GAIN IN CLIMATIC PRODUCTIVITY OF PADDY RICE BY LONG-TERM FORECAST IN JAPAN

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Abstract If long-term detailed weather forecasts were available prior to crop planting in warm periods, many advantages could be seen in paddy rice cultivation. In this paper, the gain in climatic productivity, mainly by determining the most suitable heading period, is discussed through using a climatic productivity model of paddy rice (Sugihara and Hanyu, 1980). This model of Y_p, assuming the most profitable selection of cultivating varieties, indicates the maximum yield under certain climatic conditions.

For example, if a suitable heading period could have been applied to some of the areas that suffered damage in the coolest summer in recent years–1980, then roughly more than 10% of the decrease could have been save. In addition, the effect of a monthly decrease in mean air temperature of 2°C in warm periods is also examined.

Finally, the relationship between relative Y_p and relative crops in 1980 is discussed.

1. Introduction

By fully knowing an anomal monthly mean air temperature in warm period before planting, there may be more advantages to paddy rice cultivation such as;

a) selection of the most profitable varieties,
b) determination of the most suitable cultivation period,
c) application of the most profitable cultivating technique,
d) estimation of productivity improvement,
e) others .

The maximum crop yield, which could be reached under certain climatic conditions and a certain technical level of cultivation, was named "the climatic productivity" by Hanyu et al. (1966). However, the obvious quantative relation between yield of rice and climate has not been obtained, known by the proceedings of the symposium on "Climate and Rice", which is held by I.R.R.I (short for the International Rice Research Institute) in 1974. In the discussion after the report by R. Huke, "Geography and climate of rice", Fischer asked, "What improvements can be anticipated in the art of pre-crop season forecasting, i.e., 3 to 6 month long-term forecasts ahead of the crop season? Secondly, how would these improvements affect planting strategies and productivity?" Concerning the second question, Nix said, "I think the question raised by Dr. Fischer is central to the theme of this symposium. Do we understand the relationship between climate and crops well enough to be able to predict what would happen if we could predict the weather ahead?"

The author and Hanyu have proposed a climatic productivity model; namely an index which estimates the climatic productivity of paddy rice in Japan (denoted by Y_p) (1980), as the author has noted the same subject of Fischer or Nix. The aim of this report is to indicate some examples of the estimation of gain by "long-term forecasting" on climatic productivity based on the Y_p index.

With regard to Y_p including the method of introduction and the formula, the author has introduced in the previous report, as applicational research based on Y_p (Sugihara, 1981), so that only the formula of it is given as follows:

$$Y_p = ln(1+S_R/M_G)\cdot\{260-2.70\cdot(\theta_R-\theta_o)^2\} \tag{1}$$

where M_G is "climatic index of growth" involving θ_V (mean air temperature-over the period 50th–36th day prior to heading) and θ_H (same as θ_V but for 25th–1st day), and S_R denotes the duration of sunshine, θ_R the mean air temperature during the ripening period (40 days after heading), and $\theta_o = 21.5^\circ C$.

For instance, if we gain tentatively $-2^\circ C$ from the source material, as a monthly anomal temperature in warm period, the possibility of improving productivity concerns could be obtained for paddy rice cultivation by estimating the most suitable heading date in advance.

In the following descriptions, productive efficiency of a long-range forecast affecting paddy rice cultivation is shown as a result of a study on the cool summer cultivating damages in the year of 1980.

2. Data and Method

For calculating the Y_p of a monthly anomaly, Pentad Normal Data would be used in a usual manner, but Y_p in 1980 has actually been calculated by using Decade Data. The objective points of calculation come from 99 meteorological stations from all over the country.

So as to prepare for forming the monthly mean air temperature anomaly of $-2^\circ C$ during the period of June, the author actually attempted to decrease by $2^\circ C$ the mean of every Pentad (from the 13th to the 18th Pentad) commencing on April 1.

The same method was applied to the other months as well (for reference, the 31st through the 36th – 6 different Pentad instead of the period of September).

In any certain month ($-2^\circ C$), the Y_p index was calculated for every 5 days per Eq. (1) and the M_G index as from the period of July 15, and then made the Y_{po} (a certain month, -2) stand for the maximum value of the Y_p index. The ratio of Y_{po} (a certain month, -2) to the normal Y_{po} is denoted by Y_{por} (a certain month, -2). The Y_p index on the normal suitable heading period in this case is denoted by Y_p (a certain month, -2), and the ratio of it to the normal is denoted as Y_{pr} (a certain month, -2).

Examples of variational Y_{pr} (a certain month, -2) against the heading periods in different regions based on variational patterns of Y_p; namely, Type-A, Type-B, Type-C and Type-D, due to different heading periods (Hanyu and Sugihara, 1981) are illustrated in Fig. 1, where the heavy solid line shows the normal Y_p variational pattern and the maximum of it is Y_{po}. Since the date denoted by an arrow at Y_{po} is the normal S.H.P. (short for the suitable heading period), Y_p (a certain month, −2) is obtained on that date. The gain of Y_p is defined in this paper as the difference between Y_{po} (a certain month, −2) and Y_p (a certain month, −2) in the case when a lag of S.H.P. exists. In addition, the broken curve shows the Y_p variation in the case of a tentative mean air temperature decrease by 2°C through the period of growth.

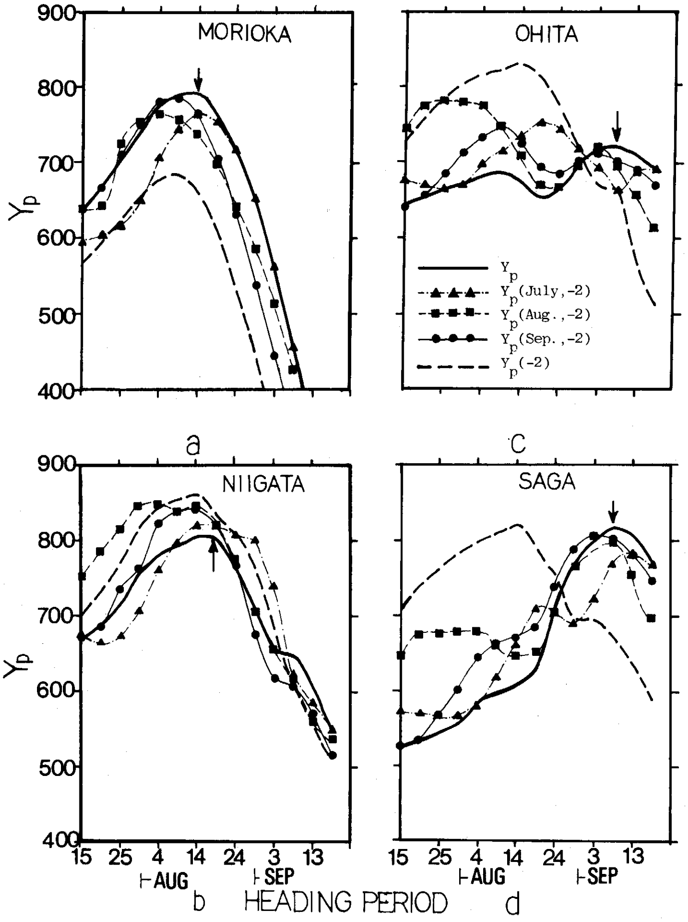

Fig. 1 Variational Y_p due to different heading periods in the case of tentative monthly mean air temperature anomaly by −2°C (thin lines with marks), normal year (thick solid line) and tentative decrease of mean air temperature by 2°C (thick broken line). (a) Morioka (Type-A: the normal Y_p variation having one peak at the 1st to 2nd decade of August), (b) Niigata (Type-B: that having one peak at the 3rd decade of August and a small secondary peak at the 1st decade of September), (c) Ohita (Type-C: that having two peaks in the almost same hight), (d) Saga (Type-D: that having one peak at the 1st decade of September)

In Morioka, Aug. 14 is the normal S.H.P., in the case of tentative mean air temperature decrease over a certain month, S.H.P. of Y_{po} (Aug., −2) is earlier than the normal one by 10 days, and that of Y_{po} (Sep., −2) by 5 days. The gain in Y_p reaches 20–30 (kg/10a) but its ratio to the normal Y_{po} is only 1–2%.

In Niigata, the normal S.H.P. is Aug. 19 when each Y_p (a certain month) is almost the same. Y_{po} (Aug., −2) is maximum at S.H.P. earlier by 15 days. Consequently, the gain in Y_{pr} is arround 3%.

In Ohita, when the heading period is advanced by 45 days from the normal S.H.P., the gain in Y_{pr} reaches 14% in the case of Y_{po} (Aug., −2). This example suggests to us that a lot of Y_p gain is produced when the variational Y_p pattern changes from Type-C to Type-B due to a temperature decrease as shown by the broken curve. In addition, in this case the role of long-term forecast is most important.

In Saga, within the monthly mean air temperature anomaly, the variational Y_p pattern does not change as it does in Ohita. However, the same incidence is caused when the mean air temperature decreases through the period of growth.

The Y_p at the normal S.H.P for the year of 1980 is denoted by Y_p (1980) and its maximum by Y_{po} (1980).

3. Result and Consideration

Y_{pr} and Y_{por} distribution in the case of monthly mean temperature anomaly

In each month from July to September, the monthly mean temperature anomaly by −2°C is tentatively calculated and in each case the geographical distributions of Y_{pr} and Y_{por} are shown in Fig. 2 and Fig. 3, respectively.

As the effect of the temperature decrease by −2°C in June is confined to several area points, the distribution maps for Y_{pr} (June, −2) and Y_{por} (June, −2) have been omitted. As the Y_p index contains only the mean temperature for a period of 36 days – 50 days before heading, Y_{pr} (June, −2) (suitable heading date after the 4th Pentad of the period of August) is hardly affected by the decrease. The heading points showing the 2nd Pentad of August as its suitable date can be observed in the areas under 95% or 105% of Y_{pr} (June, −2). However, the area under 95% can not be observed for Y_{por} (June, −2).

In the period for July, the effect of a temperature decrease by 2°C is extended to all areas around the country. It so much influences Y_p (July, −2) that the area under 95% is expanded not only to the northern region and the middle highlands of Japan but also to the middle and the southwestern regions of Japan. The reduction in ratio of Y_p (July, −2) in the latter areas which are caused by an increase of M_G means a decrease of grain production. To recover this loss, we may have to set a suitable heading date based on the newly shifted heading period. When the recovery is realized, no more area under 95% can be seen in the southwestern country in Japan as shown in Fig. 3(a).

In the period for August, the effect of the temperature decrease by 2°C shows the highest decrease ratio of Y_{pr} (Aug., −2) in the northern region of Japan as shown in Fig. 2(b). On the suitable heading date, the decrease ratio of Y_{por} (Aug., −2) could scarcely be recovered as shown in Fig. 3(b). As for the areas with an increase of Y_{por} (Aug., −2) over 105%,

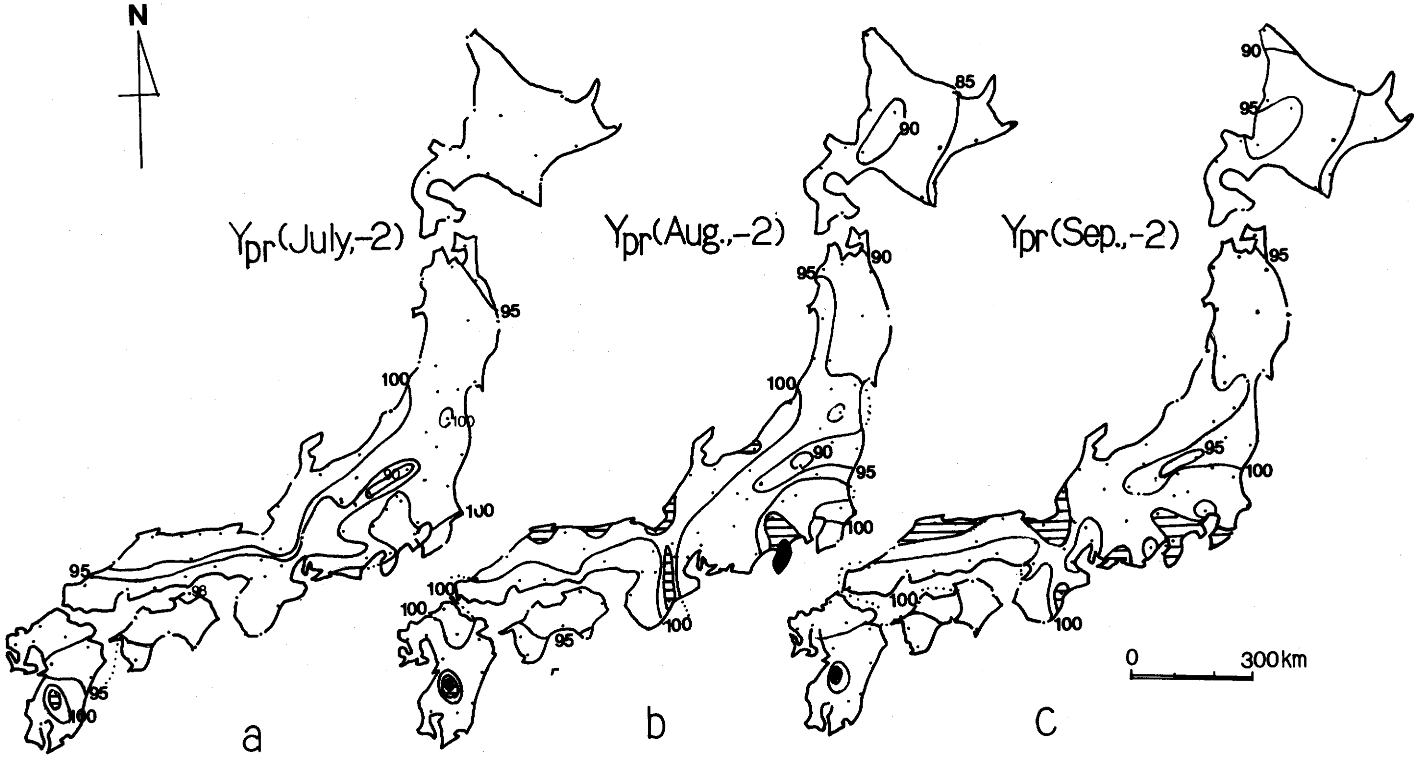

Fig. 2 Geographical distribution of Y_p at the normal suitable heading period relative to the normal maximum Y_p. (a) Y_{pr} (July, −2), (b) Y_{pr} (Aug., −2), and (c) Y_{pr} (Sep., −2). The areas covered with horizontal lines (or black) indicate Y_{pr} more than 105% (or 110%).

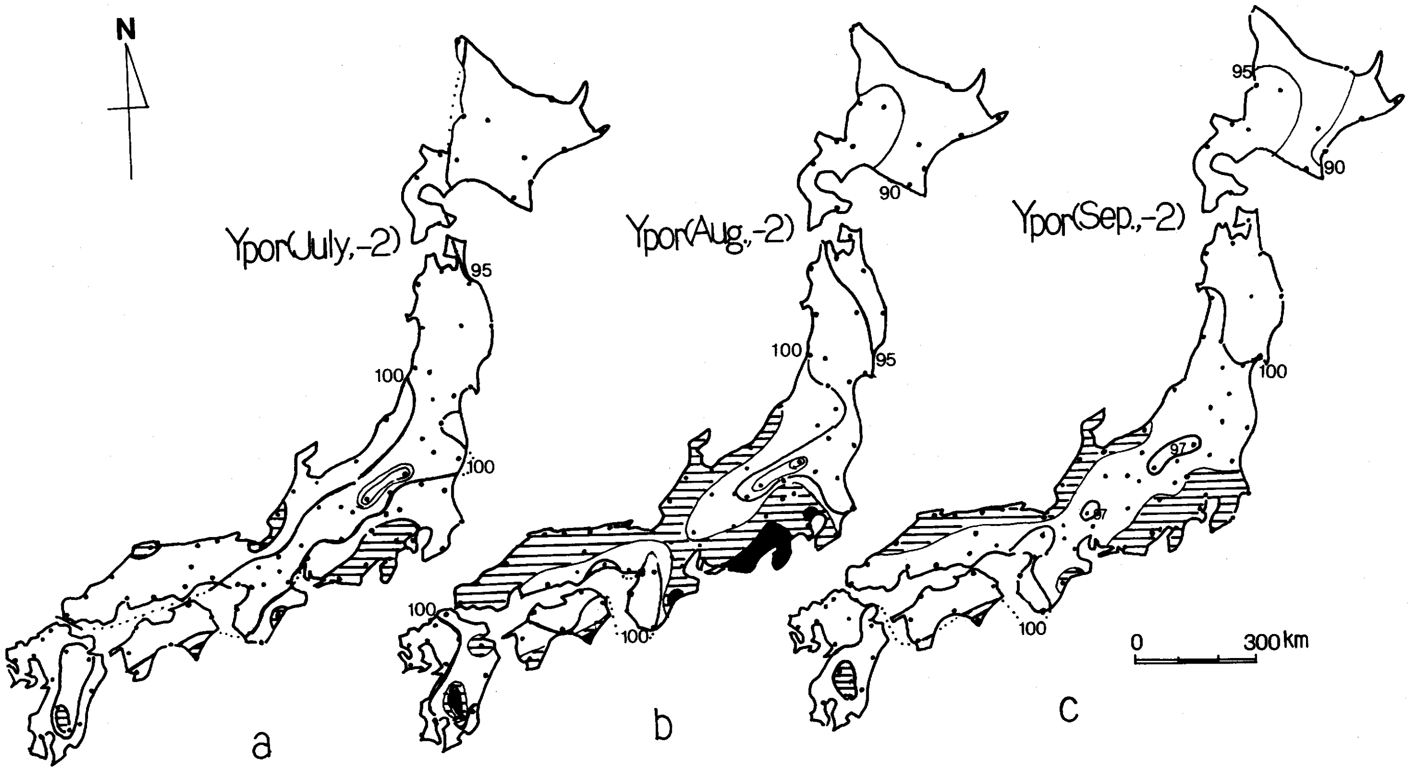

Fig. 3 Geographical distribution of the maximum Y_p in the cases of tentative monthly anomaly by −2°C relative to the normal maximum Y_p. (a) Y_{por} (July, −2), (b) Y_{por} (Aug., −2), and (c) Y_{por} (Sep., −2). The areas covered with horizontal lines (or black) indicate Y_{por} more than 105% (or 110%).

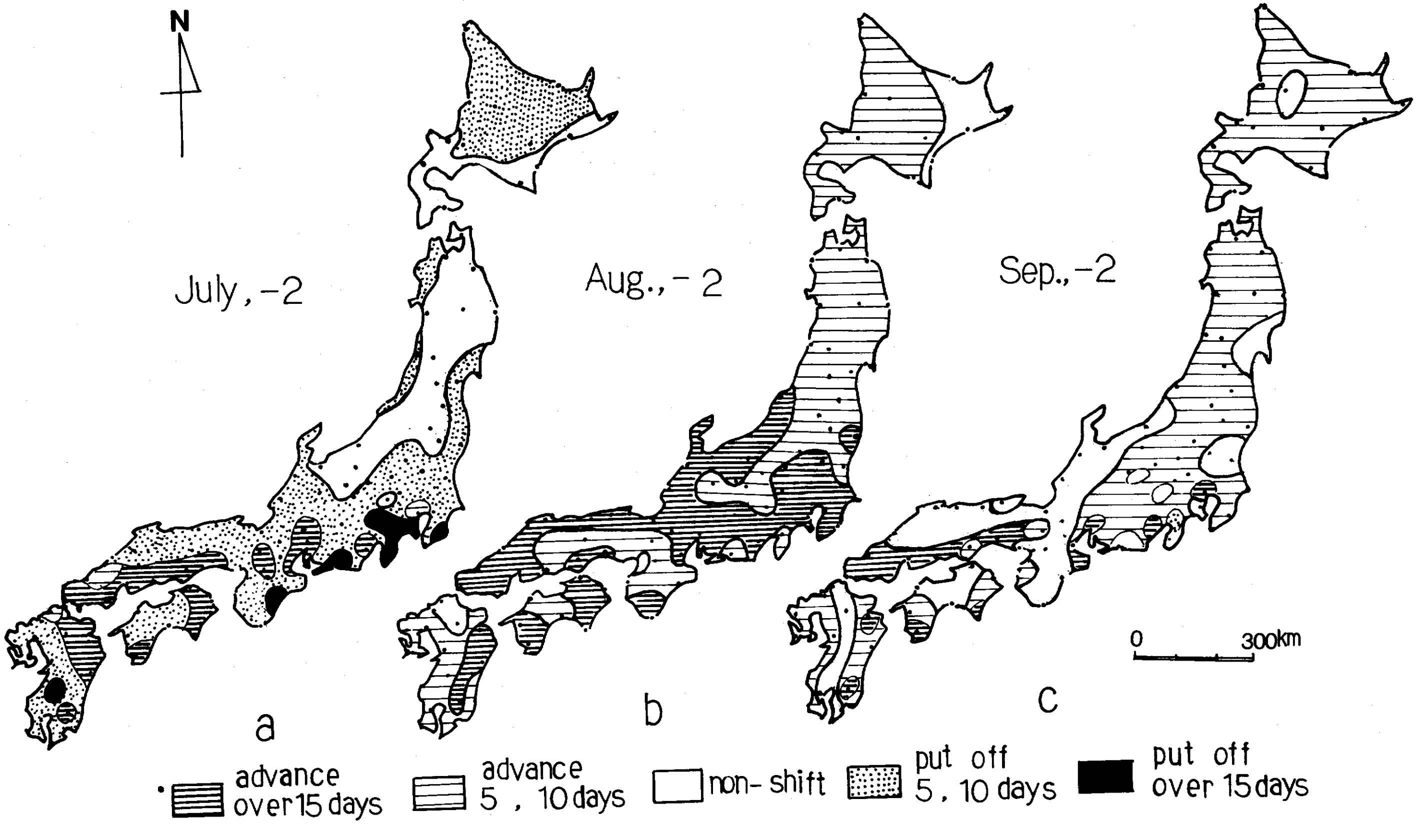

Fig. 4 Geographical distribution of shifting of the suitable heading period in the cases of tentative monthly anomaly by −2°C. (a) In July, (b) In August, and (c) In September.

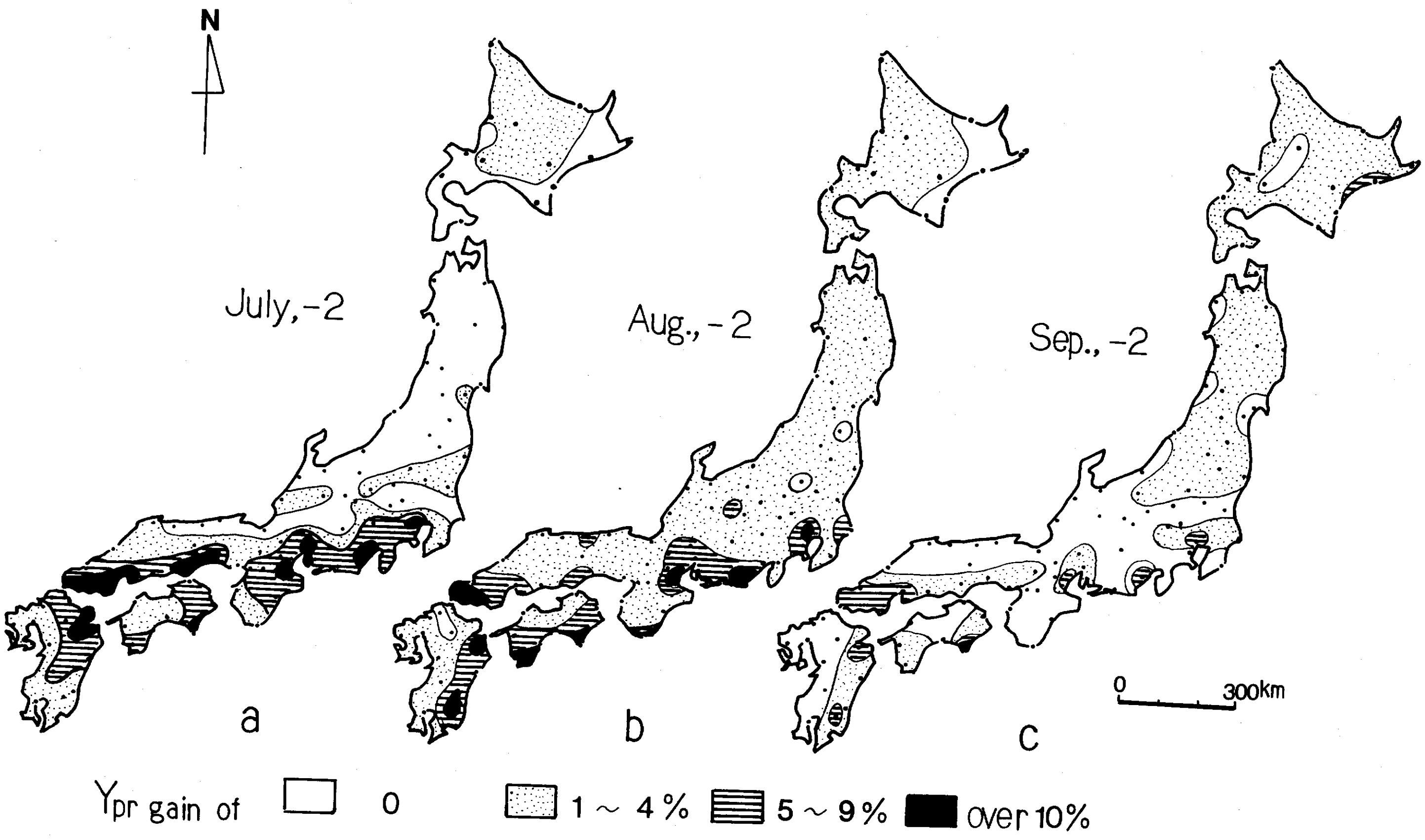

Fig. 5 Geographical distribution of the gain in Y_p (a certain month, −2). (a) July, (b) August, and (c) September.

we can find them in the Hokuriku and Sanin Districts, and in the Tokai and Kanto Districts.

In the period for September, as shown in Fig. 3(c), the effect of the temperature decrease is similar to the period of August but it is not as effective as the period for August.

The gain in Y_{pr} based on each monthly anomaly of mean air temperature

Days which should be shifted so as to obtain the Y_{por} shown in Fig. 3 are distributed geographically in Fig. 4, and the gain in Y_{pr} is illustrated in Fig. 5.

In the period for July, the areas of the central Hokkaido, the north Kanto, and a part of Sanin, a Y_{pr} gain of 1–2% results when the heading period is put off for a period between 5 to 10 days, as shown in Fig. 4(a). In addition, the areas where S.H.P. is advanced more than 15 days contain areas of Y_{pr} gain of more than 5%. This incidence has been already ascertained in Fig. 1, as is shown in the example of Ohita.

As for the monthly mean air temperature of −2°C in the period for August, shown in Fig. 4(b) and Fig. 5(b), the S.H.P. should be advanced all over the country, and then in the northern regions, the gain in Y_{pr} of 1–2% is certainly produced. In the southwestern regions, as the case of Ohita, the gain in Y_{pr} of 5–10% is produced due to advancement of S.H.P. by over 15 days.

In the period for September, S.H.P. should also be advanced by 5 days in most of the northern regions. The gain in Y_{pr} in this area is only 1%. In southwestern regions, the gain in Y_{pr} concerning Type-C reaches 5%.

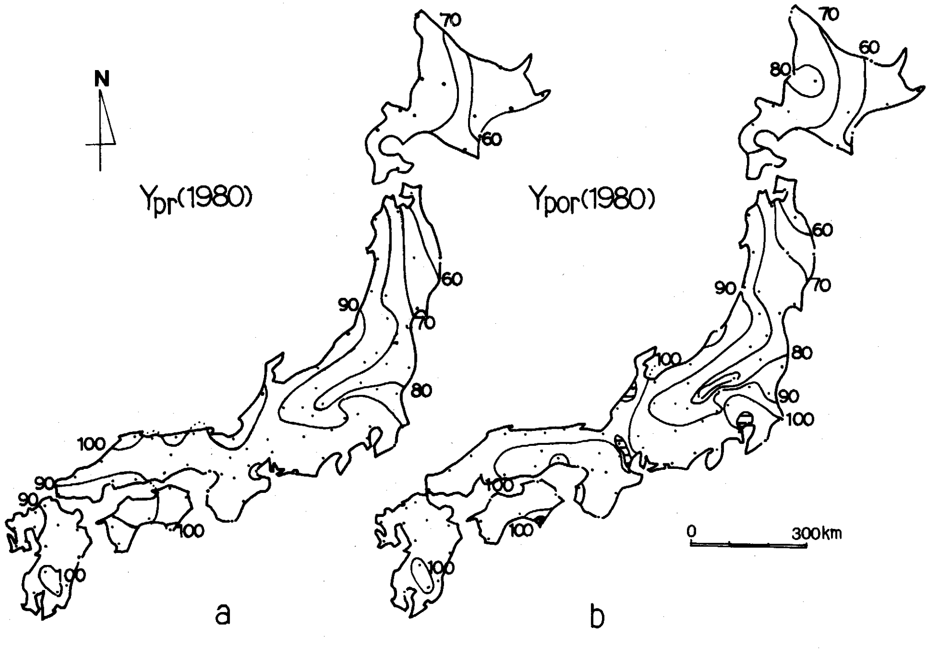

Fig. 6 Geographical distribution of Y_p at the normal suitable heading period relative to the normal maximum Y_p (a), and the maximum Y_p relative to the normal maximum Y_p (b) in the coolest summer damage year of 1980.

Y_{pr} and Y_{por} distribution in 1980

The difference between Y_{po} and Y_p is a gain in the climatic productivity made available throught knowledge of S.H.P. An accurate long-term forecast would make possible such knowledge. Fig. 6 is a distribution of Y_{pr} (1980) and Y_{por} (1980) during the coolest summer for over 50 years. The isopleth $Y_{pr} = 90\%$ (a) is being developed over regions to the south and covering northern regions as well. The area roughly corresponds to the area of Type-A with a Y_p variation due to a difference in heading dates. These are the areas with a Y_{pr} under 90% in the southwestern regions, but they show nothing for a Y_{por}(b). The areas over 100% for a Y_{por} are limited to several area points (a). Areas with a Y_{por} over 100% cover a part of the Kanto and Hokuriku Districts, and the entire Sanin District (b).

Y_{pr} gains for all areas around the country are shown in Fig. 7(b). Moreover, a change in S.H.P. can be seen in Fig. 7(a). As shown in Fig. 7(b), areas with Y_{pr} gain of over 10% and 5% are marked with black or horizontal lines, respectively. They are located in central Hokkaido, the Kanto District, a part of the Kinki District, the greater part of the coastland along the Inland Sea, and the northwestern part of the Kyushu District. A gain in Y_{pr} of more than 10% in the Kanto District is produced due to a delayed heading period of more than 10 days, while the same grade of gain in central Hokkaido and the Sanyo District is produced by an advancement of heading period of more than 10 days.

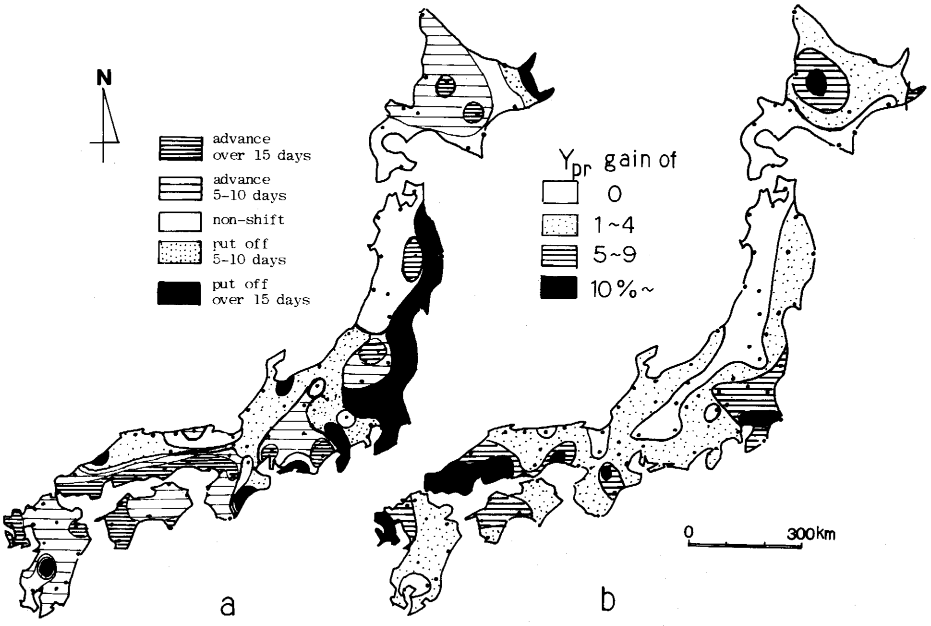

Fig. 7 Geographical distribution of (a) shifting of suitable heading period, and (b) the gain in Y_p relative to the normal maximum Y_p, in 1980.

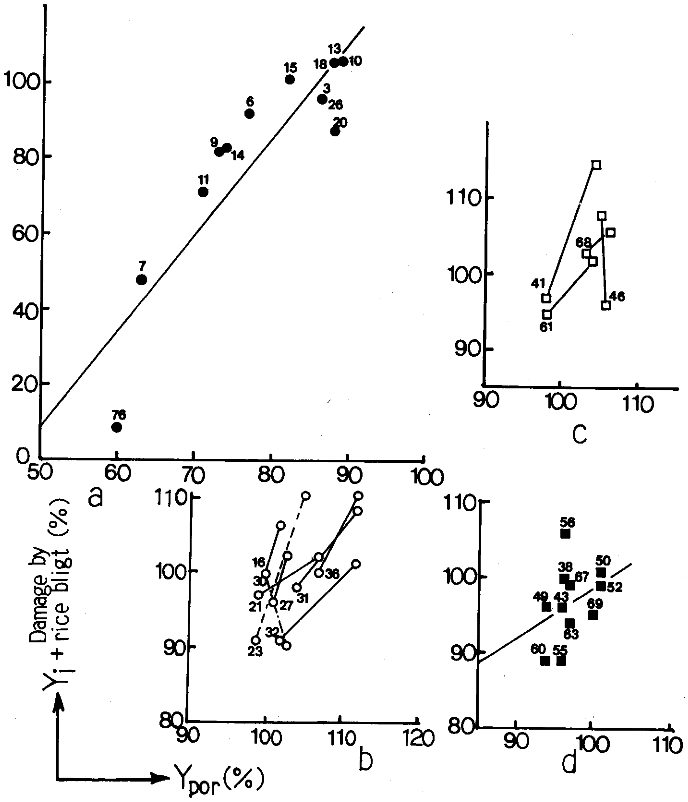

Fig. 8 Relationship between the relative maximum Y_p and the corrected relative yield of 1980 within the divisions of the following variational Y_p patterns. (a) Type-A, (b) Type-B, (c) Type-C, and (d) Type-D. However, (b) and (c) contain the same data of 1976. Numerals at the marks (1980) denote the main productive regions as follows:
3: Kamikawa Basin, 6: Ishikari Plain, 7: Tokachi P., 9: Tsugaru P., 10: Akita P., 11: Kitakami B., 13: Shonai P., 14: Sendai P., 15: Yamagata B., 16: Niigata P., 18: Aizu B., 20: Hamadori Coast, 21: Toyama P., 23: North Kanto P., 26: Matsumoto B., 30: Kujukuri C., 31: Izumo P., 32: Yonago P. 36: Ohmi B., 38: Nohbi P., 41: Enshu nada C., 43: Okayama P., 46: Ise P., 49: Sanuki P., 50: Wakayama P., 52: Tokushima P., 55: Fukuoka P., 56: Kochi P., 60: Tsukushi P., 61: Ohita P., 63: Kumamoto P., 67: Miyazaki P., 68: Miyakonojo B., 69: Kagoshima Bay C., 76: Sanbongihara Plateau

Relationship between Y_{pr} and relative crop

The relationship between Y_{pr} and relative crop is examined in about 36 points of main paddy regions on the scale of plain or basin. The crop (Y_i) is obtained as the ratio of the yield in 1980 at several smallest administration units to the mean yield over 1965 to 1979. At 36 points the correlation coefficient between Y_{por} and Y_i is 0.661 (n=36). As Y_i includes a lot of damage by rice blight, its correction based on prefectural data makes the correlation r=0.718.

The relationship between Y_{por} and the corrected Y_i in 1980 is illustrated concerning every region of variational Y_p pattern due to the heading period in Fig. 8 where portions of b and c contain the same data in 1976 because the two types have only several points. In the division of Type A (the portion of a), the correlation between both is as clear as r=0.916, and the regression coefficient is as high as 2.6. Then, the difference in Y_{por} of 1% could affect that of Y_i by 2%. In the division of Type B (the portion of b), the difference of actual heading period to normal S.H.P. is large (No. 16, No. 21 and No. 30 are the points of early delivery rice, and convercely, No. 23, No. 27 and No. 32 are the points of later season cultivation) and the characteristics of actually cultivated varieties on θ_O seem to differ from the model of Y_p. In the division of Type C, the characteristics of varieties cultivated at the point of No. 46 seems to be different from 21.5°C of Y_p. In the division of Type D, that of point No. 56 also seems to be different from 21.5°C of Y_p.

The author and Hanyu (1982) pointed out that the model of climatic productivity that is suitable for actual cultivated varieties should contain θ_O as a parameter. The parameterized θ_O and the actual mean θ_R are plotted in Fig. 9. Against Y_p with θ_O as constant of 21.5°C,

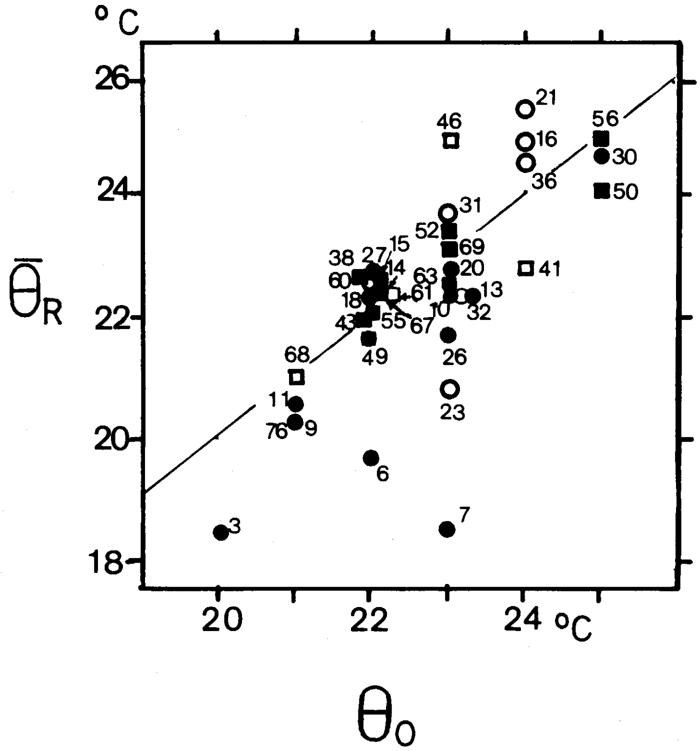

Fig. 9 Relationship between optimum temperature during the ripening period (θ_O) and actual mean air temperature during the ripening period (θ_R) in the 36 main paddy regions denoted by the numerals at the marks.

the climatic productivity model of Y_p with θ_o as a parameter has been denoted by $Y_p(\theta_o)$. It seems that the larger the difference between θ_o and 21.5°C, the greater the actual cultivating varieties are from those suitable for the Y_p model.

Then, the ratio of Y_p, $Y_p(22.5)$ and $Y_p(24.0)$ in 1980 to the normal Y_{po}, $Y_{po}(22.5)$ and $Y_{po}(24.0)$, respectively; namely Y_{pr}, $Y_{pr}(22.5)$, and $Y_{pr}(24.0)$, are illustrated against the different heading periods concerning each point representing each division in Fig. 10. The first example (Type-A) is Sendai with Y_{por}=79%, $Y_{por}(22.5)$=71%, and $Y_{por}(24.0)$= 61% and the difference of Y_{por} reaches no less than 18%. In addition, the occurence date of S.H.P. comes earlier as θ_o is higher. The second example (Type-B) is Niigata (in the portion of b), and the difference in Y_{por} is 14%. The third example is Ohita (Type-C), with the largest Y_{por}, larger by 11%. However, there are no remarkable differences among the three kinds of Y_{por} in Saga (Type-D).

Then $Y_{por}(\theta_o)$ is possibly useful for selecting the most profitable varieties for each year. For example, Type-A of cold districts, in cool summer years such as 1980, the varieties whose optimum temperature during the ripening period is low should be selected. Assuming θ_o=22.5°C on actual cultivated varieties in Sendai, selection of varieties of θ_o=21.5°C leads

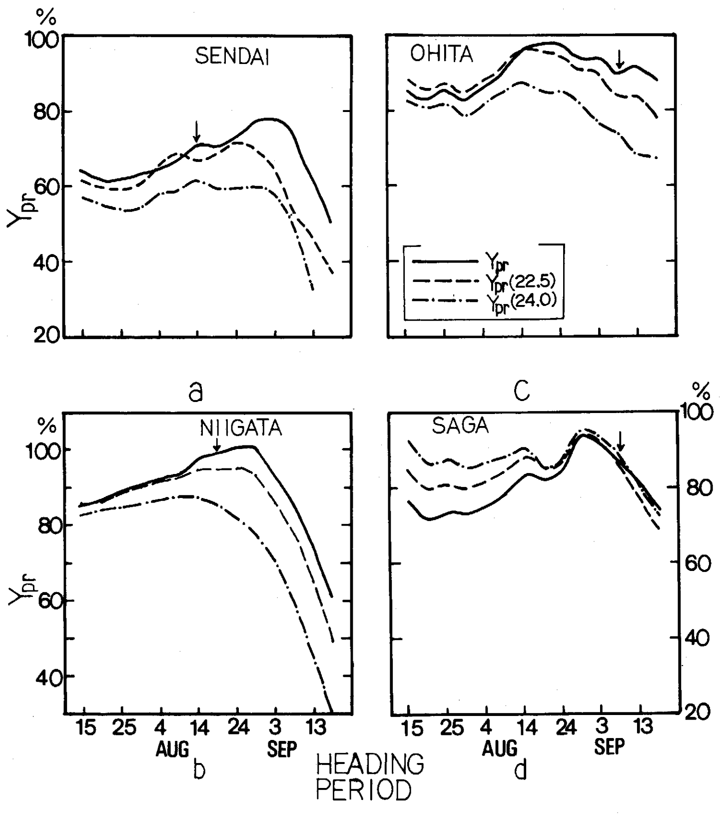

Fig. 10 Variational $Y_p(\theta_o)$ relative to the normal maximum $Y_p(\theta_o)$ due to different heading periods. (a) Sendai, (b) Niigata, (c) Ohita, (d) Saga. Arows show the normal suitable heading period.

the gain in Y_{por} by 8% which is larger than the gain in Y_{pr}(22.5), the difference of Y_{por} (22.5) and Y_{pr} (22.5). The same incidence is seen in Type-B. However, at the points in Type-C and Type-D, the shift of S.H.P. seems to mainly affect the gain in Y_{pr}.

Finally, in the 6 prefectures of the Tohoku District (Type-A) the yields at the different heading periods relative to the yield at normal heading periods has been showed in Crop Statistics of 1980 issued by the Ministry of Agriculture and Fisheries, so the author attempts to compare each $Y_{pr}(\theta_o)$ against different heading periods with the data of relative crops in Fig. 11. According to Fig. 11, the author can estimate the values of θ_o whose Y_{pr} (θ_o) is the most profitable for the relative crop. Estimations are as follows; in Aomori, θ_o=21.5°C, in Iwate θ_o=22.5°C, in Miyagi, θ_o=24.0°C, in Akita, θ_o=21.5°C, in Yamagata, θ_o=22.5°C, and in Fukushima, θ_o=22.5 or 24.0°C.

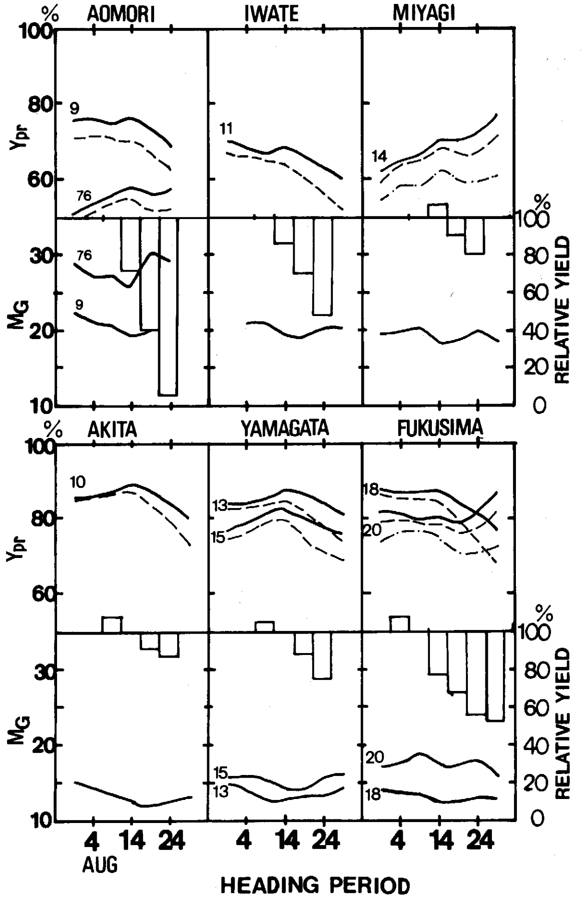

Fig. 11 Comparing relative yield due to different heading periods in 6 prefectures of the Tohoku District (after Crop Statistics of 1980) with $Y_p(\theta_o)$ at different heading periods relative to the normal maximum $Y_p(\theta_o)$ in the year of 1980. The bottom lines indicate M_G (the growth index before heading). Numerals at the lines denote the main paddy regions within the prefectures.

4. Conclusion

If long-term detailed weather forecasts were available for the warm periods, a suitable heading date prior to planting could be set, so that an improvement in climatic productivity can be expected. For example, if a suitable heading date could have been applied to some areas in the coolest summer damage year–1980, we might have saved roughly more than 10% of the decrease of the Y_p index.

The effect in decrease of the monthly mean temperature by 2°C was examined by calculating Y_p (a certain month, −2) and Y_{po} (a certain month, −2). More than a 5% decrease in Y_{po} compared to the normal Y_{po} is shown by the isopleth of 95% in Fig. 3. The strongest effect is found in the period of August and in the northern region of Japan. The effect is particularly found in the period of August and July to the next. More than a 5% increase in Y_p is shown by horizontal lines and black in Fig. 3 and in this case, the strongest effect is found in the period of August as well, but September follows it.

In addition, the gains in Y_{pr} in any month are illustrated in Fig. 5. More than 10% is the most obvious gain in the period of July and August are shown at several points in areas only in the Type-C division. The gain in Y_{pr} of more than 5% seems to be produced by the change of variational Y_p pattern; namely from Type-C to Type-B, as shown in Fig. 1.

Finally, the relationship between Y_{pr} and the actual crops in 1980 has been examined. In the division of Type-A (cold district type), the correlation is as fine as r=0.916 and the regression coefficient as high as 2.6. In the other divisions, the differences of actual heading period to S.H.P. and those of actual cultivating varieties to the Y_p model (refer to Fig. 9) seem to badly affect the relation between them. Then, the Y_p model with θ_o as a parameter should be further examined in order to discuss the relation to the actual crop.

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