# 水稲生産量の農業気候的表示方法に関する研究(1)

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# Studies on the Agro-climatological Method for Expressing the Paddy Rice Products

## Part 1. An agro-climatic index for expressing the quantity of ripening of the paddy rice

Juro HANYU, Tatsuro UCHIJIMA and Satoshi SUGAWARA

## I. INTRODUCTION

Crop seems to be a kind of factory which produce carbohydrates by solar radiation energy. But the difference of crop from the normal factory is that it enlarges its own body by absorbed energy and consequently, increases more and more the amount of its own absorbed energy. This phenomenon resembles closely to an increment of the principal on bank deposit or to the growth of a snow-ball falling down a slope. The rate of enlargement of the plant body will be greatly controlled by energy balance of the plant body, and by temperature conditions, and moreover by soil conditions, varieties of plant, and cultivation techniques. Consequently, productive processes of the yield are very complex. In order to make agricultural productions efficiently, needless to say, crop sort and variety must be selected in consideration of the climate, and agricultural form and cultivation technique must be approached the type adapted to climatic conditions.

The efforts to put together climatic conditions to agricultural production, particularly, many studies on the relationships between rice yields and weather have been made from the view of practical forecast of yield. Among these, the vast studies by Daigo (1947, 1949) are notable. Later, various yield forecast equations by weather conditions have been prepared by each office belonging to the Statistic and Investigation Division, the Ministry of Agriculture and Forestry (MAF), and by many other research workers. What are common among them were to forecast the yield statistically as exactly as possible. But, they were neither to find the general law between yield and weather, nor to find the possibility of harvest relative to weather conditions. For, as the yields were affected by soil conditions, rice varieties or cultural conditions, it was difficult to forecast the yield over a wide area from a simple climatic equation, with practically sufficient exactness.

On the other hand, trials to judge the stability of agricultural products and land adaptability for crop culture have been done by many authors from a viewpoint of climatology, using the climatic index that collectively expresses the state of climate. However, if the place is appointed, the value of climatic index is fixed, but amounts of field products will change gradually with the advance of cultivation techniques. Accordingly, the effort to combine both the above factors, i. e. the amount of field products and the fixed climatic index, is inconsistent essentially. In order to solve such difficulty, it is important to find the index estimating the volume of climate-resources, with the consideration that important climatic factors for field products are not the simple climatic index expressing some elements, but the volume of climate-resources.

We have considered "the volume of climate-resources affecting amounts of field products"*) as *the climatic productivity*. In other word, *the climatic productivity* is "the volume of climate-resources expressing possibility in agricultural production under a certain technical level". We make its index only to call *the climatic productivity index*. It has been known that the climatic optimum conditions are different according to sort of crop, and even in a crop the required amounts of the climate-resources will be different in every variety. For example, though abundant rainfall and high temperature are favorable for the production of paddy rice, these are not so for the sugar beet production. The climatic optimum condition to *japonica* type varieties will be different from that to *indica* type varieties, and even in *japonica* type, the northern varietes and the southern varieties will be characterized by response to climate, respectively. Therefore, it is desirable to make its index every main variety of crops.

Daigo (1949) looked upon the forecast relative yield (i.e. forecasted yield index) calculated from the Daigo's forecast equation of yield as an index that expresses the productivity by climate, and he called it *a climatic production index*. But this index did not mean the index expressing the possibility of production by climate, because the kinds of climatic elements, statistical time intervals and the constants including in his equation changed according to the places. The first report on *the climatic productivity index* was jointly published from Agriculture Forestry Fisheries Research of MAF, and the Rice Production Research in 1964. Afterwards, Murata (1965) who participated in these researches, roported in detail. In these reports, the definition of *the climatic productivity* was not always clear, but it was close to our opinion.

Our intention for study on the expression method of *the climatic productivity* are summarized into the following four points:

(1) Though the determination methods of suitable land and period of crop cultivation by climate have progressed, the method for planning of rice yield is not yet found. Development of such studies may contribute to planning of yield.

(2) If geographic distribution of *the climatic productivity index* is made known, the distribution of difference between this index and the yield may be known. Consequently, the causes of poor yield relatively in the area showing large difference may be investigated.

(3) A guide of cultivation technique for gaining large yield in the regions where *the climatic productivity index* is small, may be shown. For example, in the regions where the index of ripening period is small, if diminution of the index has been caused by deficiency of solar radiation amounts, it may be pointed out that the aim of the breeding is to give the variety a sufficient capacity of ripening under lower solar radiation.

(4) By analyses of the index variances based on the differences of cultivation technical level, a course of cultivation technique for increment of yield may be suggested.

With these intentions, we will describe a method to express *the climatic productivity*. Murata (1964) called for 40 days ranging from 10 days before heading time to 30 days after heading "the productive period of rice yield" and he expressed *the climatic productivity index* by average daily mean air temperature and average daily insolation amounts of this period.

*) Z. Uchijima (1964) have called it as "the climatic fertility".

However, we want to look for the index which contain climatic elements of longer duration as far as possible, for it is considered that the yield is affected by climatic conditions during a whole life period of plant. In this paper, first of all, we report the results we have analysed of relationships between climate and quantity of ripening after heading time.

## Ⅱ. RELATIONSHIPS BETWEEN QUANTITY OF RIPENING AND CLIMATIC CONDITIONS

On the degree of ripening to air temperature, Tanaka (1962) reported in deail that the critical temperature for perfect development of rice grains was 22 °C of average air temperature (mean of daily maximum and minimum air temperature) for 40 days after heading time and the critical temperature to obtain practical yield was 20 °C, if it becomes below 20 °C the damage of ripening increases remarkably. Murata (1964) studied the relationships of average rice yields in every prefecture to average air temperature (mean of observations of several time in one day) and solar radiation for 40 days ranging from 10 days before heading time to 30 days after heading, and showed the following equation as an index ($s \cdot f(t)$) of climatic productivity.

$$s \cdot f(t) = s \{1.20 - 0.021 (\theta_o - 21.5)^2\} \qquad (1)$$

Where $\theta_o$ is the average air temperature for 40 days ranging from 10 days before heading time to 30 days after heading and $s$, average amount of solar radiation per day in the same period.

In the report of Tanaka, solar radiaton having a great influence on quantity of ripening had not been considered. On the other hand, the statistic period in Murata's equation was a little before ripening period. We considered that ripening period was for 40 days after heading time with the same opinion as Tanaka, and tried to analyse the relationships between quantity of ripening and the climatic condition during ripening period.

1. Method

Materials used were the results of *the routine experiments on the response of paddy rice to climate* at the 42 stations (Table 1) throughout the country where the Statistic and Investigation Division, MAF, stands, from 1955 to 1959, and it contained 35 varieties. As the indicator of quantity of ripening, we used the total weight of rice grains ($Y$) (=weight of perfect rice grains + weight of imperfect rice grains). On the other hand, as climatic elements have relation to quantity of ripening, we used average values of daily mean air temperatures $\theta_m$ (mean of daily maxidmum and minimum air temperature) and total hours ($S$) of sun-shine for 40 days after heading time. Reasons for employing sunshine hours were due to the following to some facts, that is, the accuracy of Robitzsh pyrheliographs in most places were not uniform and were uncertain, moreover, their data of solar radiation were hard to obtain. It has been known that duration of sunshine is considerably correlative to amounts of solar radiation (e. g. Inoue (1952)).

2. *The climatic index on quantity of ripening*

It was difficult to find a certain correlation between $Y$ and $\theta_m$ or $Y$ and $S$, respectively. But the relationship between $Y/S$ (that is, a quantity of ripening per one hour of sunshine; the ripening efficiency by sunshine) and $\theta_m$ was obtained as shown in Fig.1, similar to Murata's equation. Plots are almost uniformly scattered in the parabolic area, and it is difficult to induce

Table 1. Employed experiment Places

| Region | Place |
|---|---|
| Hokkaidō | Kitami<br>Nagayama<br>Kotoni |
| Tōhoku | Kuroishi<br>Fujisaka<br>Morioka<br>Esashi<br>Furukawa<br>Sendai<br>Akita<br>Oomagari<br>Fujishima<br>Yamagata<br>Sēma<br>Kōriyama<br>Aizubange |
| Hokuriku | Takada<br>Fukui |
| Kantō-Tōsan | Mito<br>Maebashi<br>Kōnosu<br>Chiba<br>Kōfu<br>Nagano |
| Tōkai-Kinki | Gifu<br>Shizuoka<br>Anjyō<br>Issinden<br>Nara<br>Kusatsu |
| Chūgoku | Himeji<br>Tottori<br>Okayama<br>Yamaguchi |
| Shikoku | Zentsūji<br>Matsuyama<br>Kōchi |
| Kyūshū | Hainuzuka<br>Kumamoto<br>Ōita<br>Miyazaki<br>Kagoshima |

a relationship. However, if the lower values of $Y/S$ at a definite temperature grade occur on account of restriction of assimilation efficiency by differences of other climatic conditions, soil conditions and cultivation methods etc, and if such restricted elements are eliminated by some effective methods, these values would move into the high range of efficiency.

According to the above assumption, when only five plots at a higher rank of $Y/S$ values containing within interval of every 1 °C (they are shown by large black points in Fig. 1) are adopted, the parabola as shown in Fig. 1 is drawn and the following equation is obtained by the method of least squares.

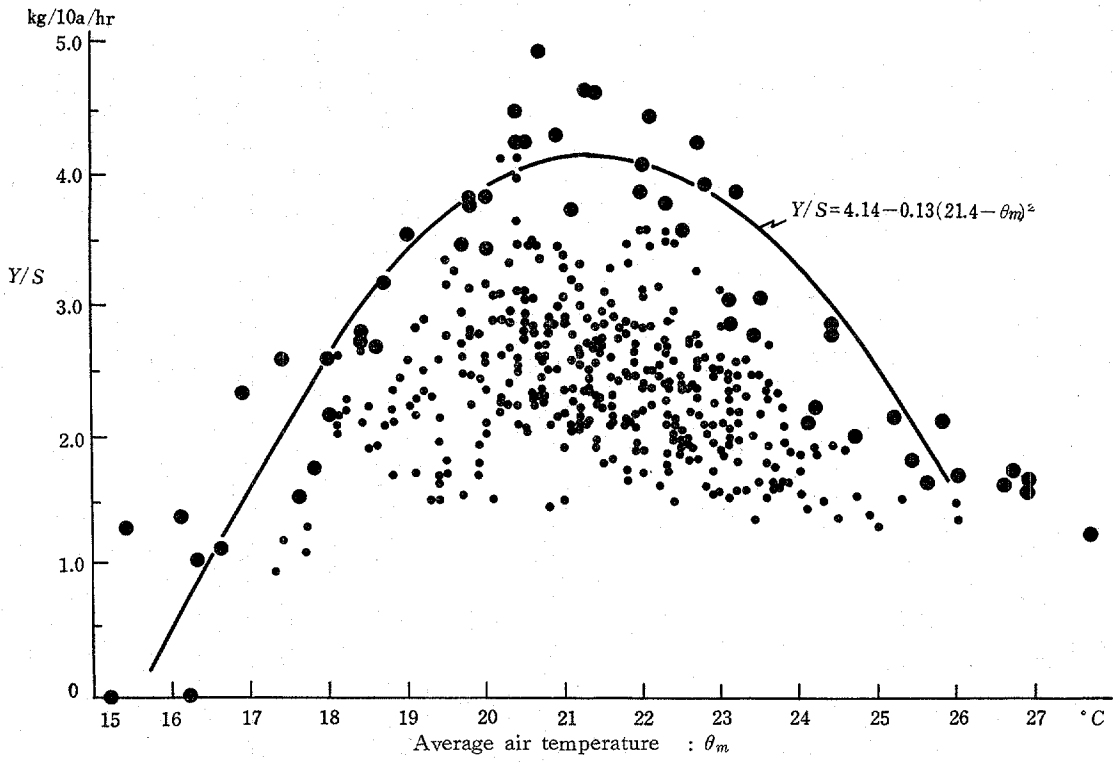


Fig. 1. Relationship between total weight of rice grains ($Y$) per one hour of sunshine ($S$) and average daily air temperature ($\theta_m$) in ripening period ranging from heading time to 40th day after heading.

$$Y/S=4.14-0.13\ (21.4-\theta_m)^2 \qquad (2)$$

Judging a quantity of ripening ($Y$) satisfying Eq. (2) to be "the quantitative index of climate-resources signifying a quantitative possibility of ripening in the technical level of *the routine experiments on the response of paddy rice to climate*, we call them *the climatic index on quantity of ripening* ($Yr$), that is,

$$(Yr)=S\ \{4.14-0.13(21.4-\theta_m)^2\} \qquad (3)$$

$Yr$ correspond to the unit weight ($kg$) per 10a. The places, where the experiments were carried out, and the varieties and other elements which have been employed to this calculation are shown in Table 2.

Eq. (3) is of the same type as Eq. (1), and the temperature corresponding to the largest value of $Y/S$ or $s \cdot f(t)$ is nearly equal to 21.5 °C However, the temperature ($\theta_o$) in Eq. (1) is expressed by the average value of observations of several times in one day, but in our eqation it is the average value ($\theta_m$) of daily maximum and minimum air temperatures. According to Hanyu (1962), relationship between both values on the season from May to August in Japan is as follows,

$$\theta_m \fallingdotseq \theta_o+0.05R\ (°C) \qquad (4)$$

where $R$ is a diurnal range of temperature, and the above relationship tends to be the same on

Table 1. Employed elements to calculate the index

| Place | Year | Variety | $\theta_m$ | $S$ | $Y$ | $Y/S$ |
|---|---|---|---|---|---|---|
| | | | °C | hr | kg/10a | kg/10a/hr |
| Kitami | 1955 | Norin No. 20 | 17.4 | 163 | 417 | 2.58 |
| | 1956 | 〃 | 15.2 | 218 | 0 | 0 |
| | 1957 | 〃 | 15.4 | 197 | 253 | 1.29 |
| | 1958 | 〃 | 17.6 | 201 | 309 | 1.53 |
| | 1959 | 〃 | 16.3 | 189 | 198 | 1.05 |
| | 1955 | Kyowa | 16.9 | 158 | 369 | 2.34 |
| | 1956 | Norin No. 33 | 16.2 | 250 | 0 | 0 |
| | 1957 | 〃 | 16.1 | 198 | 273 | 1.38 |
| | 1958 | 〃 | 17.8 | 215 | 372 | 1.74 |
| | 1959 | 〃 | 16.6 | 150 | 172 | 1.14 |
| Nagayama | 1957 | Eiko | 18.0 | 201 | 435 | 2.16 |
| Morioka | 1958 | Rikuu No. 132 | 19.8 | 127 | 479 | 3.75 |
| Esashi | 1959 | Sasashigure | 20.7 | 100 | 497 | 4.92 |
| Furukawa | 1958 | Fujisaka No. 5 | 22.0 | 105 | 425 | 4.05 |
| | 1959 | 〃 | 22.7 | 105 | 444 | 4.23 |
| | 1958 | Sasashigure | 21.3 | 104 | 483 | 4.62 |
| | 1959 | 〃 | 22.1 | 116 | 510 | 4.41 |
| Sendai | 1959 | Fujisaka No. 5 | 22.5 | 125 | 439 | 3.54 |
| | 1958 | Norin No. 24 | 22.0 | 121 | 468 | 3.84 |
| Ōmagari | 1958 | Norin No. 49 | 20.9 | 110 | 472 | 4.29 |
| Fujishima | 1958 | Obanazawa No. 1 | 22.8 | 125 | 487 | 3.90 |
| | 1958 | Norin No. 50 | 21.4 | 102 | 469 | 4.62 |
| Yamagata | 1955 | Obanazawa No. 1 | 25.2 | 261 | 552 | 2.10 |
| | 1958 | 〃 | 23.5 | 155 | 469 | 3.03 |
| Sōma | 1958 | Norin No. 10 | 19.8 | 126 | 477 | 3.81 |
| Aizubange | 1958 | Gin-bozu | 20.5 | 131 | 553 | 4.23 |
| Takada | 1958 | Norin No. 1 | 24.4 | 126 | 344 | 2.73 |
| Fukui | 1957 | Norin No. 1 | 25.6 | 249 | 398 | 1.59 |
| | 1958 | 〃 | 25.8 | 216 | 444 | 2.07 |
| | 1959 | 〃 | 26.0 | 273 | 447 | 1.65 |
| Mito | 1955 | Norin No. 1 | 24.1 | 207 | 429 | 2.07 |
| | 1959 | 〃 | 24.4 | 166 | 473 | 2.82 |
| Kōnosu | 1958 | Norin No. 14 | 23.1 | 157 | 444 | 2.82 |
| | 1959 | 〃 | 24.2 | 175 | 384 | 2.19 |
| Chiba | 1955 | Kinki No. 25 | 20.4 | 126 | 565 | 4.47 |
| | 1956 | 〃 | 20.4 | 127 | 536 | 4.23 |
| Kōfu | 1956 | Norin No. 8 | 20.0 | 138 | 472 | 3.42 |
| | 1958 | 〃 | 18.6 | 200 | 529 | 2.67 |
| Nagano | 1955 | Norin No. 10 | 18.7 | 180 | 567 | 3.15 |
| | 1957 | 〃 | 18.0 | 202 | 521 | 2.58 |
| | 1958 | 〃 | 19.0 | 155 | 548 | 3.54 |
| Sizuoka | 1955 | Norin No. 29 | 23.2 | 116 | 445 | 3.84 |
| Nara | 1956 | Senbon-asahi | 21.1 | 135 | 503 | 3.72 |
| Kusatsu | 1956 | Senbon-asahi | 19.7 | 154 | 529 | 3.45 |
| Himeji | 1957 | Senbon-asahi | 18.4 | 185 | 507 | 2.73 |
| Yamaguchi | 1955 | Norin No. 22 | 23.4 | 171 | 466 | 2.73 |
| Zentsūji | 1959 | Norin No. 6 | 24.7 | 247 | 477 | 1.95 |
| | 1951 | Norin No. 8 | 23.1 | 197 | 590 | 3.00 |
| Kōchi | 1955 | Norin No. 1 | 26.9 | 276 | 422 | 1.62 |
| | 1956 | 〃 | 27.7 | 330 | 398 | 1.20 |
| | 1957 | 〃 | 26.9 | 217 | 353 | 1.53 |
| | 1958 | 〃 | 26.7 | 250 | 416 | 1.68 |
| | 1959 | 〃 | 26.6 | 267 | 425 | 1.59 |
| | 1955 | Norin No. 22 | 25.4 | 256 | 454 | 2.07 |
| Ōita | 1956 | Norin No. 18 | 20.0 | 155 | 589 | 3.81 |
| | 1957 | 〃 | 18.4 | 214 | 594 | 2.79 |

Note: $\theta_m$ ; Average value of daily mean air temperature.
$S$ ; Accumulated hours of sunshine.
$Y$ ; Total weight of rice grains per 10a.

September, too.

If $R$ is about 10 °C, the difference between $\theta_m$ and $\theta_o$ is

$$\Delta\theta = \theta_m - \theta_o \fallingdotseq 0.5 \ (°C) \qquad (5)$$

Therefore, 21.5 °C of Murata's equation corresponds to about 22.0 °C of $\theta_m$ and is about 0.5 °C higher than the authors' value.

When Eq. (3) is shown by such co-ordinates as Fig. 2 and Fig. 3, inter-relation between the climatic elements constituting the index is made clear. Particularly, Fig. 2 may be useful to comparison of climatic conditions for ripening at various places. Further, using the index-heading time co-ordinate as shown in Fig. 4, variance curve of the index corresponding to heading times can be drawn. This figure may serve to planning of climatic safety cultivation period and as an aid of yield planning. The authors (1965) have already reported a study on climate in ripening period in Tohoku region by the method above described.

## Ⅲ. SUPPLEMENT

The authors are going to find the indexes, as above described, at every growth stage with a period as long as possible, and consequently to find *the climatic productivity index* integrated above individual indexes. Employment of cultivation data under the same technical level is

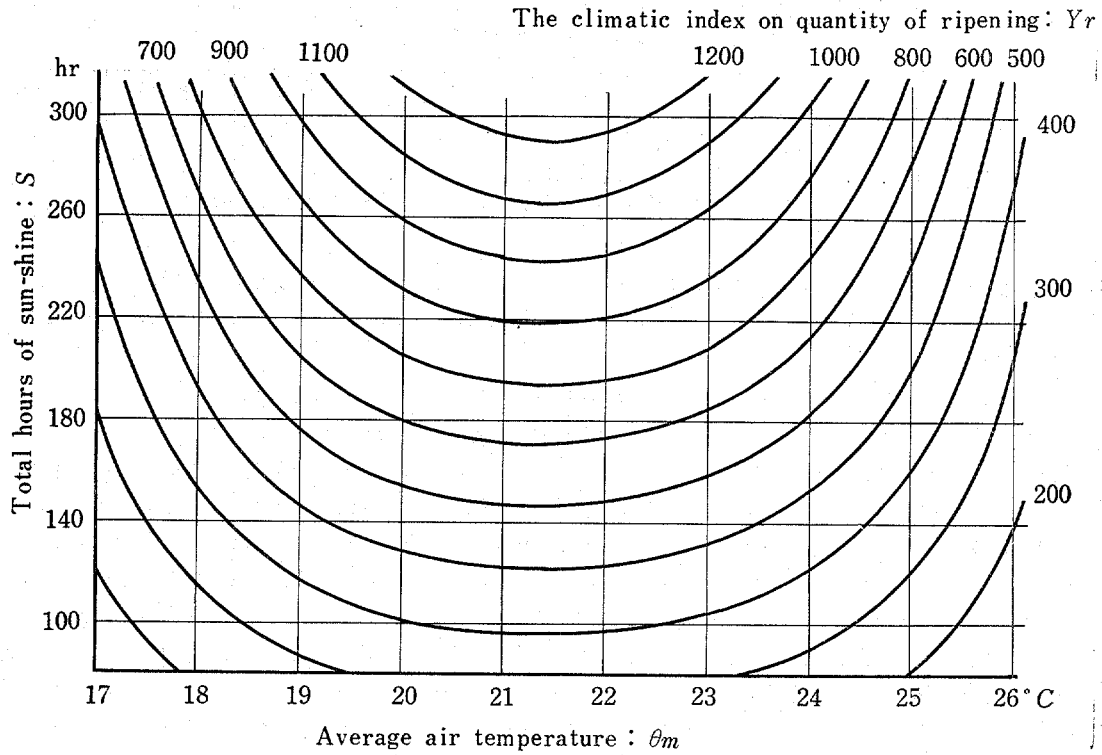


Fig. 2. Inter-relation among the climatic indexes on quantity of ripening ($Yr$), average air temperature ($\theta_m$) and total hours of sunshine ($S$).

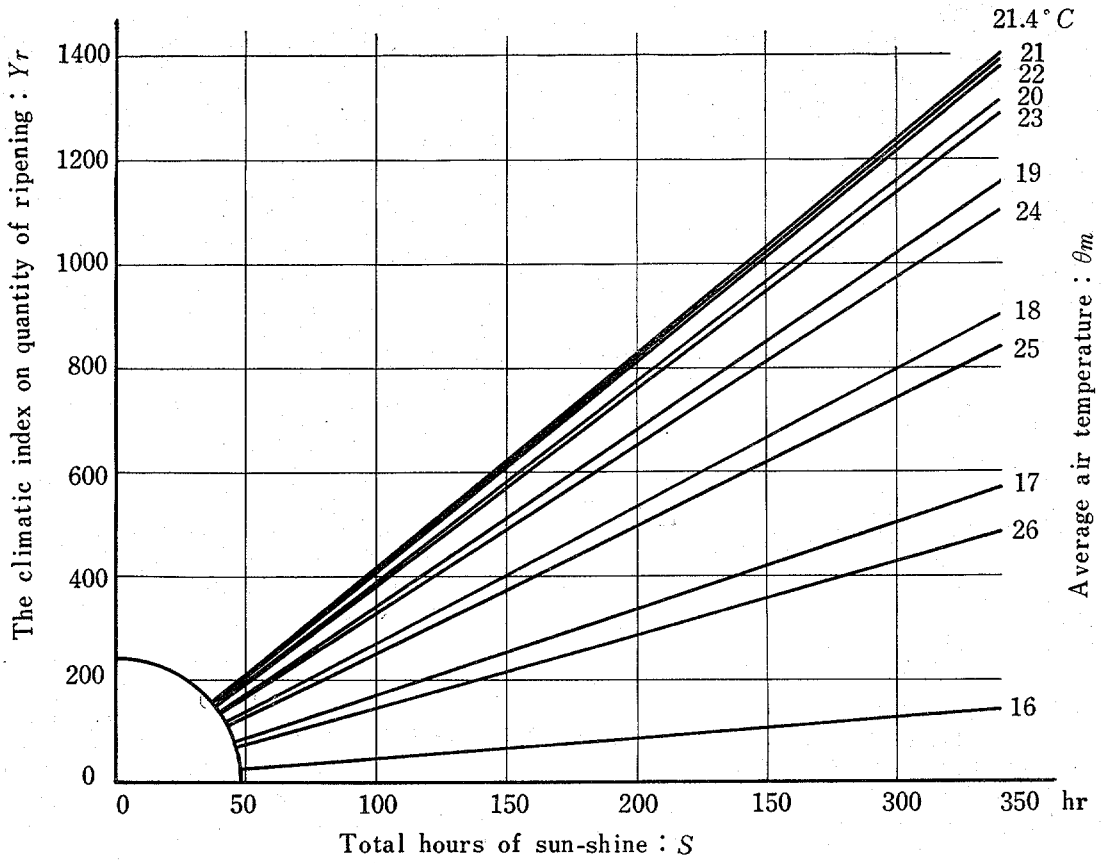


Fig. 3. Inter-relation among the climatic index on quantity of ripening ($Yr$), average air temperature ($\theta_m$) and total hours of sunshine ($S$).

necessary for these studies. Therefore, results of *the routine experiments on the response of paddy rice to climate* in the whole country, which satisfy such conditions and easily obtainable, were employed.

Though an effective method was to analyse the results of the fields of large yields it was difficult to do for lack of detailed data and for difficulty of collecting data. However, it will be necessary to try some time later. As the index we have described is very simple and may still have a few faults, we want to improve upon it in a better form in the future.

As a thought of *the climatic productivity* is a new conception, we are afraid of being misunderstood the true significance of this report. Therefore, we hope that the reader would read again carefully the introduction of Section 1 and further to pay special attention to the following points. In such studies on the index in our country, *japonica* type varieties cultured in recent years have been justly employed for the object of analyses, and it is considered that cultivation data have been obtained under recent cultivation technique. So, under such conditions as varieties other than *japonica* type, as the special paddy fields producing large yields and as some prospective new technical levels, the indexes may be naturally expressed in different types, as

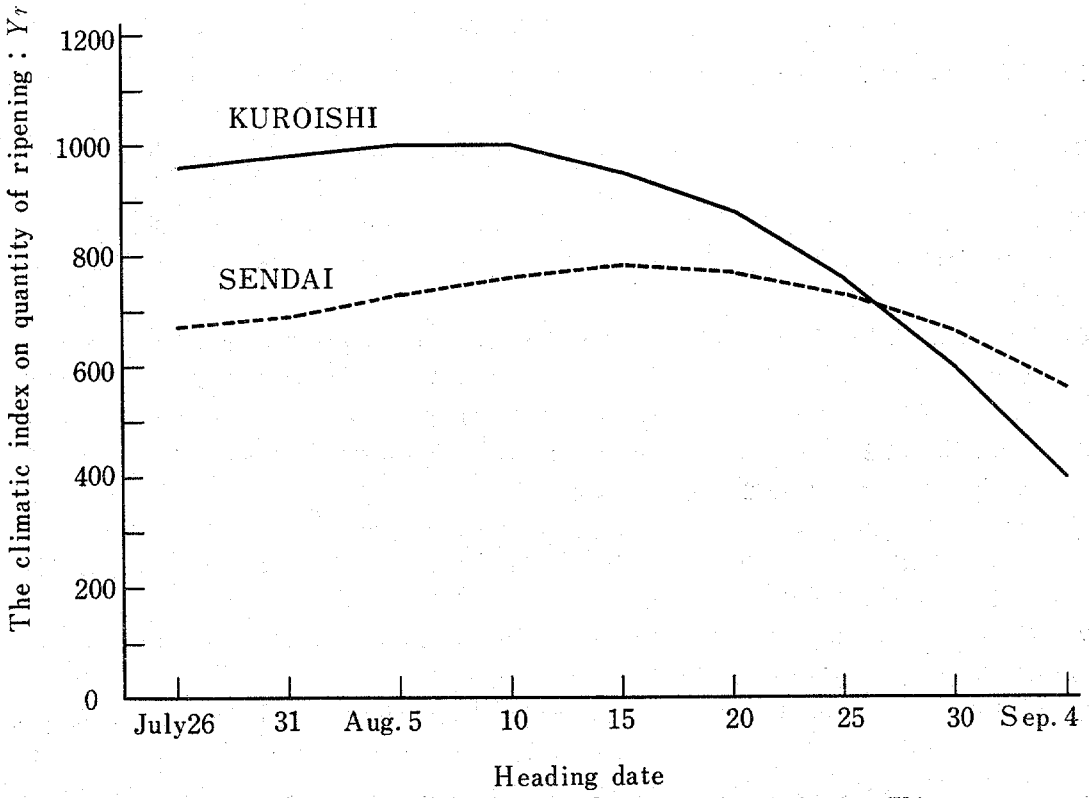


Fig. 4. Relation between *the climatic index on quantity of ripening* (*Yr*) and heading date.

described in the introduction.

An intention of this study is to give suggestions for the course of improvement of cultivation technique in the regions where *the climatic productivity* is low. Therefore, it is desirable that the index is transformed and is raised by the improvement of cultivation technique (containing the selection of variety). Neither we dare to decide possibility of rice yield as the fixed value from climatic condition, nor to ignore effects of cultivation technique. As described in the introduction, *the climatic index on quantity of ripening* is nothing but an index which expresses the volume of climate-resources affecting the ripening quantity during the ripening period. *The climatic productivity* shall be collectively decided from relationship between *the climatic index on quantity of ripening* and *the climatic index on growth amounts* before the heading time. Though it partially overlapped with the introduction, we positively described again for fear we should be misunderstood.

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LITERATURE

1) Daigo, Y. (1947) : A study on the crop-climate in Japan. Asakura Book Co., Ltd., Tokyo. (In Japanese)
2) Daigo, Y. (1947) : Method of prediction on agricultural hazard. Shiryosha Co., Tokyo. (In Japanese)
3) Hanyu, J, (1962) : Type of diurnal variations of air temperature during summer season in Japan (Studies on the agro-climate ; No. 6). J. Agr. Meteor. (Japan). 18 (3), 105-108. (In Japanese with English summary)
4) Hanyu, J., T. Uchijima and S. Sugawara (1965) : On the ripening weathers of paddy rice in 1964 and 1965 in the Tohoku region of Japan by the climatic index on quantity of ripening. Bull. Agr. Meteor. Tohoku Japan. 10, 41-44. (In Japanese)
5) Inoue, N. (1962) : On a method estimating solar radiation amount from hours with sunshine. Agr. Phys. Research 2, 15-23. (In Japanese)
6) Murata, Y. (1964) : On the influence of solar radiations and air temperature upon the local differences in the productivity of paddy rice in Japan. Proc. Crop Sci. Soc. Japan 33 (1), 59-63. (In Japanese with English summary)
7) Agriculture Forestry Fisheries Research & Rice Production Research. (1964) : On the possibility of much yield of paddy rice. (In Japanese)
8) Statistic and Investigation Division, the Ministry of Agriculture and Forestry. (1961) : The experiment results on the response of paddy and upland rice to climate. (In Japanese)
9) Tanaka, M. (1962) : Studies on the growth of lowland rice caused by cool water irrigation and delayed heading. Bull. Aomori Agr. Exp. Station. 7, 1-107. (In Japanese with English summary)
10) Uchijima, Z. (1964) : Lectures on agro-meteorology for agricultural technician (1). Agr. Technique. 19(2), 89-93. (In Japanese)

# 水稲生産量の農業気候的表示方法に関する研究

## 第1報 水稲登熟量を表わす農業気候示数

羽生寿郎・内島立郎・菅原 例

生産される農産物の量を予測したり，栽培適地の定量的判定をしようとする場合，一般気候学的観点から気候の状態を総合的に表わす気候示数によって行うことが妥当でないことを指摘し，〝農業生産に関与する気候資源の大きさ〟という考え方に立って，その大きさを評価する指標を導入することが必要であることを述べた．このような指標を気候生産力と名付けた．

気候生産力的考え方から，本報では，全国主要地点の気象感応試験のデータを用い，気温，日照時数から，気象感応試験の技術水準での登熟の可能性を表わす気候示数を見出した（(3)式）．この示数を気候登熟量示数と名付けた．この示数は先に村田（1964）が明らかにした気候生産力示数とほぼ同形であった．