A simple method for the phenological evaluation of new cereal cultivars

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Abstract

Daylength response in cereals causes variation in flowering date through influences on the number of leaves produced on the main stem. Current methods of tracking leaf numbers by frequent observation from multiple sowing dates are very time consuming, and therefore expensive. We have developed a much less labour intensive method of determining the leaf number response to daylength. The method requires only two sowing date treatments, two observations per cultivar, and the use of a simulation model to assist interpretation. The method provides most of the information needed to characterise the phenology of a cultivar.

Additional key words: *final main stem leaf number, anthesis, phyllochron.*

Introduction

Flowering time in cereals is important in determining when grain is filled, and therefore the weather and often the soil conditions the crop will experience. The ability to make management responses, particularly late season irrigation, often depends on knowing the likely time of flowering. In choosing wheat cultivars for sowing from April onwards, knowledge of the likely response of the flowering time of a cultivar to sowing time variations assists in cultivar and sowing time choices to avoid frost risk, and to minimise the risk of drought associated with late flowering.

Determining the response of flowering time to sowing time means defining cultivar responses to daylength and temperature. Until recently, this process required frequent dissections of plants to assess the state and stage of development of the apex by microscopic examination (Kirby and Appleyard, 1981) and then analysing the effects of temperature and daylength on the duration of various phases between planting and emergence (Porter et al., 1987; Slafer and Rawson, 1994, 1995). However, based on the coordination of leaf production and apical development (Kirby, 1990; Hay and Kirby, 1991), Jamieson et al. (1998a) showed that developmental responses could be defined entirely in terms of the rate of leaf appearance and final leaf number (FLN) on the main stem. The effect of temperature in spring wheats was almost entirely on the rate of leaf production (Jamieson *et al.*, 1995), although in winter wheats temperature also influences FLN (Brooking 1996). In contrast, daylength influences the FLN in both types (Brooking *et al.*, 1995), and has little or no effect on the leaf appearance rate. The combined effect of these responses determines the duration of the phase from sowing to anthesis for any cultivar.

These facts mean that to specify anthesis date responses to sowing time, the temperature response of leaf appearance and the daylength response of final main stem leaf number will be sufficient in spring wheats, while some more information about vernalisation responses will be required for winter wheats. These can be determined by counting the leaves on plants as they develop, and noting the exact leaf stage on the Haun (1973) scale; i.e., the cumulative number of fully expanded leaves plus the decimal proportion of the emerging leaf, and repeating the experiment for several sowing times to vary exposure to daylength. Usually this is done by tagging plants, tagging the position of a known leaf (because lower leaves die, making it difficult to count them), and making observations sufficiently frequently that the observer does not lose track of the number of the newest emerging leaf. This process is very time consuming and, therefore, expensive. However, the pattern of leaf production with thermal time, and the way this varies with leaf number, is common among wheat cultivars (Jamieson *et al.*, 1998a), although the base leaf appearance rate, or its inverse, the phyllochron (thermal time to produce one leaf) varies among cultivars. In principle then, it should be possible to use a single measurement of the exact Haun stage at some time, and to use this together with the temperature record since planting to determine the leaf appearance rate in thermal time. The pattern of leaf appearance is built into the wheat simulation model Sirius (Jamieson *et al.*, 1998b), so this allows the model to be used in the analysis. The purpose of this paper is to report a test of such a method against a more labour intensive method. We also report the use of the method to show cultivar differences and rank cultivars for sensitivity to daylength.

Materials and Methods

Three experiments are reported here, all performed at the Crop & Food Research Lincoln Research Station (latitude 43.7°S). In the first two of these, a collection of commercial cultivars and breeding lines were planted in 5.5m^2 plots on 5 May, 5 September and 17 October 1997 experiment 1), and on 11 May and 11 September 1998 (experiment 2). When approximately 6 - 8 leaves were formed on most of the lines, plant samples were harvested from all lines on one date and the Haun stage determined on 10 plants per line. Leaf numbers reported are means of the Haun stages of these 10 plants. The reason for choosing this stage is that then it is reasonably easy to find all the leaves, because the lowest leaves have only just died and are usually still present. It isn't possible to repeat this measurement at the flag leaf stage, because most of the lower leaves have died and cannot be found. So two further observations were recorded: the date of emergence of the flag leaf ligule (only done in 1998) and the flowering date. Both were estimated when 50% of the plot was emerged/flowering.

In the third experiment, five winter cultivars were planted in late April 1998 in small (c. 1 m^2) plots. Ten plants in each plot were tagged, and their progress monitored by counting leaves each week and determining the leaf stage. At approximately Haun stage 6, a tag was placed above leaf five to keep track of that leaf and the main stem. The tag was moved up at intervals so that it was always on the main stem and above a leaf of known number. The dates of flag leaf ligule emergence and anthesis were noted.

These data were analysed using the wheat simulation model Sirius (Jamieson *et al.*, 1998b). Sirius calculates the appearance of successive leaves in response to temperature, and the thermal rate of leaf appearance can be varied to match the observed Haun stage at the first observation. Anthesis occurs when the equivalent of 2.3 leaves after the flag leaf ligule has appeared (Jamieson *et al.*, 1998a), so that if either of those events has been observed, the final leaf number can be calculated from the leaf appearance rate and the temperature record. Where both events are recorded, there is a check on the consistency of the observations. Another check is that the final leaf numbers calculated for spring wheats from a September sowing should be only 8 or 9. Late sown winter cultivars produce many leaves and in some cases will not flower at all. This is the easiest way to identify them.

Results and Discussion

Differences in the rate of leaf appearance between two winter wheat cultivars from the third experiment are shown in Fig. 1. The cultivar with the most rapid leaf appearance rate (Hussar) had a higher leaf number (13.2 *v* 11.5) than the other (Consort) but flowered earlier. To test whether the suggested method would provide accurate estimates of final leaf number, we used the observations of Haun stage made on 11 August 1998 (Haun stage 5.5-7.5) to set the phyllochron in Sirius, specified a cultivar with a FLN of 16 (a number greater than was likely for any cultivar) and no daylength response for the simulations, and subtracted 2.3 from the predicted leaf number at the observed anthesis date. The results for the five cultivars are shown in Fig. 2. Over the range of final leaf numbers observed the correspondence is very close and the maximum error is 0.5 leaves. Such an error may lead to an error of about 5 days in predicting anthesis.

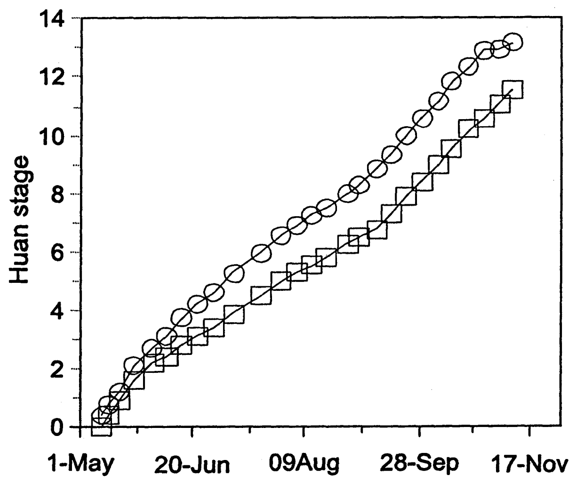

Figure 1. Observed leaf development in wheat cultivars Consort (O) and Hussar (□) sown at Lincoln in late April.

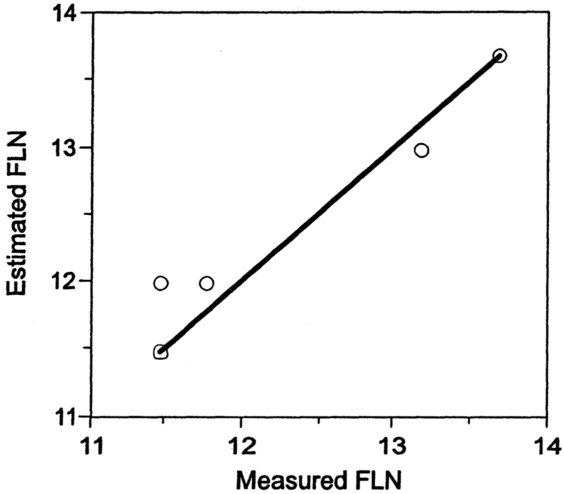

Figure 2. Relationship of estimated to measured final leaf number for five wheat cultivars planted in late April at Lincoln. The solid line represents estimated = measured.

Results for spring wheat types from experiment 1 are given in Table 1. A feature of interest is that in the late sowings, FLN was 8 ± 0.6. These values suggest full daylength saturation and vernalisation requirement. They also confirm that the method has given acceptably accurate estimates of FLN. Otherwise, the range of anthesis dates from the earliest sowings was 20 days, reducing to 12 and 11 days for the later sowings. This corresponded to ranges in FLN of 2.4 for the first sowing reducing to 1.3 and 1.5. The contraction in the range of anthesis dates for later sowings is the product of two effects - warmer temperatures mean that development is faster anyway, and the smaller range of final leaf numbers means that the number of phyllochrons from emergence to anthesis is similar. Note that the greatest change in anthesis date with the change from May to September sowing was for cv. Otane, which had the smallest change in FLN. The smallest changes in anthesis date were for the largest changes in FLN.

Results from the observations and analysis for experiment 2 are given in Tables 2 and 3, sorted into order of flowering date. True winter wheats are excluded from Table 3 because they failed to flower or flowered very late. However, that was the criterion used to identify them, and is the origin of the column in Table 2. There are a number of features of interest. For the May sowing (Table 2) most of the spring types flowered earlier than most of the winter types, but there was some cross-over. Table 3 shows that most spring types reduced their final leaf number to between 8 and 9 for the September sowings. Simulations using parameters for the old cultivar Rongotea (Brooking *et al.*, 1995) for the September sowing date for that year indicated that it would produce about one leaf more than its minimum number, but that cv. Otane, would produce its minimum number. Cv. Otane was included (Table 3) and its final leaf number for the September sowing was 7.7, about as low as is possible (Jamieson *et al.*, 1998a). Once again, results for the experiment were consistent with these predictions.

The phyllochron for the spring sowings was smaller than for the autumn sowings, regardless of cultivar. This is commonly observed, and occurs because in spring the

Table 1. Haun stage (LS) at sampling date, anthesis date and estimated final leaf number (FLN) for spring wheat cultivars sown on three dates in 1997.

	5 May			05 Sep			17 Oct		
Cultivar	LS 10 Sep	Anthesis	FLN	LS 6 Nov	Anthesis	FLN	LS 1 Dec	Anthesis	FLN
Kotuku	6.3	15 Nov	9.4	6.7	03 Dec	8.0	6.4	30 Dec	8.2
Rata	7.0	19 Nov	10.6	6.6	09 Dec	8.5	6.9	31 Dec	9.2
Impact	6.2	20 Nov	9.2	6.5	08 Dec	8.0	6.2	31 Dec	8.0
Otane	6.3	01 Nov	8.2	6.5	30 Nov	7.3	6.9	20 Dec	7.7
Endeavour	6.7	08 Nov	9.2	6.8	30 Nov	7.8	6.9	21 Dec	7.8
3424.11.04	6.6	06 Nov	8.9	6.7	01 Dec	7.8	6.8	24 Dec	8.1
995.2.3	7.8	01 Nov	10.0	7.6	27 Nov	8.6	7.5	23 Dec	8.9

soil warms faster than the air, and soil temperature controls development because the apex is underground until about the time that the last two leaves emerge (Jamieson *et al.*, 1995). Sirius is able to account for only part of this temperature change.

For the May sowing, a given flowering date could result from various combinations of leaf production rates and final leaf numbers; the final leaf number varied substantially (Fig. 3). Different cultivars could attain the same flowering date by producing 9 leaves slowly or 12 leaves more quickly. For instance, cvs. Domino and Millbrook flowered on the same day, but with FLNs of 9.4 and 11.3 respectively (Table 2). However, a large final leaf number in an autumn sown spring wheat usually means a stronger day length response, which gives more safety in earlier sowings, because the time taken to produce the extra leaves delays anthesis. This means that the order of anthesis dates will not remain the same as in Table 2 as the sowing date is varied, as is shown in Table 3. High final leaf number spring wheats have their flowering dates less affected by sowing date changes than those with low final leaf numbers.

Spring sown winter wheat types flower very late, well past the optimum time of grain filling, and mostly well

Table 2. Estimated final leaf numbers (FLN), flowering dates, phyllochrons (°C days) and types for autumn (11 May, 1998) planted wheats at Lincoln.

Cutivar	Flowering date	Final leaf number	Phyllo- chron	type
995.2.3	30 Oct	10.1	105	spring
Karamu	01 Nov	9.8	110	spring
Otane	02 Nov	9.0	120	spring
3424.11.04	06 Nov	9.3	120	spring
Kohika	13 Nov	10.9	110	spring
CSW5592	15 Nov	11.1	110	spring
Endeavour	15 Nov	10.1	120	spring
95ST207	16 Nov	11.2	110	spring
Millbrook	17 Nov	11.3	110	spring
Domino	17 Nov	9.4	130	spring
Belfield	17 Nov	11.3	110	spring
Commando	17 Nov	10.3	120	spring
Kotuku	17 Nov	10.3	120	spring
Sapphire	18 Nov	9.5	130	spring
Monad	19 Nov	9.6	130	spring
87-274	20 Nov	9.7	130	spring
3976.35.1	20 Nov	10.6	120	winter
W32344	21 Nov	9.8	130	spring
Impact	21 Nov	10.2	125	spring
PEG18	22 Nov	10.7	120	spring
Rata	23 Nov	11.9	110	spring
Centaur	23 Nov	10.8	120	winter
92-211	23 Nov	10.4	125	winter
Torfrida	24 Nov	10.0	130	winter
4134.19.4	24 Nov	12.6	105	winter
Hussar	24 Nov	12.0	110	winter
5388-96	25 Nov	11.0	120	winter
Era	27 Nov	12.3	110	winter
Wasp	01 Dec	10.5	130	winter
CM320	03 Dec	11.7	120	winter

Table 3. Estimated final leaf numbers, flowering dates and phyllochrons (°C days) for spring planted (11 September 1998) spring wheats at Lincoln.

Cultivar	Flowering date	Final leaf number	Phyllochron
Otane	06 Dec	7.7	95
Karamu	08 Dec	9.4	80
995.2.3	10 Dec	9.7	80
Kohika	10 Dec	8.2	95
3424.11.04	10 Dec	8.8	88
Endeavour	10 Dec	8.8	88
Domino	11 Dec	8.9	88
Sapphire	12 Dec	8.4	95
CSW5592	12 Dec	9.0	88
Millbrook	13 Dec	10.1	80
87-274	13 Dec	8.5	95
Belfield	13 Dec	10.1	80
W32344	14 Dec	9.4	88
Kotuku	14 Dec	8.7	95
Monad	17 Dec	9.0	95
Impact	17 Dec	9.0	95
Commando	17 Dec	9.0	95
PEG18	18 Dec	9.9	88
Rata	19 Dec	10.1	88

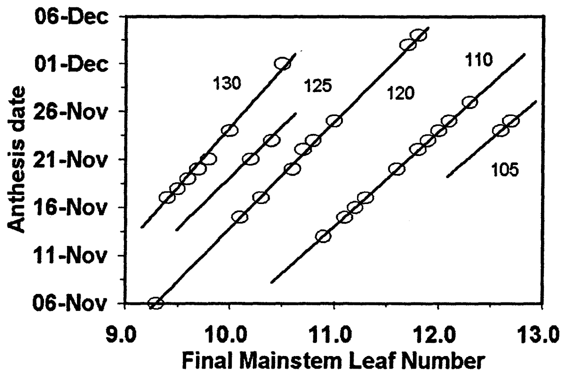

Figure 3. The relationship of anthesis date to estimated final leaf number at various phyllochrons (numbers on the graph are phyllochrons in °C days) for an 11 May Sowing. Circles represent individual cultivars from Table 2.

past the time when it is economic to continue observations. This type of response to sowing clearly identifies a winter type, but does not add much useful information on responses of flowering dates to sowing dates. In these types quite large variations in sowing time in autumn cause little change in flowering date, and this is particularly evident when sowings become earlier. To determine the response of such cultivars to sowing date changes requires that additional sowings are made very early, e.g., March.

Conclusions and Recommendations

The new methodology developed here for determining cultivar response to sowing date proved simple and effective, and provided most of the information needed to provide good predictions of flowering dates in spring wheats. However, an additional March sowing of winter types would improve the predictions. The method should be able to be extended to other cereal types, such as barley, oats and rye. Although the testing provided in the paper is limited toa few cultivars, all the results were in accord with recently developed theory.

The results in Table 2 give a useful first guide to probable anthesis date and ranking of earliness when choosing a wheat cultivar. In addition, some further general guidance can be given. Spring types should not be sown earlier than early May to avoid frost risk at flowering, and those with smaller final leaf numbers from the May sowing should be sown later. Winter types should not be sown much later than July to avoid very late flowering, but may be sown earlier than the beginning of May. Such early sowings carry an increased risk of barley yellow dwarf virus so precautions must be made.

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