Field Guide to Measurements

Growing Degree Days (GDD) and Crop Growth Stages: The Link Between Temperature and Phenological Models

ARABLE

GROWING DEGREE DAYS AND CROP GROWTH STAGES

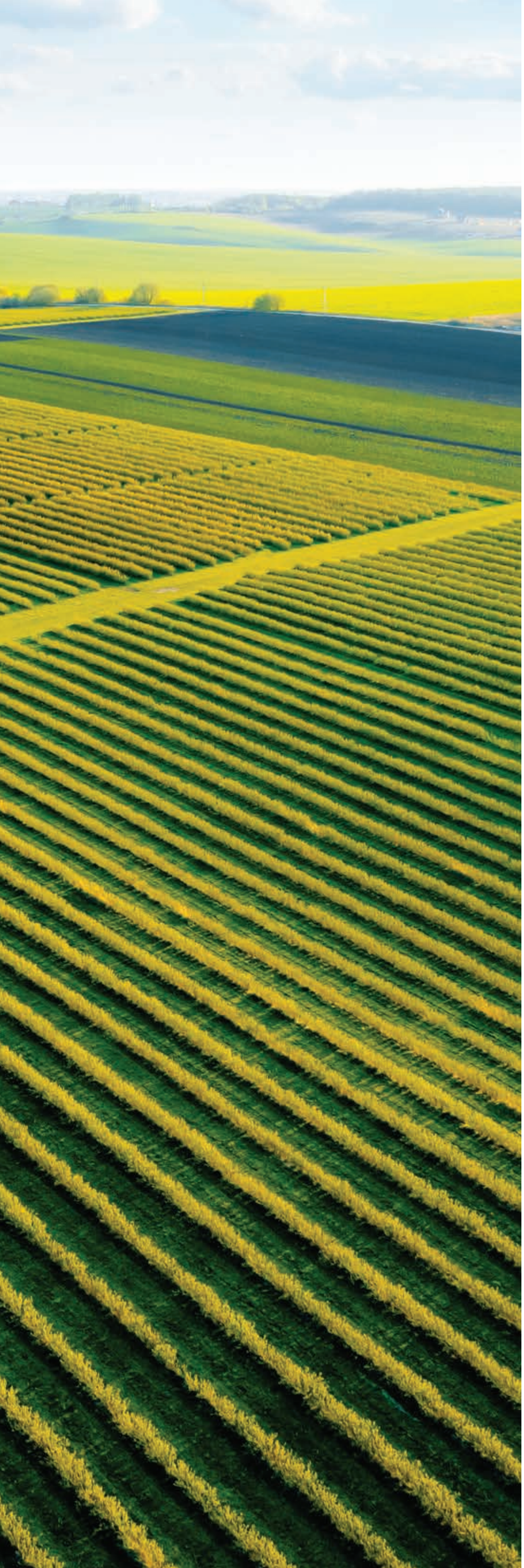
TABLE OF CONTENTS

APPLICATIONS:

Crop growth monitoring, crop protection applications, disease risk assessment, nutrient scheduling, harvest prediction, variety comparisons and breeding, field site evaluations and comparisons, plant stress monitoring

OTHER RELATED ARABLE MEASUREMENTS:

Air temperature (T)
Normalized Difference Vegetation Index (NDVI)
Chlorophyll Index (CI)
Solar Radiation (SR)
Sunshine Duration
Evapotranspiration (ET)



What are growing degree days?

The rate of crop growth depends on the metabolic responses to temperature. Generally, higher temperatures correspond to higher development until some maximum temperature is reached, at which point the metabolism shuts down. **Growing degree days (GDD)**, also called degree days or heat units, are a measurement of heat accumulation that track plant development through all stages of its growing season. GDD are related to a plant's physiological time in estimating the accumulated heat energy available to the plant over time.

Once a crop starts developing, or after winter in the case of specialty crops, the accumulation of GDD provides a clear indication of the stages the plant has reached (i.e. blooming, fruit development, harvest, senescence). The metabolic and physiological responses to temperatures differ between crops and cultivars, but the form generally applies to all species' phenology.

Why do we measure them?

As temperature is a significant determinant of metabolic rate[1], GDD are an accurate predictor of plant growth stage in healthy cropping systems[2]. Higher temperatures speed up plants' metabolic rate in some processes, accelerating the production of the organic carbons, energy, and bulk they need to grow, causing them to mature more quickly. Since temperatures and climate conditions change from season to season, it is essential to know how rapidly a crop proceeds through its growth stages to anticipate the field needs.

[1] The metabolic rate is the amount of exogenous energy consumed per unit mass per unit time. Simply put, it is the amount of energy an organism needs to grow and stay alive. In plants, the source of this energy is the sun.

[2] Healthy cropping systems are those with sufficient water, nutrients, light, and space that are undamaged by pests. Unhealthy cropping systems will have symptoms that obscure the detection of normal plant growth signals.

How can you use GDD in your farming practice?

GDD are a scheduling tool used across the agricultural spectrum. Every time-sensitive crop intervention—pesticide and fertilizer applications, irrigation, harvest—has to be done at a specific plant growth stage to be most effective. Researchers have correlated crop growth stages to growing degree days for most species. Once the number of GDD corresponding to the growth stage of interest is known, activities can be planned accordingly.

GDD can also be a straightforward way to compare fields and growing seasons. The microclimate differences between fields (and even within fields) can strongly impact the growth rate. For example, monitoring the accumulating growing degree days across fields gives insight into the fields that are ready for harvest.

Other reasons to measure growing degree days include:

- **Predicting plant growth and development:** By measuring GDD, growers can predict when key developmental stages such as emergence, flowering, and maturity will occur. This information can help them schedule management practices such as planting, irrigation, and fertilizer applications at the optimal time.

- **Comparing plant growth between locations:** GDD can be used to compare the growth of plants in different locations. This information can be used to evaluate which locations are most suitable for a particular crop and identify factors limiting plant growth.

- **Assessing the impact of weather conditions:** GDD can be used to assess the impact of weather conditions on plant growth and development. For example, if GDD accumulation is lower than expected, it may indicate that the weather is too cool for optimal plant growth.

- **Estimating crop yield:** By tracking GDD, growers can estimate the potential yield of a crop. This information can help decide crop harvesting, storage, processing, and marketing.

- **Improving crop management practices:** By tracking GDD over time, growers can identify plant growth and development trends and adjust their management practices accordingly. For example, they may adjust irrigation or fertilizer applications based on the accumulated GDD and the developmental stage of the crop.

WHY IS THE CORN SEASON 2-3 MONTHS LONGER IN IOWA THAN CALIFORNIA?

A plant's developmental stage is determined by physiological time, not chronological time. Physiological time is a function of temperature. This means that growing degree days determine how many calendar days it will take for a crop to go from seed to harvest. So in California's Sacramento Valley, where there is near-constant solar radiation, the growing season for the same varieties will be much shorter than in places such as Iowa that have lower solar radiation.

How are GDD measured?

Arable calculates crop-specific GDD using the **maximum temperature (Tmax)**, and the **minimum temperature (Tmin)**, where Tmax and Tmin are biological thresholds set for each crop and variety. Arable averages temperatures every hour and outputs the Tmin and Tmax for the corresponding hour. By subtracting Tmin from the average daily temperature, GDD capture only the heat which increases plant development.

$$\text{GDD} = \frac{\text{Tmax} + \text{Tmin}}{2} - \text{Tmin}$$

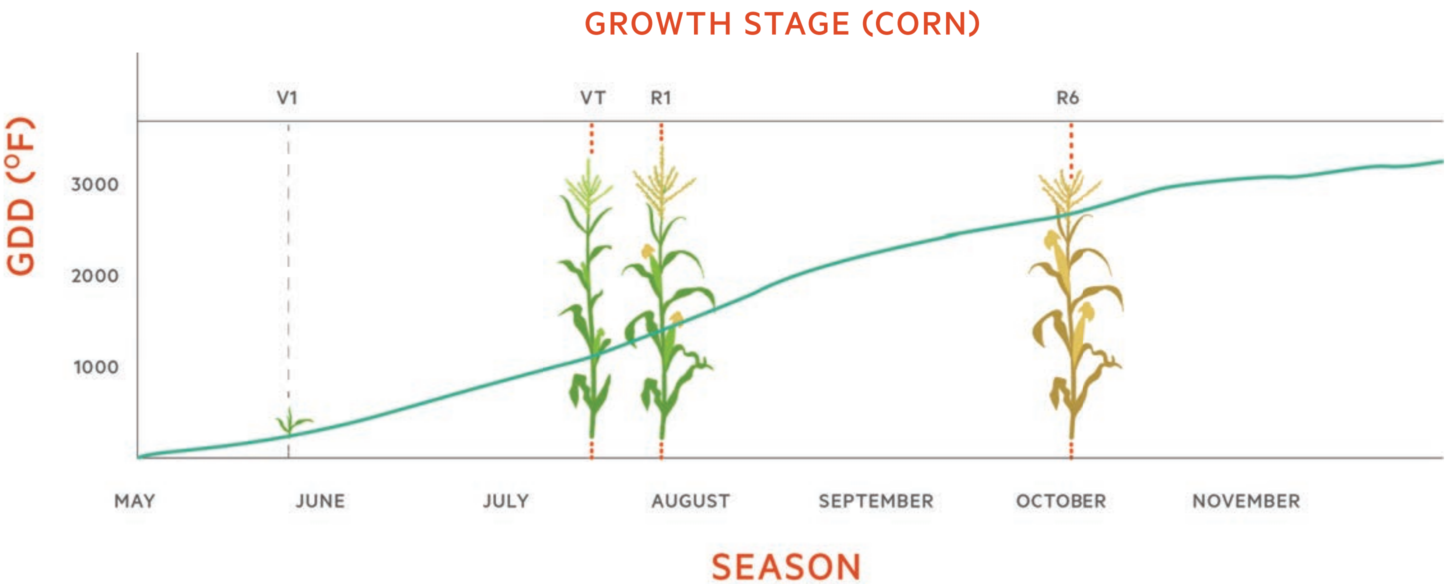
If the average daily temperature is less than the base temperature, then the GDD = 0.

The sum of all the daily GDD values, as defined by units of degrees in Celcius or Fahrenheit, results in the cumulative GDD. For the most accurate results, the Arable Mark should be set up and deployed the morning the fields are planted to capture the entire season's daily temperatures.

Arable keeps a running list of crops and cultivars—as well as the phenological models observed and modeled by researchers worldwide—for use in its web and mobile apps. The calculated GDD for each crop can then be applied to its known phenological stage. Additional crops and varietals can be added to the list by contacting Arable's Customer Success team at support@arable.com.

What does the data look like in Arable's system?

After creating a season and selecting a crop in Arable Web, the crop's current growth stage based on the accumulation of growing degree days is displayed.

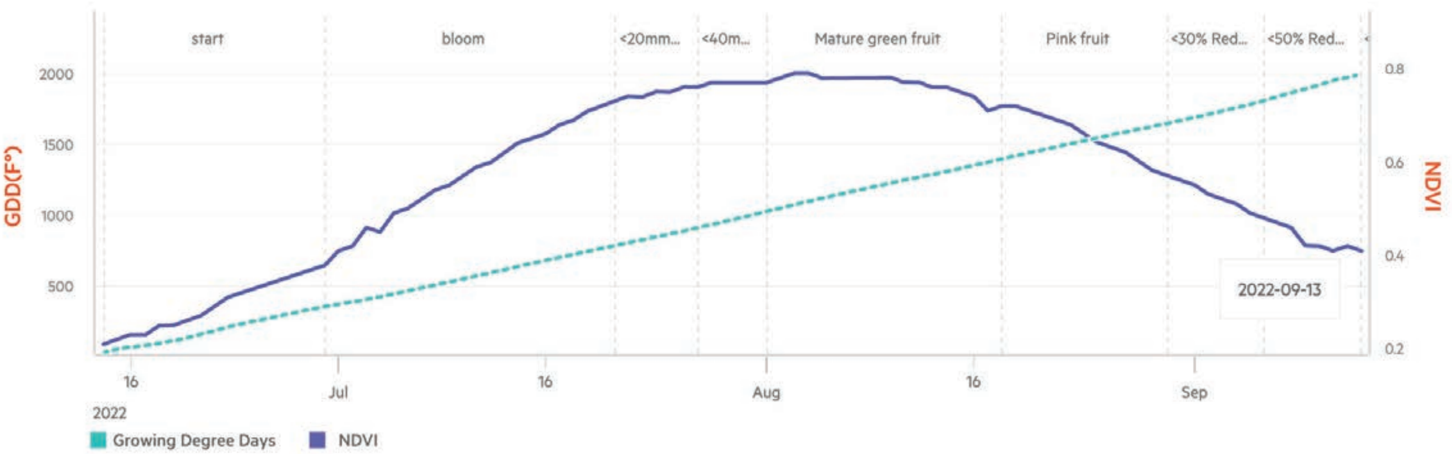


Season view of the accumulated growing degree days and growth stages in corn for illustration purposes.

Example use case

Changing management strategies based on GDD can also influence the quality of the crop yield. For example, regulated deficit irrigation (RDI) has been shown to increase the soluble solids content (also known as Brix) of several crops, including tomatoes and grapes. When a plant is in a water deficit at the correct growth stage, the storage of carbohydrates in the fruit will increase. An increase in soluble solids can increase the sweetness or improve the texture of the fruit, thus increasing the fruit's value.

Arable has shown that the normalized difference vegetation index (NDVI), which measures the percentage of green canopy cover, is strongly correlated to cumulative GDD. By actively monitoring NDVI and GDD, irrigation can be reduced at precisely the correct time to increase the soluble solids content.



Cumulative GDD from processing tomatoes in the Sacramento Valley. RDI begins at the onset of the pink stage in mid-August. See Arable's [Deficit Irrigation in Processing Tomatoes] for a complete guide on using GDD to determine target RDI.

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