# Simulation Analysis of Dry-Matter Reproduction System in Winter Cereals

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Many researchers have carried out ecological studies on the photosynthetic function of cereals during various growing stages[1,4,7]. In many cases, however, they might have faced with difficulty in compiling their experimental data into a definite relationship to grain yield productivity. For solving this problem, the present author and his co-researchers attempted to build a model for simulation of dry-matter growth in winter cereals[9,11]. This study was conducted at the Second Division of Plant Physiology (Kitamoto, Saitama), National Institute of Agricultural Sciences, to which the author had belonged formerly.

## General structure of the model

The model for winter cereals was formulated with a simulation language DYNAMO[8], using the modified structure taken from the model by Iwaki (1975, 77)[2,3] which was built to simulate total dry-matter growth of rice plant during the whole vegetative period. The model presented in this paper is different from the Iwaki's model structure in several points, especially the former is designed to know grain yield.

The crop growth cannot be maintained without reproduction of photosynthate, so-called dry-matter reproduction[6]. As shown in Fig. 1, the proposed model structure is

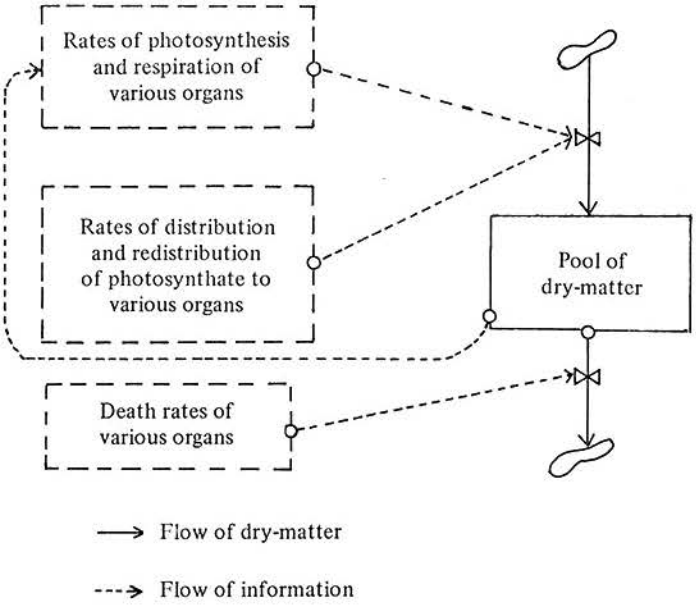

Fig. 1. Outline of the model structure

simplified as far as possible and involves "feed back system" only between dry-matter weight and rate of photosynthesis and respiration of organs. General structure is outlined as follows.

### *1) Dry-matter weight*

Dry-matter weight is simulated with a special attention to ear dry-matter weight in order to estimate grain production. One example of the equation for simulation is shown as follows:

$$\frac{\Delta LEB}{\Delta t} (= LEGR\text{-}RLDR\text{-}DLDR) \times 0.612 \cdots (1)$$

where, $\Delta LEB$: Difference in dry-matter weight of leaf blades between a day and the preceding day, $\Delta t$: one day, LEGR: $PG_T$ (daily gross photosynthesis of various organs except that of ear) × $DI_L$ (ratio of distribution of photosynthate to leaf blades), RLDR: Daily redistribution of photosynthate into ears from leaf blades, and DLDR: Death rate per day of leaf blades.

It was assumed that the product by ear photosynthesis is stored only in the ears, and dates for germination and heading of each crop are fixed.

### *2) Photosynthesis and respiration of various organs*

Firstly, it was postulated that all the ears are distributed in the top layer of the canopy, and that the other organs with photosynthetic ability (leaf blades, leaf sheaths and a part of culms) are distributed uniformly in the layer beneath the ears. Then, the daily gross photosynthesis (consists of $PG_E$: that of ears, and $PG_L$: that of leaf blades) of the canopy can be calculated by the following approximate equations;

where, $A_E$, $B_E$, $A_L$, $B_L$: Parameters which characterize the shape of light-photosynthesis curve in ear ($A_E$, $B_E$) and leaf blade ($A_L$, $B_L$), D: Day length, K: Extinction coefficient of photosynthetic organs, $I_M$: Maximum solar radiation above the crop canopy at noon. EAI: Index of logitudinal section area of ears (including awns) in the canopy, M: Light transmissibility of single organs, LAI: Leaf blade area index, TAI: Sum of area indices of plant parts except ears, $I_N$: Maximum solar radiation under the layer of ears.

The equation (2) and (3) are induced by modifying that of Kuroiwa (1968)[5]. The equations relating to leaf sheath and culm can be obtained by resembling the equation (3). Parameter A and B ($A_E$, $A_L$, $B_E$, $B_L$ etc.) are the coefficient of the following equation,

$$P = \frac{BI}{1+AI} \cdots\cdots (4)$$

where, P is gross photosynthesis of single organ, and I is light intensity.

For determining the parameter A and B, the three non-linear relationships found from experimental data were used in this model (Fig. 2)[4,10]: (1) As the photosynthetic ability of single organ begins to lower gradually according to the age, the pattern of light-photosynthesis curve also begins to change largely in A, but only slightly in B. This relationship is connected with the mean photosynthetic ability of the canopy in the model (Fig. 2-left). (2) It can be summarized roughly under the field condition that the effect of temperature on photosynthesis appears only in cold winter days in depressive direction (Fig. 2-middle). (3) Photosynthetic ability of single organ was obtained from the experimental data which were measured under the near-optimum environmental condition. In the model, the mean value of each organ is used as the basic photosynthetic parameter, determined to be dependent on the age of plants (Fig. 2-right).

$$PG_E = \frac{2B_E \cdot D}{A_E \cdot K} \times \mathrm{In} \cdot \frac{1+\sqrt{1+A_E \cdot K \cdot I_M/(1-M)}}{1+\sqrt{1+A_E \cdot K \cdot I_M \cdot \exp(-K \cdot EAI)/(1-M)}} \cdots\cdots (2)$$

$$PG_L = \frac{2B_I \cdot D}{A_L \cdot K} \cdot \frac{LAI}{TAI} \times \mathrm{In} \cdot \frac{1+\sqrt{1+A_L \cdot K \cdot I_N/(1-M)}}{1+\sqrt{1+A_L \cdot K \cdot I_N \cdot \exp(-K \cdot TAI)/(1-M)}} \cdots\cdots (3)$$

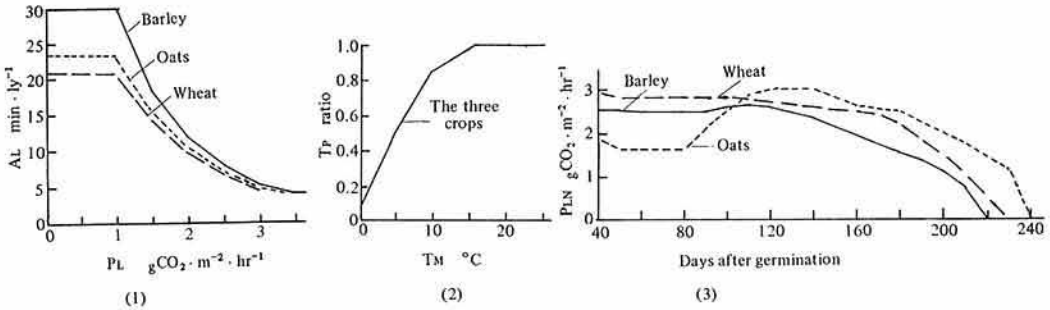

Fig. 2. Determination of parameter $A_L$
(1) Relation between $P_L$ and $A_L$ (2) Relation between $T_M$ and $T_P$
(3) Changes with time in $P_{LN}$
Note $P_L$: $P_{LN} \times T_P$, $T_P$: Coefficient of temperature effect on photosynthesis, $T_M$: Approximate average value of temperature in daytime, $P_{LN}$: Mean gross photosynthetic ability of leaf blade

In the Iwaki's model, the parameter of respiration was assumed to be a function of photosynthesis, biomass, age and temperature. But in the model proposed in this paper, the parameter of respiration was taken to be influenced by temperature, and was divided into two parts. The one part was given as time course of respiratory rate per unit dry-matter weight of plant except ear, and the other part was given as time course of the rate per unit area of ear.

### *3) Distribution and redistribution of various organs*

Time trends in the distribution ratios are used as parameters in every simulation run to calculate allocations of photosynthate to various organs. Redistribution or import of stored organic matter from other organs is assumed to occur only in ear.

### *4) Death of various organs*

The death of each organ is assumed to begin at 31st day after emergence. And the death rate after 31st day is determined by exponential delay function of the DYNAMO language. The mean life span of the organ except for ears and roots is assumed to be much longer in winter than in spring.

## Basic simulation of six-rowed barley and modified simulation by changing parameters

The parameters of the basic simulation run of six-rowed barley were determined by using the results of several field tests[9,10]. Dates for germination and heading were fixed to November 5 and April 24 (170th day after germination), respectively. Simulation of the crop growth were made for the period of 175 days from 30th day to 205th day after the germination, as shown in Fig. 3. These results show the normal growth pattern, suggesting that the greater parts of the parameters used in the model are appropriate.

Table 1 shows examples of modified simulation outputs obtained by changing parameters relating to photosynthetic function. The changing degrees of parameters in the run 5, 8 and 12 were regarded to be of practical modifications because they were assumed from the field tests of varietal difference in six-rowed barley in Japan[10]. When the photosynthetic ability of all organs was assumed to be increased by 20% (run 5), ear dry-matter weight at 205th day became 524 g m$^{-2}$, showing an increase of about 16% as compared with the basic run. But in this case, LAI before heading date tended to be over-optimal. This model shows also a sensitive reaction of ear dry-matter weight (grain

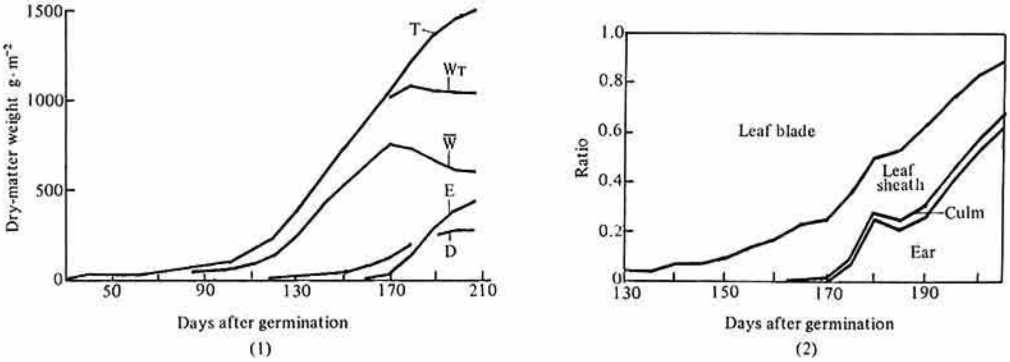

Fig. 3. Results of the basic simulation run in barley
(1) Dry-matter weight per unit of land area (2) Contribution of the various organs to total gross photosynthesis
Note T: Total dry-matter, $W_T$: Dry-matter other than ear, $\overline{W}$: Dry-matter other than ear, root and dead leaf blade, E: Ear, D: Dead leaf blade

**Table 1. Simulation results obtained by changing parameters**

| | LAI | | Ear dry-matter | | Total dry-matter |
|---|---|---|---|---|---|
| | 150th day | 170th day | 170th day | 205th day | 205th day |
| | | | $g\cdot m^{-2}$ | $g\cdot m^{-2}$ | $g\cdot m^{-2}$ |
| Basic run | 6.75 | 4.86 | 52.2 | 451 | 1502 |
| Run 5 | 8.81 | 5.85 | 57.0 | 524 | 1834 |
| Run 8 | 4.75 | 3.60 | 42.3 | 341 | 1127 |
| Run 12 | 8.51 | 6.04 | 53.1 | 478 | 1579 |

production) when the parameter A relating to the light-photosynthesis curve was reduced to about three fifths (run 8). On the other hand, the effect of changing SLA (specific leaf area) on ear dry-matter weight was slight, although the effect on LAI was large (run 12). In the run 12, parameter SLA was increased gradually with time, and by about 20% at later growth stage, as compared with the basic run.

The other results of analysis are summarized as follows:

1) There exists an optimum LAI value for the grain production.

2) Contribution of photosynthesis of various organs to grain production was calculated by eliminating the photosynthetic ability of each organ. It was 28% in ear, and 35% in leaf sheath and culm.

3) When the inhibitory effect of low temperature on photosynthesis is reduced, the LAI tends to be over-optimal in spring.

4) When the life span of photosynthetic organs is prolonged only less than 10 days at the later growth stage, the grain production is increased conspicuously.

## Comparison between model simulations and practical field tests in the three crops

The function of photosynthesis and the growth of dry-matter in the three crops (six-rowed barley, wheat, and oats) were measured in 1970/71[10]. In the field test, it was found that mean photosynthetic ability of whole leaves was high during winter in six-rowed

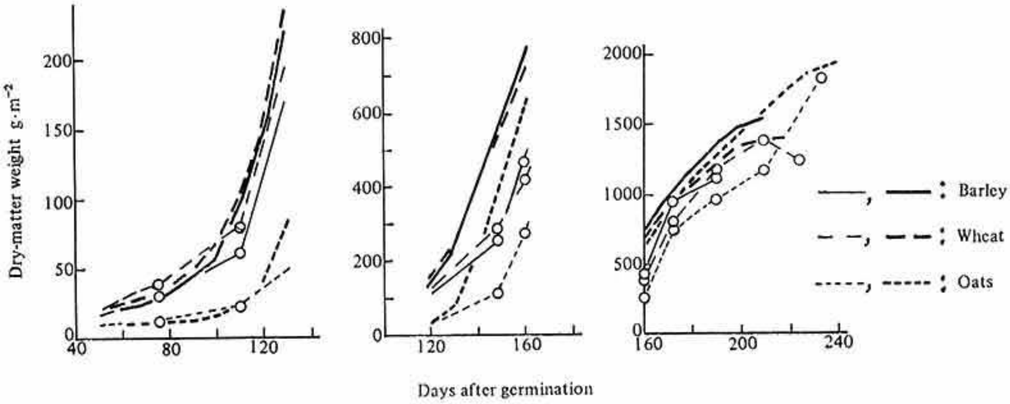

Fig. 4. Comparison between simulation and field experiment (1). Total dry-matter
Note: Thick lines indicate simulation, and thin lines field experiment

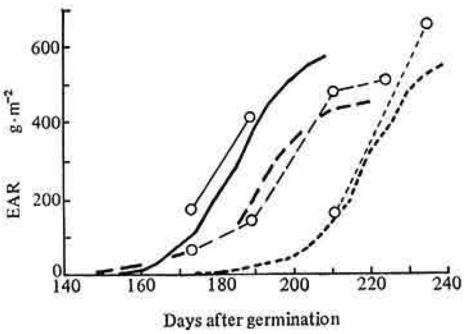

Fig. 5. Comparison betewen simulation and field experiment (2). Ear dry-matter
Note: Signs and note are the same as in Fig. 4

barley and wheat but low in oats, and that contribution of ear photosynthesis was high in six-rowed barley and oats than wheat. The parameters for model simulations of each crop were made by using these results and the other information concerning photosynthetic function. Thus the results of field experiments and simulations were compared each other.

Fig. 4 shows changes with time in total dry-matter. At the early growth stage from about 50th day to 110th day, the result of field experiments and that of the simulations resemble each other (Fig. 4-left) and both of them show similar tendencies with regard to inter-crop difference among the three crops. Thus, it is concluded that the parameters of photosynthetic function in the early growth stage are appropriate, and that the integration of the experimental data related to the

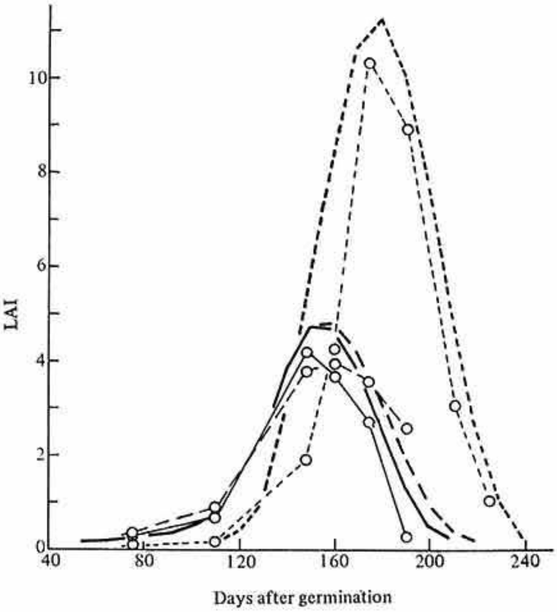

Fig. 6. Comparison between simulation and field experiment (3). LAI (leaf area index)
Note: Signs and note are the same as in Fig. 4

photosynthetic function in winter season is also appropriate at least for the comparison among the three crops. But, at the middle growth stage (Fig. 4-middle), the growth rates of the three crops begin to increase rapidly about 20 days earlier in the simulation than in the field experiments. This result might occur because the parameters adopted in relation to respiration were too simple for simulating the middle growth stage, which involves both of vegetative and reproductive growth phase. Excepting this aspect, total dry-matter growth at the later growth stage (Fig. 4-right), ear dry-matter growth (Fig. 5) and LAI (Fig. 6) showed fairly good fitness between the field experiment and the simulation.

From these results obtained, it can be concluded that the system analysis using model simulation experiment is useful for the analysis of dry-matter reproduction in winter cereals.

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