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Using the Virginia Cooperative Extension Climate Analysis Web Tool to Better Manage and Predict Wheat Development

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Introduction

Wheat development is affected by nutrients, water, light, and other factors; but temperature consistently determines how quickly or slowly plants move ahead in forming leaves, roots, tillers, and grain heads. The plant's development stage at any point during the season is affected very predictably by how warm or cool the season has been up to that point. This knowledge, combined with educated guesses about how the rest of the growing season will progress, can be extremely valuable information to the grower, who can then make more informed management decisions to include predicting the maturity/harvest schedule.

Wheat moves through a predictable sequence of development based upon environmental variables. We know that planted seeds will germinate and emerge after a certain period of time – depending especially upon temperature, but also upon adequate moisture and seedbed conditions. Young plants develop from a single stem with four or five leaves, and then begin to produce tillers. The crop often goes into winter with three or four tillers (with one to four leaves each) plus the original main stem.

After additional growth and tiller formation in the spring, environmental conditions will signal the plants to "switch over" into reproductive mode and begin to produce grain heads. The first readily visible sign of this transition to reproductive growth is the stage called jointing (Table 1, GS 31). Following jointing is the boot stage, then heading, grain fill, and eventually maturity. All of these stages will occur annually, with variations in leaf, tiller, and grain head numbers as the season progresses.

How quickly development occurs depends largely upon temperature. Because the pattern of development is repeatable, it is easy to describe key stages without reference to plant size or calendar date. An example of a developmental stage in wheat is jointing or when the first node is noticeable. Wheat at jointing could be thriving and have a large amount of biomass, or it could be doing poorly and have little biomass. Neither vigor nor size affects the developmental stage. Several developmental scales have been introduced for winter wheat to allow comparison among cultivars in varying environments and to ensure proper timing of management inputs. The two most widely used are the Zadoks scale and the Feekes scale (Table 1). Using the Zadoks scale, the jointing stage discussed earlier would be classified as GS 31, using the Feekes scale, jointing occurs at stage five.

Regardless of which scale is used, wheat plants will reach each stage at a time determined by the environmental conditions they have experienced – especially temperature. Because of the very close connection between temperature and plant development, it is possible to predict where the crop will be developmentally without going to the field. (We don't recommend this hands-off approach, but it is theoretically possible.) With data on the temperatures the crop has experienced, a grower can make an educated guess about crop developmental stage. If the crop is not at that stage in actuality, something besides temperature (moisture or nutrition) is likely limiting growth. It is also possible that a grower, with historical data on the normal or usual pattern of temperatures, could predict when the crop would be at any stage yet to come – including maturity.

Estimating wheat development based on environmental conditions is not just theory; we have such data, and growers can make such determinations. Virginia Cooperative Extension has developed an online tool making readily available historical and current data on climatic conditions – including temperature. With such data, one can make some very good guesses about current crop status/stage, and good predictions about what the future holds for the crop (in an average year at least). This can be done because research has tied environmental conditions to a developmental scale in wheat.

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Table 1. Wheat Development According to Zadoks and Feekes Scales.

Zadoks Scale	Feekes Scale	General Description	Comments
		Germination	
0		Dry seed	
1		Start of imbibition	
3		Imbibition complete	
5		Radicle emerged from caryopsis	
7		Coleoptile emerged from caryopsis	
9		Leaf just at coleoptile tip	
		Seedling growth	
10	1	First leaf through coleoptile	Second leaf visible (<1 cm)
11		First leaf unfolded	
12		2 leaves unfolded	
13		3 leaves unfolded	
14		4 leaves unfolded	
15		5 leaves unfolded	50% of laminae unfolded
16		6 leaves unfolded	
17		7 leaves unfolded	
18		8 leaves unfolded	
19		9 or more leaves unfolded	
		Tillering	
20		Main shoot only	
21	2	Main shoot and 1 tiller	
22		Main shoot and 2 tillers	
23		Main shoot and 3 tillers	
24		Main shoot and 4 tillers	
25		Main shoot and 5 tillers	
26	3	Main shoot and 6 tillers	
27		Main shoot and 7 tillers	
28		Main shoot and 8 tillers	
29		Main shoot and 9 or more tillers	
		Stem elongation	
30	5-Apr	Pseudo stem erection	
31	6	1st node detectable	Jointing
32	7	2nd node detectable	
33		3rd node detectable	
34		4th node detectable	
35		5th node detectable	
36		6th node detectable	
37	8	Flag leaf just visible	
39	9	Flag leaf ligule/collar just visible	
		Booting	
40		—	
41		Flag leaf sheath extending	Early boot stage
43		Boots just visibly swollen	
45	10	Boots swollen	
47		Flag leaf sheath opening	
49		First awns visible	In awned types only
		Inflorescence emergence	
50	10.1	First spikelet of inflorescence	Barely visible
52	10.2	1/4 of inflorescence emerged	
54	10.3	1/2 of inflorescence emerged	
56	10.4	3/4 of inflorescence emerged	
58	10.5	Emergence of inflorescence completed	
		Anthesis	
60	10.51	Beginning of anthesis	
64		Anthesis half way	
68		Anthesis complete	
		Milk Development	
70		—	
71	10.54	Caryopsis watery ripe	
73		Early milk	
75	11.1	Medium milk	Notable increase in solids of liquid endosperm when crushing the caryopsis
		Dough development	
80		—	
83		Early dough	
85	11.2	Soft dough	
87		Hard dough	Fingernail impression not held
89		Inflorescence losing chlorophyll	Fingernail impression held
		Ripening	
90		—	
91		Caryopsis hard	Difficult to divide by thumbnail
92		Caryopsis hard	No longer dented by thumbnail
93	11.3	Caryopsis loosening in daytime	Ripe
94	11.4	Overripe, straw dead and collapsing	
95		Seed dormant	
96		Viable seed giving 50% germination	
97		Seed not dormant	
98		Secondary dormancy induced	
99		Secondary dormancy lost	

The most practical method involves calculating growing degree days (GDD) and is based on the fact that wheat grows and develops when the average daily temperature exceeds 32ºF. The GDD number for each day is calculated by summing the maximum and minimum temperatures for the day, dividing by two to get the average, and then subtracting the lower growth threshold for wheat (32ºF). This formula is represented:

$((Temp_{max} + Temp_{min})/ 2) – 32 = GDD (ºF)$

Because wheat does not grow significantly when temperatures are below freezing, GDD are considered to be zero if (maximum temperature - minimum temperature)/2 is less than 32ºF. If the average temperature is <32ºF, no GDD are accumulated and none are subtracted from the GDD accumulated to that date. In addition, the upper limit for temperature response is considered to be 86ºF because temperatures above this point do not increase growth rate. In other words, 86 – 32 = 54 GDD is the maximum daily rate at which GDD will accumulate.

Using the Climate Analysis Web Tool

Current and past growing-degree-day information for 167 sites in Virginia can be accessed on the Virginia Cooperative Extension Climate Analysis Web Tool website at: www.ext.vt.edu/cgi-bin/WebObjects/ClimateAnalysis.woa.

This Web page presents a map of Virginia with usage instructions. Pointing at a specific location on the map retrieves the three nearest locations to the point indicated by the user, the distance to the stations from that point, the latitude and longitude for each station, and dates for which data are available from each station. Users can select the most appropriate station from which to generate reports. Select the dates to be evaluated, check the box to select the growing-degree-day calculation, and generate the report. The total GDD accumulated over the entire period will be calculated and reported at the bottom of the Web page.

While GDD information is not typically available to the current date, it will usually be available up through the previous few weeks. This information can greatly reduce the number of hand calculations necessary to compute GDD accumulated to the current date. Wheat development in relation to temperature can be determined by the cumulative number of wheat GDD. Large numbers of observations of wheat development and temperatures allow generalizations about what stage a plant should be in based on the duration and level of temperatures experienced.

Germination and Seedling Development

Germination begins with radicle (primary root) extension through the seed coat. It is followed by emergence of the coleoptile which surrounds and protects the emerging stem and primary leaves as they push upward to the soil surface. Wheat germinates across a range of temperatures from 39º to 90ºF, with optimal germination occurring at 68º to 77ºF. Germination normally occurs in four to six days under optimum temperatures. Wheat needs approximately 145 GDD to germinate, an additional 90 GDD to emerge, and thus a total of 235 GDD are required from planting to emergence (Figure 1).

The seedling growth stage begins with coleoptile emergence and ends with tiller development. Within genetic limits, the extent of coleoptile elongation depends on planting depth. Deeper planting necessitates greater coleoptile extension and more GDD. When the coleoptile reaches the soil surface, its growth stops and the

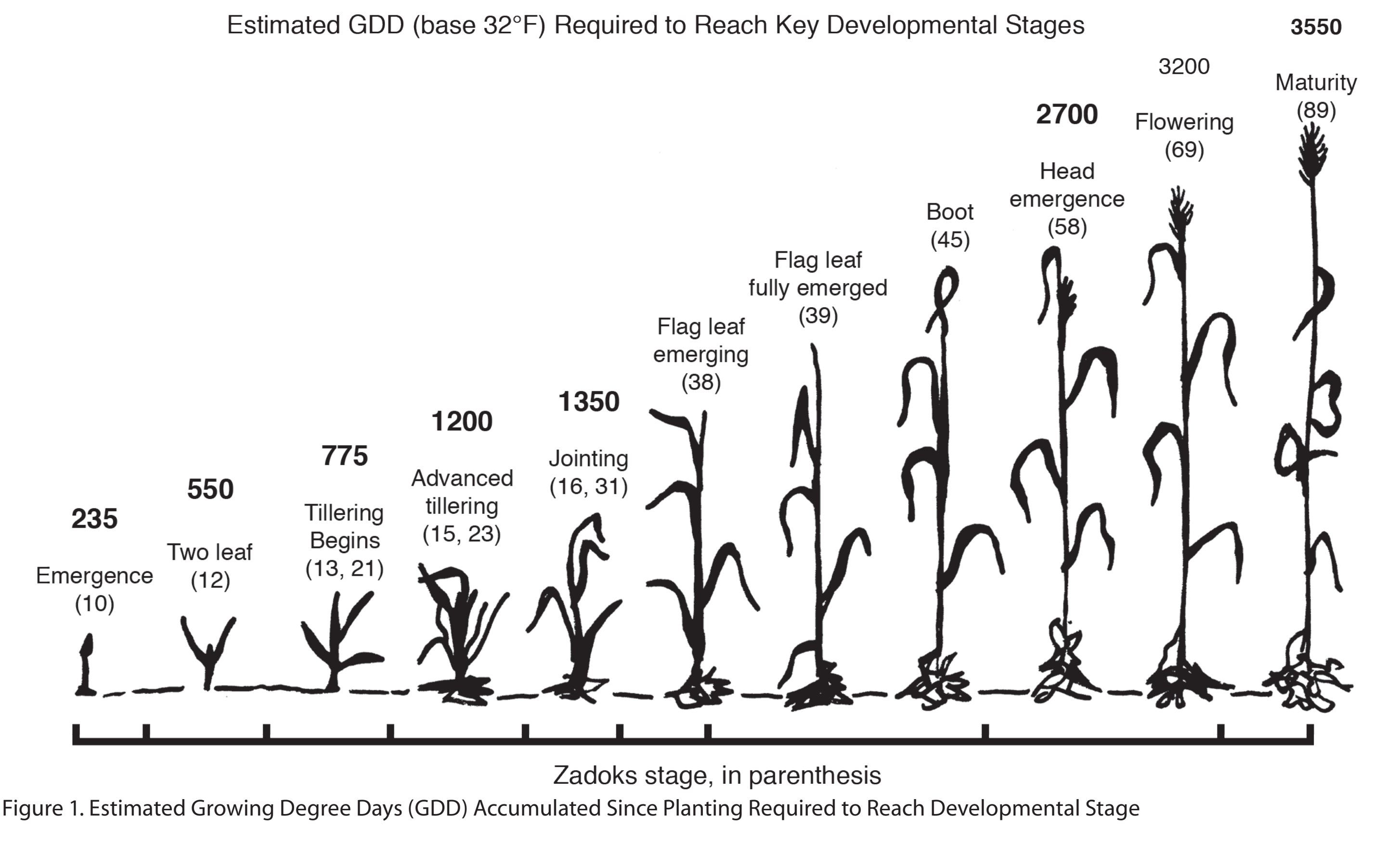

Figure 1. Estimated Growing Degree Days (GDD) Accumulated Since Planting Required to Reach Developmental Stage

first true leaf pushes through its tip. Until this first leaf becomes functional, the seedling is totally dependent on seed-stored energy for growth.

Generally, the wheat plant develops three or more leaves prior to tillering. The final size, shape, and growth rate of these leaves is determined by genetics and environment, but the rate of leaf appearance is controlled largely by temperature. Wheat requires 145 to 215 GDD per leaf developed, with an average value of around 180 GDD. Some deviation from these values has been observed. Typically, wheat planted in early fall will have a slightly higher GDD requirement per leaf when compared to later plantings. Very little difference in GDD requirement for leaf or tiller development is observed among cultivars.

As an example, if wheat emerged on October 28 and 400 GDD have accumulated since that time, the crop should have 2.25 leaves or be developing the third leaf if not exposed to other stress.

Tillering

Tillering is defined as the development of shoots from buds at the base of the main stem and is an important determinant of final grain yield. Tillers formed at the base of the coleoptile and the first true leaf generally emerge first. Subsequent tillers emerge in an ordered pattern unless they encounter stress. In Virginia, the main stem and early-formed tillers generally contribute the most to yield because they have a larger, better defined root system. The number of leaves on the main stem and each tiller is linearly related to GDD. The GDD required for wheat to go from planting to three leaves, when the first tiller usually emerges, is 775 GDD (235 GDD for planting and emergence and 180 GDD for each leaf to develop) and to six leaves on the main stem (including three tillers) is about 1200 GDD.

Jointing

When the first internode of the stem becomes evident, jointing or stem elongation has begun. An average wheat stem produces six internodes, or sections, with longer internodes near the bottom and shorter internodes near the top of the plant. Genetics dictate stem height, but environment greatly affects genetic expression. The number of potential grains and potential grain yield is determined at jointing and is heavily influenced by environmental conditions early in this stage. High temperatures increase the rate of wheat-head development but reduce the number of potential grains per head. Moisture stress decreases head numbers. High light intensities and optimal nitrogen fertilization increase head numbers. Planting to jointing requires about 1350 GDD and jointing typically lasts for about 350 GDD. The end of jointing is signaled by the appearance of the flag leaf, the last leaf to develop before grain head emergence.

Booting

The boot stage occurs when the head begins to swell within the base of the flag leaf. While the potential number of grain heads for the crop was determined at jointing, yield is also affected by stress at this stage. If the number of florets (potential grains) is lowered by drought, high temperatures, insufficient fertility, etc., yield will be lower. Once the reproductive phase begins, cultivar effects on the GDD requirement are much more prevalent. Therefore, while the GDD requirements up to this point are fairly consistent, the ones presented for booting and later vary and are more subject to error. Analysis of local data indicates that planting to booting requires a total of approximately 2100 GDD.

Heading

Heading begins when the grain head emerges from the flag leaf sheath. Pollination begins in the middle region of the head and progresses toward the tip and base. Most potential grain locations, or florets, are pollinated before anthers appear. Although tillers developed over a long growth period, bloom in that same wheat plant is usually complete four to five days after heading. The grain-fill period of wheat varies somewhat, depending upon climate, especially temperature. It is typically as little as 13 days in warmer, drier environments, and may exceed 20 days in high-yield, low-stress environments. High temperatures and drought stress during heading can reduce pollen viability and grain number. The total number of GDD necessary from planting to anthesis (flowering) ranges from 2600 to 3400, but is typically near 3200 in Virginia testing.

Making Decisions

Climatic information can make understanding crop development simpler and can help producers plan management actions.

Examples:

If a crop is slow in emerging, look at the GDD accumulated since seeding. If the number is below 230, the slow emergence is likely due to cool temperatures. If significantly more than 230 GDD have accumulated since planting and the crop is still not emerging, other problems such as low soil moisture, soil crusting, poor soil fertility, or disease are indicated.

Spring topdress nitrogen (N) application rates are based on N concentration in the plant tissue at GS 30. When the accumulated GDD approaches 1200, producers should begin checking fields for plants that are at GS 30. In this manner, a planned sampling window can be developed based on the GDD accumulated since planting.

Since the rate of leaf and tiller development is known to be correlated with GDD, if the crop is not following this pattern and is developing fewer leaves or tillers than would be indicated by the accumulated GDD, some form of growth limiting stress is likely occurring.