A Crop Calendar for Spring Wheat and for Spring Barley

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A crop calendar is a tabular depiction of the sequence of stages of plant development. The calendar provides an estimate of the time duration of a specific development stage and the time interval between stages. It can be a useful aid to management decisions.

The parts and structures of plants appear and develop in an orderly and consistent pattern. Although plant development is a continuum, the appearance and development of plant components visible to the naked eye can be separated (categorized) into stages, even sub-stages. Several plant development stage scales (often called growth stage scales) for cereal crops have been developed and are used by producers in the Great Plains. Bauer et al. (1983) provided a table to show the relationship among the most frequently used scales and how to convert from one scale to another.

The primary "driving force" that advances plant development and determines the development rate is heat (thermal energy). The development rate of the visible plant components increases as temperature increases from a minimum survival temperature to that of an optimum temperature. At temperatures greater than optimum, development rate may remain the same as at the optimum temperature or it may decline. Both the minimum survival and optimum temperatures vary with plant species. Units of heat received over time, usually a 24-hour period, are expressed in terms of growing degree-days. The number of growing degree-days for any given calendar day during the growing season is the average of that day's minimum and maximum air temperatures minus a base temperature (Bauer et al., 1984a).

A system to quantify plant development rate as a function of temperature (growing degree-days or heat units) was introduced more than two centuries ago (Wang, 1960). Bauer et al. (1984b) showed the functional relationship between plant development stage of spring wheat and growing degree-days accumulated from emergence to flowering stage. This same relationship was developed also for spring barley (Bauer et al., 1990).

This article provides a crop calendar for spring wheat and spring barley.

Materials and Methods

Information on plant development (growth) stage was developed in trials conducted at the Northern Great Plains Research Laboratory at Mandan, North Dakota. For spring wheat, measurements were made in seven trials conducted from 1979 through 1982 (Bauer et al., 1984b). Four of these were variety trials, with nine to 13 varieties (cultivars) in each trial. The other three were trials to study the relationship between soil available nitrogen levels and water levels. For spring barley, the measurements were made in variety trials, with five to eight varieties (cultivars) in each trial, conducted from 1983 through 1989 (Bauer et al., 1990). Each cultivar or treatment was replicated four times.

Planting rate in all trials was one million viable seeds per acre. Weight of seed planted per acre was determined from kernel weight, kernel water concentration, and germination percentage. Planting with a press drill was to 1.5-inch depth and in 6-inch spaced rows.

Planting and emergence dates were recorded for each trial. "Emergence" is defined as "having enough plants visible to detect the drill rows." At emergence, the first visible leaves were about half of their eventual length.

A square meter area (1.2 square yards) was staked in each plot at or near emergence. The stakes were left in place until harvest. The same drill rows were represented in each plot. Observations of plant development stages were made in these square meter areas from emergence to harvest. The observations were made five times a week in 1979, at least three times a week from 1980 through 1982, and in subsequent years at least once a week. Plant development staging was based on the Haun scale (1973) through flowering and on the Feekes scale (Large, 1954) during grain filling.

Growing degree-days (GDD) were calculated for each 24-hour period, midnight to midnight, from daily maximum (Tmax) and minimum (Tmin) air temperature measured hourly in degrees Fahrenheit at the 2-meter height (about 6.5 feet) at each site. The following formula was used for the calculation:

$$GDD = \frac{Tmax + Tmin}{2} - 32 \qquad [1]$$

Measurements of kernel-filling rate were made from plant samples cut from a meter length of row (3.3 feet) about 4 inches above the soil surface from each plot within one replicate on Tuesday and Friday of each week, from onset of anthesis (flowering) until ripe stage. Successive replicates were sampled, but the same drill row was sampled each time. The heads were cut from the stems in the laboratory, then counted, weighed, dried at 156°F. and weighed. All kernels were removed from each head of each sample, counted, and weighed. Sampling of wheat began on the Tuesday or Friday immediately after extrusion of anthers (onset of the flowering stage) was observed. Sampling of barley began at about mid-boot stage. Spring barleys grown in the northern Great Plains begin to flower when the awns are extended about an inch above the collar of the flag leaf.

The quantitative relationship between plant development stage through flowering and accumulated growing degree-days was calculated with regression techniques (Barr et al., 1976). For wheat, this relationship was determined to be linear (Bauer et al., 1984b). The crop calendar constructed for spring wheat was based on a requirement of 146 growing degree-days (Fahrenheit scale) per leaf and other development units (i.e., flag leaf extension, boot, heading, and stem extension) that appear to flowering stage. However, spring wheats with earliness characteristics like Butte 86 require about 10 growing degree-days less per leaf and other development units than those on which the crop calendar was based.

For spring barley, the quantitative relationship was determined to be curvilinear (Bauer et al., 1990). Construction of the crop calendar for barley was based on calculation of the development stages between emergence and mid-boot from growing degree-days (Table 1).

The relationship of rate of dry matter accumulation in the kernel from onset of flowering is equally well described by calendar days as by growing degree-days. For both crops, calendar days from onset of flow-ering to maximum kernel dry matter accumulation is about 35 days. Con-struction of the crop calendar for the grain filling period of both crops was based on this time interval.

The median planting date of the trials conducted at Mandan since 1979 is April 30; planting date has ranged from April 15 to June 1. Average emergence of spring wheat planted 1.5 inches deep has been about 10 days after planting, and for spring barley planted on the same day, under the same conditions and with the same equipment, about nine days. These average days to emergence were used in construction of the crop calendar. The range in time to emergence has been from 6 to 15 days from the day after planting. Bauer et al. (1984b) showed that spring wheat planted 1.5 inches deep, with the post-planting soil surface devoid of residues, required about 180 growing degree-days from the day after planting to emergence, and spring barley a few growing degree-days less (Bauer et al., 1990)

The accumulated growing degree-days used to construct the crop calendar were based on the average daily maximum and minimum air temperatures during 1951-1980 period recorded at the Bismarck weather station. (Dr. John Enz, Soil Science, NDSU, provided the weather data.)

Table 1. Growing degree-days (GDD) accumulated to specific spring barley development stage (DS) as calculated from the cubic function in Bauer et al. (1990)[1]

GDD		DS[4]
200[2]	360[3]	3.3
250	450	4.0
300	540	4.8
350	630	5.5
400	720	6.2
450	810	6.8
500	900	7.5
550	990	8.1
600	1080	8.6
650	1170	9.2
700	1260	9.7

[1]The function:
$Y = 0.0154X - 0.00000000391x^3 + 0.24$. is based on the centigrade temperature scale, where X = growing degree-days and Y = Haun stage.
[2]Based on Centigrade scale.
[3]Converted to Fahrenheit scale.
[4]Haun stage.

Discussion

The crop calendars for spring wheat and spring barley are shown on Table 2 and Table 3, respectively. The major difference in crop calendars between the two crops is the time of onset of flowering.

Emergence of spring wheat requires about one day more than spring barley (Bauer et al., 1990). Trials from which this was determined were all planted on the same day and under the same management.

Axillary tillers begin to appear at about stage 3, when three leaves are fully expanded (Bauer et al., 1984b; Bauer et al., 1990). Coleoptile tillers, however, can appear at earlier stages.

The head begins to form at about stage 4.0 in spring wheat (Frank and Bauer, 1982; Frank et al., 1988), when four leaves on the main stem are fully expanded, and at about stage 3.5 and 3.8 for two-rowed and six-rowed spring barleys, respectively (Frank et al., 1992). The head of spring wheat is completely formed by about stage 5.5 and that of two-rowed and six-rowed barleys at about stage 5.4 and 6.0, respectively.

After the juvenile head is formed, the internodes begin to elongate, moving the growing point upward from the crown. This usually is referred to as the "jointing" stage (Bauer et al., 1983). From this point on, the plant assumes an erect position. Wheel traffic after this stage can cause plant stem breakage.

Most spring wheats and spring barleys produce eight leaves on the main stem, so when the flag leaf has fully expanded, development stage is designated as 8.0.

Tillers can continue to form while leaves are being added to the main stem of the plant, and even at later stages. However, tillers formed after the "jointing" stage are unlikely to produce a head complete with kernels. Tiller activity is synchronized to the activity of the main stem (Frank and Bauer, 1982). Hence, whatever has occurred on the main stem will occur on the tillers in a matter of a few days. At Mandan, planting a million viable seeds per acre usually results in no

Table 2. Spring wheat calendar based on plant development stage, Haun scale, in relation to average daily accumulated growing degree-days (GDD), Mandan, N.D. (Planted April 30.)

Day of Month	May		June		July		August	
	GDD	Stage	GDD	Stage	GDD	Stage	GDD	Stage
1	17		28	4.5	35		38	
2	17		29		35	11.5[9]	38	
3	18		29		35		38	
4	18		30		36		38	
5	18		31		37		38	
6	19		31	Head complete[3]	37	[10]	38	↓
7	19		31		37		38	Kernel hard[11]
8	19		31	Jointing[4]	37		38	
9	19	0.5 (emergence)	31		38		37	
10	19		31		38		37	Ripe
11	20		32	6.5[5]	38		37	
12	20		32		38		37	
13	21	1.2	32		38			
14	22		32		39			
15	22		31		39	Grain filling		
16	24		33		39			
17	24		32	8.0[6]	38			
18	24		32		32			
19	24		31		38			
20	25	2.3	32		39			
21	25		32		40			
22	25		32		39			
23	25		33		40			
24	26		32		39			
25	26	Tillering[1]	34		39			
26	26	3.4	34	10.0[7]	39			
27	26		34		39			
28	27		24		39			
29	26	Head initiated[2]	35		39			
30	26		35	11.0[8]	39	↓		
31	27				38			

[1] Axillary tillers begin to appear at about stage 3.0. Coleoptile tillers can appear before stage 3.0.

[2] The growing point, called the apex, begins to differentiate from the vegetative to reproductive stage. The head begins to form.

[3] The head is completely formed. The number of spikelets has been determined. (This is about stage 5.5.)

[4] Internode elongation has begun, moving the growing point upward from the crown. The plant begins to assume an erect position.

[5] Tillers can form after this stage. However, the tillers formed after this stage are unlikely to form a head.

[6] The flag leaf is fully expanded. (Nearly all hard red spring wheats produce eight leaves on the main stem.)

[7] The head on the main stem begins to emerge through the collar of the flag leaf.

[8] The head on the main stem has passed the collar of the flag leaf. Of the total uptake in the aerial tissue at harvest, about 70% of the nitrogen and about 60% of the phosphorus are present in these tissues at this stage.

[9] Flowering has begun. The pollen is first seen on the middle to upper two-thirds of the head, then progresses upward and downward from there.

[10] Flowering is complete, essentially coinciding with kernel "water-ripe" stage.

[11] Swathing can be underway at this stage without experiencing any loss of yield or quality factors.

Table 3. Spring barley calendar based on plant development stage, Haun scale, in relation to average daily accumulated growing degree-days (GDD), Mandan, N.D. (Planted April 30.)

Day of Month	May GDD	May Stage	June GDD	June Stage	July GDD	July Stage
1	17		28		35	11.0[8]
2	17		29		35	
3	18		29	5.5	35	
4	18		30		36	
5	18		31		37	
6	19		31	6.2[3]	37	
7	19		31	[4]	37	
8	19	Emergence	31		37	
9	19		31		38	
10	20		31		38	
11	20		32		38	
12	21		32		38	
13	22		32		38	
14	22		32	8.0[5]	39	
15	22		31		39	
16	24		33		39	
17	24		32		38	
18	24		32		38	
19	24		31		38	
20	25		32		39	
21	25		32		40	
22	25		32	9.5[6]	39	
23	25	[1]	33		40	
24	26	3.3	32		39	
25	26		34		39	Kernel hard
26	26	[2]	34	10.2[7]	39	
27	26	4.0	34		39	
28	27		34	Grain filling	39	
29	26		35		39	
30	26		35		39	
31	27				38	

[1]Axillary tillers begin to appear at about stage 3.0

[2]The growing point, called the apex, begins to differentiate from the vegetative to the reproductive stage. The head begins to form.

[3]The head is completely formed.

[4]Internode elongation has begun, moving the growing point upward from the crown. (Jointing)

[5]Flag leaf is fully expanded. (Most spring barleys in North Dakota produce eight leaves on the main stem.)

[6]Flowering begins. (This is about mid-boot stage.)

[7]The head has begun to emerge from the collar of the flag leaf.

[8]The head on the main stem has passed the collar of the flag leaf. Of the total uptake in the aerial tissue at harvest, about 90% of the nitrogen and about 45% of the phosphorus are present in these tissues at this stage.

more than the main stem and two tiller heads contributing to grain yield.

Onset of flowering in spring wheat usually begins after the head extension stage (Haun, 1973), about four days after the head has cleared the flag leaf collar. Flowering usually is complete in about four days. In contrast, onset of flowering in spring barley begins at about mid-boot stage and is complete by the time the head has emerged from the flag leaf collar. The plant development stage at which flowering begins contributes to the main difference between spring wheat and spring barley in time interval from planting to maturity (Bauer et al., 1989).

Uptake of nitrogen occurs in largest quantity through the heading stage. By the time the head on the main stem clears the collar, spring wheat contains about 70 percent (Bauer et al., 1987) and spring barley about 90 percent (Bauer et al., 1990) of the total nitrogen uptake in aerial tissues at harvest. The uptake of phosphorus in aerial tissues at the time the head clears the collars is about 60 percent and 45 percent, respectively, for spring wheat and spring barley.

Grain (or kernel) filling begins with onset of flowering. Both crops require about the same number of days from flowering to maximum kernel dry matter accumulation. Since average kernel weight of spring barley is heavier than that of spring wheat, the rate of dry matter accumulation during the linear (constant-rate) phase averages about 1.0 milligram per kernel of spring wheat and about 1.46 and 1.22 milligrams per kernel of two-rowed and six-rowed barleys (Bauer et al., 1990).

Swathing, if that is the desired harvesting procedure for wheat, can be under way by the time kernel dry matter accumulation has maximized — about 28 to 30 days after onset of flowering (Bauer and Black, 1989). Head water concentration calculated on an oven-dry basis is about 60 percent by weight at that stage.

Using the Calendar

Users of these crop calendars need to recognize that they are based on growing degree-days calculated from normal temperatures (average daily temperature from 1951-1980). Hence, the number of calendar days between specific plant development stages that may actually occur in a field may not always be the same as these calendars indicate. Also, planting and emergence dates used in the crop calendars are based on historical information.

The time from emergence to heading can differ between so-called "early" and "late" maturing varieties. Therefore, the number of growing degree-days required for each morphological unit also will vary slightly.

Heat (thermal) energy is recognized as the principal environmental factor determining rate of plant development. Accumulated heat, expressed in terms of growing degree-days, is superior to other methods of predicting plant development stage. Spring wheat and spring barley plant development stage can be predicted by (1) determining the date of emergence in terms of the definition of emergence provided in this article, and (2) maintaining a record of maximum and minimum daily temperatures. These data allow calculation of daily growing degree-days as described in this article. Maximum and minimum temperatures are provided in daily weather reports by the news media.

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