Growth Characteristics and Dry Matter Production of Rice Plants in the Warm Region of Japan

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It is important to clarify characteristics of growth and of yield determination of rice plants in the warm region of Japan for improving cultural practices and for developing high-yielding varieties more adapted to the warm region. However, as far as the author knows, there has been no study so far made on this aspect from the viewpoint of dry matter production. The present study[7] attempts to examine growth characteristics of rice plants in the warm region from the standpoints of dry matter production,[4,5] efficiency of solar energy utilization,[1] and relations between climatic conditions and yields and yield components,[2] with the purpose of making clear the characteristics of yield determination** of rice plants in the warm region and also of finding out how to improve cultural practices on the basis of the characteristics of yield determination.[3]

Characteristics observed in growth pattern

1) CGR

Relations between mean temperature at each growth period and CGR (Crop growth rate) are shown in Fig. 1. At the initial growth stage, a significant, positive correlation was observed between the mean temperature and CGR, i.e. the higher the mean temperature the higher was CGR. However, with the advance of growth, the correlation was lowered, and then it turned to be significantly negative for the period from 3 weeks to 6 weeks after heading. In this period, the higher the mean temperature the lower was CGR.

In Fig. 2, relations between amount of solar radiation and CGR at different growth periods are shown. In the period from 6 weeks to 3 weeks prior to heading, a significant, positive correlation ($r=0.806^{**}$) was recognized between solar radiation and CGR, but no significant correlation was observed in other growth periods. With the advance of growth, CGR value itself showed a tendency to decrease, and at the same time, CGR increment caused by an increasing solar radiation tended to become less.

2) Ratio of dry matter distribution

Distribution of produced dry matter into different organs of plants varied with growth stages and environmental conditions. In general, the ratio of distribution to roots and leaf blades was high in an early growth stage, that to stems and leaf sheaths became high in the subsequent stage, and finally in the stage after heading that to panicles was predominant.

As to the relation between dry matter distribution and climatic factors, correlation coefficients calculated with data collected from various places of the whole country are given in Table 1. In the period of −9/−6 (from 9 to 6 weeks before heading), dL (ratio of dry matter distribution to leaf blades) was positively correlated to the mean temperature in that period, while dR (ratio of distribution

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** The process through which the final grain yield is obtained is called the yield determination.

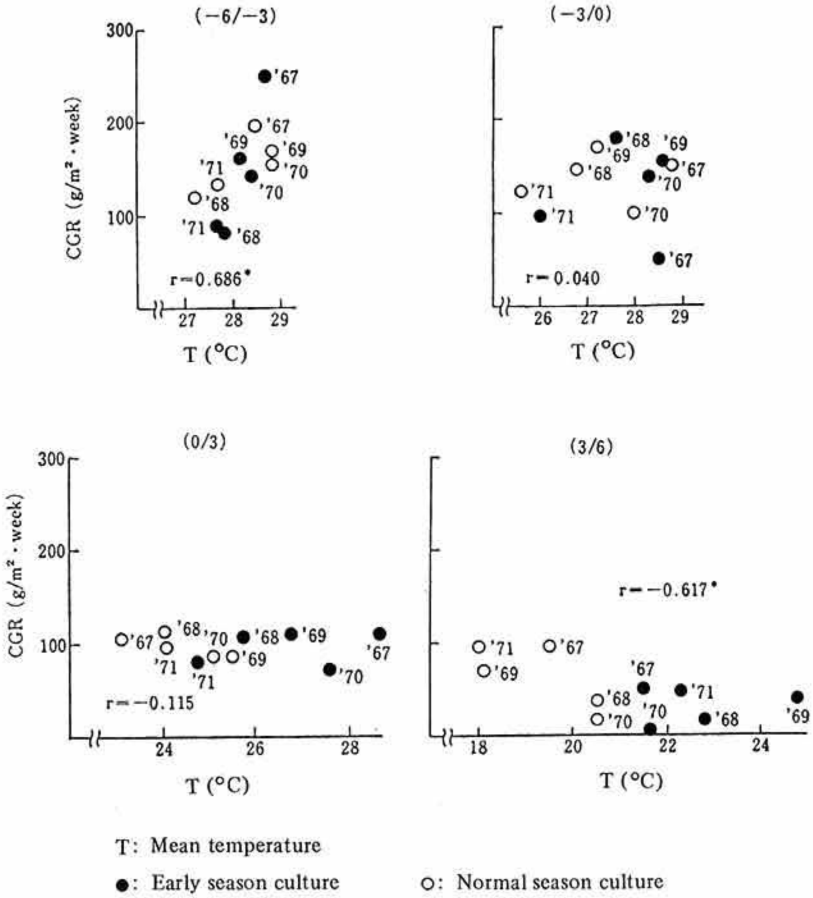

Fig. 1. Correlation between mean temperature and CGR

−6: 6 weeks before heading, −3: 3 weeks before heading, 0: heading time, 3: 3 weeks after heading, 6: 6 weeks after heading
For example, (−6/−3): the period from 6 to 3 weeks before heading.
Numerals affixed to circles show the year in which the data were obtained.

Table 1. Correlation coefficient between ratio of dry matter distribution and climatic factors

Item	Growth stage	d. f.	Mean temperature	Solar radiation
d_L	−9/−6	53	0.469***	−0.301*
	−6/−3	63	−0.139	−0.266*
d_R	−9/−6	53	−0.591***	0.182
	−6/−3	63	−0.408**	−0.018
d_S	−9/−6	53	0.321*	0.035
	−6/−3	63	0.336**	0.163

d_L: ratio of dry matter distribution to leaf blades
d_R: ratio of dry matter distribution to roots
d_S: ratio of dry matter distribution to leaf sheaths

to roots) was negatively correlated to the mean temperature.

From these results, it can be noted that the characteristics of rice plants in the warm region are as follows: As compared with rice plants in the cold region, the rice plants in the warm region are characterized by a higher ratio of dL owing to higher temperature in the vegetative period, which results in a faster increase of leaf area and hence faster expansive reproduction. Consequently, nitrogen concentration in plants is lowered rapidly so that the maximum tillers stage comes earlier, with a result of vegetative lag phase.[8] After the heading, CGR is negatively correlated to mean

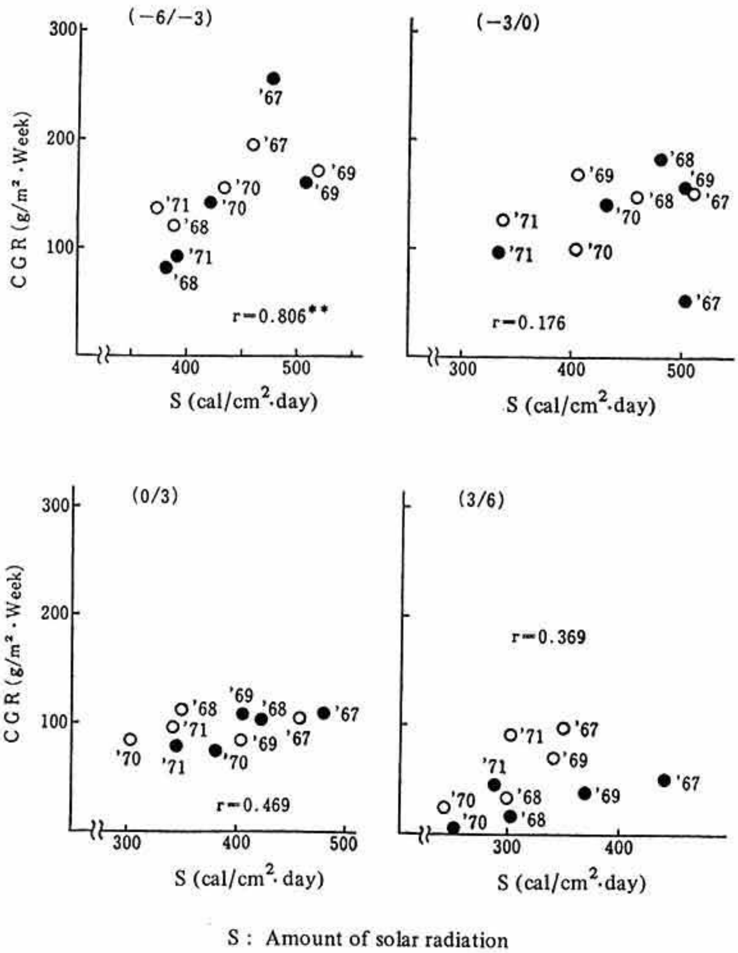

Fig. 2. Correlation between solar radiation and CGR Symbols and abbreviations are the same as in Fig. 1.

temperature and positively correlated to solar radiation, so that CGR tends to increase when solar radiation is plenty and temperature is relatively low during the period after heading.

Solar energy utilization and net production

1) Efficiency of solar energy utilization

The energy source for dry matter production of rice plants is solar radiation. Efficiency of solar energy utilization (Eu),[1] shown by the following equation, was measured with rice plants grown by the early season culture and the normal season culture in 5 successive years from 1967 to 1971.

$$Eu = \frac{(\text{g. of dry matter produced}) \times 3.750 \text{ cal}}{\text{Incident solar energy (cal)}} (\%)$$

The mean Eu of 5 years was 1.24% for the early season culture, and 1.35% for the normal season culture. In the former with a longer growth duration of rice plants due to an early transplanting, Eu was lower than that of the latter. This difference in Eu was mainly due to the difference in Eu after heading (Table 2).

Relation of Eu to mean temperature during

Table 2. Efficiency of solar energy utilization (%)

	tp～−6	−6～−3	−3～0	0～3	3～6	tp～0	0～6	tp～6
Early season culture								
1967	0.99	2.81	0.56	1.22	0.64	1.41	0.94	1.24
1968	0.92	1.18	2.03	1.39	0.27	1.30	0.99	1.20
1969	0.67	1.71	1.66	1.22	0.58	1.27	1.10	1.20
1970	1.09	1.82	1.72	1.04	0.11	1.49	0.74	1.27
1971	1.52	1.19	1.57	1.34	0.90	1.44	1.14	1.31
mean	1.04	1.74	1.51	1.24	0.50	1.38	0.98	1.24
Normal season culture								
1967	0.91	2.14	1.49	1.22	1.45	1.45	1.32	1.41
1968	0.89	1.07	1.71	1.74	0.65	1.39	1.24	1.34
1969	0.77	1.74	2.29	1.14	1.28	1.54	1.19	1.43
1970	0.84	1.88	1.31	1.52	0.53	1.32	1.06	1.18
1971	0.67	1.88	2.00	1.52	1.54	1.41	1.53	1.39
mean	0.82	1.74	1.71	1.43	1.09	1.42	1.27	1.35

Calculation was done assuming dry weight 1 g as 3.75×10^3 cal.
tp: transplanting time

the period of 6 weeks after heading is given in Fig. 3, which shows a significant negative correlation, $r=-0.788$.** Namely, the higher the temperature in 6 weeks after heading, the lower is Eu. This result seems to reflect the above-mentioned fact that the higher the mean temperature in the later growth period the less is the dry matter production, as shown in Fig. 1.

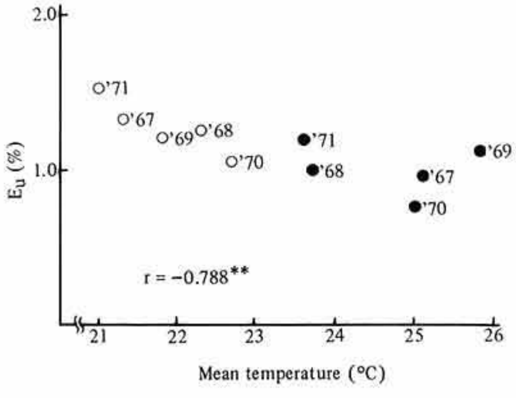

Fig. 3. Correlation between mean temperature and efficiency of solar energy utilization during the period from heading to 6 weeks after heading
Symbols are the same as in Fig. 1.

2) Efficiency of light energy conversion by photosynthesis in fields

Ratio of chemical energy fixed by photosynthesis to the photosynthetically active radiation (PAR) absorbed by rice plant population is closer to the efficiency of photosynthetic mechanism itself than Eu. The efficiency of photosynthetic conversion of light energy ($E\phi$) was obtained by actual measurements of the amount of net dry matter production, the amount of respiration, and PAR.

$E\phi$ obtained at different growth periods is shown in Table 3. The $E\phi$ values were more or less constant during the whole growth period except the later half of ripening period with advanced aging. The values ranged from 4.6 to 7.7% (the highest) for the early season culture, and from 5.3 to 7.0 (the highest) for the normal season culture.

Proportion of net production to gross production, i.e., efficiency of net production, in different seasons and different growth periods is shown in Table 4. It was 72–55% in the early season culture, and 77–60% in the normal season culture. The later the growth period the lower its value tends to be to some extent. Mean value for the whole growth period was 67% for both cultures, indicating

Table 3. Efficiency of photosynthetic conversion ($E\phi$) of light energy

Period	Respired CO^2 g/m², day	Respired CO^2 kcal/m², day	P_n g/m², day	P_n kcal/m², day	P_g kcal/m², day	P_n/P_g %	Absorbed PAR kcal/m²	$E\phi$ %
Early culture								
June 23～July 13	7.897	20.64	14.39	53.96	74.60	72.4	19480	7.7
July 13～Aug. 3	9.921	25.93	19.07	71.51	97.44	73.5	37842	5.4
Aug. 3～Aug. 23	10.954	28.63	17.17	64.39	93.02	69.3	40040	4.6
Aug. 23～Sept. 14	18.428	48.17	15.95	59.81	107.98	55.4	34034	7.0
Sept. 14～Oct. 5	3.202	8.37	3.82	14.33	22.70	63.0	26229	1.8
Normal culture								
July 1～July 27	3.614	9.45	8.44	31.65	41.10	77.0	15314	7.0
July 27～Aug. 17	16.982	44.39	21.43	80.36	124.75	64.3	40299	6.5
Aug. 17～Sept. 6	13.810	36.10	21.66	81.23	117.33	69.3	34880	6.7
Sept. 6～Sept. 27	10.219	26.71	13.33	50.00	76.71	65.1	30240	5.3
Sept. 27～Oct. 18	4.644	12.14	4.87	18.26	30.40	60.0	24822	2.6

Note: P_n, net production (=CGR); P_g, gross production

Table 4. Efficiency of net production

Period	Pn/Pg (%)
Early culture	
June 23— July 13	72.4
July 13—Aug. 3	73.5
Aug. 3—Aug. 23	69.3
Aug. 23—Sept. 14	55.4
Sept. 14— Oct. 5	63.0
Normal culture	
July 1— July 27	77.0
July 27—Aug. 17	64.3
Aug. 17—Sept. 6	69.3
Sept. 6—Sept. 27	65.1
Sept. 27—Oct. 18	60.0

that about 1/3 of the production was lost by respiration.

Characteristics of yield determination process

1) *Growth pattern and number of spikelets/leaf blade weight*

Balance between vegetative growth and reproductive growth influences growth pattern. As an index expressing the balance, the number of spikelets per unit weight of leaf blades at the heading time was taken up in this study. Effect of the mean temperature in a period of 6 weeks prior to heading on the number of spikelets/leaf blade weight at the heading time was shown in Fig. 4 for early and medium-late varieties, and for warm and cold regions. In any case, the number of spikelets/leaf blade weight was found to be negatively correlated to the mean temperature. It implies that in the warm region where temperature is higher at that period than in the cool region with lower temperature a greater leaf blade weight is apt to be required to produce the same number of spikelets as obtained in the cool region. The correlation coefficients shown in Fig. 4 are not so high, probably due to the fact that the number of spikelets/leaf blade weight is influenced by other factors such as varieties, soil conditions, etc.

2) *Relation of grain yield to climate and other factors*

The relations found in the cultural experiments conducted in different years, with different varieties and in different cropping seasons are shown by simple correlation coefficients and standard partial regression coefficients in Table 5. As to simple correlation coefficients, significant positive correlations were found between the number of spikelets/m² and grain yield, and between solar

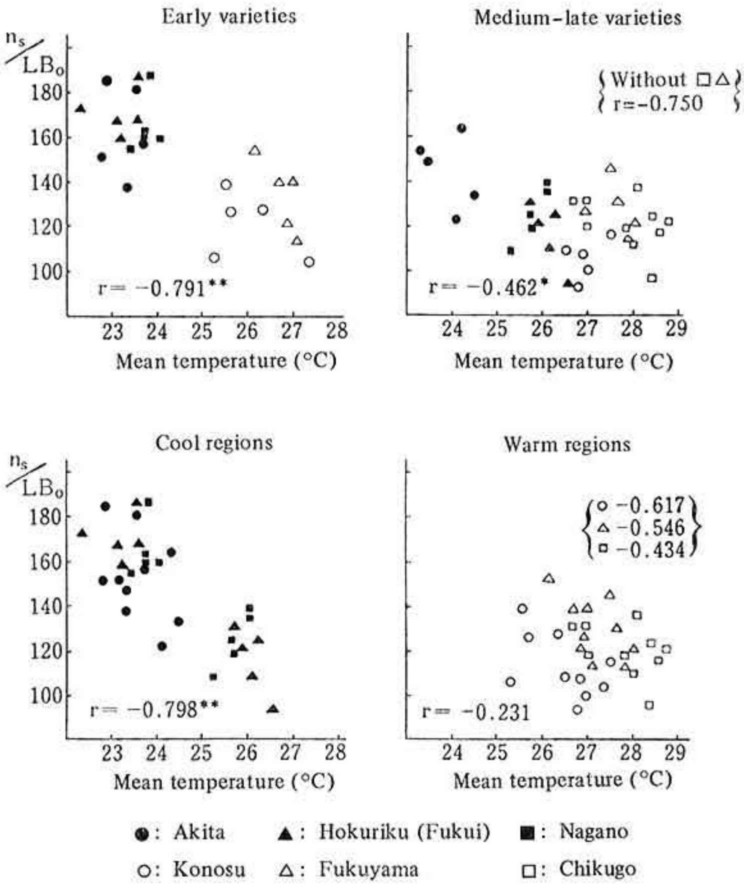

Fig. 4. Correlation between the number of spikelets/leaf blade weight at heading (ns/LB_0) and mean temperature during 6 weeks before heading

Table 5. Relation of grain yield to climatic factors after heading and to some plant characters at heading

	Simple correlation coefficient	Standard partial regression coefficient
S(0/3)	0.668***	0.552
T(0/3)	−0.029	−0.531
ns	0.659***	0.423
LS+C(0)	0.355	0.031
LAI(0)	0.398	0.064

S: amount of solar radiation
T: mean temperature
ns: the number of spikelets/m²
LS+C: weight of leaf sheath + culm
LAI: leaf area index
(0/3): the period of 3 weeks after heading
(0): heading time

Note: The multiple correlation coefficient calculated by multiple regression analysis with these 5 factors is R=0.824.***

radiation in a period of 3 weeks after heading and grain yield. From the standard partial regression coefficients obtained by multiple regression analysis, it was also found that the mean temperature in 3 weeks after heading was influencial to grain yield to an extent not less than the influence of above-mentioned solar radiation in 3 weeks after heading and of number of spikelets/m². The only difference is that the value of standard partial regression coefficient for the mean temperature is negative, i.e., the higher the mean temperature, it causes, the less yield.

3) Relation of climatic factors to yield components

(1) Number of spikelets/m²

Grain yield is greatly influenced by the

Table 6. Correlation between the number of spikelets/m² and the amount of solar radiation or mean temperature

	Correlation coefficient	Partial correlation coefficient
S (-6/0)	0.571**	0.946***
T (-6/0)	0.005	-0.923***

S(-6/0): amount of solar radiation during 6 weeks before heading
T(-6/0): mean temperature during 6 weeks before heading
Note: Correlation coefficient between S(-6/0) and T(-6/0) is 0.806.

number of spikelets/m² as shown above. How is the latter influenced by climatic factors?

Table 6 shows correlation coefficient and partial correlation coefficient between number of spikelets/m² and solar radiation or mean temperature during 6 weeks before heading. The number of spikelets/m² showed a high, positive partial correlation to the solar radiation, and a high, negative partial correlation to the mean temperature. Therefore, in the warm region, characterized by greater amount of solar radiation and higher temperature in that period, the greater solar radiation exerts a positive effect, but higher temperature gives a negative effect on the number of spikelets/m².

(2) Weight of 1,000 kernels

Relation of mean temperature during 3 weeks after heading to 1,000-kernel weight is shown in Fig. 5. A significant, high, negative correlation was found in both cultivars, Hoyoku and Shiranui: the higher the temperature, the lower is the 1,000-kernel weight. The negative effect of mean temperature during 3 weeks after heading on grain yield, as described above, can be explained to have been caused mainly by the lowering of 1,000-kernel weight.

4) *Improvement of cultural methods of rice in the warm region*

From these results, it was made clear that, in the warm region with a great amount of solar radiation and high temperature during the period before and after heading, the great solar radiation exerts a favorable effect, while the high temperature an adverse effect. The general tendency that yields of rice in the warm region are lower than those in the cool region can be attributed to an insufficient number of spikelets produced/m², rather than retarded ripening. Accordingly, the direction of improving rice cultivation in the warm region is to adopt the following methods:

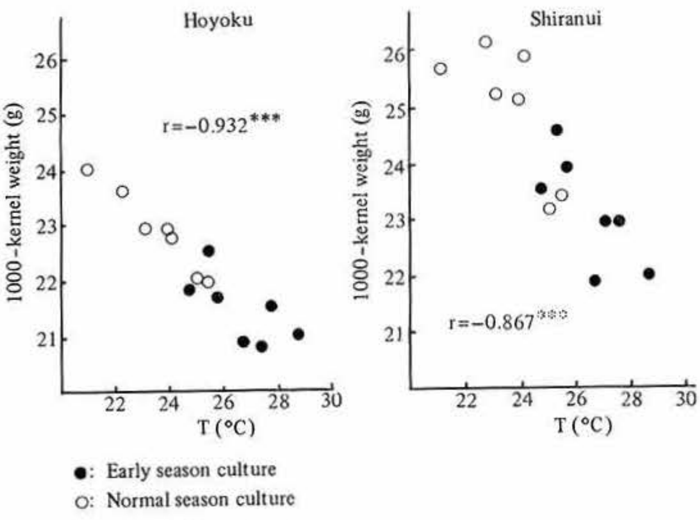

Fig. 5. Correlation between mean temperature during 3 weeks after heading and 1000-kernel weight

(1) Decrease the number of seedlings/hill.

(2) In case of short-culm varieties, reduce the rate of nitrogen application at an early growth stage, and apply a small amount of nitrogen at the panicle neck-node differentiation stage.

(3) Adopt varieties of short-culm, panicle weight type, which are apt to produce a sufficient number of spikelets.

All of these methods proposed have a common purpose, i.e., by reducing the early growth of plants to some extent, the occurrence of their overgrowth at the middle growth stage, that causes a reduced number of spikelets,[6] should be avoided.

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