

Phenological development of oat crops in response to sowing dates

Marcio Sônego, P.D. Jamieson¹, D.J. Moot and R.J. Martin¹

Soil, Plant and Ecological Sciences Division, PO Box 84, Lincoln University, Canterbury
¹ New Zealand Institute for Crop & Food Research Ltd., Private Bag 4704, Christchurch, New Zealand

Abstract

Observations of apical development in oats were made from sowings made on six occasions through an annual cycle. These were analysed to determine the effects of temperature and daylength on the duration of the period from sowing until anthesis. A simple, two-phase thermal time accumulation model, modified by daylength in the post emergence phase, accounted for most of the variation ($n = 6$, $CV = 6\%$).

Addition key words: *Avena sativa*, *photo-thermal*, *degree days*

Introduction

The adaptation of annual cereals to the climate is such that crops sown at quite widely varying times flower and produce grain when the weather is most favourable. Hence a wide variation in sowing dates tends to produce a narrow range of flowering times (Hay and Kirby, 1991), and the duration from sowing to anthesis varies considerably in response to environmental signals. The dominating environmental influences are temperature and daylength (Porter and Delécolle, 1988), and responses vary substantially among cultivars (White, 1995; Kirby and Appleyard, 1986).

Traditional phenological analysis divides the duration from sowing to anthesis into phases between observable events on the apex (Slafer and Rawson, 1994). This has been done partly because some pre-anthesis events in the life of cereal crops are important in their own right, and partly because better predictions could be made with a piecewise continuous model. For instance, in the simulation model ARCWHEAT1 (Weir *et al.*, 1984), the durations of the interval from sowing to emergence is assumed to be constant in thermal time. However, the duration of the phases from emergence to floral initiation and beyond are constant in various modified versions of thermal time, with the modifications depending on vernalization duration and photoperiod. This approach was used successfully to predict the anthesis dates of a single cultivar of wheat planted over a range of sowing dates and latitudes within the UK (Porter *et al.*, 1987).

Cultivated oats (*Avena sativa* L.) share many characteristics with wheat, but little work has been published on their phenological responses to temperature

and daylength. In this paper, we investigate whether the simple approaches used in traditional wheat phenological analysis can be used to develop a simple predictive model for oat phenological development.

Materials and Methods

Oats, cv. Cashel, were planted on six dates (23 April, 21 May, 8 August, 20 September, 25 November 1996 and 22 January 1997) on the Crop & Food Research Experiment Station at Lincoln (latitude 43°E 36'S). The soil was a Templeton silt loam. Plots 10 m long by 1.35 m wide with rows 0.15 m apart were sown to establish a plant population of 300 plants/m² in a randomised complete block design with three replicates. Insecticides and fungicides were applied as required but no herbicides or fertilisers were applied. The experiment was irrigated four times with applications of 50 mm in response to water budget calculations. Meteorological data were obtained from a weather station within 300 m of the experiment.

Observations of external morphological development of plants were made twice weekly on ten tagged plants within each replicate for each sowing date treatment. On the same day, five plants were removed randomly from each plot and dissected under a binocular microscope to determine the developmental stage of the apex, using the methodology of Kirby and Appleyard (1986). The sampled plants, including the soil around their roots, were sealed in plastic bags and stored at 2-4°C until dissected. The times of six phenological stages were determined. They were similar to those reported by Hay (1986) for winter wheat crops:

- plant emergence (EM)
- double ridges (DR)
- beginning of stem elongation (SE; substitutes for terminal spikelet)
- flag leaf ligule appearance (FL)
- panicle emergence (PE)
- anthesis.

EM, FL and PE were observed in the field, while DR, SE and anthesis were determined by dissection. The interval between EM and DR is designated the vegetative phase, and the post-DR phases are designated reproductive.

Durations between apical events were compared in chronological time, thermal time, and thermal time modified by a photoperiod factor. Thermal time (TT_b) was calculated as the sum of the excess of the daily mean temperatures over a base temperature (T_b):

$$TT_b = \sum (T - T_b) \quad T > T_b \quad ^\circ\text{C-days} \quad (1)$$

Where T is the daily mean temperature and the summation starts at one event and ends at the next. T_b was assumed to be similar to that for wheat development, so was set at 0°C (Jamieson *et al.*, 1995). For the period before EM, we assumed that soil temperature at 10 cm would better approximate the temperature of the apex than air temperature (Jamieson *et al.*, 1995), so two versions of thermal time, using air and soil temperature, were calculated.

Thermal time, modified by daylength, was similar to the photo-thermal time used in ARCWHEAT1 (Weir *et al.*, 1984). Each day, the increment of thermal time was modified by a dimensionless factor (F_p), where:

$$F_p = (P - P_b)/(P_s - P_b) \quad (2)$$

where P is the daylength, P_b is a base daylength below which development is assumed to cease, and P_s is a saturation daylength beyond which development is maximal. We used two different P_b values of 0 and 7 hours, and P_s of 16 hours, as used in ARCWHEAT1 (Weir *et al.*, 1984). The base temperature was again set at 0°C . Thus,

$$POTT = \sum T P/16 \quad T > 0, \quad ^\circ\text{C-days} \quad (3)$$

and

$$P7TT = \sum T (P - 7)/9 \quad T > 0, P > 7 \quad ^\circ\text{C-days} \quad (4)$$

= 0 otherwise

Statistical analysis

The time of occurrence of apical stages was taken as the day on which at least 50% of the plants sampled had reached the stage. Comparisons of the durations in the various forms of thermal time were made in terms of the coefficient of variation (CV) of the thermal duration, and also in terms of the root mean square deviation (RMSD) of the difference between the prediction based on the mean thermal duration, and the observed day of occurrence.

Results and Discussion

Duration of phases

There was large variation among sowings in the time from sowing to anthesis, ranging from 53 days for the November sowing to 186 days for the April sowing. The variation was systematic, with duration decreasing from autumn through spring sowings, and increasing again after November. Therefore, for a seven month span of sowing dates, there was a span of only three months in flowering dates. The greatest variation was in the vegetative phase (Table 1). In autumn sowings, the vegetative phases were longer than the reproductive phases, but this was reversed in spring and summer sowings. Late phenological phases (from stem elongation onwards) were much less variable than the early phases (Table 1). For instance, the interval from FL to anthesis was nearly constant at 16 days, with a standard deviation of only 2 days.

Effect of temperature

As a first attempt to unify the results, the intervals between events were compared in thermal time. Although this decreased the CVs and RMSDs, there was still substantial systematic variation in the length of some phases, notably those between emergence and stem elongation (Table 1). There was a substantial reduction of variation for the sowing to EM interval, and for some of the intervals beyond SE (Table 1). The improvement in the CV of the sowing-EM interval was similar for thermal time using air or 10 cm soil temperature.

Effect of daylength

The second approach was to compare the post-emergence intervals in photo-thermal time. Using a base daylength of zero resulted in a further reduction in the variability of the pre-FL phases, but a large and systematic variation remained in the intervals up until SE. However, using a base daylength of seven hours removed most of the systematic variation in these phases

Table 1. Mean durations of phenological phases of oat cultivar Cashel sown on six dates. Durations are expressed in calendar time (days), thermal time (TT and TT_{soil}), photothermal time (P0TT and P7TT), with respective coefficients of variation (CV) and root mean square deviation (RMSD).

	Phenological phase*					
	SO-EM	EM-DR	DR-SE	SE-FL	FL-PE	PE-AN
Days (d)	14	39	20	18	7	9
CV (%)	49	88	61	23	16	13
RMSD (d)	6	31	12	4	2	2
TT (°C.d)	151	322	221	240	91	118
CV (%)	12	55	31	14	9	11
RMSD (d)	2	22	6	2	1	1
TT soil (°C.d)	138	-	-	-	-	-
CV (%)	12	-	-	-	-	-
RMSD (d)	2	-	-	-	-	-
P0TT (°C.d)	-	224	175	205	80	103
CV (%)	-	36	18	10	13	7
RMSD (d)	-	16	3	2	1	1
P7TT (°C.d)	-	149	139	176	70	92
CV (%)	-	14	6	13	19	10
RMSD (d)	-	4	1	2	1	1

*Stages are: SO (sowing); EM (emergence); DR (double ridges); FL (flag leaf ligule emergence); PE (panicle emergence) and AN (anthesis).

(Table 1), and substantially reduced the CVs and RMSDs. The use of the daylength adjustment did not decrease the variability of phases after FL.

The best model

Which was the best combination of phases and either thermal time or photo-thermal time to predict the timing of developmental stages in this oat cultivar? From table 1, the best sequence was thermal time from sowing to EM, P7TT for the phases from EM until SE, and thereafter thermal time. Hence, only three phases are required in a model: sowing-EM, EM-SE and SE-anthesis. However, the mean P7TT value for EM-anthesis was 627 °C-days with a CV of only 6%, suggesting that a two phase model may be adequate for predicting anthesis.

Conclusions

The duration from sowing to anthesis varies substantially with sowing date in oats. These variations are associated with responses to temperature and

daylength, and variations of the durations of specific phases, although large in time, are quite small in photo-thermal or thermal time, depending on the phase. This provides a basis for predicting the occurrence of phases that has not been tested here with independent data, but has been successful with other cereals, notably wheat (Porter *et al.*, 1993).

Although the analysis presented explains most of the variation in phase durations, this explanation is purely statistical. We have not attempted to explain why such responses occur, or their underlying mechanisms. These mechanisms are mostly through an influence of temperature on the rate at which organs are formed (Jamieson *et al.*, 1995), and of daylength on the numbers of organs (Brooking *et al.*, 1995), although in cultivars that have a vernalization requirement, temperature can also influence the number of organs (Brooking, 1996). Hence, the response of duration to daylength and temperature is a combination of these effects on rates and numbers (Jamieson *et al.*, 1998). Therefore explanations of the variation of phase durations should account for the rates of production and ultimate numbers of primordia

and leaves (Jamieson *et al.*, 1998). We are currently analysing our results using this approach.

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