Modeling the Wheat Growth under Drought-Prone Environments
- Structure and Parameterization -

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1. Introduction

Simple and robust crop simulation models are required for the impact assessment of climate change on crop production. We have almost developed a simplified process model for simulating wheat growth under drought-prone environments. Our model has two features. Firstly we use an empirical relationship between transpiration rate and soil moisture based on an experimental result to simulate Crop Growth Rate (CGR). This approach would give us robust simulation results of CGR under drought conditions with the minimized numbers of input variable. Another feature is that the model is equipped with a submodel to estimate the effect of frost damage, which wheat crops sometimes encounter in Turkey, on yield.

In this report, the general structure of the model and the partly finished parameterization process are explained.

2. Structure of a Wheat Growth Model

Our wheat model consists of four sub-models related to phenology, LAI growth, biomass production and yield formation process.

2.1 Phenology

Crop development stage is quantified by a continuous variable termed DVS (Development Stage) as in de Wit et al. (1970). DVS is defined to be 0, 1 and 2 at emergence, anthesis and maturity, respectively. The value of DVS at any moment is given by integrating the development rate with respect to time:

DVR in the preanthesis phase can be given by the following equation.

$$\mathrm{DVS} = \sum_{i=0}^{t} \mathrm{DVR}_i \qquad (1)$$

where DVR_i is the development rate at the ith day.

Temperature (T) and daylength (L) responses of DVR in the preanthesis phase can be given by the following equation.

$$\mathrm{DVR} = \frac{1}{G} f(T) g(L) \qquad (2)$$

where G is the minimum number of days required for the completion of one phenophase under optimum T and L, and $f(T)$ and $g(L)$ are the functions giving the temperature and daylength effects on development.

Introduction of the G parameter makes the ranges of $f(T)$ and $g(L)$ 0 to 1, respectively.

For the function $f(T)$, the beta equation (3) can be successfully applied to the preflowering development process (Yin and Kropff 1996).

$$f(T) = \begin{cases} \left[\left(\dfrac{T - T_b}{T_o - T_b} \right) \left(\dfrac{T_c - T}{T_c - T_o} \right)^{(T_c - T_o)/(T_o - T_b)} \right]^{\alpha}, & (T_b \le T \le T_c) \\ 0, & (T < T_b,\ T > T_c) \end{cases} \qquad (3)$$

where T_b, T_o, T_c and α are parameters.

The effect of daylength, $g(L)$, can be approximated by the following equation:

$$g(L) = \begin{cases} 1 - P \exp\{-B(L - Lc)\}, & (L \ge Lc) \\ 1 - P, & (L < Lc) \end{cases} \qquad (4)$$

where P, B and L_c are parameters. P is the daylength sensitivity factor ($0 \le P \le 1$) and L_c means the critical daylength if $P = 1$.

Those eight parameters can be estimated from the phenology data in winter cereal crop species grown under various environmental conditions with iteration methods.

2.2 Biomass Production

A simplified process approach was employed in the model to simulate crop growth rate (CGR) based on radiation use efficiency (RUE) and intercepted solar radiation. To estimate CGR under drought conditions, we use an empirical relationship between transpiration rate and soil moisture based on an experimental result (Kobata 2004, Kobata et al.

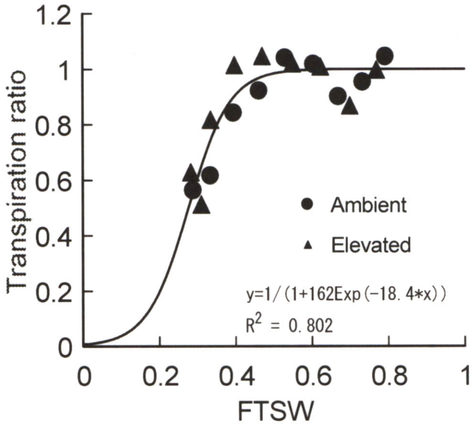

Fig. 1. The ratio of transpiration rate under desiccated soil to under well-irrigated condition for a spring wheat 'Adana99' grown under different CO_2 conditions with pots as a function of the fraction of transpirable soil water content (FTSW) (Kobata et al. unpublished)

unpublished, Fig. 1). These processes are expressed as the following equation:

$$CGR = RUE \cdot S_s \{1 - \exp(-k \cdot LAI)\} \frac{T_a}{T_p}$$

$$\frac{T_a}{T_p} = f(FTSW) \qquad (5)$$

where S_s, k, LAI, T_a, T_p and $FTSW$ is global shortwave radiation, light extinction coefficient, leaf area index, actual and potential transpiration rate, and fraction of transpirable soil water content.

2.3 Leaf Area Growth

The growth of Leaf area index (LAI) has not yet been modeled, but a temperature-driven function and a reduction factor caused by biomass limitation will be used to calculate LAI growth.

2.4 Yield Formation

The model is based on the principle that the grain yield (Y_G) forms a specific propotion of the total dry matter production (Wt) of a crop:

$$Y_G = hWt \qquad (6)$$

where h is the harvest index. In the model, h is represented as a function of yield loss rate (γ):

$$h = h_m(1-\gamma) \qquad (7)$$

where h_m is the maximum harvest index and γ is defined as a function of temperature.

Global warming should accelerate the phenological development of winter cereal crops and then would increase the possibility to make the sensitive stage of them meet the coldest season in a year. Thus, we have to know the effect of low temperature on yield loss rate (γ) at a given phenological stage and also need a precise prediction of phenological stage. For the latter requirement, our phenology sub-model can accurately predict phenology, as demonstrated in the application to a wheat cultivar 'Adana99' (Table 2).

For the former requirement, we can fortunately use published data. For example, Tajima (1982) gave cold temperature treatments to barley at different development stages of young panicle. They measured the mortality of young panicle under various temperature conditions and showed the sensitivity to freezing temperature increased with the progress of panicle development. Dead panicles are partly compensated by the growth enhancement of remaining tillers. Therefore, he also gave a relationship between mortality rate of young panicle and yield loss rate.

In our model, the phenological stage of young panicle is converted into DVS in the phenology model. We made an expression to give a relationship among yield loss rate for barley (γ), daily minimum temperature (T_{min}) and DVS, based on reanalysis of the published data (Tajima, 1982):

$$\gamma = \begin{cases} 0.406(DVS - 0.523)(-T_{\min} - 2), & (0.523 \le DVS \le 0.8) \\ 0.113(-T_{\min} - 2), & (0.8 < DVS < 1.2) \end{cases} \qquad (8)$$

γ equals zero in the case of T_{min}>-2 °C or DVS<0.523. When the DVS is between 0.523 and 1.2, daily values of γ are calculated with equation (8) and finally the maximum value of γ is chosen for the calculation of yield.

We are now searching similar data to make an equation for estimating the frost damage on wheat production.

3. Wheat Experiments for Parameterization of the Model

Wheat field experiments has been done and are being carried out in Adana, Turkey, to obtain crop data which are required for the development and test of wheat growth models including our model. A Turkish wheat cultivar 'Adana 99' is used for the experiments. Two or three cropping seasons were and will be planned in Adana in 2003/2004 and 2004/2005, respectively. The phenology of 'Adana

99' has been and is continued to be observed also in a series of field experiments with different sowing dates in Ishikawa, Japan.

4. Parameterization of the Model

Parameters of the phenology model were estimated from anthesis dates (Table 1) of 'Adana99' and meteorological data (6 data sets) under the assumption that Adana99 does not have photosensitivity. Table 2 shows the estimated parameters and the related statistics. The present model could well explain the heading dates of 'Adana99' grown under a wide range of environmental conditions with relatively high accuracy (se=6.1 days, r=0.986).

Table 1. Sowing, emergence, anthesis and maturity dates of a Turkish spring wheat 'Adana99' grown at different growth seasons in Ishikawa, Japan, and Adana, Turkey in 2003/2004.

Sowing	Emergence	Anthesis	Maturity
Ishikawa, Japan			
10 Oct, 03	16 Oct, 03	30 Apr, 04	15 Jun, 04
2 Jun, 04	6 Jun, 04	2 Aug, 04	-
16 Jun, 04	20 Jun, 04	11 Aug, 04	-
2 Jul, 04	6 Jul, 04	9 Sep, 04	-
Adana, Turkey			
17 Nov, 03	30 Nov, 03	9 Apr, 04	17 May, 04
4 Mar, 04	15 Mar, 04	18 May, 04	14 Jun, 04

Table 2 Phenological parameters of 'Adana99' wheat estimated by days to anthesis obtained from field experiments in Adana and Ishikawa.

G (day)	T_b (°C)	T_o (°C)	T_c (°C)	α	se (day)	r^2
44.1	-10.0	23.5	34.5	4.925	6.1	0.986

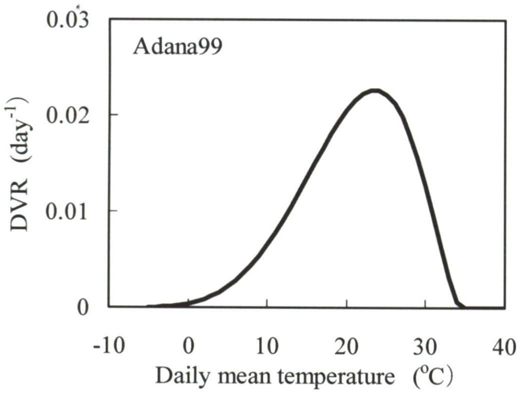

Fig. 2 Development rate (DVR) as a function of daily mean air temperature for a wheat cultivar 'Adana99' estimated from the phenology data in Table 1.

The response of DVR to temperature was drawn with parameters in Table 2 (Fig. 2). This figure shows the curvilinearity of the temperature response of phenological development towards heading in 'Adana99', implying that the simple day-degree method will fail to simulate wheat phenology under global warming environments.

We are also parameterizing other processes of the model with the use of our and reported experimental data on wheat.

5. Research Plan

After finalizing the model construction, we will test the model using the data obtained from wheat field experiments in Cukurova University and also using statistical yield data. The former data sets will be used for checking biomass and LAI dynamics of wheat, and the latter for checking year-to-year and site-to-site variations of wheat yields near Adana. Also sensitivity analysis will be done for checking the responses of our model to environmental factors. Following them, we will run the model under pseudo global warming climate in Turkey (Yoshikane et al., 2001; Yukimoto et al., 2001).

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