# Computer Simulation of Growth Process of Paddy Rice

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Recently much effort has been given to elucidate physiological bases of plant growth. Many physiological processes such as photosynthesis, respiration and translocation have been studied thoroughly in relation to environmental factors. However, it is difficult to predict the effect of such a factor on plant growth throughout the whole life-cycle, because these physiological studies were usually made in a defined situation at a defined stage of plant development. Thus crop physiologists have to face the problem to integrating all detailed information about the physiological processes into the whole of a system, when they want to predict successfully the response of the whole plant to the variation of internal and external factors. Model of plant growth proposed by de Wit et al. (1970)[1] has been shown to be useful tools for a better understanding of the behavior of crop plants as a system.

A growth model[2] described here is developed to provide simulation of the growth of paddy rice over the whole growing period, and involves the basic processes of plant growth such as photosynthesis, respiration and distribution of photosynthate into the component organs in relation to light, temperature and age of plants. The purpose of the present study is 1) to examine the effect of variation in photosynthetic activity or in canopy structure on the dynamic process of plant growth and 2) to predict the growth of rice plants under different climatic conditions.

## Structure of the growth model

This model has been programmed using a simulation language DYNAMO. The basic structure of the model is shown in Fig. 1, and is composed of four subsystems calculating gross photosynthesis, respiration, allocation of photosynthate into component organs, and leaf senescence.

1) Daily rates of gross photosynthesis (PG) of the leaf canopy is calculated as a function of light, leaf area and leaf arrangement. The basic equation used in the model is after Kuroiwa (1968)[3], and is expressed as follows.

$$PG=\frac{2B\cdot D}{A\cdot K}\ln\frac{1+\sqrt{1+AKI_0/(1-M)}}{1+\sqrt{1+AKI_0\exp(-KF)/(1-M)}}$$

where $I_0$ is daily maximum of solar illumination at noon, $D$ day length, $K$ extinction coefficient of light within leaf canopy, $M$ light transmissibility of single leaves, A and B constants related to the shape of light-photosynthesis curve.

2) In this model respiration (RSP) is assumed to be a function of photosynthesis, biomass, age and temperature. Daily rate of net production (PN) is net difference of gross photosynthesis and total respiration.

3) The distribution of dry matter accumulation between the component organs in rice plants is assumed to be dependent on the age of plants. Using an empirical relationship between the distribution ratios and the age (Monsi & Murata, 1970)[4], the daily net pro-

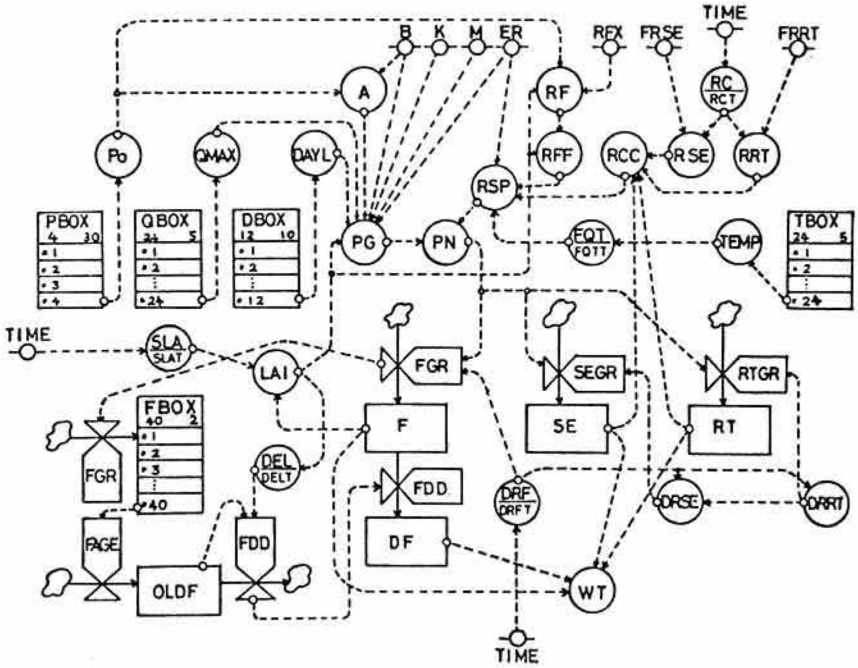

Fig. 1. Flow-diagram for simulation of growth process of paddy rice. Rectangles show pools of dry matter of the component plant organs. F: living leaves, DF: dead leaves, OLDF: living leaves of more than 80 days old, SE: ears and culms including leaf sheaths, RT: roots. Valves show daily rates of growth (FGR, SEGR and RTGR) and death (FDD). PBOX, QBOX, DBOX and TBOX: pools of input data for Po, QMAX, DAYL and TEMP respectively, FBOX: function for aging of leaves, FAGE: daily rate of increment of OLDF, DRF, DRSE and DRRT: distribution ratios for F, SE and RT respectively, SLA: specific leaf area, RFF: daily respiration of foliage, RF: average rate of respiration of leaf blades, RCC: daily respiration of non-photosynthetic organs, RSE: daily respiration of SE, RRT: daily respiration of RT, RC: standardized respiratory rate of non-photosynthetic organs, FQT: correction factor of RSP for temperature, DEL: delay function for dying process of OLDE, TIME: days from transplanting.

Explanations for other abbreviations, see the text and Fig. 2.

duction (PN) is allocated to each component organs so that daily growth rates for leaves (FGR), for culms, leaf sheaths and ears (SEGR) and for roots (RTGR) can be calculated.

4) The rate of leaf senescence was calculated as a function of age and leaf area index (LAI) assuming that longevity of single leaves is more than 80 days after their emergence.

## Execution of the computer simulation

Simulation of the growth of paddy rice was made using HITAC 5020 digital computer. As initial values for plant dry weight are given actual values of the seedlings at transplanting. The environmental parameter inputs are daily solar radiation and air temperature observed at the locality of crop cultivation. In this model it is assumed that water and nutrient

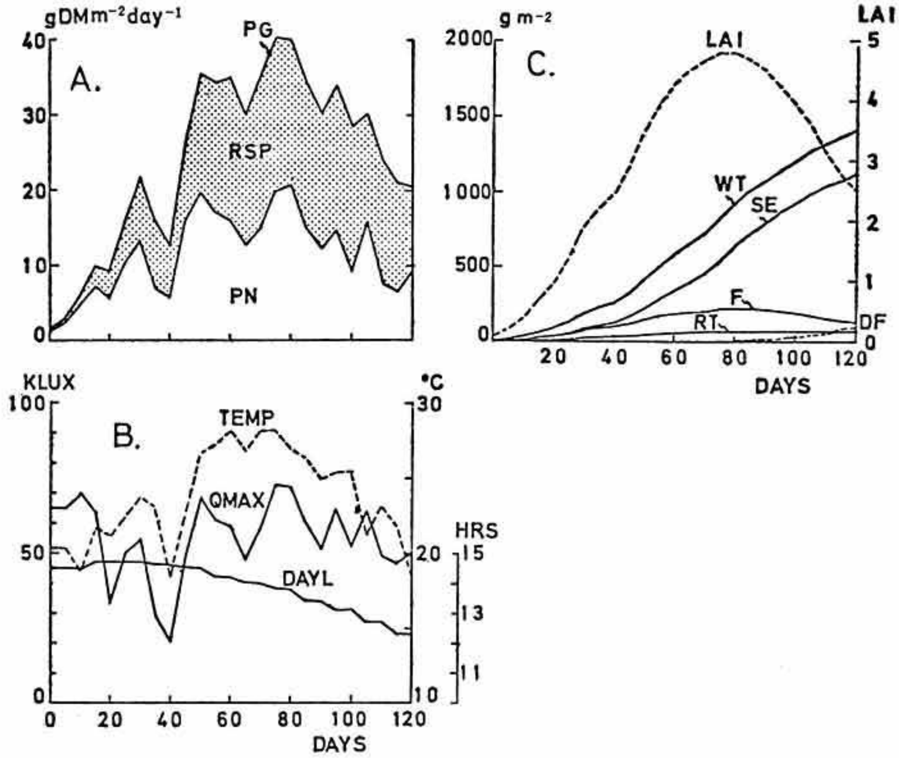

Fig. 2. An example of model output. (A): Time trends of gross photosynthesis (PG), total respiration (RSP), and net production (PN) in paddy rice grown at Konosu in 1967. (B): Seasonal variation in mean air temperature (TEMP), daily peak of solar illumination (QMAX) and daylength (DAYL). (C): Time trends during the growing season of LAI, WT (total dry weight), F, DF, SE and RT.

availability is non-limiting. Starting from the day of transplanting, daily rates of photosynthesis, respiration and allocation of photosynthate to the component organs are calculated and integrated in a step-wise manner so that growth in dry weight and in leaf area can be simulated over the whole growing period (120 days).

An example of output of the model simulation is shown in Fig. 2, which illustrates seasonal changes in daily gross photosynthesis, total respiration and net productivity as well as in LAI and dry weights of the component organs of paddy rice grown at Konosu, Saitama Pref., in 1967.

## Sensitivity analyses of the growth model

One of the major objectives of simulation experiment is to predict reaction of the whole and parts of the plant system to the variation of physiological and morphological features. Sensitivity analyses of the model were made to study the time-varying behavior of the crop system as affected by the change of model parameters. In the present study, a series of simulation experiment was made by changing parameters related to 1) photosynthetic activity, 2) shape of light-photosynthesis curve of single leaves and 3) ligth interception within leaf canopy.

1) In the experiment 1, the value of para-

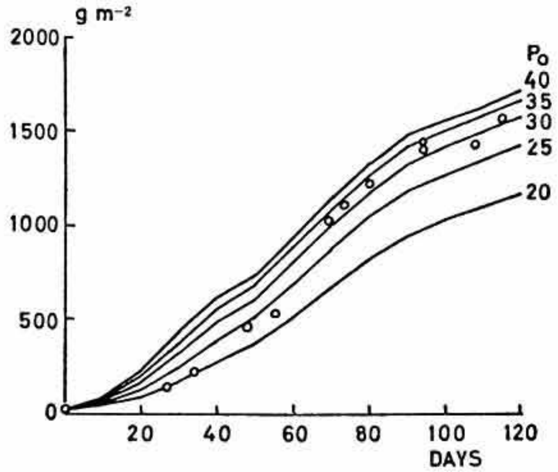

Fig. 3. The effect of the change in Po on the growth in total dry weigh of paddy rice. Open circles represent values obtained by actual measurement at Konosu in 1967.

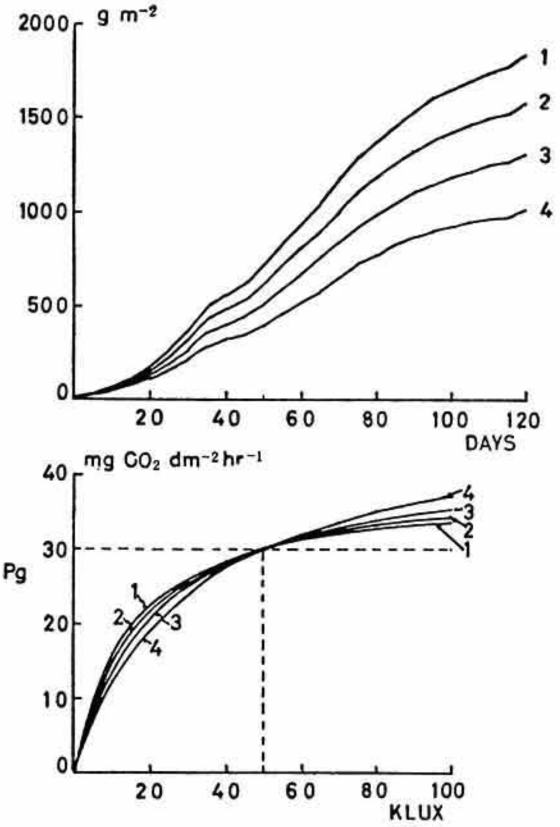

Fig. 4. The effect of variation in parameter B on the growth process of paddy rice (above) and light-photosynthesis curves of single leaves which are used in the simulation.

meter Po, or photosynthetic rate of single leaves under the light of 50 klux, was varied (20, 25, 30, 35 and 40 mg $CO_2/dm^2$. hr.) to evaluate the effect of photosynthetic activity on the growth over the whole life-cycle. Meteorological parameters used in this simulation are based on the observation at Konosu in 1967. For each simulation run, values of parameters other than Po were set to be the same. Initial value of WT, or total dry weight was 16.0 $g/m^2$.

Fig. 3. shows the simulated growth at various Po values. Comparison of the simulated with the observed growth indicates good agreement at the Po value of 30 $mg/dm^2$. hr. It is also shown that decrease of the Po values below 30 mg causes significant decline in the growth rate. But the increase of the Po value above 30 mg has no marked beneficial effect on the growth rate, because of the simultaneous increase in total respiration caused by the over-growth of plant biomass.

2) In the previous experiment 1, the value of B, or a parameter related to the slope of light-photosynthesis curve at the lowest light intensity, was assumed to be constant, irrespective of difference in the

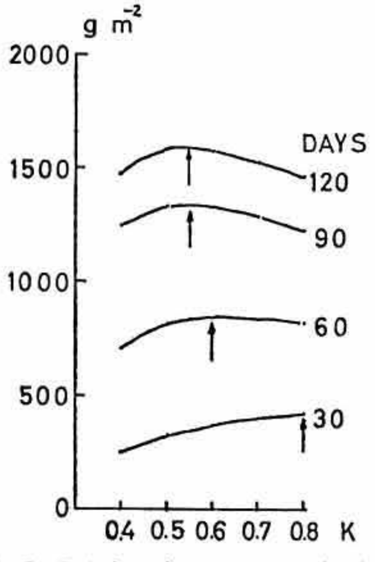

Fig. 5. Relationship between extinction coefficient K and total plant weight at 30, 60, 90 and 120 days after transplanting.

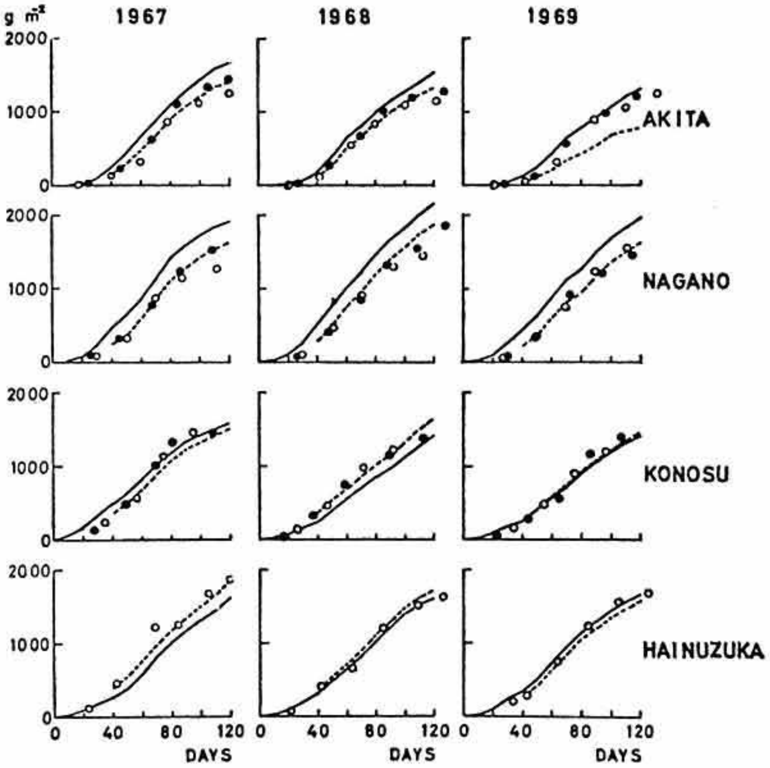

Fig. 6. Comparison of the simulated with the actual growth of paddy rice grown at Akita, Nagano, Konosu and Hainuzuka in 1967–1969. Open and closed circles represent the observed plant dry weight. Solid lines show simulated growth curves for 120 days starting from the day of transplanting. Broken lines show simulated growth curves for 80 days starting from 40 days after transplanting.

Po value. In the experiment 2, the parameter B was changed, while the Po value remained unchanged (Po=30). Results of simulation experiments show that the growth rate can be markedly affected by the variation of the slope of light-response curve (Fig. 4). A slight increase of the slope of the light curve has resulted in a striking enhancement of dry matter production, presumably due to a cumultive effect of more efficient use of weak light by photosynthesis of lower leaves within canopy.

3) Leaf arrangement of the canopy has a close relationship with light interception within canopy and therefore with canopy photosynthesis. Monsi & Saeki (1953)[5] have revealed that daily photosynthesis of foliage with erect leaves (extinction coefficient K is 0.3–0.5) is large as compared to those with horizontal leaves (K is ca. 1.0). In the experiment 3, the parameter K was changed from 0.4 to 0.8 in order to examine the relationship between K and growth rate.

It is evident from Fig. 5 that in an early stage the dry matter production is larger in plants having higher K, but in later stages the largest growth is found at smaller K. The optimum K value at 120 days after transplanting was 0.5 in this case. Both upward and downward shifts of the K value from this value have resulted in reduced dry matter production. It was also indicated that the optimum K value tended to decrease as the initial planting density increases.

## Prediction of growth of paddy rice in different localities

In order to know whether this model can predict the growth of rice plants at different localities and in different years, a series of simulation was made based on the meteorological data at Akita, Nagano, Konosu and Hainuzuka (Fukuoka Prefecture) for three years from 1967 to 1969. Data for actual plant growth were obtained from the studies by the Local Productivity Group of Japanese IBP/PP⁶⁾. Values of parameters Po, B and K were the same in every simulation run, i.e. Po=30, B=2.319 and K=0.5. Initial plant dry weights of the seedlings were based on the actual measurement at transplanting. Other parameters and procedures of the simulation are the same as in the previous experiments.

As shown in Fig. 6, the simulated growth curves agreed fairly well with the observed one, except for the case of Nagano, where temperature in the early growth stage of rice plants are relatively low. Over-estimation of the growth for Nagano is due probably to the lack in the model structure of the function regulating growth rate in relation to temperature. Simulation of plant growth during the period of 80 days, starting from 40 days after transplanting, has indicated a fairly good agreement of the simulated with the actual growth.

The simulation results mentioned above indicate that the model is acceptable as a first approximation of the actual plant growth in the field. Although much refinement of the model is needed, the model of this type will be used as an efficient tool in extrapolating knowledge from physiological studies to the field and in predicting the effect of environmental factors on the growth dynamics of crop plants in the field and in the greenhouse.

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