

Using the Virginia Cooperative Extension Climate Analysis Web Tool to Monitor, Predict, and Manage Corn Development

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Introduction

How a corn crop develops is affected by many factors: fertilization, rainfall, sunny or cloudy weather, hybrid or maturity group, etc. But these factors generally play second fiddle to **temperature** in determining when a corn crop tassels or is ready to harvest. Many years of observation have shown that plant development at any point during the season is affected very predictably by how warm or cool the season has been to that point. This knowledge, combined with projections about the remainder of the growing season, can sometimes be used to make mid-season adjustments in management and to predict harvest schedules.

This bulletin describes the temperature-driven **stages of development** through which corn plants grow, some important **management considerations** at key stages, and how to use the Virginia Cooperative Extension **Climate Analysis Web Tool** to make decisions about mid-season management as well as to predict maturity.

Corn Development: The General Pattern

Corn moves through a very repeatable, predictable sequence of development. Seeds germinate and seedlings emerge after some period of time – depending especially on temperature but also on moisture and other seedbed conditions. Young seedlings develop quickly – especially in warm weather – producing four leaves

in as little as a month after planting. The plants continue to grow and develop more leaves through late spring and early summer. The total number of leaves produced is genetically determined; for the hybrids we use in Virginia, that number is generally 15 or so. Typically ears begin to appear at the same time as the last few leaves. Once the final leaf has appeared, the tassels emerge; and then silks emerge from ears at about the same time pollen is shed by the tassels. Pollination and fertilization are followed by the critical period when grain is being made in the ear. If all goes well, many kernels form on each ear, and those kernels fill to full size. Eventually the kernels stop filling, and the plants dry down to harvestable moisture levels.

Producing leaves, stalks, and roots is described as **vegetative** growth, while tassels and ears are produced by **reproductive** growth. Corn plants tend to do one or the other: grow vegetatively (make roots, stems, and leaves) or reproductively (make tassels, ears, and grain). They switch from vegetative to reproductive development at some point during the season. For practical reasons, we say the switchover happens when tassels and silks emerge. Clearly, though, tassels and ears do not instantly appear; the plant begins to make them while it is still producing its final leaves. Typically (and reasonably), the plant is described as switching over to reproductive growth when it produces **visible** tassels and silks.

The section that follows looks more closely at stages of corn development – first vegetative, then reproductive.

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These are not just descriptions of what a plant looks like at a particular point in its life; they also describe what is going on in the plant and how the grower might be able to use such information (and additional information about temperature's important effects on development) to make some mid-course decisions about a planting.

Corn Development: Some Key Stages

Agronomists at Iowa State University developed a handy way to describe corn's very predictable pattern of growth. They named several easily observed events, or **stages**, that occur in every plant's life. The markers for each stage are readily seen with the naked eye – no need to bring a magnifying lens to the field and no need to pull plants up to see what is going on underground. Each developmental (growth) stage has a word descriptor and a shorthand abbreviation (Table 1). The first several stages are keyed to leaf number and vegetative development, particularly the development of the leaf collar (Figure 1). The later stages rely on easily identified reproductive events, such as the development of tassels and silks and the advancing maturity of the kernels. More information and photos are available on the Web at: <http://maize.agron.iastate.edu/corngrows.html>.



Figure 1. Photo of a corn plant at the V10 stage when the collar of the tenth leaf (the one growing toward the upper left) has become evident. The collar of leaf nine is labeled, and the collar of leaf eleven is not yet visible.

The following brief discussion of growth stages has multiple purposes: 1) to describe the identifying characteristics (some field markers) for the stage, 2) to discuss some parallel – but maybe not so obvious – things that are also happening in the plant, and 3) to consider what one might be able to do if a crop were in stress at a key stage.

Table 1. Some developmental stages and the cumulative number of Growing Degree Days (GDD) required to reach that stage for a typical Virginia mid-season hybrid.

Developmental Stage	Abbreviation	GDD
Vegetative Stages		
Emergence	VE	0
Two-leaf (two leaves fully emerged)	V2	200
Four-leaf	V4	345
Six-leaf	V6	475
Eight-leaf (tassels developing)	V8	610
Ten-leaf	V10	740
Twelve-leaf (ear appearance)	V12	870
Fifteen-leaf (tip of tassels emerge)	V15	1060
Tasseling	VT	1200
Reproductive Stages		
Silking	R1	1400
Blister	R2	1660
Milk	R3	1925
Dough	R4	2190
Dent	R5	2450
Physiological maturity (black layer forms)	R6	2700
Harvest maturity (plants have dried to proper moisture)	R7	*

* depends more on drying conditions (rainfall, humidity, wind, etc.) than on just temperature; also depends on whether corn is to be harvested for grain or for silage.

Emergence – VE: The coleoptile – a small, hollow tube that helps the seedling push its way up through the soil – reaches the soil surface. Exposure to sunlight causes the coleoptile to stop elongating. Leaves develop rapidly and emerge through the coleoptile. The growing point of the seedling – the site where new leaves and stem are being formed – remains below the soil surface (at the depth the seed was planted). Seminal (seedling) root growth slows; and nodal (crown) roots, which will become the dominant roots of the plant, are initiated at the crown.

One-leaf stage – V1: The first leaf, which is relatively short and oval or rounded, has a visible leaf collar (Figure 1). The nodal, or crown, roots begin to lengthen. The growing point remains well below the soil surface. The young plants are relatively safe from mild freezes (or leaf-chewing insects) at this point, because their growing points are protected.

Three-leaf stage – V3: Very little stalk elongation has occurred to this point, and the growing point remains below the soil surface. Branches begin to form on nodal roots, and seminal root growth has ceased. Although they are quite small and fully hidden, all leaves and ears that the plant will produce have been initiated by this stage. Since the growing point remains below the soil surface, cold soil temperatures may slow development, increase the total number of leaves formed, delay tassel formation, and reduce nutrient uptake. Corn at the V3 to V4 growth stage is typically about 12 inches tall.

Five-leaf stage – V5: The uppermost ear and tassel are initiated within the plant. The growing point nears the soil surface as stem elongation begins.

Six-leaf stage – V6: The growing point (now developing as a tassel) has risen to above the soil surface – making plants increasingly vulnerable to damage. Ears continue to develop, but are quite small. Nutrient deficiencies, especially nitrogen, should be addressed at or before this growth stage.

Seven-leaf stage – V7: During the V7 and V8 stages, growth is rapid; and the kernel row number (ear girth) is being determined within the developing ears.

Nine-leaf stage – V9: At the V9 and V10 growth stages, the stalk is rapidly growing taller. The tassel has begun growing rapidly as well (although still invisible). Many ear shoots are easily visible if the stalk is dissected.

Twelve-leaf stage – V12: Kernel row determination is nearly complete, with the number of kernels per row (ear length) being determined up to the time just prior to silking. Moisture stress at this time can severely limit yield potential.

Fifteen-leaf stage – V15: This is the beginning of the most critical period for yield determination and the “official” end of the vegetative growth phase. At this point, ear shoots are clearly evident without dissection.

Tasseling – VT: The last branch of the tassel becomes visible, but silks have not yet emerged. The plant is almost at its full height, and pollen shed (anthesis) will begin shortly. The VT/R1 stages are most vulnerable to moisture stress.

Silking – R1: This stage begins when any silk is visible outside the ear husks. Pollen shed typically occurs in the morning and evening. Falling pollen grains land on the silks, germinate, and begin to grow down the silk to fertilize the ovules. An ovule can develop into a kernel only if it is fertilized. It can take three days for all silks on an ear to be exposed and become pollinated. Earworms and other pests can cut the silks and prevent fertilization/seed set from occurring. Moisture stress at this time is detrimental to pollination and seed set, causing desiccation of the silks and pollen grains. Nutrient concentrations in the plant are highly correlated with final grain yield, as nitrogen and phosphorus uptake are rapid.

Blister stage – R2: Developing kernels are white and look like little “blisters.” If squeezed, the inner fluid is clear, and a tiny embryo might be seen. Starch begins to accumulate, and kernel moisture is approximately 85 percent. Nitrogen and phosphorus are accumulating as they relocate from vegetative tissues in the plant. This stage typically occurs 10 to 14 days after silking/pollination.

Milk stage – R3: About 18 to 22 days after silking, R3 kernels are yellow on the outside, with a milky white fluid inside. The embryo is growing rapidly and is easily seen when dissected. Silks are brown and drying. Kernels are rapidly gaining dry matter and are at around 80 percent moisture. Potential yield losses from drought or other stresses, e.g., disease, become less likely as kernels mature.

Dough stage – R4: At approximately 24 to 28 days after silking, the endosperm has accumulated enough starch to thicken to a pasty, or doughy, consistency.

The embryo is substantially larger than at the R3 stage. The cob appears white when kernels are removed, and kernels are at about 70 percent moisture.

Dent stage – R5: The cob turns red (for most hybrids); and beginning at the base of the ear, kernels develop a sunken “dent.” This stage typically occurs 35 to 42 days after silking. Stresses at this growth stage can reduce kernel weight, but not kernel number. Kernel moisture is about 55 percent at the beginning of the dent stage.

Physiological maturity – R6: Approximately 55 to 65 days after silking; all kernels have reached maximum dry weight. A black layer has formed where the kernel attaches to the cob, indicating no more material can be transported into the kernel. The stalk of the plant may remain green, but leaves and husks lose greenness. Kernel moisture content ranges from 30 percent to 35 percent, with large variation due to hybrid and environmental conditions. Damage before this stage will significantly reduce yield. (The earlier the stage, e.g., R4 or R5, the greater will be the loss to a freeze.)

Harvest maturity – R7: This is the stage when the crop can/should be harvested. The timing is determined almost entirely by the moisture content of the kernels and/or the rest of the plant. If the harvest is for grain, the optimum moisture content for kernels is 12 percent to 15 percent.

Developmental Stage vs. Plant Size

Some of the stage descriptions above offer a typical plant height. Why isn't plant height, then, a good indicator of how far along the plants are? Height is certainly easy to measure; however, it doesn't reliably tell how far along the plants may be in their development. Plant size can be quite variable at any stage. For example, when corn tassels (stage VT), it may be thriving with 8-foot plants. But the same hybrid planted on the same date in an adjacent un-irrigated field might tassel at only 3 feet tall. And, while those 3-foot tasseling plants may go on to produce some grain, they will never get more than 3 feet tall.

And here is a very important point about those two plantings – the irrigated one and the drought-stressed one. If they were planted at the same time, they should tassel at pretty much the same time. The VT stage should occur simultaneously in each field; and the time that it will take each field to move from VT to R3, or to R6, should be the same as well. That is because tem-

perature – not moisture – is the main determinant of the pace at which the plants move through their developmental stages.

Explaining/Predicting Corn Development with Growing Degree Days

Many years of observation by researchers have revealed a very close relationship between the developmental stage of a corn planting and the temperatures the plants have experienced. Because of that connection, it should be possible to predict a crop's stage if the appropriate information on the season's temperatures is available. With temperature data, a grower might be able to make an “educated guess” about how far along the crop should be even before going out to the field. It might also be possible for a grower, with data on the normal pattern of temperatures, to predict when a crop may reach stages yet to come, including maturity.

Estimating corn development based on temperature requirements is not just a theoretical or academic pursuit. It's very important at the farm level. For example, the choice of which hybrids to plant is based very importantly upon information about how much heat they must experience to reach maturity. Growers choose hybrids for Virginia that will reach maturity after receiving the amount of heat they are likely to get during the growing season (with some safety margin built in). As long as the growing season is not seriously below normal temperature-wise, growers expect the crop to mature before a freeze, all other things being equal.

It's easy to tell someone how hot or cold it is right now – just look at the thermometer. But how to describe the relative warmth or coolness of an entire growing season with enough accuracy to be able to predict corn's development? The most common method involves calculating growing degree days (GDD) – sometimes also called “heat units.”

The GDD approach to tracking corn development is based on research showing that corn plants begin to grow/develop at temperatures above 50°F. As the temperature rises above 50°F, the plants will grow faster – up to around 86°F. (Put another way, things begin happening at 50°F, but things don't happen any faster at 90°F or 100°F than at 86°F.) The number of GDD for a date is calculated by finding the day's average temperature (maximum plus minimum divided by two) and subtracting 50 (the growth threshold).

Formulaically, that looks like this:

$$((\text{Temp}_{\max} + \text{Temp}_{\min}) / 2) - 50 = \text{GDD } (^\circ\text{F}),$$

where Temp_{\max} is maximum daily temperature (but is set equal to 86°F when temperatures exceed 86°F),

and Temp_{\min} is the minimum daily temperature (but is set equal to 50°F when temperatures fall below 50°F)

A couple of examples:

On a day when Temp_{\max} is 78°F and Temp_{\min} is 62°F, $\text{GDD} = ((78 + 62)/2) - 50 = 20$.

On a day when Temp_{\max} is 56°F and Temp_{\min} is 42°F, $\text{GDD} = ((56 + 50)/2) - 50 = 3$.

The cumulative GDD for a crop, then, will be the sum of GDD for all of the days since the seeds were planted or since the crop emerged. The starting point for beginning calculations and calculating relative maturity of a hybrid varies among seed companies. Some count from planting, but most count from emergence so growers must be aware of how the relative maturity is estimated for a particular hybrid.

Figure 2 illustrates 30-year average GDD accumulations from April 15 to September 15 for three locations in Virginia. The greatest number of accumulated GDD normally occurs at West Point, in the Coastal Plain, as compared to either the Piedmont or Shenandoah Valley. Accumulated GDD are typically much less in the Ridge and Valley and Mountain regions of the state.

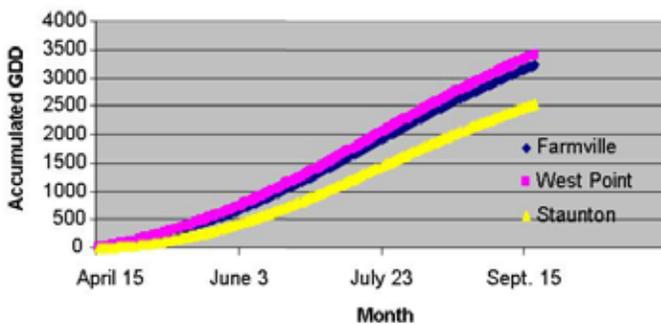


Figure 2. Thirty-year average GDD accumulations from April 15 to September 15 for West Point, Farmville, and Staunton, Virginia (1975-2005).

According to Table 1, a typical, mid-season Virginia hybrid requires 2,700 GDD to reach R6. The table, in fact, shows how many GDD are needed to reach any of the stages (except VE). Knowing how many GDD a crop has experienced, allows the grower to make a very good guess about where it should be developmentally. When a crop is not at the predicted stage, something besides temperature (perhaps nutrition) could be limiting growth. “Falling behind schedule” can be a signal that management is needed.

Table 1 also shows that, in this schedule, GDD begin to accumulate only after emergence. (GDD at emergence is 0.) Cumulative GDD is often reported this way because soil temperature is obviously much more important than air temperature during germination and emergence; and by definition, GDD calculations are based on air temperatures. Depth of planting also can make a significant difference in how quickly the coleoptile makes its way to the surface. For these reasons, GDD data are often accumulated beginning at emergence (VE). Sometimes, though, cumulative GDD are computed from planting date. Growers must be sure to take note of the method used for cumulative counts for whatever hybrid they may be using.

Using the Climate Analysis Web Tool to Manage a Corn Crop

Virginia Cooperative Extension developed its Climate Analysis Web Tool using historical averages and current-year data on climatic conditions – including temperature. The tool can very quickly calculate GDD, which can be a very time-consuming job at 75 or 100 days into the growing season. With such data, the grower can make some very good guesses about current crop status and generate predictions about what the future may hold for the crop. 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: <http://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 reporting stations 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 of the stations. 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 requested period will be calculated and reported at the bottom of the Web page.

Knowledge of climatic conditions can help producers better manage their corn crops. For example, if a crop is slow in emerging, the producer should look at the GDD accumulated since seeding. If the number is below 150, the slow emergence is probably due to cool soils (<50°F). If significantly more than 150 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 should be investigated.

Since the rate of leaf emergence and development is so strongly correlated with GDD, if the crop is not following the predicted pattern and is developing more slowly than would be indicated by the accumulated GDD, some stress is likely occurring.

Understanding the accumulation rate of heat units in a particular season can help producers avoid being late or early with herbicide or nitrogen applications. Sidedress nitrogen applications should occur at, or prior to, the V6 growth stage in order to ensure the presence of adequate N for growth and ear development. The V6 stage will occur at around 475 GDD after emergence so anticipating this can assist the producer with the timing of fertilizer application. Some herbicide labels state specific growth stages for when application is appropriate or inappropriate. For example, the ACCENT® herbicide label states that the product should not be applied to corn that has reached the V10 growth stage and that ear malformation or pinching can occur with applications between V7 and V10 (approximately 540-740 GDD).

Moisture stress that occurs near the silking stage in corn results in the largest potential yield losses. It is important to choose appropriate hybrids and planting dates so that the crop is least likely to undergo stress at this stage. Understanding climatic history using the Climate Analysis Web Tool and crop development can help producers determine the planting window that most likely will result in a successful crop. In some cases, the decision may be to plant an earlier/shorter-season hybrid, as might be wise if planting has been much delayed by wet conditions – especially in the shorter-season areas in the western side of the state.

While GDD information may not always be available to the current date on the Web site, it usually will 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.

Summary/Conclusions

Agronomists have developed some very good connections between the developmental stages of corn plantings and seasonal temperatures. Accordingly, corn development can be pretty well predicted if producers know the requirements of the hybrid they are working with and the number of GDD that have accumulated. The Virginia Cooperative Extension Climate Analysis Web Tool allows growers to “check up” on their corn plantings (to see if they are on schedule) and to make predictions about when they might be ready to harvest. In cases where the actual stage falls behind predictions, growers are encouraged to look more closely at the crop’s status.