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Agronomic Crops

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Introduction to Growing Degree Days

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Key Messages:

- Temperature affects the development of crops, insects, weeds, and other organisms that are relevant to farming.
- Temperature is usually a better predictor of the rate of development of crops and other organisms than calendar time.
- Growing degree-days (GDD), which is an index calculated using temperature data, is often used to estimate the time needed for a crop or other organisms to reach maturity or to reach a certain stage of development.
- GDD is calculated from air temperature measurements usually reported by weather station networks.
- A GDD calculator for the southeast USA is freely available at: http://agroclimate.org/tools/Growing-Degree-Days/.

Temperature and development rate

For many years, researchers and practitioners working with biological ecosystems have been trying to find effective ways of predicting how different types of organisms develop and grow in different environments. Although it is understood that genetics plays an important role on how rapidly an organism develops and reproduces, of especial interest has been the question of how environmental conditions affect growth and development for a particular organism.

It is especially important to be able to model and predict how plants and other organisms are impacted by changing environmental conditions. This has become particularly relevant in recent years as scientists are trying to predict the potential impact of climate change and climate variability on the development and adaptability of different organisms.

In agriculture, this understanding is certainly important for crops and farm animals, but it is also important for other species that are considered as pests, such as weeds, bacteria, fungi, nematodes, insects, rodents, etc. For example, in agriculture, it is important to understand the life cycle of insects to be able to control and manage them more effectively.

Information regarding the duration of a given stage in the development cycles of an insect, weed, pathogen, or other agronomic pest may be crucial for effective control. For crops, for example, understanding the duration from planting to maturity or from planting to flowering is important for properly timing and applying management practices such as application of crop inputs (fertilizers, water, pesticides) and scheduling other farm inputs such as labor, farm machinery and financial resources.

Researchers have found that temperature has a significant impact on the rate of development of crops and many other organisms. In general, warmer temperatures, within a certain limit, tend to accelerate the rate of development while cooler temperatures tend to delay development. For example, Fig. 1 shows published data illustrating the measured relationship between rate of development and temperature for two different types of organisms, a type of nematode and corn rootworm eggs. For the nematode, the measured rate of development increased almost linearly from a minimum temperature required to initiate development, called the *Base Temperature* (T_b), to an *Optimum Temperature* (T_o) where development rate reached its maximum. After the temperature increased above T_o, the rate of development linearly declined, suggesting a negative impact of excessive heat on the rate of development. The corn rootworm eggs (Fig. 1B) show a similar behavior, but it appears that in this case the measurements were performed under temperatures too cool to reach or exceed T_o.

In the two examples shown in Fig. 1, it is noticeable that growth did not start until the *Base Temperature* was reached. But, the *Base Temperature* was different for each organism, with $T_b \approx 35$ °F for the nematode and $T_b \approx 50$ °F for the corn rootworm eggs. These differences in T_b are common among different organisms, including crops, which are indicator of the adaptability of a crop to grow in a particular environment.

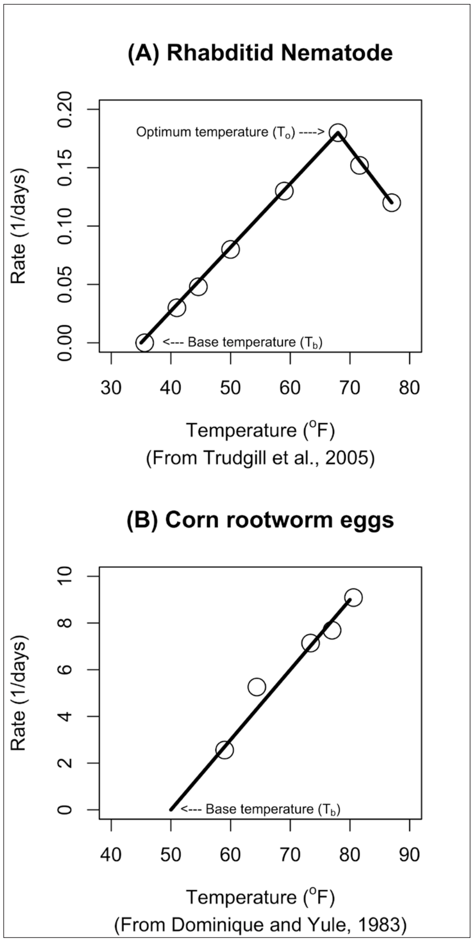

Figure 1. Sample relationship between temperature and the development rate of two types of organisms: (A) one generation of Rhabditid nematode and, (B) Corn rootworm eggs.

Table 1 shows the *Base Temperature* for different crops commonly grown in the USA. It shows that the winter crops (wheat and barley) have a lower T_b compared to the summer crops (cotton, corn, peanut, and soybeans).

Table 1. *Base Temperature* (T_b) for different crops.

Wheat	Barley	Cotton	Corn	Peanut	Soybeans
32 °F	32 °F	54 °F	50 °F	48 °F	50 °F

The rate of development of agricultural crops usually responds to temperature in a similar fashion as the examples shown in Fig. 1. Therefore, a crop hybrid grown in a cool environment would normally take longer to develop and reach maturity compared to growing the same crop hybrid in a warmer environment. Calendar time has been found no to be a very reliable indicator when trying to compare when a crop would mature or reach certain stage of development in different growing environments.

Because ambient temperatures can vary greatly with locations, growing seasons, time of day, and time of year, it is difficult to predict crop growth based on calendar time. Therefore, researchers have tried and develop other ways of expressing some measure of "time" to characterize growth. The most common choice has been to express "time" in terms of temperature, although it is also well known that some crops, like soybeans, also respond to photoperiod, the duration of daily exposure to light. However, it is most common to relate development rate to some indicator of temperature, rather than photoperiod. For agriculture, it is most common to relate development rate to Growing Degree Days, derived from air temperature measurements.

Growing Degree-Days

Since the rate of crop growth depends on temperature, the more temperature (heat) is accumulated during a period of time, the more growth is expected (within some limits). This is assuming that no other factors, such as water stress, insects, weeds, nutrient deficiency, etc, would limit growth. In general, for a given day, Growing Degree Days (*GDD*) is the difference between the average air temperature and the *Base Temperature* (T_b) for a particular crop. *GDD* is usually calculated on a daily basis and then accumulated during the number of days of interest. In production agriculture, GDD is often also known as *Degree Days* (DD) or *Heat Units* (HU).

There are different ways of calculating *GDD*, which can significantly impact results. There are also preferred methods to calculate GDD depending on the crop. GDD is calculated from air temperature measurements usually reported by weather station networks. Since weather stations usually report air temperature as daily maximum (T_{max}) and minimum (T_{min}), the average daily air temperature is usually approximated as the average of T_{max} and T_{min}, as:

$$T_{avg} = [(T_{max} + T_{min})/2] \qquad (1)$$

In the United States, temperature is commonly expressed in °F, but in other countries °C is more commonly used. Here we will use T_{avg}, T_b , T_{max} and ,T_{min} in °F and, therefore, GDD will be expressed in units of (°F day).

McMaster and Wilhelm (1997) found that researchers utilized two different methods to calculate daily *GDD*, which resulted in significant differences in results. They reported that the basic equation to calculate *GDD* was:

$$GDD = T_{avg} - T_b = [(T_{max} + T_{min})/2] - T_b \qquad (2)$$

But, in Method 1:

$$\text{if, } T_{avg} < T_b, \text{ then } T_{avg} = T_b \quad (3)$$

while in Method 2:

$$\text{if , } T_{max} < T_b, \text{ then } T_{max} = T_b$$

$$\text{and, if, } T_{min} < T_b, \text{ then } T_{min} = T_b \quad (4)$$

A common variation of *Method 2* is to only compare T_{min} to T_b. In *Method 1*, the comparison to T_b occurs after calculating T_{avg}, but in *Method 2* the comparison of T_{max} and T_{min} to T_b occurs before calculating T_{avg}. *Method 1*, however, is the most common method to calculate *GDD*. Another common variation to both methods is to impose an upper limit to T_{max}. For example, McMaster and Wilhelm (1997) used upper limits of 77 °F and 86 °F as upper limits to calculate GDD for wheat and corn, respectively. This upper limit accounts for the fact that growth may be restricted if the temperature exceeds the *Optimum Temperature* (T_o), as shown in Fig. 1A.

It should be noted that Eq. 2 only calculates GDD for one day, but in practice it is more relevant to obtain the GDD accumulated during a period of days, weeks, months, or for the entire growing season. This is accomplished by adding the daily GDD obtained from Eq. 2 during the period of interest. In other words, to get the GDD accumulated during a period of time, Eq. 2 can be transformed as:

$$GDD = \sum_{i=1}^{n} \left(\frac{T_{max} + T_{min}}{2} \right) - T_b \quad (5)$$

where n is the number of days used in the summation. In the literature, however, it is common to find reference to GDD as both the results of Eq. 2 and Eq. 5. In reality, the accumulated GDD during a given period of time (Eq. 5) is what is relevant for practical applications. Also, researchers often refer to the GDD obtained using Eq. 5 as "*Thermal Time*" in addition to Growing Degreed Days. Crops need to accumulate certain number of GDD to reach different growth stages from planting to maturity. Table 2 shows an example of the GDD needed for a particular corn hybrid to reach different growth stages. This type of information is available for many commercial crops (Miller et al., 2001).

Table 2. GDD (°F day) needed to reach growth stages for a 2700 GDD corn hybrid (Neild and Newman 1987).

Growth Stage	V2	V6	V12	VT	R1	R6
GDD	200	475	870	1135	1400	2700

GDD Calculation Examples

Example 1:

Calculate daily GDD for cotton and wheat, given: T_{max} = 85°F, T_{min} = 65°F, and T_b is 54 °F for cotton and 36 °F for wheat.

$$GDD = T_{avg} - T_b = [(T_{max} + T_{min})/2] - T_b$$

$$T_{avg} = [(85°F + 65°F)/2] = 75°F$$

$$GDD_{Cotton} = 75 °F - 54 °F = 21°F \text{ day.}$$

$$GDD_{wheat} = 75 °F - 36 °F = 39 °F \text{ day.}$$

Example 2:

Calculate daily GDD for cotton and wheat, given: T_{max} = 60 °F, T_{min} = 42 °F, and T_b is 54 °F for cotton and 36 °F for wheat.

$$GDD = T_{avg} - T_b = [(T_{max} + T_{min})/2] - T_b$$

$$T_{avg} = [(60 °F + 42 °F)/2] = 51 °F$$

$$GDD_{Cotton} = 54 °F - 54 °F = 0 °F \text{ day}$$

(For cotton, since $T_{avg} < T_b$, then $T_{avg} = T_b$)

$$GDD_{wheat} = 51 °F - 36 °F = 15 °F \text{ day.}$$

Example 3:

Calculate daily GDD for corn, given: T_{max} = 95 °F, *Tmin* = 76 °F, and T_b = 50 °F. Also, use an upper limit for T_{max} of 86 °F, which is common for corn.

$$GDD = T_{avg} - T_b = [(T_{max} + T_{min})/2] - T_b$$

Since there is an upper limit on T_{max} for corn, then T_{max} = 86 °F instead of 95 °F.

$$T_{avg} = [(86 °F + 76 °F)/2] = 81 °F$$

$$GDD_{Corn} = 81 °F - 50 °F = 31 °F \text{ day}$$

Example 4:

Calculate daily and total GDD for corn during a period of a week, given the following T_{max} and T_{min} air temperature values, T_b = 50 °F, and an upper limit for T_{max} of 86 °F.

The solution is given in Table 4, indicating that a total of 183 °F day were accumulated during the 7-day period.

Table 3. Daily maximum (T_{max}) and minimum (T_{min}) temperature measured during a 7-day period.

Measured Temperature	Days						
	1	2	3	4	5	6	7
T_{max} (°F)	91	86	82	88	91	75	75
T_{min} (°F)	70	70	72	70	72	70	66

GDD Calculator

An online Growing Degree Days Calculator for the southeast USA region is freely available at the AgroClimate website (http://agroclimate.org/tools/Growing-Degree-Days/). A screen shoot of the GDD calculator is shown in Fig. 2.

Table 4. Calculation of daily and cumulative GDD for corn during a 7-day period.

	Days						
	1	2	3	4	5	6	7
T_{max} (ºF)	91	86	82	88	91	75	75
T_{min} (ºF)	70	70	72	70	72	70	66
Upper T_{max} (ºF)	86	86	86	86	86	86	86
T_b (ºF)	50	50	50	50	50	50	50
New T_{max} (ºF) [a]	86	86	82	86	86	75	75
T_{avg} (ºF) [b]	78	78	77	78	79	73	71
New T_{avg} (ºF) [c]	78	78	77	78	79	73	71
Daily GDD (ºF day) [d]	**28**	**28**	**27**	**28**	**29**	**23**	**21**
Cumulative GDD (ºF day) [e]	**28**	**56**	**83**	**111**	**140**	**162**	**183**

[a] Set $T_{max} \leq 86$ ºF, [b] $T_{avg} = (T_{max} - T_{min})/2$,
[c] If $T_{avg} < T_b$, then $T_{avg} = T_b$, [d] GDD = New $T_{avg} - T_b$

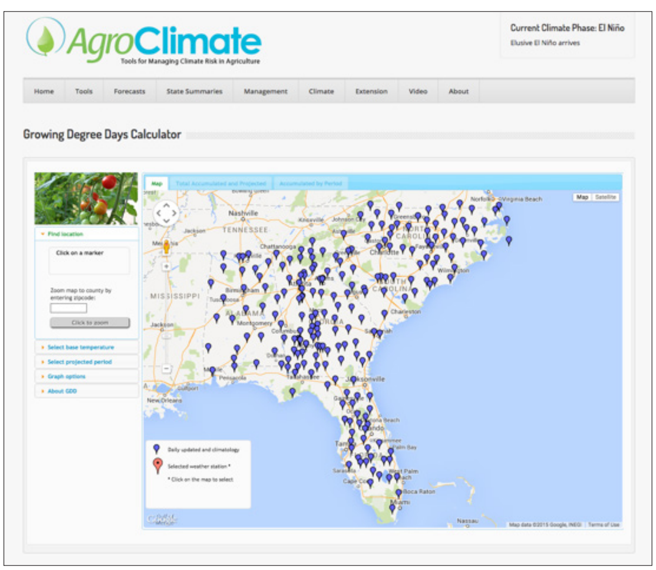

Figure 2. Screen shot of the Growing Degree Days Calculator.

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The mission of the Irrigation Water Management program at Clemson University is to develop advanced irrigation technologies and educate farmers on how to improve irrigation water management to increase farm profitability and environmental sustainability in South Carolina.

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