

Drought Decision-Support Tools: Introducing the Agricultural Reference Index for Drought—ARID¹

Clyde W. Fraise, Eduardo M. Gelcer, and Prem Woli²

Introduction

Agriculture is inherently risky. Drought is a recurring phenomenon that has plagued civilization throughout history (Heim 2002). Agriculture is often the first sector affected by the onset of drought because it depends on precipitation and soil moisture reserve during various growth stages (Narasimhan and Srinivasan 2005). In fact, drought takes a bigger economic toll in the United States than other natural disasters. It was the predominant source of crop insurance indemnities paid because of crop losses between 1999 and 2009, totaling \$15.3 billion or an average 37% of the indemnities paid during that time (USDA/RMA 2010).

Drought differs from other natural hazards in several ways. First, drought is a slow-onset natural hazard often referred to as a creeping phenomenon (Gillette 1950). Because of drought's creeping nature, its effects accumulate slowly over a substantial period of time, making its beginning and end difficult to determine. The first evidence of drought is based on rainfall records, while the next piece of evidence to appear is often an effect on

vegetation. The capacity of soil to store water affects the period of time until a drought starts affecting crops. The effects of a drought on flow in streams and rivers may not be evident for several weeks or months. Drought impacts are non-structural and generally spread over a larger geographical area than damages resulting from other natural hazards such as floods and hurricanes. Also, drought does not have a precise and universally accepted definition. Over the years, drought has been defined in many ways. However, droughts are generally classified into four categories, including meteorological, agricultural, hydrological, and socio-economic droughts (Wilhite and Buchanan-Smith 2005).

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

Agricultural drought is characterized by a shortage of moisture in the root zone of crops and does not depend only on the amount of precipitation. The same amount of precipitation in January and July will have

-
1. This document is AE469, one of a series of the Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date February 2011. Visit the EDIS website at <http://edis.ifas.ufl.edu/>.
 2. Clyde W. Fraise, assistant professor, Department of Agricultural and Biological Engineering, University of Florida; Eduardo M. Gelcer, graduate student, Department of Agricultural and Biological Engineering, University of Florida; Prem Woli, postdoctoral associate, Department of Agricultural and Biological Engineering, Mississippi State University.

different impacts. A drought occurring in the winter may have little or no observable effects on crops. However, during the summer, when temperatures are warmer and days are longer, plants will extract more water from the root zone. Consequently, summer droughts are more apparent and cause more damage. Moderate drought during crop growth periods can result in stunted growth of the crop and reduced crop yields. A severe drought during the same period may result in a total crop failure.

Hydrological drought is characterized by decreased flows in rivers and streams and below-average water levels in lakes, reservoirs, and groundwater.

Socio-economic drought differs from the other types because it associates the supply and demand of economic goods (e.g., water, grains, hydro-electrical power) with elements of meteorological, hydrological, or agricultural droughts.

Currently, several products can help managers and stakeholders generally understand and monitor drought conditions, including the Palmer Drought Severity Index (PDSI), the Standardized Precipitation Index (SPI), and also online early warning and decision-support tools such as the U.S. Drought Monitor (<http://drought.unl.edu/dm/monitor.html>). Recently, researchers at the University of Florida developed another index, called the Agricultural Reference Index for Drought or ARID (Woli 2010), which is designed to better characterize agricultural droughts. ARID is a simple and reliable index to monitor and predict agricultural drought. It is based on a reference crop (grass) and takes into account the soil-plant-atmosphere relationships.

The nuts and bolts of ARID

ARID is based on a reference crop, which is actively growing grass that completely covers the soil surface. ARID uses a simple soil water balance for a soil profile assumed to be 16 inches (40 cm) deep with evenly distributed roots. The amount of soil water is calculated daily based on how much water is added to the system by rainfall and how much water

leaves the system by transpiration, runoff, and deep percolation (drainage) (Figure 1). The profile has just one soil layer, and the downward flow at the bottom of the layer is assumed open.

$$SM_i = SM_{i-1} + P_i - RO_i - D_i - T_i$$

Where:

- SM_i is the available soil moisture for the i -th day (mm);

- SM_{i-1} is the available soil moisture for the previous day (mm);

- P_i is the precipitation (rainfall) for the i -th day (mm);

- RO_i is the runoff for the i -th day (mm);

- D_i is the deep percolation (drainage) for the i -th day (mm);

- T_i is the transpiration for the i -th day (mm).

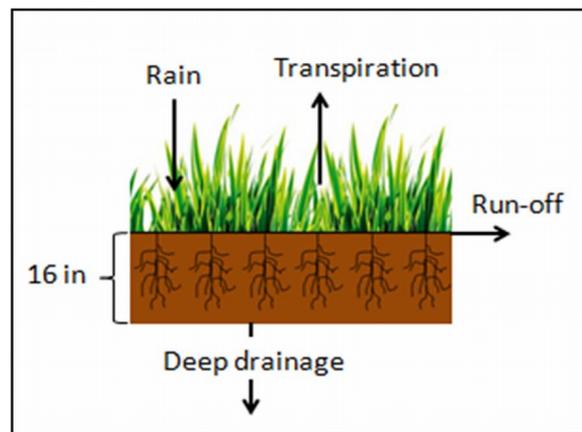


Fig. 1. Soil water balance components

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.

How to quantify water stress at a particular time?

ARID answers this question. It is an indication of the crop water deficiency caused by aerial and subsurface environments. ARID can be defined as a ratio of actual transpiration to potential evapotranspiration:

$$ARID = 1 - \frac{T}{ET_0}$$

Fig. 2.

Where:

T = actual transpiration or crop water uptake in a particular day (mm day^{-1}),

ET_0 = potential evapotranspiration (mm day^{-1}).

ARID values range from 0 to 1. When no transpiration occurs ($T = 0$), ARID takes a maximum value of one, indicating a full water deficit; whereas ARID is zero when transpiration occurs at potential rate ($T = ET_0$), indicating no deficit at all. Between these two extremes, water deficit decreases linearly with increase in actual transpiration.

Typical ARID values for Florida vary during the year. During cold months, average temperatures are higher in the south than in the northern parts of the peninsula and in the panhandle, which results in higher evapotranspiration in southern Florida. The southern parts of the state also receive less rainfall during the winter. The combination of higher evapotranspiration and lower input of water to the soil results in higher ARID values in the southern parts of the state (Figure 3A).

During the summer, average temperatures are higher and more uniform across the state. Rainfall gains importance because of its high concentration in this period, particularly in the southern parts of the peninsula. These conditions result in more uniform values of ARID throughout the state. Still, ARID values are slightly lower for the southern region and slightly higher in the panhandle (Figure 3B).

Monitoring ARID on AgroClimate.org

The ARID Tool available on *AgroClimate.org* (Fraisse et al. 2006) (<http://www.agroclimate.org/tools/drought/>) allows

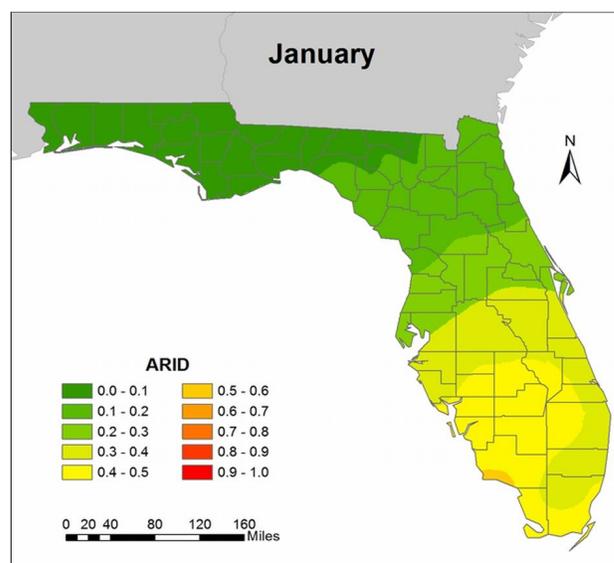


Fig. 3A. Typical average values of ARID for a sand soil in January

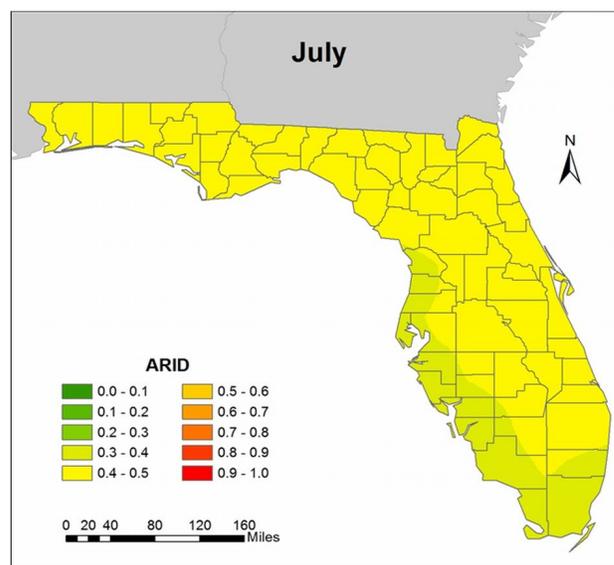


Fig. 3B. Typical average values of ARID for a sand soil in July

users to monitor the values of ARID during the last 90 days based on data collected at weather stations belonging to Florida Automated Weather Network (FAWN) and the Georgia Automated Environmental Monitoring Network (GAEMN). The information available in the ARID Tool is displayed in a GIS format using Google Maps API, a free mapping technology developed by Google and currently used in many systems around the world. Since Google Maps is based on satellite imagery, the tool allows the users to interact with the map through page movements and zooming capabilities. Each point on

the map is associated with specific information and can be viewed as text or images.

When the ARID Tool is loaded, a map indicating the ARID current conditions for all FAWN and GAEMN weather stations is shown. The main web page is divided into five sections (Figure 4). Section A shows information about AgroClimate, the current El Niño Southern Oscillation (ENSO) phase, and other tools.

The desired weather station or county can be selected either by name in section B or by location in section D. Section C explains ARID and how it is calculated, and provides other information. Section E includes links, contact information, and the gate to the administration page.

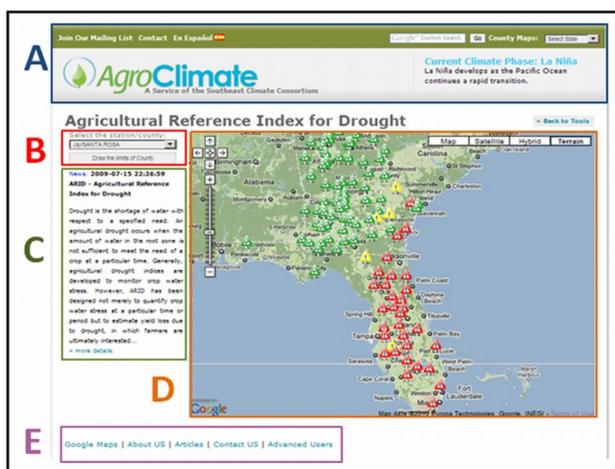


Fig. 4. The main web page for the ARID Tool

When a weather station is selected, the map moves to the corresponding location and a graph pops up showing ARID values over the past 90 days (Figure 5). The graph contains three lines corresponding to three types of soil commonly found in the southeastern United States: sand, sandy-loam, and loam.

The different colors indicate different classes of ARID values and soil conditions:

- Green: ARID values between 0.0 and 0.3 – Little or no stress;
- Yellow: ARID between 0.3 and 0.6 – Stress watch or moderate stress;

- Red: ARID between 0.6 and 1.0 – Stress warning or high stress.

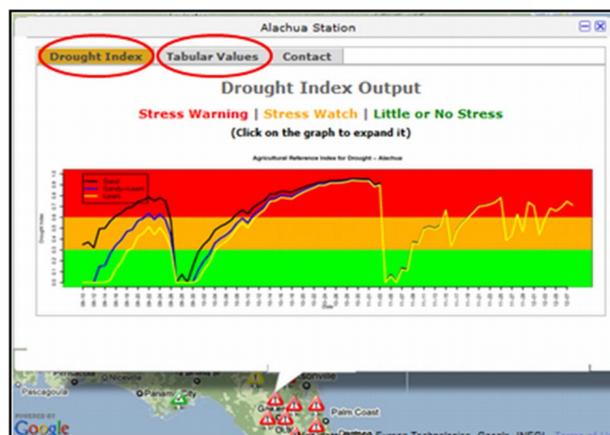


Fig. 5. Graph showing ARID values for the past 90 days for three types of soil: sand, sandy-loam, and loam

Users can also click in the Tabular Values tab and select the soil type to display daily values of solar radiation ($\text{MJ m}^{-2} \text{ dia}^{-1}$); maximum, minimum, and dew point temperature ($^{\circ}\text{C}$); rainfall (mm); wind speed (m s^{-1}); potential and actual evapotranspiration (ETo and ETa); and ARID values (Figure 6).

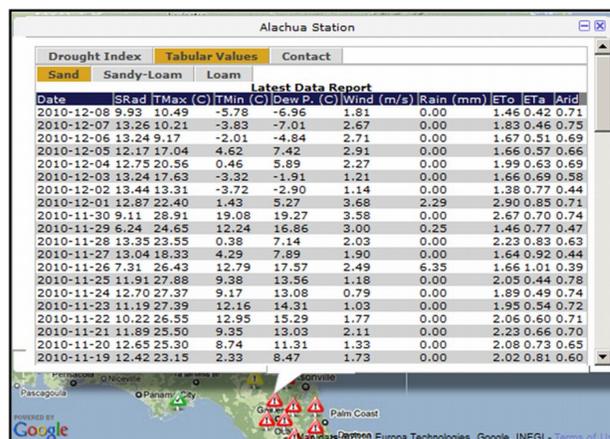


Fig. 6. Tabular Values tab showing daily values of weather parameters and ARID

ARID indicates how dry the soil is. Also, ARID increases gradually during dry spells or longer periods without rainfall and decreases rapidly with rainfall events. As the index represents cumulative days under water stress conditions, it can be associated to yield losses and compared to historical typical values for the same period of time in the same location, allowing users to track and quantify drought conditions.

References

Fraisse, C.W., N.E. Breuer, D. Zierden, J.G. Bellow, J. Paz, V.E. Cabrera, A. Garcia y Garcia, K.T. Ingram, U. Hatch, G. Hoogenboom, J.W. Jones, and J.J. O'Brien. 2006. AgClimate: A climate forecast information system for agricultural risk management in the southeastern USA. *Computers and Electronics in Agriculture*. 53(2006):13-27.

Gillette, H.P. 1950. A creeping drought under way. *Water and Sewage Works*. March, pp. 104-105.

Heim Jr., R.R. 2002. A review of twentieth-century drought indices used in the United States. *Bulletin of the American Meteorological Society*, 83, no. 8, 1149-1166.

Narasimhan, B., and R. Srinivasan. 2005. Development and evaluation of soil moisture deficit index and evapotranspiration deficit index for agricultural drought monitoring. *Agricultural and Forest Meteorology*, 133, 69-88.

USDA-Agricultural Research Service. 2010. Causes of loss historical data files. [On-line] Available at <http://www.rma.usda.gov/data/cause.html>.

Wilhite, D.A., and M. Buchanan-Smith. 2005. Drought as a natural hazard: understanding the natural and social context. In: Wilhite, D.A. (ed) *Drought and water crises: science, technology, and management issues*. CRC Press, Boca Raton, FL, pp. 3-29.

Woli, P. 2010. Quantifying water deficit and its effects on crop yields using a simple, generic drought index. PhD Diss. Department of Agricultural and Biological Engineering, University of Florida, Gainesville.