Effects of Climatic Factors on Productivity of Rice

KEN MUNAKATA

Researcher, 1st Laboratory of Physiology, 1st Division of Physiology, Department of Physiology and Genetics, National Institute of Agricultural Sciences

Introduction

Recently, the farmers' technical levels of rice culture in Japan have become comparatively uniform due to the development of the information service systems.

Therefore, it may be surmised that the effect of climatic factors on the productivity of rice in each district has become more apparent both in the local and yearly differences of rice output than in the past.

Dr. Murata's work[1], which dealt with this problem and explained the major part of the local differences in the productivity of rice plant in Japan by the deviation in air temperature and solar radiation during the August and September period, seems to have substantiated the above reasoning.

The information to be acquired along this line may be useful not only for the systematic cultivation of rice, but also for evaluating the effects of soil conditions, cultivating techniques, variety, etc., separately from those of climatic factors.

With the aim to research the above relationship quantitatively between the grain yield of rice plants and the climatic factors during these ripening periods, a series of experiments have recently been conducted at the Chugoku Agr. Expt. Station, Fukuyama, in 1962~1966. The following is a brief introduction of the report[2].

When we analyze how the environmental or internal factors affect the yield, it is very important in the first place to consider what kind of factors the productivity consists of and in the second place to postulate a "yield model" which incorporates all the previously acquired knowledge on this problem.

The yield model adopted here consists of several internal factors of rice stands at the heading stage and a few climatic factors during the ripening period.

The internal factors at the heading stage are, of course, determined by all the external factors from sowing to heading, but this point will not be discussed in the following, because the latter must have only indirect connections with grain yield.

Productivity and internal factors of a rice stand at the heading stage

For excluding by calculation the effects of the the internal factors from the variation in rice yield, it is necessary to know the relation between the productivity and the internal factors.

The internal factors picked up here are the leaf dry weight per unit area (LB, g/m^2) and the number of spikelets per unit area (N, number/m^2).

As there was a high correlation found between the leaf weight and the number of spikelets, care must be taken in analyzing the effect of individual factors on the rice yield.

The effect of the number of spikelets, on the other hand, was in direct and linear proportion to the yield, but the effect of the leaf weight did not show any clear relationship within the range of 100~250 g/m^2(the latter effect on yield seems to be variable with the temperature during the ripening period).

It was, therefore, concluded that the number of spikelets was the most important among internal factors.

Fig. 1. shows an example of the relationships between the number of spikelets (N)and the yield (Y). Here the same marks stand for the values obtained in the plots of the same heading date in the same year and, therefore, they were exposed to the same climatic conditions during

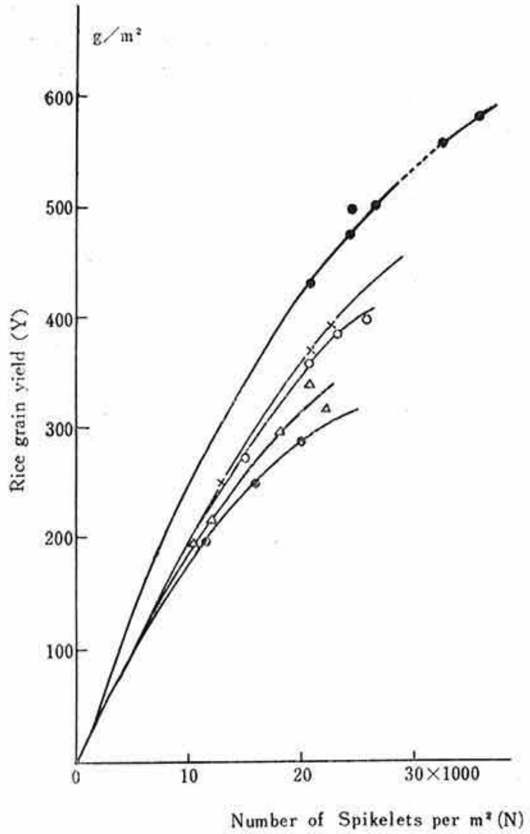

Fig.1. Relation between the number of spikelets per square meter (N) and the rice grain yield (Y)

the ripening period.

From the above relationship between N and Y, it was found that the rice grain yield could be shown by the following formula :

$$Y = a_1 \frac{N}{N+5\times10^4} \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

where Y, N and a_1 stand for the weight of hulled rice (g/m^2), the total number of spikelets per m^2, and the yield index excluding the effect of N, respectively.

The amount of solar radiation, air-tempereture during the ripening period and productivity

Each a_1 was calculated by dividing each yield of the test plot with the corresponding ($N/N+5\times10^4$) value according to the formula (1). The value a_1 seems to represent mainly the effect of climatic factors during the ripening period.

Then, the relationship of a_1 to the amount of solar radiation and the air-temperature during the ripening period was analyzed.

There was a high correlation found between the amount of solar radiation and the air-temperature, and therefore it was thought to be difficult to extract the effect of each factor on rice yield separately from the yield variation which was obtained only by shifting the cultivation season.

So, in the next place, an experiment was carried out in which rice stands were shaded by cheese cloth during the whole ripening period. It seems that there was little difference in the air temperature between the shaded plot and the non-shaded control plot.

From the result of this shading test, it was found that the relationship between a_1 and the amount of solar radiation can be shown by an asymptotic curve (Fig. 2.), a hyperbola shown by the following formula just as in the case of photosynthetic activity and light intensity:

$$a_1 = a_2 \frac{S}{S+500} \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

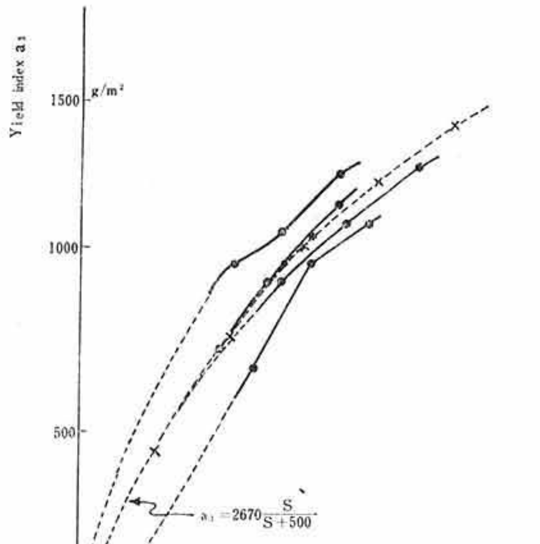

Fig.2. Relation in shading tests between the yield index and the amount of solar radiation during the thirty days after heading (S) (1965).

a_1 : The calculated values free from the effect of N.

where a_2 stands for the rice yield index (g/m^2) free from the effect of both the number of spikelets and the amount of solar radiation, and S, for the amoumt of solar radiation during the thirty days after heading ($cal/cm^2 \cdot day$), respectively.

No "saturation point" seemed to exist at lower intensities of solar radiation than 500 $cal/cm^2 \cdot day$ within the range of usual temperature.

Using the formula (2), the yield index a_2 which represents the effect of other factors than N and S was calculated from given data, and then the relationship between a_2 and the air-temperature during thirty days after heading (T, °C) was investigated.

This relation was proved to be a mono-polar curve decreasing slowly on the high temperature side and rapidly on the low temperature side, respectively (Fig.3). This curve had the optimum point for a_2 at 20~21°C.

The relationship between T and a_2 seemed to vary according to variety ; namely, at low temperatures those varieties having longer vegetative growth stage with more leaves seemed to show higher values of a_2, while, on the contrary, at high temperatures those varieties with less leaves seemed to display higher values of a_2.

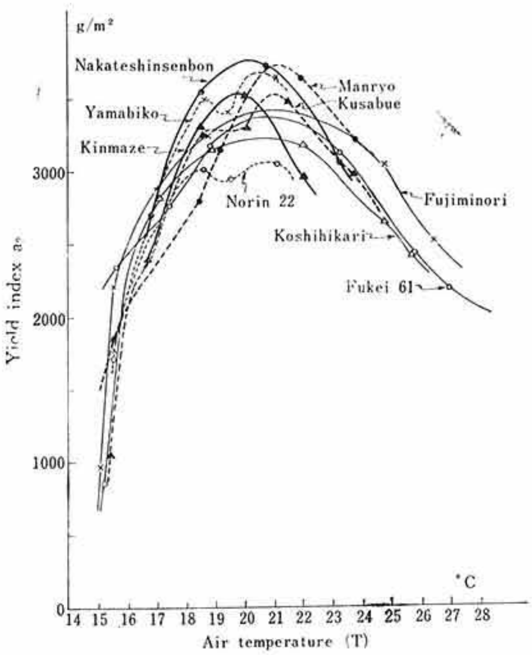

Fig.3. Relation within a variety between the yield index and the air-temperature (T) (1965).
a^2 : A calculated value free from the effects of both N and S.
T : Mean daily air-temperature during thirty days after heading.

Then, the interrelationships among a_2, T, and the leaf weight per square meter at heading stage (LB, g/m^2) were analyzed. The relationship between a_2 and LB could generally be expressed by a mono-polar curve. At higher temperatures the curve became steeper with a lower maximum point, that is, an optimum point for the yield.

The graph showing the composite effect of the leaf weight (LB) and the air-temperature (T) was illustrated in Fig. 4., where the function F(LB,T) stands for this composite effect.

Fig. 5. shows the relationship between the air-temperature (T) and the optimum leaf weight

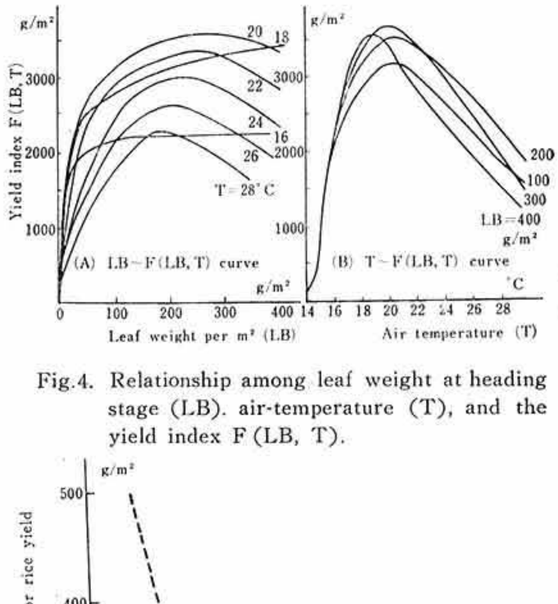

Fig.4. Relationship among leaf weight at heading stage (LB). air-temperature (T), and the yield index F (LB, T).

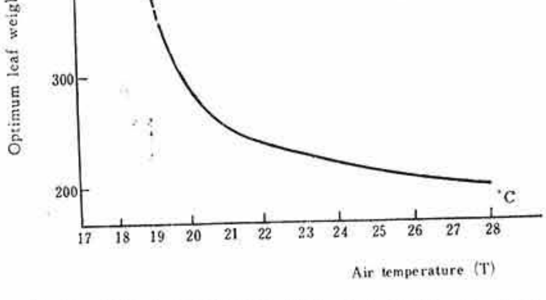

Fig.5. Air temperature (T) and optimum leaf weight for the rice yield.

for the rice yield, and Fig. 6. shows a threedimentional relationship among T, LB, and the yield index F(LB,T).

In spite of excluding the above effects of four factors (N, LB, S and T), this yield index (a_2/F(LB,T)) still showed a little deviation. They seemed to vary little with the culture season, but a little with the varieties (Table 1. for example).

Table 1. Comparison among cultivation seasons or varietes, as an example, in the yield index a_v excluding the effects of N, LB, S and T.

Variety	No.	a_1	S cal/cm²·day	T °C	a_v
Koshihikari	2	1170	459	25.9	0.935
	3	1230	427	24.8	0.985
	4	1270	330	22.0	0.952
	5	1310	347	18.9	0.935
	6	1210	370	17.1	0.983
	mean				0.958
	5	1470	325	20.8	1.057
Nakate-shin	6	1470	325	20.8	1.057
senbon	7	1140	373	16.9	1.015
	mean				1.034

No. : No. of cultivation seasons. Each differs in planting date.
a_1 : Yield index (g/m²), Y/(N/N+5×10⁴).
a_v : a_1/(S/S+500). F(LB, T).

The varietal difference was called as the varietal characteristics index (a_v), whose values for main varieties at Chugoku district were calculated from given data (Table 2.).

Table 2. The Varietal index of productivity a_v as main varieties at Chugoku district

Variety	Varietal index
Fukei 61	1.003
Fujiminori	1.015
Koshihikari	0.958
Manryo	0.976
Kusabue	1.001
Yamabiko	1.042
Norin 22	0.902
Nakateshinsenbon	1.034
Kinmaze	0.981

From these results, the following rice yield formula which includes the factors of the number of spikelets (N), leaf weight (LB), the amount of solar radiation (S), air-temperature (T), and the varietal index (a_v) has been proposed:

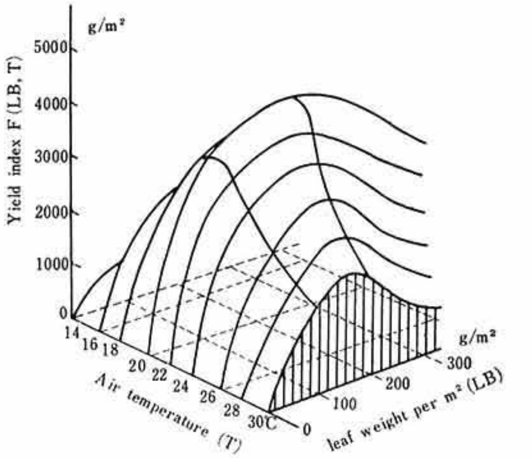

Fig.6. Three-dimensional relationship among air temperature, leaf weight and the yield index F (LB, T)

$$Y=\alpha \cdot a_v \cdot \frac{N}{N+5\times10^4} \cdot \frac{S}{S+500} \cdot F(LB,T) \quad \cdots\cdots(3)$$

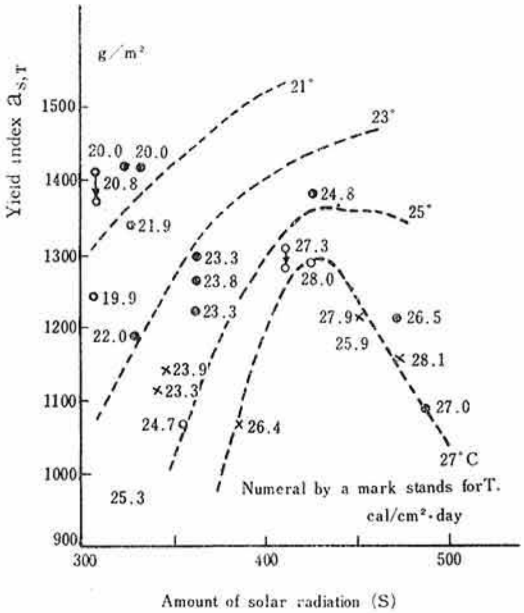

Fig.7. Effect of the amount of solar radiation(S) and the air-temperature (T) on the rice yield (As,T).
S, T : Daily mean value during thirty days after heading
As,T,: A calculated value free from the effects of N and LB.

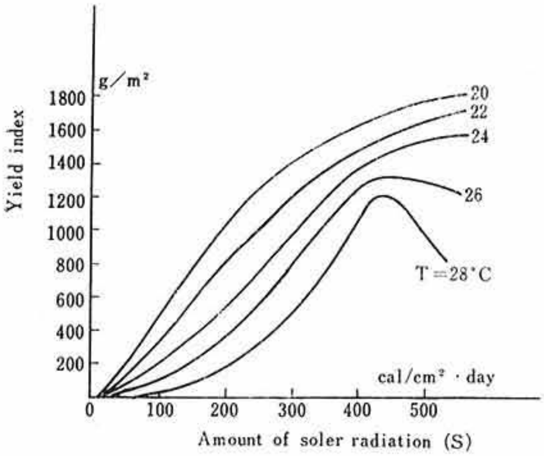

Fig.8. Effect of solar radiation on the rice yield at various air-temperatures.

where α stands for the index of technical level in rice culture ($\alpha=1$, in this experiment).

In addition to this, investigation on the five-year data has revealed that the hyperbolic relationship is not always found between the rice yield and the amount of solar radiation. At extremely high temperatures (T>27°C), the solar radiation stronger than 450 cal/cm² day seemed to give negative effects on the rice yield (Fig. 7.), and the effect of weaker solar radiation than 100 cal/cm² day seemed to be shown by a sigmoid curve (Fig. 8.).

Except for these ranges of temperature, however, the effect of the amount of solar radiation seems to be shown by the hyperbolic curve.

References

1) Murata, Y. : On the influence of solar radiation and air temperature upon the local differences in the productivity of paddy rice in Japan. Proc. Crop. Sci., Japan 33, 59-63(1964).

2) Munakata, K., Kawasaki I., and Kariya K.: Quantitative studies on the effects of the climatic factors on the productivity of rice. Bull. Chugoku Agr. Exp. Sta. A 14, 59-96(1967).