ARTICLE IN PRESS

Climate Risk Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Climate Risk Management

journal homepage: www.elsevier.com/locate/crm

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

James R. Angel [a,*], Melissa Widhalm [b], Dennis Todey [c], Ray Massey [d], Larry Biehl [b]

[a] Illinois State Water Survey, Prairie Research Center, University of Illinois, 2204 Griffith Drive, Champaign, IL 61820-7463, USA
[b] Department of Forestry and Natural Resources, Purdue University, 195 Marsteller Street, West Lafayette, IN 47907, USA
[c] USDA Midwest Climate Hub, National Laboratory for Agriculture and the Environment, USDA-ARS, 1015 N. University Boulevard, Ames, IA 50011, USA
[d] Department of Agriculture and Applied Economics, University of Missouri, 223D Mumford Hall, Columbia, MO 65211, USA

ARTICLE INFO

*Article history:*
Received 15 April 2016
Revised 23 September 2016
Accepted 10 October 2016
Available online xxxx

*Keywords:*
Climate variability
Corn Belt
Corn
Growing degree days
Frost
Planting
Harvesting
Decision support tool

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. Survey results, web statistics, and user feedback indicate that this tool is being actively used by decision makers.



## 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.

* Corresponding author.
*E-mail address:* jimangel@illinois.edu (J.R. Angel).

http://dx.doi.org/10.1016/j.crm.2016.10.002
2212-0963/

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:

$$\text{Corn GDD} = (\text{Tmax} + \text{Tmin})/2 - \text{Tbase} \quad (1)$$

where Tmax is the daily maximum temperature and is reset to 86 °F (30 °C) if the high temperature exceeds 86 °F (30 °C), Tmin is the daily minimum temperature and is reset to 50 °F (10 °C) if the minimum temperature drops below 50 °F (10 °C), and Tbase 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