The U2U Corn Growing Degree Day tool: Tracking corn growth across the US Corn Belt

James R. Angel, Melissa Widhalmb, Dennis Todeyc, Ray Masseyd, Larry Biehlb

Abstract

The Corn Growing Degree Day (Corn GDD) tool is a web-based product that can provide decision support on a variety of issues throughout the entire growing season by integrating current conditions, historical climate data, and projections of Corn GDD through the end of the growing season based on both National Weather Service computer model forecasts and climatology. The Corn GDD tool can help agricultural producers make a variety of important decisions before and during the growing season. This support can include: assessing the risk of early and late frosts and freezes that can cause crop damage; comparing corn hybrid maturity requirements and Corn GDD projections to select seed varieties and plan activities such as spraying; guiding marketing decisions based on historical and projected Corn GDDs when considering forward crop pricing (i.e., futures market). The Corn GDD tool provides decision support for corn producers in the central U.S. corn-producing states.

Introduction

The Useful to Usable (U2U) project was funded by the USDA to improve farm resilience and profitability in the North Central U.S. by transforming existing climate data into usable products for the agricultural community. The goal is to help producers to make better long-term plans for what, when, and where to plant, and how to manage crops for maximum yields and minimum environmental impacts.

Climate variability and change are major challenges for corn producers in the central United States. The U.S. National Climate Assessment (NCA) chapter on agriculture (Hatfield et al., 2014) stated that “climate disruptions in agriculture production have increased in the past 40 years and are projected to increase over the next 25 years. By mid-century and beyond, these impacts will be increasingly negative on most crops …” Walthall et al. (2012) explores these issues in great detail. Among their key findings are that the direct effect of changes in temperature and precipitation as well as the occurrence of extreme events require a climate-ready US agriculture to adapt to these changes. The expected adaptation strategies include adjusting fertilizer, planting, and harvesting strategies. These adjustments will require the use of adaptive and robust decision support strategies.

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Among those climate disruptions are wet springs that lead to planting delays, late spring and early fall frosts that can damage crops, and summer temperatures that are either too warm or too cool. A challenge in recent years has been exceptionally wet springs. For example, in Illinois planting season (April–June) precipitation has been 8.3 to 19.6 cm above average in seven out of eight years. Other Corn Belt states have experienced similar conditions. These wet springs have led to significant planting delays. Producers have been forced to re-assess their planting strategies on short notice, such as switching to a faster-growing but lower-yielding hybrids without a tool to assess the risk of the crop not reaching maturity in the fall. With this pattern of wetter springs projected to continue or worsen in the central United States (Pryor et al., 2014), the problem will remain and likely get worse.

These challenging conditions require the use of adaptive and robust decision support strategies. This requires producers to better use already available climate information in decision support tools. However, research has shown that climate information has been underutilized throughout the agricultural sector (Mase and Prokopy, 2014), leaving opportunities for developing new tools to address these issues.

One of the outcomes of the U2U project was a web-based Corn Growing Degree Day (Corn GDD) tool. While there are available on-line tools that provide year to date Corn GDDs, this tool does more. It tracks current conditions, provides a 30-year historical perspective, and offers trend projections through the end of the calendar year based on both National Weather Service forecasts for the next 30 days and climatology. Furthermore, this innovative tool integrates corn development data with critical weather parameters to help agricultural producers make a variety of important decisions before and during the growing season. This support can include: assessing the climate risk from the likelihood of early and late frosts and freezes causing damage to the crop; comparing corn hybrid maturity requirements with Corn GDD projects to select seed varieties and plan later activities such as spraying; comparing conditions with individual years (e.g., 2012); guiding marketing decisions based on historical and projected Corn GDDs when considering forward pricing (i.e., futures market).

This paper will discuss the data behind the Corn GDD tool, the important aspects of the tool itself, as well as provide examples of how the tool can be used to support on-farm decision making.

Methods

Corn GDDs have been widely used since they were first proposed by Gilmore and Rogers (1958) to track crop progress. Several land-grant universities have released Extension publications that have related the accumulation of Corn GDDs with the stages of corn development. These relationships were based on empirical field studies and span the Corn Belt (e.g., Abendroth et al., 2011; Neild and Newman, 1990). Corn GDD are calculated daily using the standard formula of:

\[
\text{Corn GDD} = \frac{(T_{\text{max}} + T_{\text{min}})}{2} - T_{\text{base}}
\]

where \(T_{\text{max}}\) is the daily maximum temperature and is reset to 86 °F (30 °C) if the high temperature exceeds 86 °F (30 °C), \(T_{\text{min}}\) is the daily minimum temperature and is reset to 50 °F (10 °C) if the minimum temperature drops below 50 °F (10 °C), and \(T_{\text{base}}\) is the base temperature for corn (50 °F or 10 °C). This approach allows for Corn GDDs to be accumulated when the temperature conditions are optimal for corn development (above 50 °F (10 °C) but below 86 °F (30 °C)). Because this is an operational tool used in the U.S., the temperature and GDD units in the examples used in this paper are based on degrees Fahrenheit.

The Corn GDD tool uses daily gridded minimum and maximum temperature data from 1981 to present using the Applied Climate Information System (ACIS), a quality controlled database maintained by the National Oceanic and Atmospheric Administration (NOAA) Regional Climate Centers. The gridded dataset is built upon daily observations from 1981 to present that come from the Cooperative Observer Network of the National Weather Service. Gridded data were used instead of station data to avoid the issue of missing data that would lead to an under-accumulation of growing degree days and to allow more complete spatial coverage. The grid spacing is approximately 4-km resolution.

Accumulated Corn GDD GeoTIFF files were created for each year from 1981 thru the last calendar year. GeoTIFF files were also created for the average and median accumulated Corn GDDs for the 30-year period from 1981–2010. GeoTIFF is a public domain metadata standard for creating and sharing georeferenced raster images.

A script is used to download year-to-date growing degree data. The script is run just after midnight each day to keep the current year Corn GDDs up to date. All of the data for the year is downloaded each time the script is run. This will allow for incorporation of any updates in prior data in the year to be taken into account. More details on the cyber infrastructure for this project can be found in Biehl et al. (this issue).

The Corn GDD Projection starts from the current day and goes through the end of the current year. The first 30 days of the Corn GDD Projection are based on the operational NWS Climate Forecast System version 2 (CFSv2) 20-member ensemble forecast. The 20-member ensemble is generated from the four daily model runs at 00, 06, 12, and 18 UTC over the past five days. More details on this model are found in Suranjana et al. (2014). The remaining projection through the end of the year is based on the 30-year (1981–2010) average rate of Corn GDD accumulations (climatology).

The estimate of corn growth stage is based on ISU publication PMR 1009 entitled Corn Growth and Development (Abendroth et al., 2011). It states that leaf appearance can be predicted from emergence (VE) to final leaf (Vn) based on GDD accumulation. From VE to V10, a new collared leaf appears approximately every 84 GDD accumulated. Regardless of corn variety planted, leaf appearance is estimated to occur every 84 GDD. The Corn GDD product assumes crop emergence
after 105 GDD, although the scientific literature states emergence can occur after 90–200 accumulated GDD depending on factors such as ground cover and tillage practices.

Two very important milestones in corn plant development are silking and black layer. The silk emerges from the ear shoot and is the functional stigmas of the female flowers of the corn plant. Each one is connected to one potential kernel in the ear of corn. The silk must be pollinated for an actual kernel (or seed) to develop (Abendroth et al., 2011). This process is extremely vulnerable to severe drought and/or high temperatures over 95 °F (35 °C). At the end of the grain filling period, when the kernel has reached maximum weight, a black layer forms at the base of the kernel and signals the physiological maturity of the kernel. At this stage, called R6, the kernel requires no more moisture or nutrient input from the plant. Kernel moisture is relatively high at this stage and additional drying usually takes place before harvest.

Most corn seed bags are labeled with a Comparative Relative Maturity rating (CRM), usually reported in calendar days such as 100-day corn. Increasingly seed companies are also including growing degree days to silking and to physiological maturity, or black layer. The relative maturity rating is related to growing degree units to silking and black layer. We obtained maturity rating, GDD to silking and GDD to black layer data from 557 Pioneer (2013), 65 Golden Harvest (2013) and 69 Northrup King (2013) corn hybrids. Simple linear regression yielded the following: Silking GDD = 192.8 + 10.66 CRM with $R^2 = 0.88$ and Black Layer GDD = 129.1 + 22.8 CRM with $R^2 = 0.94$. These linear equations are used in the Corn GDD tool to estimate Silking GDDs and Black Layer GDDs.

The probability of last spring freeze shows the number of time the last freeze occurred after the selected planting date from 1981 to last year. For example, if the last spring occurred after the start date 16 times in the last 33 years, the probability would be 16/33 or 48 percent. The probability of the first fall frost shows the likelihood of the first freeze occurring before black layer is achieved. Based on recommendations from Purdue University statisticians. We use the following formula:

$$P(\text{First freeze day } < \text{ Black Layer}) = \text{sum of } P(\text{First freezing day } = t) \times P(\text{Black Layer } > t)$$

where P is probability and t is the date.
Results

Users begin by selecting the location of interest by clicking on the map, or by entering a location name or zip code. Fig. 1 shows the base map that includes the original 12 states in the study area (North and South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, and Ohio) plus Kentucky and Tennessee where corn is a significant crop.

Once a location is selected, a GDD graph is generated for the user in a matter of a few seconds. The key features of the graph are shown in Figs. 2 and 3.

Fig. 2 shows the key components of the graph itself. The range of dates for the last spring freeze and first fall freeze are presented as light blue vertical bars, based on freeze data since 1981. It is important to know the historical distribution of the freeze dates along with the average to better assess the risk to the crop. The temperature threshold can be selected. The height of the bar indicates the number of years that recorded a last spring or first fall freeze on that date. However, the tallest and thickest vertical bar represents the 30-year historical average date of the last spring or first fall freeze. Next, the solid curved line shows the 1981–2010 average daily GDD accumulation, and the dashed curved line shows the GDD projection for the current year. In this example, the 2016 growing season has not started so the default projection for the year is the 1981–2010 average. An example of the in-season projection is discussed later.

In the following examples, the lighter grey shading represents the historical variability of the daily GDD accumulation from the GDD start date. The darker grey shading represents the minimum and maximum GDD accumulation range for the GDD projection. The solid red and black vertical lines indicate the estimated average dates of silking and black layer respectively, two important corn crop phenological milestones, computed as both a function of the GDD start date (assumed planting date) and the selected Corn Maturity Days. Any time the dates of the expected black layer fall within the dates of the first fall frost there is a concern if the kernel has not reached maximum size, resulting in a loss of overall yield. The dashed lines on either side of those two solid lines are the earliest and latest silking and black layer dates based on historical data and GDD projections.

Fig. 3 shows the key components of the top control panel. Users are able to interact with the graph to create their own set of conditions. For example, the user can choose the start of the growing period (Fig. 3a) based on expected planting dates if...
it’s before the growing season or actual planting dates once the season has arrived. Changing the start date can have significant impacts on the risk to spring and fall frost, as well as when silking and black layer are reached.

The Comparison Years selection (Fig. 3b) allows users to compare GDD accumulation for the current growing season with up to 3 previous seasons (back to 1981). A common phrase at corn producer meetings is that they remember three years vividly, “their worst year, their best year, and last year.” This tool allows them to examine those three critical years more closely. The addition of a very hot summer like 2012 or a cool summer like 2014 can make significant differences in the rate of GDD accumulations.

The tool allows users to specify corn maturity requirements for their specific hybrid using the Corn Maturity Days selector (Fig. 3c). Many corn hybrids are labeled as having a certain CRM, as mentioned earlier, that is related to the total accumulation of GDDs. The tool calculates Silking GDDs and Black Layer GDDs from the CRM associated with the corn hybrid under consideration. Alternatively, the user is able to enter (override) specific Silking GDDs and Black Layer GDDs if they choose not to input the CRM. In general, hybrids with shorter days to maturity are used in cooler climates to assure maturity before the fall frost. However, they tend to be lower yielding. As a result, the user typically wants to optimize the hybrid for their area or set of circumstances.

Freeze temperature thresholds (Fig. 3d) can be customized from 25° to 35 °F (−3.9 to 1.7 °C); default is set to 28 °F. Users may want to review different thresholds depending on circumstances. For example, different temperature thresholds may be warranted in spring when corn is more sensitive to a light frost than in the fall when the corn is near maturity.

The Variation selection (Fig. 3e) allows the user to adjust the range of GDD and temperature data that are displayed on the graph. Options include displaying all years in the historical record (1981–2010), the middle 20 years of data, the middle 10 years of data, or none. This is important for representing the variance around the mean values of the GDD accumulation as well as the dates for silking and black layer. Finally, the Current Day option (Fig. 3f) allows users to look at GDD projections throughout the current and previous year.

Other key features of the GDD graph are that variables can be turned off and on by clicking on the corresponding item in the legend. Hover the mouse pointer over the graph and a pop-up box will appear, displaying a table of the data for that point in the graph. Zoom in by clicking above or below the plotted data and dragging the cursor diagonally in either direction to select the magnified region.

More detailed information is found by clicking on the data tab, which reveals all the data from the graphs in tabular form as well as additional quantitative information for producers. These include the estimated dates for more thresholds in corn development (stages V2, V4, V6, V8, and V10) for the current year, as well as the average and range. The probability of a spring freeze after the selected start date (planting date) and the probability of a fall freeze before the projected Black Layer date at the user-selected temperature are shown. For example, on April 8 in Champaign County, IL, the probability of reaching 28 °F (−2.2 °C) after this date in spring stands at 42 percent. More detailed daily data are provided in tabular form, including the running daily accumulation of Corn GDD, the Corn GDD for each day, the estimated vegetation stage, the projection of GDD accumulations.

Discussion and conclusion

Now that the fundamentals of the Corn GDD tool have been described, two real-world case studies are used to illustrate how the tool is used in practice. The first case is an example of when the farmer is faced with delayed planting because of wet conditions in spring. This was a common scenario throughout portions of the Corn Belt in 2013, 2014, and 2015. The decision facing the producer is “Can I plant the planned corn hybrid late and still reasonably expect it to reach maturity by fall frost? Or should I switch to a shorter-season hybrid to assure crop maturity before the fall frost, keeping in mind that short-season hybrids are typically lower yielding.”

In the hypothetical case of a farmer in Winnebago County in northern Illinois in 2016, using a planting date of May 15, while well outside the risk of spring frost, puts the crop squarely at risk for damage from fall frost (Fig. 4). In fact, the estimated date for the formation of the black layer occurs right at the average date of the first fall frost. Delaying planting even further would only increase the risk of frost damage. However, switching from a CRM of 108 days to a shorter season hybrid
of 100 days (selected in Fig. 5), reduces the risk of not reaching maturity by fall frost. In fact, the estimated date for the formation of the black layer falls outside the historical first fall frost dates for this location since 1981. There is a yield penalty by choosing a shorter season variety that must be considered in the decision.

The second case shows how the Corn GDD tool looks during the middle of the 2015 growing season (Fig. 6). The orange line is the comparison year of 2012, noted for its heat and represents the case for the rapidly accumulated Corn GDDs. The purple line is the 1981–2010 average. The green line is the accumulated Corn GDD to date (in this case July 26, 2015). The dashed line shows the projected Corn GDDs using the CFSv2 ensemble forecast out to 30 days, and the 30-year climatology for the balance of the growing season. The lighter grey shading represents the historical variability of the daily GDD accumulation from the GDD start date. The darker grey shading represents the minimum and maximum GDD accumulation range for the GDD projection. Based on these results, the crop is accumulating Corn GDDs at a rate below the 1981–2010 average. However, it is likely to reach black layer before the risk of fall frost becomes large enough. As a result, the farmer may decide to employ more aggressive marketing strategies such as forward pricing (also known as the futures market) with the increased confidence in the fall harvest.

While the examples used here are site specific, many farm operations now cover multiple counties and even multiple states. This tool allows them to easily move their attention from one area to the next. In addition, farmers may use the tool to plan for in-season applications of fertilizers, herbicides, and fungicides based on the anticipated dates of the crop reaching certain growth stages. For example, the best time to ground-apply nitrogen fertilizer is by the V8 development stage so that it is available before the corn plants reaches pollination. Consulting the data tab of the chart reveals the estimated date for when the V8 stage is expected to arrive.

This tool focuses on corn development as it relates to the accumulation of corn GDDs. However, other factors also influence corn development including tillage practices, fertility, drainage, availability of soil moisture, and heat stress. For example, studies have shown (e.g., Al-Darby and Lowery, 1987) that no-till corn can lag behind conventional-till corn in emergence and early development due to no-till soils having cooler soil temperatures in spring. Depending on the magnitude and timing, soil moisture stress may delay silking and tasseling and/or hasten maturity. However, many of these factors occur at the field level and are more difficult to address without appropriate data, especially the lack of measured soil moisture and soil temperatures, than the widespread effects of accumulated GDDs during the growing season. Because the Corn
GDD tool does not address these factors, producers need to apply their own knowledge and experience of their fields when using this tool.

The Corn GDD tool has been in operation since late 2013 with refinements added in 2014 and 2015, including the 30-day NWS forecast. Based on web statistics, the tool has received over 21k hits from 9k users from November 2013–December 2015.

The Corn GDD tool has several features that stand out. One, it is available across the Corn Belt with unlimited access to users at a high resolution and updated daily. Two, it includes a rich database of historical information that allows users to examine frost risk, the average and range of Corn GDD through the year, as well as the tracks of specific years, all customized to farm level for decision making needs. Three, it includes the 30-day NWS forecast to increase the skill of projecting Corn GDDs during the growing season.

Historically, corn producers have had to contend with a large amount of year to year climate variability. This tool can help in addressing those needs. The tool also has the potential ability to address producer needs under the larger context of climate change in the 21st Century. For example, according to the National Climate Assessment (Pryor et al., 2014), Midwestern temperatures are expected to warm by 4–5 °F (2.2–2.8 °C) by 2041–2070. Producers could use the tool to look at locations where the climate is about 4–5 °F warmer in the current climate as proxies for examining future frost risk and rates of Corn GDD accumulation. For most of the Midwest, that is the difference between the northern and southern portions of the state. They could also use particular years as proxies for future warming. For example, the 2012 growing season was about 4–5 °F warmer than normal. Furthermore, it is conceivable that climate change model runs could be directly integrated into the framework of this tool to better understand the agricultural impacts resulting from particular future emission scenarios and specific time periods in the future.

Data availability

The tool is currently housed at Purdue University's website for U2U: www.agclimate4u.org and will be switched over the High Plains and Midwestern Regional Climate Centers once the project is completed in April 2017.
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References


Northrup King, 2013. 2013 Seed guides (multiple).


