The calibration of a model for daylength responses in spring wheat for large numbers of cultivars.

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Abstract

A method has recently been developed for specifying daylength response parameters in spring wheat cultivars for the wheat simulation model Sirius. This is an extension of methodology described earlier, and allows the prediction of flowering date from any sowing date x cultivar combination. The method is based on the estimation of the final mainstem leaf number in an autumn sowing, and the systematic estimation of the response of final leaf number to the daylength experienced midway through leaf production. The method has good internal consistency in reproducing final leaf numbers from the calibration dataset. It also predicts the flowering response to changes in sowing date from autumn to spring very well. Tests of the calibration with independent data showed that it still captured most of the observed variation in flowering date with both sowing date and cultivar.

Additional key words: *leaf appearance rate, final leaf number, daylength response.*

Introduction

In many environments the anthesis date in wheat is a major determinant of its performance (Jamieson and Munro, 1999). Anthesis date is influenced by sowing date and cultivar responses to daylength and temperature. Until recently, the determination of these responses required developmental observations of plants from a wide range of sowing dates, and these observations themselves required microscopic examination of the developing apical meristem (Delécolle *et al.*, 1989; Porter *et al.*, 1987). From these observations and their associated dates, the intervals between apical events in various sorts of modified thermal time were derived, as done for oats by Sônego *et al.* (1997), so that a predictive model could be developed. Such models have been very successful in predicting anthesis (Porter *et al.*, 1993), but the time and effort required to derive the model parameters is a strong disincentive for them to be found for many cultivars. However, recent advances in describing the mechanisms of cultivar responses to these factors (Jamieson *et al.*, 1995a, 1998a) have allowed the development of a simplified methodology for determining these responses so that flowering dates may be predicted for any cultivar/sowing date combination in a known environment. It is particularly suitable for spring wheat, where there is no complication from vernalisation. The method relies on the fact that the cause of variation in the time interval from sowing to anthesis is the combination of the rate at which leaves appear, controlled mostly by temperature (Jamieson *et al.*, 1995b), and the final mainstem leaf number (FLN), controlled by daylength at some time during development (Brooking *et al.*, 1995). So if the rate of leaf appearance and FLN can be predicted, the prediction of anthesis date logically follows. In principle, intermediate apical states can be predicted from the Haun stage and FLN, as shown by Sônego *et al.* (2000) for oats, because of the close co-ordination between apical and leaf development (Kirby, 1990).

For spring types, the key to determining the daylength response is the estimation of FLN from an autumn sowing of the cultivar. The methodology for this was set out by Jamieson and Munro (1999). It involves the measurement of the exact Haun (1973) stage (fully expanded leaves plus the decimal proportion of the newest expanding leaf extended) when five to seven leaves have appeared on the mainstem, and recording of the date of anthesis. These data and a simulation model, Sirius (Jamieson *et al.*, 1998b), are used to estimate the phyllochron (thermal time per leaf, the inverse of the leaf appearance rate in thermal time) and the FLN. Jamieson and Munro (1999) showed that FLN estimated this way was very close to that determined directly by counting leaves through the development of the crop. The method has now been extended so that the daylength effect on FLN can be calculated and therefore the flowering date can be estimated for any sowing date. This can be done accurately for spring cultivars, but the experimental data are insufficient to give complete information about winter cultivar responses because the vernalisation response (effect of exposure to low temperatures on FLN) cannot be extracted from just autumn and spring plantings, although spring plantings unequivocally identify winter types.

The advantages of the method are that it requires only a few measurements of the external morphology of plants to be made, and that most of the information is gained from a single sowing date in autumn. Hence it can be applied to a large number of cultivars at once. Here we explain the method in detail and present results of the calibrations and validations with independent data.

Materials and Methods

A total of 39 cultivars, comprising both spring and winter types, were sown in plots in a single replication on 13 May 1999 at the Crop & Food Research Station at Lincoln. These same cultivars and an additional 12 were sown in adjacent plots on 27 August 1999. At approximately the 6-7 leaf stage, a measurement of the exact Haun stage was made on a sample of 10 plants per plot. The date of the emergence of the flag leaf ligule and anthesis date were also observed for each cultivar. True winter cultivars in the spring sowings did not flower. The following procedure was used to derive parameters so that anthesis date could be predicted.

- The phyllochron in Sirius was adjusted for each cultivar so that "predicted" and observed Haun stage matched. This was taken as the phyllochron for the cultivar.
- Sirius was then run for an arbitrary cultivar whose phyllochron was defined as above, with a fixed FLN that substantially exceeded any observed. This had the effect that the simulation was still producing leaves at the anthesis date. The cultivar FLN was estimated as 2.3 Haun stages less than the calculated Haun stage at the observed anthesis date. On the basis that Jamieson and Munro (1999) established this method to be very accurate, this was taken as the observed FLN.
- Using this estimate of FLN, a first approximation to the daylength response parameter (in leaves per hour of daylength) was estimated as the ratio J = (FLN - 8)/(15 - DL) where DL is the daylength when the Haun stage is exactly FLN/2 (Brooking *et al.*, 1995). The equation assumes that spring wheat saturates to a minimum FLN of 8 in daylengths greater than 15 hours. This used data only from the May 1999 sowing.
- The model was run using the derived parameters, and these (both phyllochron and J) were tuned to improve the fit of both FLN and leaf production rate for each cultivar, again using only the May 1999 sowing.

A total of 21 cultivars were common to sowings in 1998 (Jamieson and Munro, 1999) and 1999. Parameters for Sirius derived from the 1999 observations were used to predict the anthesis dates for the 1998 sowings using weather observations from Lincoln.

Results

The first assumption to be tested was that the anthesis date was a good predictor of the date of flag leaf ligule appearance and, by implication, of FLN. The day of flag leaf ligule appearance predicted using the assumption above was compared with the observed date (Fig.1). On average, the date was predicted 1.7 days early, with a root mean square deviation (RMSD) of 2.9 days. The predictions and observations were very closely related, with an R^2 of 0.93 and a slope not significantly different from unity (df = 36). The assumption appears to be good for this sowing time.

The first approximation to J resulted in predictions that were correlated with observations (R^2 = 0.31; Fig. 2), but where the errors were reasonably large (maximum error 1.3 leaves, RMSD 0.84 leaves. Tuning was able to improve both the correlation and the error (Fig.3; R^2 = 0.79, maximum error 0.6 leaves, RMSD

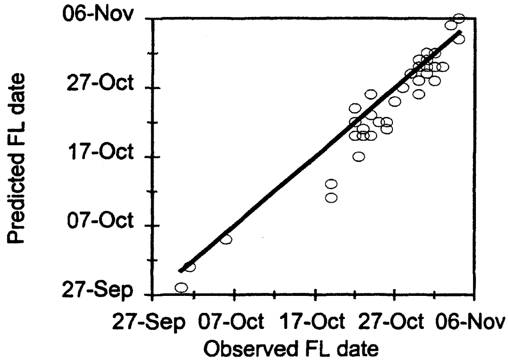

Figure 1. Comparison of observed and predicted flag leaf ligule (FL) appearance date from the 1999 Autumn sowing. The solid line is y=x.

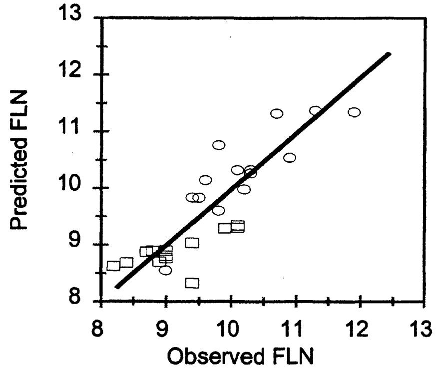

Figure 3. Comparison of predicted and observed final leaf numbers after tuning for the 1999 experiment. Autumn sowing (○), spring sowing (□). The solid line is y=x.

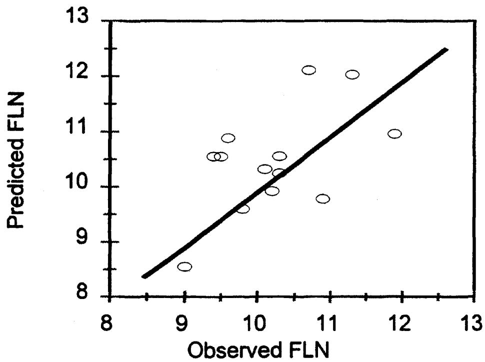

Figure 2. Predictions of final leaf number from first approximation for the 1999 Autumn sowing. The solid line is y=x.

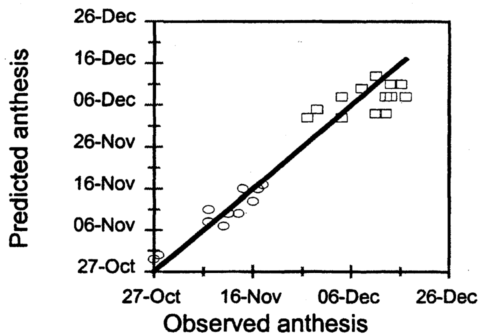

Figure 4. Comparison of observed and simulated anthesis date for the calibration set (1999). Symbols as in Fig. 3. The solid line is y=x.

0.37 leaves). The parameters derived succeeded in predicting final leaf numbers in spring sowings as well (Fig.3; RMSD 0.51 leaves), although in this case lower FLNs were slightly overestimated and higher FLNs underestimated.

Anthesis dates predicted from the model using the derived parameters and Lincoln weather data were plotted against observed dates for the same year (1999) to check for internal consistency (Fig. 4). Spring data were independent, and even these dates were predicted closely (Fig.4). The simulations largely preserved the order of cultivar flowering. A check using independent data from the previous year (Fig. 5) showed predictions to be highly correlated (R^2 = 0.94, df = 19) with observations and, with few exceptions, within a few days of the dates observed. The RMSD was 4.9 days, but there was a large bias component in this, because the model tended to predict anthesis early, by an average 3.5 days. The difference in anthesis date associated with spring v autumn sowing was well reproduced by the model.

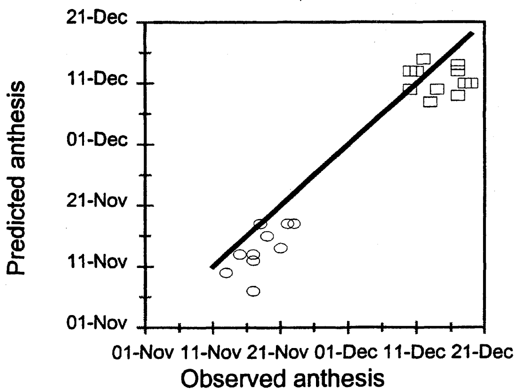

Figure 5. Comparison of observed and simulated anthesis dates for the independent (1998) dataset. Symbols as in Fig. 3. The solid line is y=x.

Discussion and Conclusions

These results confirm that this rapid method provides most of the information about cultivar phenological response. It allows a reasonable prediction of likely flowering date that is useful to growers when choosing cultivars. The method is particularly good for spring cultivars, but needs further development to deal with winter cultivars properly. Estimating the effects of vernalisation will require an additional sowing in late summer (March) so that early development is in warm conditions

This information is the first step in producing a computer decision support system for assessing wheat sowing date/cultivar combinations, fertiliser requirements, in-season irrigation and fertiliser management so that consistently high value grain can be produced for particular uses.

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