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Modelling and Simulation of Growth and Yield of Paddy Rice in Relation to Weather and Climate

Takeshi Horie

INTRODUCTION

Rice is the most important crop in Monsoon Asia and sustains as a single crop approximately one-third of the world population. Under the pressure of increasing world population, it is predicted that 60% more rice production is required in the forthcoming 30 years in the world(IRRI, 1989). This, together with fear of a drastic change of global climate due to the increasing greenhouse effect gasses in the atmosphere, is requiring to develop more stable and efficient rice production systems which allow to exploit climatic resources more fully.

Although the enormous influence of climate and weather on rice crop performance and productivity is beyond doubt, our knowledge about climatic influence on crops is still far short of allowing quantitative evaluation. It will, therefore, be valuable to develop a rational crop-climate model which explains and predicts the crop growth and yield from climatic conditions, not only for evaluation of climatic productivity but also for identification of suitable cultivars, determination of optimal cropping seasons and for offer of information for adequate crop managements under given climate. With the advancement of play a role in a realtime forecasting of regional crop growth and yield formation processes, by combining it with weather information network systems to provide, timely information for crop managements under changing weather.

For these reasons we have developed SIMRIW, a dynamic model for simulating rice growth and yield in relation to weather and climate(Horie, 1987 and 1988). Unlike the traditional regression models relating crop yield to weather or climate, SIMRIW is a physiologically-based mechanistic model, because the traditional regression models cannot be extrapolated beyond the conditions under which they were developed. Although the existing rice growth simulation models (Iwaki, 1975 : McMennamy and O'toole, 1983) are comprehensive and meaningful from the viewpoint of crop physiology, they require that a multiplicity of experiments be conducted to evaluate their enormous parameters and to validate the model before they can be applied to a specific purpose. For this reason, SIMRIW has been developed on the basis of a rational simplification of the individual physiological and physical processes of the crop growth and development, so that it may be universally applicable with a minimum set of crop parameters.

This model does not give actual yield, but gives climatically potential yield that may be expected under a given climate from the physiology of a given cultivar raised under an optimal cultivation technology. This implies that water, nutrients, pests, disease and weeds are optimally managed. Despite this, it will be shown that the simulated rice yield by the model has a close relation to actual regional yield.

In this report the author would like to explain the basic idea and essential structures of the model, and to show the results of the model application to spatial and secular variations of rice yield in Japan and in the U.S.A. in order to explain them from climatic conditions. Finally, research subjects for further imrovement of the model will briefly be discussed.

THE MODEL

Overview

Processes of growth, development and yield forma-

(Laboratory of Crop Science, Dept. of Agronomy Kyoto University, Kitashirakawa, Sakyo-ku, Kyoto 606 Japan)<Recived May 12.1990>

tion of rice crop was modeled in the SIMRIW (Simulation Model for Rice-Weather relationships) according to the scheme shown in Fig.1. The ontogeny of rice crop such as panicle initiation, heading and maturation is important process for determining duration of each developmental phase and hence total growth period. In SIMRIW the developmental process is represented by a continuous variable termed developmental index DVI which is a function of daily mean temperature T and day length L, and thus can be simulated continuously from time course of these environmental conditions.

It has been shown that crop dry matter production is proportional to the photosynthetically active radiation (PAR) or the shorthwave radiation absorbed by a crop canopy (Shibles and Weber 1966 ; Monteith 1977 : Gallagher and Biscoe 1978). Horie and Sakuratani (1985) showed that this is also true for rice, and that the proportionality constant, the conversion effeciency from the radiation to biomass, is constant until the middle of the ripening stage, thereafter decreasing curvilinearly (see Fig.2). They also showed by simulation and experiment that the conversion efficency is practically unaffected by climatic con -ditions over a wide range of environments.

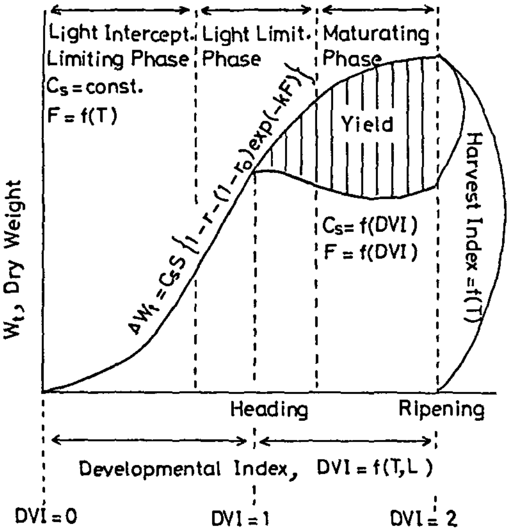

Fig. 1. Schematic representation of processes of growth, development and of yield formation of rice modeled in SIMRIW, the model for simulating rice-weather relationships.

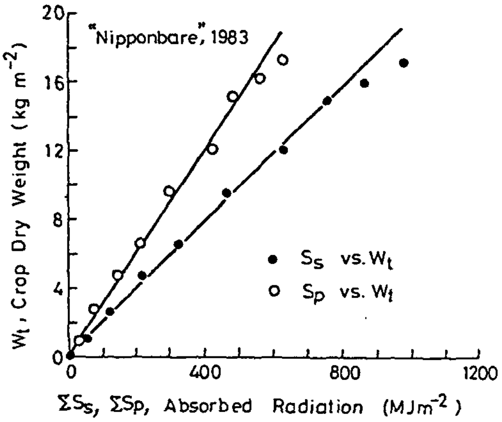

Fig. 2. Relationship between total crop dry weight (W_t) at different times of growth and absorbed shortwave radiation (S_s) or PAR (S_p) cumulated over time for Nipponbare rice grown at Tsukuba (Horie and Sakuratani, 1985).

The model is based on the following general principle :

$$\triangle W_t = c_s S_s \cdots\cdots\cdots (1)$$

where $\triangle W_t$ is the daily increment of the crop dry weight, c_s is the conversion efficiency of absorbed shortwave radiation to rice biomass (g/MJ), and S_s is the daily total absorbed radiation. The crop absorbed radiation S_s is given by a function of incoming solar radiation S, canopy reflectivity r, soil reflectivity r_o, radiation extinction coefficient of canopy k and of leaf area index F.

The crop dry matter accumulation process can conceptually be divided into the three phases : the light interception limiting phase, light limiting phase and maturating phase. At the light interception limiting phase, the dry matter production is mainly limited by leaf area index F, and the radiation conversion efficiency may be constant under an optimal thechnolgy. The growth in leaf area at the light interception limiting phase was modeled as a function of daily mean temperature T. At the light limiting phase the dry matter production is mainly limited by supply of solar radiations S and Cs can be assumed to be constant. At the maturating phase the conversion efficiency can no longer be constant, but decreases with time toward zero at the ripeining. This feature of C_s at the maturating phase was formulated simply as a function of the developmental index DVI.

SIMRIW simulates grain yield on the basis of the general principle that the grain yield forms a component of the total dry matter production W_t. Namely,

$$Y = hW_t, \cdots\cdots(2)$$

in which h is the harvest index. The harvest index was modeled as a function of genetic attributes of rice cultivar and temperature conditions during sensitive period of rice panicle to cool temperature (meiosis to immediately after heading).

The growth in dry weight, leaf area index or in yield is computed in SIMRIW day by day by inputting daily weather data.

The above is the brief description of the model structure and some more detailed explanation about the individual processes will be given in the subsequent sections.

Crop development

The developmental processes of a rice crop, such as ear initiation, booting, heading, flowering and maturation, are strongly influenced both by the environment and by the crop genotype.

In this model, the developmental process of rice is represented by a continuous variable called developmental index, DVI, in a similar way to that employed by de Wit et al. (1970). DVI is defined in such a way that it is zero at the onset of the crop emergence, 1.0 at heading and 2.0 at maturation. Thus, the development at any moment in time is represented by a DVI value between 0 and 2.0.

The value of DVI at any moment of the crop development is given by integrating the developmental rate DVR with respect to time. That is,

$$DVI\ (t) = \sum_{t=1}^{d} DVR_i \cdots\cdots(3)$$

where DVI(t) is the developmental stage at the tth day and DVRi is the developmental rate at the ith day from the emergence. It is well known that day length and temperature are the main determinants of DVR. We found that the following equation predicts very well the crop developmental process until heading ($0 \leqq DVI \leqq 1.0$) (Horie et al. 1986).

$$DVR = \frac{1}{G} \frac{1-\exp\{B(L_o-L_d)\}}{1+\exp\{-A(T-T_h)\}},\ \text{for}\ L_o \leqq L_c \cdots(4)$$

$$= 0,\ \text{for}\ L_o \geqq L_c$$

in which T and L_o are daily mean temperature and day length ; G is the minimum number of days for the heading of a given cultivar ; L_c the critical day lenth for the development of a given cultivar ; A, B and T_h are parameters. By using field experimental data on the heading of a given cultivar, the values of these crop parameters can be determined by the simplex method, a trial-and-error method for estimating the parameters of non-linear functions. The best estimates of these parameters for 'IR36' rice, for instance, were $G=65.6$ days ; $L_c=16.8$ hours ; $T_h=17.3$ ℃ ; $A=0.421$; $B=0.479$. It should be noted that these values are strongly dependent upon the cultivar.

The DVR of IR36 is given in Fig.3 as a function of temperature T and day length L_o. By using equation (4) with these parameters, the day of heading of IR36 can be well estimated from climatic conditions (Fig. 4.). As the figure shows, number of days required for the heading of IR36 varies from 75 days at IRRI (Philippines) to 145 days of one crop at Tsukuba (Japan), depending on the climatic conditions. The model predicts these heading days from the climate with a standard error of only 1.8 days.

By a similar equation to equation (4), the crop developmental processes during the grain-filling stage ($1 \leqq DVI \leqq 2$) can be predicted as a function of temperature T alone.

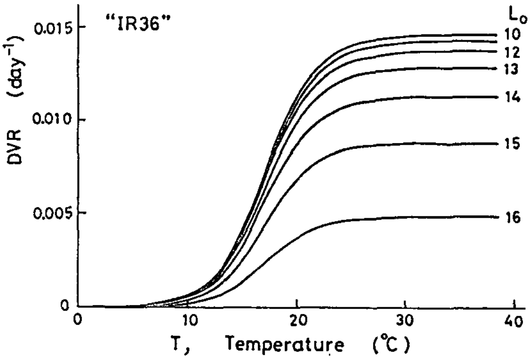

Fig. 3. Estimated developmental rate (DVR) of IR36 rice as a function of daily mean temperature (T) and day length (L_o), (Horie, 1987).

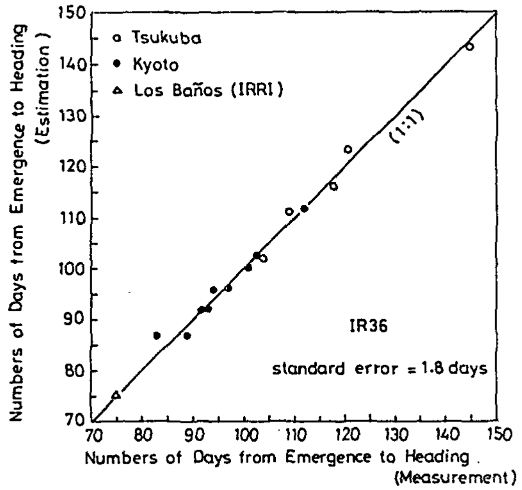

Fig. 4. Relationship between estimations and measurements of the numbers of days from the emergence to the heading of IR36 rice grown in different season at Kyoto, Tsukuba(Japan) and Los Banos(Philippines), (Horie, 1987).

Dry matter Production

To simulate the crop dry matter production by eq. (3), it is necessary to compute the absorbed radiation by the crop canopy S_s, which is a function of the incident solar radiation S, leaf area index(LAI ; F) and the structure and optical properties of the canopy. Using the crop micrometeorological theory originating from Monsi and Saeki (1953), S_s is given by,

$$S_s=S[1.0-r-(1-r_o)\ \exp\{-(1-m)k*F\}], \cdots \quad (5)$$

where r and r_o are the reflectances of the canopy and the bare soil, m the scattering coefficient and k the extinction coefficient of the canopy to daily shortwave radiation. The canopy reflectance r can be approximated well by the following equation (Research Group of Evapotranspiration 1967),

$$r=r_f-(r_f-r_o)\exp(-0.5F), \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (6)$$

in which r_f is the reflectance when the surface is completely covered by the vegetation. From Horie and Sakuratani(1985), the following values of these parameters were adopted for all the cultivars used : $k=0.57, m=0.25, r_f=0.22$ and $r_o=0.1$.

In most simulation models for crop growth so far developed, leaf area growth has been calculated from its weight growth by multiplying by a simple conversion factor, the specific leaf area. In this model, however, the leaf expansion growth of rice is modeled independently of the weight growth, for the reason already described in Horie et al.(1978).

Under the optimal cultivation conditions on which the model is based, it can be assumed that water and nutrients are not limiting factors to the expansion of the leaf area. Under this circumstance, LAI growth is mainly governed by the temperature. In this model the growth of LAI(F) until just before heading is given by the following function of daily mean temperature :

$$\frac{1}{F}\frac{dF}{dt}=R[1.0-\exp\{-K_f(T-T_c)\}]\{1.0-(F/F_a)^n\},$$
$$\text{for } T\geqq T_c$$
$$=0 \text{ for } T<T_c$$

in which R is the maximum relative growth rate of LAI, T_c the minimum temperature for LAI growth, F_a the asymptotic value of LAI when temperature is non-limiting, and K_f and n are parameters. For these crop parameters, the following values were adopted for all the cultivars used on the basis of the field experimental data : $R=0.247$ day^{-1}, $T_c=115$℃ $K_f=0.07$ and $n=0.723$. The asymptotic LAI (F_a) when temperature is not limiting depends to a large extent on the amount of nitrogen application. Under the optimal cultivation conditions, however, nitrogen is applied in such a way as to control the maximum LAI within an optimal range. Since the optimal LAI is usually 5 to 6, we assumed F_a to be 5.5.

In rice, it is commonly observed that LAI attains a maximum at about the heading stage and declines gradually during the maturing stage. However, the physiology and the environmental response of the leaves during this maturation process are obscure. For this reason, the change in LAI from the time just before the heading to the maturation of the crop is represented by a unique function of only the crop developmental stage DVI.

By use of the above equations, the crop absorbed radiation S_s in each day can be obtained, and the dry matter production can be simulated by equation(3). As Fig.4 showed, the conversion factor c_s is constant until the middle of the grain filling stage, and thereafter it decreases gradually to zero. These features of the change of c_s may be represented by,

$$c_s = C_m \text{ g/MJ}, \quad \text{for } 0 \leqq \text{DVI} \leqq 1.0$$
$$= C_m \frac{1+C}{1+C\exp\{(\text{DVI}-1)/\tau\}} \quad \text{for } 1.0 < \text{DVI} \leqq 2.0 \qquad \cdots\cdots (8)$$

in which C_m is the potential conversion efficiency of a given cultivar and τ and C are parameters. The best estimates of τ and C were 0.1 and 0.001, irrespective of cultivars.

Harvest index

The harvest index is one of the genetic attributes of cultivars, and for a given cultivar the index is mainly governed by percentage sterility of spikelets and of ripening ratio under an optimal cultivation technology, and thus a function of weather

The harvest index decreases if the percentage of sterile spikelets increases (Fig. 5), or if the crop ceases growth before completing its development due to environmental adversity. If water conditions are not limiting, cool temperature is the largest environmental factor that affects the sterility percentage and hence, the harvest index h. The increased number of sterile grains brought about by cool temperature at the booting and flowering stages is called cool-summer damage due to floral impotency, and the premature cessation of growth due to autumn coolness is called cool-summer damage due to delayed growth

In this model, the harvest index h is represented as a function of the percentage sterility of rice spikelets τ and the crop developmental stage DVI, in order to take account of both types of the cool-summer damage, as follows :

$$h = h_m(100-\gamma)[1.0 - \exp\{-K_h(\text{DVI}-1.22)\}],$$
$$\text{for DVI} > 1.22 \qquad \cdots\cdots (9)$$

where h_m is the potential harvest index of a given-cultivar and K_h a parameter E_q.(9) implies that the harvest index decreases as γ increases due to cool temperature at the booting and flowering stages, or as the cessaton of the growth is earlier than the full maturation (DVI=2.0) due to cool autumn temperature.

By use of the cooling degree-day concept of Uchijima (1976), the relation between daily mean temperature T and the percentage sterility γ may be approximated by the following equation (c.f. Fig. 6) :

$$\gamma = \gamma_0 + K_q Q_T{}^a, \qquad \cdots\cdots (10)$$

where γ_0, K_q and a are empirical constants, and Q_T is the cooling degree-days given by

$$Q_T = \sum_i (22.0 - T_i), \quad T_i \leqq 22.0, \qquad \cdots\cdots (11)$$

From the experimental data of Shibata et al. (1970), we estimated the values of these parameters as : $\gamma_0 = 4.6$, $K_q = 0.054$ and $a = 1.56$

By taking into account the sensitivity of the rice panicle to cool temperatures, eq. (11) is summed over

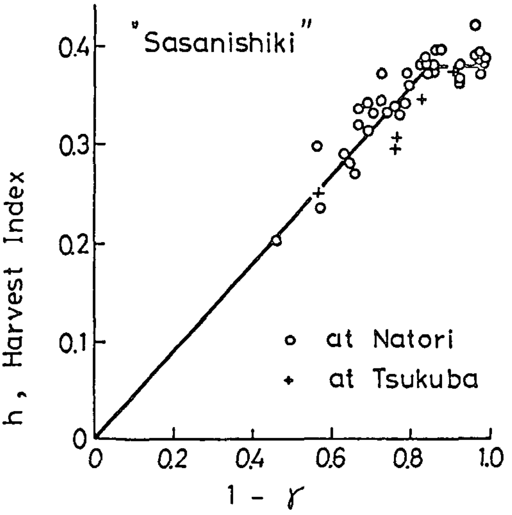

Fig. 5. Relation between percentage ripening (1-r) and harvest indix for 'Sasnishiki' rice.

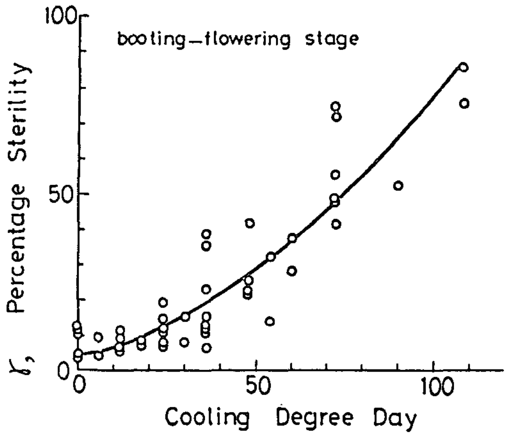

Fig. 6. Relation between cooling degree-days and percentage sterility of spikelets of 'Eiko' rice between the booting and flowering stages (From the data of Shibata et al., 1970).

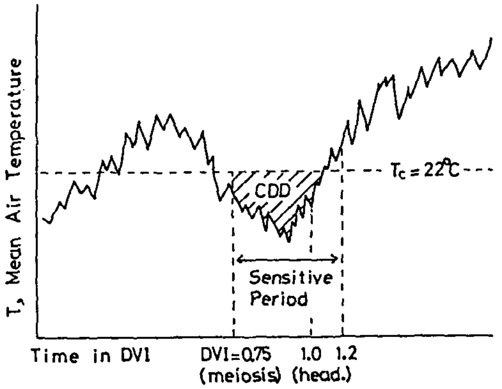

Fig. 7. Schematic representation of computation process of cooling degree-days (CDD) during rice development.

the sensitive period $0.75 \leqq DVI \leqq 1.2$ in the developmental stage. The procedure to calculate the cooling degree-day (Q_T) is schematically represented in Fig. 7.

In this model the potential growing season of the rice crop starts when daily mean temperature T exceeds 12.0℃ in Japonica rice and 13.0℃ in Indica rice (IR36), and terminates when T becomes lower than 11℃ in Japonica and 13℃ in Indica rice. Hence, the terminal condition of the simulation occurs either when DVI reaches 2.0 (full maturation), or when the air temperature reaches this critical value. The latter means premature cessation of the growth.

CROP PARAMETERS AND CLIMATIC DATA USED IN THE SIMULATION

Crop Parameters

Values of crop paramters were determined from the data of well specified field experiments conducted under widely different environmental conditions for major rice cultivars in Japan and also for 'IR36' the most dominant Indica variety in the world.

Crop parameters on 'IR36' were adopted as a standard cultivar for the simulation of the location-to-location yield variation over Japan and the U.S.A.. For simulating year-to-year yield variation in Hokkaido rice, crop parameters on 'Ishikari' were adopted, because this cultivar had been the dominant variety in this district for a long time. For the same reason, the parameters on 'Mizuho' were used for the simulation of Saga in Kyushu rice.

Weather and Climatic Data

The model SIMRIW requires data of daily mean temperature and daily solar radiation as the driving input variables. Temperature data can be applied directly, but consistent daily solar radiation values are not available for the entire period of the model simulation. As a substitute, solar radiation was estimated from daily sunshine hours using the method of Yoshida and Shinoki (1978). The simulation for the year-to-year yield variation in Japan was made by inputting the daily weather data, but that for the location-to-location yield variation over Japan and the U.S.A. was made by inputting the monthly climatic data, because data were not availavle for the U.S.A.. In the latter case, the daily climatic data could be estimated from the mothly data by using Fourier series for each location.

SIMULATION OF SPATLAL YIELD VARIATION OVER JAPAN AND THE U.S.A..

-A MODEL VALIDATION-

Fig. 8 illustrates the results of a model simulation of the growth processes of a rice crop under changing weather conditions. For daily inputs of air temperature and solar radiation, the crop developmental stages (DVI), leaf area expansion and dry matter weight of the whole crop and of the grain are depicted along the same time axis.

As has already been described, the model simulates climatic productivities in grain yield of rice, but not the actual yield. The climatic productivity of a given cultivar was defined as the yield that may be expected under a given climate from its physiology. To examine the validity of the model evaluation, the evaluated yields were compared with the actual yields over climatically different areas of rice production in Japan and the U.S.A.. These countries were selected because rice production technologies are fairly uniform there and hence the location-to-location yield variation can be considered to be climatic variation. The crop parameters for 'IR36' were adopted as a standard cultivar for the comparison. The actual and

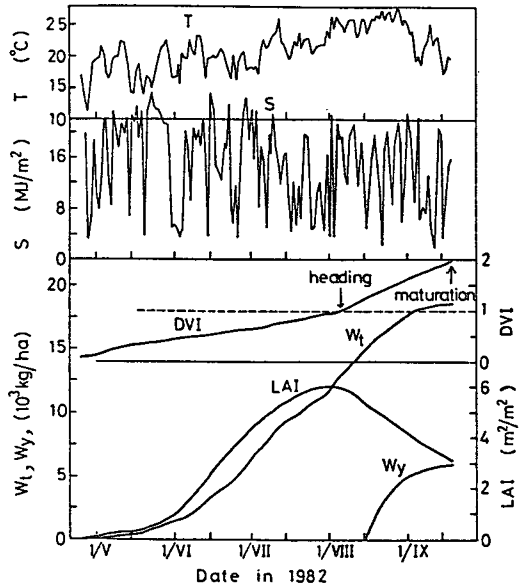

Fig. 8. Simulated dynamics in crop developmental index (DVI), leaf area index (LAI) and dry weights of brown rice (W_y) and whole crop (W_t), together with the daily mean temperature (T) and radiation (S), conditions during the growth period of 'Nipponbare' rice in 1982 at Tsukuba (Horie, 1988).

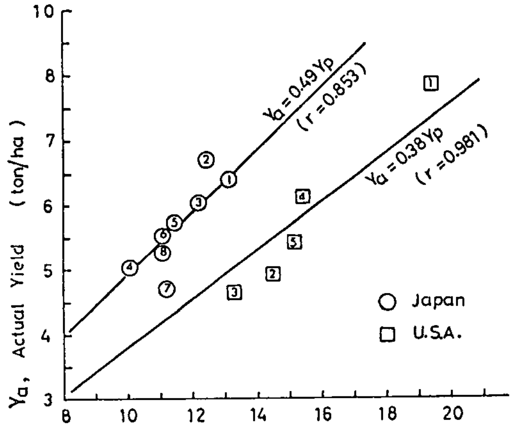

Fig. 9. Relationship between the evaluated climatic productivity and the actual rice yield for climatically different locations in Japan and U.S.A., (Horie, 1987). The numerals on the figure are : 1, Niigata ; 2, Nagano ; 3, Toyama ; 4, Saitama ; 5, Okayama ; 6, Aichi ; 7, Kohchi ; 8, Kagoshima in Japan ; and 1, California ; 2, Mississippi ; 3, Louisiana ; 4, Arkansas ; and 5, Texas in the U.S.A..

the evaluated yields are compared in Fig.9. In the Japanese results, the productivities at the south of Niigata are represented, because Niigata was found to be the northern limit for the cultivation of 'IR36' rice. As in Fig.9 shown, linear relationships are obtained between the simulated yield and the actual yield for both Japan and the U.S.A.. This indicates that the location-to-location yield variations in Japan and the U.S.A. are mainly caused by climatic variations, and that the model simulates well the climatic productivity of rice. The relation between the simulated climatic yield Y_p and the actual yield Y_a can be represented by the following equation with a high correlation coefficient (r=0.981 for the U.S.A. and r=0.853 for Japan) :

$$Y_a = KY_p, \quad \cdots\cdots (14)$$

in which K is the proportionality factor.

The proportionality factor K in Equation (14) is an index of the overall technology level for rice production, which includes soil improvement, irrigation systems, managements of the crop, water, nutritions, pests, diseases and weeds, and selection of cultivars. The values of K are 0.49 in Japan and 0.38 in the U.S.A., suggesting that the prevailing overall technology level for rice production is more than 20% higher in Japan than in the U.S.A.. In this way, the model is also applicable to the evaluation of technology, by excluding the climatic effects.

In conclusion, the model here proposed can successfully be applied for the evaluation of climatic productivity and overall cultivation technologies in rice production in different locations of the world.

SIMULATION OF YEAR-TO-YEAR YIELD VARIATION IN THE NORTH AND SOUTH JAPAN

The model SIMRIW was applied for the analysis, in terms of the weather, of the year-to-year variations of rice yield in Hokkaido island and in Saga prefecture in Kyushu island. We selected these two districts because these two are typical representatives of the rice production in the north and the south Japan, respectively. Weather data observed at Sapporo and Saga weather stations were used for the simulation, because these stations are located near the center of the respective rice producing districts

Simulation for Hokkaido rice

For Hokkaido, the decade from 1974 to 1983 and that from 1957 to 1966 were selected for the analysis because a very unstable variation in the summer temperature was observed in the former decade, while that in the latter decade was stable Fig.10. shows the year-to-year changes in actual and simulated rice yields for the stable decade(1957-1966) and unstable decade(1974-1983), together with anomalies from the 30-year baseline period(1951-1980) of total sunshine hours over the main growth preiod (July-September) and the average air temperature over July and August. The simulated yields in Fig.10 indicate the adjusted values of the direct simulatiom results by multiplying the overall technological factor K in equation(14). A value of 0.84 was obtained for the technology adjustment factor K by comparing the trial simulation results with the actual yields for the recent decade(1974-1983), implying that the present level of cultivation technology of Hokkaido rice farmers is 84% of what is expected from the physiology of Ishikari rice under an optimal condition.

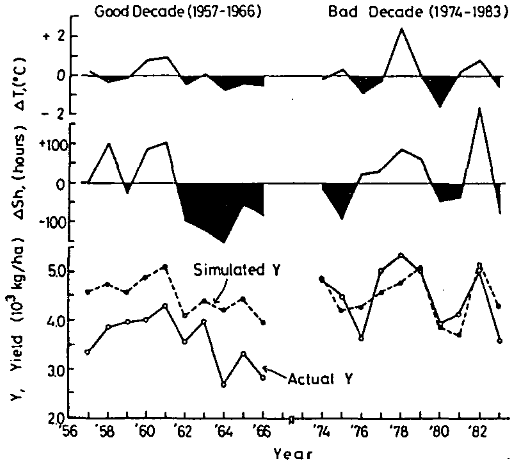

Fig. 10. Year-to-year variation in simulated and actual rice yields in Hokkaido for the stable(1957-1966) and unstable (1974-1983) decades, (Horie, 1988). ΔS_h is the deviation from the baseline of the total sunshine hours from June to September, and ΔT is the deviation of July-August mean temperature.

Fig.10 indicates that very large variations in the year-to-year rice yield are observed in Hokkaido, both in the unstable decade(1974-1983) and the stable decade(1957-1966), and that the model well explains the variation of in the unstable decade from the weather conditions, implying that the yield variation is mainly derived from the weather variation. For the stable decade(1957-1966), the simulated yields are consistently higher than the actual yields, although the patterns of the variations are similar between them. Since the simulated yield has been adjusted to the farmers technological level of the present decade, the difference between the simulated and the actual yields observed in the stable decade (1957-1966) can be ascribed to the advance in the technology during the period between the two decades. Thus, in Hokkaido the increase in the rice yield due to the advance of the technology is estimated to be about 25% for the 17 years from 1961 (middle of the stable decade) to 1978 (middle of the untable decade).

The computed difference in the simulated average yield between the stable and unstable decades is negligibly small, while the coefficient of variation(CV) of the simulated yield in the two decades are 7.8% and 11.6%, respectively. These values of CV of simulated yields are somewhat smaller than the CV of actual yields in Hokkaido(about 15% in both decades). The difference is considered to be derived from the effects of the other factors than the temperature and radiation modeled in SIMRIW : insects and disease as well as weather factors of floods and storms.

Sensitivity analysis of Hokkaido rice yield to a range of climatic perturbations was made by use of the model and the results are given in Fig.11, in which yield isoplenths are depicted as a function of the baseline period(1951-80).Fig.13 shows that, with a negative anomaly of the average temperature over the whole growth period of greater than -1℃, a large yield reduction is expected, being almost independent of the sunshine hours. This due to the overriding influence of the cool -summer damage at these temperatures. However, as the temperature anomaly increases from -1℃, the effect of sunshine hours becomes more conspicuous.

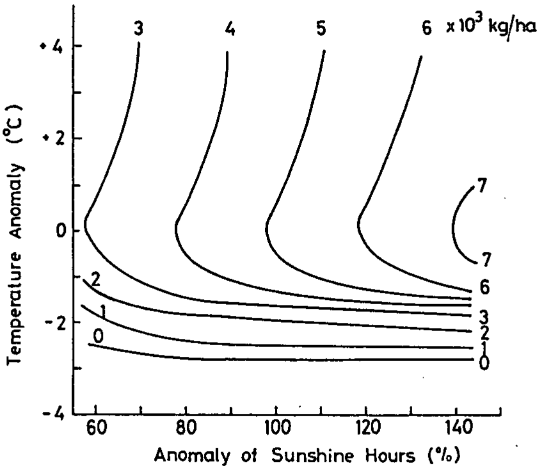

Fig. 11. Isopleths of simulated rice yield in Hokkaido as a function of anomalies relative to baseline (1951-80) of temperature and sunshine hours over the whole growing period (Horie, 1988).

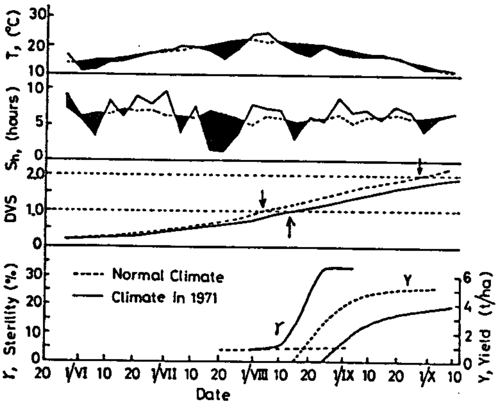

Fig. 12. Simulated growth and yield of rice in the extremely cool year (1971) and in the average climate in Hokkaido. T and S_h denote daily mean temperature and sunshine hours, respectively.

Fig.11 also shows that the maximum yield at a given level of sunshine hours is obtained temperature anomaly of about 0℃, and that as anomaly deviates in both the positive and negative directions, a significant reduction in the yield occurs. The yield reduction under the positive temperature anomaly conditions is derived from the fact that 'Ishikari', the rice cultivar adopted for the simulation, develops too rapidly, reaching the reproductive stage before establishing a sufficient vegetative growth for maximun productivity. The above result implies that this rice cultivar is very well suited to the present climate in Hokkaido, having been selected during about 100 years of rice breeding there.

Fig.12 shows the simulated growth yield of rice under the 1971 climatic conditions, in which Hokkaido rice suffered from the severest cool summer damage in the recent years, together with those under normal climate. In 1971 the mean air temperature was below normal for almost the entire growth period, and sunshine hours were also lower than normal for most of the period. The anomalously low temperature in July brought about cool-summer damage due to floral impotency, and those in August and September caused cool-summer damage due to delayed growth. In this year the actual rice yield in Hokkaido was 66% of the averaged level at that time, while the simulated yield for that year, assuming the present advanced technology, is 73% of the normal (i.e. simulated for the baseline climate). This suggests that, if the climatic conditions, comparable with those in 1971, were observed today, the yield reduction would be similar to that in 1971, even under the present advanced technology for rice cultivation.

The simulation results shown in Fig.12 suggest that this type of model will be applicable to realtime prediction of regional rice yield by combining it with weather information network systems.

Simulation for Saga Rice

Fig.13 shows the year-to-year variation of rice yield simulated for Saga prefecture in Kyushu for recent 10 years, was obtained by adjusting the direct output with technolonical factor in a similar way to that in Hokkaido. With the exception of 1985, a fairly good agreement can be seen between the simulated and the observed yields. The extremely low yield observed in 1985 was due to a heavy flood during rice growth season in Saga district, which the model failed to explain. The results represented here suggests that SIMRIW can also be applicable to the prediction of regional rice yield in the south Japan.

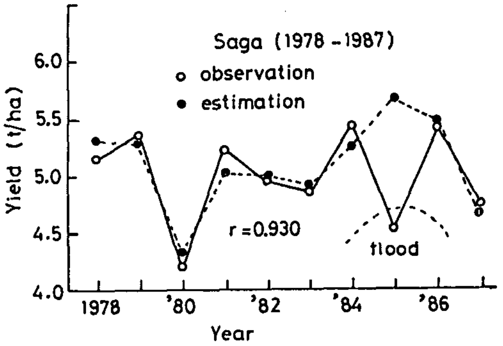

Fig. 13. Year-to-Tear variation in simulated and actual rice yield in Saga, Kyushu island for the recent decade (1978-1987).

CONCLUDING REMARKS

It was shown that, despite the very simple structure of the model SIMRIW, it explained fairly well the location-to-location variations of rice yield both in Japan and the U.S.A., and also the year-to-year yield variations in the north and south Japan from climatic conditions. This suggests that the model may be applicable for the prediction of regional rice yield from climatic conditions. The simulation results so far represented also encourage us to further improvement of the model, in order to make it applicable for a realtime growth and yield prediction and diagnosis for crop managements, by combining it with weather information network systems. For this, two efforts are considered to be important at the present. The first is to incorporate nitrogen dynamics into the present model, because the nitrogen is the most important measure for the growth control. The second is to incorporate into the model the processes of formation of spikelet number per unit area and of grain filling as a function of genetic attributes of cultivars, nitrogen content and weather conditions. Experimental work is be being conducted at our laboratory to improve SIMRIW to such a structure and function. Experiment and modelling are the equally important measures for better understanding of the real world of crop production processes.

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