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

Takeshi Horie

(Laboratory of Crop Science, Faculty of Agriculture, Kyoto University, Sakyoku, Kyoto 606, Japan)

Abstract

Although the enormous influence of climate and weather on crop performance and productivity is beyond doubt, our knowledge about climatic influence on crops has been still far short of allowing quantitative evaluation and prediction. The objective of this study is to propose a dynamic simulation model for quantitative evaluation and prediction of growth and yield of paddy rice from climate and weather conditions.

The model has been developed on the basis of rational simplification of underlying physiological processes to give climatic potential yield under an optimal cultivation technology. In this model three important processes of the crop development, drymatter accumulation and yield formation have been incorporated.

The developmental processes of a rice crop, such as ear initiation, booting, heading, flowering and maturation, are quantified by a continuous variable termed developmental index, DVI in a similar way to de Wit et al. (1970). The DVI is defined to be zero at the emergence, 1.0 at the heading and 2.0 at the maturation. Thus, the development of rice crop at any moment in time is represented by DVI value between 0 and 2. Under this defining condition of DVI, the value of DVI at any moment of rice development is given by integrating the developmental rate DVR with respect to time :

$$DVI_n = \int_0^n DVR\,dt = \sum_{i=0}^{n} DVR_i \qquad (1)$$

where DVI_n is the developmental index at the nth day and DVR_i is the develop mental rate at the ith day from the emergence, respectively. We found that

the following equation predicts very well the crop developmental process until heading ($0 \leq DVI \leq 1.0$) :

$$DVR = \frac{1}{G} \frac{1-\exp(B(L-Lc))}{1+\exp(-A(T-Th))}, \quad \text{for } L \leq Lc$$
$$= 0, \quad \text{for } L > Lc \qquad (2)$$

in which T and L are daily mean temperature and day length ; G is the minimum number of days for the heading of a given cultivar ; Lc the critical day length for the development ; A, B and Th are paramaters. By using field experimental data on the heading of a given cultivar, the values of these crop parameters can be determined the Simplex method, a mathematical algebra for estimating parameters of non-linear functions. By a similar equation to eg.(2), the crop developmental process during grain filling stage ($1 \leq DVI \leq 2.0$) can be predicted as a function of the temperature T alone. It was found that the development model predicts phenological stage of rice grown under widely different environments, with errors of less than 2 days, from time course of the environments(Horie, 1987).

The rate of drymatter accumulation of rice canopy is given by,

$$\Delta W = Cs*S, \qquad (3)$$

where ΔW is the daily increment of the crop dry weight, Cs is the conversion efficiency of absorbed radiation to rice biomass, and S is the daily total of absorved solar radiation by the crop. From Horie and Sakuratani (1985), the conversion efficiency can be regarded to be independent of climatic conditions, and is approximately 2.0 g/MJ for rice crop under optimal cultivation conditions. The crop absorbed radiation S can be obtained by applying crop micrometeorological theory originating from Monsi and Saeki (1953), as a function of daily shortwave radiation, radiation extinction coefficient, LAI and optical properties of the canopy. The growth in LAI is formulated in this model as a function of the temperature and the crop developmental index DVI (Horie, 1987). The drymatter accumulation model here described simulated satisfactorily the growth curves of rice crops under different environmental, conditions.

The grain yield in this model is obtained from the crop total drymatter by multiplying by harvest index. The harvest index is modelled as a function of DVI and percentage sterility of rice spikelets. The percentage sterility, in turn, is represented as a function of cooling degree-days of Uchijima(1976). The calculation of the cooling degree-days is made for the period $0.75 \leq DVI \leq 1.2$ in the developmental index, by taking account the sensitivity of the rice panicle to cool temperatures

The above processes of rice growth and development were represented by simultaneous differential equations, and programmed by BASIC to give potential growth and yield of rice under different weather conditions. The model well explained location-to-location variation of actual rice yield in Japan and the U.S.A. from the climatic conditions. The model also explained, with satisfactory accuracy, the year-to-year variations of actual rice yield in Hokkaido and Kyushu from those of weather conditions. The model is to be utilizaed for a realtime prediction of rice growth and yield in some prefectures in Japan, by combining it with meshed weather information system.

Reference

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