Modeling the wheat growth under drought-prone environments

- A phenology model for winter cereal crops and its parameterization -

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1. Introduction

Crop simulation models are indispensable for the impact assessment of climate change on crop production. We will develop a simplified process model for simulating wheat growth under drought-prone environments and will compare several wheat growth models, including the crop sub-model of SWAP (Ashby et al., 1996), SUCROS (van Laar et al. 1997) and our original model. This year, a phenology sub-model was created for winter cereal crops and was parameterized for a barley cultivar grown under well-watered conditions.

2. Structure of a phenology model

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, 2 at emergence, heading and maturity, respectively. The value of DVS at any moment is given by integrating the development rate with respect to time:

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

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 logistic equation (3) can be successfully applied to the preflowering development process if the supraoptimum temperature range can be omitted from the analysis (Horie and Nakagawa 1990).

$$f(T) = \frac{1}{1 + \exp\{-A(T - Th)\}} \qquad (3)$$

where A and Th are parameters.

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

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

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

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

3. A series of field experiments in barley

A two-rowed barley cultivar 'Amagi-Nijo' was periodically sown at the experimental farm of Kyoto Univ. in Kyoto, Japan about every two weeks from mid September in 1988 to the end of September in 1989. A standard cultivation method was employed. Soil moisture was well maintained during the entire cropping seasons.

Emergence, spikelet initiation, floret initiation and heading dates were recorded for each cropping season. Heading dates could be successfully recorded in 18 out of total 23 cropping seasons (partly published in Oh et al., 1990). For 5 cropping seasons, conditions of plant materials were abnormal due to some diseases and those data were excluded for the further analysis. Days after sowing to heading widely varied depending on the sowing date, that is, temperature and daylength conditions (Fig. 1).

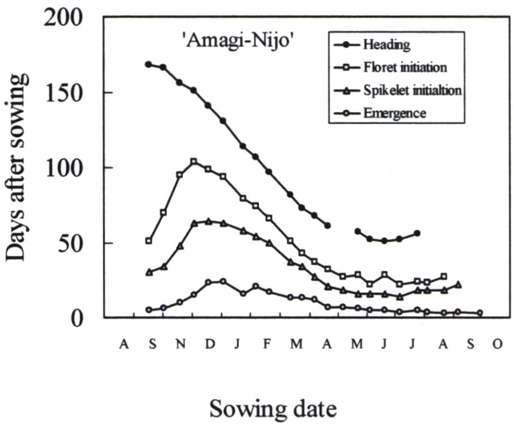

Fig. 1 Days after sowing to emergence, spikelet initiation, floret initiation and heading in a two-rowed barley cultivar 'Amagi-Nijo' grown under different cropping seasons at Kyoto in Japan.

4. Parameterization of the model

Parameters of the phenology model were estimated from heading dates (Fig. 1) of 'Amagi-Nijo' and meteorological data (18 data sets). Table 1 shows the estimated parameters and the related statistics. The present model could well explain the heading dates of 'Amagi-Nijo' grown under a wide range of environmental conditions with high accuracy (se=1.43 days, r=0.999).

The response of DVR to temperature and daylength was drawn with parameters in Table 1 (Fig. 2). This figure shows the curvilinearity of the temperature response and that long day conditions promote phenological development towards heading in 'Amagi-Nijo'.

The model with parameters in Table 1 was tested by using independent data sets of

Table 1. Values of six parameters in equation (2) estimated from phenology data (days after sowing to heading) of a barley cultivar 'Amagi-Nijo' (Fig. 1), the number of data sets (n), standard error (se) and correlation coefficient for the linear regression between predicted and observed days (r).

Parameter	Value
A	0.3527
Th (°C)	4.466
B	1.007
Lc (hours)	11.58
G (days)	47.96
P	0.60
n	18
se (days)	1.43
r	0.999

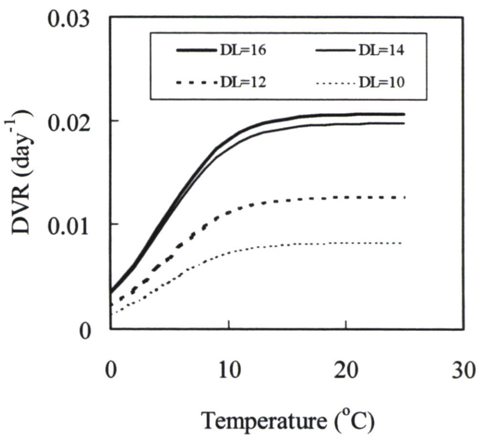

Fig 2. Development rate (DVR) as a function of daily mean air temperature and daylength (DL, hours) for a barley cultivar 'Amagi-Nijo'

'Amagi-Nijo' grown in 13 prefectures in Japan, which were documented in annual reports of agricultural research institutes in those prefectures. The present model could well explain the site-to-site difference and yearly variations of heading date without any adjustment of parameters.

These results suggest that the present model can be applied for simulating the phenological development of winter cereal crops grown under a wide range of temperature and daylength conditions, if the vernalizaion effect can be omitted as in the case of 'Amagi-Nijo'.

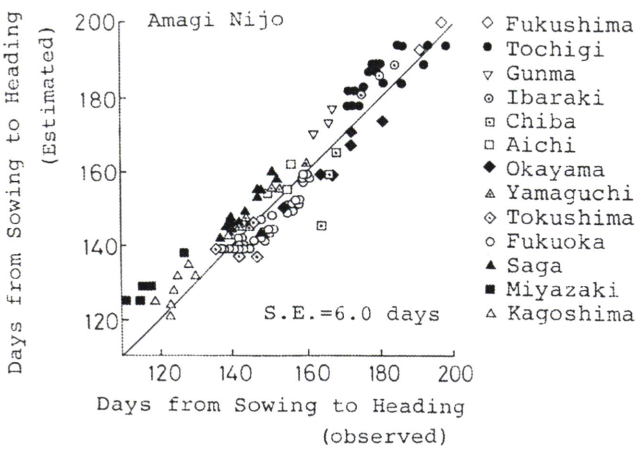

Fig 3. Comparison between estimated and observed days after sowing to heading in a barley cultivar 'Amagi-Nijo' grown at different sites in Japan.

5. Ongoing experiments in wheat

Wheat field experiments are being carried out in Adana, Turkey to obtain crop data which are required for the development and test of crop growth models. 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' will be observed also in a series of field experiments with different sowing dates in Ishikawa, Japan. Those phenology data both in Adana and Ishikawa will be used for the estimation of parameters of the model.

6. References

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