KANSAS STATE UNIVERSITY | Extension

Understanding Growing Degree Days:

Temperature Limits and Their Role in Crop Growth and Development

Temperature is a driver for plant growth

Temperature is a major environmental driver for nearly all aspects of crop growth and development. Within the optimal temperature range, crop physiological processes, such as germination, photosynthesis, leaf expansion, and reproductive development, are maximized. Figure 1 shows a conceptual view of the plant response to temperature. Different crops thrive at different temperatures. For instance, sorghum and maize prefer higher temperatures, whereas wheat prefers cooler environments. The typical lower and upper temperature limits of the optimal ranges are presented in Table 1 for different major crops in Kansas. When temperatures exceed or fall below these limits, crop development slows or ceases altogether. In extreme conditions, plants may suffer tissue damage, reproductive failure, and reduced yields, especially during critical stages of germination, flowering, or grain filling.

Temperature affects plant metabolic functions, enzymatic activities, and water-use efficiency, thus shaping crop responses to environmental factors, including soil moisture and atmospheric CO_2. Higher temperatures generally accelerate crop development and lead to faster maturity. However, extreme heat can cause plants to alter leaf orientation and increase transpiration to prevent heat damage

Table 1. Temperature thresholds for major crops in Kansas.

Crop	T_{lower} (°F)	T_{upper} (°F)
Corn (Grain and Silage)	50	86
Winter wheat	32	79
Sorghum (Grain and Silage)	46	100
Cotton (Upland)	60	95
Oats	41	86
Canola	36	86
Alfalfa	32	86
Sunflower	46	86
Barley	32	86

Sources: Luo, 2011
Note: These values may vary by crop variety or hybrid. Temperature thresholds can also vary across phenological stages, especially in wheat. The values in the table represent generalized parameters for calculation purposes.

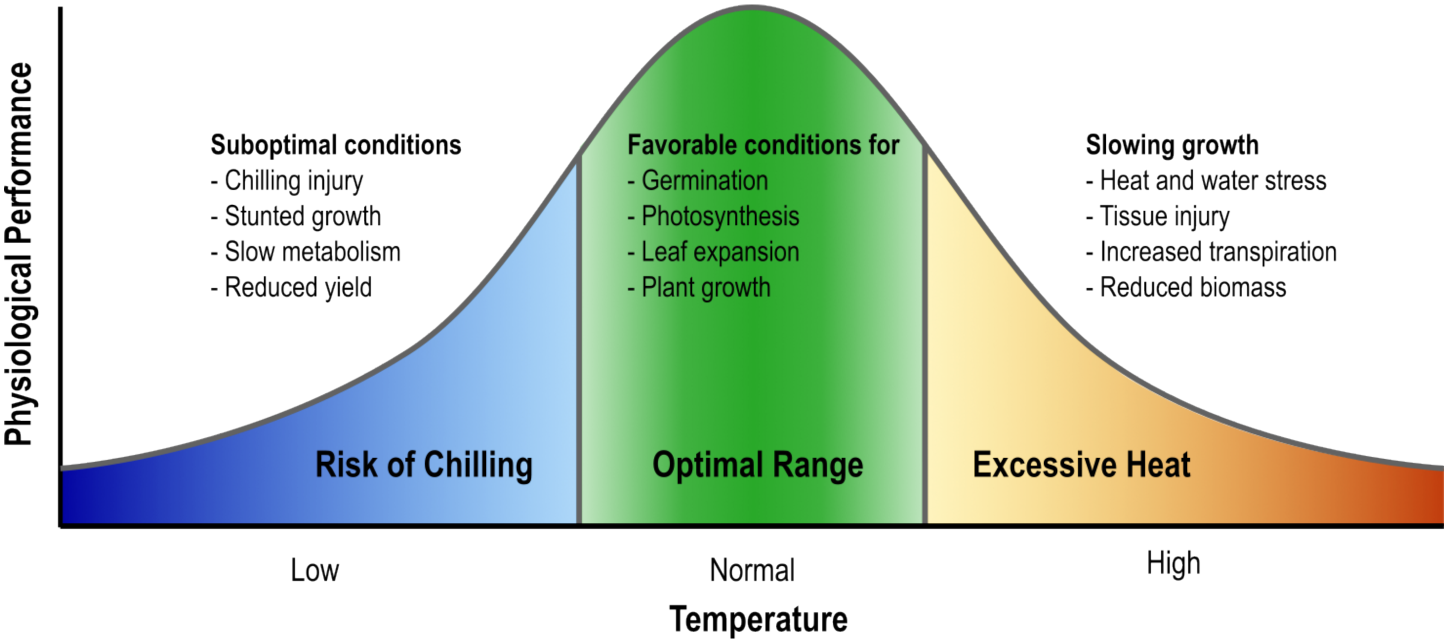


Figure 1. *Conceptual relationship between temperature and crop physiological performance.*

during critical growth stages. High temperatures may also shorten the duration of nutrient uptake and increase water stress, driven by higher evaporative demand, leading to decreased biomass and potential yield losses.

Low temperatures, on the other hand, can hinder crop growth by suppressing metabolic activity and inhibiting photosynthesis. Stress from chilling may cause severe damage to plants, including cellular dehydration, membrane damage, reduced leaf area, stunted roots, and chlorosis. Extended exposure to suboptimal temperatures can delay flowering, reduce yield, and degrade yield quality.

Therefore, understanding crop temperature requirements and managing the impacts of temperature limits is crucial for optimizing crop productivity and resilience to climate variability (Soni et al., 2025).

What are the Growing Degree Days?

Growing degree days (abbreviated GDD), also called **heat units** (HU), measure *cumulative heat (or thermal energy)* that a plant receives during the day. GDD represents a mathematical way of relating air temperature to crop growth. Summing daily GDD throughout the season and calculating **cumulative GDD** gives an estimate of season-long plant growth and can help track crop development, support management planning, and predict planting and harvesting dates. GDD can vary across crops, as optimal temperature ranges differ based on crop species-specific physiology (see the upper and lower limits in Table 1).

Daily GDD are calculated by subtracting a crop-specific base temperature (T_{base}) from the average daily temperature (T_{avg}) that is measured as the average of the daily maximum (T_{max}) and minimum (T_{min}) air temperatures:

$$GDD = T_{avg} - T_{base} \qquad (1)$$

$$T_{avg} = \frac{T_{max} + T_{min}}{2} \qquad (2)$$

The base temperature T_{base} in Equation (1) is typically set to a lower limit T_{lower}, and daily T_{max} and T_{min} are taken from atmospheric measurements. On hot days when T_{max} exceeds T_{upper}, the GDD formula can overestimate the amount of actual heat acquired by a plant and produce an error in seasonal plant growth estimations. A similar error can be seen if the temperature falls below T_{lower}. To address this, some approaches apply upper and lower limits to T_{min} and T_{max} in Equation (2).

Figure 2 shows a schematic comparison between the biological plant response to temperature and the linear GDD formula in Equation (1). Within the optimal temperature range between the lower and upper thresholds,

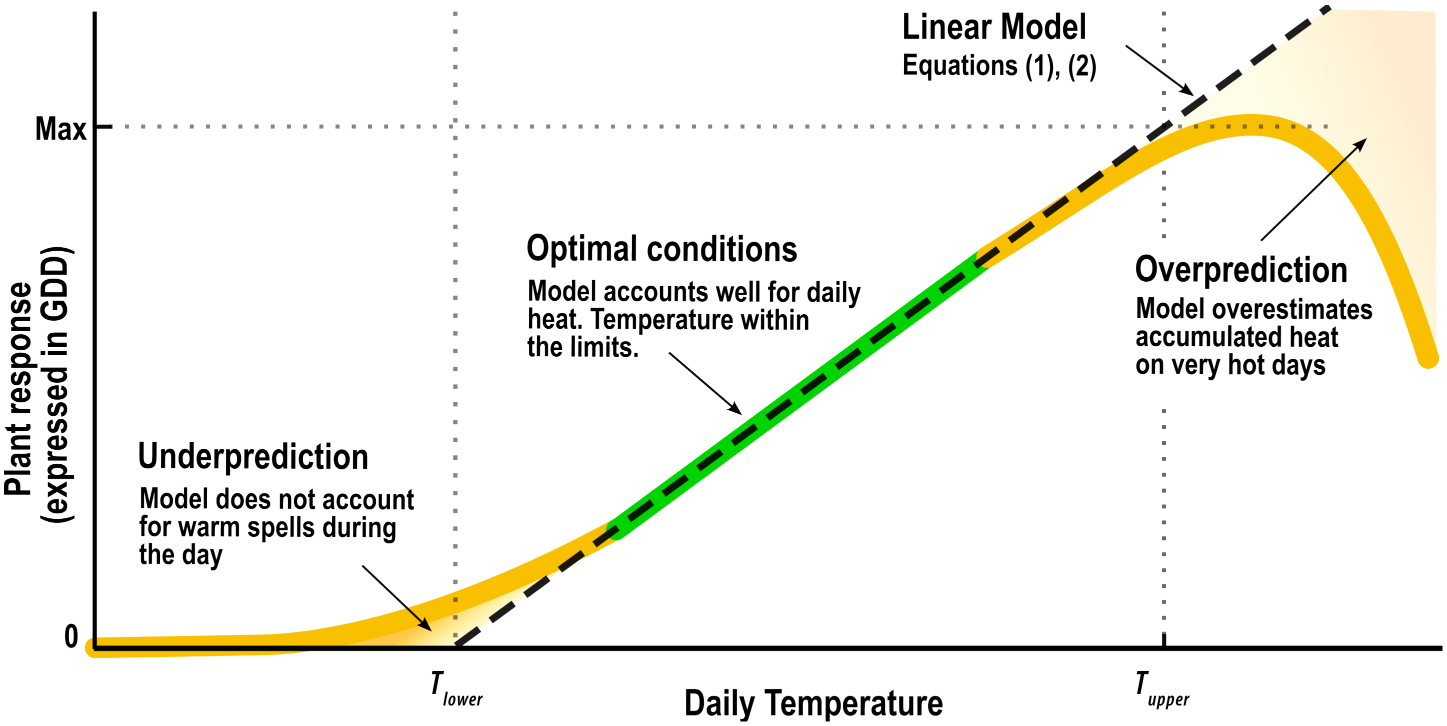


Figure 2. *Conceptual comparison between the linear GDD response (dashed line) to daily temperature and the biological plant response (bold line). The regions between the two curves indicate possible departures of the simplified linear model.*

the linear approach captures plant response well, but it tends to underpredict at low temperatures and overpredict at high temperatures. Incorporating temperature limits can reduce the error in matching the actual response curve, especially outside of the optimal range. Although several approaches have been introduced for GDD calculations, none has been found to be universally superior.

Methods to calculate GDD

Growing Degree Days (GDD) are calculated using Equations (1) and (2) and applying temperature limits to the measured daily maximum and minimum temperatures. The way the limits are applied can significantly affect results, particularly in regions with large diurnal temperature ranges, such as Kansas. Three documented methods widely used in research and extension publications are discussed below, with the calculation logic, benefits, and drawbacks of each method summarized in Table 2.

Example GDD calculations

Three examples show how distinct daily conditions during winter, spring, and summer can affect GDD calculations using three methods. We use corn as a growing crop with temperature limits taken from Table 1: T_{base} = 50 °F, T_{upper} = 86 °F. The figures for each example show temperature contribution limits and GDD accumulation for each method.

From the examples presented, the differences and similarities of the methods can be observed. Plant development is essentially zero below T_{base} when both minimum and maximum temperatures are below the lower limit, thus producing zero GDD in Example 1. As temperatures move into the optimal range in Example 2, the three methods largely overlap, except when T_{min} or T_{max} fall outside one of the limits (T_{base}, T_{upper}). In that case, Method 2 shows a slightly elevated biological response due to heat in the afternoon. It is during very hot days as in Example 3 that the three methods diverge due to the upper limit adjustment in Methods 2 and 3. The higher the extreme T_{max}, the greater the differences in GDD.

Differences in daily GDD calculations by the three methods may accumulate over a growing season and affect the interpretation of crop development and the timing of growth stages. In Figure 3, we present cumulative GDD for the Mesonet station in Hutchinson, Kansas, for 2011. Method 2 accumulates more GDD earlier in the season than Methods 1 and 3 because it limits the minimum temperature to a lower threshold, while Method 1 has no restrictions on the upper limit and exceeds cumulative GDDs from Methods 2 and 3 during the active growth season when the temperatures are high. Method 3 calculates the most conservative GDD count by only capping the average temperature at the upper threshold.

Table 2. Logic, benefits, and drawbacks of three common GDD calculation methods.

	Method 1	**Method 2**	**Method 3**
	No temperature thresholds	*Temperature limits applied to measured extremes*	*Temperature limits applied to measured average*
Logic	Use measured T_{max} and T_{min} to calculate T_{avg}, then subtract T_{base}. Set negative values to zero.	Limit T_{min} to T_{lower} and T_{max} to T_{upper} before calculating T_{avg}. Then subtract T_{base}. Set negative values to zero.	Calculate T_{avg} and limit it to the range between T_{lower} and T_{upper} before subtracting T_{base}. Set negative values to zero.
Benefits	Simple to compute; widely used for basic GDD calculations.	Prevents unrealistically high GDD from extreme T_{max} values; prevents lowering GDD from very low T_{min} on short, early-morning cold dips.	Simpler than Method 2, but accounts for the upper limit; matches Method 1 when the average remains within the limits.
Drawbacks	Can overestimates GDD on very hot days; may underestimate daytime warmth when cool mornings reduce the daily average.	Produces more conservative GDD values on hot days because high temperatures are set within the limits.	Can differ from Method 2 when T_{max} and T_{min} are far apart or outside the limits; very high T_{max} values can increase GDD if the average does not exceed the upper limit.

Example 1.
Cold winter day

$T_{min} = 36$ °F, $T_{max} = 48$ °F

Average temperature

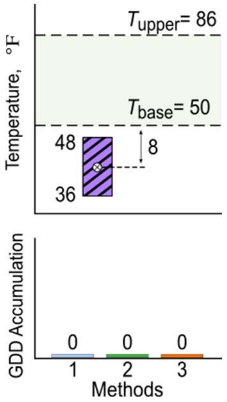
$T_{avg} = (36 + 48)/2 = 42$ °F

All temperatures are below

$T_{base} = 50$ °F

Method 1	Method 2	Method 3
GDD = 42 − 50 = −8	$T_{\min(adj.)} = 50$ $T_{\max(adj.)} = 50$ $T_{avg(adj)} = (50 + 50)/2$ $= 50$ GDD = 50 − 50 = 0	$T_{avg} < T_{base}$ $T_{avg(adj.)} = T_{base} = 50$ GDD = 50 − 50 = 0
GDD = 0	**GDD = 0**	**GDD = 0**

Outcome: All methods agreed on *zero* GDD on a cold winter day.



Example 2.
Cold spring morning, warm afternoon

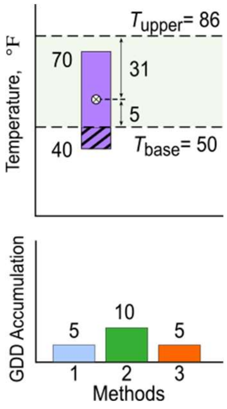
$T_{min} = 40$ °F, $T_{max} = 70$ °F

Average temperature

$T_{avg} = (40 + 70)/2 = 55$ °F

Method 1	Method 2	Method 3
GDD = 55 − 50 = 5	$T_{min} < T_{base}$ $T_{min(adj.)} = T_{base} = 50$ $T_{avg} = (50 + 70)/2$ $= 60$ GDD = 60 − 50 = 10	$T_{base} < T_{avg} < T_{upper}$ $T_{avg} = 55$ GDD = 55 − 50 = 5
GDD = 5	**GDD = 10**	**GDD = 5**

Outcome: Methods 1 and 3 produced the same GDD= 5°F since the average temperature was within the limits. Method 2 gave a higher GDD value of 10°F since it accounted for warmth in the afternoon when the maximum temperature was higher than the base temperature.



Example 3.
Warm summer morning, very hot afternoon

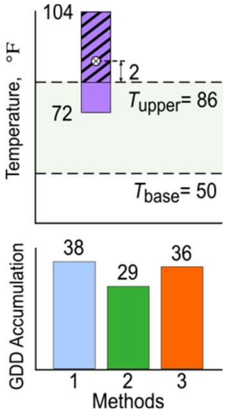
$T_{min} = 72$ °F, $T_{max} = 104$ °F

Average temperature

$T_{avg} = (72 + 104)/2$
$= 88$ °F

Method 1	Method 2	Method 3
GDD = 88 − 50 = 38	$T_{base} < T_{min} < T_{upper}$ $T_{max} > T_{upper}$ $T_{max(adj.)} = T_{upper} = 86$ $T_{avg(adj)} = (72 + 86)/2$ $= 79$ GDD = 79 − 50 = 29	$T_{avg} > T_{upper}$ $T_{avg(adj.)} = T_{upper} = 86$ GDD =86 − 50 = 36
GDD = 38	**GDD = 29**	**GDD = 36**

Outcome: All methods produced different GDDs. Method 1 showed the highest GDD at 38F since the temperatures were unrestricted. Method 2 yielded the lowest GDD at 29°F, indicating plant adjustment to the extreme temperature in the afternoon by not counting heat units above the maximum limit. Method 3 produced GDD value of only 2°F lower than Method 1 highlighting a slight heat unit reduction to the extreme maximum temperature.



How to Use Growing Degree Days

- **Tracking crop development.** Summing daily GDD values over time yields *cumulative* GDD, which is the total usable warmth received by the crop throughout the growing season. Cumulative GDD provides a practical way to track crop progress from planting through maturity. Each crop requires a characteristic amount of cumulative GDD to transition between phenological stages. By continuously monitoring cumulative GDD throughout the season, growers can estimate the onset of these stages. Example ranges of cumulative GDD are shown in Tables 3 to 6 for different crops.

- **Management planning.** GDD is a useful tool for optimizing the scheduling of management practices. By predicting specific developmental stages, growers can better time irrigation, fertilizer application, pest and disease scouting, and harvest. Even in two seasons with the same planting date, a crop can reach phenological stages at different times due to seasonal temperature variations. Using GDD instead of specific calendar dates helps support informed, weather-based decision-making.

- **Crop suitability in a new location.** GDD can be used to determine if a location is suitable for a specific crop. As an example, upland cotton typically requires 2,200 to 2,600 °F cumulative GDD from planting date to harvest (Table 4). Analyzing historical weather data helps growers estimate potential cotton production, making it useful for regional comparisons or assessing the suitability to new production areas.

- **Comparing seasons and temperature patterns.** Analyzing GDD across seasons helps explain annual variability in crop development and harvest timing. Seasons with higher cumulative GDD typically accelerate crop development, while those with lower cumulative GDD tend to delay crop progress. Long-term cumulative GDD trends can serve as indicators of changing temperature patterns. Observing shifts in heat units across seasons and locations, growers can better predict changes in crop development rates and adjust their management strategies.

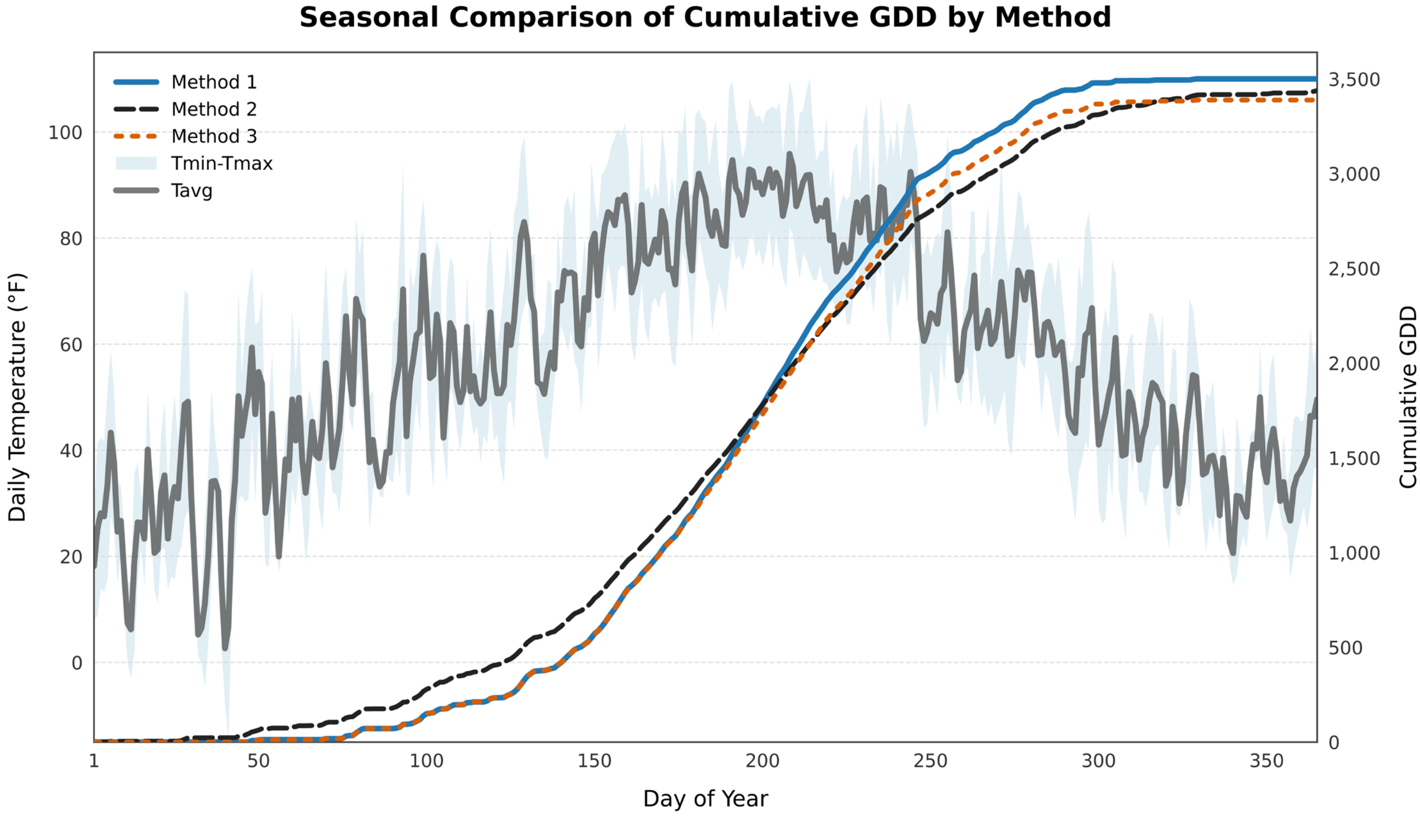


Figure 3. *Comparison of cumulative GDD calculated at the Mesonet site in Hutchinson, Kansas, in 2011 using Methods 1, 2, and 3. The temperature (min-max range and daily average) curves show variability throughout the year.*

Table 3. Corn GDD requirements.

Phenological stages	GDD ranges
VE - Emergence	100 – 200
V6 – Tassel initiation	475 – 590
VT – Tassel emergence	1,000 – 1,170
R1 – Silking	1,400 – 1,830
R4 – Dough stage	1,925 – 1,980
R5 – Dent stage	2,190 – 2,450
R6 – Black layer	2,650 – 2,700

1) Corn hybrid maturity is commonly classified as early-, mid-, and full-season. Typical seasonal ranges are 2100 – 2400, 2400 – 2800, and 2900 – 3200, respectively.
2) GDD values for corn are typically referenced to physiological maturity, while harvest-ready grain maturity is reached several days later.
References: Hoeft et al., 2000; Fjell et al., 2007; Ortez & Lindsey, 2023.

Table 4. Cotton GDD requirements.

Phenological stages	GDD ranges
Emergence	50 – 130
First square	425 – 550
First flower	775 – 900
Open boll	850 – 950
Peak blooming	1350 – 1500
Defoliation/harvest	1900 – 2600

GDD requirements of cotton are sensitive to early-season temperatures. Cool soil can delay emergence.
References: Main, 2012; Soni et al. 2025

Table 5. Sorghum GDD requirements.

	GDD	
Phenological stages	Short season hybrid	Full season hybrid
Emergence	200	200
3-leaf	500	500
5-leaf	660	660
Panicle initiation	924	1365
Flag Leaf visible	1287	1470
Boot	1683	1750
Heading	1749	1890
Flowering	1848	1995
Soft dough	2211	2310
Hard dough	2508	2765
Black layer	2673	3360

Sorghum is more sensitive to cool temperatures than corn. Early season GDDs may overestimate actual development.
References: Kelley, 2011; Gerik et al., 2003

Table 6. Sunflower GDD requirements.

Phenological stages	GDD
Emergence	206
4 true leaves (V4)	347
12 true leaves (V12)	627
20 true leaves (V20)	908
Miniature terminal bud (R1)	1048
Bud < 1” from leaf (R2)	1188
Bud > 1” from leaf (R3)	1328
Bud open ray flowers visible (R4)	1469
Early flower (R5)	1609
Flowering complete (R6)	1889
Back of head – pale yellow (R7)	2030
Bracts green – head back yellow	2170
Bracts yellow – head back brown	2310

The physiological development of sunflower is influenced by *both* temperature and daylength. Relying on GDD alone may not accurately capture progress timing.
Reference: Kandel et al., 2020

Where to obtain temperature data

Daily minimum and maximum temperature records for GDD calculations can be obtained from historical and forecasted weather data from the following sources:

1. Kansas Mesonet (Kansas stations only): *mesonet.k-state.edu/weather/historical/*
2. NOAA Daily Summaries (official archived station data): *ncei.noaa.gov/maps/daily-summaries/*
3. National Weather Service Hourly Weather Forecast (for forecast-based GDD): *weather.gov/wrn/hourly-weather-graph*

How to interpret cumulative GDD values

- GDD requirements for crop development stages are specific to crop physiology but can be affected by planting date, variety selection, local climate, and management practices. Recommended ranges are presented in Table 3 (corn), Table 4 (cotton), Table 5 (grain sorghum), and Table 6 (sunflower), showing variability across crop varieties and environmental stressors.
- Growers may use these tables for general planning purposes, and it is recommended to review extension publications and consult local variety trials for more area-specific GDD numbers.

Limitations of the GDD approach

- While the GDD concept provides a useful temperature-based index of crop development, these values should not be interpreted as a complete predictor of crop performance.
- GDD does not consider many other environmental factors and resource limitations, including water stress, nutrient availability, or the presence of pests or diseases. All of these factors can slow growth even when temperature conditions are favorable.
- Applying temperature limits to prevent unrealistically large GDD values does not prevent the fact that extreme heat damage to a plant occurs even when GDD values are capped.
- Crop management practices, such as optimal planting date, cultivar selection, timely irrigation, and sufficient residue cover, can change GDD requirements for plant development-stage planning.

Practical recommendations

- Methods can produce different GDD values on a given day and predict different dates for fulfilling cumulative GDD requirements for phenological stages. Therefore, using all three methods instead of a single one can provide a useful range of dates for effective management planning.
- Soil temperature around the seed zone often lags air temperature; delaying crop planting by several (3 to 5) days after favorable air temperatures or GDD are met is recommended.

Key takeaways

- Temperature drives crop growth and GDD quantifies the impact.
- Extreme temperatures can overestimate accumulated heat units, so applying limits can bring GDD closer to biological growth rates.
- GDD provides a valuable tool for planning but does not account for non-temperature related environmental stresses, crop variety differences, and other management practices.
- Documenting the method used for GDD calculations is recommended to avoid inconsistencies and misinterpretations of GDD applications.

References

Fjell, D. L., Vanderlip, R. L., & Roozeboom, K. L. (2007). Corn production handbook (C560). K-State Research and Extension, Kansas State University.

Gerik, T., Bean, B., & Vanderlip, R. (2003). Sorghum growth and development (B-6137). Texas Cooperative Extension.

Hoeft, R. G., Nafziger, E. D., Johnson, R. R., & Aldrich, R. A. (2000). Modern corn and soybean production. Donnelley & Sons.

Kandel, H., Endres, G., & Buetow, R. (Eds.). (2020). Sunflower production guide (A1995). North Dakota Agricultural Experiment Station & North Dakota State University Extension.

Kelley, J. (2011). Grain sorghum production handbook: Growth and development (MP 297). University of Arkansas Cooperative Extension Service.

Luo, Q. (2011). Temperature thresholds and crop production: A review. Climatic Change, 109(3), 583–598.

Main, C. L. (2012). Cotton growth and development (Bulletin W287). University of Tennessee Extension.

Ortez, O., & Lindsey, A. (2023). Corn growing degree days: A method of maturity rating for hybrids (Fact Sheet AGF-0101). The Ohio State University Extension.

Soni, M., Sheshukov, A. Y., & Aguilar, J. (2025). The critical role of temperature in determining optimal planting schedule for cotton: A review. Agricultural and Forest Meteorology, 373, Article 110741.

Authors:

Menard Soni*, PhD student,*
Carl and Melinda Helwig Department of Biological and Agricultural Engineering, Kansas State University

Aleksey Sheshukov*, Professor and Water Quality Specialist,*
Carl and Melinda Helwig Department of Biological and Agricultural Engineering, Kansas State University

Jonathan Aguilar*, Professor and Irrigation Specialist,*
Southwest Research-Extension Center, Kansas State University

Logan Simon*, Assistant Professor and Southwest Area Agronomist,*
Southwest Research-Extension Center, Kansas State University

Xiaomao Lin*, Professor and State Climatologist,*
Department of Agronomy, Kansas State University

Additional Reviewer:

Dr. Richard Vanderlip*, Emeritus Professor, Department of Agronomy*

KANSAS STATE
UNIVERSITY
Extension

MF3740 | June 2026