

# Simplified Irrigation Scheduling on a Smart Phone or Web Browser

## **R. Troy Peters, P.E., Ph.D.**

Washington State University  
Irrigated Agriculture Research and Extension Center, Prosser, WA.  
troy\_peters@wsu.edu

## **Gerrit Hoogenboom, Ph.D.**

Washington State University  
AgWeatherNet Director, Prosser, WA.  
gerrit.hoogenboom@wsu.edu

## **Sean Hill**

AgWeatherNet Web Developer  
Irrigated Agriculture Research and Extension Center, Prosser, WA.  
sehill@wsu.edu

**Abstract.** *Irrigation Scheduler Mobile is a free and open source irrigation scheduling tool that runs on any smart phone or any web browser. The focus was placed on designing it for simplicity and intuitive usability. Setting up a field is simply a matter of naming it, selecting the nearest weather station, and choosing a crop and soil type. It automatically populates all of the necessary parameters from tables of default values for the chosen crop and soil texture. It automatically pulls weather data from any weather station in a large variety of different weather networks to calculate and use reference ET. It readily displays useful charts and tables for visual evaluation of soil water status and model inputs. It is flexible and allows educated users to change any of the model parameters. There are integrated help menus on each page. The model can be corrected using soil water measurements or estimates. It includes a one-week forecast of crop water use and soil water status for irrigation decision planning. It works with cutting dates to model forage regrowth. It can send out push notifications to growers in the form of an email or as a text message. It has many additional useful features that growers have requested. It currently works with weather networks in 11 different states. It is possible to set up different crop defaults for different climatological regions (groups of weather stations). This manual describes this tool and its use. The model is at <http://weather.wsu.edu/is>.*

**Keywords.** Irrigation Scheduling, weather networks, checkbook, mobile apps, crop coefficients.

## Quick Start

The mobile irrigation scheduler is at <http://weather.wsu.edu/is>. To use it you must have an AgWeatherNet username and password. This is free and easily set up on the AgWeatherNet website (<http://weather.wsu.edu>). To start using Irrigation Scheduler Mobile point your mobile browser to above URL, and log in (Figure 1). Bookmark this page, or better yet, put a shortcut icon on your mobile device's home screen for quick access in the future (Figure 2).

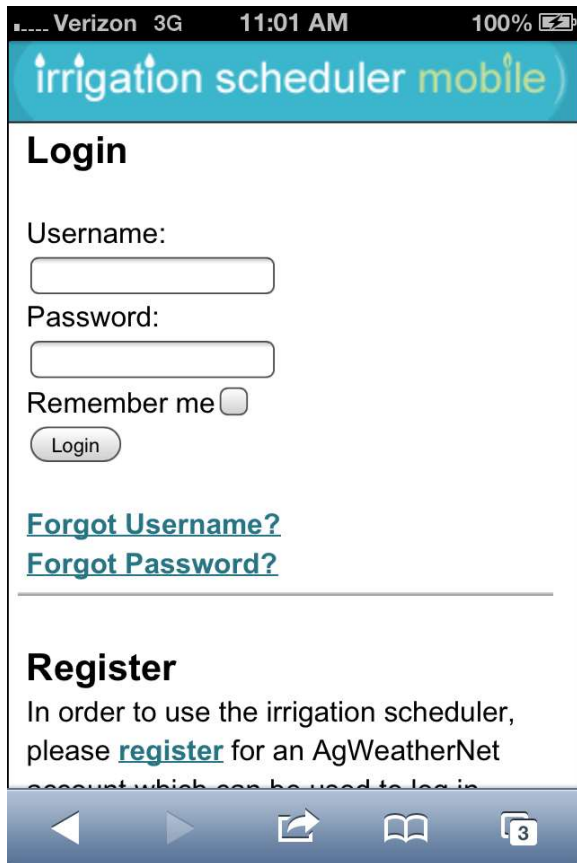


Figure 1. Login Page.

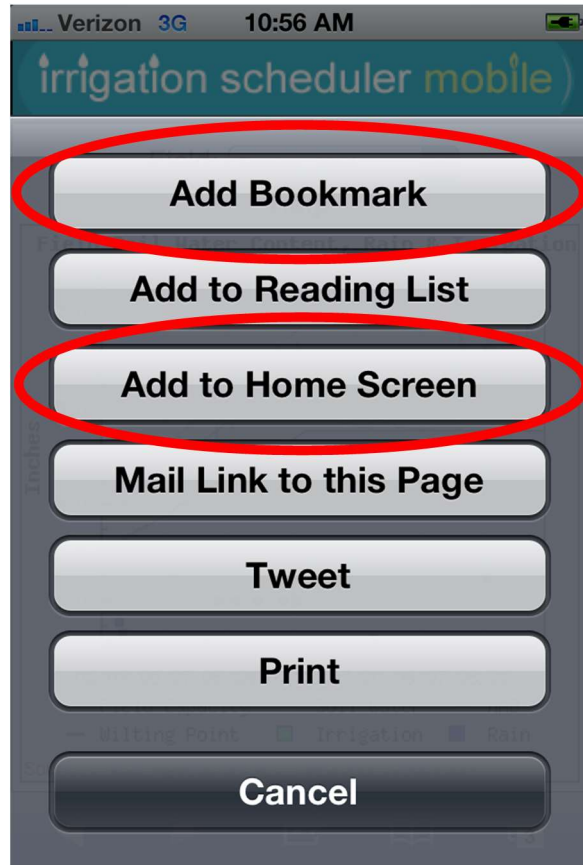


Figure 2. Bookmark or add to your home screen.

After logging in click "Add New Field" (Figure 3) to bring up the screen in Figure 4 where you can give the field a descriptive name, choose the growing year (past years are available for comparison purposes or what-if scenarios), choose the weather network from your state, select the weather station in that network that is nearest or best represents your field's growing climate, and select the crop grown and the soil texture. Click "Add Field" and you're done with the setup! Follow the on-screen instructions. Help is available for each page by clicking the "Help" link on that page.

Additional information is available below in the Using the Model / In-Depth Descriptions section.

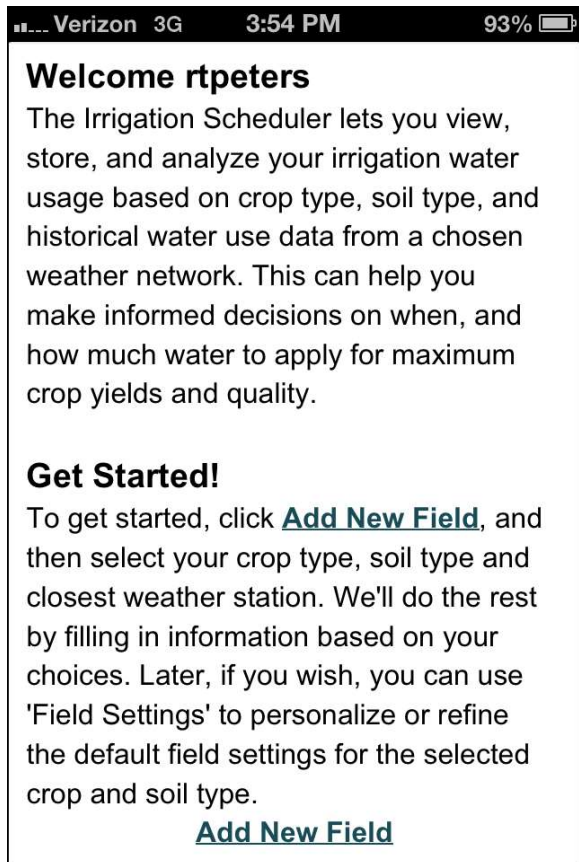


Figure 3. Welcome and Getting Started Screen



Figure 4. Add a New Field

## Introduction

Irrigation scheduling is finding the answers to two basic questions: “When do I turn the water on?” and, “How long do I leave it on?” Improved irrigation scheduling has tremendous public and private benefits. It has been shown in various studies to decrease irrigation water use by 10-30% while resulting in equivalent or better crop yields and quality. Since irrigation is responsible for 80-90% of the consumptive water use in most arid areas, the total water and energy savings from improved irrigation management is tremendous. Irrigation scheduling has the following benefits:

### Benefits to the grower:

- Improved crop yields,
- Improved crop quality,
- Lower pumping energy costs,
- Lower irrigation-related labor costs, and
- Decreased loss of expensive fertilizers to runoff or leaching.

### Benefits to the environment:

- Less movement of fertilizers and pesticides with the water off of farms fields into streams, water-bodies, and groundwater (non-point source pollution), and
- More water remains available in groundwater and in streams for alternative uses including fish and wildlife habitat.

### Benefits for energy supply:

- Decreased irrigation energy pumping costs (typical values are 10-20% savings), and
- Water remains in rivers to drive power-generation turbines at multiple dam sites.

There are many irrigation scheduling tools available including paper-and-pencil versions (e.g. Wright, 2002), spread sheet versions (e.g. Clark et al., 2001), compiled program versions (e.g. Rogers et al., 2009), and online versions (e.g. Hillyer and English, 2011). However these tools are not widely used and most of them are not readily adaptable to the Pacific Northwest State. The most common reason cited for not using these tools is that they are difficult to learn, time consuming to use, and that the grower does not feel that it is worth this time and effort required. Agricultural producers are also rarely in the office and don't get many chances for, and tend to not enjoy doing “desk-work.” A simple and user-friendly irrigation scheduling tool that is accessible from a smart phone that is already in most producer's pocket is needed to increase the adoption of data-based irrigation scheduling.

Irrigation Scheduler Mobile is a soil water balance model that meets these requirements. It is a free irrigation scheduling tool developed by Washington State University that is designed for use on a smart phone or on a desktop web browser for doing simplified check-book style irrigation scheduling. It is a basic soil water budget model.

In addition Irrigation Scheduler Mobile has the following features:

- It is simple to set up and intuitive to use.
- There are integrated help menus on each page.
- It uses tables of default crop and soil parameters to simplify setup
- It automatically pulls daily crop water use (evapotranspiration, or ET) estimates from a chosen weather station in a fairly expansive number of agricultural weather networks.
- It readily displays useful charts and tables for visual evaluation of soil water status and model inputs.
- It is flexible enough to allow modifications by educated users for improved accuracy.
- The model can be corrected using soil water measurements or estimates.
- It includes a one-week forecast of crop water use and soil water status for irrigation decision planning.
- It works with cutting dates to model forage regrowth.
- Growers can interact with it in terms of hours of irrigation run time or in inches of water applied. Simple calculators are included to help calculate irrigation application rate if required.
- A correction for the smaller active soil volume due to un-irrigated inter-rows is included.
- Soil water can be displayed as a percent of the total available water (100% = full, 0% = empty), or as volumetric soil water content (water's percentage of the total soil volume) for better comparison with soil moisture sensors.
- It can send out push notifications to growers in the form of an email or as a text message.
- When adding a new field you can copy settings from an existing field.
- Since it is designed as a web application, it can be run on any mobile phone platform with internet access, or directly from a full sized computer web browser.
- There is a full-size computer web browser interface from <http://weather.wsu.edu>.
- You can download all of the data to a comma-separated variable (csv) file for more detailed analysis.
- It can do use reporting of the number of days each field was viewed and or edited by month. This was requested for cost-share documentation.
- It is possible to set up different crop defaults for different climatological regions (groups of weather stations).

## Background Information and Model Assumptions

Soil serves as a reservoir to store water and nutrients for use by the plant. Knowing when to irrigate and how much water to apply requires knowledge of three things:

1. How much water can the soil hold?
2. How much water is the plant using?
3. At what point (soil water content) will the plant begin to experience water stress?

Let's discuss each of these separately.

### How Much Water Can the Soil Hold?

Water is held in the empty spaces between soil particles. When these empty spaces are completely filled, the soil is said to be saturated (Figure 5). Excess water will drain out over time until a point where the soil can hold a certain amount of water indefinitely against the downward pull of gravity. This soil water content is the soil's *full* point called **field capacity (FC)** and in this application is measured in inches of water per foot of soil depth. The excess water that drains will move down to lower soil layers. Applying more water than a soil can retain in the plant's managed root zone results in water loss to **deep percolation (DP)** or "deep water loss". Water loss to deep percolation wastes water, pumping energy, and vital plant nutrients that are held in the soil water solution.

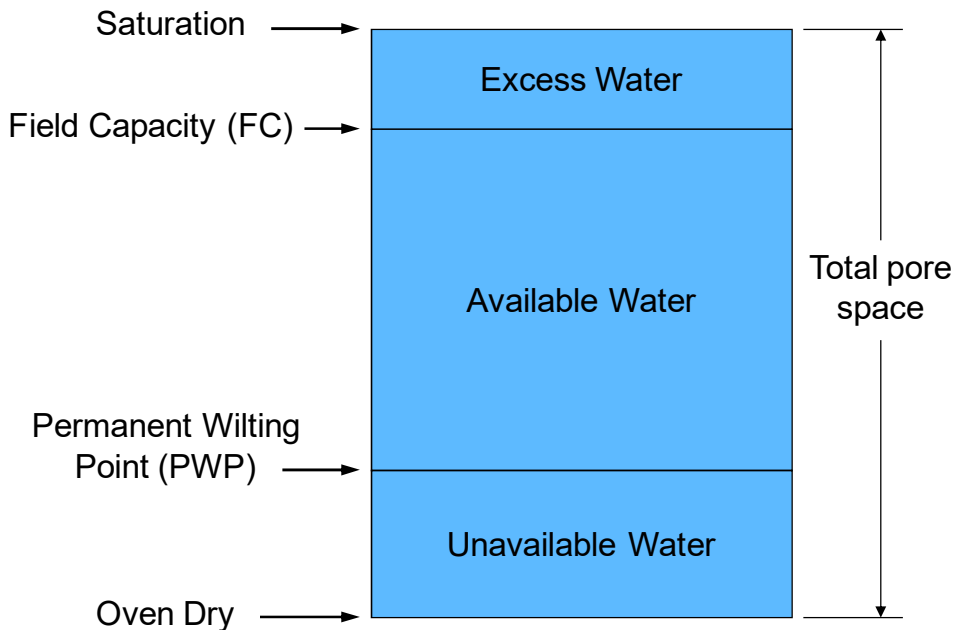


Figure 5. The various components of the soil water content.

As a plant's roots remove water from the soil, the soil dries out to the point where the suction or pull of the soil on the water is greater than the plant's ability to absorb water. At this point the plant will wilt and die. Although there is water left in the soil, from the plant's

perspective the soil is *empty*. This soil water content is referred to as the **permanent wilting point (PWP)** and is also measured in inches of water per foot of soil depth. The difference between field capacity and permanent wilting point is known as the **available water-holding capacity (AWC)** again given in inches of water per foot of soil depth.

$$AWC = FC - PWP$$

Different soils have different available water-holding capacities. For example, sand cannot hold as much water as a silt soil. The default values of FC, PWP, and AWC that are used in this model for different soil textures are given in Appendix A.

A plant's rooting depth is also an important consideration. A plant with deeper roots has access to much more soil and consequently has a larger reservoir of soil water to draw upon compared to plants with shallower roots. The FC, PWP, and AWC are multiplied by the rooting depth to get the *amounts* of water held at those points in inches. Rooting zone depths change over time as the plant and its roots grow. Root growth in Irrigation Scheduler Mobile is assumed to increase linearly from a beginning depth at the planting or emergence date and is assumed to reach their maximum depth at the same time the crop canopy reaches full cover or covers (shades) 70-80% of the field area (Figure 6). After this time the root depth is assumed to remain constant until the end of the growing season.

Default values for the parameters that define the changing root zone depth for the various crops are given in Appendix B.

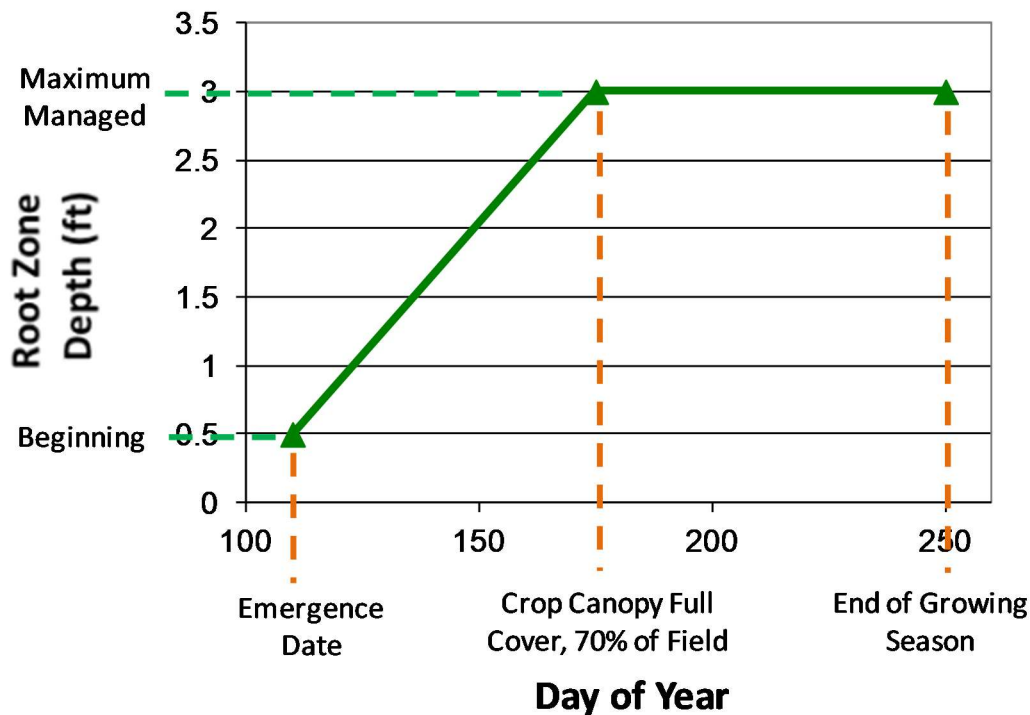


Figure 6. Parameters that define the changing root zone depth. Defaults values for these parameters are set based on the crop chosen, but can be modified in “Advanced Field Settings.”

## How Much Water is the Plant Using?

The amount of water required to grow a crop consists of the water lost to evaporation from a wet soil surface and leaves, and transpiration of water by the plant. Together these are called **evapotranspiration (ET)** and are also referred to as crop water use. ET is measured in inches of water used per day. The crop evapotranspiration ( $ET_c$ ) is calculated as:

$$ET_c = K_c \times ET_r$$

where  $ET_r$  is the estimated evapotranspiration of a reference surface of full grown alfalfa that is calculated from measured weather data. The weather data used to calculate  $ET_r$  include solar radiation, air temperatures, humidity, and wind speed data. Irrigation Scheduler Mobile uses alfalfa reference  $ET_r$  as calculated by the ASCE standardized Penman-Monteith Equation (ASCE – EWRI, 2005).  $K_c$  is a crop coefficient specific to a crop and that crop's growth stage over the season. Crop coefficients Irrigation Scheduler Mobile are mean crop coefficients and defined as in the FAO-56 publication (Allen et al., 1998; Figure 7). Default dates and crop coefficient values for different crops are given in Appendix B.

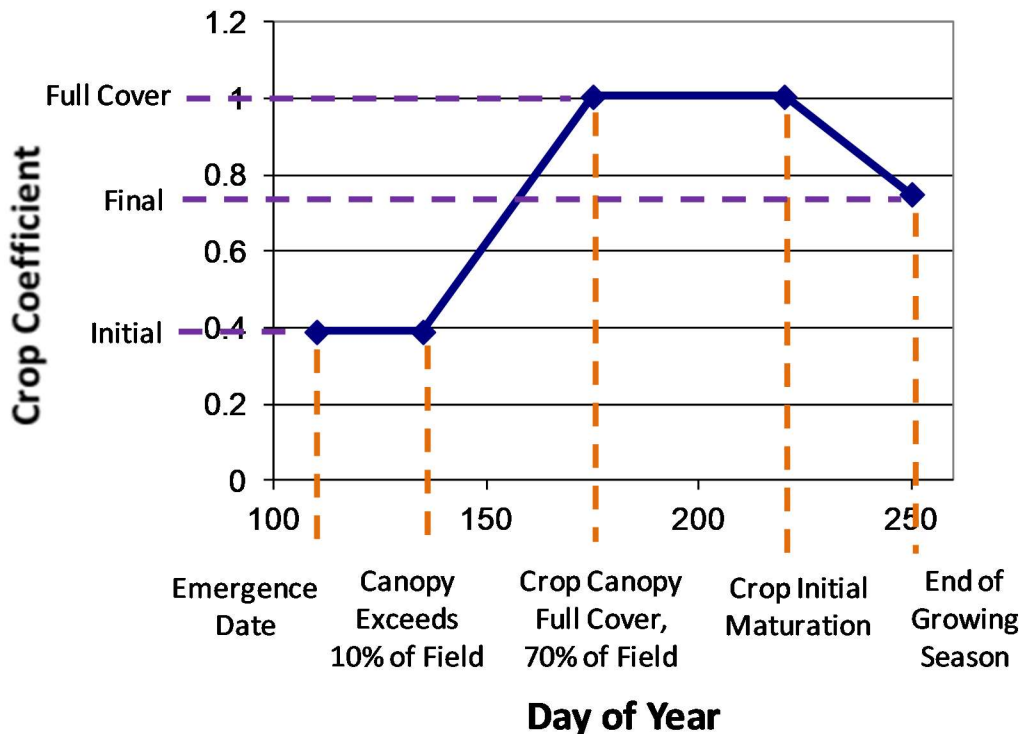


Figure 7. Parameters that define the crop coefficient curve.

## At What Point Will the Plant Experience Water Stress?

As water is removed from the soil through ET there is a point below which the plant experiences increasing water stress. This point is known in this model as the first stress point or more generally as the **management allowable depletion (MAD)**. To manage the soil water for maximum crop growth, depletion below this point is undesirable. As the soil water content decreases below MAD the stomata in the plant leaves will begin to close, the leaves will often



curl or droop, and the plant will use less water and the growth will decrease. *The model estimates this decrease in water use according to Figure 8.* Daily crop water use is proportionately decreased as the % of available water decreases below MAD towards the PWP. This follows the water stress coefficient (Ks) concept as described by Allen et. al. (1998). Irrigation scheduling for maximum crop growth requires maintaining the soil water content between field capacity and the MAD.

Different plants are more resistant to water stress than others and therefore the MAD for each crop may be different. The default MAD values for the various crops are given in Appendix B.

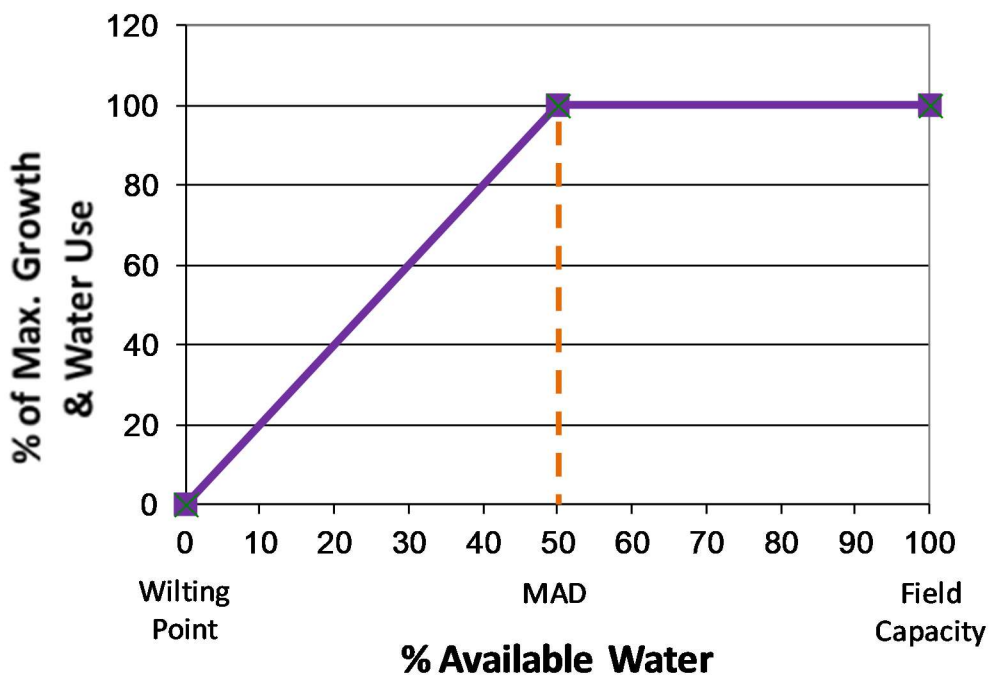


Figure 8. Water use is proportionately decreased as the % of available water goes below the MAD. Yield is also assumed to decrease in the same pattern. Defaults values for MAD is set based on the crop chosen, but can be modified in “Advanced Field Settings.”

### Other Model Assumptions

The following additional assumptions are made by this soil water balance model.

- All water entered as an irrigation amount infiltrates into the soil.
- Water in the plant’s root zone is equally available to the plant regardless of depth.
- The season begins with a full soil profile (at field capacity). This can be modified by using the “Reset/ Correct Soil Water Availability” option on the first day in the Daily Budget table. Plant roots grow into soil at field capacity.
- Water moves quickly into the soil and excess water is lost quickly to deep percolation.
- All rainfall goes towards satisfying the calculated ET demand.

## Using the Model / Page Descriptions

### 7-Day Daily Budget Table

The Daily Budget Table screen (Figure 9) shows the most relevant values from a daily soil water budget and allows the user to edit the inputs for each day using the “Edit” link.

The data in each column is described below:

**Water Use (in/day):** This is the daily crop water use (evapotranspiration or ET<sub>c</sub>) estimated from measured weather parameters from the selected weather station, and the entered crop coefficients. This model uses alfalfa reference evapotranspiration calculated using the standardized ASCE Penman-Monteith method. The model gets the weather data from the weather network when the model is first opened, if it has been greater than two hours since the data was pulled, or after a change is made in Field Settings. Because of this, if the weather network managers make corrections to the historical data for that weather station, these changes are reflected in the model.

**Rain& Irrig. (in):** This is the sum of the measured rainfall at the weather station for that day and/or and the irrigation amount. Irrigation events must be entered using the Edit link. This is net irrigation, not gross. Some applied irrigation water is lost to evaporation. Therefore gross irrigation amounts must be discounted for irrigation efficiency. Typical irrigation efficiency values are: drip-95%, center pivot-85%, wheel/hand lines/lawn sprinklers-70%, big guns-60%. For example a gross depth of 1 inch of water is applied by a center pivot, enter 0.85 here (1 inch x 85%/100). If you use measured application depths, don't correct for efficiency. *For surface irrigation, a reasonable assumption is that you completely refill the soil to field capacity, or replace the soil water deficit.*

**Soil Water (%):** This is the calculated daily soil water content expressed as a percent of the available soil water. 100% is equivalent to field capacity, and 0% is equivalent to wilting point. Entering a measured or estimated soil moisture value here (using the Edit link) will correct the model to the entered value from that day forward. Volumetric soil water content for comparison with soil moisture sensor readings is available in the expanded information (click the date; Figure 13).

**Water Deficit (in):** The soil water deficit in the root zone. This is the amount of "space" in the soil, or the depth of irrigation water that can be applied before the soil is full again (reaches field capacity).

**Edit Data:** Use this link at each line to add irrigation amounts or correct the model for measured soil water contents (Figure 11).

Some descriptions of how the page operates:

**Line Colors:** When the calculated soil water content is well above the MAD point and the plant growth should be at maximum, then the row is highlighted green (Figure 9). When the soil water content gets close to the MAD line (only 15% of the readily available water remaining)

then the row turns yellow. And when the soil water content goes below the MAD line the row is highlighted red as a warning of crop water stress.

**The Most Important Number:** The most important value for irrigation scheduling is *this morning's soil water deficit*. This is the amount of water that I need to apply today to completely refill my soil profile. If I apply more water than this, some will be lost to deep percolation because the soil can't hold it all. It is highlighted in **red** (can be seen in Figure 13).

**Navigation:** You can navigate to other dates in the growing season using the buttons at the bottom of the table. The date button in the middle is used to go to the week starting with the chosen date (Figure 10). Note that you cannot navigate outside of the growing season as defined by the crop's planting date and end-of-season or harvest date as defined in Field Settings. The [<<](#) and [>>](#) buttons takes you to the beginning of the growing season and to today (or to the growing season) respectively. The [<<<](#) and [>>>](#) buttons navigation you forward or backwards respectively in time by one week.

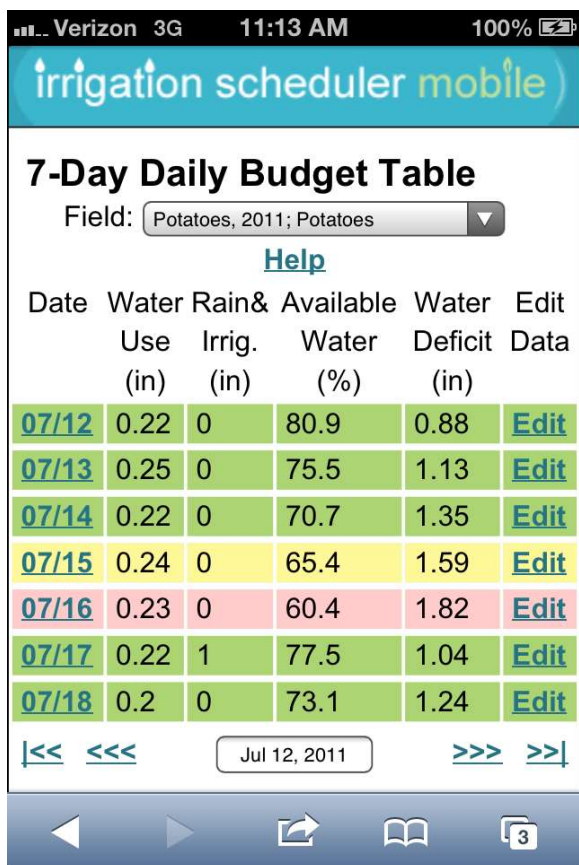


Figure 9. Daily Budget Table screen

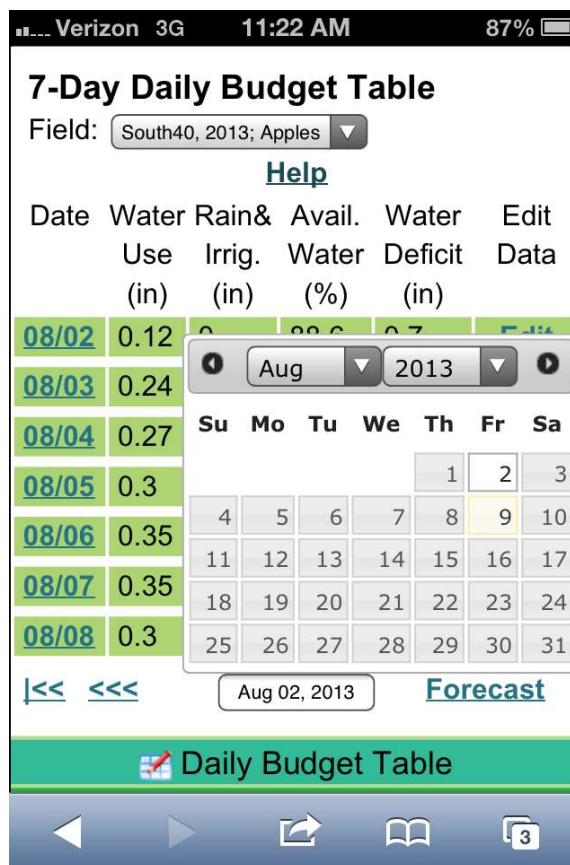


Figure 10. Choose first date of week to view.

**Forecast:** The last day on the Budget Table represents very early this morning. A seven-day forecast is available. This forecast is based on the projected maximum and minimum temperatures from the National Weather Service (NWS) for those days at the latitude and longitude of the chosen weather station. The Hargreaves equation is used with these temperature data to estimate grass reference ETo which is then multiplied by 1.2 for alfalfa reference ETr which is used in the model. If the model is viewed late in the day, the 7th

forecasted day is from the NWS. However before 6 PM the 6th forecasted day is repeated for the 7th forecasted day. Irrigations can be entered in the future to do planning. These irrigation events will remain as time passes from the future to the past. Historical ET information always overwrites forecasted values. Forecast values are pulled when the field is first viewed, once every two hours, or after a change is made in Field Settings.

**Edit Data:** Clicking the Edit link on that day expands the screen to accept inputs for that day as shown in Figure 11. From here you can add or edit irrigation amounts, or reset or correct the soil water availability to make it better match reality based on observations or soil moisture measurements. Click **Cancel** closes the table up again. You must click **Save** for these changes to be applied.

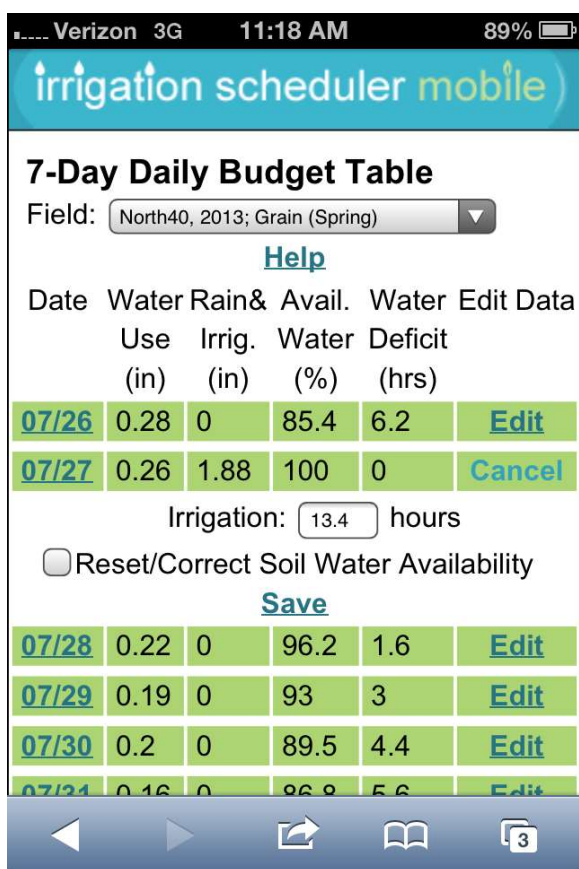


Figure 11. Edit button expands table for inputs.

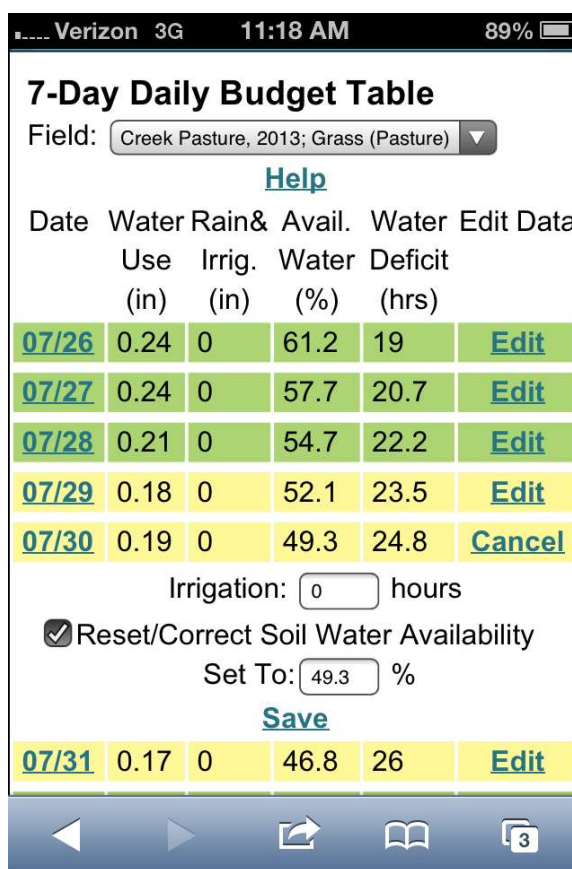


Figure 12. Reset/Corrective Soil Water Availability

**Irrigation:** Enter the net amount of irrigation applied to the field on this date. If you chose to use hours instead of inches in Field Settings then you can enter this value in hours of irrigation run time. Some applied irrigation water is lost to evaporation. Therefore *gross irrigation amounts must be discounted to account for irrigation inefficiency*. This is done by multiplying by the irrigation efficiency as a decimal ( $\% / 100$ ). Typical irrigation efficiency values are: drip-95%, center pivot-85%, wheel/hand lines/lawn sprinklers-70%, big guns-60%. For example, a gross depth of 1 inch of water is applied by a center pivot, enter 0.85 here (1 inch x 85%/100). If you

use measured application depths, don't correct for efficiency. For surface irrigation, either use a very large number (like 3-4 inches at each irrigation) or a reasonable assumption is that you completely refill the soil to field capacity to 100% Available Water, or completely replace the soil water deficit.

**Reset/Correct Soil Water Availability:** Check this box to overwrite the calculated percent of available soil water with an entered number (Figure 7). You might want to do this to correct the model to make it better match observations or a soil moisture measurement. The model will use your entered value as the new value and will calculate the estimated soil water content from that point on. Unchecking this box will make model return to the calculated value.

**Correcting Rainfall (in):** Measured rainfall is automatically included from the weather station. If you measured rainfall at your field and it differs significantly from the existing value, you can correct it by adding *the difference* as an irrigation. If you measured less rainfall than the weather station reported, you can subtract the difference by adding this difference as a *negative* irrigation value. It makes the soil water chart look funny to plot that negative value, but the math works correctly.

**Additional Details:** Additional details of the daily soil water budget are available by clicking on the date (Figure 13). This will expand the table to show these details. The table can be returned to normal again by clicking the date again.

Date	Water Use (in)	Rain& Irrig. (in)	Avail. Water (%)	Water Deficit (in)	Edit																																
08/14	0.12	0	97.8	0.1	Edit																																
08/15	0.13	0	95.4	0.3	Edit																																
08/16	0.13	0	93	0.4	Edit																																
<table border="0"> <tr> <td>Day of Year:</td> <td>227</td> <td>Measured Available Water:</td> <td>0%</td> </tr> <tr> <td>Irrigation:</td> <td>0 in.</td> <td>Modeled Available Water:</td> <td>93%</td> </tr> <tr> <td>Precipitation:</td> <td>0 in.</td> <td>Field Capacity:</td> <td>10 in.</td> </tr> <tr> <td>Reference ET:</td> <td>0.15 in.</td> <td>Wilting Point:</td> <td>4.5 in.</td> </tr> <tr> <td>Crop Coefficient:</td> <td>0.88</td> <td>Avail. Water Capacity:</td> <td>5.5 in.</td> </tr> <tr> <td>Crop ET:</td> <td>0.13 in.</td> <td>Water Storage At MAD:</td> <td>8.08 in.</td> </tr> <tr> <td>Root Depth:</td> <td>30 in.</td> <td>Current Water Storage:</td> <td>9.61 in.</td> </tr> <tr> <td>Root Zone Water Deficit:</td> <td>0.39 in.</td> <td>Volumetric Water Content:</td> <td>32 %.</td> </tr> </table>						Day of Year:	227	Measured Available Water:	0%	Irrigation:	0 in.	Modeled Available Water:	93%	Precipitation:	0 in.	Field Capacity:	10 in.	Reference ET:	0.15 in.	Wilting Point:	4.5 in.	Crop Coefficient:	0.88	Avail. Water Capacity:	5.5 in.	Crop ET:	0.13 in.	Water Storage At MAD:	8.08 in.	Root Depth:	30 in.	Current Water Storage:	9.61 in.	Root Zone Water Deficit:	0.39 in.	Volumetric Water Content:	32 %.
Day of Year:	227	Measured Available Water:	0%																																		
Irrigation:	0 in.	Modeled Available Water:	93%																																		
Precipitation:	0 in.	Field Capacity:	10 in.																																		
Reference ET:	0.15 in.	Wilting Point:	4.5 in.																																		
Crop Coefficient:	0.88	Avail. Water Capacity:	5.5 in.																																		
Crop ET:	0.13 in.	Water Storage At MAD:	8.08 in.																																		
Root Depth:	30 in.	Current Water Storage:	9.61 in.																																		
Root Zone Water Deficit:	0.39 in.	Volumetric Water Content:	32 %.																																		
08/17	0.12	0	90.7	0.5	Edit																																
08/18	0.12	0	88.5	0.6	Edit																																
08/19	0.12	0	86.2	0.8	Edit																																
08/20	0.11	0.22	88.2	0.7	Edit																																

Navigation: <<< Aug 14, 2013 >>> Forecast

Figure 13. Clicking on the date expands the table to show additional details for that date.

## Soil Water Chart

The soil water chart (Figure 14) shows the estimated soil water content (blue line) over time in relation to the field capacity (light green line), management allowable depletion (MAD; red line), and the wilting point (black line). All of these may change over time as the soil volume available to the plant increases with the growing plant roots (i.e. the upwards slopes in the first part of the season).

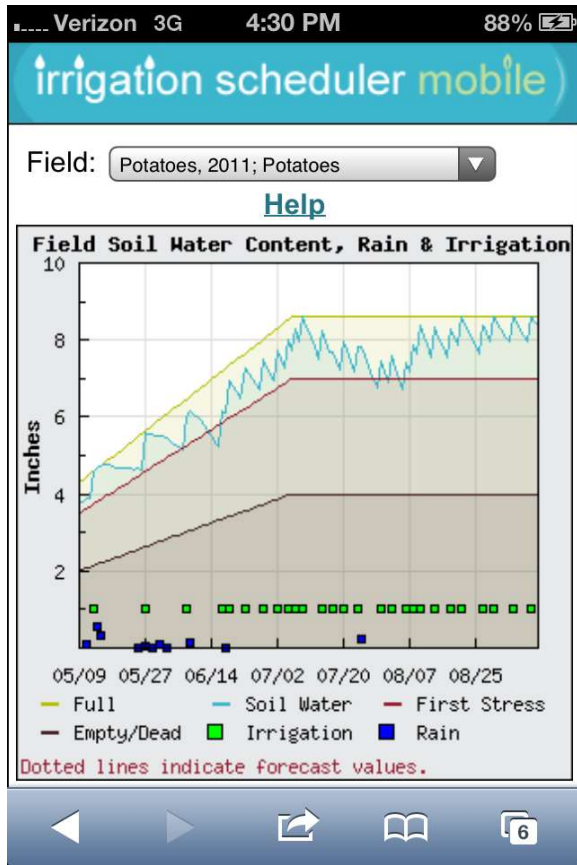


Figure 14. Soil Water Chart

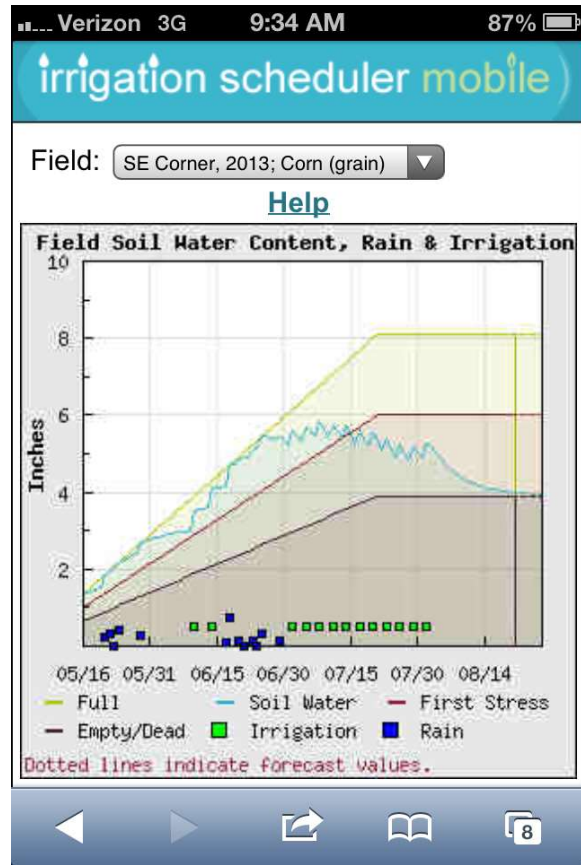


Figure 15. Shows how water stress (below the MAD line) causes daily water use to decrease.

Enter irrigation events (green points), or correct the estimated % available water content based on soil moisture measurements or estimates in the “Daily Budget Table” to make the soil water content better represent your field conditions. Rainfall amounts are pulled from the weather station (blue points). If you find that this model is consistently off, try editing the dates and crop coefficients in “Field Settings”.

Figure 15 is an example of a field where the irrigation system cannot keep up with crop water use demands and also shows how the model will modify daily crop water use numbers using the assumptions illustrated by Figure 5. As the soil dries below the First Stress (MAD) point, the *rate* of drop in the soil water content decreases over time as the plant shuts down.

For maximum crop growth and production keep the soil water content (blue line) between the Full point, or field capacity; top green line) and the and the First Stress (MAD, middle red line).

## More Charts

Clicking the “More Charts” button will give you access to the additional charts shown in Figure 16 that help you understand and evaluate your field and your soil water balance model. Clicking “Less Charts” hides these charts again.

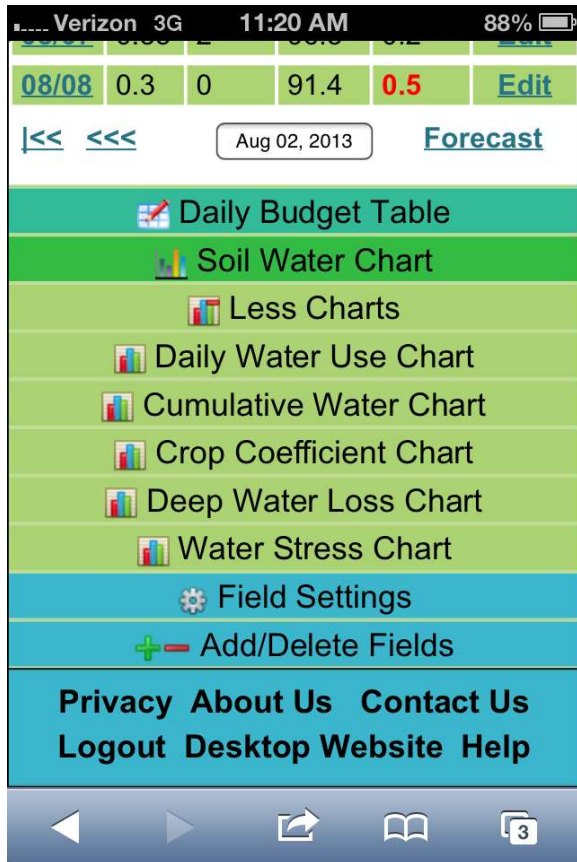


Figure 16. Clicking More Charts

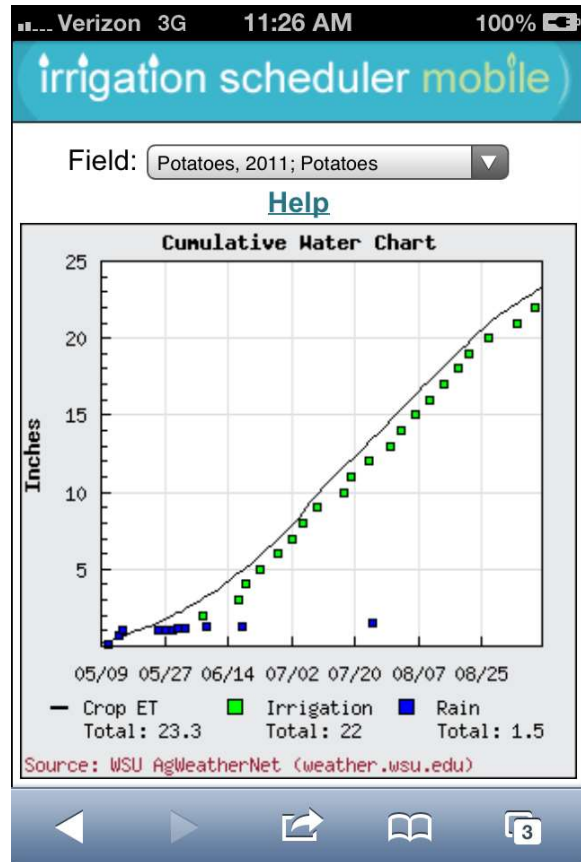


Figure 17. Cumulative Water Chart

## Cumulative Water Chart

Figure 17 shows the cumulative crop evapotranspiration (ETc, or crop water use), irrigation, and rainfall over the specified growing season. The season totals are given in the chart legend.

## Crop Coefficient Chart

Crop coefficients (Kc) are multiplied by the daily reference alfalfa evapotranspiration (ETr) rate that is calculated from the measured weather parameters from your chosen weather station. The Crop Coefficient Chart (Figure 18) shows the crop coefficient curve used for this

field over the growing season. Also shown is the root zone depth over time. The values that define these curves can be viewed and edited on the “Advanced Field Settings” page

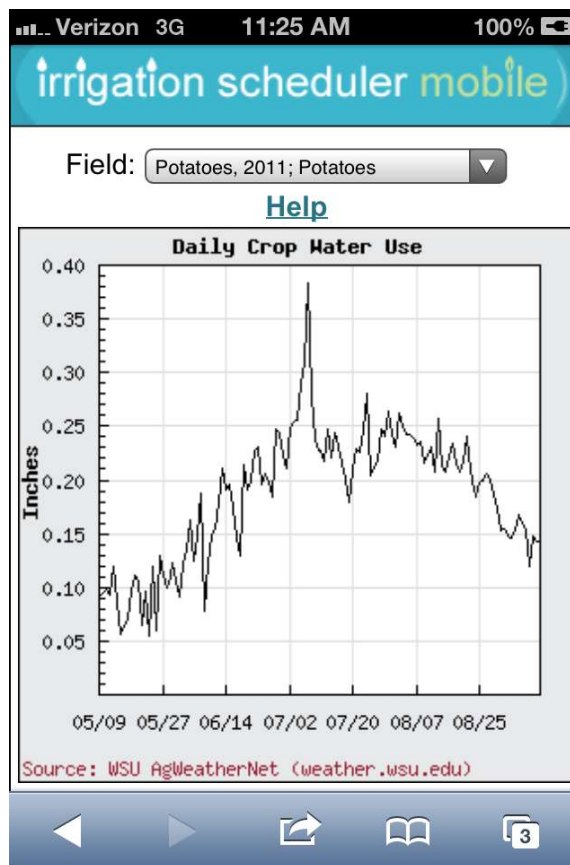
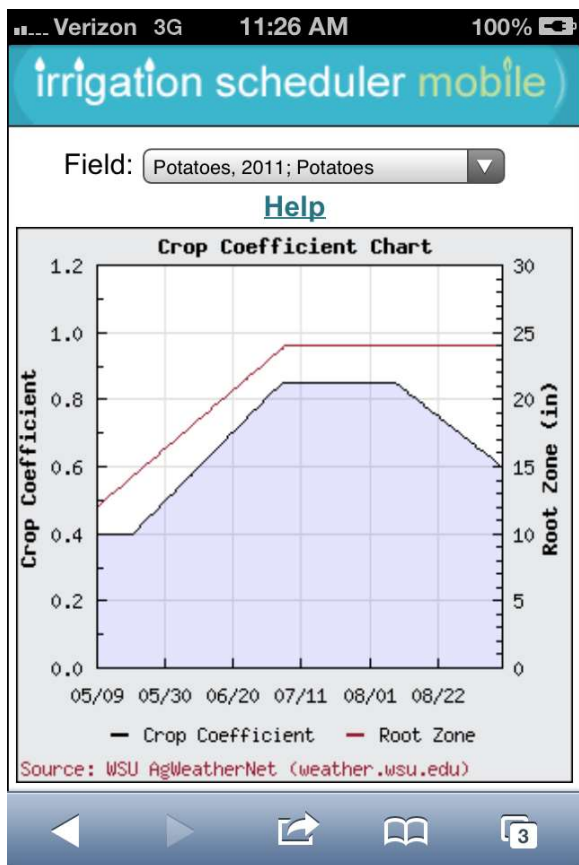


Figure 18. Crop Coefficient and Root Depth Chart. Figure 19. Daily Crop Water Use Chart

### Daily Water Use Chart

The Daily Water Use Chart (Figure 19) shows the daily crop water use (evapotranspiration, or  $ET_c$ ) over the specified growing season. This is calculated as  $ET_c = ETr \times Kc$  where  $ETr$  is alfalfa reference evapotranspiration and  $Kc$  is the crop coefficient for that day. These values are affected by the weather (hot, dry, sunny, and windy days cause the plants to use more water), the crop coefficients, and the water stress status of the plant (below MAD, the crop water use is proportionately decreased as described in the user’s manual).

### Deep Water Loss Chart

When more water is applied than can be held in the root zone (soil water content exceeds field capacity), then this water moves down past the bottom of the root zone and is lost to deep percolation. The deep water loss chart (Figure 20) shows the cumulative water losses to deep percolation.



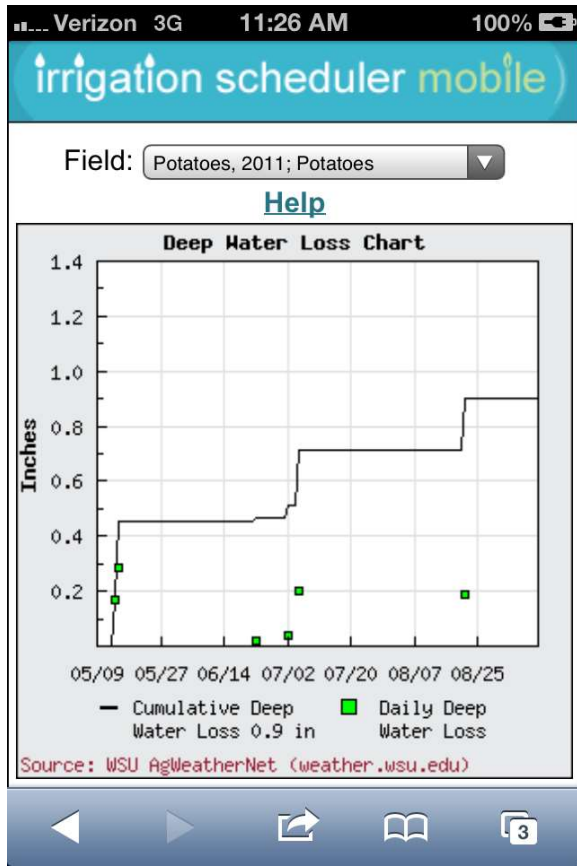


Figure 20. Cumulative Deep Water Loss

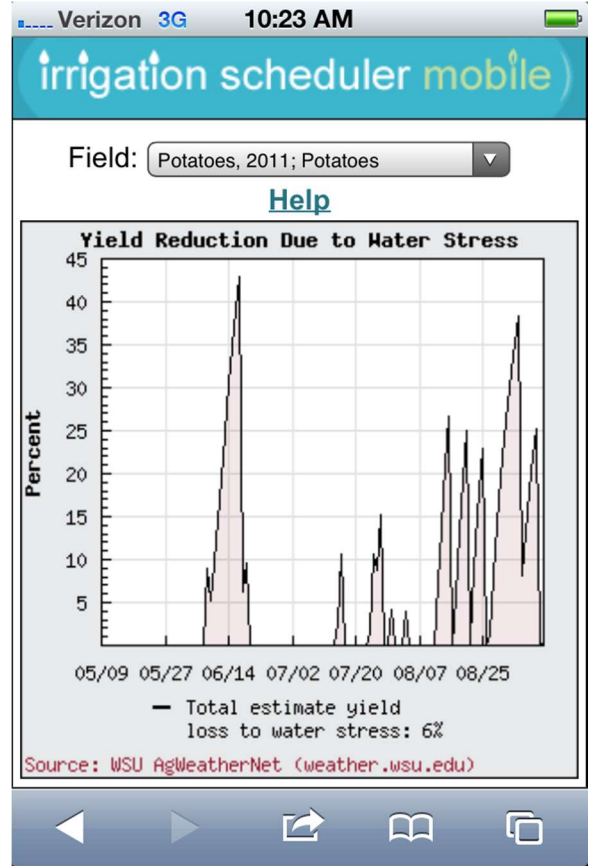


Figure 21. Corresponding Water Stress Chart

### Water Stress Chart

This model uses a very simplified method of yield loss estimation. When the soil water content goes below the red MAD line as in Figure 21 it is assumed that there is yield loss that is equivalent to the amount of decreased water use similar to Figure 5. In other words:

$$\frac{Y}{Y_m} = \frac{ET}{ET_m}$$

Or solved for yield,

$$Y = Y_m \times \frac{ET}{ET_m}$$

where  $Y$  is the actual crop yield,  $Y_m$  is the maximum obtainable crop yield,  $ET$  is the actual crop water use, and  $ET_m$  is the maximum possible crop water use. The right-hand portion of this equation can be simplified as a crop water stress coefficient ( $K_s$ ) that behaves as shown in Figure 8 as:

$$K_s = \frac{ET}{ET_m}$$

The % yield reduction on any particular day is therefore  $(1 - K_s) \times 100\%$ . This is what is charted (Figure 21).

The season-long total estimated yield loss due to water stress as shown on this chart is therefore calculated using the season-long mean  $K_s$  ( $K_{sm}$ ) as:

$$(1 - K_{sm}) \times 100\%$$

## Field Settings

Field Settings allows users to select model interaction options and to change the field defaults that were chosen based on the crop and soil type chosen during field setup. Default values for each crop and soil are in Appendix A & B. Entering alternate values here overwrites these defaults. *The "Update Field" button must be clicked for any changes to be applied.*

Additional information about each option follows:

**Show Forecast Values:** If checked, the model will get a seven day forecast of the maximum and minimum temperatures from the National Weather Service based on the location of the chosen weather station. The Hargreaves equation is then used to estimate grass reference evapotranspiration (ET<sub>o</sub>) and multiplied by 1.2 to estimate alfalfa reference evapotranspiration (ET<sub>r</sub>). Forecasts are refreshed every 2 hours. (See Figure 23)

**Send Me Notifications:** Check this box to get email or text message notifications sent to you on the status of your field. If you choose to be notified by email you will be asked for your email address. If you choose to be notified by text (SMS) message you will be asked for your mobile phone number and your service provider. You can also choose what time of day the notification will be sent. You can also elect to only be notified when your percent of available soil water has been depleted to less than an entered threshold value. (See Figure 16)

**Use Hours Instead of Inches:** Many irrigators think in terms of hours of irrigation run time instead of inches of water applied. Applied irrigation can be entered in hours, and the soil water deficit can be displayed in hours instead of inches. If you prefer to use hours an irrigation application rate in inches per hour must be provided. Calculators are available on this page to "Help Calculate My Application Rate" for drip, sprinkle, and general irrigation systems using a variety of different units. Reasonable assumptions of irrigation application efficiency are provided for each system. (See Figure 23)

**Use Volumetric Soil Water Content:** Most soil moisture sensors display volumetric soil water content (volume of water/volume of soil) instead of the percent of available water (which is easier to understand). If you would prefer to see and enter volumetric soil water content in the Daily Budget Table then check this box.

**For Drip/Micro, % of Soil Wetted:** In many perennial cropping systems under drip or micro irrigation, the entire soil volume is not used. For example a drip irrigation system in a wine grape vineyard may wet a 4 ft width of soil in an 8 ft row spacing. In this case only 50% of the soil is used to store water since the inter-rows remain dry. The soil's water holding capacity can be reduced by multiplying by this percentage to reflect this.

**Soil Water Content at Field Capacity:** This is the maximum amount of water that the soil can hold long term against gravity. After a soil is at the field capacity (Full point) adding more water will result in the water moving down through the soil profile and possibly past the bottom of the root zone (tracked on the “Deep Water Loss Chart”). Field Capacity is measured in inches of water per foot of soil depth.

Verizon 3G 3:23 PM 95%  
weather.prosser.wsu.edu

### Advanced Field Information

Field: Creek Pasture, 2013; Grass (Pasture)

[Help](#)

Show Forecast Values

Send Me Notifications By Text (SMS)

Phone Number: 5097781748

Service Provider: Verizon

Each day at: 08:10

Only If % Avail. Water Is < 60 %

Use Volumetric Soil Water Content

Use Hours Irrigation Instead of Inches

Irrigation Application

Rate: 0.141 in/hr

[Help Calculate My Application Rate](#)

For Drip/Micro

% of Soil Wetted: 100 %

Soil Water Content at

Field Capacity: 4.5 in/ft

Verizon 3G 3:24 PM 95%  
weather.prosser.wsu.edu

Send Me Notifications By Text (SMS)

Phone Number: 5097781748

Service Provider: Verizon

Each day at: 08:10

Only If % Avail. Water Is < 60 %

Use Volumetric Soil Water Content

Use Hours Irrigation Instead of Inches

Irrigation Application

Rate: 0.140 in/hr

[I know my Application Rate](#)

Irrigation Type: Sprinkler Irrigation

Nozzle Diameter: 5 32nds in

Pressure: 50 psi

Head Spacing: 40 ft

Line Spacing: 60 ft

Sprinkler Efficiency: 70

Calculate Rate

For Drip/Micro

% of Soil Wetted: 100 %

Figures 22-23. Advanced Field Information Setup Screen

**Soil Available Water Holding Capacity (AWC):** This is field capacity minus wilting point, or the amount of water the soil can hold between full and empty. AWC times the soil depth gives the available water supply. The Empty/Dead (permanent wilting point) is calculated using this number and field capacity. Soil Available Water Holding Capacity is measured in inches of water per foot of soil depth.

**Management Allowable Deficit (%):** Abbreviated MAD, this is the percent depletion of the total available water below which the plant begins to experience water stress. *100% minus MAD is the First Water Stress point* as a percent of the available water holding capacity. As the soil dries down below this point the plant will experience increasing amounts of water stress until the plant will die when it reaches the Empty/Dead (permanent wilting) point. Daily crop water use estimates are proportionately decreased from the full value to zero as the soil water content decrease from MAD to the soil’s permanent wilting point.

**Planting/Emergence Date:** Date the plant that the crop emerges and/or the plant starts using water. This is the start date for the soil water budget model. (See Figure 24.)

**Crop Canopy Cover Exceeds 10% of Field:** The date that crop water use starts increasing. (See Figure 24.)

**Crop Canopy Exceeds 70% of Field (Full Cover) Date:** The date that the crop canopy exceeds 70% - 80% of the field area or shades 70% - 80% of the ground area. At this point the crop coefficient reaches a maximum and stays at this maximum until the Initial Maturation Date (below). (See Figure 24.)

**Crop Initial Maturation Date:** After this date the crop begins to dry up, senesce or otherwise shut down and water use begins to decrease. (See Figure 24.)

**End of Growing Season Date:** Water use stops on this date. Often this coincides with harvest, or the first killing frost. This is the last date of the model. (See Figure 24.)

**Root Depth on Start Date:** The effects of a growing root depth is included in the soil water budget model. This is the root depth in inches on the starting or plant emergence date. (See Figure 24.)

**Maximum Managed Root Zone Depth:** This is the maximum root depth reached in the season. It is assumed that the plant root reaches this depth on the Crop Canopy Full Cover Date. (See Figure 24.)

**Initial Crop Coefficient:** The crop coefficient ( $K_c$ ) from emergence to the 10% Cover date. (See Figure 24.) This  $K_c$  is based on alfalfa reference  $E_{Tr}$ .

### Crop Coefficient and Root Zone Depth Parameter Explanation Chart

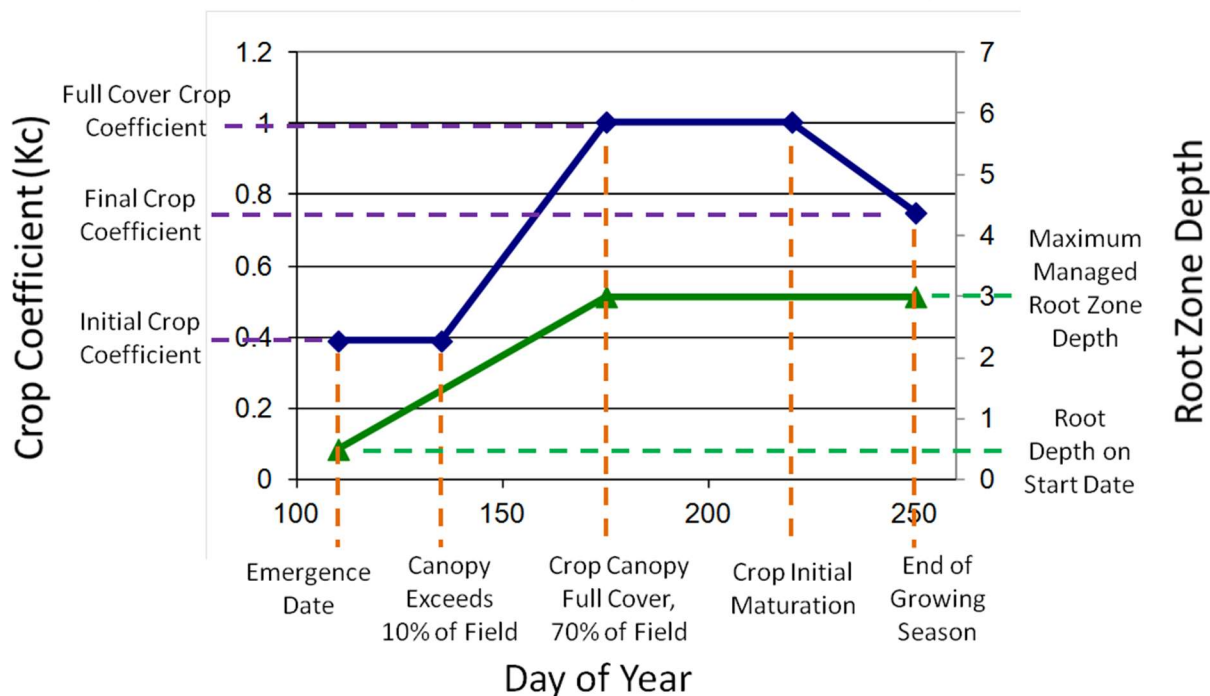


Figure 24. How crop coefficients and root growth are defined by the parameters in Field Settings.

**Full Cover Crop Coefficient:** The crop coefficient (Kc) at full cover. This is the peak, or maximum crop coefficient. (See Figure 24.) This Kc is based on alfalfa reference ETr.

**Final Crop Coefficient:** Crop coefficient (Kc) at the end of the season. (See Figure 24.) This Kc is based on alfalfa reference ETr.

**Post Cutting Kc Flat Days:** After cutting a forage, this is the number of days before regrowth starts.

**Post Cutting Kc Recovery Days:** After cutting a forage this is the number of days after regrowth starts for the forage to regrow to full cover again.

## Add/Delete Fields

Selecting this menu brings up the screen in Figure 25. You can add a new field, or completely delete an existing field from this menu.

**Add New Field:** Use this to add a new field.

**Delete Selected Field:** Permanently removes the currently selected field and all of its settings and associated data.

**Field Name:** Use this to name the field.

**Field Year:** This is the growing year. If a previous year is selected, then that previous year's weather data will be used in the water budget. Use the current year for ongoing or current irrigation scheduling.

**Network:** Pick the agricultural weather network from your state that has the station that best represents your location. A list of agricultural weather networks whose data can be accessed by this irrigation scheduling tool are given in Table 1. Figure 30 is a map of these stations.

Table 1. Irrigation Scheduler Mobile currently can work with data from the following networks.

<u>Network</u>	<u>States Served</u>	<u>Managed By</u>	<u>Website</u>
AgWeatherNet	Washington	Washington State University	<a href="http://weather.wsu.edu/">http://weather.wsu.edu/</a>
CoAgMet	Colorado	Colorado State University	<a href="http://www.coagmet.colostate.edu/">http://www.coagmet.colostate.edu/</a>
AZMET	Arizona	University of Arizona	<a href="http://ag.arizona.edu/azmet/">http://ag.arizona.edu/azmet/</a>
NDAWN	North Dakota	North Dakota State University	<a href="http://ndawn.ndsu.nodak.edu/">http://ndawn.ndsu.nodak.edu/</a>
ADAWN	South Dakota	South Dakota State University	<a href="http://climate.sdstate.edu/climate_site/ag_data.htm">http://climate.sdstate.edu/climate_site/ag_data.htm</a>
CIMIS	California	California Dept. Water Resources	<a href="http://www.cimis.water.ca.gov/cimis/welcome.jsp">http://www.cimis.water.ca.gov/cimis/welcome.jsp</a>

AgriMet	WA, OR, ID, NV, MT	US Bureau of Reclamation, Pacific Northwest Region	<a href="http://www.usbr.gov/pn/agrimet/">http://www.usbr.gov/pn/agrimet/</a>
AgriMet	MT	US Bureau of Reclamation, Great Plains Region	<a href="http://www.usbr.gov/gp/agrimet/">http://www.usbr.gov/gp/agrimet/</a>

**Weather Station:** This tool automatically pulls the calculated daily reference evapotranspiration (ET) rates and measured precipitation from this station. Choose a station that best represents the weather conditions at your field.

**Field Crop:** Based on the selected crop, default growing season dates, crop coefficients, management allowable deficit (MAD) rates, and rooting depths are chosen. These crop parameters can be later edited in “Field Settings”.

**Field Soil:** Based on the soil texture chosen, default field capacity, wilting point, and water holding capacity values are chosen. These soil parameters can be later edited in “Field Settings”.

### Forage Cuttings

Harvested forages such as alfalfa, grass hay, and sometimes mint can have multiple cuttings per season. After a forage crop is cut the crop coefficients are greatly decreased since the height and leaf area of the forage has been removed. The model knows which crops are forages and has default lag and recovery periods for these crops where the crop coefficients are temporarily reduced following a cutting (Appendix B). For these crops there will be an additional check box titled “Apply Forage Cutting Today” in the “Edit” expansion menu on the “Daily Budget Table”. Checking this box on the day that the forage was cut will alter the crop coefficients during the recovery phase of the forage (Figure 25). It will also put a mark on the Soil Water Chart to indicate the forage cutting (Figure 26).

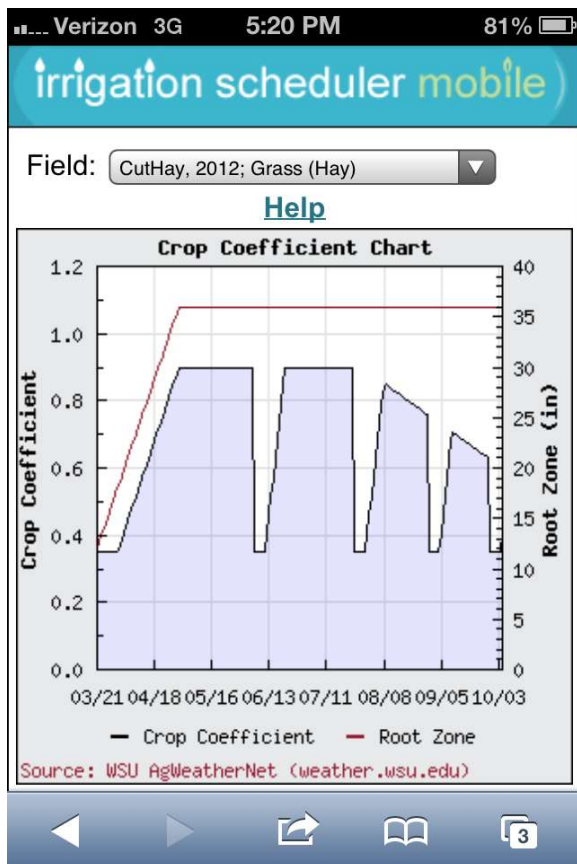


Figure 25. Crop Coeff. Chart showing cuttings.

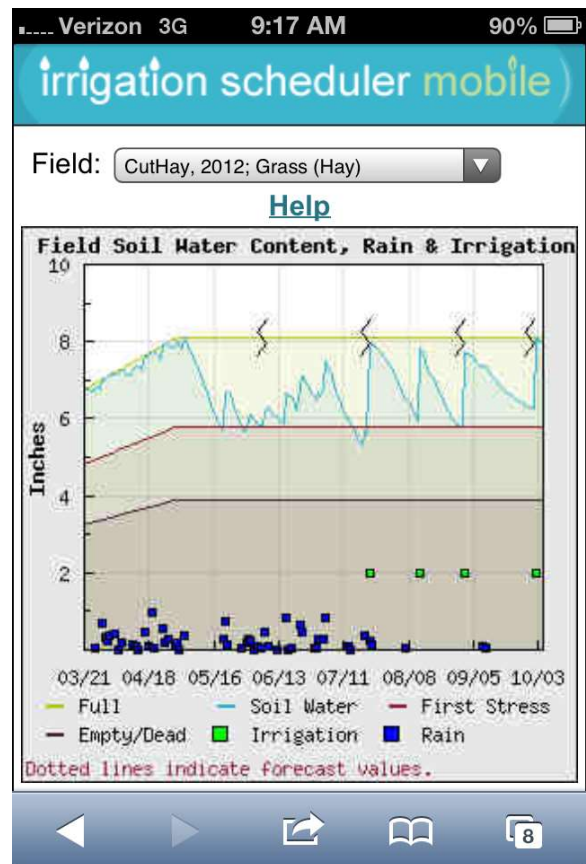


Figure 26. Cutting dates shown on the Soil Water Chart.

## Full Size Screen Version

There is a version of this model that is set up for use on full-size computer screens at <http://weather.wsu.edu> (Figure 27). The operation of this is essentially identical to the mobile version, except that the charts are larger. Making changes to fields in this version will apply the changes to the mobile version and vice-versa.

**Field Activity Reports:** One feature that is available on the full size version that is not available on the mobile version is the option to show a report of your interaction with the Irrigation Scheduler. This was requested as a way to show certain agencies that you have been actively using the model for irrigation scheduling so that they will feel that incentives for irrigation scheduling are well spent.

The model counts the number of days that you view or edit that field in a month (Figure 28). Views or Edits are counted whether you use the full-page or small screen (mobile) version. Loading any page for the field is counted as a view. Making an edit in the Daily Budget Table (such as adding an irrigation event), or in the Field Settings is counted as an edit.

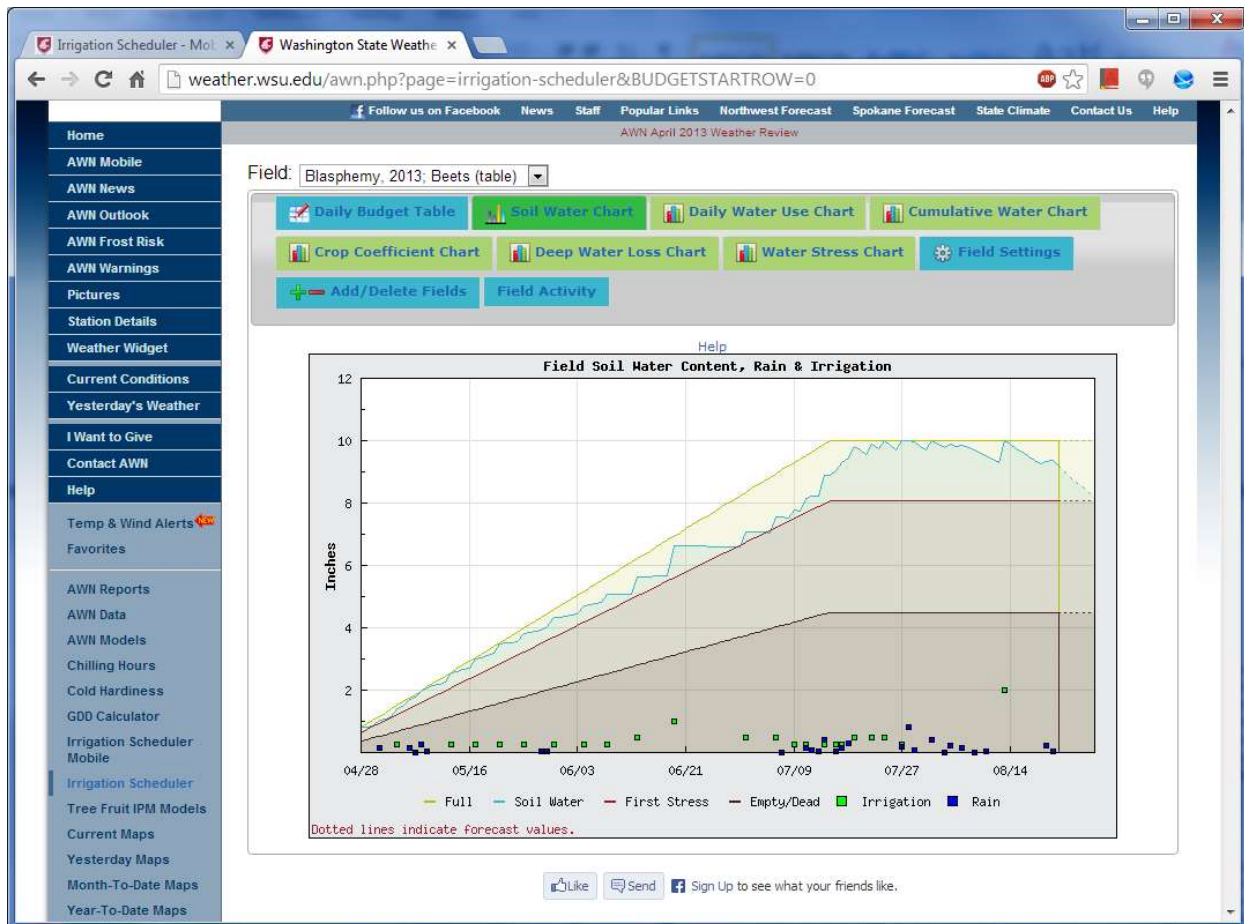


Figure 27. Full Screen version.



The screenshot shows the AgWeatherNet interface. At the top, the navigation bar includes links for 'A-Z Index', 'Campuses', 'myWSU', 'WSU Search', and 'WSU Home'. The main header identifies the site as 'The Washington Agricultural Weather Network Version 2.0, WSU Prosser'. A sidebar on the left lists various navigation options such as 'Home', 'AWN Mobile', 'AWN News', and 'AWN Reports'. The main content area features a dropdown menu for the selected field: 'Creek Pasture, 2013; Grass (Pasture)'. Below this, there are several interactive buttons for data visualization, including 'Daily Budget Table', 'Soil Water Chart', 'Daily Water Use Chart', 'Cumulative Water Chart', 'Crop Coefficient Chart', 'Deep Water Loss Chart', 'Water Stress Chart', and 'Field Settings'. The 'Field Activity' section provides user and field metadata and a table of activity.

Field: Creek Pasture, 2013; Grass (Pasture)

[Daily Budget Table](#)
[Soil Water Chart](#)
[Daily Water Use Chart](#)
[Cumulative Water Chart](#)

[Crop Coefficient Chart](#)
[Deep Water Loss Chart](#)
[Water Stress Chart](#)
[Field Settings](#)

[Add/Delete Fields](#)
[Field Activity](#)
[IS Statistics](#)

### Field Activity

User Name: tpeters  
 Field Name: Creek Pasture  
 Soil Type: Silt Loam  
 Crop: Grass (Pasture)

Weather Station: WSU HQ, WA  
 Start Date: Mar 05, 2013  
 End Date: Sep 05, 2013

Month, Year	Days with Views	Days with Edits
May, 2013	9	4
June, 2013	11	3
July, 2013	13	5
August, 2013	13	2

[Like](#)
[Send](#)
 7 people like this. Sign Up to see what your friends like.

Figure 28. Field Activity report that is available from the full-screen version.

## Suggestions for Different Irrigation/Cropping Systems

**Rill or Furrow Irrigation:** With surface irrigation methods it is difficult to know exactly how much water infiltrated into the soil. A good assumption is that at each irrigation event you completely refill the soil water deficit to field capacity in the entire root zone. Simulate this by entering a large number at each irrigation event (like 3-4 inches), entering a number equivalent to the soil water deficit, or resetting the Percent Available Water number to 100% at each irrigation event.

The model is useful with surface irrigation in that it will indicate when the soil is getting dry again and when to irrigate. To be the most efficient with your water resources, wait to irrigate when the soil water content is near the First Stress (MAD) line. Often growers learn they can wait a little longer than they thought before irrigating again and they end up saving an irrigation or two over the season.

**Moving Irrigation Sets:** With many irrigation systems it takes many days to irrigate an entire field. This brings up the question, "Which date should I put the irrigation on?" Simply choose one part of the field and throughout the whole season enter the irrigation on the date that that part of the field receives irrigation water. Be aware that the soil water content in the other parts of the field will either be slightly ahead or behind the model. It might be easier if you choose a location that is easier to remember when it was irrigated, such as the first set. If correlating/correcting with soil moisture measurements, be sure to choose the part of the field where the measurements are being taken.

**Use with Soil Water Content Sensors:** Updating the model with periodic soil moisture measurements will greatly improve the accuracy of the soil moisture estimate. These can be used to fine-tune the model as well. For example, if you find that the soil moisture measurement is consistently higher than that estimated, then the model is over-estimating crop water use and the crop coefficients should be adjusted down for that time period. Be aware that soil moisture measurements are quite variable and may be high one time then low the next. Use seasonal trends and your good judgment to adjust the model.

Most soil water content sensors provide in the number as a volumetric soil water content (% water of total soil volume) this number is available by clicking the date in the Daily Budget table for expanded information (Figure 13).

**Use with Soil Water Tension Sensors:** Tensiometers and Granular Matrix (Watermark) sensors don't measure soil water content and therefore it is very difficult (although not impossible) to compare the measurements directly with the model. However, these sensors should indicate that the soil is drier (greater soil water tension) as the soil water content approaches and goes below the MAD line. For additional help see the publication "Practical Use of Soil Moisture Sensors for Irrigation Scheduling" by Troy Peters.

**The Effects of Irrigation Frequency.** With center pivots and some solid-set irrigation systems water is applied much more frequently than other irrigation systems such as surface (rill) or hand-lines and wheel-lines. High frequency irrigations mean that the soil surface and plant leaves are wet a greater percentage of the time and therefore a greater amount of water is lost

to evaporation. In other words, the crop uses/needs more water. Because of this, you might need to adjust the crop coefficients *up* 5-10% in Field Settings to compensate for this.

**Deliberate Water Stress:** With some crops, such as wine grapes, it is desirable to deliberately cause water stress to get the desired crop quality results. Recall that the plant will see approximately linearly increasing water stress from barely any at the red, First Stress (MAD) line to maximum stress at the black, Empty/Dead (Permanent Wilting Point) line (see Figure 5). Deliberately causing stress is done by purposefully allowing the soil water to dry down below the First Stress line (Figure 29).

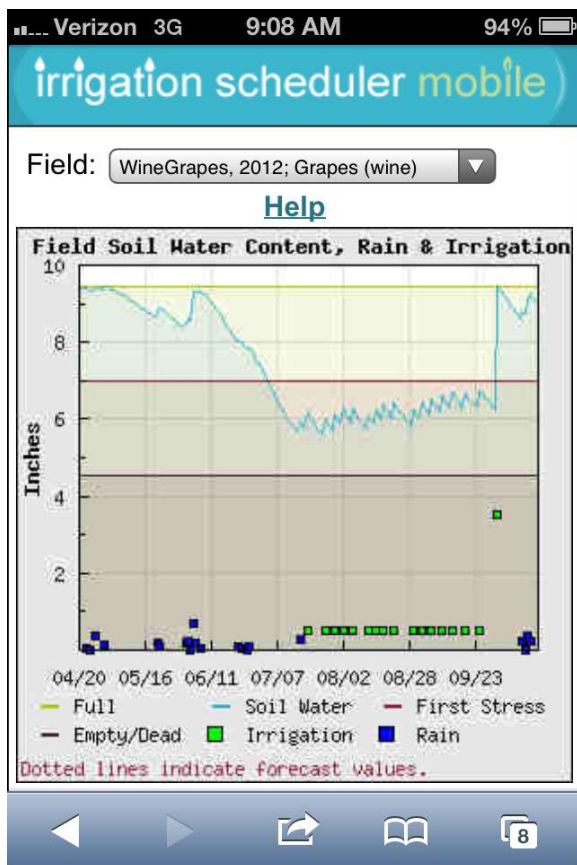


Figure 29. Water stressing wine grapes. Irrigation after harvest was done to restore the health of the vines.

## Technical Details on Adapting the Model to Your Area

This model was set up to be used outside of just Washington State. It was written in PHP and MySQL, both of which are free, open-source applications that run on a web server. The code is freely available under an open source, GPL license if someone wants to set it up to run on a different server. It is permissible to re-brand it as long as the developers are acknowledged and it is freely available to users.

**Other Weather Networks:** It can easily accept rainfall and weather data for evapotranspiration calculations from any weather network whose data can be accessed over the internet (Table 1). Additional states or networks can be fairly easily added if there is an automated way to get access to up-to-date historical weather data. Please contact us ([troy\\_peters@wsu.edu](mailto:troy_peters@wsu.edu)) to add your network. It should also work well with international data networks.

**Alternative Crops and Crop Defaults:** Unfortunately crop coefficients are not always accurately transferrable from one climatological region to another. Also the growing season dates used as defaults in the model obviously vary with different climates. To account for this Irrigation Scheduler Mobile can accept different default crop coefficients and season growth dates that are attached to administrator-defined groups of weather stations. For example, the model is now set up so that when a grower chooses a weather station in Western Washington (the evergreen side) it will use different crop coefficients than if a weather station in Eastern Washington (the ever-brown side) is chosen. Different states can also have their own set of default crops, crop coefficients, and growth season dates. Please contact Troy Peters ([troy\\_peters@wsu.edu](mailto:troy_peters@wsu.edu)) for more information on how to get these made specific to your state or growing area. This only affects the default crop values automatically populated when a grower sets up a new field.

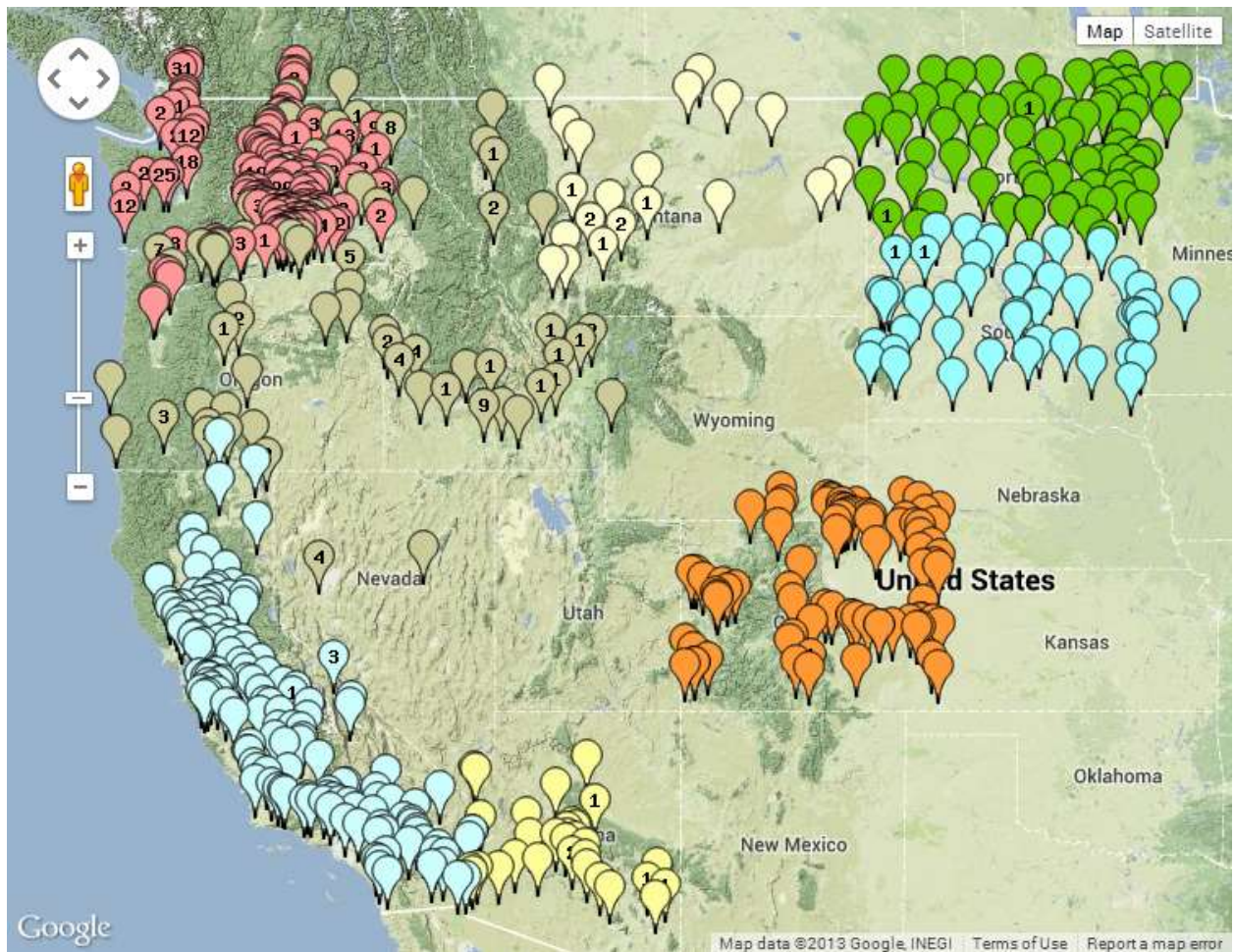


Figure 30. A map of the stations and weather networks that Irrigation Scheduler Mobile currently works with (as of Oct. 1, 2013). See Table 1 for additional details. The numbers in the balloon markers are the current number of fields set up using that station.

## Conclusion

Irrigation Scheduler Mobile is a free, easy to use, and flexible irrigation scheduling tool that can be used from any smart phone or any web browser. It is simple to use and flexible. It also can work with any weather data that can be automatically accessed over the internet.

## Acknowledgements

Sean Hill was the primary developer of Irrigation Scheduler Mobile. He is a very bright, capable developer who conceived many of the concepts used in this program. He deserves the lion's share of the credit for making this happen. He is a web developer for AgWeatherNet. Funding for Sean's time was graciously provided by the director of AgWeatherNet; Gerrit Hoogenboom. Additional funding for prior development by Cynthia Tiawana was provided by the USDA Water Quality Research Initiative. The American Society of Agricultural and Biological Engineers is also providing funding for additional development and to turn this into a downloadable smart phone app. Thank you!

## References

Allen, R.G., L.S. Pereira, M. Sith, D. Raes, and M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. "Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome, 300 pp.

ASCE – EWRI. 2005. The ASCE Standardized Reference Evapotranspiration Equation. R.G. Allen, I.A. Walter, R.L. Elliott, T.A. Howell, D. Itenfisu, M.E. Jensen, and R.L. Snyder. Reston, VA: ASCE/The Irrigation Association.

Clark, G., D. Rogers, and S. Briggemen. KanSched, A Water Management and Irrigation Scheduling Program for Summer Crops. Available online at: <http://mobileirrigationlab.com/kansched-microsoft-excel>. Last accessed 3/21/2012.

Hillyer, C., and M. English. 2011. Irrigation Management Online. Available online at: <http://oiso.bioe.orst.edu/RealtimelIrrigationSchedule/>. Last accessed 3/21/2012.

Peters, R.T, K. Desta, and L. Nelson. 2012. Practical Use of Soil Moisture Sensors for Irrigation Scheduling. WSU Extension publication.

Rogers, D., G. Clark, and M. Alam. KanSched2. Available online at: <http://mobileirrigationlab.com/kansched2>. Last accessed 3/21/2012.

Wright, J. 2002. Irrigation Scheduling Checkbook Method. Available online at: <http://www.extension.umn.edu/distribution/cropsystems/DC1322.html>. Last accessed 3/21/2012.

**Appendix A:** Defaults by Soil Texture. All units are in inches of water per foot of soil depth. More accurate estimates for your particular soil are available from the NRCS Web Soil Survey (<http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm>)

Soil Texture	Soil Water Content (in/ft)		
	Field Capacity	Wilting Point	AWC
Coarse Sand	1.2	0.6	0.7
Fine Sand	1.5	0.7	0.8
Loamy Sand	2.2	1.2	1.0
Sandy Loam	2.7	1.3	1.4
Fine Sandy Loam	3.4	1.6	1.8
Sandy Clay Loam	4.0	2.0	2.0
Loam	4.0	1.8	2.2
Silt Loam	4.3	2.0	2.3
Silty Clay Loam	4.6	2.8	1.8
Clay Loam	4.8	3.0	1.8
Silty Clay	4.8	3.2	1.6
Clay	4.8	3.4	1.4
Peat Mucks	5.0	2.6	2.4

**Appendix B:** Crop defaults used. These can be customized to weather networks, or even groups of weather stations within a network.

Crop Name	Crop Development Dates for Crop Coefficient Curve (DOY)					Crop Coefficients			Root Depths (ft)		MAD %
	Planting/ Emergence	> 10% of Field	Full Cover/ > 70%	Initial Maturation	End of Season	Initial	Full Cover	Final	Starting	Max.	
Alfalfa *	91	100	122	139	278	0.33	1.07	0.95	4.0	5.0	55
Apples	100	112	149	240	290	0.39	1.05	0.50	3.5	3.5	50
Apricots	100	112	149	220	278	0.39	1.10	0.50	3.5	3.5	50
Asparagus	120	130	214	260	278	0.36	1.00	0.87	3.5	5.0	55
Beans (dry)	146	156	191	211	242	0.25	0.95	0.30	0.4	2.5	50
Beans (green)	146	150	180	200	211	0.25	0.95	0.80	0.4	2.5	40
Beets (table)	117	135	195	239	276	0.40	0.88	0.79	0.2	2.5	35
Blackberries	90	95	145	190	280	0.25	1.05	0.70	3.5	4.0	50
Blueberries	85	90	111	195	225	0.25	1.03	0.90	3.0	4.0	50
Bluegrass Seed	72	80	126	155	192	0.25	0.95	0.25	1.0	2.5	50
Broccoli	91	119	160	218	243	0.50	0.87	0.80	0.2	2.0	35
Brussel Sprouts	91	119	160	218	243	0.58	0.88	0.79	0.2	2.0	35
Cabbage	91	92	160	185	243	0.25	1.00	0.25	0.5	2.0	40
Canola	76	83	122	164	183	0.20	1.05	0.30	0.5	4.0	55
Cantaloupe	136	153	195	229	243	0.42	0.71	0.50	0.5	3.0	50
Carrots	91	119	160	220	243	0.70	0.85	0.75	0.2	2.0	35
Cauliflower	91	119	160	218	243	0.58	0.87	0.79	0.2	2.0	35
Celery	127	140	186	220	253	0.65	0.80	0.80	0.2	1.5	40
Cheatgrass	60	62	83	104	130	0.25	0.80	0.25	0.5	2.5	65
Cherries	110	112	141	220	278	0.39	1.12	0.50	3.5	3.5	50
Clover *	91	95	117	244	278	0.33	0.92	0.75	2.0	2.5	45
Corn (grain)	129	151	201	236	259	0.25	1.00	0.75	0.4	3.5	50
Corn (sweet)	130	152	203	230	240	0.25	1.00	0.86	0.4	2.5	40
Cranberries	105	106	121	277	278	0.33	0.75	0.42	0.2	0.3	40
Cucumbers	136	140	174	240	278	0.50	0.70	0.70	0.5	2.5	40
Garlic	91	119	160	218	243	0.58	0.83	0.57	0.5	1.5	30



**Appendix B:** Crop Defaults Used in the Model, Continued.

Crop Name	Crop Development Dates for Crop Coefficient Curve (DOY)					Crop Coefficients			Root Depths (ft)		MAD %
	Planting/ Emergence	> 10% of Field	Full Cover/ > 70%	Initial Maturation	End of Season	Initial	Full Cover	Final	Starting	Max.	
Grain (Spring)	92	100	160	195	213	0.25	1.05	0.70	0.3	3.5	50
Grain (Winter)	66	85	128	184	196	0.25	1.05	0.90	1.0	3.5	50
Grapes (juice)	110	114	180	277	278	0.25	0.90	0.75	3.0	3.0	40
Grapes (wine)	110	135	210	277	278	0.15	0.70	0.70	3.0	5.0	65
Grass (Hay) **	80	90	120	209	278	0.50	0.90	0.72	1.0	3.0	55
Grass (Pasture)	80	87	118	244	278	0.25	0.65	0.50	2.0	3.0	55
Grass (Tall Pasture)	80	87	118	244	278	0.25	0.80	0.50	2.0	3.0	55
Grass (Turf)	72	80	108	244	278	0.80	0.80	0.80	1.0	1.5	50
Hops	110	158	230	250	274	0.25	1.05	0.20	3.0	4.0	50
Lentils	105	115	155	182	215	0.25	1.02	0.30	0.5	2.5	50
Lettuce	95	96	110	123	125	0.58	0.83	0.79	0.2	1.5	25
Melons	136	140	174	240	278	0.25	0.80	0.60	0.5	2.5	40
Mustard	76	83	122	164	183	0.25	0.85	0.30	0.5	2.0	55
Onions (dry)	90	122	162	212	239	0.50	1.07	0.50	0.2	1.5	35
Onions (green)	74	99	129	139	144	0.50	1.00	1.00	0.5	1.5	35
Peaches	110	112	145	220	278	0.39	1.12	0.50	3.5	3.5	50
Pears	110	112	149	226	278	0.39	1.15	0.50	3.5	3.5	50
Peas	90	97	163	174	198	0.30	1.00	0.50	0.5	2.5	40
Peppermint *	86	93	156	270	278	0.25	0.98	0.85	1.5	2.0	40
Peppers	136	153	195	232	243	0.50	0.85	0.71	0.5	2.0	35
Plums	110	112	149	239	278	0.20	1.05	0.50	3.5	3.5	50
Potatoes	127	140	186	220	253	0.40	0.85	0.60	1.0	2.0	35
Pumpkin	136	161	212	250	278	0.42	0.83	0.67	0.5	3.0	45
Radishes	95	96	110	123	125	0.53	0.72	0.67	0.5	1.0	40
Raspberries	90	95	144	227	278	0.20	1.08	0.70	3.5	4.0	50

**Appendix B:** Crop Defaults Used in the Model, Continued.

Crop Name	Crop Development Dates for Crop Coefficient Curve (DOY)					Crop Coefficients			Root Depths (ft)		MAD %
	Planting/ Emergence	> 10% of Field	Full Cover/ > 70%	Initial Maturation	End of Season	Initial	Full Cover	Final	Starting	Max.	
Safflower	90	98	143	193	220	0.20	1.08	0.25	0.5	5.0	55
Sorghum	130	150	185	230	260	0.25	0.90	0.85	0.5	2.0	55
Soybeans	121	140	175	235	260	0.36	0.96	0.30	0.5	3.0	55
Spearmint *	110	124	165	212	243	0.25	1.03	0.80	1.5	2.0	40
Spinach	88	120	168	206	215	0.55	0.80	0.75	0.5	1.5	25
Squash	136	161	212	250	278	0.40	0.80	0.60	0.5	3.5	50
Strawberries	80	93	164	207	278	0.33	0.70	0.55	1.0	1.5	30
Sugar beets	117	135	195	239	276	0.25	1.05	0.70	0.5	4.5	50
Sunflowers	105	130	165	210	234	0.25	0.92	0.29	0.5	4.5	65
Tomatoes	136	153	195	229	243	0.50	0.95	0.70	0.5	3.0	40
Tubers	80	93	164	207	278	0.42	0.92	0.79	0.5	3.5	40
Watermelon	105	130	165	210	234	0.33	0.85	0.85	0.5	3.5	50

\* Default post-cutting lag and recovery time periods are 7 and 14 days respectively.

\*\* Default post-cutting lag and recovery time periods are 5 and 10 days respectively.