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Cyberinfrastructure for the collaborative development of U2U decision support tools

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ABSTRACT

This paper describes the use of cyberinfrastructure to create interactive applications as part of the Useful to Usable (U2U) project. These applications transform historical climate data, knowledge, and models into decision support tools for end users such as crop farmers, university Extension educators, and other agricultural advisors. In creating a cyberinfrastructure to support the U2U project, four major challenges have been addressed: designing and developing highly usable web applications with frequent feedback, establishing a software engineering environment to support iterative development, integrating and synthesizing historical and current datasets from a variety of sources (local vs. remote, different access methods, and formats), and supporting project collaboration needs of data and document sharing, project management, and public outreach. The overall goals of the cyberinfrastructure and its architecture design are described. Methods for data retrieval and synthesis, as well as the various software components utilized are discussed. The development and integration of tools into the collaborative HUBzero framework are highlighted, including the use of HUBzero's core features to share ideas, algorithms, and results. A highly iterative development process that includes feedback from experts and end-users to feed requirement definition, design and application updates are also examined.

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1. Introduction

The Useful to Usable (U2U) project aims to enhance the usability and uptake of climate information and bolster university Extension capacity to address agro-climate concerns. The approach taken by the U2U project is to leverage a rich set of existing data and knowledge from a partnership of ten midwest academic and research institutions, and develop tools and training materials, along with the university Extension outreach effort, leading to rapid adoption and dissemination of the tools and knowledge base (Prokopy et al., [this issue](#)). The U2U team conceptualized and developed climate-based tools to assist Corn Belt farmers and agriculture consultants with decisions related to purchasing, marketing and activity planning throughout the growing cycle. In the long term, these efforts are expected to lead to more profitable agricultural systems and greater resilience to a changing climate.

The project team determined early on that a web-based platform would be needed to support the research and collaboration, encourage communication among active communities of practice, deliver decision support tools (DSTs) to stakeholders, and support extension-oriented initiatives, and selected the HUBzero Platform for Scientific Collaboration. HUBzero(R), a National Science Foundation funded cyberinfrastructure, is an open source software platform that originated from the

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nanotechnology community and has since evolved into a general-purpose web platform for scientific collaboration. Each HUBzero site is often referred to as a “hub”. HUBzero is built on a number of open source packages (Linux, Apache, LDAP, PHP, MySQL, etc.) and middleware that was developed at Purdue University to provide a virtualized computing environment and connection to advanced computing systems including campus, regional and national facilities. The hubs are self-service and support online interactive computational tools, management, sharing and publication of data and other content, along with collaboration tools (more details in [McLennan and Kennell \(2010\)](#)).

Specifically, the U2U hub (<http://AgClimate4U.org>, 2016) supports, among other features: interactive modeling tools or DSTs with GIS support, online presentations/webinars, uploaded resources for stakeholders, social features such as wikis and blogs, private groups for collaboration, and connections to our social research work. In addition, the technology is low-bandwidth and can be accessed, like any website, through tablets and smart phones, a method that has been found important to our producer stakeholders. Using a mature technology as HUBzero, the project was able to establish its virtual collaboratory from the beginning and fully engage the partnership. The DSTs are the main products from the U2U project. The current tools include: AgClimate View (ACV), Corn Growing Degree Days (GDD), Climate Patterns Viewer (CPV), Corn Split Nitrogen Application (SplitN), and Irrigation Investment.

Significant efforts have gone into the U2U hub development to address several major challenges including:

- *Usability*: The most critical of challenges for the DSTs are delivering a high degree of usability by transforming large amounts of scientific data into actionable information, ease of use, and accessibility by end users. A well-defined and continuous process of gathering requirements and user feedback, combined with a highly iterative software development process proved to be successful.
- *Data-driven*: The DSTs are based on many data sources, including those locally hosted and those residing in remote data repositories, with different formats and storage requirements. The data infrastructure design, including storage, processing, updating, and access interfaces was part of the overall U2U hub design from the very start.
- *Software development environment*: The software team had to address the challenge of providing the partnership and users with access to a production quality hub and tools while the DST development was in process. A comprehensive software engineering process has been employed throughout the project where a DST goes through phases of requirement gathering, user interface design, software development, testing, limited deployment for feedback, and release to production. The software environment was created to provide virtual machines for individual developers, a stage server for integration and testing, and a production hub for deployment of tools. The U2U DST development involves collaboration from multiple sub-teams. This combined production/development setting has been effective in allowing all partners to access product information, documents, discussions, and new tool prototypes, while the completed DSTs and engagement materials are available publically 24×7.

The rest of the paper is organized as follows: Section 2 describes the system architecture of the U2U cyberinfrastructure and its components (software, data, software engineering process). Section 3 describes each of the DSTs in more detail and highlights the relevant issues with data processing, user interface, and software components employed. Section 4 provides the results and community feedback on the DSTs. Section 5 provides our conclusions.

2. System architecture

The overall system architecture of the U2U collaborative environment is shown in [Fig. 1](#). One of the key features in HUBzero is the ability to develop dynamic web applications (called components within HUBzero) composed primarily of JavaScript/JQuery, PHP, HTML & CSS. HUBzero also provides out-of-box support for social networking functions such as user created groups, forums, wikis, projects, reviews and ratings. End users can easily upload their data and documents into the hub as resources and publish them with a digital object identifier (DOI) if needed. The five U2U tools provide GIS-enabled user interfaces for researchers, farmers, advisors, and policy makers to dynamically fetch, process and explore a diverse set of climate and agricultural datasets and study the relationship between climate change and crop production in the Corn Belt region.

The U2U collaborative environment is a ‘super group’ on a single HUBzero instance along with other geospatial related groups and projects. The super groups share the same underlying infrastructure. A super group is an advanced type of hub group that allows a project to create and manage a customized web space that has its own branding. The U2U hub provides the front face of the U2U program to the public. Anyone can access the U2U decision support tools, newsletters, videos, presentations, blog posts, factsheets, press releases, publications, contact information and links to many other decision support tools, maps and resources related to the U2U project. The U2U team members use an internal group to share data and documents, and discuss ideas in a private blog and forum among the team. The following subsections discuss the three main components comprising the U2U cyberinfrastructure.

2.1. Software

The U2U system is built based on the HUBzero platform that provides the cyberinfrastructure supporting online education and research needs. The U2U decision support tools are implemented as hub components using JavaScript and PHP. The

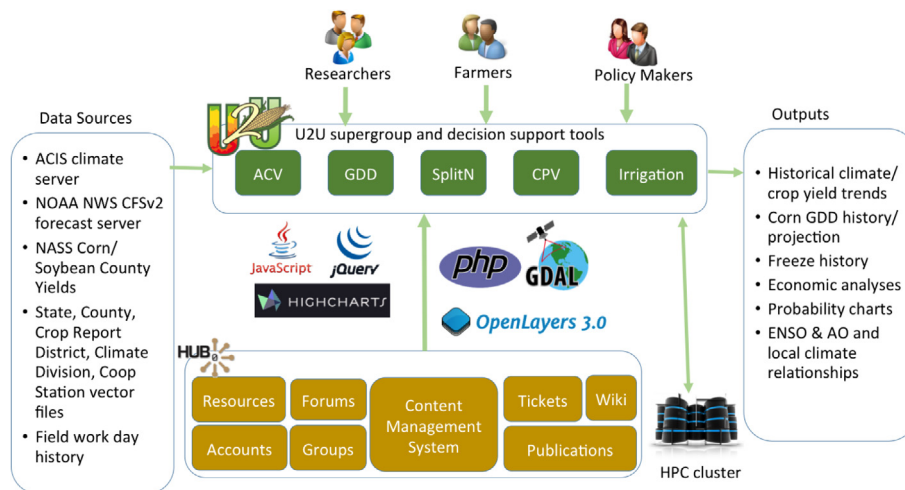


Fig. 1. System architecture of the U2U collaborative environment.

JavaScript libraries were selected because they provided out-of-the-box features that worked well together; the libraries had been used in other projects. The U2U tools share common features that allow users to select a specific location or weather station, display and download plots and tables of the data, and access step-by-step help. The software used to support these functions is discussed below.

2.1.1. Maps

OpenLayers 3 JavaScript library (<http://openlayers.org>, 2016) is used to handle the display of maps and selection of the locations on the map. The interface elements on the map, see Fig. 2 for an example, allow one to go directly to the user location defined by the network being used (upper right icon) or search for a location by state, city, county, zip code or COOP weather station name (strip along upper left of map). A popup is displayed when one clicks on a location on the map with information about the location such as latitude/longitude, state, county, station name, etc. depending on the tool (see Fig. 3). Some effort has been made to make the tools usable on tablets, but these devices were not a part of the original design.

2.1.2. Graphs and charts

HighCharts (<http://www.highcharts.com>, 2016) is used to generate and display graphs and handle user interaction with the graphs. Fig. 4 illustrates a graph displayed by ACV. The user can select data by turning legend items on and off, zooming the graph in and out, switching between line chart and scatter chart, and obtaining data values using tool tips. One can also save a copy of the chart to disk in several formats including png, jpg, pdf and svg vector.

2.1.3. Step-by-step guides

Intro.js (<http://introjs.com>, 2016) is used to incorporate step-by-step guides in each of the tools. When selected by the blue question mark icon on the tool page (shown upper right of the graph shown in Fig. 4), a popup is displayed with information describing how to use the data entry option it points to. One can use the left/right arrow keys to go backward and forward in the step list or use the direction options in the popup itself. See Fig. 5 for examples of this guide.

2.1.4. Geospatial access library

The Geospatial Data Abstraction Library (GDAL, <http://www.gdal.org>, 2016) raster utility tool named gdallocationinfo is used to access the gridded Corn growing degree data for a selected location (pixel) in the GeoTIFF formatted raster data files used as inputs for the Corn GDD and Corn Split Nitrogen decision support tools.

2.2. Data

Transforming heterogeneous datasets into usable information by end users is a major challenge of the project. The data are either static (already downloaded, processed and stored) or dynamically retrieved via web services. Dynamic data retrieval includes climate data from a third party vendor, the Applied Climate Information System (ACIS, <http://www.rcc-acis.org>, 2016; DeGaetano et al., 2015), which has a web service definition for climate data retrieval defined at http://www.rcc-acis.org/docs_webservices.html, 2016, and forecasted 90-day minimum and maximum temperatures from the CFSv2 model (Saha et al., 2014) provided by a NOAA National Weather Service server. ACIS is a quality-controlled historical climate database developed and maintained by NOAA Regional Climate Centers (RCCs).

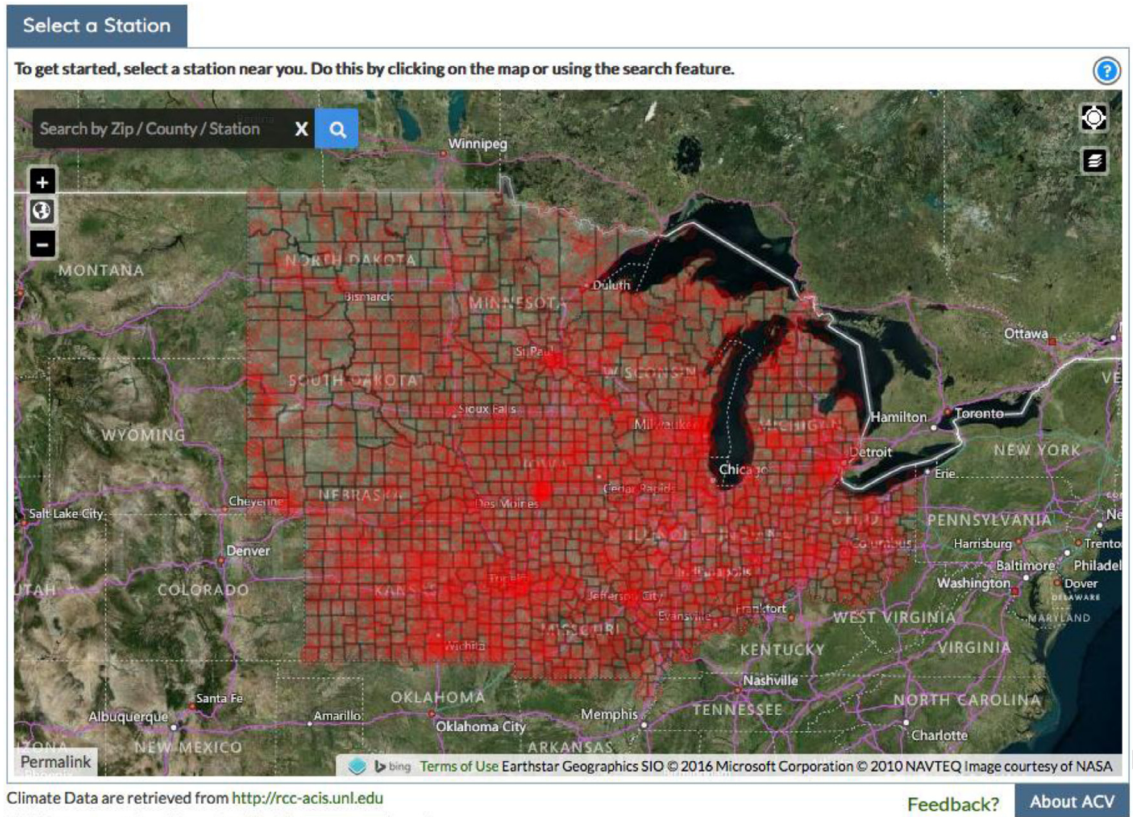


Fig. 2. Illustration of map used for selection of coop weather station location.

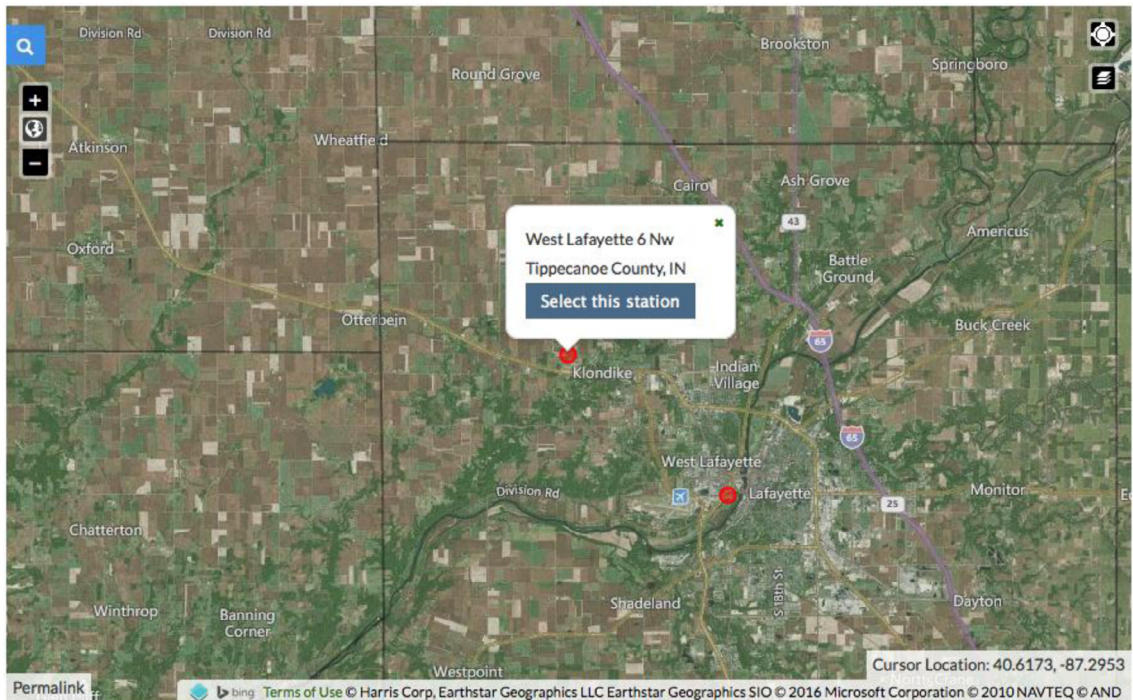


Fig. 3. Illustration of a popup on the map indicating the location selected by the user.

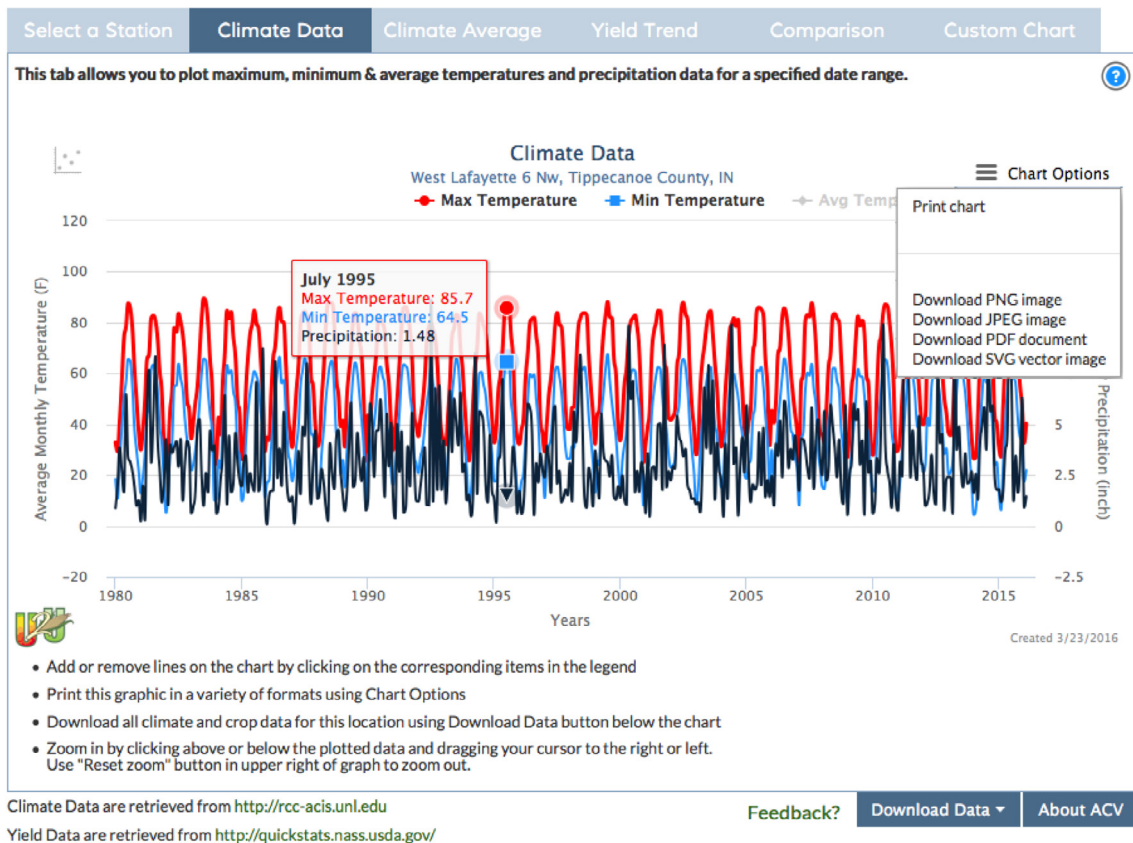


Fig. 4. Illustration of a graph displayed by the ACV tool.

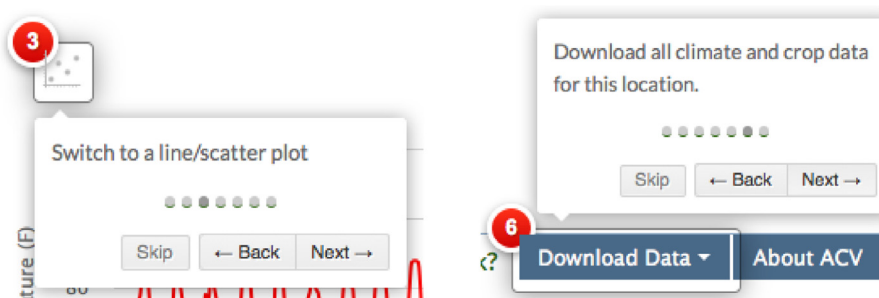


Fig. 5. Illustration of a couple of the guides for a graph from the ACV tool.

ACIS is used to provide station climate measurements for the ACV tool in real time and the gridded minimum and maximum temperatures for the 12-state U2U region (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin) used for the Corn GDD and Corn Split N tools in 'batch' mode. The ACIS batch mode feature is used by a script which runs automatically each night to download the min and max temperatures. The script then converts these data to accumulated corn growing degree days to be ready for use later that day. Data processing is done on a Purdue campus supercomputer (Hansen). Although, the use of Hansen is lightweight, the infrastructure allows for the processing of more complex data that would need to be run across multiple nodes. Similar pre processing is done with NOAA/CFSv2 weather model data to create forecasted GDDs from the daily forecast models for min and max temperatures.

For the geospatial map data used by the DST tools, a geoserver (<http://geoserver.org>, 2016) was originally used to supply the vector files used for the tools with the Openlayers library. The vector files have now been converted to GeoJSON (<http://geojson.org>, 2016) files and moved to the hub server to be more locally contained. The other static files (csv or comma-separated values, GeoTIFF/TIFF, pdf, and mp4 files) used by the DSTs are stored on the hub server as well.

A user can save data and information specific for the tools in csv format so that they can be used for other analyses and workflows.

2.3. Tool development process and software engineering environment

The U2U project involves multiple institutions and stakeholders from different sectors. New feature requirements and feedback emerge continuously during tool development. Hence it is critical for tool development to be a highly iterative process that uses feedback from experts and end-users to feed requirement definition, design and application update. For that purpose, an adaptive software development process (Highsmith, 2013) was adopted by the team. The project started with many features needed by the user community. The development team employed iterative, short development cycles to deliver milestones in 3–6 month phases. User feedback and input, as well as evaluation, are incorporated to guide the team in adjusting implementation and priorities.

The U2U social science team was tasked with gathering information about stakeholders' climate information needs and engaging them in developing usable decision support tools that will enhance their resilience to climate variability and change. This research utilized several strategies to better understand Midwestern farmers and their advisors including surveys, focus groups, interviews, and network analysis (Prokopy et al., this issue; Morton et al., 2016; Prokopy et al., 2013; Arbuckle et al., 2013). Findings from these activities directly influenced the identification, design and dissemination of the decision support tools.

Three tools, ACV, Corn GDD and CPV, were identified as having the highest priority based on these results. The U2U tool development team, consisting of state climatologists, Extension educators and IT professionals, was formed to direct the design of the tools. ACV was the first tool under active development, followed by Corn GDD and CPV. The tools were developed in staggered fashion with no more than two tools being actively developed in their initial stages at the same time to maximize developer productivity. The tool development team worked closely with the U2U project evaluators to enhance tool usability and usefulness. Details about the process used to determine the tools and features to be developed and the iterative user evaluation during the tool development are available in Klink et al. (this issue).

Three servers were used to support the development and deployment of the U2U system. A development server with restricted access was used by developers to create and test their code. The team members also had access to the development server for testing using a virtual private network (vpn) connection. Once the code is tested on the development server, it is pulled to a stage server for integration testing. A regular code push from the stage server to the live server is performed weekly when the stable code is deployed to the production U2U hub site and become available to the public. Besides the development server, developers can also download a HUBzero virtual machine (VM) and use that as their personal development environment for web components.

Professional software developers, graduate and undergraduate students have participated in the tool development throughout the U2U project. A professional IT staff member on the U2U project oversaw the development to ensure continuity as personnel changed due to graduations and job transfers.

3. U2U decision support tools

The U2U decision support tools were released in 2013–2016. The following sections provide a basic description of what the purpose of the tool is and how the input files are processed. Each of the tools have an 'About' link which provides a background, data sources and frequently ask questions about the tool. Each 'About' page also provides a link to a User Guide (U2U, 2014, 2015a–c, 2016) with a detailed description on how to use the respective tool.

3.1. AgClimate view decision support tool

AgClimate View (ACV, 2016a,b) provides a convenient way to access customized historical climate and corn/soybean yield data for the U.S. Corn Belt. One can create graphs of climate data including monthly temperature and precipitation, growing degree day (GDD), and stress degree day (SDD90), plot corn and soybean yield trends, and compare climate and yields over the past 30 years.

3.1.1. Climate data

All climate and GDD data used in ACV are retrieved from ACIS. All climate stations in ACIS identified as currently collecting data are included in ACV regardless of the station's length of record or number of missing data points. If a station is selected that does not contain any data, ACV will automatically redirect one to another nearby station. GDD data are calculated using a base temperature of 50⁰ F and no upper limit. SDD90 data is calculated using a 90⁰ F threshold.

3.1.2. Climate averages and variation

The monthly climate averages displayed on the 'Climate Average' tab (see Fig. 6) are pulled in real time when a user selects a station on the map (Fig. 2). The ACIS database uses the National Climatic Data Center (NCDC) 1981–2010 averages. NCDC applies a number of quality adjustments to account for missing data, station moves, equipment changes, and other

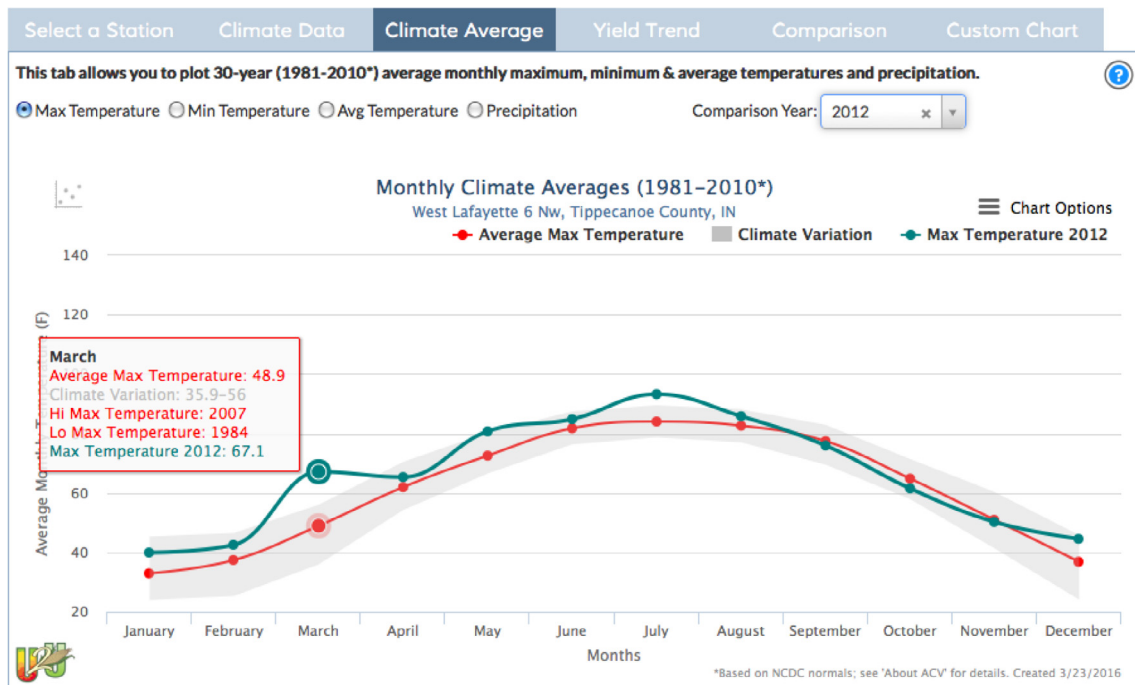


Fig. 6. Graph of the average monthly maximum temperature for West Lafayette 6 NW coop weather station. The gray bar reflects the total variation in monthly maximum temperatures for the 1981–2010 period. The monthly averages for 2012 were plotted as a comparison year.

factors that can influence the climate record (NCDC, 2016). Therefore, the climate averages might not be exactly equal to the 30-year average as calculated from the observed daily data.

Climate Variations displayed as gray area on the 'Climate Average' tab are based on the maximum and minimum monthly average values. The user can select a comparison year to compare with the 30-year average and move the cursor over the data points on the graph to see a popup with the actual values for that point.

3.1.3. Crop yields and trends

The 'Yield Trend' tab (see Fig. 7) provides a graph of the historical (1980 to previous year) county-level corn and soybean yield data that are made available by the USDA National Agricultural Statistics Service (NASS) Quick Stats Database. Yield trends are calculated as a straight linear trend of county yield data from 1980 to 2010.

3.1.4. Climate and crop yield comparisons

The "Comparison" tab allows one to link weather and crop data together for decision analysis (see Fig. 8). One can compare corn or soybean yields with selected weather variables measured at a selected location since 1980. One can use the actual weather measurements or the deviation from the 1981 to 2010 monthly average. The plot for SDD90 is computed in real time from the daily maximum temperature. The values plotted represent the sum of the daily SDD90. If a site has more than three days in the month with missing maximum temperatures, the monthly total is set to the 'no data' value.

3.1.5. Custom Charts

The "Custom Chart" tab allows one to customize the chart (Fig. 9) with other measurements including snowfall, snow depth, cooling degree days (CDD65), heating degree days (HDD65) in addition to the temperature and precipitation measurements available in the charts for the other tabs. The user will find that many stations do not include all of these measurements.

3.2. Corn growing degree day (GDD) decision support tool

The Corn GDD tool (GDD, 2016a,b; Angel et al., this issue) puts current growing degree day conditions into a 30-year historical perspective and offers trend projections through the end of the calendar year. GDD is a measure of heat accumulation within a specified temperature range. It is important for agriculture since they can be directly related to plant growth and development stages. The Corn GDD tool aims at helping farmers make decisions about seasonal climate risks, activity planning, and marketing decisions.

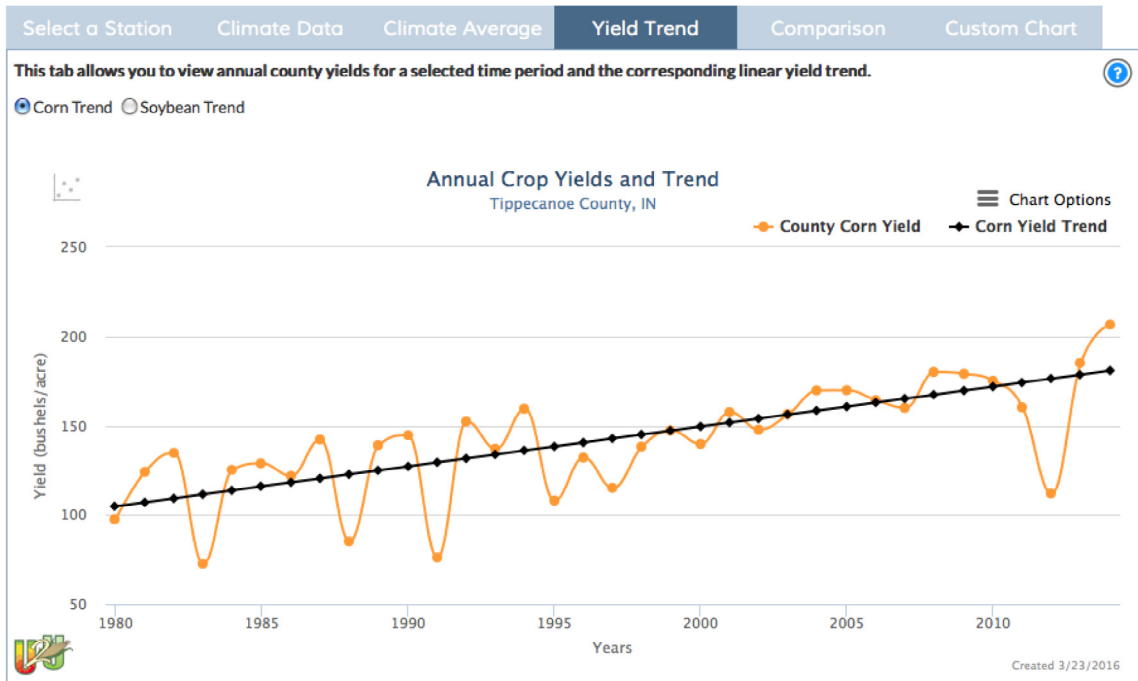


Fig. 7. Graph of the county yields and straight line trend for Tippecanoe County, Indiana.

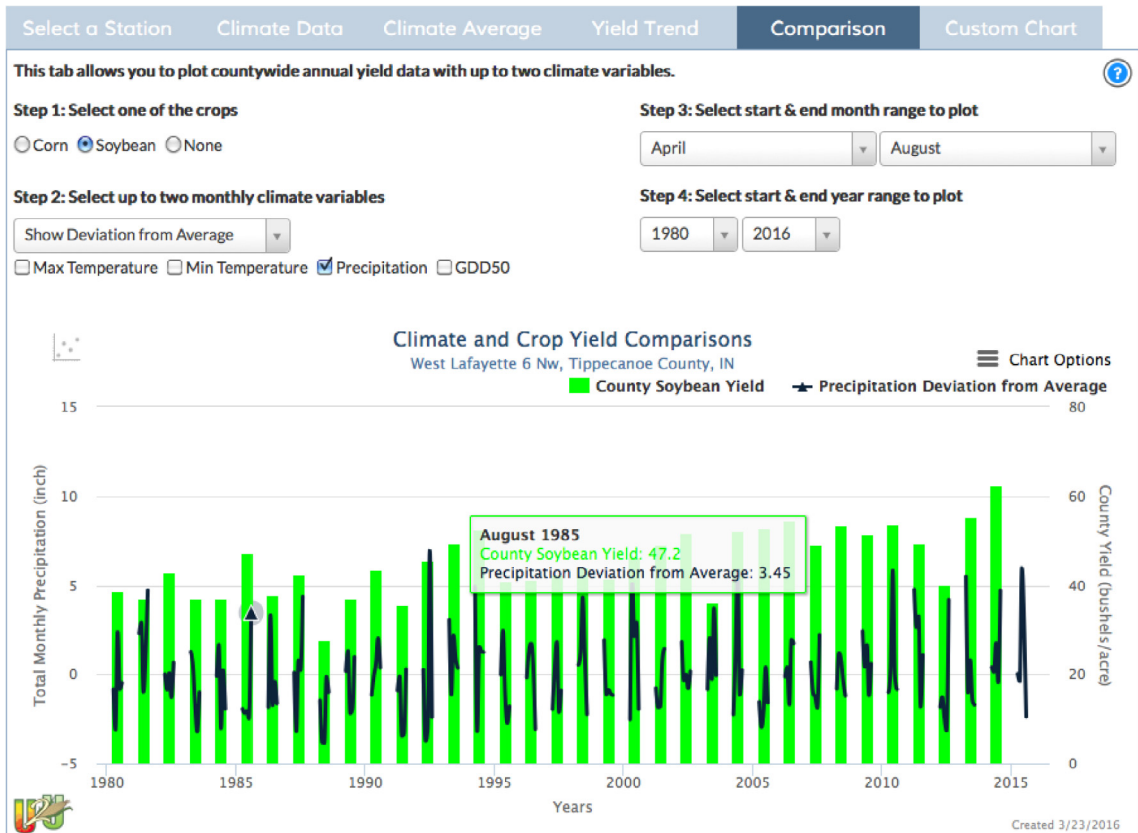


Fig. 8. Illustration of the comparison of soybean yields for Tippecanoe County in Indiana with the monthly deviation from average for total precipitation from April through August at the West Lafayette 6 NW coop weather station for 1980 through 2014.

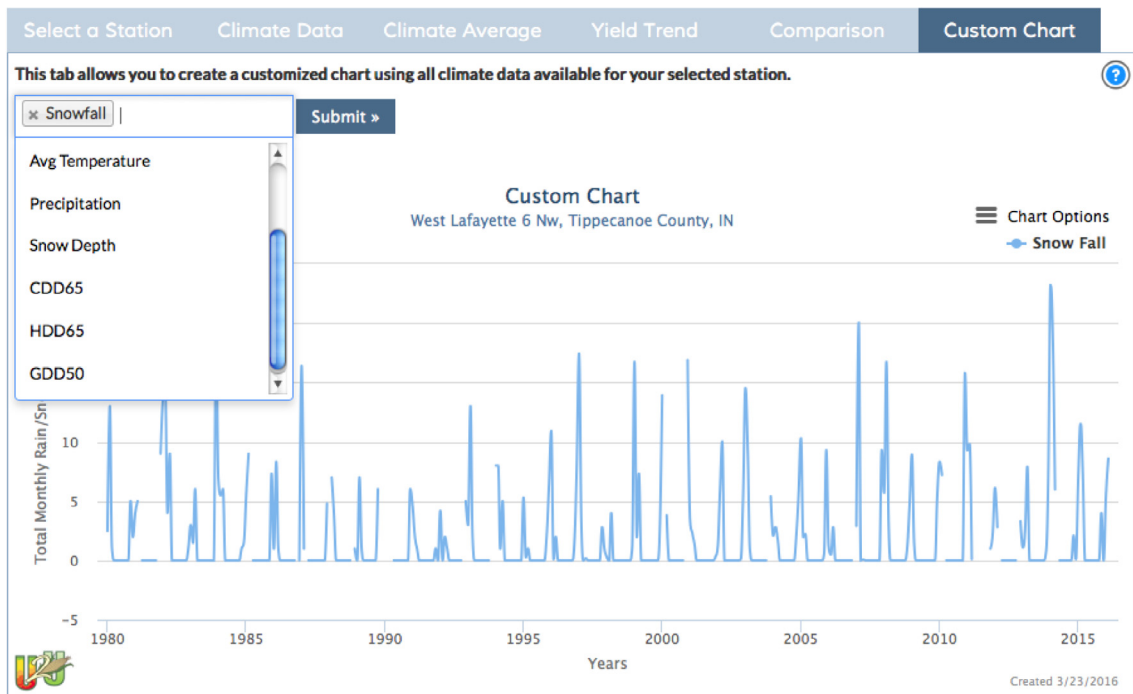


Fig. 9. Example of graph created in the 'Custom Chart' tab displaying the monthly snowfall from 1980 through 2015 for West Lafayette 6 NW coop weather station.

The Corn GDD interface lets users choose a location of interest on a map, adjust the configurations and generate a customized GDD graph in comparison to the 30-year average. An example is shown in Fig. 10. The 'Data' tab provides a text summary of the data on the graph, estimate dates for growth stages (V2–V10), freeze probabilities, and the daily Corn GDD accumulations. One can view data for current year and historical average and high/low range. The 'Animation' tab allows users to view and download animations of the accumulated growing degree days for the U2U region for selected years.

The tool uses daily gridded minimum and maximum temperature data for the 12-state U2U region (plus Kentucky and Tennessee) from ACIS. The gridded temperatures provided by ACIS are based on the ACIS point station data using a 'Natural Neighbor' algorithm (Noon, 2013; Hemsley, 2009). Each pixel in the gridded data represents a resolution of around 4 km. GDDs are calculated from the gridded temperature data using the 86/50 method (Gilmore and Rogers, 1958). Four types of gridded input files were generated for the GDD tool including (1) GDD for 30-year average, 30-year median, yearly from 1981 – previous year, (2) day of year file with average, and yearly last and first thresholds for 11 temperatures from 25 to 35 degrees Fahrenheit, (3) current year GDD file which is updated daily, and (4) CFSv2 forecast file which is updated daily. These files are saved in 'day' interleaved by pixel format. More details on the data processing steps are explained in the following sections.

3.2.1. 30-Year historical GDD and freeze data

Each of the daily gridded minimum and maximum temperature images for the U2U area was viewed to verify that the data looked valid. Anomalies in the data for some areas were discovered in this verification process e.g., some station recorded temperatures for a portion of a year were very different from the surrounding stations and, in one case, the max temperature was less than the min temperature (found that max temperature was reported by a station as Celsius and the min as Fahrenheit). ACIS staff corrected the problems.

An accumulated GDD GeoTIFF files was then created for each year from 1981 thru the last calendar year that includes 365 layers representing the 365 days of the year; December 31 is ignored for leap years. The GDD value for a given day represents the total GDDs that have accumulated from the beginning of the year through that day. GeoTIFF files were also created for the average and median accumulated GDDs for the 30-year period from 1981 to 2010. The average, median, and yearly accumulated GDD files are combined into a single GeoTIFF file, which represent all days for that time period. The layers (or days) are organized in layer (or day) interleaved by pixel format so that all data for a given location are contiguous within the file which makes data reads as efficient as possible.

Another input needed for the tool is the last 'freeze' in the spring and the first 'freeze' in the fall. The desire was to allow the user to select the 'freeze' value from a range of 25 through 35 degrees Fahrenheit. The gridded minimum temperature

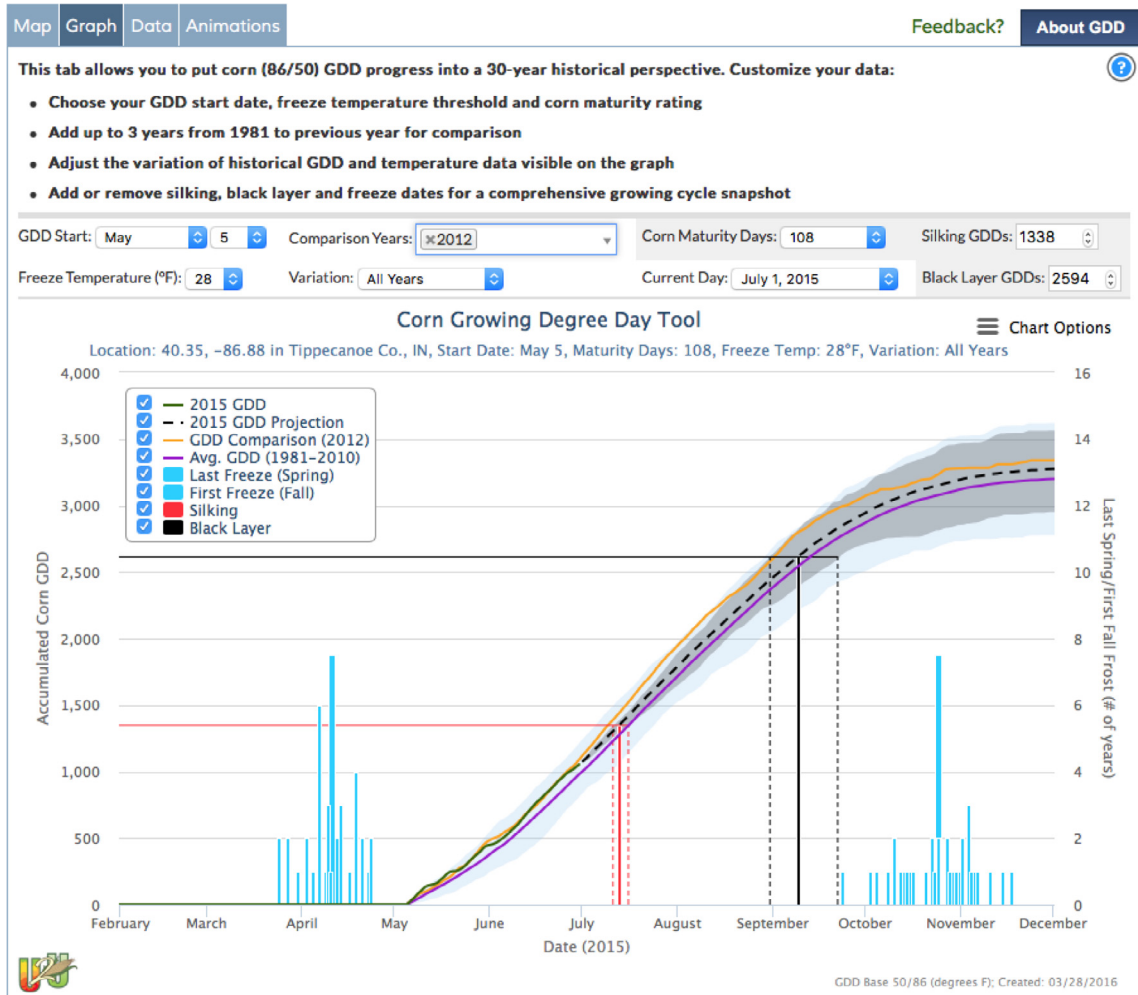


Fig. 10. Illustration of graph of accumulated GDDs from GDD Start (May 5 planting date) and projection based on 30-day prediction of min/max temperatures and 30-year history from the current day (7/1/2015) for 108 day maturity corn. Other information on the chart includes 30-year history of last and first 'freezes', projection of silking and black layer development stages and a comparison year for GDD accumulation from May 5. The shading represents 30-year variation of accumulated GDDs from planting date (light gray) and the current day (dark gray). The next sections provide more details on how the data displayed was created.

files from ACIS were used to create a threshold temperature day-of-year GeoTIFF file. This file includes the day-of-year for the last and first minimum temperatures for each of the 11 threshold temperatures for the 30-year average and yearly information from 1981 through previous year. For 2015 data this file includes 792 layers of data. This file is also organized to be in layer interleaved by pixel format for efficient data accesses for a selected location (pixel).

These two files are updated during March of each year to add the data for the previous year. The history file is not updated immediately after the new year starts because the coop weather stations may update their reported temperature measurements in ACIS for the previous two or three months.

3.2.2. Current year corn GDD data

A shell script is used to download year-to-date gridded minimum and maximum temperatures for an area encompassing the 12-state U2U region. Shell and python scripts control the calculation of the accumulated GDDs and the creation of a GeoTIFF file. The script, triggered by a cron job (a time-based job scheduler) on a Linux server, is run after midnight each day to keep the current year GDDs up to date. All of the data for the year is downloaded each time the script is run to incorporate any changes in prior data for the year.

The GDD Projection starts from the current day and goes through the end of the current year; see the description in [Angel et al. \(this issue\)](#) for details of the projection.

3.3. Climate patterns viewer decision support tool

Climate Patterns Viewer (CPV, 2016a,b) provides a historical look at how two teleconnections, the El Niño Southern Oscillation (ENSO, 2016a) and the Arctic Oscillation (AO, 2016a), have affected local climate conditions across the Corn Belt. A teleconnection is simply an atmospheric circulation or pressure pattern in one part of the world that can alter weather conditions in another part of the world. Impacts can be immediate or have a delayed onset, and can last for weeks or months at a time. Different configurations of a teleconnection (also called “phases”) result in different types of impacts, and knowledge about the relationship between phase and impact can help corn farmers make more informed management decisions.

The effects of ENSO and AO on local temperatures, precipitation, and crop yields in the U.S. Corn Belt are less uniform and less predictable than in other parts of the world. CPV helps Corn Belt farmers and advisors identify those locations where specific ENSO and AO phases have historically resulted in notable local impacts throughout the year.

CPV provides information on spatial variation of the climate division monthly temperature and precipitation and corn yield for the 12-state U2U area in two (Fig. 11) or four maps and an optional chart (Fig. 12).

The following sections provide information on the source of the data used in the CPV tool.

3.3.1. Teleconnections

Teleconnection data for ENSO and AO are from 1981 to 2010 and obtained from the National Oceanic Atmospheric Administration (NOAA) Climate Prediction Center (CPC) (ENSO, 2016a; AO, 2016a). Climate Patterns Viewer uses the Oceanic Niño Index (ONI) to determine ENSO events. ONI is based on the three-month running mean of sea surface temperature (SST) in the Niño 3.4 region. Classification of months as El Niño, La Niña, or neutral in the Climate Patterns Viewer are based on the 0.5 or greater and -0.5 or less cold and warm thresholds, respectively, with neutral events ranging from -0.4 to 0.4. Events were not further classified as weak, moderate, or strong events. The same classification scheme is applied to the AO.

The current phase for the ENSO and AO climate patterns can be found at ENSO (2016b) and AO (2016b), respectively.

3.3.2. Precipitation and temperature data

The observed monthly precipitation and temperature data used in CPV are as discussed in Kellner and Niyogi (2015). Data are for the climate division level for the 12-state U2U region and utilize the NCEI DRD964x dataset (dataset available prior to the nClimDiv dataset now in use). Climate normals, or averages, are calculated at the climate division level based on 30 years of observations (1981–2010), which is consistent with the time periods used by the World Meteorological Organization. The

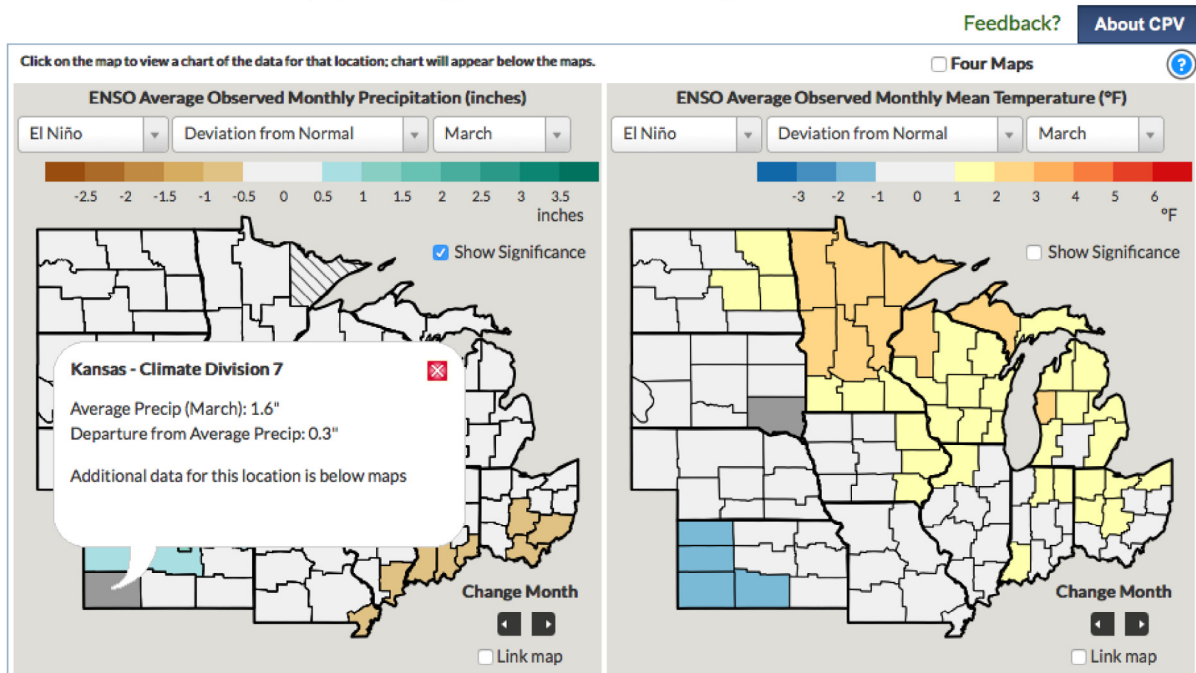


Fig. 11. Two maps illustrating the spatial variation of deviation from normal monthly precipitation (left) and monthly mean temperature for March during the El Niño ENSO phase for each climate division. The user can select phase (El Niño, Neutral, La Niña, AO Positive, AO Neutral & AO Positive), measurement (precipitation, temperature, corn yield, deviation from normal, deviation from neutral), month to be displayed and 95% level significance indication of measurement being different from normal with cross-hatching. One also has the option to change the months for all maps with one click if they are linked together.

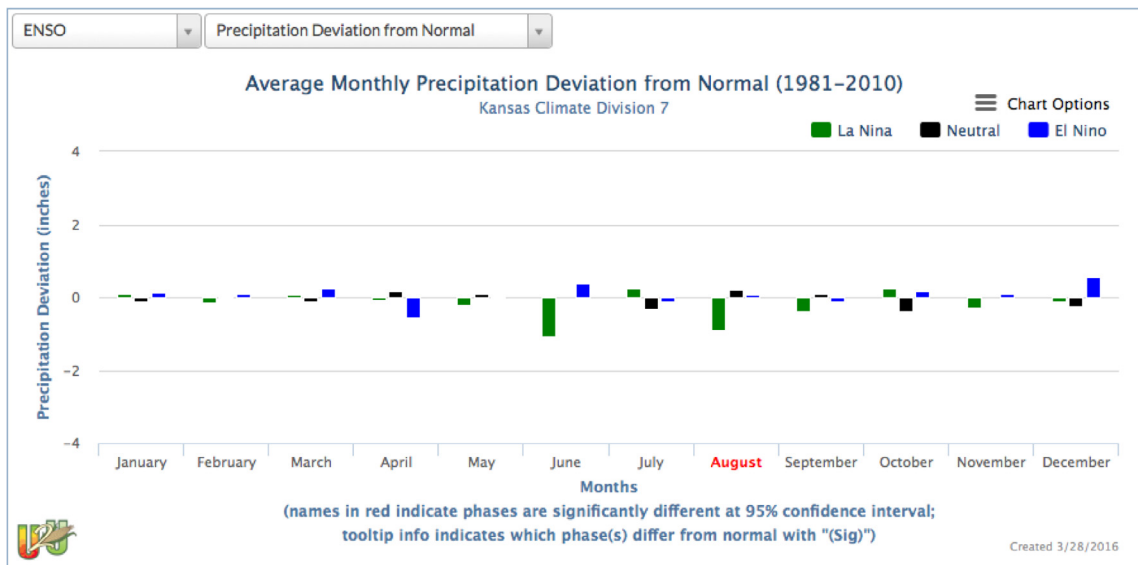


Fig. 12. The chart compares the selected measurement for each of the ENSO phases for each month of the year. Month name in red indicate that at least one of the phases were different from the 1981 to 2010 normal at the 95% confidence level.

temperature data came from ACIS through the Midwestern Regional Climate Center (MRCC) cli-MATE user interface. The monthly sea surface temperature data used to determine ENSO-episode classification (e.g. La Niña, neutral, or El Niño) for CPV were updated during 2015 to reflect the Oceanic Niño Index Extended Reconstructed Sea Surface Temperature (ERSST) v4 dataset (i.e. they differ from those in Kellner and Niyogi (2015)). This dataset is available from the Climate Prediction Center (<http://www.cpc.ncep.noaa.gov>, 2016).

3.3.3. Crop yield data

Observed Crop Reporting District (CRD)-level corn yield data from 1981 to 2010 were obtained from the USDA National Agricultural Statistics Service (NASS) Quick Stats Database. Corn yields in the CPV tool have been adjusted, or detrended, to remove the effect of improved technology on yield over time. One can think of it like an inflation adjustment. For decades farmers in the Midwestern U.S. have observed a 1–3 bushel/acre yield increase annually due to better seed traits, better equipment, and more efficient farming practices. This annual upward trend makes it difficult to detect the impact of weather and climate on crop yields, and it creates challenges for comparing yields in the 1980 s and 1990 s with yields today. By adjusting historical yields to current-day levels of technology we can avoid these issues and more clearly identify the impacts of ENSO and AO on midwestern crop production. CPV uses 2010 yield trend data as the baseline adjustment value.

Each corn yield map in CPV lists the calendar years associated with the selected ENSO or AO phase in the lower left corner of the map. As one interprets these maps, one should be aware that some phases will include more years than other phases. A calendar year is classified in the appropriate phase based on the growing season (April–October) average of the climate pattern. For example, if the growing season average of the AO index is above 0.5, that calendar year would be classified as AO-Positive for purpose of the CPV yield map.

3.3.4. Significance information

CPV uses as input the temperature and precipitation measurement differences from normal for AO/ENSO phase that are significant at 95% confidence level. The 95% confidence significance measures were determined using a bootstrap *t*-test to determine if the monthly average temps or total monthly rainfall during a given phase was different from the respective grand mean across the 31 years from 1980 to 2010. A bootstrap (resampling) approach was used to obtain an empirical distribution of *T* to approximate the actual ones because the number of samples (31 observation years) was so small.

3.4. Corn Split Nitrogen Application decision support tool

The Corn Split Nitrogen Application decision support tool (SplitN, 2016a,b) helps farmers and advisors understand the risks and benefits of using a post-planting nitrogen (N) application for corn production. This product combines historical weather data and fieldwork conditions with economic considerations to determine the feasibility and profitability of completing a second (split) N application within a user-specified time period.

The inputs required for the tool to determine the economics of splitting the nitrogen application include estimate of corn growth to determine length of time nitrogen can be applied post emergence, estimates of the number of field work days

available to apply nitrogen, yield penalties and benefits relative to applying or not applying nitrogen and the equipment available to apply nitrogen. Fig. 13 illustrates the web page that allows the user to specify the input scenario being evaluated and the economic results of that scenario. Fig. 14 illustrates the summary of the acres completed using 30 plus years of field work days history in chart and graph formats. Fig. 15 provides details on the estimated dates for corn development stages V2 through V10. The following sections provide a summary of how the inputs are handled in this tool.

3.4.1. Corn growth estimates

Corn height is an important factor in determining the probability of successful post-planting N application since the equipment must be able to travel through growing corn without damaging it. SplitN provides estimates of corn development stages based on location (specified on the map), selected planting date (see entry in Fig. 13), and the accumulated corn GDDs for the year.

SplitN uses the same daily gridded growing degree days file as is used for the Corn GDD tool as a proxy for corn height. The relationship between accumulated GDD and plant growth comes from recommendations found in Abendroth et al. (2011). Corn emergence in the Corn Split N tool is assumed to occur at 105 GDD post planting, although the scientific literature states emergence can occur at 90–200 accumulated GDD post planting depending on factors such as ground cover and tillage practices (Abendroth et al., 2011; Nielson, 2014; Hall, date unknown).

GDD accumulations and associated corn growth beyond the current day are estimated based on the 30-year (1981–2010) average GDD accumulation for the selected location.

3.4.2. Historical field work data

SplitN uses historical observations (1981–last year) and model simulations of days suitable for field workday (FWD) to estimate the probability of being able to fertilize corn during the user-defined application period (SplitN, 2016a,b).

The historical FWD input file is a TIFF formatted file with the observed or modeled number of FWD in each week of the year for each state, year, and CRD. When viewed as an image the columns represent the work week, the lines represent the state and CRD, and the layers represent the years. The file is layer interleaved by pixel so that all of the data for a given location can be read efficiently. The data values in the file range from 0 to 7 (workdays); –9 is used for missing data.

3.4.3. Yield penalties and benefits

Corn plants require adequate N for optimal growth. In the event that plant-available N is limited, there could be an associated yield reduction. Conversely, a “rescue” application of N could result in a yield increase. The Corn Split N tool allows one to customize yield (bu/acre) penalties and benefits to account for these situations since they will vary by location and time of year. (See Fig. 13).

The default values used for Yield Benefit and Reduced N are based on data reported in the literature. The user is encouraged to seek information from university Extension or crop consultants on what values should be used for the particular soil and climatic conditions at the selected location.

3.4.4. Equipment and hours settings

The Start and End Date to apply N will change with the planting date. The start date can be any time after the planting date depending on when one is likely to have time to begin applying N. The end date needs to be before the vegetative stage that is chosen. For convenience, SplitN estimates when the selected vegetative state is expected to occur.

The right side of the Scenario input section (Fig. 13) allows one to determine the number of hours required to apply N to the defined number of acres based on implement width, application speed, and field efficiency. This section also allows one to estimate the number of hours available to apply N between the selected start and end dates based on hours in the field and days available to work per week.

3.5. Irrigation investment decision support tool

The Irrigation Investment tool (Irrigation, 2016a,b) lets one explore the profitability of installing irrigation equipment at user-selected locations across the Corn Belt. One can discover how many years from 1980 to 2005 that irrigation would have been profitable, the expected net present value of investment, and compare non-irrigated and irrigated corn and soybean yields under different rainfall conditions. This tool can be customized based on yields and irrigation costs, and provides valuable insight on an expensive long-term investment that may help cope with variable climate conditions.

This tool is the most complex of the five DSTs that were created. The tool has been designed to allow the user to display sub-groups of related inputs so as not to overwhelm the user. Fig. 16 illustrates the page being used for the user to define the scenario for his/her situation for evaluation of the economics of irrigation and the display of the results. The blue buttons along the top help guide the user through the steps that need to be completed or at least verified; default values are included in all fields. The red and green headings are visual cues to help the user easily identify if they are within sections dealing with data inputs (red) or tool results (green). Adjusting the values within the red sections will potentially change the results displayed in the green sections. The cogwheel such as that with ‘Additional Tax Option’ allows one to expand that specific section to add additional information that could be important for the economic analysis. The ‘About Irrigation’ link on the tool

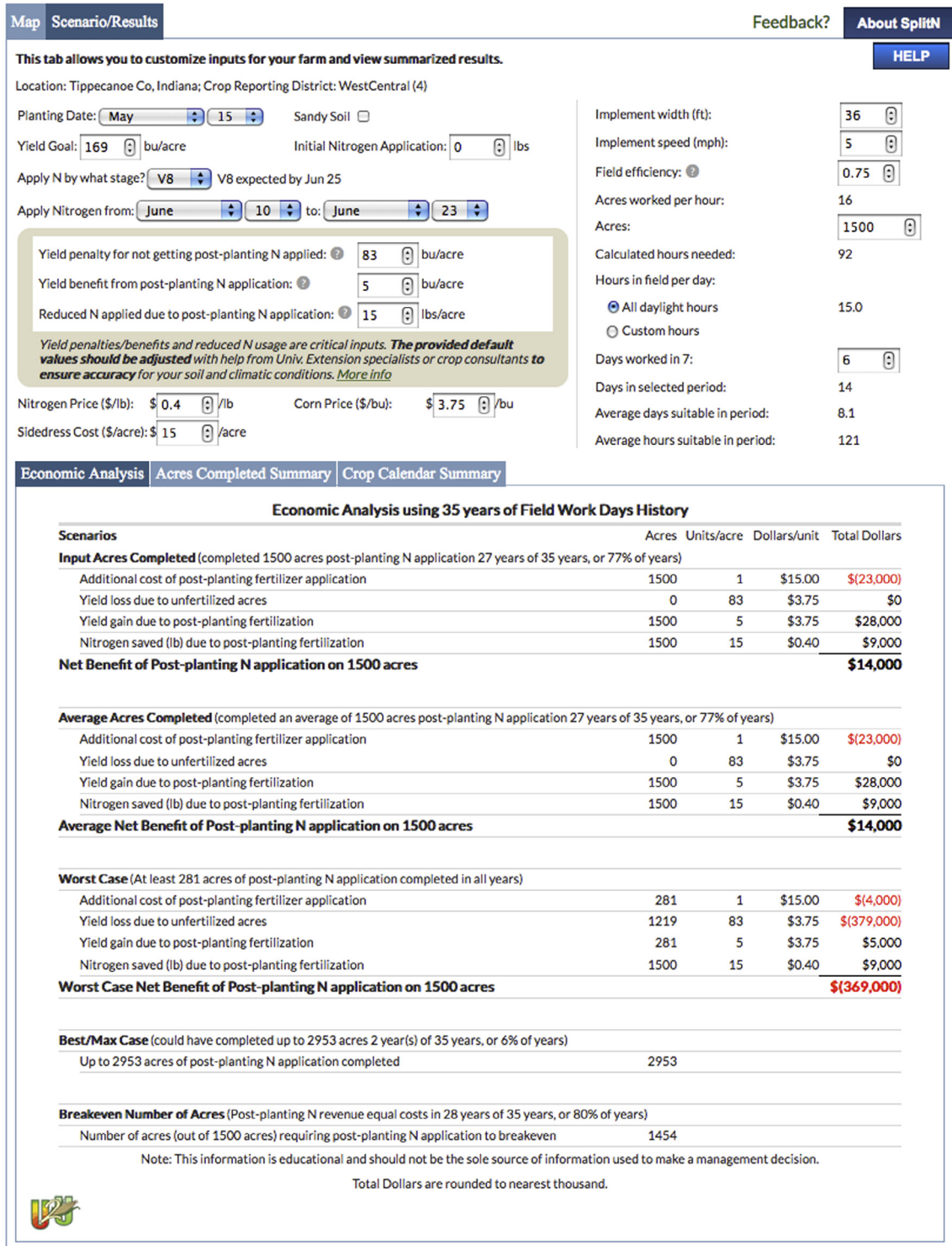


Fig. 13. Illustration of the input scenario and output results for a location within Tippecanoe County, IN and in Indiana crop reporting district 4. The user can enter inputs such as soil information, planting date, prices, penalties and information for determining the acres on which N can be applied during a specified time period. The economic analysis section summarizes the net benefits if nitrogen is applied on all of the desired acres. Summaries are also provided for the average acres that one can expect to cover and the worst case based on the history of field work days for the crop reporting district.

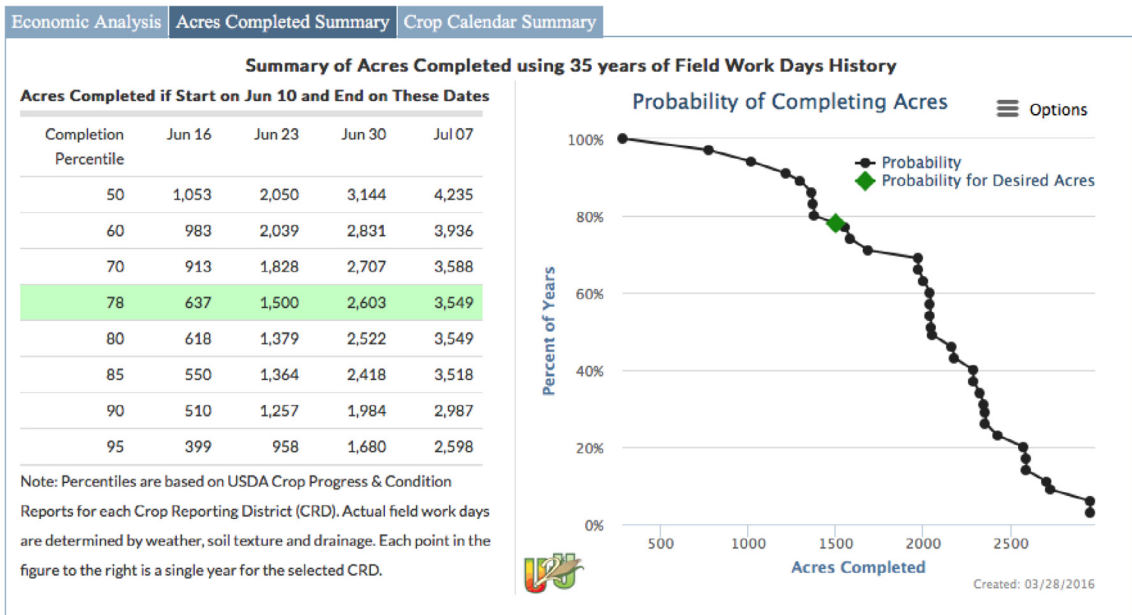


Fig. 14. Table and chart information providing information on the probability of completing nitrogen application for the designated acres based on the 30 plus year workday history.

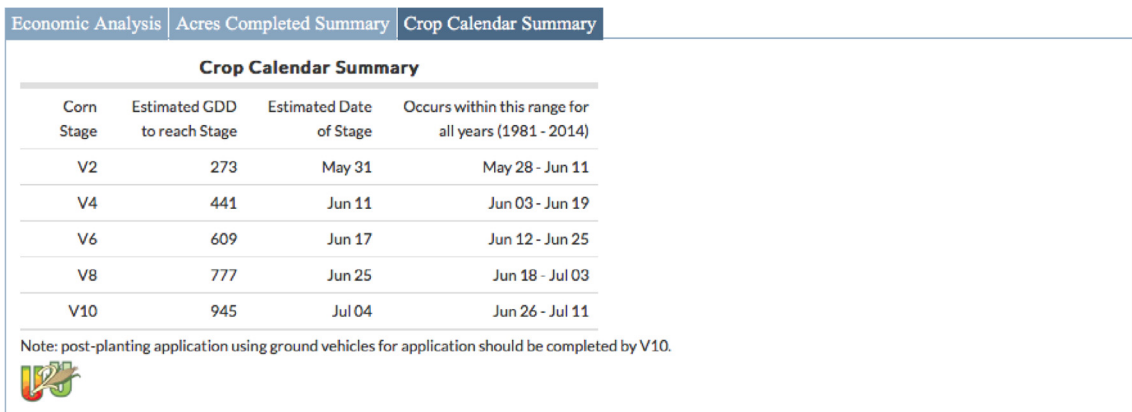


Fig. 15. SplitN tool crop calendar summary output table providing estimates on the dates when early development stages of corn will occur based on the planting date and 30-year history of accumulated GDDs for the selected area.

page provides details about the sources and technical details behind the tool. The user can download a comma delimited text file that includes a 20-year depreciation table and a cash flow table based on the scenario defined in the tool.

This application relies on PHP to perform initial data processing. The application is displayed with a combination of HTML, CSS and JavaScript. User interactions are handled with various JavaScript libraries, and adjustments to any of the values in the entire tool triggers an immediate recalculation of most, if not all of the output values. Through code optimization, these calculations are done nearly instantaneously, with refresh rates occurring in milliseconds.

The tool uses simulated historic yields and potential irrigation water quantities for corn and soybeans based on historic rainfall data and soil texture information that have been spatially weighted to represent individual counties. Simulated dryland and irrigated corn and soybean yields are from the CERES Maize and CROPGRO models implemented in the parallelized version of the Decision Support System for Agrotechnology Transfer (pDSSAT) as part of the Agricultural Model Intercomparison Project (Rosenzweig et al., 2014). The tool also accounts for tax and loan information to identify whether irrigation investment will be profitable long-term. The data inputs and calculations used within the Irrigation Investment DST are described below.

Map
Scenario/Results
Feedback?
About Irrigation

Use this tool to determine if investment in an irrigation system may be profitable by customizing your farming inputs and loan information (red sections), and exploring the gross margins and Net Present Value of an investment over the system lifetime (green sections). The inputs are pre-populated with location-based default values that you should customize to increase the accuracy of your personalized results.

How to use this tool: [Click here to start](#)

1. Capital Costs

2. Yield Goals

3. Crop Rotation & Price

4. Water Applied

5. Gross Margins

6. Net Present Value

Location: Dodge County, NE

Inputs: Capital Cost & Loan Information

Year Purchased:	<input type="text" value="2016"/>	Salvage Value of Investment at End of Evaluated Time Period:	\$67,500
Purchase Price for Entire System Installed:	<input type="text" value="\$ 225000"/>	Amount of Purchase Price Borrowed:	<input type="text" value="\$ 200000"/>
Size of Irrigation System:	<input type="text" value="164"/> acres	Annual Interest Rate for Borrowed Money:	<input type="text" value="4.5"/> %
Life of Irrigation System in Years:	<input type="text" value="20"/> years	Loan Terms in Years:	<input type="text" value="7"/> years

[Additional Tax Options](#) ⚙️

Inputs: About Your Farm +

Inputs: Crop Production Information +

Inputs: Advanced Cost Configurations (Optional) +

Results: Gross Margins based on Crop Rotations and Weather +

Results: Returns over System Lifetime -

The NPV is negative.

More analysis is needed to determine if irrigation may be profitable.

Net Present Value (NPV)	-\$-34,229
Discounted After Tax Cash Flow: ⓘ	
Internal Rate of Return Before Tax: ⓘ	0.5%
Internal Rate of Return After Tax: ⓘ	0.5%


How is this calculated?

HISTORICAL SCENARIO

Suppose you had an irrigation system installed from 1980-2005.

In how many years would it have been profitable?

Based on 26 years of data from 1980–2005 an irrigation system would have increased profit in 11 years and decreased profit in 15 years.



Not Profitable
Profitable

Location: Dodge Co., NE; Created: 08/22/2016

Note: Use of this tool is not a guarantee of any particular economic or yield result, nor of the availability or cost of irrigation water in any location. This tool should not be used as the sole basis for making an irrigation investment decision. Default values are approximate and should be customized for the tool to be most helpful to the user. Consultation with an agronomic expert or irrigation professional should always occur before making major investments or farm management changes.

Fig. 16. Illustration of the scenario/results page being used to allow the user to define the irrigation scenario of interest and display the results of the economic analysis based on 26 years of climate history.

3.5.1. Irrigation investment calculator template

The Irrigation Investment DST is based on a decision support tool by Roger Betz, with contributions from Lyndon Kelley and Dennis Stein, from Michigan State University's Extension Service. Their spreadsheet-based tool provided the framework for this Irrigation Investment DST. The Net Present Value, tax information, and gross margin calculations were derived from

their spreadsheet. Roger Betz and Lyndon Kelley were also consulted during the development of the Irrigation Investment DST.

3.5.2. *When is irrigation worth it?*

The Irrigation Investment DST calculates the number of years (from 1980 to 2005) an irrigation investment would be profitable. The gross margins and net present value are calculated individually, for each year in the historic time period, to see if investment would pay for itself. This calculation does not take the salvage value of the irrigation equipment into consideration, but merely considers if the gross margins under that year's specific conditions would be great enough to cover the average costs and loan repayments for the equipment. Rather than averaging the yield, weather, and irrigation information (as done throughout the rest of the tool), this is calculated individually for each year, using the gathered crop model information. This is done to capture unusual conditions that may show the value (or lack thereof) for irrigation equipment in areas where it may not be profitable to otherwise irrigate. For example, if a location experienced significant drought conditions during two years of the historic period, it may have been profitable to own irrigation equipment during those two years, when over the entire period, the irrigation investment may not be a valuable investment.

3.5.3. *Data processing & tool calculations*

After the user selects a location within the U2U region, corn and soybean yield data are segmented into normal, dry and wet years based on the county yearly Standardized Precipitation Evapotranspiration Index (SPEI).

Calculations that are performed within the tool as the inputs are changed include those related to adjusting yield goals, gross income, variable costs, gross margin, investment costs, depreciation tables and cash flow tables. Several of these calculations are done iteratively over all years of the system life and include a calculation of the present value in each year. By summing all of the annual present values over the life of the system, one can determine a total Net Present Value (NPV) that takes into account all of the user inputs and is an indicator for the soundness of investing in an irrigation system. Additionally, by looking at all of the before tax and after tax cash outflow over the life of the system, the tool calculates an internal rate of return (IRR) for the investment which also assists in the financial decision.

More details on the data processing and tool calculations can be found at [Irrigation \(2016a,b\)](#).

4. Results and lessons learned

The length of time of development of the DSTs from the initial commitment to releasing the first version to the public varied from 14 to 16 months. Using the ACV tool as an example, the initial beta version of the tool was ready for focus group testing (those outside of the U2U project) nine months after the initial commitment to develop the tool. This time included several weeks of design and planning and several iterations before deciding on the layout and software packages that worked well and provided the best user experience. The tool was officially released six months after the start of focus group testing to be ready for the 2014 growing season. The Corn GDD tool took 12 month from commitment to focus group test but was ready for release four months later. The time for development was based on the complexity of the tool and the programming resources available during the development phase. The latest tool, Irrigation Investment, took the most programming resources due to the complexity of the tool. The overall designs of the tools were based on what was learned from the ACV tool that was the first one under active development. A number of software elements (e.g., maps, plots, tab-based layout, etc.) were reused across different tools. Some of the DST development phases overlapped (e.g., fleshing out UI design vs. coding, focus group testing vs. starting on a new tool with a different sub team), allowing a small number of developers to complete all five tools throughout the project.

Additional programming time was needed to account for system changes, including updates of new versions of HUBzero and other open source software packages being used. For example, one of the HUBzero updates, Super Group, allowed for the U2U project to create their own brand (web site design) while being hosted on a shared hub, but also required changes in the DSTs' underlying code. The latest changes are related to making the tools easier to transfer to other sites. The tools have been converted to use OpenLayers 3 instead of OpenLayers 2 that is no longer being updated. Also the tools now do not need to access a GeoServer to provide the vector files.

Faster tool development occurred when a programmer was assigned as the tool developer as their primary task to work on for several months. Continual communication with short turnaround feedback from the design team was a key factor of meeting delivery timelines. The development team during the course of the project consisted of one or two professional programmers along with a graduate and an undergraduate student during portions of the project.

Responsive feedback for users of the tools was an important criterion. An extreme example of a change for faster feedback involved the Corn GDD tool. Initially the time between selecting a location to the plot of the data for that location took up to 80 s; the time delay made the tool unusable. The data behind the tool was reorganized from a separate GeoTIFF file for each of the 30 plus historical years to one GeoTIFF file with the data organized in layer (year and day) interleaved by pixel (location). This allowed the tool to read all of the data for the selected location with one file read. This reduced the time from selecting a location to the display of the plot to three seconds; the Corn GDD tool became useable. Another change that was made during the tool development process, as mentioned before, was to reduce the dependencies on other servers such as a GeoServer to provide vector files. The GeoServer would experience periodic downtimes that caused the U2U tools to not work.

Table 1

Summary of the number of users and pageviews for the U2U web site and for the four tools which are available on the production web site for the duration of the project to date and for the last 3 months of 2015 (Klink et al., *this issue*). At the time of this writing the Irrigation Investment tool was in the final development stages and therefore usage statistics were unavailable.

	Users		Pageviews	
	Oct–Dec 2015	Entire duration	Oct–Dec 2015	Entire duration
U2U Website	3,147	26,818	13,927	115,486
<i>Decision support tools</i>				
Corn GDD	625	9276	1,196	21,964
SplitN	947	2894	1,394	5689
ACV	540	3340	1,067	6938
CPV	328	2304	450	5686

Users: Those that have had at least one session; this includes both new and returning users.

Pageviews: Total number of pages viewed; repeated views of a single page are also counted.

One way to evaluate the usefulness of web-based tools is to track the usage with a web analytics service like Google Analytics (Table 1). The usage statistics in Table 1 indicate that the U2U website has been active. The usage statistics also indicate that the Corn GDD tool is the most popular. SplitN and ACV are the next most used. The time up front in designing the DST user interfaces and the extensive outreach and training efforts through university Extensions of the U2U partnership are recognized as the key to the rapid adoption and usage uptake of the DSTs.

5. Conclusions

In this paper we described the overall HUBzero based cyberinfrastructure design to support the research, collaboration, and dissemination needs of the U2U project. Five decision support tools were developed using the software stacks and computation resources provided by the cyberinfrastructure with the focus on building rich and user friendly interfaces and delivering knowledge of climate impact on agricultural production based on historical and prediction datasets. An adaptive software development process was adopted which supports a fast and iterative development cycle that is continuously driven by user feedback and expert validation. These U2U decision support tools will be transferred to the appropriate Regional Climate Centers for continued public access after the U2U project is completed.

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