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MontGuide

Using Growing Degree Days to Predict Plant Stages

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It's tough to predict plant growth based on the calendar because temperatures can vary greatly from year to year. Instead, growing degree days, which are based on actual temperatures, are a simple and accurate way to predict when a certain plant stage will occur.

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This research on plant growth stage response to growing degree days was completed in the mid 1990s at two locations in semiarid Saskatchewan by Perry Miller and Stu Brandt, research scientists at that time with Agriculture and Agri-Food Canada. This has been by far the most popular Extension article in Perry Miller's career at MSU. This type of information is rarely collected in such a comprehensive manner and plant species growth rates are a highly conserved aspect, with only minor variation due to cultivar differences. Thus, this information is expected to be somewhat 'timeless'. In 2018, we initiated a 3-year follow-up study in Bozeman that will provide additional information on plant-specific growth rates.

PLANT DEVELOPMENT DEPENDS ON TEMPERATURE. Plants require a specific amount of heat to develop from one point in their lifecycle to another, such as from seeding to the four-leaf stage.

People often use a calendar to predict plant development for management decisions. However, calendar days can be misleading, especially for early crop growth stages. For example, a cool May can greatly delay a plant reaching the four-leaf stage, which affects optimal weed control tactics. Or two weeks of hotter-than-normal July weather can advance lentils from green pod to harvest-ready, meaning you should have had the combine in the field three days ago! Research has shown that measuring the heat accumulated over time provides a more accurate physiological estimate than counting calendar days.

The ability to predict a specific crop stage, relative to insect and weed cycles, permits better management. This is especially important when three or more crops are being grown on the same farm, each with a different management schedule for pesticide application, fertility management and harvest.

Degree day calculations

Though temperatures often average out from year to year over an entire growing season, there are usually cooler- or warmer-than-normal times during significant parts of the growing season. As the saying goes, "normal" weather is an average of extremes. Warmer-than-normal days advance the plant and insect growth rapidly, while cooler-than-normal days slow them.

"Growing degree days" (abbreviated GDD or DD) is a way of assigning a heat value to each day. The values are added together to give an estimate of the amount of seasonal growth your plants have achieved. Degree days are easy to calculate:

- Add each day's maximum and minimum temperatures throughout the growing season,
- divide that sum by two to get an average, and
- subtract the "temperature base" assigned to the plant you are monitoring. (Temperature base is the temperature below which plant development stops).

The resulting "thermal time" more consistently predicts when a certain plant stage will occur. When summed together, these thermal times are sometimes referred to as a "thermal calendar."

Figure 1 (page 2) illustrates the relationship between time, temperature and the accumulation of degree days. One degree day is one day when the average daily temperature is at least one degree above the lower developmental threshold (the temperature below which development stops). For example, if the low for the day was 33°F and the high was 67°F, then the day had an average temperature of 50°F. If a plant had a temperature base of 32°F, like wheat does, then that day counts as 18 DD on the Fahrenheit scale (67 + 33 / 2 - 32 = 18).

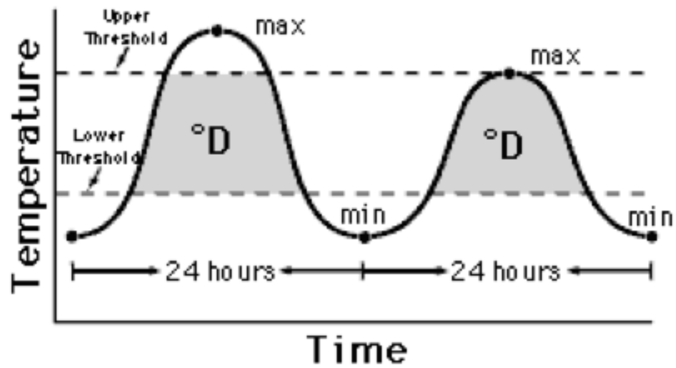

FIGURE 1. Thresholds and degree-days. Note: It takes nine Fahrenheit degree-days to make five Celsius degree-days. DD°C = 5/9 (DD°F) and DD°F = 9/5 (DD°C).

Table 1 (page 4) shows the growing degree days required to reach various plant stages for several crops. The range in reported GDD values encompasses 95 percent of the observations taken at two sites in Saskatchewan. Many locations in Montana offer a running tally of degree days, allowing accurate tracking of plant and insect development. The web site http://uspest.org/wea/ has a degree day report, and the report is also published in the Montana Crop Health Report available from the MSU Entomology Department for a small fee.

Accumulated degree days

Each developmental stage of an organism has its own total heat requirement. Development can be estimated by accumulating degree days between the high and low temperature thresholds throughout the season. The date to begin accumulating degree days, known as the biofix date, varies with the species. Biofix dates are usually based on specific biological events such as planting dates or first occurrence of a pest. Accumulation of degree days should be done regularly, especially when a control action decision is near.

Common questions and answers

What are degree days and what are they used for?

Degree days are commonly used in agriculture and natural resources management to predict events and schedule management activities, such as when to sample or control a pest.

What is a biofix?

A biofix is the date to start accumulating degree days for a particular plant. Examples are the first date a weed seedling is observed or the date tree buds start to break. Degree days are reset to zero at the biofix date, no matter how many were accumulated before that.

How do I interpret degree day calculations?

Degree days can take some of the calendar variations out of predicting events influenced by temperature. For example, compare a growth stage calculation using calendar days and degree days: The fifth-leaf stage of wheat occurs either at an average of 21 calendar days after germination or 350 degree days after germination. If you used calendar days, you would have a potential error of plus or minus nine calendar days. Using an estimate of 350 degree days, the potential error is two to three calendar days. The difference is important if you are trying to schedule weed control and a herbicide that is most effective after the fifth-leaf stage.

To fine tune weed control efforts, observe germination, then add up the degree days every day thereafter until 350 degree days accumulate, when you can expect the fifth-leaf stage to occur.

Where are degree day reports available and how do I use them?

Degree day reports are created using weather monitoring networks coordinated by the National Oceanic and Atmospheric Administration (NOAA). In Montana, the Great Falls National Weather Service produces a report every evening that supplies basic degree day information for many sites across Montana. See a summary of this report at http:// IPM.montana.edu. The report can factor in elevation, terrain and local effects to show degree day accumulations over a given time period, for a large or local area. Accurate management decisions are possible by monitoring these reports and applying them to growing conditions and management decisions.

Crop development

The stages and the duration of the stages through which a maturing organism passes are determined by climate, soil fertility, cultural practices and genetic make-up, to mention a few. Timing of many management practices like weed and insect control, applications of fertilizer or the decision to reseed in the event of winter kill or cutworm damage are usually determined by crop development stage. Several numbering systems or scales have been developed for naming and describing crop stages. As these scales became more widely used and degree day-based growth stage (phenology) models were developed, it was apparent that combining crop staging information could forecast management practices. In Table 1, growth stage calculations using 0°C and 32°F base temperatures are combined with the Universal Growth Staging Scale descriptive terms for crops grown in Montana.

Growth stage (phenology) models

Growth stage models predict the time of stages in an organism's development using developmental thresholds. Upper and lower developmental thresholds have been determined for some organisms through carefully controlled laboratory and field experiments. For example, the winter wheat lower developmental threshold, or base temperature, is 32°F and the upper developmental threshold is 130°F (winter wheat crop model of Karow et al. 1993).

The lower developmental threshold temperature or base temperature for an organism is the temperature below which development stops. The lower threshold is determined by the organism's physiology and is independent of the method used to calculate degree days. Base thresholds vary with different organisms, but for cool season crops grown in Montana, 0°C (32°F) is often the best base temperature for predicting development. The upper developmental threshold is the temperature above which the rate of growth or development begins to decrease or stop. Determining a consistent upper threshold is difficult. Often, they are unavailable for use in phenology models, and may occur at higher temperatures than typically seen in Montana. Growth models start accumulation of degree days at a starting point, usually the base temperature. These models do not indicate whether control is warranted, but rather when a pest will reach susceptible life stages. If pests are abundant, such models help eliminate the guesswork when choosing a time for a control action.

Note: Phenology models, especially in Montana, are affected by available moisture. For example, there must be sufficient seedbed moisture to begin the germination process. If sufficient moisture does not exist at seeding, a model starts accumulating degree days coinciding with the first significant precipitation after seeding.

There is some evidence that when seedbed moisture is less than optimal, emergence is delayed but will occur in the absence of significant rainfall. This likely occurs because the seed requires more time to take up sufficient moisture to begin the germination process.

Many crops also increase the rate of growth in response to drought stress. The most probable reason is that when moisture is limited, temperatures in the crop canopy rise more than they would normally, because water transpired by the crop is reduced. This increased temperature is not reflected in standard temperature measurements made above a crop canopy.

Using and validating growth models

Most growth model information comes from published literature that have been assembled and put in a standard format. To be most confident in a particular model, it should be field-tested in your locality or a similar one.

The key to using a phenology model is to compare the models' predicted degree day accumulation to the actual degree days using a local sampling method such as simple observation for weeds or, in the case of insects, a pheromone trap. By observing and recording the same events and comparing your records with model predictions over several years, you can fine-tune the model for your management area. In other words, informal validation of a model simply involves testing it in your region and observing how it works.

Formal validation of a model is usually done by scientists and involves:

1. obtaining weather data from a given site (and preferably several other sites, some of which have unique climates or other variables);
2. sampling for the particular arthropod, nematode or plant species, preferably at several stages of its development;
3. combining the weather and sampling data from a minimum of three years in conjunction with statistical computer programs to compute the degree days and start dates (or biofixes).

Why determine and forecast crop stages using phenology models and the Universal Growth Staging Scale?

Probably the most effective use of phenology models is in timing of crop scouting or field checks. Having a reasonable estimate of crop stage without actually visiting the field could save considerable time and expense. In many cases, field visits can be planned several days in advance of the time when a field operation is required.

Examples are:

– accurate prediction of crop stages can determine the growth progress of cereal crops in relation to temperature and moisture;
– predicts and defines the time when herbicides or insecticides can be applied for optimum activity, efficacy and control;
– predicts and indicates the time when rust, root rot and other diseases develop. Effective corrective measures can sometimes be taken at certain growth stages;
– permits accurate comparisons of crop development in different years at widely separated locations;

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TABLE 1. Phenology calculations using 0°C and 32 °F base temperatures are combined with the Universal Growth Staging Scale descriptive terms for crops grown in Montana.

BARLEY	**Data source: Perry Miller, Swift Current, SK 1996-98**	**Stage**	**GDD°C**	**GDD°F**
Emergence	Leaf tip just emerging from above-ground coleoptyle.	1.0	109-145	228-293
Leaf development	Two leaves unfolded	1.2	145-184	293-363
Tillering	First tiller visible (tillering of cereals may occur as early as stage 1.3, in this case continue with 2.1)	2.1	308-360	586-680
Stem elongation	First node detectable	3.1	489-555	912-1031
Anthesis	Flowering commences; first anthers of cereals are visible	6.1	738-936	1360-1716
Seed fill	Seed fill begins. Caryopsis of cereals watery ripe (first grains have reached half of their final size).	7.1	927-1145	1700-2093
Dough stage	Soft dough stage, grain contents soft but dry, fingernail impression does not hold.	8.5	1193-1438	2179-2620
Maturity complete	Grain is fully mature and drydown begins. Ready for harvest when dry.	8.9	1269-1522	2316-2771

WHEAT (Hard Red)	**Data source: Stu Brandt, Scott, SK 1993-97 and Perry Miller, Swift Current, SK 1995-98**	**Stage**	**GDD°C**	**GDD°F**
Emergence	Leaf tip just emerging from above-ground coleoptyle	1.0	125-160	257-320
Leaf development	Two leaves unfolded	1.1	169-208	336-406
Tillering	First tiller visible (tillering of cereals may occur as early as stage 1.3, in this case continue with 2.1)	2.1	369-421	696-789
Stem elongation	First node detectable	3.1	592-659	1097-1218
Anthesis	Flowering commences; first anthers of cereals are visible	6.1	807-901	1484-1653
Seed fill	Seed fill begins. Caryopsis of cereals watery ripe (first grains have reached half of their final size).	7.1	1068-1174	1954-2145
Dough stage	Soft dough stage, grain contents soft but dry, fingernail impression does not hold.	8.5	1434-1556	2613-2832
Maturity complete	Grain is fully mature and drydown begins. Ready for harvest when dry.	8.9	1538-1665	2800-3029

OAT	**Data source: Stu Brandt, Scott, SK 1993-97**	**Stage**	**GDD°C**	**GDD°F**
Anthesis	Flowering commences; first anthers are visible	6.1	760-947	1400-1736
Seed fill	Seed fill begins. Caryopsis of cereals watery ripe (first grains have reached half of their final size).	7.1	1019-1229	1866-2244
Dough stage	Soft dough stage, grain contents soft but dry, fingernail impression does not hold.	8.5	380-1625	2516-2957
Maturity complete	Grain is fully mature and drydown begins. Ready for harvest when dry.	8.9	1483-1738	2701-3160

CANARY SEED	**Data source. Perry Miller, Swift Current, SK 1995-9**	**Stage**	**GDD°C**	**GDD°F**
Leaf development	First two leaves unfolded	1.2	202-259	395-498
Tillering	First tiller visible (tillering of cereals may occur as early as stage 1.3, in this case continue with 2.1)	2.1	378-452	712-845
Stem elongation	First node detectable	3.1	574-667	1065-1232
Anthesis	Flowering commences; first anthers are visible	6.1	771-920	1419-1688
Seed fill	Seed fill begins. Caryopsis of cereals watery ripe (first grains have reached half of their final size).	7.1	975-1140	1787-2084
Dough stage	Soft dough stage, grain contents soft but dry, fingernail impression does not hold.	8.5	1261-1447	2301-3636
Maturity complete	Grain is fully mature and drydown begins. Ready for harvest when dry.	8.9	1342-1535	2447-2795

FLAX	**Data source. Stu Brandt, Scott, SK, 1993-97. Perry Miller, Swift Current, SK 1997-98.**	**Stage**	**GDD°C**	**GDD°F**
Emergence	Cotyledons completely unfolded.	1.0	104-154	219-309
Leaf stages	First pair of true leaves unfolded.	1.2	150-208	302-406
	Four true leaves unfolded.	1.4	197-262	386-503
	Six true leaves unfolded.	1.6	243-315	469-599
Flowering	Flowering begins. First flowers open on at least 50% of plants. Stage flax early in morning before flower petals fall off.	6.0	582-706	1079-1302
	Flowering 50% complete.	6.5	758-895	1396-1643
Seed fill	Seed fill begins. 10% of seeds have reached final size.	7.1	969-1121	1776-2049
Maturity	Seed begins to mature. 10% of seed has changed color.	8.1	1321-1499	2409-2730
Maturity complete	90% seed color change. Seeds brown and rattle in capsules. Ready for swathing or wait until drydown complete for direct harvesting.	8.9	1603-1801	2917-3273

CANOLA (*B. napus*)	**Data source: Stu Brandt, Scott, SK 1993-97 and Perry Miller, Swift Current, SK 1995-98**	**Stage**	**GDD°C**	**GDD°F**
Emergence	Cotyledons completely unfolded.	1.0	152-186	305-366
Leaf Stages	Two leaves unfolded.	1.2	282-324	539-615
	Four leaves unfolded.	1.4	411-463	771-865
Flowering	Flowering begins. At least one open floret on 50% or more plants.	6.0	582-666	1079-1230
	Flowering 50% complete.	6.5	759-852	1398-1565
Seed fill	Seed fill begins. 10% of seeds have reached final size.	7.1	972-1074	1781-1965
Maturity	Seed begins to mature. 10% of seed has changed color.	8.1	1326-1445	2418-2633
Swathing	40% of seed on main stem has changed color. Swathing recommended at this stage.	8.4	1432-1557	2609-2834

CANOLA (*B. rapa*)	**Data source: Stu Brandt, Scott, SK 1993-97 and Perry Miller, Swift Current, SK 1995-98**	**Stage**	**GDD°C**	**GDD°F**
Emergence	Cotyledons completely unfolded.	1.0	102-143	215-289
Leaf Stages	Two leaves unfolded.	1.2	201-254	393-489
	Four leaves unfolded.	1.4	300-365	572-689
Flowering	Flowering begins. At least one open floret on 50% or more plants.	6.0	467-554	872-1029
	Flowering 50% complete.	6.5	630-726	1166-1338
Seed fill	Seed fill begins. 10% of seeds have reached final size.	7.1	826-934	1518-1713
Maturity	Seed begins to mature. 10% of seed has changed color.	8.1	1152-1279	2105-2334
Swathing	40% of seed on main stem has changed color. Swathing recommended at this stage.	8.4	1249-1382	2280-2519

MUSTARD (*B. juncea*)	**Data source: Stu Brandt, Scott, SK 1993-97 and Perry Miller, Swift Current, SK 1995-98**	Stage	GDD°C	GDD°F
Emergence	Cotyledons completely unfolded.	1.0	108-136	226-276
Leaf Stages	Two leaves unfolded.	1.2	214-251	417-483
	Four leaves unfolded.	1.4	320-365	608-689
Flowering	Flowering begins. At least one open floret on 50% or more plants.	6.0	506-567	942-1052
	Flowering 50% complete.	6.5	679-747	1254-1376
Seed fill	Seed fill begins. 10% of seeds have reached final size.	7.1	886-962	1626-1763
Maturity	Seed begins to mature. 10% of seed has changed color.	8.1	1232-1322	2249-2411
Swathing	70% of seed on main stem has changed color. Swathing sometimes recommended at this stage.	8.7	1440-1538	2624-2800
Maturity complete	90% of seed changed color. Await completion of drydown if direct harvesting.	8.9	1509-1610	2748-2930

MUSTARD (*S. alba*)	**Data source: Stu Brandt, Scott, SK 1994-97 and Perry Miller, Swift Current, SK 1995-98**	Stage	GDD°C	GDD°F
Emergence	Cotyledons completely unfolded.	1.0	110-136	230-276
Leaf Stages	Two leaves unfolded.	1.2	209-243	408-469
	Four leaves unfolded.	1.4	308-349	586-660
Flowering	Flowering begins. At least one open floret on 50% or more plants.	6.0	468-529	874-984
	Flowering 50% complete.	6.5	650-718	1202-1324
Seed fill	Seed fill begins. 10% of seeds have reached final size.	7.1	868-945	1594-1733
Maturity	Seed begins to mature. 10% of seed has changed color.	8.1	1231-1322	2247-2411
Maturity complete	90% of seed changed color. Await completion of drydown for direct harvesting.	8.9	1521-1625	2769-2957

CHICK PEA Desi	**Data source: Stu Brandt, Scott, SK 1995-97 and Perry Miller, Swift Current, SK 1995-98**	Stage	GDD°C	GDD°F
Leaf Stages	Two leaves unfolded.	1.2	179-243	354-469
	Four leaves unfolded.	1.4	262-337	503-638
	Six leaves unfolded.	1.6	346-431	654-807
	Eight leaves unfolded.	1.8	429-525	804-977
Flowering	Flowering begins. At least one open floret on 50% or more plants.	6.0	645-724	1193-1335
	Flowering 50% complete.	6.5	823-910	1513-1670
Seed fill	Seed fill begins. 10% of seeds have reached final size.	7.1	1037-1133	1898-2071
Maturity	Seed begins to mature. 10% of seed has changed color.	8.1	1394-1505	2541-2741
Maturity complete	90% of seed changed color. Await completion of drydown for direct harvesting.	8.9	1679-1803	3054-3277

LENTIL	Data source: Stu Brandt, Scott, SK 1993-97 and Perry Miller, Swift Current, SK 1995-98	Stage	GDD°C	GDD°F
Leaf Stages	Two leaves unfolded.	1.2	161-192	321-377
	Four leaves unfolded.	1.4	248-285	478-545
	Six leaves unfolded.	1.6	335-378	635-712
	Eight leaves unfolded.	1.8	423-471	793-879
Flowering	Flowering begins. At least one open floret on 50% or more plants.	6.0	762-853	1403-1567
	Flowering 50% complete.	6.5	931-1030	1707-1886
Seed fill	Seed fill begins. 10% of seeds have reached final size.	7.1	1133-1241	2071-2265
Maturity	Seed begins to mature. 10% of seed has changed color.	8.1	1470-1594	2678-2901
Swathing	70% of seed changed color. Recommended stage for swathing.	8.7	1673-1806	3043-3282
Maturity complete	90% of seed changed color. Await completion of drydown for direct harvesting.	8.9	1740-1876	3164-3408

PEA	Data source: Stu Brandt, Scott, SK 1993-97 and Perry Miller, Swift Current, SK 1995-98	Stage	GDD°C	GDD°F
Leaf Stages	Two leaves unfolded.	1.2	198-230	388-446
	Four leaves unfolded.	1.4	301-340	573-644
	Six leaves unfolded.	1.6	404-449	759-840
	Eight leaves unfolded.	1.8	507-558	944-1036
Flowering	Flowering begins. At least one open floret on 50% or more plants.	6.0	724-835	1335-1535
	Flowering 50% complete.	6.5	862-982	1583-1799
Seed fill	Seed fill begins. 10% of seeds have reached final size.	7.1	1028-1158	1882-2116
Maturity	Seed begins to mature. 10% of seed has changed color.	8.1	1305-1451	2381-2643
Maturity complete	90% of seed changed color. Await completion of drydown for direct harvesting.	8.9	1527-1686	2780-3066

SUNFLOWER (depends on maturity class).	Data source: Perry Miller, Swift Current, SK 1995-98 and Stu Brandt, Scott, SK 1995 and (Early maturing,	Stage	GDD°C	GDD°F
Emergence	Cotyledons completely unfolded.	1.0	138-191	280-375
Leaf Stages	Two leaves unfolded.	1.2	249-313	480-595
	Four leaves unfolded.	1.4	359-435	678-815
	Six leaves unfolded.	1.6	470-558	878-1036
Flowering	Flowering begins. At least one open disc floret on 50% or more plants.	6.0	935-1077	1715-1970
	Flowering 50% complete.	6.5	1081-1232	1977-2249
Seed fill	Seed fill begins. 10% of seeds have reached final size.	7.1	1255-1417	2291-2582
Maturity	Seed begins to mature. 10% of seed has changed color.	8.1	1547-1725	2816-3185
Maturity complete	90% of seed changed color. Await completion of drydown for direct harvesting.	8.9	1780-1972	3236-3581

– predicts and determines when nutrient and irrigation scheduling can correspond to crop deficiencies. Fertilizers can be added during early growth stages to correct deficiencies and increase yields;
– predicts and identifies the location of embryonic heads so assessment of potential damage to crop by grazing, hail or chemical application is possible.

How to predict a crop stage using degree days

STEP 1. Monitor for suitable soil temperature and seed into sufficient moisture to allow germination.

STEP 2. Record the seeding date and coinciding degree day value (beginning accumulation) by running the degree day accumulation report at http://uspest.org/wea/ using the correct base temperature for the crop in question.

STEP 3. When the difference between the beginning accumulation value (which may be zero) and the current accumulated value approaches the Table 1 values, watch for that corresponding crop stage to occur in the field. The descriptive terms included in Table 1 should help.

Note: Under drought stress, GDD requirements will be toward the low end of the reported range for each stage, and wet environments delay crop advancement toward the high range values reported for each stage.

STEP 4. Validate the Table 1 values for your area by recording when the crop stage actually occurs in the field (see Validate Crop Stage below). The difference between the accumulation report value for the day you determine a stage and the Table 1 values is the local correction value. Over time, making this adjustment to the table values will increase the accuracy of degree day forecasting.

Validate crop stage

To validate that the stage predicted is occurring in your crop, walk an "M" or zig zag pattern to select a plant from 10 locations in the field. Drop to one knee and immediately place your index finger on the ground. Carefully remove the plant nearest your finger. Refer to the descriptive terms listed in the table to decide if the stage you are predicting has occurred or is about to occur.

STEP 5. Repeat this process for other crop stages and pests, like wild oats.

Sources

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Lancashire, P.D., H. Bleiholder, T. van den Boom, P. Langeluddeke, R. Stauss, E. Weber and A. Witzenberger. 1991. *A uniform decimal code for growth stages of crops and weeds.* Ann. Appl. Biol. 119:561-601.

The Montana Small Grain Guide, Cooperative Extension Service Agricultural Experiment Station, Montana State University, Bozeman Bulletin 364, August 1985.

Consult Baskerville & Emin (1969), Andrewartha & Birch (1973), Allen (1976), Zalom et al. (1983), and Wilson & Barnett (1983) if you are interested in the historical development of the degree-day concept.

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