change of day-length, and this angle thus calculated will be good as an unit of the sensibility to day-length. It was named provisionally as T. D. M. (Tangent Day Minute), as day and minute were used as the units of growth period and day-length. In Fig. 3, the critical day-length is shorter in the order of A<B<C<D, and the sensibility is higher in the order of A>B>C>D. Examples of the calculation of T. D. M. and critical day-length in these varieties are given in Table 1.

Fig. 3. The relation between the days of growth period day-length.

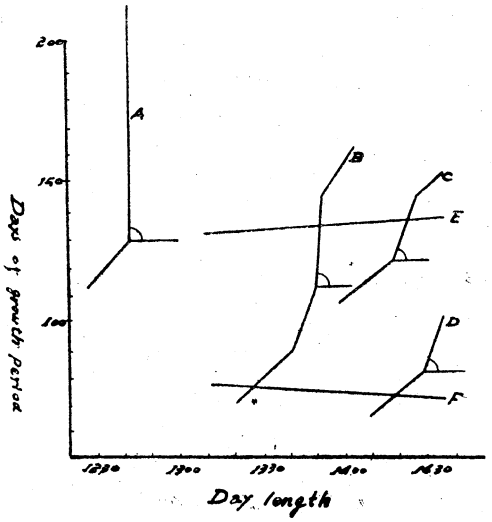


Table 1. Examples of the relation between the days of growth period and day-length and the calculatiation of the coefficient of day-length sensibility (T. D. M.) the critical day-length.

No. of variety	I	(dif.)	II	(dif.)	III	(dif.)	IV	Maximum ratio	T. D. M.	Critical day length
A head.	Nov.10	0	Nov.10	0	Nov.10	3	Nov.23			
(230)days	254	61	193	64	129	18	111	$\frac{64}{0}=\infty$	90	12h.43m.
d.l.	12h43m	0	12.43	0	12.43	17	12.26			
B head.	Sep.14	4	Sep.18	2	Sep.20	13	Oct.3			
(28) days	180	42	138	39	99	24	75	$\frac{39}{3}=13.0$	85.6	13.54
d.l.	14.00	5	13.55	3	13.52	16	13.36			
C head.	July20	43	Sep.1	16	Sep.17	13	Sep.30			
(109)days	124	3	121	25	96	24	72	$\frac{25}{18}=1.39$	54.3	14.05
d.l.	14.38	24	14.14	18	13.56	18	13.38			
D head.	Aug.8	23	Aug.31	29	Sep.29					
(546)days	97	18	79	8	71			$\frac{18}{17}=1.06$	46.7	14.24
d.l.	14.32	17	14.15	34	13.41					
E head.	Aug.9	36	Sep.14	39	Oct.23	47	Dec.9			
(310)days	137	3	134	2	132	-10	142	$\frac{3}{32}=0.09$	5.2	
d.l.	14.32	32	14.00	53	13.07	59	12.08			
F head.	June4	40	July14	42	Aug.25	36	Sep.30			
(102)days	78	6	72	-1	73	1	72	$\frac{1}{43}=0.02$	1.2	
d.l.	14.08	-29	14.37	16	14.21	43	13.38			

(dif.) : Difference between the results of two successive seedings.

head. : Date of heading.

days : Number of days of growth period (from seeding to heading).

d. l. : Day-length at 30 days before the heading.

varieties :

A (230) : Rosil str. 8 (philippine)

B (28) : 241 lum chim (Indochina)

C (109) : Chüh-tzu (Formosa)

D (546) : Ginbôzu (Japan)

E (310) : Ketan poetik (Sunda Islands)

F (102) : Peh-mi-fen (Formosa)

For measuring the sensibility exactly by such a method as this, we shall eliminate the errors due to the seasonal change of temperature involved simultaneously. In the present work, however, the most radical change of growth period was found in most varieties between the plants seeded on May and on June, and their dates of heading were between early August and late October. And as the temperature is relatively uniform throughout the summer in Taichung district, average temperatures of these growth periods were within a narrow range as given below.

Date of seeding	Average temperatures of growth periods in different dates of heading (in 1946)				
	Aug. 13	Sep. 12	Sep. 27	Oct. 12	Oct. 27
May 3	27.5 °C	27.7	28.1	27.4	29.1
June 13	28.4	28.4	28.3	27.8	27.3

And these slight differences in the average temperature were corrected by assuming $Q_{10}=2$.

The range of natural change of day-length must be considerd further. If the critical day-length of a variety was longer than or approximately equal to the longest day of a year at the summer solstice, the response to day-length of the variety will not be shown exactly by the present method. At Taichung, day-length inclusive of twilight varies from 11h. 40m. to 14h. 40m, while a greater part of the varieties used in the present study was between 12h, 40m. and 14h. 30m. in their critical day-length. Therefore, the natural variation range at Taichung seems suitable for observing the response of most varieties.

Having calculated the sensibility of varieties from the data of 1945, 1946 and 1948 independently. the results agreed well with one another in each variety.

Intervarietal Variation of the Response to Day-length.

Hundred and sixty-three varieties of different districts of Asia were observed with regard to the sensibility to day-length and critical day-length. And from those results, the following facts were recognized as seen in Table 2:

The varieties are to be classified into two groups, sensible and insensible to day-length, as the variation of sensibility was discontinuous among them. Northern parts of Japan and China, as well as the equatorial zone, showed no sensible varietes. From the regions between Japan proper and Philippine, i. e. roughly 35° to 15° in the north latitude, both sensible and insensible varieties were found. So far as the sensible varieties are concerned, the lower the latitude was, the higher seemed the sensibility of varieties.

Table 2. Geographical variation of the sensibility to day-length.

Districts	Latitude (north)	T.D.M.(Coef. of sensibility) 0 10 20 30 40 50 60 70 80 90 (Insensible) (Sensible)	Total num. of vars.	Continental group Ins. Sen.	Insular group Ins. Sen.
North Japan	46–41	1	1		1
North China	40–35	1 3 1 1	6	2	3 1
Japan Proper	40–32	2 8 1 3 2	16		11 5
Central & West China	35–27	1 7 1 1 2 2	14	7 1	2 4
South China	27–22	3 3 2 1 4 1	14	8 3	3
Formosa	25–22	8 3 1 5 3 4	24	10 7	2 5
Hai-Nan Is.	20–18	1 1 1 1 1	5	1	4
Indochina	22–15	1 1 9 6	17	1 16	
India & Siam	25–13	3 2 2 1 1 1 1 14	25	7 17	1
Philippine	17–14	6 6 5	17	5	12
Sunda Islands	4– 9*	5 4 3	12		12
Celebes	5– 0	3 6 2 1	12	1	8
Total		30 44 11 5 1 7 11 12 16 26	163	39 50	52 22

*South latitude.

Ins. : Insensible, Sen. : Sensible.

In the northern part of the temperate region, since the period of rice crop is short and of long-day season, early varieties insensible to day-length only can be grown. In the temperate region, sensible means lateness and insensibie means earlyness. In the subtropical region, sensible and insensible correspond to second-crop-nature and first-crop-nature respectively. In the tropical region, though the system of cultivation is complex, sensible varieties, called as the seasonal blossumer aud to be grown in the rainy season, are known to be the most important varieties for rice production. Scripchinsky (16) has pointed out these varietes to be capable of responding to the slight change of day-length in low latitudal regions.

While the above mentioned facts have been well known separately, the results of the present work will give a general view in a synthetical manner. The tendency found among sensible varieties that, the lower the latitude, the higher the sensibility, will be an adapatation, because the lower the latitude is, the smaller becomes the range of annual change of day-length, and then the higher sensibility is necessary for responding it. And it will be attributable to the constancy of day-length that sensible varieties are very few in the regions under the equatorial line.

Table 3. Geographical variation of critical day-length for the maximum change of growth period among varieties sensible to day-length.

Districts	Latitude	Critical day-length 12.45	13.00	13.15	13.30	13.45	14.00	14.15	14.30	Total num. of vars.
North China	40–35								1	1
Japan Proper	40–32								6	6
Central & West China	35–27							2	3	5
South China	27–22				1	1	1	1	2	6
Formosa	25–22					4	5	2	1	12
Hai-Nan Is,	20–18					2	1	1		4
Indochina	22–15			4	1	6	5			16
India & Siam	25–13	4		3	7	3				17
Philippine	17–14	1	1	2	1					5
Celebes	5– 0			1						1

Table 3 gives the geographical variation of critical day-length among sensible varieties. As seen in this table, the lower the latitude the shorter the critical day-length. This will be presumable also as a result of adaptation to the environment.

Continental and Insular variety-groups showed no essential difference in the range of intervarietal variation of day-length sensibility and critical day-length. It was pointed out, however, as seen in Table 2, that in continental group sensible varieties were distributed predominantly over low latitudal districts, while in Insular group over high latitudal districts.

Method to Measure the Sensibility to Temperature.

In varieties insensible to day-length, the later the date of heading in spring is, the shorter becomes the growth period generally. This will be due to the gradual rise of temperature in spring. In order to gain more detailed informations on this point, the relation between the days of growth period and the average temperature during the growth period was investigated on several varieties. Table 4 gives a part of those results.

Table 4. Examples of the relation between the days of growth period and the average temperature during the growth period (exclusive of 5 days after the seeding).

No. of variety		Dates of seeding					
		July20	Sep.5	Oct.5	Nov.5	Dec.14	Feb.1
102	head.	Sep. 30	Nov. 28	Jan. 31	Mar. 26	May 1	May 23
	days	72	84	118	141	138	111
	temp.	28.0°C	23.9	19.8	17.4	17.8	19.9
310	head.	Dec. 9	May. 21	May 28	June 1	June 23	July 13
	days	142	258	235	208	191	162
	temp.	25.1	20.4	19.8	19.4	20.0	21.9
563	head.	Sep. 17	Nov. 14	Jan. 30	Mar. 20	Apr. 26	May 10
	days	59	70	117	135	133	98
	temp.	28.3	24.6	19.8	17.4	17.7	19.1
571	head.	Sep. 19	Nov. 16	Jan. 18	Mar. 29	May 1	May 12
	days	61	72	105	144	138	100
	temp.	28.3	24.5	20.3	17.5	17.8	19.4
638	head.	Nov. 20	Apr. 14	May 8	May 20	June 11	July 2
	days	123	221	215	196	179	151
	temp.	25.9	19.8	19.3	19.0	19.6	21.5

head. : Date of heading.

days. : Number of days of growth period.

temp. : Average temperature of the growth period.

102 : Peh-mi-fen (Formosa)

310 : Ketan Poetik (Sunda Islands)

563 : Kinoshita-mochi (Japan)

571 : Mansaku (Japan)

638 : Poenoet hitam (Celebes)

In some varieties, notwithstanding the average temperatures being approximately same, the growth period was found to be shorter in spring than in autumn. And in other varieties, the days of growth period did not always go with the average temperature. These phenomena may suggest that the stage of flower bud formation is quickened by the rise of temperature, and this response is somewhat different from the response of vegetative growth.

In order to distinguish these seemingly different responses, the following method of calculation was attempted : To find on each variety the days of growth period in different dates of heading (Y), avergne temperatures of respective growth period (X) (exclusive of 5 days after the water soaking of seed), and average temperatures of the period of flower bud formation (35-15 days before the heading) (Z), and to calculate the partial regression coefficients $b_{yx.\,z}$ and $b_{yz.\,x}$. These were expressed in terms of the percentage to the average of the days of growth periods. $'b_{yx.\,z}$ (%)' will stand for the rate of accerelation of general growth for the rise of 1°C, and $'b_{yz.\,x}$ (%)' will stand

for the rate of hastening of flower bud formation for the rise of 1° C. An example of calculation is as follows : (Variety : 571; Mansaku, Japan, day-length insensible)

Date of heading (1946-47)	Apr. 30	May 28	July 8	Aug. 17	Sep. 19	Nov. 16	Jan. 18	Mar. 29	May 1	May 12	Average
Number of days of growth period (Y) :	88	71	66	65	61	72	105	144	138	100	91.0
Average temp.of growth perlod (X) :	21.1	24.7	26.9	27.9	28.3	24.5	20.3	17.5	17.8	19.4	22.8
Temp. of the time of flower bud formation (Z) :	21.9	26.3	27.4	27.5	28.2	23.3	18.2	16.4	20.4	21.6	23.1

Sum of squares and products; (n=10)

$Sy^2=8266$, $Sx^2=163.34$, $Sz^2=154.66$, $Syx=-1046.8$, $Syz=-1005.2$, $Sxz=143.12$

Partial regression coefficients (according to Snedecor' s formula):

$$byx.z=\frac{(-1046.8)\,(154.66)-(-1005.2)(143.12)}{(163.34)\,(154.66)-(143.12)^2}=-3.774 \quad \frac{\%\text{ to Y}}{4.15\%}$$

$$byz.x=\frac{(-1005.2)\,(163.34)-(-1046.8)\,(154.66)}{(163.34)\,(154.66)-(143.12)^2}=-2.454 \quad 2.70\%$$

Test. of significance:

$$Sye^2=(-3.774)\,(-1046.8)+(-2,454)\,(-1005.2)=6417.38$$

$$F=\frac{6417.38}{8266-6417.33}\cdot\frac{10-(2+1)}{2}=12.13 \text{ (significant)}$$

Regression equation:

$$Ye=91.0+(-3.77)(X-22.8)+(-2.45)(Z-23.1)$$

When $X=Z=25$, $Ye=78.27$

Correlation coefficients:

$$r_{yx}=-0.901,\quad r_{yz}=-0.889,\quad r_{xz}=0.901,\quad r_{yx.z}=-0.501,\quad r_{yz.x}=-0.410$$

In addition to this, another method was attempted further to find the rate of hastening of flower bud formation due to the rise of temperature. Namely, two successive cultivations (heading in spring) between which the difference of growth period was largest were taken, and the observed number of days of growth period in each were replaced by a corrected number so as to elliminate the difference in the average temperature (Snyder' s formula $\left(\frac{T_1}{T_2}\right)^{\frac{10}{t_2-t_1}}=Q_{10}$ was used, assuming $Q_{10}=2$), and the ratio of the difference between those two corrected numbers to the difference of the temperature at the time of flower bud formation was regarded as a measure of the temperature response in question. It was expressed in a same manner as the case of day-length sensibility by an angle. This will be of similar nature with $b_{yz.x}$. Its variation was similar with that of $b_{yz.x}$, and a significant correlation was found between them ($r=0.485$).

In day-length sensible varieties, the influence of day-length is evidently larger than that of temperature, and the sensibility to day-length will vary, as shown by Suenaga

(17), with the temperature. It is difficult, therefore, to analyse their temperature response by the above mentioned methods. From this reason, only the varieties insensible to day-length (below 30 in T. D. M.) were used for the observation of temperature responses. And in regard to several varieties slightly sensible to day-length, the observed numbers of days were corrected by refering to the day-lengthes at different dates of heading and day-length sensibility of the given variety.

Intervarietal Variation of the Sensibility to Temperature.

On each of 82 varieties insensible or slightly sensible to day-length, the two different coefficients of temperature, byx.z and byz.x, were calculated. Table 5 gives their variations among varieties.

Table 5. Varietal variation of the coefficients of temperature sensibility, $b_{yx.z}$ and $b_{yz.x}$ (for the hastening of general growth and flower bud formation respectively).

Districts (north)	Latitude	byx.z (%)				byz.x (%)							Total num. of vars.
		3	4	5	6	0	1	2	3	4	5	6	
North Japan	46–41	1										1	1
North China	40–35	1	4		1		1	2	2	1			6
Japan Proper	40–32	1	6	1					6	1	1		8
Central & West China	35–27		3	3	1		1	4	2				7
South China	27–22	2	2	3			2	3	2				7
Formosa	25–22	2	7	3			5	5	1	1			12
Hai-Nan Island	20–18			1				1					1
Indochina	22–15			1			1						1
India & Siam	25–13		4	3	1		4	4					8
Philippine	17–14	6	4					2	6	2			10
Sunda Islands	9–4*	2	9	1			1	3	6	2			12
Celebes	5–0	3	6	1		1		2	4	3			10
Contineutal group		2	19	15	2	1	12	21	4				38
Insular group, tropical		10	20	1	1		3	5	17	7			32
Temperate		6	6	1					8	3	1	1	13
Total		18	45	17	3	1	15	26	29	10	1	1	83

*South Latitude

Unlike the case of the response to day-length, these temperature responses showed no definite relation with the latitude, but showed some difference in the mode of variation between Continental and Insular variety groups. Varieties of Continental group were generally larger in byx.z, but smaller in byz.x than Insular varieties. In other words, Continental varieties have such a tendency that the rise of temperature accerelate general growth largely, but hastens flower bud formation litttle, and are in

contrast to Insular varieties.

A minus correlation (r=-0.615) was found between byx.z and byz.x. Further, as given in Table 6, byx.z was found to correlate with Belehradek's temperature constant in the germination of seed (to be reported in another paper). This will be proof that byx.z stands for the rate of general growth accerelation by temperature. byz.x was found to correlate negatively with the temperature constant (r=-0.576).

Table 6. Correlation between byx.z (coefficient of growth acceleration by temperature) and Belehradek's temperature constant of seed germination, (r=0.433)

	Temperature constant						Total
	1.8	2.0	2.2	2.4	2.6	2.8	
3	1	2	4				7
byx.z (%) 4		4	10	1	5	1	21
5			2	3	2		7
Total	1	6	16	4	7	1	35

Vrietal Variation of the Number of Days of Growth Period:

According to various short-day experimens of the rice plant, the days of growth period in day-length sensible varieties is known to become the minimum at an extremely short-day such as eight or ten hours, which will be never realized naturally during the period of rice crop at any latitude. And growth being very poor in such a case, these varieties must be of such a nature that a proper duration of excessive vegetative growth is necessary for exhibiting their own producing capacity. Therefore, even though the minimum growth period under an extreme short-day was a character inherent to the variety, it will be of little value in ecological studies. The combination of sensibility and critical day-length seems to represent the reaction norms of these sensible varieties,instead of the number of days of growth period.

In varieties insensible to day-length, on the other hand, the days of growth period may be dependent principally on the given temperature. Each of them was found to have a definite number of day of growth period in summer, where the temperature is relatively uniform as mentioned in the section of day-length sensibility.

In order to find the number of days of growth period inherent to the variety as precisely as possible, the number of days of theoretical growth period at 25°C was calculated from the multiple regression equation, $Ye=Y+byx.z\ (25-X)+byz.x\ (25-Z)$.

Table 7 gives its intervarietal variation. It was found as a rule that, the lower the latitude, the longer the growth period.

Table 7. Geographical variation of the days of growth period (theoretical number at 25°C) among day-length insensible varieties.

Districts north Latitude		Number of days											Total num. of vars.
		50	60	70	80	90	100	110	120	130	140	150	
North Japan	46–41		1										1
North China	40–35	1			5								6
Japan Proper	40–32			5	3								8
Central & West China	35–27			2	4	1							7
South China	27–22			3		3			1				7
Formosa	25–22				3	8	1						12
Hai-Nan Island	20–18				1								1
Indochina	22–15								1				1
India & Siam	25–13				3	5							8
Philippine	17–14							3	5		2		10
Sunda Islands	9–4*						1	1	3		3	4	12
Celebes	5–0							2	3	2	3		10
Continental group				5	12	15	1	1	3		2		38
Insular group, tropical		1		1	2		1	5	10	2	6	4	32
Temperate			1	4	5	2			1				13

*South Latitude

Discussion

So far as the conditions of growing, such as fertilizing, water supply and others, are definite, the days of growth period of a rice variety will depend upon the given day-length and temperature. According to the above mentioned observations, varieties are to be classified in respect to the response to day-length into sensible and insensible groups. Day-length sensible varieties seem to have no definite numder of days of growth period practically, and their day-length response seems to be analysable into two compo nents, sensibility and critical day-length. The response to temperature, which was studiedwith day-length insensible varieties, seemed to be twofold: The response in flower bud formation seemed to be somewhat different from that of vegetative growth.

Having examined the geographical variation of these physiological characters, day-length sensibility and critical day-length in sensible varieties, as well as the number of days of growth period (at 25°C) in day-length insensible varieties, were found to correlate intimately with the latitude. These reaction-norms will be of primary importance for determining the number of days of growth period under a given condition, and thererfore, selection pressure on the genes controlling these reaction norms may have been so effective as to give rise to such a complete adaptation to the meteorological

conditions which is dependent upon the latitude. Such an adaptatation to the latitude may be hardly found in other characters.

As pointed out in the preceding paper, the direction of phylogenetic differentiation of rice varieties will be shown by dividing the varieties into Continental and Insular variety groups. As these variety groups are distributed similarly from tropical to temperate regions, the difference between tropical varieties and temperate ones is not so distinct in such characters as being different between these variety groups. Even in such a physiological character as low temperature resistance or minimum germination temperature, the difference between Continental and Insular variety groups was larger than the difference between tropical varieties and temperate ones (15). The response to temperature seems to be of the same nature to these in the mode of intervarietal variation. Possibly selection pressure on these characters may be less effective than on those having immediate influence on the days of growth period.

From the view point of breeding, the responses to temperature and day-length are important in relation to the regional adaptability of varieties. These reaction-norms not only control the days of growth period, but are related with the behavior of "yield-composing-characters". Some studies on this point will be reported in another paper.

Dr. Eikichi Iso (8) classified the varieties of Formosa and Japan into five groups on the ground of the responses to day-length and temperature, and advanced considerations on the regional adaptability and agricultural value of those groups. There may be found a number of problems for further studies as to what kinds of varieties are necessary under different environments.

Wada (21) and Matsuo (12) observed, in Japan, varietal varietion of the responses to day-length and temperature by comparing the date of natural heading with that under a higher temperature, and by examining the relation of the days of growth period under high temperature and short-day to its difference from the days of growth period in natural heading. Their results seem somewhat different from the writer's. This may be due to that they have forced to observe the response to temperature in day-length sensible varieties, and they have not made a distinction of flower bud formation and vegetative growth as to the response to temperature.

Summary

1. Rice varieties of various districts of Eastern Asia, 163 in total number and same to the materials of the preceding works, were seeded repeatedly throughout a year at the intervals of 30 to 50 days, and the relation between the dates of heading and the days of growth period (from seeding to heading) was investigated on each variety. The same experiment was repeated three times in 1945, 1946-'47 and 1948-'49.

2. For measuring the sensibility to day-length, the ratio of the shortening of growth period to an unit shortening of day-length at the time of flower bud formation (assumed as 30 days before the heading) was calculated on each variety. This ratio varied in a same variety with the day-length; the day-length at which the ratio was

largest was regarded as "critical day-length" and the angle the tangent of which was corresponding to the largest ratio was used as a measure of the sensibility to day-length (named as T. D. M.).

3. As in day-length sensible varietes the days of growth period differed strikingly with the day-length, the response to temperature was measured only on day-length insensible varieties by the following method: to find on each variety the days of growth periods in different dates of heading (Y), average temperatures of respective growth periods (X), and average temperatures at the time of flower bud formation (25-15 days before the headlng) (Z), and to calculate the percentage of partial regression coefficients byx.z and byz.x to the average of the days of growth period. byx.z (%) and byz.x (%) will stand for the rates of accerelation of general growth and flower bud formation for the rise of 1°C respectively. In addition to this, the rate of hastening of flower bud formation by the rise of temperature in spring was measured by another method, and was found to agree well with byz.x.

4. Varietal variation of T. D. M. (coefficient of day-length sensibility) was discontinuous and the varieties were divided into two groups sensible and insensible to day-length. While northern temperate regions and districts under the equator showed no sensible varieties, from the regions between Japan Proper and Philippine both sensible and insensible varieties were found. Among day-length sensible varieties, the lower the latitude was, the higher was the sensibility to day-length as a general tendency, and the shorter was the critical day-length. These phenon ena were considered to be the adaptation of varieties to the environmental conditions which would be dependent upon the latitude.

5. Among day-length insensible varieties, varieties of Continental group were generally larger in byx.z (the rate of accerelation of general growth for the rise of 1°C) and smaller in byz.x (the rate of hastening of flower bud formation) than Insular varieties. A minus correlation was found between byx.z and byz.x. Further, they were found to correlate with Belehrádék's temperature constant in the germination of seed.

6. Day-length sensible varieties were thought to have no definite number of days of growth period practically. In insensible varieties, on the other hand, the days of growth period seemd to be constant when the temperature was uniform in summer. The number of days of theoretical growth period at 25°C was calculated on each variety from the multiple regression equation of byx.z and byz.x. The lower the latitude was, the longer was the days of growth period as a general rule among day-length insensible varieties.

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