# Plant Available Water Model with Alignment Option (*pawmod2*)

## Introduction

Soil plant available water models that can be user-corrected using simple empirical data have the potential of predicting crop performance with the input of few variables that can be easily obtained or estimated as well as minimizing the prediction error.

Soil pores represent the space in which water is reserved in the soil profile. However, the totality of stored water in the soil pores is not available for plant roots. Some of this water is strongly retained by soil particles and roots have little access to it. Therefore, the portion of soil water storage that is susceptible to be extracted by crop roots is called plant available water (*PAW*) (Veihmeyer and Hendrickson, 1927). Because water is a vital resource for plant growth, crop production is tightly linked to plant available water. However, obtaining daily field measurements is time-consuming and/or costly compared to computer models.

A model that accurately predicts PAW is a powerful tool to understand crop performance across different environments and/or different years. Also, the model can be used as a complimentary tool assessing real-time crop performance and post harvest soil plant available water.

Simple approaches in modeling plant available water rely on soil, plant, and climatic variables. Using these variables, a variety of models that simulate plant available water have been developed. For instance, a soil-plant-atmosphere water model was developed by Saxton et al (Saxton and Bluhm, 1982; Saxton et al., 1986), and the popular model called Aquacrop was developed by FAO (Steduto et al., 2009). More simple models can be found as the one proposed by Dardanelli et al. (2004), which calculate PAW based on crop-specific lower limits of volumetric water content for each soil depth. Most of the models require soil moisture or PAW to be specified at the start of the simulation period, and the models do not allow for assimilation of subsequent soil moisture data during the simulation period. Therefore, errors can accumulate in the PAW prediction and large deviations from the actual PAW are possible. Consequently, this model satisfies the need for a model that allows users (researchers, students, and consultants) to correct the PAW simulations based on field data collection. The objective of this project was to develop a model that describes plant available water in a single layer soil profile including an option that allows users to correct the model using empirical data.

## About the Model

The model consists in two main parts linked to each other; the calculation of crop evapotranspiration (*ET*), and the calculation of PAW in the root-zone.

Firstly, the calculation of *ET* in this model was based on the potential evapotranspiration ($ET_o$) concept developed by Penman-Monteith from the Food and Agriculture Organization (FAO)(Allen et al., 1998). This information can be obtained from weather stations. As an example, for the state of

Oklahoma this data can be obtained from the Mesonet weather stations network (www.mesonet.org). In the case that $ET_o$ is not available, it can be estimated by using other climate data. For this purpose, models such as the proposed by Thorntwite and Hargraves can be used. The $ET_o$ parameter is multiplied by specific crop coefficients ($K_c$) to calculate the potential crop evapotranspiration ($ET_c$)(Doorenbos and Pruitt, 1975). Also, $K_c$ was modified according to soil water deficits to account for *ET* under water stress conditions because Oklahoma croplands are subjected to frequent water deficits. In other words, $K_c$ is modified whenever the model detects that the crop is under water stress and therefore cannot meet the potential ET. Water stress has been proven to occur when PAW in the soil is below 65% of the maximum capacity of PAW in the soil (Ritchie, 1981). Therefore, this constitutes the threshold value that is compared with the $PAW_{ratio}$ to trigger if adjustment in the $K_c$ will be made or not. This step clearly establishes a relationship among soil, water, plant, and atmosphere. Secondly, an initial *PAW* content in the soil is needed as input from where the simulation will be based on. This initial PAW is critical for the model. To determine PAW as a function of time, effective rainfall is added to this initial PAW content, and *ET* is subtracted from daily PAW. The effective rainfall term results from subtracting any possible runoff from to the recorded precipitation. This has been done by using the curve number method (USDA), which is a well known method in hydrologic engineering. This methodology relies on empirical data has three strong advantages, which are its convenience, simplicity, and stability. The curve number model ranges from 0 to 100 (the greater the curve number the greater the runoff) (Ponce and Hawkins, 1996).

After the two main components of the model have been defined and how they are related, an option to include actual PAW from field data collection was set available to correct the model if necessary. After the correction the model starts simulating from this new value. Thus, the error accumulated over time is reduced, and the model starts over again. Many corrections as needed are possible in this option. The PAW measured values need to be inserted in Excel and from there the MatLab function can read it. This means that the model can be run from beginning to end by setting the required inputs, or it can be interrupted by the user to re-adjust the model based on measured PAW. This is particularly useful to estimate soil PAW in real time while the crop is in the field, to obtain daily resolution PAW information in situations where less frequent measurements are available.

**Simulation**

Simulation can be made either running the PAW model as a function (***pawmod function***) in the main command windows of MatLab, or by calling the graphic user interface (GUI) file by writing "***pawmod2***". There are 14 variables that can be adjusted according to soil type, initial soil water content, crop stages, landscape, growing season length, etc. The model, when executed as a function, displays PAW, rainfall, runoff, and cumulative crop ET. Graphs automatically pop up, and the variables are displayed in the main command window, and also in the workspace as column vector (this can be avoided by inserting a semicolon). Also, the data is exported to the file "Climate.xlsx" next to the information already provided.

**Algorithm**

The main Equations that support this model are:

$$PAW_t(mm) = P - Q + PAW_{t-1} - ET \qquad [1]$$

Where *P* is precipitation in mm, *Q* is runoff in mm, *ET* is evapotrasnpiration in mm, and PAW is plant available water at time t, also in mm. The variable $PAW_t$ can be calculated from $PAW_{t-1}$, or by interrupting the model and adding measured PAW value. Drainage will be considered negligible for crop season.

$$PAW_{max}(mm) = \int_a^a \theta_{fc\ (z)} - \int_a^a \theta_{wp\ (z)} \qquad [2]$$

Total PAW (PAW*max*) can be obtained by subtracting the wilting point (wp) from the field capacity (fc). Field capacity represents the maximum water holding capacity of the soil, and wilting point represents the soil water content at which roots cannot access water. Nonetheless, plants do not need to reach this point to enter in a water-stress situation. When plants start depleting water from the soil profile, and assuming that for some time there is no rainfall or irrigation, plant roots need to obtain water held at higher suctions. For this reason, even soil water stored that represent 50% of the PAW*max* can be relatively hard to absorb for plants.

$$PAW_{ratio} = \frac{PAW_{t-1}}{PAW_{max}} \qquad [3]$$

Ritchie(1981) showed that plants generally are under water stress at about 65% of PAW*max*. This assumption is used in the model to account for low crop evapotranspiration under these conditions.

$$PAW_{treshold} = 0.65 \qquad [4]$$

For the cases where PAW is lower than the $\mathrm{PAW}_{treshold}$ the specific crop coefficient that determines the amount of reference $ET_o$ is therefore affected. This can be expressed by:

If $PAW_{ratio\ t-1} > PAW_{treshold}$ $\qquad K_{cadj} = K_c$ $\qquad$ [5]

If $PAW_{ratio\ t-1} \leq PAW_{treshold}$ $\qquad K_{cadj} = \frac{K_c\ at\ PAW_{t-1}}{PAW_{treshhold}}$ $\qquad$ [6]

Finally, crop evapotranspiration is obtained by the following equation:

$$ET\ (mm) = ET_o\ K_{cadj} \qquad [7]$$

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