UF | IFAS Extension
UNIVERSITY of FLORIDA

AgroClimate

# AGROCLIMATE WORKBOOK

USDA

Florida Climate Institute

SERCH
Southeast Regional Climate Hub

# AGROCLIMATE WORKBOOK

## A Guide for Climate and Agriculture in the Southeastern U.S.

## Overview

The long-term sustainability of the nation's farms, ranches, and forests depend on raising productivity while protecting the environment and being resilient to changes in climate. The sustainable intensification of agricultural production is a central component of a global vision to ensure food security and feed a world population of more than9 billion people by the year 2050. Weather and climate extremes such as droughts, floods, and heat waves are expected to have a significant impact on global agricultural production. This workbook has been developed to serve as a basic introduction to the effects of climate on agriculture, and to be used in conjunction with AgroClimate.org decision support tools and information. In each chapter, you will find an introduction to a new concept with background information, an introduction to related AgroClimate tools, and an activity to demonstrate the tools' uses and functions. At the end of the workbook we provide a glossary for ease of use and understanding.

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# CHAPTER 1

## Introduction to Weather and Climate

### Key messages

- Weather represents changes in the atmosphere at any particular time and place.
- Climate describes the combination of weather and its extremes over a long period of time.
- While changes in weather can occur in a moment, changes in climate take place gradually over many years.
- Every year, extreme weather events such as heat waves, prolonged dry and cold spells, and floods have a big impact on human lives and livelihoods.
- Changes in climate cause variations in the frequency and magnitude of weather events, which may result in more frequent and/or severe floods, droughts and heat waves.

## Weather vs. Climate

Weather and climate are often used interchangeably, but have an important distinction. While they both rely on observations of temperature, pressure, sunlight, clouds, rain, and snow, their time scales are very different. Weather describes a snapshot of the atmosphere at a single point in time or over a period of a few days. Climate, in contrast, looks at atmospheric conditions spanning months, years, and even decades. A good way to remember this difference is: *Weather tells you what to wear on any given day; climate tells you what wardrobe to own*.

## Factors Driving Our Climate

**There are many factors that influence climate. A few of them are described below:**

## Latitude and Sun Angle

As the Earth rotates around the sun, the tilt of its axis causes changes in the angle at which the sun's rays reach the earth. As a result, the number of daylight hours varies at different latitudes. The North and South poles experience the greatest differences, with long periods of darkness in winter and up to 24 hours of daylight in the summer (Ahrens, 2012).

**Topography and Altitude**

The topography and altitude of an area have an important influence on our climate. Mountain ranges represent natural barriers to the flow of air and can have a major effect on rainfall distribution. When wind blows over a mountain, moist air expands and cools as it is forced up the slope, and rain is produced when the air becomes saturated. Altitude also influences the climate, since temperature usually decreases as altitude increases (Ahrens, 2012).

**Geography**

The position of a town, city or place and its distance from mountains and large water bodies influences prevailing wind patterns and the types of air masses that affect it. Coastal areas often experience refreshing breezes in summer, when cooler ocean air moves towards the shore (Ahrens, 2012).

**Climate Cycles**

A climate cycle is a recurring and persistent pattern in the atmospheric and or ocean circulation. The best known example is the El Niño - Southern Oscillation (ENSO). During El Niño, sea surface temperatures in the Eastern and Central Pacific Ocean are much warmer than usual and easterly winds are less strong, causing a knock-on effect on weather patterns around the world. Conversely, La Niña is associated with cooler sea surface temperatures and stronger easterlies in the Pacific. The effects of La Niña on weather patterns tend to be the reverse of those associated with El Niño. ENSO is the most important source of global climate variability at the interannual scale and impacts rainfall and temperature patterns in many parts of the world (Trenberth et al. 2007). Other climate cycles include the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO).

## Climate Tools on AgroClimate

**Freeze Risk Probabilities**
(http://agroclimate.org/tools/Freeze-Risk-Probabilities/)

The Freeze Risk Probabilities tool is a simple index used to monitor and predict probabilities of reaching critically low temperatures at least once during the ongoing winter. The following statistics are provided:

**All Season Risk Freezes:** Probabilities of reaching critical temperatures at least once during the ongoing winter.

**Early Season Freezes:** The expected dates of *first* freezes at the 10%, 50%, and 90% probability levels. Each of the probability maps show the average dates when the first 32°F freeze has occurred in your county. 50% probability maps show that, historically, half of the freezes have occurred before a given date and half after that date. 10% probability maps show the first freeze has occurred on a given date or before in only 1 out of 10 years. 90% probability maps show that the first freeze has occurred before a given date in 9 out 10 years, and only in 1 out 10 years has the first freeze occurred by or after that date.

**Late Season Freezes:** The expected dates of *last* freezes at the 10%, 50%, and 90% probability levels. Each of the probability maps show the average dates when the last 32°F freeze has occurred in your county. 50% probability maps show that, historically, half of the freezes have occurred before a given date and half after that date. 10% probability maps show that the last freeze has occurred on a given date or later in only 1 out of 10 years. 90% probability maps show that in 9 out 10 years, the last freeze has occurred by a given date or later, and only in 1 out 10 years has the last freeze occurred that soon.

**Rainfall and Temperature Monitoring**
(**http://agroclimate.org/tools/Climate-Monitoring/**)

The Rainfall and Temperature Monitoring tool provides an opportunity to visualize and monitor total rainfall, maximum temperature and minimum temperature patterns across the Southeast for the current season. The user can select a time period for accumulated rainfall and average temperatures going back 2, 3, 7, 15, 30, 45, 60, 90, 120 and 150 days.

**Climatology**
(**http://agroclimate.org/tools/Climate-Anomalies/**)

This tool provides US-wide gridded, monthly, ENSO-specific climate data for rainfall, minimum temperature, and maximum temperature using PRISM monthly data (PRISM Climate Group, 2004) from 1950 to 2013. ENSO classification is based on MEI index (Wolter and Trimlin 1993). Deviations from average are calculated using the 1950-2013 years as the average. An interactive map is also available, whereby individual county-specific data may be visualized.

**Weather Stations**
(**http://agroclimate.org/tools/climate-risk/**)

This tool provides station-based current observations and long-term climatology for several weather stations in the Southeast US, as well as multiple statistics including average and deviation, probability distribution and probability of exceedance for all years, El Niño, La Niña and ENSO Neutral years. Also offered is the possibility to compare ENSO phases. Station data sources include Florida Automated Weather Network (FAWN), NWS Cooperative Observer Network (COOP) and Georgia Automated Environmental Monitoring Network (GAEMN). Selected data sources include both current and historical data while others only have historical.

## Rainfall and Temperature Monitoring Tool Activity

Navigate to the **Rainfall and Temperature Monitoring** tool in your browser. (**http://agroclimate.org/tools/Climate-Monitoring/**)

## Activity Questions

1. Under *Current Season:* Where in Florida (Panhandle, North, Central or South) can you observe highest and lowest a) total rainfall amounts b) maximum temperature c) minimum temperature over the past 60 days?

________________________________________
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2. Under *Climatology and Deviation:* Select the Last 30 days period. Which part of the Florida (Panhandle, North, Central or South) experienced the most pronounced a) positive and b) negative deviation in maximum temperature relative to the long term (historical) climatology?

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**Navigate to the Weather Station Tool** (**http://agroclimate.org/tools/climate-risk/**)

1. Under the first tab Map, choose a station in Alachua County (Zipcode: 32611). NOTE: Make sure that you pick a FAWN station, which contains both current and climatology data, the information is contained in the legend of the map. Select the Average tab. Select "Click for Graphs/Data". For a) El Niño, b) La Niña and c) Neutral years, list the Average and Deviation in total rainfall and absolute maximum temperature for the month of February.

2. Select the Probability Distribution tab. What is the probability that there will be 4-5 inches of rainfall in November in Alachua County during a) El Niño, b) La Niña and c) Neutral years?

3. Select the Probability of Exceedance tab. What is the probability of having 4 or more inches of rainfall in November during a) El Niño, b) La Niña and c) Neutral years?

4. Select the Current tab. How does rainfall observed during the last 30 days compare with the long term average for the current ENSO phase?

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# CHAPTER 2

## Climate Information and Decision Making in Agriculture

### Key messages

- Agricultural production is always subjected to production risks associated with climate variability.
- The use of short-term weather forecasts and seasonal climate outlooks can help reduce production risk in agriculture.
- El Niño - Southern Oscillation (ENSO) phase forecasts help most strategizing actions during the fall and winter seasons.
- AgroClimate provides ENSO phase and seasonal forecasts produced by NOAA and other sources.

Agricultural production is always subjected to risks associated with climate variability. Producers are often at the mercy of natural forces they cannot control, especially changes in rainfall from season to season and year to year.

Figure 2.1. Most crop losses are due to excess or lack of rainfall.

Variations from the "normal" climate can set the stage for other kinds of production risks, such as pest and disease incidence. Some weather patterns, such as high temperatures, high humidity, or higher than normal rainfall, can raise the chances of fungal diseases. They can also improve conditions for insects and other pests that spread disease among plants and fields (Fraisse et al., 2006). Crop development and yield responds to both individual weather events and seasonal climate variation.

Producers can use weather and climate information to reduce production risk, increase resource use efficiency and the profitability of agricultural operations. Depending on the decision to be made, either short-term weather forecasts or seasonal climate outlook can be incorporated into their decision-making process together with other important factors such as commodity prices, government programs, and consumer preference.

Decisions such as which crop and variety to plant and whether or not to purchase crop insurance need to be made well ahead of the planting date. The lead-time required for making a decision is an indicator of what sort of forecast would be needed. It is well known that short-term weather forecasts are usually fairly accurate in terms of predicting the significant weather features for the coming 1 to 3 days. As lead times increase to 7 or 10 days, the accuracy decreases significantly and needs to be revised as that day approaches. Seasonal climate forecasts or outlooks are probabilistic by nature and predict anomalies of the climate (i.e., the probabilities of seasonal precipitation amounts or air temperature being above, below or within the long-term climatological average). The total rainfall, for example, may be predicted to be higher than the climatological average due to a greater-than-normal expected frequency of a specific atmospheric circulation pattern such as an ENSO event that is conducive to rainfall at the location in question. However, the specific timing of rainfall events or days with temperature above or below climatological averages remains unknown (IRI, Tutorial #2, 2015).

Short-term **weather forecast** indicates the state of the atmosphere with respect to air temperature, rainfall, wind speed and other variables for the next hours or few days. **Seasonal climate outlooks** normally predict the probabilities of rainfall or air temperature in the coming months being above, below, or within the long-term climatological average.

Seasonal forecasts are often presented by comparing the expected conditions in the coming months to the long-term average conditions during those months (based on recent 30-year monthly averages). Seasonal forecasts are regularly provided by the NOAA Climate Prediction Center as maps (Figure 2.2) with shaded areas indicating the most likely of 3 categories: above average, near average, and below average for seasonal precipitation and temperature. These 90-day seasonal forecasts of precipitation and temperature are made based on ENSO

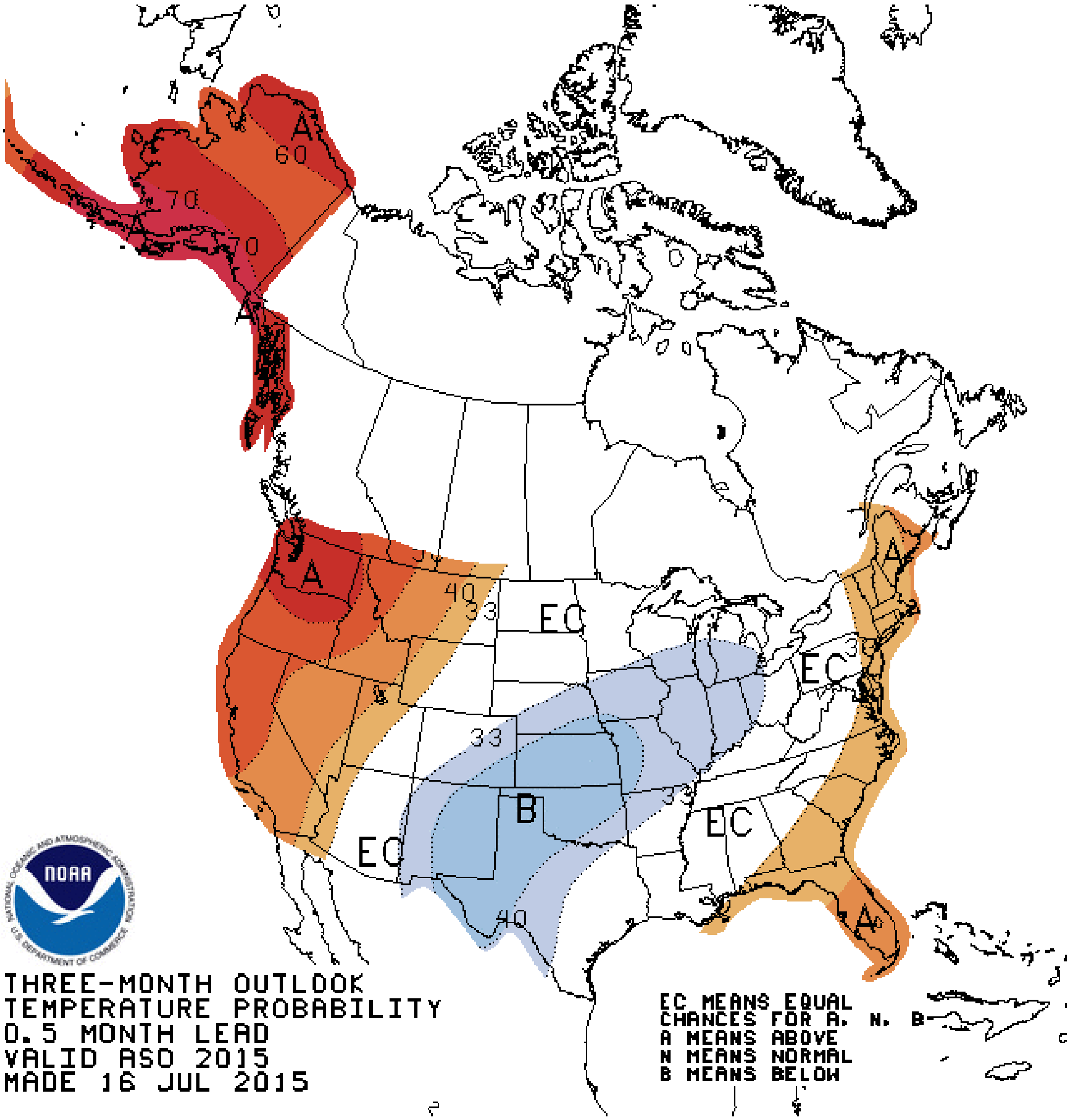


Figure 2.2. Seasonal outlook for August, September and October of 2015 showing an increased chance of above average temperatures for the Southeast (NOAA Climate Prediction Center, July 16, 2015).

phase (El Niño, La Niña, Neutral), recent climate trends, soil moisture, and several other factors. The accuracy of these forecasts is generally greater than just using the climate normals (averages from 1981-2010) to forecast climate.

The shaded areas on the maps above show the probability that temperature is above normal (A), about average (N), or below normal (B). For each location and month, the coldest (or driest) 10 years from the 30 years of 1981-2010 define the “B” below-normal category; the warmest (or wettest) 10 years define the “A” above-normal category, and the remaining 10 years define the “EC” equal chances or normal category. Without any forecast, the chance of conditions being in each of the 3 categories is 33.3%. With a forecast, shading is used to show areas where probability is greater than 33.3%. At any location on the map, the probabilities for each of the 3 categories (above normal, near normal, or below normal) adds up to 100%.

## How can weather and climate forecasts help in making decisions on the farm?

Producers make decisions every day on a farm, and while many of them are not affected by the weather or climate, conditions change dramatically when crops are on the ground or even before that. A typical flow chart of actions taken during a cropping season is presented in Figure 2.3.


Figure 2.3. Farmer decisions during a typical growing season.

Before a crop is planted, a producer must make a number of decisions, including what crop and variety to plant, the acreage allocation for different crops and varieties, a fertilization strategy, and whether or not to purchase crop insurance, as well as the level of coverage. The choice of a crop to plant is mostly driven by commodity prices and crop rotation schedules. The heavy financial investment in equipment and infrastructure (such as cotton combines or grain storage facilities) also reduces farmers' flexibility to respond to changing conditions (Crane et al., 2008).

Seasonal climate outlooks can also help in deciding about crops, varieties, crop insurance coverage levels and marketing. However, unlike short-term forecasts, farmers are normally not in the habit of actively seeking seasonal climate forecasts for use in management decisions. Instead, 90-day climate forecasts are occasionally encountered in the farm press, mainstream media, or other sources. Additional tools such as crop growth and yield simulation models may be needed in conjunction with seasonal forecasts to translate meteorological variables into a decision aid tool. If a seasonal forecast indicates a high probability of below average precipitation a producer may rethink the insurance coverage level for rainfed crops, perhaps tone down the investment in fertilizer or consider planting a more drought resistant crop. Decisions made with input from seasonal forecasts are more strategic in nature and demand a more in-depth analysis of how expected weather patterns in the season may affect crop development and yield.

Table 2.1 gives examples of management options that could be adjusted in fall and spring, when the ENSO signal is stronger in the southeastern US, based on the expected seasonal climate outlook. Any management modifications based on ENSO phase or seasonal climate outlooks are typically location-specific and season-specific; therefore, no general "best practices" for modifying agricultural management are available. However, producers can make some management changes when lower-than-average rainfall and higher-than-average temperatures (or higher-than-average rainfall and lower-than-average temperatures) are expected. The nature of the management adjustments will depend on a producer's system and on the direction and probability of rainfall and temperature departures from average.

**Table 2.1.** Management options across seasons for the southeastern US.

| Season | Management options |
|---|---|
| Fall | Harvest planning: Schedule labor and equipment to adjust timing of harvest in order to avoid damage/losses from excess rainfall. |
| | Choice of winter cover crop. |
| | Cover crop establishment: Hasten the establishment of cover crop in seasons when it is expected that cover crop growth will be reduced because of lower than average rainfall or when excess rainfall is expected to avoid soil erosion. |
| | Fertilization of cover crop. |
| | Winter pasture: invest on winter pasture when climate conditions are expected to be favorable, otherwise plan ahead for feed purchase. |
| Spring | Insurance coverage adjustments. |
| | Termination of cover crop: Could be early or late depending on recent and expected rainfall. |
| | Crop and variety selection: Decide which cash crop(s) to plant and to what extent. |
| | Planting dates of cash crops. |
| | Plant population: Adjust seeding rates based on expected seasonal rainfall, for example, lower than average rainfall, lower plant population. |
| | Fertilization: Adjust fertilization strategy based on expected rainfall. |

Once the cropping season starts short-term forecasts can help farmers decide about a range of field operations such as planting, application of agricultural chemicals, irrigation timing and amounts, and harvesting. Over-use of agricultural chemicals like fungicides and inorganic N fertilizers can lead to the contamination of food produce, water resources and soils. Table 2.2 lists examples of decisions that can be made based on short-term weather forecast and seasonal climate outlooks.

**Table 2.2.** Potential decisions that can be made based on short-term weather forecast and seasonal climate outlooks

| Seasonal Climate Outlook Strategic Decisions | Short-term Weather Forecast Operational Decisions |
|---|---|
| Crop and variety selection | Planting |
| Acreage allocation | Application of fungicides and insecticides |
| Planting dates | Fertilization |
| Crop insurance | Irrigation (when and how much) |
| Marketing | Harvesting |
| Purchase of inputs | Hay cutting |
| Fertilization strategy | Cold protection |
| Pest and diseases control strategy | |

## Climate Information and Decision Making in Agriculture Activity

ENSO phase forecast and seasonal outlooks can help producers strategizing field activities for the coming months while short-term weather forecasts can help deciding about field operations. Select a region of interest to you in the southeastern U.S. for this activity. Check the ENSO phase forecast for the next three months available in the main page and all the forecasts provided in the Forecasts section: **http://agroclimate.org/forecasts/**

## Activity

Answer each question below using the forecasts as well as the precipitation and temperature monitoring and climatology tools available on AgroClimate.

1. What is the current forecast for the ENSO phase during the next 3 months?

    ______________________________________________

    ______________________________________________

    ______________________________________________

2. Does the current NOAA seasonal forecast show any probability "shift" for precipitation or temperatures in your region of interest? If yes provide details.

    ______________________________________________

    ______________________________________________

    ______________________________________________

3. Given the current season and forecasts are there any opportunities to adjust management practices in order to reduce agricultural production risk in your region of interest?

    ______________________________________________

    ______________________________________________

    ______________________________________________

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# CHAPTER 3

## Drought and Agriculture

### Key messages

- Droughts are prolonged dry spells that are sometimes accompanied by high temperatures.
- Agricultural drought directly affects agricultural systems. It is characterized by moisture shortage in the root zone restricting crop or forage growth, which can have devastating impacts on agriculture.
- Drought indices can be used to quantify drought intensity, compare drought in different regions, compare current to past conditions, and provide a regional overview of potential impacts of droughts.
- The ARID tool can be used to monitor current drought conditions in the southeastern U.S., to determine historical drought and to verify how the El Niño - Southern Oscillation (ENSO) influences it.

## What is drought?

Droughts are a natural part of the climate system and affect most parts of the world. This natural hazard is the main cause of losses in agriculture around the globe. **Drought** is defined as insufficient soil moisture. It can be caused by a lack of significant rainfall, increased water losses (by evaporation or evapotranspiration) due to abnormally elevated temperatures, or a combination of the two (Mckee et al. 1993; Mo and Schemm 2008; Piechota and Dracup 1996). The beginning (drought onset) and end of a drought are often difficult to determine. Several weeks, months, or even years may pass before people know that a drought is occurring. The end of a drought can occur as gradually as it began (Moreland 1993). As drought is commonly characterized as a deviation of current conditions from average ones, it is extremely important to define historical conditions for each location.

## Types of drought

Depending on a drought's features, it can be characterized into different categories. The most important categories for agricultural purposes are **meteorological**, **agricultural** and **hydrological** droughts.

**Meteorological drought** is characterized by a situation in which the precipitation (rainfall or snow) is significantly lower than the climatologically expected precipitation over a region. Drought onset generally occurs with a meteorological drought.

**Agricultural drought** is a drought that directly affects agricultural systems. It is characterized by moisture shortage in the **root zone**, restricting crop or forage growth. It occurs when water losses resulting from evapotranspiration, runoff, and percolation are higher than precipitation. Therefore, it depends not only on precipitation amounts, but also on precipitation intensity, crop water demand (i.e., **crop evapotranspiration**), soil type, previous soil moisture conditions, slope, and **infiltration rates**. The impact of agricultural drought also varies depending on the crop growth stage, since some growing stages (such as flowering) are more sensitive to water stress. Agricultural drought is typically last for days to weeks. Depending on the growth stage, plants can recover from drought with sufficient precipitation or irrigation.

**Hydrological drought** is characterized by below-average levels of surface and subsurface water, such as decreased reservoir, lake and groundwater levels as well as a reduced flow of streams. If this type of drought develops gradually and rainfall continues at reduced rates, the drought may not strongly influence agricultural systems. However, hydrological droughts that last for an extended period of time can negatively impact crops and pastures. Moreover, hydrological droughts can affect farm systems that use irrigation and livestock operations.

## How to quantify drought

As drought is part of the climate system and has a diverse geographical and temporal distribution, it is difficult to quantify and to determine its onset. One way to quantify drought is by using **drought indices**. Drought indices produce a number from the integration of several components of a drought, such as precipitation, streamflow, temperature, evaporation, etc. Through this integration, a bigger picture of the problem can be seen. Drought indices

It is crucial to compare current drought conditions with historical ones to determine if what is currently observed is above or below the expected. Drought indices allow this comparison because they are calculated using weather information.

can be used to quantify drought intensity, compare drought in different regions, compare current conditions to previous ones, and provide a regional overview of the potential impacts of droughts.

As there are several types of drought with complex interactions between components, there is no drought index that is suitable for all situations. Commonly used indices include the Agricultural Reference Index for Drought (ARID), the Keetch-Byram Drought Index (KBDI), the Lawn/Garden Moisture Index (LGMI), the Palmer Drought Severity Index (PDSI), and the Standardized Precipitation Index (SPI).

There are several products that can help stakeholders to understand and monitor drought conditions. These include the U.S. Drought Monitor, the U.S. Monthly Drought Outlook, the U.S. Drought Portal, the U.S. Drought Impacts Report and others. All of these products can be found at the **U.S. Drought Portal**, **http://www.drought.gov/**.

## Agricultural Reference Index for Drought (ARID)

For agricultural purposes, ARID is a more valuable index because it takes into account the soil-plant-atmosphere relationship. ARID is a simple index that indicates how dry the soil is, and it is used to monitor and predict agricultural drought. ARID uses a simple water balance for a soil profile assumed to be 40 cm (16 in) deep with evenly distributed roots. The soil water is calculated based on how much water is added into the system by rainfall and how much water is lost by through transpiration, runoff, and drainage (Figure 3.1).

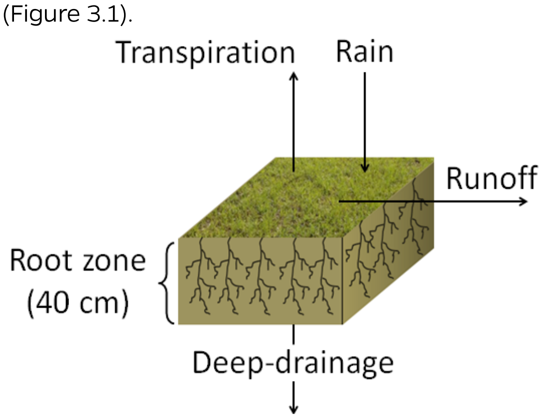


Figure 3.1. Soil water balance components

A plant water deficit occurs when there is insufficient water in the soil profile to meet the needs of plants. When the amount of water available in the soil satisfies plant needs, transpiration reaches maximum values (the same of potential evapotranspiration). If water available in the soil does not satisfy plant needs, plants cannot have the normal transpiration. Therefore, transpiration is smaller than potential evapotranspiration. ARID can be defined as the ratio of actual transpiration (T) to potential evapotranspiration ($ET_o$):

$$ARID = 1 - \left(\frac{T}{ET_o}\right)$$

ARID values range from 0 to 1. When no transpiration occurs (T = 0), ARID takes a maximum value of 1, indicating a full water deficit, whereas ARID is 0 when transpiration occurs at potential rate ($T = ET^o$), indicating no deficit at all. ARID values increase gradually during dry spells and decrease rapidly with rainfall events. As the index represents cumulative days under water stress conditions, it can be associated with yield losses and compared to historical typical values for the same period in the same location, allowing users to track and quantify drought conditions.

## Lawn/Garden Moisture Index (LGMI)

The LGMI is an index used to indicate current soil moisture to support healthy lawns and gardens. It is calculated in two steps:

1. The precipitation of the previous 21 days is taken into account, with the more recent precipitation events being more significant than the last ones. For LGMI, the 7 days before the current day are considered equally important, while the contribution of the previous 14 days declines in a linear way, as shown in Figure 3.2.

2. Calculate how much the current rainfall differs from the standard amount rainfall considered adequate to support healthy lawns and gardens. The standard rainfall amount varies depending on the time of the year. During winter, the requirement is much lower than during summer. To keep the index simple, the standard requirement does not vary depending on the location and soil or grass type.

## Drought Monitoring Tools on AgroClimate

**ARID Monitoring and Forecast (http://agroclimate.org/tools/ARID-Monitoring-and-Forecast/)**

The ARID Monitoring and Forecast tool monitors ARID values during the last 90 days based on data collected at automated weather stations from the Florida Automated Weather Network (FAWN) and the Georgia Automated Environmental Monitoring Network (GAEMN). Moreover, this tool provides average ARID values for each month and for each phase of **ENSO**, as well as the probability of ARID

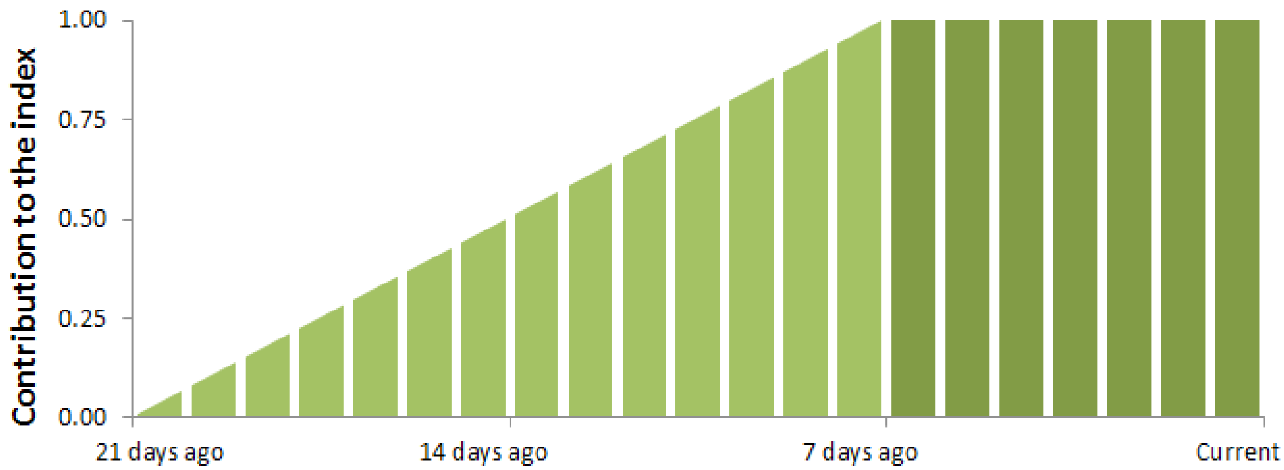


Figure 3.2. Scale used to determine the contribution of each day on the LGMI.

## Why the ARID tool was developed

The ARID Monitoring and Forecast tool was created to monitor current drought conditions in the southeastern U.S., to determine historical drought and to verify how ENSO influences it. As the region's soil is almost always somewhat dry, it is very important to compare current conditions with historical ones to determine if current observations are above or below the average.


Figure 3.3. Daily ARID values (line graph) and ENSO phases comparison (table and bar graph) indicating that ARID is on average higher during La Niña years.

exceeding certain values. It is done for most counties in the southeastern U.S., based on data obtained from National Weather Service COOP (Cooperative Observer Program) weather stations. The user can select among three soil types (sand, sandy loam, and loam) and the ENSO phase of interest. The tabs "Current" and "Tabular Data" are available only on locations with current weather data. Under the tab "Current", the user can monitor ARID values up to the last 90 days. Moreover, the user can compare ARID from the selected period with historical values for the same period to verify how current conditions differ from the expected ones. Under "Tabular Data", the user can see daily weather data, $ET_o$, ETa (actual evapotranpiration) and ARID values for the selected period. Under "Average/Deviation", the user can see monthly average ARID or monthly deviation from historical values. Under "Probability of Exceedance", the user can see the probability of ARID exceeding certain values.

**The LGMI Monitoring Tool**
**(http://agroclimate.org/tools/LGMI-Monitoring/)**

The Lawn/Garden Moisture Index (LGMI) measures the capacity of current soil moisture to sustain healthy lawns and gardens. This index is calcu lated in two stages: 1) the amount of recent precipitation contributing to current soil moisture, and 2) the amount of rainfall adequate for that time of the year. If current precipitation is higher than the adequate one, the index is positive indicating satisfactory precipitation. If current precipitation is lower than the adequate one, the index is negative indicating precipitation deficit.

## ARID Drought Index Activity

A peanut grower in Attapulgus City, GA observed some drought in the last 3 months. He is concerned that the crop could have suffered water stress during development. The grower knows that, for peanut, the most sensitive growing phases for water deficit are flowering and yield formation, especially the pod-setting period. **Is the drought observed by the grower normal? Is the drought likely last until the end of the season? Do you think the grower will have yield losses caused by drought problems?**

## Information

- Attapulgus City, Georgia – zip code 39815
- Sowing date = 60 days ago
- Growing period (days from sowing to harvest) = 120 days
- From sowing to flowering = 40-50 days

## Activity Questions

Answer each question below using the Information above and the Agricultural Reference Index for Drought (ARID) tool (**http://agroclimate.org/tools/ARID-Monitoring-and-Forecast/**):

1. What was the average ARID for a sand soil since sowing date?

   ______________________________________
   ______________________________________
   ______________________________________

2. Was the soil moisture during flowering above or below historical average for the current ENSO phase?

   ______________________________________
   ______________________________________
   ______________________________________

3. Do you expect dry conditions during harvest?

   ______________________________________
   ______________________________________
   ______________________________________

4. If the crop was sowed 30 days later (30 days ago), would it suffer higher or lower water stress during flowering period? (hint: Use the "Climatology: Probability of Exceedance" tab)

   ______________________________________
   ______________________________________
   ______________________________________

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# CHAPTER 4

## Crop Yield Risk

### Key messages

- Rainfall and temperature variability are important risk factors in crop production.
- Variable weather patterns may increase pressure from diseases and pests.
- Historical crop yield records can help understand and quantify production risk associated with climate variability.
- Crop growth models can help evaluate the effects of climate on crop yield and develop yield risk mitigation strategies.
- Several strategies exist to help increase the resilience of cropping systems.

The bottom line in production agriculture is crop yield. Improving crop yield is the subject of continual study as researchers produce new plant varieties and agrochemicals and seek out the best management practices. Producers use these science-based tools to overcome challenges due to factors such as soil type and quality presented by their location (Fraisse et al., 2006). However, as discussed in Chapter 2, most agricultural production is always subject to risk associated with climate variability. Crop yield risk comes from the unpredictable nature of natural factors such as weather or the performance of crops under the pressure of diseases and pests or other unforeseen factors.

In the U.S., yields tend to be most dependable in the central Corn Belt, where soils are deep and rainfall is mostly reliable (Harwood et al., 1999). Nevertheless, modern agriculture is practiced successfully in all parts of the U.S. In the Southeast, there is plenty of rain -- annual rainfall averages around 50 inches (1,270 mm) (https://climate.ncsu.edu/edu/k12/.SEPrecip) -- and that should ensure good crop yields. However, other factors can reduce the usefulness of available rainfall. For example, in certain areas, such as the Florida panhandle, yields can vary substantially because soils have a low water-holding capacity, and there is always a potential for poor rainfall distribution, dry spells or low rainfall amounts during critical phases of crop growth.

Temperature is also an important risk factor in crop production and of great importance to crop growth and development. Air and soil temperatures affect the germination of seeds, the rate of plant growth and development, the functional activity of plant roots, and also the severity of certain plant diseases. Although heat stress is detrimental to all phases of plant development, the reproductive phase is much more susceptible, especially relative to short but extreme stress conditions during the flowering and early grain-filling periods (Barnabas et al, 2008). For example, the effect of extreme temperature events on winter wheat yield has been studied in the southeastern U.S. using several indices, such as the Daytime Heat Stress Index (DHI), Nighttime Heat Stress Index (NHI), Freeze Damage Index (FDI), Precipitation Availability Index (PAI), and Vernalization Completion Date (VCD) (Woli et al., 2015).

Producers in the southeastern U.S. can choose from several strategies to help minimize the impacts of adverse climate on crop yield. As described in chapter 2, seasonal climate outlooks can help define potential strategies, such as changing crops or varieties and planting dates. Nevertheless, the process of minimizing yield risk must include an understanding or quantification of the risk involved based on historical records of crop yield and weather patterns for the region of interest and the ability to simulate "what-if" scenarios that take into consideration the location, management practices combined with forecasts, and in-season monitoring of weather conditions (Figure 4.1).

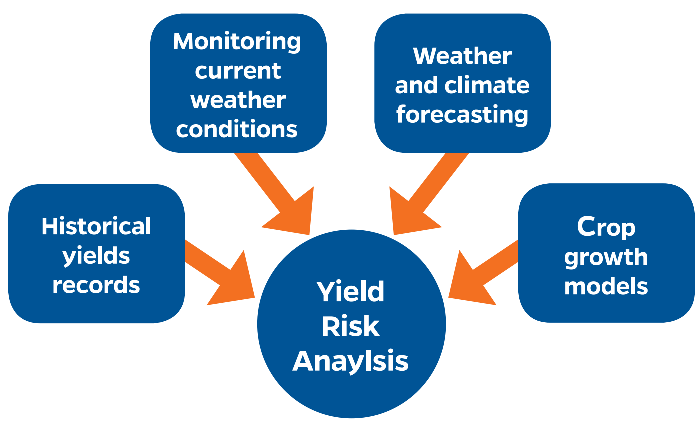


Figure 4.1. A framework for analyzing crop yield risk includes the analysis of historical yield records, monitoring current conditions, use of short-term weather and seasonal climate forecasts, and the use of crop growth models to simulate "what-if" conditions.

## County Yield Statistics on AgroClimate

### Why the County Yield Statistics tool was developed

Past yield records can be studied alongside historical weather information to help producers understand the effects of climate variability and ENSO phases on crop yield. This kind of analysis can give producers insight into the production history of their own operation and that of their region.

The **AgroClimate County Yield Statistics** tool (**http://agroclimate.org/tools/County-Yield-Statistics/**) (Figure 4.2) can be used to visualize crop yield and associated variability over time in the southeastern U.S., with a particular focus on observed yield during El Niño, La Niña and neutral years. Crop yield statistics are available for several crops, including corn, cotton, hay, oat, peanut, potato, rye, soybean, sorghum, sugarcane, tobacco, and wheat. Historical yield data are drawn from the records of USDA's National Agricultural Statistics Service (NASS).

Users can select a crop and county of interest to visualize historical yield records. Once a crop is selected, more than one county may be selected simultaneously by holding the "Control" or "Shift" keys. Once a crop and location have been selected, historical yield statistics will be plotted for the selected crop in that particular county (or multiple counties). Annual yields and the historical trend are displayed as a solid line on the graph.

The table located above the graph displays key statistics, namely the average, median, standard deviation, minimum and maximum yield during El Niño, La Niña and Neutral years. **It is important to note that absolute yield values vary not only due to climate but also due to changes in technology such as the development of new varieties, improved farm equipment, and management practices. Historical yield trends** are represented by a straight line on AgroClimate to simplify the analysis and can be either positive or negative depending on the crop and location. Positive yield trends are normally representative of technological improvements. The linear trend also represents the "expected yield" across the different years. The difference between the expected and actual yield is called "yield residual". County yield data can be exported and saved as a spreadsheet by clicking on the "Download" link.

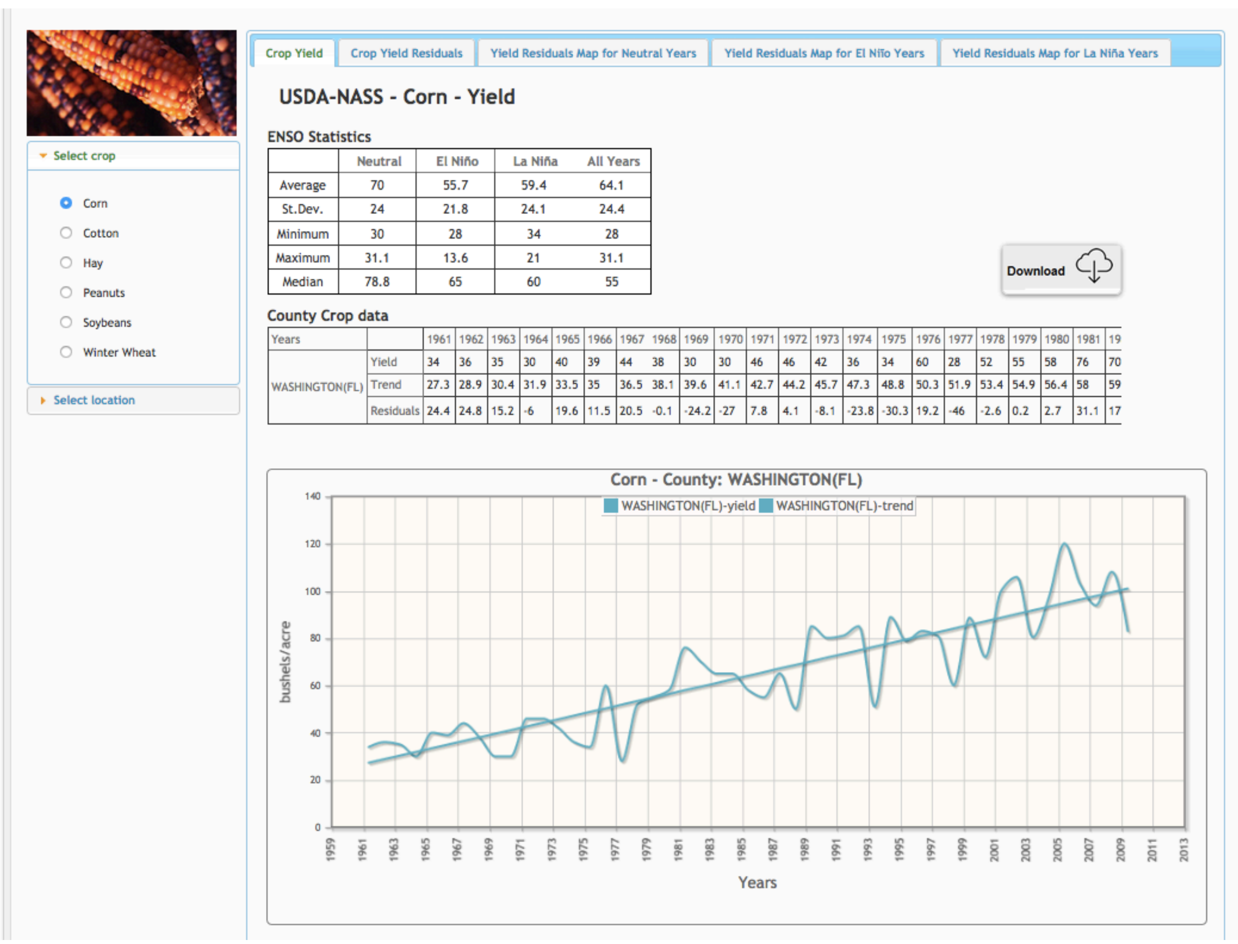


Figure 4.2. County yield statistics tool on AgroClimate. Users can select different counties and commodities to visualize NASS-based yield statistics and potential effects of ENSO phases on yield variability.

The second tab, "Crop Yield Residuals", shows "detrended" yield values, allowing for a better evaluation of the effects of climate on yield variability. Residuals are classified according to ENSO phase and are presented in a graph for the commodity and county selected. Average residuals at the regional scale for different ENSO phases are presented in the form of maps (Figure 4.3) above the graph.

## Yield Residuals

The difference between observed yield and expected yield represented by a linear trend on the AgroClimate County Yield Statistics tool is called "yield residual". Calculation of yield residuals facilitates the evaluation of climate variability effects and ENSO phases on crop yield.

$(Y_{Obs} - Y_{Exp}) / Y_{Exp}) * 100$

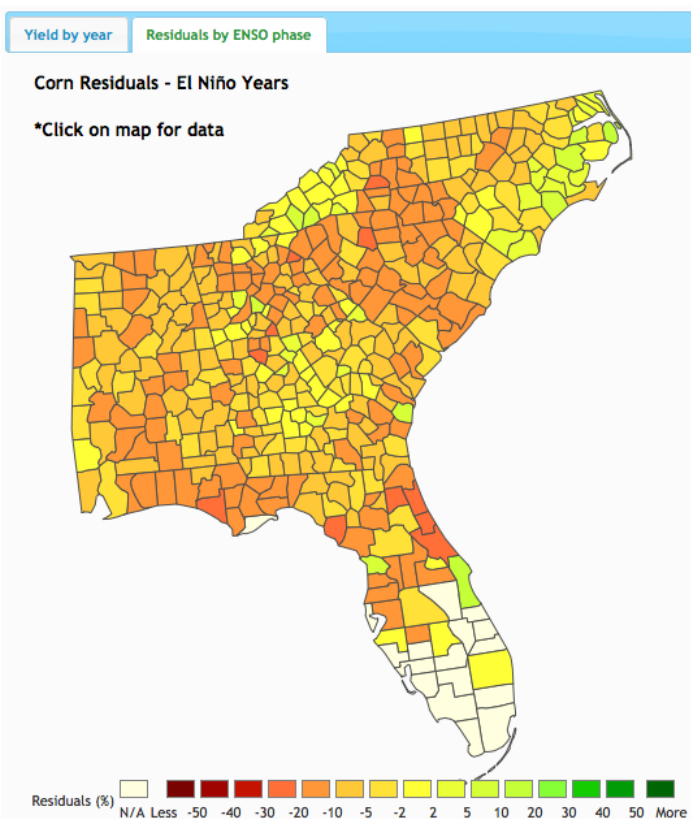


Figure 4.3. Average corn yield residuals indicating that corn yields tend to be below average during El Niño years.

Residuals are given here as a percentage rather than a raw number. A positive residual indicates a better crop year compared to the average expected yield for that year, since the actual yield is higher than the trend line. On the other hand, negative residuals indicate below- average crop years. By plotting residuals the long-term trend is removed from consideration, allowing the annual variability to be better visualized. Average positive or negative residuals indicate if yields are tending to be above or below average for a given ENSO phase.

Equipped with the historical yield tool and regional yield residuals maps, producers can better understand crop yield risk associated with climate variability in their area. With the help of seasonal climate outlooks, they have the ability to anticipate how climate might vary from normal during an upcoming season and adjust their practices to reduce risk.

## Crop Growth Models

The need for sustainable intensification of crop production systems requires information for agricultural decision making at all levels. Traditional agronomic experiments are conducted at particular points in time and space, making results site- and season-specific, time consuming and expensive (Jones et al., 2003). Crop models are mathematical models that simulate crop growth and development, integrating knowledge about plants, soil, climate, and management. Crop models can be used to predict the behavior of production systems under alternative scenarios and help develop strategies to mitigate risk associated with climate variability and change.

A suite of crop models, the Decision Support System for Agrotechnology Transfer-Cropping System Model (DSSAT-CSM) (Jones et al., 2003) has been used on AgroClimate to help producers understand and mitigate climate risks. The DSSAT-CSM includes models for 16 crops derived from the DSSAT CROPGRO and CERES models (maize, wheat, soybean, peanut, rice, potato, tomato, drybean, sorghum, millet, pasture, chickpea, cowpea, velvet bean, brachiaria grass, and faba bean). The models are process-based and simulate crop growth and development, soil water processes, and nitrogen balances. AgroClimate uses long-term historical weather data compiled from the National Weather Service for simulating historical yield patterns and helping users understand the effects of different management options and climate patterns on crop yield.

## Planting Date Planner on AgroClimate

### Why the Planting Date Planner was developed

The DSSAT-CSM suite of crop models was used to develop the Planting Date Planner tool on AgroClimate (**http://agroclimate.org/tools/Planting-Date-Planner/**). This tool provides producers and extension agents with the ability to simulate "what-if" scenarios that take into consideration the location, management practices, current ENSO phase combined with historical weather conditions to define the planting dates with higher chances of crop success.

Crop model runs for a range of planting dates and typical management practices were used to investigate the probability of obtaining below-average, average, and above-average yields. The user can select from five crops including corn, cotton, peanut, potato and three varieties of tomatoes (Fall, Spring, and Winter) and select soil type, irrigation, and fertilizer application. Phenological development and freeze probabilities are also presented for El Niño, La Niña, and Neutral years.

Users can select crop, variety, location, soil type, and irrigation practices using the options provided in the menu on the left hand side of the screen. Once these have been selected, the % probability for low-, medium- and high-yield crops will be plotted. The user can compare planting dates by selecting it above the graph. A second tab, entitled "Phenology Table / Freeze probability", provides the user with an estimate of the range of dates during which flowering and maturity will be reached as well as probability of freezing temperatures will occur during crop development. The user can also explore potential differences in yield and freeze probabilities under El Niño, La Niña, and Neutral years based on historical data.

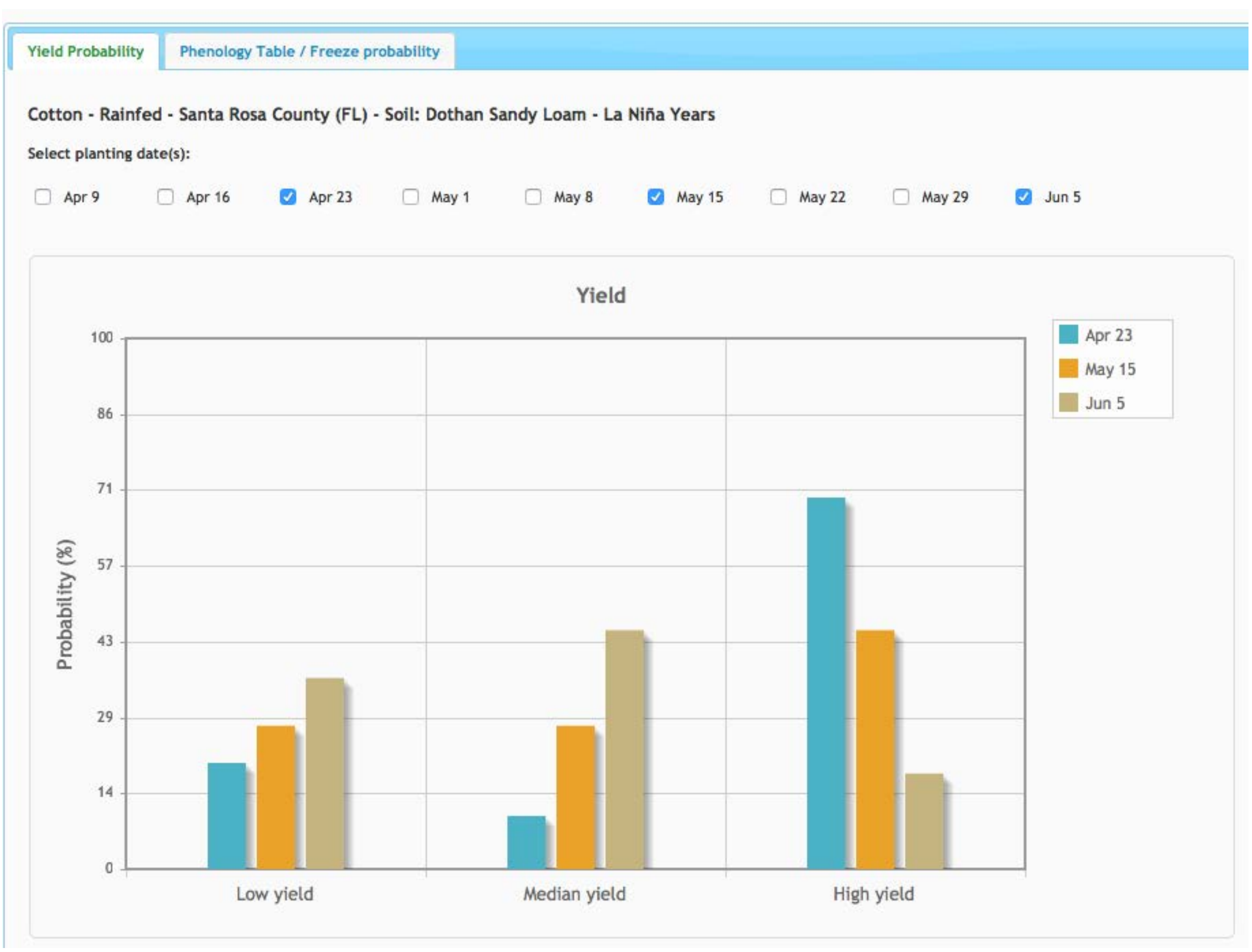


Figure 4.4. The planting date planner tool on AgroClimate is based on crop simulation models. This example shows that early planting of rainfed cotton in Santa Rosa County (sandy loam soils) during La Niña years may increase the chances for above average yields.

## CROP Yield Risk Activity

Peanut growers in Jackson County, FL can explore county-level yield records using the County Yield Statistics tool on AgroClimate: **http://agroclimate.org/tools/County-Yield-Statistics/**.

1. Based on the yield (lbs/ac) records for all years, what is the historical average, standard deviation, maximum, minimum, and median peanut yield for Jackson County? What was the ENSO phases with highest and lowest average yields?

   ______________________________________________
   ______________________________________________
   ______________________________________________

2. Since 1990 what were the years with the highest and lowest yield values? Using the csv file created by the "Download" link, estimate yield residual (%) values. Do the years with highest and lowest yields (lbs/ac) correspond to the highest and lowest residuals (%)?
   Using the "Crop Yield Residuals" tab provide the average, minimum, and maximum residuals for each ENSO phase. What ENSO phases seem to be the most and least favorable for peanut planting in Jackson County? What would you tell a farmer planning to grow cotton in Jackson County this year?

   ______________________________________________
   ______________________________________________
   ______________________________________________

3. Plot in the same graph peanut yield values for Washington and Jackson counties. Do you see the same pattern during the last 15 years (since 1990)? If not, what is the difference?

Using the Planting date Planner tool on AgroClimate (**http://agroclimate.org/tools/Planting-Date-Planner/**) explore the yield risk scenarios for cotton growers in Santa Rosa County, FL and answer the following questions:

4. A farmer in Santa Rosa County, FL is planning to grow rainfed cotton this year. Most of his fields have Troup Loamy sand soils. Based on the ENSO forecast for the next 3 months, what planting dates seem to be more favorable to plant this year? Why?

   ______________________________________________
   ______________________________________________
   ______________________________________________

5. What are the most and least favorable planting dates when is the crop expected to reach flowering and maturity?

   ______________________________________________
   ______________________________________________
   ______________________________________________

6. Repeat the questions above for a different ENSO phase (provide the ENSO phase selected)

   ______________________________________________
   ______________________________________________
   ______________________________________________

## References


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# CHAPTER 5

## Climate and Plant Diseases

### Key messages

- Plant diseases can reduce crop yield and quality while increasing production costs.
- Disease occurrence is governed by the interactions between a host, a pathogen and the environment.
- The development of many common diseases is highly affected by temperature and leaf wetness duration (LWD).
- Most common pathogens (fungi and bacterium) require free water to grow and penetrate the plant tissue and start the infection process.
- The AgroClimate Strawberry Advisory System (SAS) is a disease alert system that warns growers when there is need of control of anthracnose or Botrytis fruit rot.

## How might plant diseases affect agricultural production?

Plant diseases potentially reduce crop production and quality, while increasing expenses to control them, impacting growers' income. According to a 2012 report by the University of Florida, citrus greening, a bacterial disease, cost Florida's economy $4.5 billion and 8,000 jobs between 2006 and 2012. Application costs to control the major diseases of Florida strawberries, anthracnose fruit rot and Botrytis (also known as gray mold) (Figure 5.1), represent about 15% of operational costs per growing season for growers in the region (MacKenzie and Peres, 2012). Disease control costs in Florida sugarcane fields have recently increased with the discovery of orange rust (Figure 5.2) during the summer of 2007, when yield losses caused by the disease amounted to about 10%. Since 2008, approximately 10,000 acres of sugarcane have been sprayed once per year to control orange rust, costing $30 per acre. Citrus growers in Florida apply copper compounds for controlling a range of foliar diseases including Asian citrus canker, melanose, alternaria brown spot, greasy spot, citrus scab, and citrus black spot.

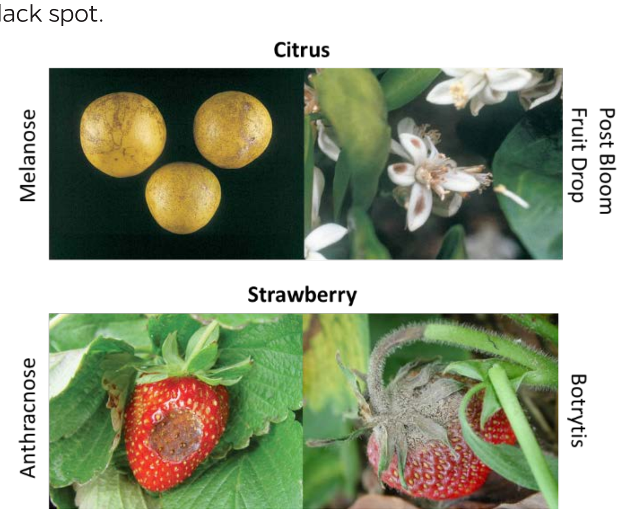



Figure 5.1. Anthracnose and botrytis diseases on strawberries in Florida.

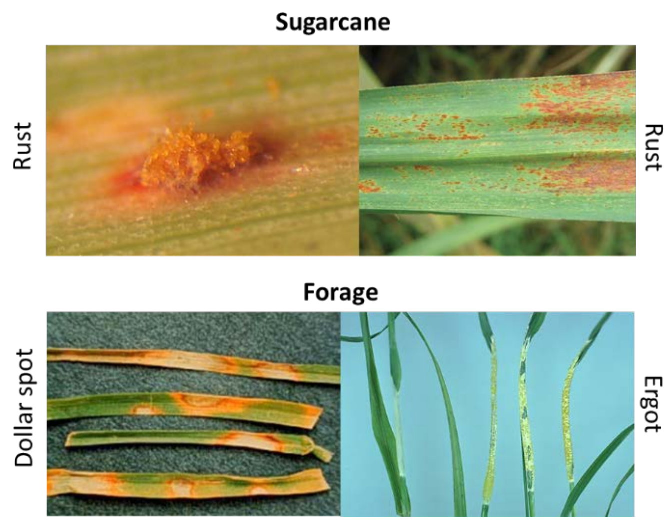



Figure 5.2. Orange rust disease on sugarcane and dollar spot on forage.

## Disease Occurrence Variability

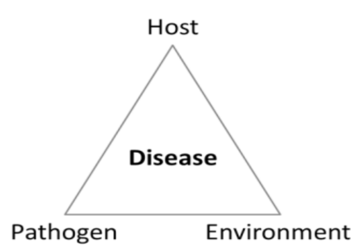



Figure 5.3. The plant disease triangle showing the pathogen-environment-host interaction for disease occurrence.

Diverse diseases commonly affect crop fields, but why are some growing seasons and regions much more damaged by diseases than others? The explanation is given by the disease triangle shown in Figure 5.3 (Gaumann, 1950). The interaction between the three components of the disease triangle, host (plant), pathogen (disease-causing agents, such as fungus, bacteria, virus) and environment, govern the occurrence of a disease. Disease occurs when the pathogen is virulent (i.e., can cause damage) to a susceptible host and the environment is favorable. The weather conditions that affect pathogen development explain most of the disease occurrence variability between growing seasons and regions. In particular, wet conditions and temperatures between 68°F and 77°F (20°C and 25°C) are highly favorable for disease development. Wind currents also contribute to pathogen dispersal to nearby locations.

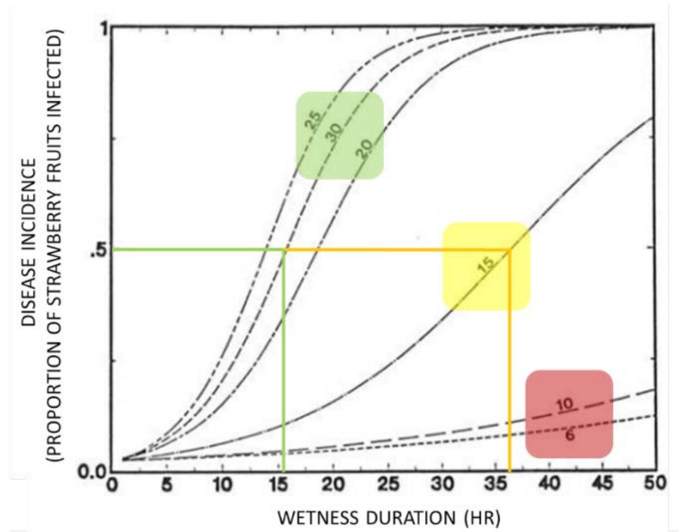
**Key environmental factors for disease development**

Figure 5.4. Wetness on orange leaf.

Most common pathogens in agricultural production systems (fungi and bacterium) require free water to grow and penetrate the plant tissue and start the infection process. Temperature influences the speed of the pathogen's metabolic reactions and development (Gillespie and Sentelhas, 2008). The period with free water available on crop leaves is called leaf wetness duration (LWD), and is usually related to dew formation, rainfall and irrigation (Figure 5.4). Favorable environmental conditions for disease development are specific for each host-pathogen interaction and are commonly inferred by the combination of temperature and LWD. Generally speaking, the closer the environment temperature is to the pathogen optimal development temperature, the shorter wetness duration necessary, and vice-versa (Huber and Gillespie, 1992). In Figure 5.5, for example, we observe the effect of temperature and wetness on anthracnose development (main strawberry disease in Florida, as previously mentioned). The optimal development temperature for the fungus causing anthracnose lies between 68°F and 86°F (20°C to 30°C). When the environment is at this optimal condition, the necessary wetness duration so that half of strawberry fruits are infected is 15 h, whereas it is approximately 35 h (more than doubled!) if temperature is marginal at 59°F (15°C). If temperature is below 50°F (10°C), it would take the pathogen about 95 h of wetness to infect 50% of strawberry fruits (Wilson et al., 1990).

**Monitoring the environment: the role of disease alert systems**

Knowing that the development of many common diseases is greatly affected by temperature and LWD, it is possible to monitor these factors and determine when environmental conditions favor disease occurrence and control is required. This is the role of disease alert systems: they integrate environmental monitoring with pathogen development information related to a particular crop, recommending pesticide spray applications if the combination of temperature and LWD represents high risk of disease occurrence. In comparison with the traditional calendar-based application schedules (fixed applications on a weekly basis, for example), disease alert systems bring benefits to growers, the environment, and society by lowering production costs as well as environmental and health hazards(Gillespie and Sentelhas, 2008).




*Adapted from Wilson, et. al 1990. Influence of Temperature and Wetness Duration on Infection of Immature and Mature Strawberry Fruit by Colletotrichum acutatum. 1990. Phytopatology, v.80-1.*

Figure 5.5. Effect of temperature (°C) and wetness duration (hours) on anthracnose in strawberry fruits caused by fungus *Colletotrichum acutatum*. Colored boxes indicated optimal (green), marginal (yellow) and limiting (red) temperatures for pathogen development. Colored lines indicate the wetness duration necessary so that 50% of the strawberry fruits are infected according to optimal and marginal temperatures.

**Leaf wetness duration as bottleneck of disease alert systems**

A critical limitation of disease alert systems use is the lack of availability and reliability of LWD data. Leaf wetness sensors are rarely deployed in weather stations, and data available might not be reliable due to the non-existence of a standard for LWD measurement despite some efforts (Sentelhas et al., 2004b). There are different types of sensors, and their calibration, color, deployment angle and orientation, and height of installation are not standardized (Gleason, 2007; Sentelhas et al., 2004a, Madeira et al., 2002).

**Types of leaf wetness sensors**

Electronic leaf wetness sensors are predominant in the market. They measure resistance or dielectric constant. Model 237 leaf wetness sensor produced by Campbell Scientific®, (Figure 5.6a), is an example of resistance-based sensor – a widely used type of sensor. It has a printed circuit configured as half-bridge, meaning that the circuit is open. The circuit reaches a maximum value when completely dry, whereas the presence of moisture connects the half-bridge and decreases the resistance value until it reaches a threshold that indicates the circuit is wet. The threshold is established in field or laboratory experiments (Campbell Scientific, 2010). An example of a leaf wetness sensor based on dielectric constant is a leaf-shaped sensor produced by Decagon® (Figure 5.6b). Time intervals are classified as wet or dry according to a threshold as well, but in this case the measurements are voltage values proportional to the dielectric constant of the media about 1 cm from the sensor's surface (Decagon, 2015).

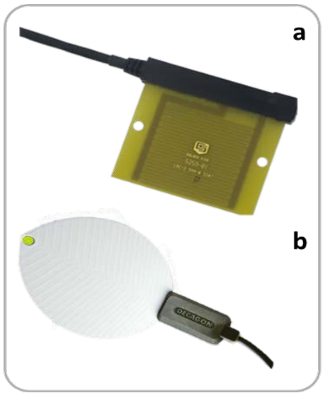



Figure 5.6. Electronic leaf wetness sensors based on resistance (a) and dielectric constant (b).

## Operational use of leaf wetness sensors

Even though there is no standard for LWD measurement according to the World Meteorology Organization (WMO, 1992), there are some guidelines available on literature about sensors preparation, installation and calibration processes. Some main recommendations are mentioned below.

**Preparation**

The pre-calibration is necessary, especially for resistance-based sensors. Resistance-based sensors usually come uncoated from the factory and contain a gridded-circuit spaced about 0.1 mm, see Figure 5.7. Droplets smaller than the spacing are undetected, underestimating LWD, and potentially underestimating disease risk. Sensor preparation minimizes this problem.

The preparation process consists of coating and heat-treating leaf wetness sensors. It is recommended to add two coats of latex white paint to spread tiny droplets, which enables its detection by connecting the half-bridges. After coating, sensors need thermal-treatment during 24 hours under 70°C to deactivate hygroscopic substances contained in the paint formula, which could absorb water and result in LWD overestimation. A third coat is recommended after the sensors are immersed in distilled water for 30 minutes, and should then be thermal-treated again (Gillespie & Kidd, 1978; Sentelhas et al., 2004b).

Figure 5.7. Grid-circuit scheme of resistance-based leaf wetness sensors.

**Installation**

When installing a leaf wetness sensor, care must be taken on the sensor's height above ground, angle, orientation and surface of deployment. The greater the sensor's height, the shorter the LWD and the larger the sensor's angle, the longer the LWD (Sentelhas et al., 2004a). Usually, the sensor's height has more influence on LWD measurements than the angle itself. The direction of orientation should minimize the interception of solar radiation, but it has no significant effect on LWD (Madeira et al., 2002). The general recommendation is that sensors should be installed at 30 cm, with an angle of deployment between 30° to 45° and face north above turfgrass (Figure 5.8) (Sentelhas et al., 2004a). Turfgrass is used as a reference surface to enable comparisons of LWD measurements from different locations.

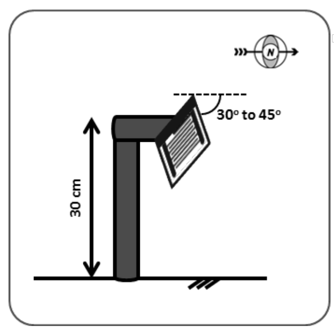



Figure 5.8. Scheme of leaf wetness sensor installation.

**Calibration**

Calibration is required to determine a threshold from which resistance readings are classified as wet or dry. (This is a crucial step to measure LWD correctly.) Figure 5.9 shows the effect of choosing an incorrect threshold. If the threshold is less strict, more LWD is accumulated in comparison with the correct setting. On the other hand, if the threshold is stricter, LWD periods are shorter than they should be. Underestimation of LWD potentially underestimates disease risk occurrence, and results in lack of disease control, whereas overestimation of LWD potentially overestimates disease risk occurrence, and results in overspray (Montone et al., 2016).

The calibration process occurs in the field or laboratory. The field calibration consists of visual observations of dew on-set and dry-off on turfgrass, determining the resistance threshold that represents the transition point between wet and dry (Rao et al., 1998). At least two weeks of observations are recommend to obtain a reliable threshold. In the laboratory, the threshold is set by observing output values from the sensor when a drop of 1 mm diameter is applied on its surface (Sentelhas et al., 2004b).

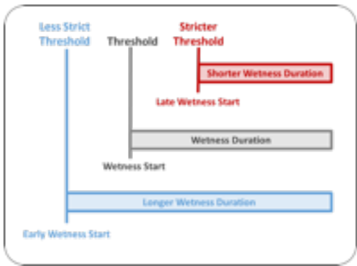



Figure 5.9. The impact of threshold setting in leaf wetness duration.

As final remarks about leaf wetness sensors for operational purposes, a pair of sensors is recommended per location for disease monitoring. In case one of the sensors has missing values, the other one can be used to keep monitoring diseases uninterrupted. In addition, sensor maintenance is important; cleaning sensor surfaces with a moisture cloth when necessary and checking the threshold stability – for at least one week every season – are advised for data reliability. Sensors might need replacement if their coating is washed-off or the threshold is not stable even after recalibration.

## Weather data and models to obtain leaf wetness duration

An alternative solution to obtain LWD is to estimate it using models. LWD models require weather data as input. Common weather variables for LWD modeling include relative humidity, temperature, rainfall, net radiation, and wind speed. There are two categories of LWD models: empirical and physical-based (Huber and Gillespie, 1992). Physical-based models are complex and try to mimic the processes of dew formation and evaporation usually based on energy balance approaches, whereas empirical models are mostly based on regression analysis and relationships between wetness and weather data. The advantage of using empirical models is the simplicity of input variables and calculations, but there is the disadvantage of calibration requirement if the model in applied in a location with different environmental conditions from where it was developed (Gillespie and Sentelhas, 2008). The simplest LWD model is based on the number of hours with relative humidity above a threshold, often set as 90%. In this model, it is assumed that the LWD corresponds to the accumulated number of hours in which relative humidity values are above 90% (Sentelhas et al., 2008).

## Strawberry Advisory System (SAS)

The Strawberry Advisory System (**SAS - http://agroclimate.org/tools/Strawberry-Advisory-System/**, Figure 5.10), is a disease alert system that warns strawberry growers in Florida when there is a need to control anthracnose or botrytis fruit rot. It monitors temperature and LWD in locations near the Florida Gulf Coast, where most of the strawberry production in the state is concentrated. Color-coded tags represent low (green), moderate (yellow) or high (red) risk of disease development, and A and B represent anthracnose and botrytis, respectively. Sprays are recommended if the risk of disease occurrence reaches moderate or high levels. The user may also select a weather station and receive a recommendation about whether to spray or not after answering a few questions. In addition to disease considerations, SAS spray recommendations take into account the rotation of chemical products to avoid the development of pesticide resistance. The user may also access graphs and tables with weather data and risk infection levels simulated for the past 30 days.

A mobile version of the Strawberry Advisory System has also been developed for smartphones with iOS and Android operating systems (Figure 5.11).

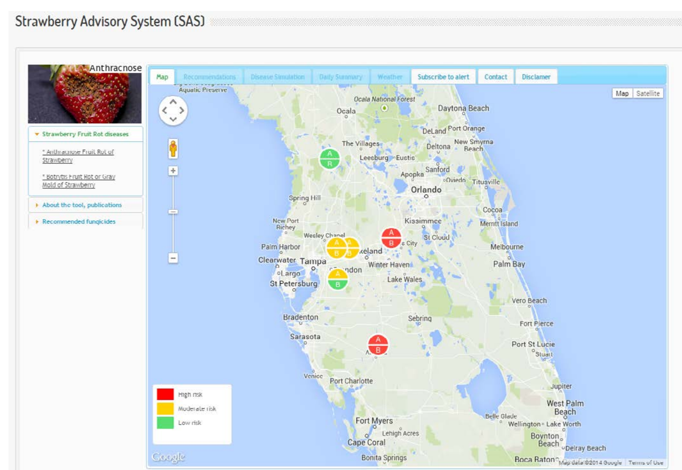



Figure 5.10. The Strawberry Advisory System (SAS) on AgroClimate: **http://agroclimate.org/tools/Strawberry-Advisory-System/**

## Citrus Copper Application Scheduler

Copper products are applied on citrus canopies to form a thin protective sheet on fruits to control important diseases such as melanose, greasy spot, and canker. Growers often follow a 21-day interval between copper applications. However, as the fruit grows rapidly during their initial development, the protective layer may crack, leaving some parts of the fruit unprotected for days before the next application. In addition, heavy rain events can wash off the copper layer from the fruits' surface before the next

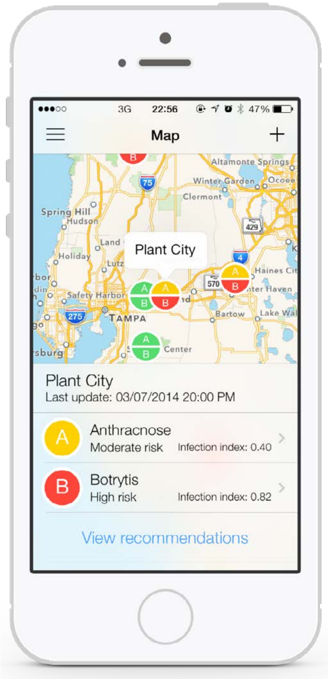



Figure 5.11. Mobile SAS app available for iOS and Android smartphones.

application. Conversely, during dry periods and slow fruit growth, one application might be enough to protect fruits for longer than 21 days. Following an ordinary 21-day interval may therefore incur unnecessary application costs and might cause phytoxicity and soil contamination (Dewdney et al., 2012).

The **Citrus Copper Application Scheduler** (**http://agroclimate.org/tools/Citrus-Copper-Application-Scheduler/**) simulates copper decay according to fruit growth and rainfall events. To use this tool, begin by selecting a weather station or uploading a spreadsheet with rainfall information. Next, choose a citrus scion, enter bloom and spray dates, and enter information related to the spray applications. The tool will then generate a graph showing if the level of residual copper is adequate for fruit protection. In Figure 5.12, the graphed line represents the residual copper available for fruit protection and blue bars represent rainfall events. Copper applications are recommended when the residual copper reaches the yellow hatching in the graph, whereas the red hatching shows when fruits are not protected due to lack of copper.

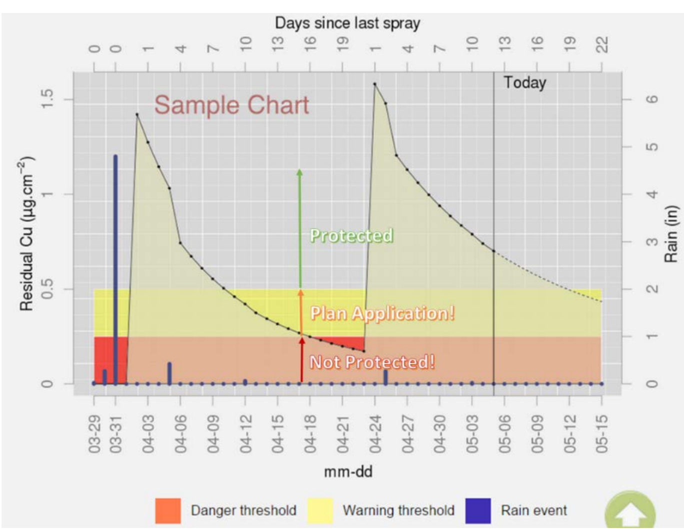



Figure 5.12. Using the Citrus Copper Application Scheduler to plan copper application.

# SAS and Citrus Copper Tool Activities

*Use the* **SAS tool** (**http://www.agroclimate.org/tools/strawberry/**) *to answer the following questions.*

1. Move your mouse over the weather station tags to find and select "Balm" as your weather station.

    a. What is the risk of anthracnose and Botrytis in this location?
    Anthracnose: ____________________
    Botrytis: ______________________

2. Click the "Click for Simulation Graph" button.

3. Select "None" for the question "When was your last fungicide application?" and then choose "View Recommendation".

    a. Is there a spray recommendation?
    Anthracnose: ____________________
    Botrytis: ______________________

4. Now, answer "More than 7 days" to the question "When was your last fungicide application?" and select the products "Cabrio" and "Fontelis" (press and hold CTRL on your keyboard while you select more than one product).

    a. Does the recommendation change?
    ________________________________

    b. What if you choose another product?
    ________________________________

5. Navigate to the "Disease Simulation" tab located on the top menu to see the history of disease risk for the past month on graph.

    a. Fill in the table below to answer the following: when was the highest and lowest peak of disease risk for anthracnose? Botrytis? Some of this information is located under the "Weather" tab.

*Use the* **Citrus Copper Application Scheduler tool** (**http://agroclimate.org/tools/Citrus-Copper-Application-Scheduler/**) *to answer the following questions:*

1. Select "Lake Alfred" as your weather station and "Orange (generic)" for the Scion drop-down menu.

2. Select the "Click to add" option located next to Bloom Date and choose a date about a month ago, then click on "Simulate copper residue".

3. You will notice that the spray date corresponds to a peak in residual copper, which decreases with time.

    a. How do rainfall events affect residual copper decay? ____________________

    b. Is decay slower with a rain event or more rapid in comparison with natural decay related to fruit growth? _____________

4. The yellow band of hatching on the simulated graph corresponds to the period when copper applications need to be planned to avoid residual copper lower than the recommended (represented by the red hatch), to be efficient in controlling diseases.

    a. Based on graph, how many days are available to apply copper products before it reaches low levels? _________

5. Now, based on your answer to the previous question, add another spray date within this period by selecting the green plus button ( ) and clicking "Simulate copper residue" again.

    a. Is the copper residue always above the danger threshold (red hatch), indicating that there is enough residual copper to protect fruits against diseases? _______

    b. What would happen if the standard calendar approach of a 21-day interval were used to determine the next copper application? _______________________

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# CHAPTER 6

## Degree-Days: Heating, Cooling, and Growing

### Key messages

- Degree-days can be used to track how much air temperature has been above, below, or within a certain range during a day or a period of days.
- Heating and cooling degree-days are used to relate daily air temperature to the demands for heating or cooling buildings.
- Growing degree-days (or heat units) relate air temperature to plant growth.
- AgroClimate degree-days calculators can monitor and forecast accumulation and compare to the last season and long-term averages.

Growing degree-days (GDD) or heat units originated in assessment of crop growing conditions. Many methods of calculating degree-days have been successfully used to describe and predict crop phonological events, but basically they represent a difference between the observed temperature and a reference temperature. The concept of degree-days is also applied to building energy, where the reference temperature is represented by a balance-point temperature at which the heating (or cooling) systems do not need to run in order to maintain comfort conditions.

## Heating and Cooling Degree-Days

People often discuss how hot or cold it is. Usually, it is a question of comfort, and it is simple enough to measure the temperature. But in some industries, it is not enough to know the temperature; it is important to find a way of measuring the impact of the temperature.

> It is important to remember that a Celsius degree-day is not the same as a Fahrenheit degree-day, because Celsius degrees are almost twice as "large" as Fahrenheit degrees. It takes nine Fahrenheit degree-days to make five Celsius degree-days.

For example, if you are in charge of a power company trying to run hundreds of thousands of air conditioners or heaters at the same time, it is a question of whether there will be enough power to run all those homes or enough fuel to run the generators. Understanding heating and cooling degree-days can take some of the guesswork out of these questions and allow engineers do their jobs more effectively and make good decisions about resources. **Heating degree-days (HDD),** are used to estimate the amount of space that will need to be heated during the cold months. On the other hand, **cooling degree-days (CDD)**, are used to estimate how much air conditioning will be used by customers during the hotter months of the year.

There are different ways of measuring HDD and CDD. The simplest way to do this is to use a base temperature of 65 degrees Fahrenheit (18.3 degrees Celsius) for calculating both HDD and CDD. We assume that if the current air temperature is below 65°F, energy will be used for heating, and if it is above 65°F, energy will be needed for air conditioning. Therefore, a day with an average temperature of 55°F will correspond to 10 HDD, and a day with an average temperature of 75°F will correspond to 10 CDD.

## Growing Degree-Days or Heat Units

**Growing degree-days (GDD),** sometimes called *heat units*, have been used as a means to predict growth stages of many living things since the 1700s, when they were introduced by French scientist Rene A. F. de Réaumur (Cross and Zuber, 1972; Gilmore and Rogers, 1958; McMaster and Smika, 1988; McMaster and Wilhelm, 1997; Russelle et al., 1984). Because the growth rate of many organisms is controlled by temperature, growers can use GDD, a concept related to CDD and HDD. GDD are used to relate plant growth, development, and maturity to air temperature.

GDD is based on the idea that the development of a plant will occur only when the temperature exceeds a specific base temperature for a certain number of days. Each type of plant is adapted to grow best above its own specific base temperature, called **Tbase**. Even cultivars of the same plant species sometimes have different Tbase. Table 6.1 lists values of Tbase that researchers have determined for various crops. Growth does not increase constantly with temperature. Just as there is a minimum, or base temperature for growth, there is also a maximum temperature above which growth is not favored (**Tcutoff**), which is most commonly assumed to be equal to 86°F. We count one GDD for every 24-hour period during which the average temperature is one degree greater than Tbase. If the average temperature is two degrees above Tbase, then we count two GDD, and so on.

GDD provides growers with a more scientific way of understanding how plant growth is related to the daily warmth provided by the sun. Growers can use the number of GDD (or heat units) required for a given crop and variety to reach maturity to estimate when to be ready for harvest. Cold region crops (wheat, barley, oats, and others) have lower Tbase than warm region crops (corn, soybean, cotton, peanuts, and others).

**Table 6.1.** Base temperature (Tbase) for selected crops in degrees Fahrenheit.

| Crop | Base Temperature (Tbase) |
|---|---|
| Corn, sweet corn, sorghum, rice, soybeans, tomato | 50°F (10.0 °C) |
| Cotton | 60°F (15.6 °C) |
| Peanuts | 56°F (13.3 °C) |
| Wheat, barley, rye, oats, flaxseed, lettuce, asparagus | 40°F ( 4.4 °C) |

$$CDD = \left(\frac{(T_{MAX} + T_{MIN})}{2}\right) - 65$$

$$HDD = 65 - \left(\frac{(T_{MAX} + T_{MIN})}{2}\right)$$

$$GDD = \frac{(T_{MAX} + T_{MIN})}{2} - T_{base}$$

Figure 6.1. Standard method for calculating CDD, HDD, and GDD.

## Calculating HDD, CDD, and GDD

*Standard (Averaging) Method*

The simplest form of degree-day calculation is by the standard method, also called averaging or rectangle method, which uses simple averaging. Degree-days for a single day using the standard method can be calculated using the formulae in Figure 6.1.

In these equations, the average or mean temperature is calculated by adding together the high for the day (Tmax) and the low for the day (Tmin), and dividing the result by 2. For CDD and HDD, the result is subtracted from or by 65, whereas GDD uses Tbase. If the average temperature is equal to 65°F, then both HDD and CDD are equal to zero. In the case of GDD, if the average temperature is less than or equal to Tbase, then GDD is equal to zero.

*Modified Method*

$$GDD = \frac{(T_{cutoff} + T_{MIN})}{2} - T_{base}$$

Figure 6.2. Modified method for calculating GDD when $T_{max} > T_{cutoff}$.

The standard method for calculating growing degree-days can be modified to consider Tcutoff or other Tcutoff temperature adjustments. Tcutoff is most commonly assumed to be equal to 86°F. Other literature may refer to the upper developmental threshold as *ceiling*, the *upper cutoff*, *the upper developmental cutoff*, or *cutoff*. In this case GDD for a single day can be calculated using Tmax if Tmax is lower than Tcutoff. Otherwise, the formula in Figure 6.2 can be used.

## Growing Degree-Days Calculator on AgroClimate

### Why the GDD Calculator was developed

Growers often keep track of GDD accumulation as the growing season progresses to keep informed about in-season crop development. Tracking and forecasting GDD accumulation can be used to determine when a crop will flower or mature, and help growers in scheduling scouting activities, field application of chemicals, or any other activity that needs to be performed during a specific development stage.

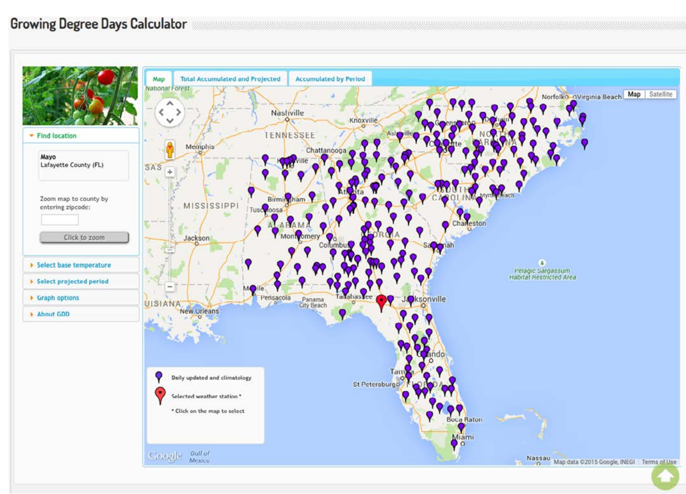


Figure 6.3. Growing Degree-Days calculator tool.

**AgroClimate GDD Calculator**
(**http://agroclimate.org/tools/Growing-Degree-Days/**)

The AgroClimate GDD Calculator (Figure 6.3) can be used to track GDD accumulation for three different base temperatures (40°F, 50°F, and 60°F) using the modified or cutoff method. Also available is a map version of GDD accumulation for the region using grid-based temperature data from the PRISM (Parameter-elevation Relationships on Independent Slopes Model) (PRISM Climate Group, 2004). A **Cooling/Heating Degree Days Calculator,** (**http://agroclimate.org/tools/Cooling-and-Heating/**) can also be found on the AgroClimate website.

Open up the GDD Calculator in your browser by clicking the link above (or navigating to it using your preferred internet browser). You can select a weather station on the map tab or enter a zip code in the left side menu to zoom in to an area of interest. Once a station is selected, GDD accumulation during the last 30 days will be displayed in the form of graphs and tables for the default base temperature (50 °F). The projection cone for the next 30 days represents the possible range of degree-days accumulation predicted for the current climate El Niño - Southern Oscillation (ENSO) phase. The color of the projection cone indicates if the forecast is for El Niño (red), La Niña (blue), or Neutral (green) phases. Users can select a different base temperature from Table 6.1, depending on the crop they are planting or interested in and modify the start/end dates for the calculation. The graph options allow the user to plot the long-term average and/or last year's GDD accumulation for the selected base temperature and period of time together with current accumulation and projection. The user can also visualize 7-day period accumulations using the "Accumulated by Period" tab.

## GDD Calculator Activity

Cotton growers are quite familiar with the concept of growing degree-days as they can track and forecast the development of the crop based on GDD accumulation with a base temperature of 60 °F. The table below indicates the typical accumulation required for the various cotton development phases. During years with colder springs the plant will take longer to develop, as more days are required to reach the required GDD accumulation. A cotton grower in Marianna, FL planted cotton on April 15 and would like to use the GDD track crop development during the season. Will he/she be able to determine if crop development during the season is progressing on a typical pace?

## Activity

Answer each question below using the information and Table 6.2 provided and the GDD Calculator (**http://agroclimate.org/tools/Growing-Degree-Days/**).

## Information

- Marianna, FL – zip code 32446
- Crop: Cotton

**Table 6.2.** Typical GDD accumulation for a cotton plant (Tbase = 60 °F) to reach different growth stages.

| Growth stages | GDD required - 60 °F |
|---|---|
| Planting to emergence | 0 – 50 |
| Emergence to first square | 51 – 550 |
| First square to first flower | 551 – 950 |
| First flower to first open boll | 950 – 2150 |
| First open boll to › 60% open bolls | 2151 – 2450 |
| ›60% open bolls to harvest | 2451 – 2600 |

## Questions

1. Insert zipcode for Mariana County, FL (32446). Select a base temperature to 60 °C. What was the GDD accumulation during the last 30 days?

   ________________________________________

2. Considering the current ENSO phase, how much accumulation is projected for the next 30 days?

   ________________________________________

3. Change the planting date to April 15th of last year, when can the grower expect the crop to reach first square stage? ____________________

   a. How many days since planting?

   ______________________________

b. Is this in line with typical years in the region? Hint: Use Graph Options

___________________________________
___________________________________
___________________________________

3. If the crop was planted on June 1st of the same year, would you expect to reach first square stage in approximately the same number of GGDs?

___________________________________
___________________________________
___________________________________

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# CHAPTER 7

## Chill Hours Accumulation

### Key messages

- Most temperate plants enter a dormant period during late fall and early winter.
- Chilling requirement is the amount of accumulated cool temperature exposure for bud break and the resumption of normal growth during the spring.
- Insufficient chilling may result in delayed foliation, reduced fruit set and quality.
- AgroClimate chill hours calculator can monitor and forecast accumulation and compare to the last season and long-term averages.

## Chilling Requirement

Most temperate plants, including orchard crops and deciduous trees, enter a dormant period during late fall and winter, characterized by a state of reduced or suspended metabolic activity of aboveground parts (Lyrene and Williamson, 2004). The development of dormancy and cold hardiness is a gradual process which begins in late fall or early winter. Dormancy enables plants to tolerate freezing temperatures and prevents growth during mid-winter warm spells. Once dormant, plants require accumulated exposure to cool temperatures for bud break and the resumption of normal growth in the spring. The amount of accumulated cool temperature exposure required for normal growth varies by species and cultivar and is referred to as **chilling requirement**.

All economically important fruit and nut tree species that originated from temperate and cool subtropical regions have chilling requirements that have to be fulfilled each winter to ensure homogeneous flowering, adequate fruit set, and economically sufficient yields (Luedeling et al., 2009). Each species and cultivar has its own specific chilling requirement that can be measured either by the accumulated hours below a chilling temperature threshold, or by cumulative chill units, which are hours that are weighted for temperature effects at breaking dormancy. Insufficient chilling may result in one or more of the following physiological symptoms: a) delayed foliation, b) reduced fruit set and increased buttoning, and c) reduced fruit quality (Byrne and Bacon, 2004).

## Chill Accumulation Models

Estimating the amount of chilling accumulation requires the definition of what temperatures are needed to satisfy chilling requirements. Most people agree that temperatures below 32°F (0°C) or above 60°F (15.6°C) are not effective. Using blueberries as an example, temperatures between 32°F and 45°F (7.2°C) appear to be the most effective at satisfying the chilling requirements, temperatures between 45°F and 55°F (12.8°C) also contribute to chilling, and temperatures above 70°F (21.1°C) between mid-November and mid-February probably negate some chilling. The concepts of **chill hours** and **chill units** can be used for predicting the breaking of dormancy.

**Chill Hours (CH)** are generally determined in two different ways:

- Number of hours below 45°F
- Number of hours with air temperature between 45°F and 32°F.

Producers generally use the concept of chill hours to estimate chill accumulation during late fall and winter because they are relatively easy to calculate.

When calculating **Chill Units (CU)**, the hours are weighted for their effectiveness of satisfying chilling requirements depending on the temperature. Classical chill unit methods for predicting the breaking of dormancy include the Utah model (Richardson et al., 1974), the North Carolina model (Shaultout and Unrath, 1983), the Low Chilling model (Gilreath and Buchanan, 1981), and the Positive Chill model (Linsley-Noakes et al., 1995). The weighting factors for the classical chill unit models (Table 7.1) were mainly determined in laboratory tests and differ because they were derived using different species and varieties. The Utah model used Redhaven and Elberta peach, the North Carolina model used Starkrimson delicious apple, and the Low Chilling model used Sungold nectarine.

**Table 7.1.** Temperature conversion to chill unit factors for the Utah, North Carolina, and Low Chilling models. Adapted from Cesaraccio, et al. (2004).

| Utah Model | | North Carolina Model | | Low Chilling Model | |
|---|---|---|---|---|---|
| Temp (°F) | CU | Temp (°F) | CU | Temp (°F) | CU |
| < 35 | 0.0 | < 35 | 0.0 | < 35.2 | 0.0 |
| 35 - 36.5 | 0.5 | 35 – 45 | 0.5 | 35.2 – 46.2 | 0.5 |
| 36.5 – 48.6 | 1.0 | 45 – 55.4 | 1.0 | 46.2 – 57.2 | 1.0 |
| 48.6 – 54.5 | 0.5 | 55.4 – 61.7 | 0.5 | 57.2 – 62.6 | 0.5 |
| 54.5 – 60.8 | 0.0 | 61.7 – 66.2 | 0.0 | 62.6 – 67.1 | 0.0 |
| 60.8 – 64.4 | -0.5 | 66.2 – 69.3 | -0.5 | 67.1 – 70.7 | -0.5 |
| > 64.4 | -1.0 | 69.3 – 71.8 | -1.0 | > 70.7 | -1.0 |
| | | 71.8 – 74 | -1.5 | | |
| | | > 74 | -2.0 | | |

## Chill Hours Calculator on AgroClimate.org

**Chill Hours Calculator**
(http://agroclimate.org/tools/Chill-Hours-Calculator)

Growers in the southeastern Growers in the southeastern U.S. can track and forecast chill hours accumulation during the winter season by using the Chill Hours Calculator on AgroClimate.org.

The information available in the AgroClimate.org Chill Hours Calculator tool includes the monitoring and forecasting of chill accumulation starting on October 1st of each year. Chill accumulation can be calculated using the number of hours below 45°F (7°C) and the number of hours with air temperature between 45°F and 32°F.

The Chill Hours Calculator tool, when loaded, shows chill accumulation up to the current date observed at the weather station selected by the user. Weather stations from the Florida Automated Weather Network (FAWN) have temperature sensors installed at 2 m (6.56 ft) and at 60 cm (1.97 ft). The tool to calculate chill accumulation uses temperatures measured by the 2-meter sensor. The default model is in number of hours with air temperature below 45°F, but the user can also select the model to calculate the number of hours between 45°F and 32°F. The projection cone beyond the last observation represents the possible range of chill accumulation predicted for the current climate El Niño - Southern Oscillation (ENSO) phase. The color of the projection cone indicates if the forecast is for El Niño (red), La Niña (blue), or Neutral (green) phases.

Chill accumulation is presented in two different graphs; the default tab (Figure 7.1) shows the cumulative chill in the current winter season since October 1st. The user can select the "graph options" menu in the left side of the screen to plot last season and long-term average accumulation observed in the selected station (Figure 7.2). It is also possible to compare typical chill accumulation for different ENSO phases. The cone of projection shows the 25th and 75th percentiles of the historical chill accumulation observed at the selected weather station.

### Why the Chill Hours Calculator was developed

Monitoring and forecasting chill accumulation is most important in areas with mild winters, such as the southeastern US, where winter chilling is often variable. Growers keep track of chill accumulation as the winter progresses to decide about management practices needed and comparison of past year's weather and crop load. They also need to evaluate if the use of hydrogen cyanamide is necessary to replace lack of chilling and enhance flowering and fruiting.

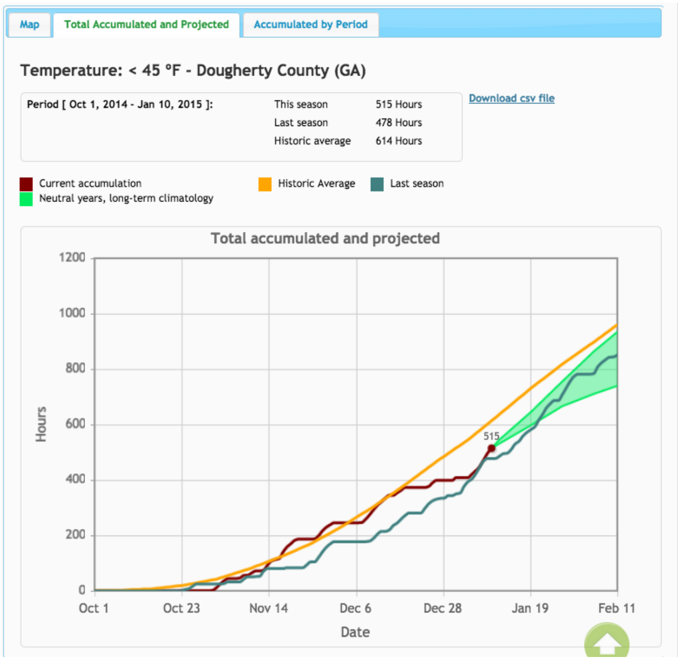


Figure 7.1 Cumulative chill accumulation (number of hours < 45°F) from Oct 1st through January 10, 2015 in Dougherty County, GA.

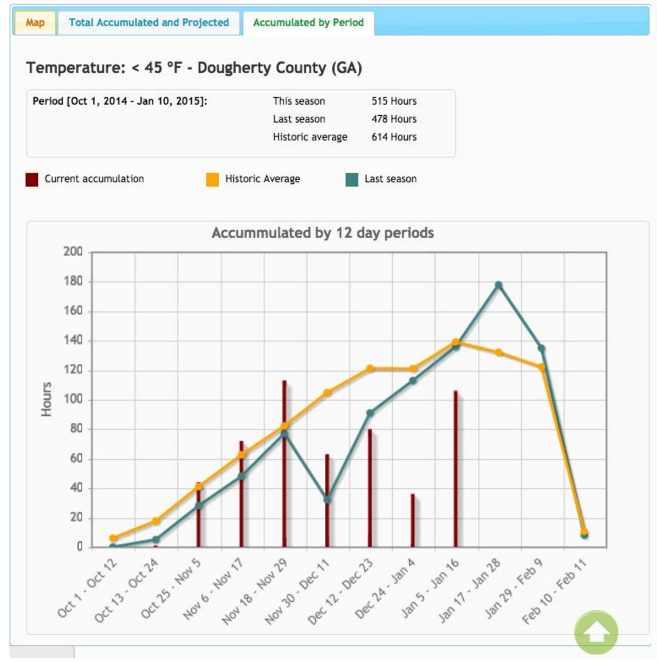


Figure 7.2 Chill accumulation by 12-day periods (number of hours < 45°F) from Oct 1st through January 10, 2015 in Dougherty County, GA.

## Chill Hours Calculator Activity

Peach trees bloom following a dormancy period and an accumulation of chill hours. Chill hours are hours with temperatures below 45°F. Most of the peach varieties recommended for north central Florida have chill hour requirements between 300 and 500 hours. If a peach tree has a lower chill hour requirement, it may accumulate the chill hours for the year early in the winter and after a few weeks of warm temperatures, be ready to break bud or flower.

Peach buds, flowers and fruits can be damaged by freezes. However, buds can take temperatures as low as 18°F. Fully opened flowers can withstand temperatures in the high 20s with a slight percentage loss of fruit. Severe temperatures (low 20s for several hours) usually destroy the entire buds, flowers and seeds in the fruit, which causes the small fruits to drop off. Commercial growers often ice over their orchards to protect the flowers. In a backyard situation, it is better to cover the tree with a high-quality frost cloth and place incandescent light bulbs in the canopy, or string

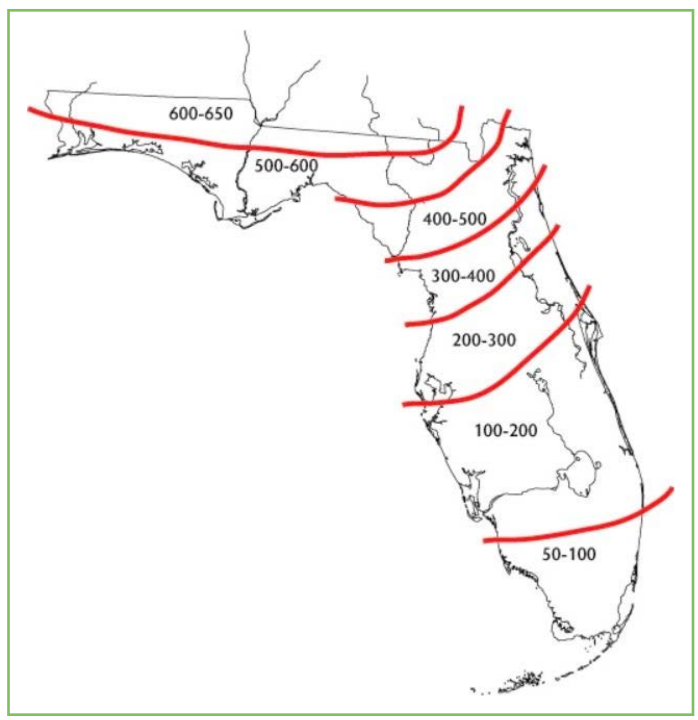


Figure 7.3 Typical chill hours accumulation below 45 °F (7.2 °C) in Florida by February 10th. Credit: Florida State Historical Society.

old-fashioned Christmas tree lights (the large bulbs that get warm when they are lit) in the tree.

**Table 7.2.** Chill accumulation requirements in hours < 45°F (7.2°C) for peach cultivars recommended for north central Florida.

| Peach cultivar | Chill hours requirement |
|---|---|
| Gulfcrest | 525 |
| Gulfcrimson | 400 |
| Gulfking | 350 |
| Flordabest | 250 |

## Activity

*Answer each question below using the Information and table above and the Chill Hours Calculator* (**http://agroclimate.org/tools/Chill-Hours-Calculator/**).

1. Select the Alachua weather station located north of Gainesville, Florida. What is the chill hours accumulation (both models < 45°F and between 32 and 45 °F) by February 10th (use last season if necessary)?

   ______________________________________________
   ______________________________________________
   ______________________________________________

2. Using the table above when was the chill requirements for each of the cultivars reached?

   ______________________________________________
   ______________________________________________
   ______________________________________________

3. How do the dates above compare to last season?

   ______________________________________________
   ______________________________________________
   ______________________________________________

4. Is this in line with the long-term average for this location?

   ______________________________________________
   ______________________________________________
   ______________________________________________

5. Looking at the "Accumulation by Period" tab, were there differences between this season and last season?

   ______________________________________________
   ______________________________________________
   ______________________________________________

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# CHAPTER 8

## Sustainable Intensification of Agriculture

### Key messages

- Sustainable intensification means growing more food and fiber while improving the efficiency of resource use and limiting the expansion of agricultural areas.
- Sustainable practices in this context refer to management strategies that help maintain or improve conditions for human existence and for the ecosystem simultaneously.
- AgroClimate contributes to sustainable intensification by delivering educational resources and decision-support tools that can improve production efficiency and can reduce climate risk.
- Footprint tools such as the Carbon and Water Footprint tools on AgroClimate can help food production professionals to improve their understanding of management impacts on production efficiency and the sustainability of production systems.

## What is Sustainable Intensification?

Sustainable intensification in agriculture describes the increase in food and fiber production while using inputs in a way that minimizes the use of resources and the stress to the environment. Resources in this case include the area used for production and inputs such as organic and chemical fertilizers, irrigation water, fossil fuels, and electricity. This term has emerged as a response to the challenge of providing sufficient food for a global population that is expected to top 9 billion by 2050. The potentially increased environmental risks associated with a changing climate are expected by some to make this challenge even more difficult. Sustainable intensification is one of the ways to ensure there is sufficient food and fiber for our growing and changing world (Figure 8.1). Other approaches to the food demand challenge include reducing food demand through dietary changes and reducing food waste throughout the entire food supply chain.

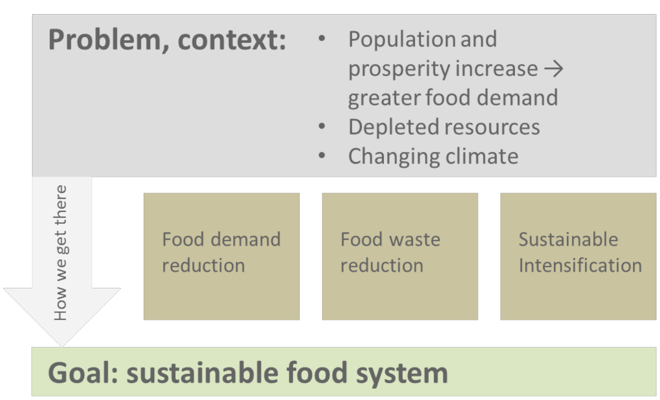


Figure 8.1 Sustainable intensification as one of the pathways to a more sustainable food system.

## How Can AgroClimate Support Sustainable Intensification?

Progress toward sustainable intensification will involve producers, public- and private-sector research and extension, and government regulators. AgroClimate is part of the pathway to sustainable education by providing information that can shape management decisions to bring about increased yield stability, more efficient applications of irrigation water and crop protection chemicals, and more strategic economic decisions.

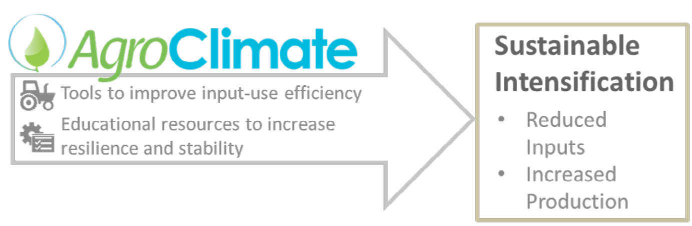


Figure 8.2. AgroClimate contributes to sustainable intensification by providing tools and educational media that can help extension professionals and producers increase production and improve input-use efficiency.

Environmental footprint analysis – for example, carbon, water, and nitrogen footprints – can be useful for estimating the direct and indirect resource consumption in an agricultural system. Footprint tools available on AgroClimate, are one way to evaluate progress toward sustainable intensification. In the U.S., it is estimated that about 10% of national greenhouse gas emissions are from agricultural production (Figure 8.3). About a third of that amount is from enteric fermentation and manure methane emissions from livestock. If you look at the total consumptive freshwater use from surface and groundwater in the U.S., about 82% of national freshwater is consumed in agriculture (Figure 8.3). So agriculture is responsible for 10% of the U.S. carbon footprint and 80% of the U.S. water footprint. The Carbon and Water Footprint calculators on AgroClimate can help interested stakeholders assess the system-specific water and carbon footprints as a way to measure production efficiency and evaluate management changes to improve efficiency.

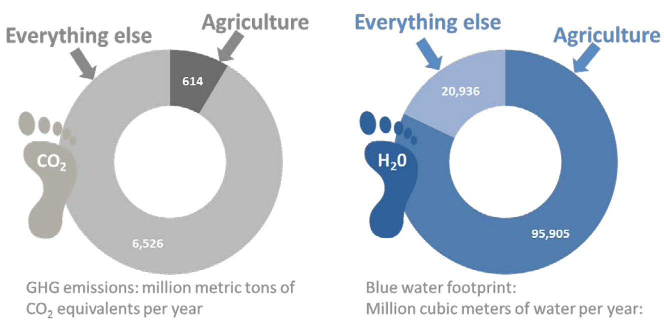


Figure 8.3. U.S. carbon and water footprints for agriculture and all other sectors combined.

A carbon footprint, sometimes called a greenhouse gas footprint, is a measurement of the greenhouse gas emissions of a production system, person, business, or any given source. Carbon footprint is typically expressed in terms of $CO_2e$, or carbon dioxide ($CO_2$) equivalents. This means that all greenhouse gas emissions are expressed in terms of $CO_2$ based on their global warming potential (GWP), which is a relative measure of how much heat a gas traps relative to $CO_2$. $CO_2$ is the reference for GWP, so it has a GWP of 1; methane ($CH_4$) has a GWP of 25; and nitrous oxide ($N_2O$) has a GWP of 298, based on a 100-year time horizon.

A carbon footprint in agriculture is sometimes defined as the on-farm greenhouse gas (GHG) emissions from an agricultural production system. In beef cattle production, about half of GHG emissions are from $N_2O$ emissions from soil (agricultural soil management), about a third are from $CH_4$ emissions, mostly from enteric fermentation in cattle feeding, and about 10% are directly from fuel combustion in operating farm equipment (Figure 8.4). In crop systems, emissions vary according to management practices. In general, more intensive systems that include the use of irrigation and fertilizer application have more total emissions, but lower emissions per unit produced. Conventional till also results in more emissions compared to strip-till. For example, total emissions estimated for cotton produced with strip-till amounts to about 3,500 kg $CO_2/ha^{-1}$, or 3,200 lb $CO_2e/acre^{-1}$. Of these emissions, about 60% come from on farm emissions (till, application of fertilizer, lime, and other chemicals) while the remainder comes from pre-farm emissions related to fertilizer and chemical production, transportation, and others. In an intensive management system using conventional till and no irrigation, 2,400 kg $CO_2$/ha or 2,140 lb $CO_2e$/acre are emitted. In this system, on-farm emissions represent 52% of emissions while pre-farm emission are 48%. In the more intensive system (strip-till, with irrigation), 2.6 lb $CO_2e$/lb of product; in the less intense system (conventional strip, no irrigation), emissions per product are 3.1 lb $CO_2e$/lb. This is an example that, from the standpoint of GHG emissions, shows sustainable intensification, since the most intense system results in lower emissions per unit product.

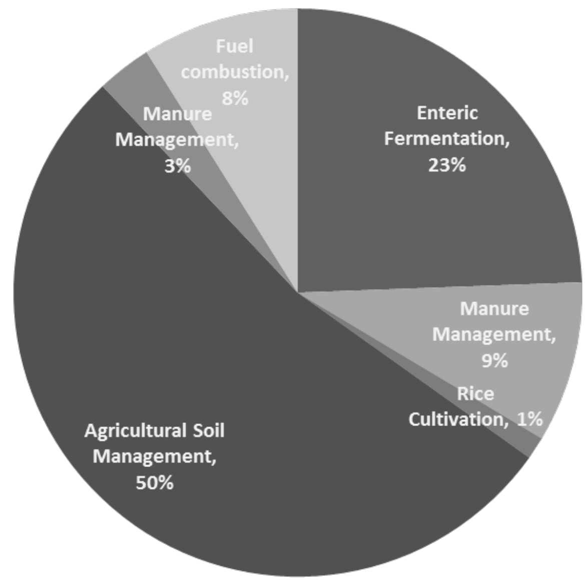


Figure 8.4. U.S. Greenhouse gas emissions from the agriculture sector, 2012, as percent of total agricultural emissions of 614 million metric tons of $CO_2$ equivalents. Source: **http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html**

## Carbon Footprint Calculator on AgroClimate

**Carbon Footprint Calculator**
(**http://agroclimate.org/tools/Carbon-Footprint**)

The Carbon Footprint Calculator tool on AgroClimate accounts for both on-farm and off-farm GHG emissions in units of lbs $CO_2e$/acre. This tool can be used as a way to evaluate the overall production efficiency of a farm. The AgroClimate Carbon Footprint Calculator allows for system-specific adjustments for nutrient and crop protection chemical application rates and for diesel consumption rates for various field operations. It presently works for 5 different crops: corn, cotton, peanut, wheat, and strawberry. For strawberry, the carbon footprinting accounts separately for 1) production, 2) packaging and storage, and 3) transportation to market. For corn, cotton, peanut, and wheat the tool accounts for production carbon footprint only. After the user selects which commodity to

## Corn Farm Machinery

| | | |
|---|---|---|
| Heavy disk | 33.7 | CO2e (lbs/acre) |
| Bed - disk | 23.3 | CO2e (lbs/acre) |
| Plant | 16.0 | CO2e (lbs/acre) |
| Spin spreader | 0.0 | CO2e (lbs/acre) |
| ST plant rigid | 0.0 | CO2e (lbs/acre) |
| Disk harrow | 13.8 | CO2e (lbs/acre) |
| Fertilizer application | 16.6 | CO2e (lbs/acre) |
| Spray | 4.2 | CO2e (lbs/acre) |
| Header - corn | 43.5 | CO2e (lbs/acre) |
| Grain cart corn | 14.4 | CO2e (lbs/acre) |
| Other | 0.0 | CO2e (lbs/acre) |
| **Total farm machinery** | **165.5** | **CO2e (lbs/acre)** |
| **Total farm machinery** | **185.3** | **CO2e (kg/ha)** |

Click to recalculate

| | | | | |
|---|---|---|---|---|
| Heavy disk | 1.52 | Bed - disk | 1.05 | diesel/gal/acre |
| Plant | 0.72 | Spin spreader | 0.00 | diesel/gal/acre |
| ST plant rigid | 0.00 | Disk harrow | 0.62 | diesel/gal/acre |
| Fertilizer application | 0.75 | Spray | 0.19 | diesel/gal/acre |
| Header - corn | 1.96 | Grain cart corn | 0.65 | diesel/gal/acre |
| Other | 0.00 | | | diesel/gal/acre |

## Corn Agrochemicals

| | Off-farm | On-farm | |
|---|---|---|---|
| Nitrogen(N) | 1141.2 | 1485.5 | CO2e (lbs/acre) |
| Phosphorus(P) | 31.9 | | CO2e (lbs/acre) |
| Potassium(K) | 91.1 | | CO2e (lbs/acre) |
| Lime | 645.1 | 524.2 | CO2e (lbs/acre) |
| Boron | 0.0 | | CO2e (lbs/acre) |
| Insecticide | 0.0 | | CO2e (lbs/acre) |
| Herbicide | 237.2 | | CO2e (lbs/acre) |
| Fungicide | 0.0 | | CO2e (lbs/acre) |
| **Total AgroChemicals** | **2146.5** | **2009.6** | **CO2e (lbs/acre)** |
| **Total AgroChemicals** | **2404.1** | **2250.8** | **CO2e (kg/ha)** |

Click to recalculate

| | | |
|---|---|---|
| Nitrogen(N) | 239.41 | lbs/acre |
| Phosphorus(P) | 43.56 | lbs/acre |
| Potassium(K) | 165.55 | lbs/acre |
| Lime | 1099.62 | lbs/acre |
| Boron | 0.00 | lbs/acre |
| Fungicide | 0.00 | lbs/acre |
| Herbicide | 10.27 | lbs/acre |
| Insecticide | 0.00 | lbs/acre |

Figure 8.5. AgroClimate Carbon Footprint Calculator showing an example of GHG emissions due to farm machinery operations.

work with, the required inputs are grouped into 3 different tabs: “Farm Machinery”, “Irrigation”, and “Agrochemicals”. In the “Farm Machinery” tab, the user can adjust the fuel consumption rate, in gallons of diesel fuel per acre, from the default average values for the provided field operations. In the “Irrigation” tab, the user first inputs the area irrigated, then how many applications or irrigation events during the season, and finally the average time of each irrigation event. In dryland or rainfed systems that are not irrigated, the user should make sure some number (not zero) is input in the area field, but either the time or number of applications (or both) can be set to zero. In the “agrochemicals” tab, the user can adjust the total seasonal applic on amounts (gallons/acre) of 8 inputs: nitrogen, phosphorus, potassium, lime, boron, fungicide, herbicide, and insecticide. After adjusting the inputs in any of the 3 tabs, the user should click the “Click to recalculate” button. The results showing Total Production Carbon Footprint are viewed in the Total Production tab with a four-part breakdown of the results by farm machinery, irrigation, off-farm agrochemicals, and on-farm agrochemicals. For the Strawberry Carbon Footprint, the tool has 3 additional tabs for inputs for transportation, plastic, and nursery.

## Carbon Footprint Activity

1. A strawberry producer in Plant City, Florida is contacted by a strawberry buyer who says they can offer a higher price in their purchasing contract if they can provide a Carbon Footprint label on their packaging. However, the buyer says they don’t have the resources to do a detailed farm-specific accounting of greenhouse gas emissions. The producer has been using the Strawberry Advisor System on AgroClimate and they noticed a Carbon

Footprint calculator on the site. How might this help the producer in marketing their strawberries?

What is the total Carbon Footprint for strawberries in lbs $CO_2e$ / lb strawberry? How much of that is from production?

1. Navigate to the Carbon Footprint Calculator directly **http://agroclimate.org/tools/Carbon-Footprint/** or from the tools page on AgroClimate

2. Select "Strawberry" and leave inputs as the default values. What is the carbon footprint of strawberries? How much is related to the production phase only?

______________________________________
______________________________________
______________________________________

How does the carbon footprint change if strawberry seedlings are sourced closer to the farm?

1. Select "Production" from left menu and then select "Transportation" tab.

2. Change the "Seedlings – Distance from nursery" from default value of 1,502 miles to 15 miles. Click the recalculate button to obtain results from this modification.

3. Select "Total" from left menu – how much did the total carbon footprint change?

______________________________________
______________________________________
______________________________________

Why does this make so little difference? Two reasons – If you look at the "Strawberry Production" tab, Transportation is a very small part of production carbon footprint. Also, the large yields (around 24,000 lbs/acre) are used to divide the total emissions from lbs $CO_2e$/acre to get lbs $CO_2e$/lb of strawberries, and this large denominator reduces the impacts from a per acre basis.

4. Refresh the tool from your web browser (click refresh button or hit Enter key after putting cursor at end of web address) to return values to defaults. Select "Strawberry" again.

5. Select "Production" from left menu and then select "Plastic" tab. Change "Do you burn plastic?" to "No" (unselect "Yes"). Click to recalculate.

How much does this change the Total Production carbon footprint?

______________________________________
______________________________________
______________________________________

1. A diversified row crop producer near Tifton, GA grows cotton as part of his rotation. A recent news article reported that agriculture could reduce its carbon footprint by 50% if farms were not irrigated. How can we test this claim for cotton production using the AgroClimate Carbon Footprint calculator?

What is the total carbon footprint for 1,000 acres of irrigated cotton in lbs $CO_2e$/acre? Navigate to the Carbon Footprint Calculator directly **http://agroclimate.org/tools/Carbon-Footprint/** or from the tools page on AgroClimate.

Select "Cotton" and click on the "Irrigation" tab to change irrigated area to 1000 acres. Set application to 5 hours and application number to 10 days. What is the carbon footprint of cotton production? How much of that is from off-farm manufacturing of fertilizer and crop protection chemicals? 1,137 lbs $CO_2e$/acre. What happens if there is no irrigation? Change the application time or days or both to 0.

## Water Footprint

A water footprint is a way to measure efficiency of water consumption. In agriculture, it is the amount of water consumed per unit of production. For example, the total water footprint for peanut production might be around 1,800 liters of water per kilogram of peanut (216 gallons per lb of peanut), depending on the location, climate, and management. A water footprint differs from the typical measure of water use and water withdrawals because a water footprint only accounts for consumptive water use, which is water that becomes unavailable locally in the short term due to evaporation and transpiration.

A water footprint accounts separately for three types of freshwater consumption: (1) green water use, which is consumption from rainfall; (2) blue water use, which is consumption from groundwater or surface water; and (3) grey water use, which would be the dilution water required to reduce pollutant concentrations to acceptable values (Figure 8.6). This distinction among green, blue, and grey water footprints recognizes that the consumptive use of rainfall, groundwater or surface water, and their water quality impacts in turn have different economic costs and ecological impacts. Comparing water footprints of different management practices in agriculture can help evaluate drought tolerance, water use efficiency, effective use of rainfall, and significance of irrigation.

# Water Footprint on Agroclimate

**Water Footprint**
(**http://agroclimate.org/tools/Water-Footprint**)

The Water Footprint tool on AgroClimate provides an estimate of the consumptive use of rainfall (green water) and the consumptive use of irrigation water (blue water) relative to crop production for a specific time, location, and management. The required inputs include: 1) location, 2) crop, 3) planting and harvest dates, 4) yield as input or simulated, 5) soil characteristics (texture, root zone depth, organic matter), 6) tillage, and 7) irrigation management. Location can be selected on a map or by inputting a zip code. Crop choice is based on user selection from five groups: 1) cereals, pasture and forage, 2) fiber, 3) legumes, fruits and vegetables, 4) sugar, and 5) stimulants. Currently, users can select from among approximately 70 annual crops.

Planting and harvest dates can be anytime in the past from last season back to about 1950. Soil information is based on the HC27 generic soil profiles that have been used for global crop modeling applications (Nelson et al., 2009). This gives three choices for texture (sandy, silty, clayey), three choices of root zone depth (60, 120, and 180 cm), and three choices of organic matter content (1.4%, 1.0%, and 0.4%, 1.0% and 1.4% in the top layer of soil). Tillage implement is based on one of four groups: conservation, subsoil, conventional, or weed-control. Tillage implement and direction (straight-row or contour) are used by the model to adjust runoff curve number (USDA, 1954). Irrigation management is either rainfed (no irrigation), auto-irrigation (irrigation is applied by the model based on a user-defined water stress threshold), or manual irrigation (total seasonal irrigation depth and average irrigation frequency are input by user).

The estimates of crop growth and water balance in the Water-Footprint tool are based on simulations from the EPIC crop growth model (Environmental Policy Integrated Climate; Williams et al., 1989) within the framework of the SWAT hydrology model (Soil and Water Assessment Tool; Arnold et al., 1998). EPIC uses a generic growth model, with different crops being described using approximately 30 plant-specific parameters.

Daily weather data are required for the simulations water balance and crop growth. The Water Footprint tool automatically retrieves and formats daily rainfall and temperature data from a network of 5953 active U.S. weather stations that are part of the Global Historical Climatology Network – Daily Menne et al., 2012). The tool chooses the closest station having adequate data (complete records of maximum temperature, minimum temperature, and precipitation), based on user-selected farm location. Solar radiation, wind speed, and relative humidity are generated using the WXGEN weather generator implemented in SWAT (Sharpley and Williams, 1990). The Water Footprint tool is currently functional in the U.S., but by changing the routines for weather data retrieval and formatting, it could easily be adapted for use in other parts of the world.

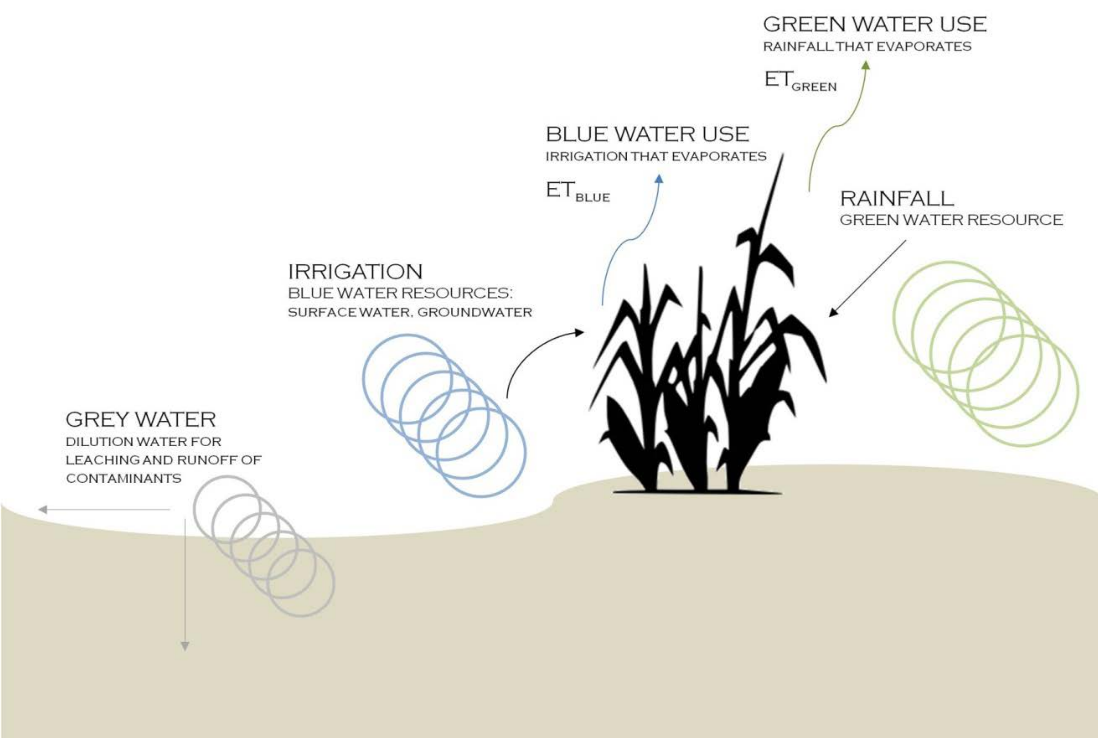


Figure 8.6. Green, blue, and grey water flows in an agricultural system. Credit: Daniel Dourte

**Calculating a Crop Water Footprint:** Following the methods standardized by the Water Footprint Network (Hoekstra et al., 2011), the procedure for water footprint accounting of an agricultural crop is summarized below. While the grey water footprint is an important way to represent water quality impacts, the AgroClimate Water Footprint tool focuses only on blue and green water footprints. The detailed input data needed to accurately account for contaminants in water make this too cumbersome for a web-user interface. The water footprint of a crop is calculated as:

$$WF_{crop} = WF_{crop,green} + WF_{crop,blue} \text{ [volume/mass]},$$

where

$$WF_{crop,green} = \frac{ET_{green} \text{ [volume/area]}}{\text{(Yield [mass/area]}}; \ldots$$

$$WF_{crop,blue} = \frac{ET_{blue} \text{ [volume/area]}}{\text{(Yield [mass/area]}};$$

Crop water footprint units are expressed in volume per unit mass (often liters/kg or, equivalently, $m^3$/ton). Both time and area are included implicitly in the calculation of a crop water footprint. The yield of a system is usually measured in mass per unit area, and the yield is produced during some time (typically around 4–6 months for most annual crops). Yield may be simulated using a crop growth model, or it may be input based on recorded data at the appropriate location. Also, green and blue evapotranspiration (ET) are measured in units of depth (mm), and converting these units of depth requires multiplication of ET depth by the area used to measure yield (hectare or acre), giving ET in units of volume/area. The crop under consideration could be any agricultural or forestry product from either annual or perennial systems.

*Simulating Evapotranspiration:* Both the estimation of ET and the separation into $ET_{green}$ and $ET_{blue}$ generally requires the use of water and energy balance models. ET can be measured, but the instrumentation required to measure ET is expensive and the measurement is only valid for a small area under specific management. ET estimates for a variety of climate regimes, seasons, crops, and management require the use of mathematical models that account for the environmental demand of the atmosphere. These models are based on the physics of heat transfer, measured weather variables, and the physical properties of the crop and management system, based on crop type, growth stage, irrigation, and tillage management. Crop ET ($ET_c$) is often estimated by multiplying a growth-stage-dependent crop coefficient ($K_c$) by a measure of reference evapotranspiration ($ET_o$), giving $ET_c = K_c * ET_o$ (Allen et al., 1998).

*Separating Blue and Green ET:* As with estimating ET, the separation of ET into blue (from irrigation) and green (from rainfall) components requires the use of mathematical models because the required instrumentation to observe the separation is too expensive to be practical in most situations. $ET_{green}$ is the depth of rainfall that stays in the plant root zone that is available for use by the plant. It can be referred to as effective rainfall ($P_{effective}$), and it is expressed by the following equation:

$$P_{effective} = P - RO - DP \text{ [depth/time]},$$

where P is total rainfall, RO is runoff of excess rainfall, and DP is deep percolation or drainage below the root zone of excess soil water. Peffective can be estimated using a variety of models. Two examples are the empirical USDA SCS method (United States Department of Agriculture, Soil Conservation Service; USDA, SCS, 1967) or a physically based soil-water balance model, like that of a hydrology (SWAT; Arnold et al., 1998) or crop model (EPIC; Williams et al., 1989). Green and blue ET can be calculated as follows (Hoekstra et al., 2011):

$$ET_{green} = \min(ET_c, P_{effective}) \text{ [depth/time]}$$

$$ET_{blue} = ET_c - ET_{green} \text{ [depth/time]}.$$

Figure 8.7 shows the Florida and U.S. national average blue and green water footprints for wheat, corn, soybean, peanut, and cotton (Mekonnen and Hoekstra, 2010b). The figure illustrates the importance of green water use and ET of rainfall, which is not accounted for in traditional water use measures. The global water footprint of crop production is 7,404 billion $m^3$/year (Mekonnen and Hoekstra, 2011), of which 78% is from rainfall (green water), 12% is from freshwater resources (blue water, meaning irrigation), and 10% is grey water.

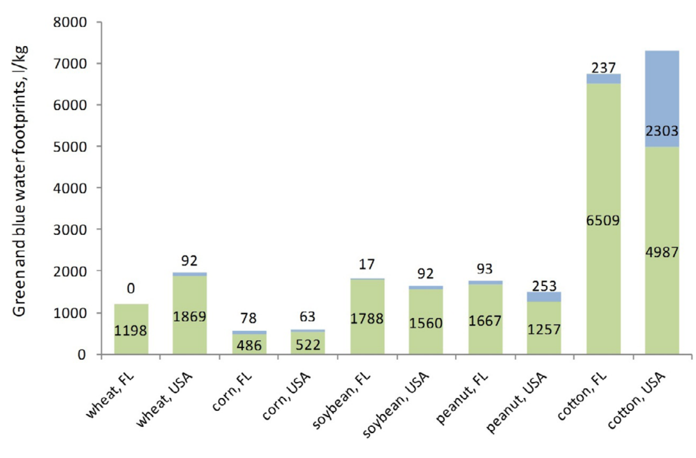


Figure 8.7. Green and blue water footprint averages of selected crops in Florida and the whole U.S. (Mekonnen and Hoekstra 2010b) during 1996-2005. Credit: Daniel Dourte

A surprising result of separating green and blue water footprints is that the total water footprints of many irrigated crops are actually less than that of rainfed crops. This can happen because the yields of irrigated crops increase more than the associated ET increase, and the water footprint as a ratio of ET volume to yield mass can show similar or lower total water footprints for irrigated crops compared to rainfed crops. However, the blue water footprint of rainfed crops is zero, and it is consumption of blue water that typically has more important environmental impacts and greater competition for its use.

**What's the Purpose of a Water Footprint?** We monitor freshwater use because, despite its renewability, its availability is limited in space and time. In order to sustain human populations, a certain amount of consumptive water use is needed, estimated at about 1,300 $m^3$/year/person (Rockström et al., 2009). Water footprinting provides a way to account for what types of freshwater resources are used (rainfall, surface water, or groundwater) and where they are used. The following list summarizes some applications of water footprint accounting:

- Making comparisons of consumptive water use among different agricultural management systems: For example, converting a rainfed system to no-tillage may decrease the water footprint as there may be an increase in infiltration of rainfall and a reduction in non-beneficial soil evaporation. However, in some soil types, compaction problems could increase the water footprint because of reduced crop yields. Adding a high-residue cover crop that slowly increases soil organic matter may increase $ET_{green}$, while actually lowering the water footprint, because of yield increases.
- Evaluating drought tolerance of agricultural management systems: When comparing different management strategies, a lower water footprint in a low-rainfall or a highly variable rainfall situation suggests higher water use efficiency (WUE), which is the ratio of yield or biomass to volume of ET.
- Comparing management systems in different regions/climates: Regional comparisons of water footprint of some crops may suggest that production should be shifted to an area where production would have a lower water footprint.
- Labeling products to increase awareness of water use: Providing a water footprint label on food products could give consumers more information about the size and location of a product's water footprint.

Blue water resources, including lakes, rivers, and groundwater resources, are replenished at a rate determined by atmospheric and landscape characteristics. The available green water resource (or the amount of rainfall that is consumptively used) depends on rainfall during some time period and the partitioning of that rainfall into green and blue flows, which is determined by land management and landscape characteristics. Sustainability of blue water use can be evaluated by comparing a blue water footprint of some area [volume/time] with the estimated renewal rate of the blue water resource(s). This has been done on a global scale, and it was estimated that up to 25% of consumptive uses of irrigation water are unsustainable (Rost et al., 2008), meaning they exceed local renewal rates. The complementary nature of blue water use and green water use has important management implications. For example, if the blue water footprint of some agricultural system is found to be substantially larger than the renewal rate of blue water resources, then an expansion of green water use may be evaluated as a way to satisfy crop water requirements while reducing the blue water footprint. Green water use in global agriculture is important because making rainfall more productive– that is, increasing the green water use– shows great potential for providing the increased consumptive water use required to increase agricultural production (Rockström et al., 2009).

The strength of water footprint accounting is that it measures consumptive water use separately for rainfall and irrigation water, and then it connects those water uses to a specific place and time. This recognizes the renewability of freshwater, but also emphasizes the need to use it efficiently because of its limited availability in an area during some time. Water footprinting can provide even more information when it is used alongside some measure of water scarcity. For example, consider cotton grown in Arizona compared with that grown in north Florida. Total water footprints are about the same, but the per capita renewable freshwater is much lower in Arizona. That is an important consideration when using water footprints to evaluate the hydrologic sustainability of a system. Finally, it is suggested to always make the distinction between consumptive use of rainfall (green water use) and of groundwater or surface water (blue water use) because this separation between water of different value is an important part of water footprinting.

## Water Footprint Activity

A peanut producer in Plains, Texas has been farming there for almost 20 years. He grows peanut and cotton and sometimes hay. In the past 5 years his wells have been unreliable as groundwater levels have dropped. Much of his family lives in the Florida panhandle and they have several hundred acres in pasture; he is considering moving his production to Florida because of his recent and expected water shortages. How can the Water Footprint tool (**http://agroclimate.org/tools/Water-Footprint/**) help give him some more information about what to do?

Calculate the water footprint of irrigated peanut production in Plains, TX and compare it to that for Milton, FL. These are leading peanut growing areas in TX and FL.

1. Use the “Change units” tab/button along the left to select Water footprint units of gallons/lb. This tab is the second one from the bottom.
2. Select “Location.” Input location using zip code: 79355 for Plains, TX. Click the button to select/set zip code location.
3. Select crop: legumes – peanut.
4. Select planting and harvest dates: 5/15/2014, 9/18/2014
5. Specify yield: you can choose to either have yield be simulated by the model or provide it as an input. For the purposes of this exercise, input 4000 lbs/ac for yield.
6. Select soil: Texture– silt, Rooting zone depth– average, Soil organic matter– medium.
7. Select tillage: Conservation– strip tillage.
8. Water management: auto-irrigated (0.75 water stress threshold). This irrigates when crop growth is reduced by water stress to below 75% of maximum growth.
9. Leave fertilizer application as default
10. Click blue button: “Click to calculate water footprints”

What is the blue water footprint of 2014 irrigated peanut in Plains, TX? What is the seasonal total rainfall?

1. Change locations to compare water footprint for a different region (same time, same management). Select scenario 2 using the top tab. All the input data from the Plains, TX scenario is automatically applied to the second scenario. The only thing we will change is the location.
2. Input location using zip code: 32571 for Milton, FL. Click the button to select/set zip code location.
3. Click blue button: “Click to calculate water footprints”

What is the blue water footprint of 2014 irrigated peanut in Milton, FL? What is the seasonal total rainfall?

______________________________________________

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Check your results again in the screenshots below.

Change the year to 2011(this has to be done for each scenario one at a time). How do the results change? Why?

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Why is the Water Stress Index (WSI) so different between the two locations?

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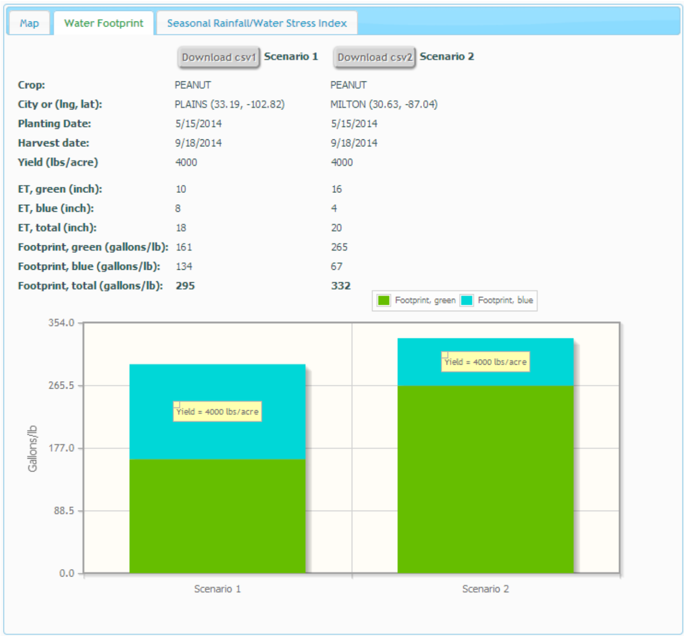
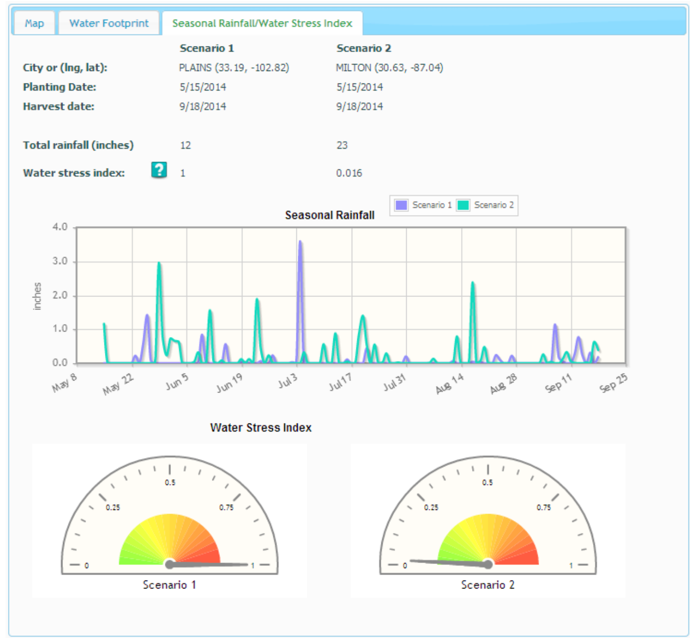
## Nitrogen footprint Introduction

A nitrogen footprint is the amount of nitrogen released to the environment through production and consumption activities. As with carbon and water footprints, a nitrogen footprint can be calculated for a nation, business, farm, manufacturing process, person, or another quantity of interest. The average nitrogen footprint in the U.S. has been calcvlated to be 41 kg N/capita/year. This means that each year, on average each person is responsible for about 40 kg of N entering the environment. 23 kg of N, more than half of the total per capita value, are from food production.

**The Nitrogen Footprint calculator on AgroClimate is presently under development.** The goal of this tool will be to allow users to assess the farm-specific efficiency of nitrogen use based on farm management practices. Additionally, a real-time nitrogen monitor is being developed for AgroClimate to allow users to track nitrogen applications and losses in real-time using hyper-local soil and weather data and user-provided inputs.

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# GLOSSARY

**Circulation** - The flow, or movement, of a fluid (e.g., water or air) in or through a given area or volume.

**Climate** - The average of weather conditions prevailing in an area over at least a 30-year period. Note that the climate taken over different periods of time (30 years, 1000 years) may be different. The old saying is that climate is what we expect and weather is what we get.

**Climate Change** - A non-random change in climate that is measured over several decades or longer. The change may be due to natural or human-induced causes.

**Climate System** - The system, consisting of the atmosphere (gases), hydrosphere (water), lithosphere (solid rocky part of the Earth), and biosphere (living organisms) that determines the Earth's climate.

**Climatology** - (1) The description and scientific study of climate. (2) A quantitative description of climate showing the characteristic values of climate variables over a region.

**Cooling Degree-Days** - A form of degree-day used to estimate energy requirements for air conditioning or refrigeration (See degree-day)

**Degree-Day** - For any individual day, degree days indicate how far that day's average temperature departed from 65°F. Heating Degree-Days measure heating energy demand. It is a measure to indicate how far the average temperature fell below 65°F. Similarly, Cooling Degree Days, which measure cooling energy demand, indicate how far the temperature averaged *above* 65°F. In both cases, smaller values represent less fuel demand, but values below 0 are set equal to 0, because energy demand cannot be negative. Furthermore, since energy demand is cumulative, degree day totals for periods exceeding 1 day are simply the sum of each individual day's degree day total. For example, if some location had a mean temperature of 60°F on day 1 and 80°F on day 2, there would be 5 HDD's for day 1 (65 minus 60) and 0 for day 2 (65 minus 80, set to 0). For the day 1 + day 2 period, the HDD total would be 5 + 0 = 5. In contrast, there would be 0 CDD's for day 1 (60 minus 65, reset to 0), 15 CDD's for day 2 (80 minus 65), resulting in a 2-day CDD total of 0 + 15 = 15.

**Dew Point** - The point at which the air at a certain temperature contains all the moisture possible without precipitation occurring. When the dew point is 65°F, one begins to feel the humidity. The higher the temperature associated with the dew point, the more uncomfortable one feels.

**Drought** - A deficiency of moisture that results in adverse impacts on people, animals, or vegetation over a sizeable area. NOAA, together with its partners, provides short- and long-term Drought Assessments.

**El Niño** - El Niño, a phase of ENSO, is a periodic warming of surface ocean waters in the eastern tropical Pacific along with a shift in convection in the western Pacific further east than the climatological average. These conditions affect weather patterns around the world. El Niño episodes occur roughly every 4-5 years and can last up to 12- 18 months. The preliminary Climate Prediction Center (CPC) definition of El Niño is a phenomenon in the equatorial Pacific Ocean characterized by a positive sea surface temperature departure from normal (for the 1971-2000 base period), averaged over three months, greater than or equal in magnitude to 0.5°C in a region defined by 120°W-170°W and 5°N-5°S (commonly referred to as Niño 3.4). El Niño, which would appear off the coast of Peru around Christmas time, is Spanish for "the boy" referring to the Christ child.

**ENSO (El Niño-Southern Oscillation)** - Originally, ENSO referred to the combined atmosphere/ocean system during an El Niño warm event. However, the ENSO cycle includes La Niña and El Niño phases, as well as Neutral phases. The Southern Oscillation is quantified by the Southern Oscillation Index (SOI).

**Evaporation** - The physical process by which a liquid or solid is changed to a gas; the opposite of condensation.

**Evapotranspiration** – The sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere.

**Forecasts** A weather forecast, or prediction, is an estimation based on special knowledge of the future state of the atmosphere with respect to temperature, precipitation, and wind. Weather forecasts are now routinely provided for up to 14 days in advance, without looks for seasonal and longer timescales.

**Global Warming** - An overall rise in the temperature of the Earth's atmosphere caused by natural and human-produced gases preventing the sun's energy from escaping back to space.

**Greenhouse Gas** - Certain gases, such as water vapor, carbon dioxide, and methane, that more effectively trap heat, affecting the Earth's surface temperature.

**Growing Degree-Days** (GDD) - A heat index that relates the development of plants, insects, and disease organisms to environmental air temperature. The index varies depending on whether a certain plant is a cool, warm, or very warm season plant. For example, a corn GDD is an index used to express crop maturity. The index is computed by subtracting a base temperature of 50°F from the average of the maximum and minimum temperatures for the day. Minimum temperatures less than 50°F are set to 50, and maximum temperatures greater than 86°F are set to 86. These substitutions indicate that no appreciable growth is detected with temperatures lower than 50 or greater than 86. If the maximum and minimum temperatures were 85 and 52, you would calculate the GDD by ((85+52/2) - 50) = 18.5 GDD.

**Heating Degree-Days** - A form of degree-day used to estimate energy requirements for heating. (See degree-day)

**Hurricane** - Tropical cyclones with sustained winds above 73 miles per hour are known as hurricanes in the North Atlantic Ocean, Caribbean Sea, Gulf of Mexico and the Eastern North Pacific (east of the date line). They are known as cyclones in the Indian Ocean, and typhoons in other areas of the world. Both mid-latitude and tropical storms serve an important function in transferring warmth away from the tropics to the poles.

**Hydrology** - The scientific study of precipitation, evaporation, distribution, and effects of water on the Earth's surface, in soil and rocks, and in the atmosphere.

**Infiltration** – The process by which water on the ground enters the soil. The rate at which soil is able to absorb rainfall or irrigation is known as the infiltration rate.

**Intraseasonal Oscillation**s - Variability on a timescale of less than a season. One example is the Madden-Julian Oscillation.

**La Niña** - La Niña, a phase of ENSO, is a periodic cooling of surface ocean waters in the eastern tropical Pacific along with a shift in convection in the western Pacific further west than the climatological average. These conditions affect weather patterns around the world. The preliminary Climate Prediction Center (CPC) definition of La Niña is a phenomenon in the equatorial Pacific Ocean characterized by a negative sea surface temperature departure from normal (for the 1971-2000 base period), averaged over three months, greater than or equal in magnitude to 0.5°C in a region defined by 150°W-160°E and 5°N-5°S (commonly referred to as Niño 4).

**Mean** - The arithmetic average, or the middle point between two extremes.

**National Oceanic and Atmospheric Administration (NOAA)** - A government agency within the US Department of Commerce focused on describing and predicting changes in the Earth's environment, conservation and the management of coastal and marine resources. (See http://www.noaa.gov)

**Probability** - A chance, or likelihood, that a certain event might happen.

**Relative humidity** - An estimate of the amount of moisture in the air relative to the amount of moisture that the air can hold at a specific temperature. For example, if it's 70°F near dawn on a foggy summer morning, the relative humidity is near 100%. During the afternoon the temperature soars to 95°F and the fog disappears. The moisture in the atmosphere has not changed appreciably, but the relative humidity drops to 44% because the air has the capacity to hold much more moisture at a temperature of 95°F than it does at 70°F. But even when the relative humidity is "low" at 44%, it's a very humid day when the temperature is 95°F. For this reason, a better measure of comfort is dew point.

**Root Zone** – The portion of the soil profile which contains plant roots. Soil chemistry and biology in the root zone are directly affected by root secretions and associated soil microorganisms.

**Sea Surface Temperatures (SSTs)** - The mean temperature of the ocean in the upper few meters.

**Subtropical** - A climate zone adjacent to the tropics with warm temperatures and little rainfall.