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A smartphone application for estimating irrigation frequency and runtime for Californian crops based on the water balance approach

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सार – सिंचाई को अनुकूलित करने से यह सुनिश्चित होता है कि पौधों को गहरे रिसाव या जल निकासी से किसी भी नुकसान के बिना सही मात्रा में पानी मिले। हालांकि, गैर-पेशेवर फसल उत्पादक, जैसे कि माली और बागवानी के शौकीन, सिंचाई चक्रों को अनुकूलित करने के लिए डेटा-संचालित समाधानों तक सीमित पहुंच रखते हैं। इस ऐप का उद्देश्य कैलिफ़ोर्निया में चयनित फसलों की एक श्रृंखला के लिए सिंचाई आवृत्ति और रनटाइम प्रदान करके इस अंतर को भरना है। वाष्पोत्सर्जन-आधारित स्मार्ट फ़ोन ऐप औसत दैनिक सिंचाई रनटाइम निर्धारित करने के लिए स्थानीय रूप से कैलिब्रेटेड फसल गुणांक, अधिकतम अनुमत कमी कारक और मौसम डेटा का उपयोग करता है। यह पहला स्मार्ट फ़ोन एप्लिकेशन भी है जो कैलिफ़ोर्निया में किसी भी चयनित स्थान के लिए प्रभावी वर्षा की गणना करता है। भविष्य में, ऐप को अन्य अमेरिकी राज्यों में भी लागू किया जा सकता है।

ABSTRACT. Optimizing irrigation ensures that plants receive the right amount of water without any loss from deep percolation or drainage. However, non-professional crop growers, such as gardeners and garden hobbyists, have limited access to data-driven solutions to optimize irrigation cycles. This app aims to fill this gap by providing Irrigation Frequency and Runtime for a range of selected crops in California. The evapotranspiration-based smartphone app uses locally calibrated crop coefficients, Maximum Allowed Depletion factors, and weather data to determine the average daily irrigation runtime. It is also the first smartphone application that calculates effective rainfall for any selected location in California. In the future, the app could be applied to other U.S. states.

Key words – Crops, Irrigation Scheduling, Water Management, California, Water balance Approach.

1. Introduction

Precision irrigation involves the precise and timely application of water based on real-time data about soil moisture, crop needs, and environmental conditions (Mateo-Aroca *et al.*, 2019; Owino & Söffker, 2022). It utilizes data analytics and automated systems to deliver water accurately and in a controlled manner to meet plants' specific needs. This method conserves water by providing it directly to the plants and adjusting irrigation to their specific requirements. Precision irrigation also minimizes water wastage and enhances overall water efficiency, improving plant health and increasing crop productivity while reducing crop strain. Farmers can benefit economically by adopting precision irrigation, as it reduces energy costs, fertilizer expenses and water bills.

Precision irrigation involves the utilization of various technologies and techniques.

(*i*) Soil moisture sensors evaluate the moisture content in the soil. Real-time data is provided to assist farmers in determining the appropriate timing and quantity of water to be applied.

(*ii*) Weather stations gather meteorological information such as temperature, humidity, wind speed and solar radiation. These data are used to adjust irrigation timetables according to evapotranspiration rates and water loss.

(*iii*) The utilization of remote sensing techniques such as satellite imagery and aerial drones can identify water-stressed areas.

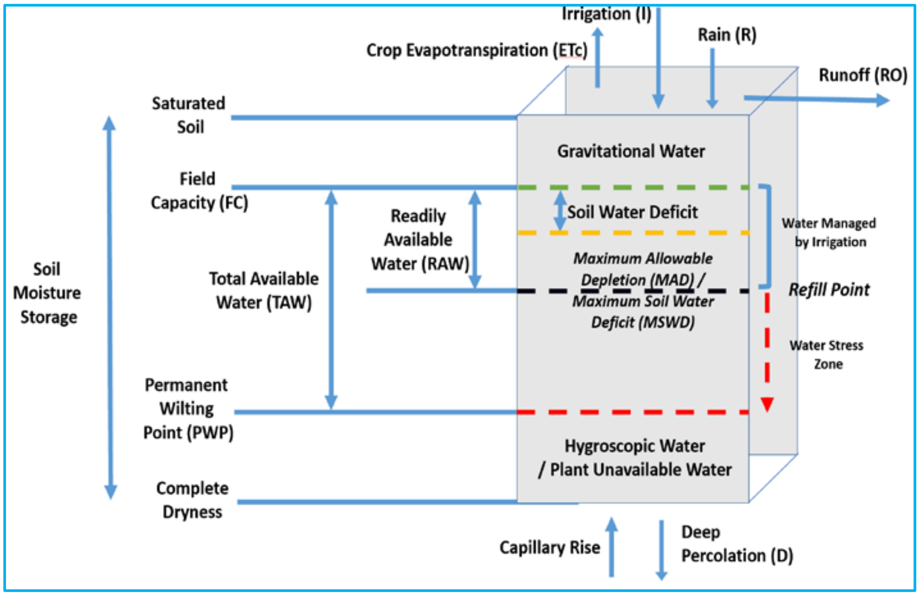


Fig. 1. Soil Water Balance (*Source* : https://www.fao.org/3/x0490e/x0490e0o.jpg)

Smart farming applications, such as SmartFarm Irrigation, Irricontrol and IrriCheck, provide real-time irrigation schedules for specific crops (Migliaccio *et al.*, 2016; Karetsos *et al.*, 2022). These apps assist farmers in managing irrigation schedules by using soil moisture data, weather forecasts, and plant water requirements to monitor and adjust soil moisture levels. In addition, there are crop-specific apps like CropXfor soil moisture, 365Crop for fertilization, Plantix and Map My Crop for disease detection and Farmable for farm management. Other apps like Outgrow provide comprehensive services such as irrigation planning, farm health monitoring, and soil testing. Most apps are designed for professional farmers, offering recommendations for fertilizers and pesticides. However, there is a shortage of open-access precision irrigation solutions for non-professional growers. This app aims to fill this gap by providing an irrigation solution for farmer hobbyists and gardeners. Additionally, it does not recommend the use of fertilizers and pesticides and is free of charge for users. California is a key market for this app due to the importance of farming, specific crop needs, and drought conditions.

2. Method

2.1. *The soil water balance approach*

The Soil Water Balance Method is crucial for determining crop water requirements. This approach, also known as the water balance budget method, assesses the amount of water available in a given area. It conceptualizes the soil as a bucket and provides guidance on the necessary amount of water to replenish it. This method considers factors that impact water availability for crop growth and assumes that inflows to any water system or region equal its outflows plus changes in water storage. However, it is important to consider several limitations. Its accuracy depends on the availability and quality of data such as precipitation, evapotranspiration, runoff, soil moisture, groundwater levels, and deep percolation, which can be difficult to obtain.

There are additional limitations due to the following factors:

(*i*) Limited consideration of human factors: Although the water-balanced budget method considers precipitation and evapotranspiration, it may not integrate human practices, such as local irrigation practices (watershed basins, terrace farming, furrow…), which can significantly impact water availability.For example, furrow irrigation has been a traditional method in California agriculture due to its simplicity and low cost. Sprinklers are also widely used and can be adjusted for different crop heights. However, both methods can lead to higher water loss through evaporation and runoff. Drip irrigation is, therefore, increasingly preferred as it can reduce water usage by 30% to 50% compared to traditional sprinkler systems.

(*ii*) Future climate change: The water-balanced budget method uses historical data (average precipitation, weekly, and monthly evapotranspiration) to estimate water availability and demand. However, it may not consider the impact of climate change, such as changes in precipitation patterns and rising temperatures. Users must, therefore, input the current daily evapotranspiration and monthly rainfall to compute theirrigation runtime and frequency at the selected location.

2.2. *Plant water requirements*

Plant water requirementsdepend on water inputs such as precipitation (or Rainfall) and Irrigation (*I*), as well as water outputs such as Runoff (*RO*), Deep Percolation (*D*), and Crop Evapotranspiration (*ETc*) (Fig. 1).

Rainfall (*R*) and Irrigation (*I*) increase the soil moisture balance**.** Rainfall (*R*) is the primary source of incoming water, a portion of which is lost due to Crop Evapotranspiration (*ETc*). The remaining adds to the water pool contained in the soil. Water that drains beyond the crop root zone is no longer available to the crop (Landsberg *et al*., 2011). Deep percolation (*D*) corresponds to a water loss and occurs when plant roots cannot receive water because it has penetrated too deeply into the soil, beyond the reach of the crop roots.

If the soil water content exceeds the soilwater holding capacity, the surplus is lost due to Runoff (*RO*) or drainage. The surplus water will drain away and flow to a lower spot in the landscape.

Crop Evapotranspiration (*ETc*) is the water lost into the air by combining evaporation and transpiration. Evaporation is the phase transition from liquid to gas that releases water from a moist surface into the surrounding air. Transpiration occurs when the plant releases water into the air. Evapotranspiration is the main source of outgoing water, especially in windy and dry circumstances (Dukes *et al*., 2009) or in arid and semi-arid conditions in inland regions of California. Variations in temperature, precipitation, and vegetation patterns directly impact evapotranspiration rates.

Irrigation (*I*) and Rainfall (*R*) are deposits in the soil,while Crop Evapotranspiration (*ETc*), Runoff (*RO*) and Deep percolation (*D*) are water losses (Equation 1).

Water-based inputs and outputs equation:

$$\Delta S = R - ETc + I - D - RO \quad (1)$$

(Kisekka *et al*., 2019)

where,

ΔS = Change in soil water storage (*inches*) / differences between inputs (water gain) and outputs (water loss)

R = Rainfall (*inches*)

ETc = Crop Evapotranspiration (*inches*)

I = Net Irrigation (*inches*)

D = Deep Percolation (*inches*)

RO = Surface Runoff (*inches*)

We understand that this model has certain limitations. For instance, it can be challenging to determine the deep percolation (D) below the active root zone. Calculating ΔS components in the field is intricate (Evett *et al*., 2012). Nonetheless, both D and ΔS vary with irrigation (I) (Friedman, 2023). Often, it is assumed that D is small compared to I and *Etc* and that the soil water balance is constant (*i.e*., $\Delta SW \approx 0$).

Various factors affect effective rainfall (*Pe*). Steeper slopes, compacted soil, or impermeable surfaces can increase Surface Runoff (*RO*) and reduce effective rainfall. Impermeable surfaces can also increase runoff, decreasing rainfall effectiveness.

Once we remove the water lost due to Surface Runoff (*RO*) and Deep percolation (*D*), which the plant cannot use, we obtain the effective rainfall ($Pe = R - D - RO$), which is the quantity of water that the plant can use for its growth (Dastane, 1974).

Equation (1) becomes Equation (2) if changes in the volume of water (ΔS) are negligible, as in reservoirs, water storage in the soil, or aquifers (Brouwer *et al*., 1989; Dukes *et al*., 2009). This approach assumes that the water balance in the soil remains relatively constant and stable (*i.e*., that $\Delta SW \approx 0$).

Deep percolation is not negligible under specific conditions, such as substantial rainfall, high soil moisture, or considerable groundwater depth. Deep percolation becomes significant during periods of intense rainfall, as these events enhance infiltration and subsequent percolation into deeper soil layers (Hess *et al*., 2018). Deep percolation is also more pronounced during wet seasons when precipitation is higher. However, these instances of intense rainfall are increasingly rare in California.

$$I = ET_c - P_e \quad (2)$$

where,

I = Net Irrigation *(inches)*

ETc = Crop Evapotranspiration *(inches)*

Pe = Effective Rainfall *(inches)*

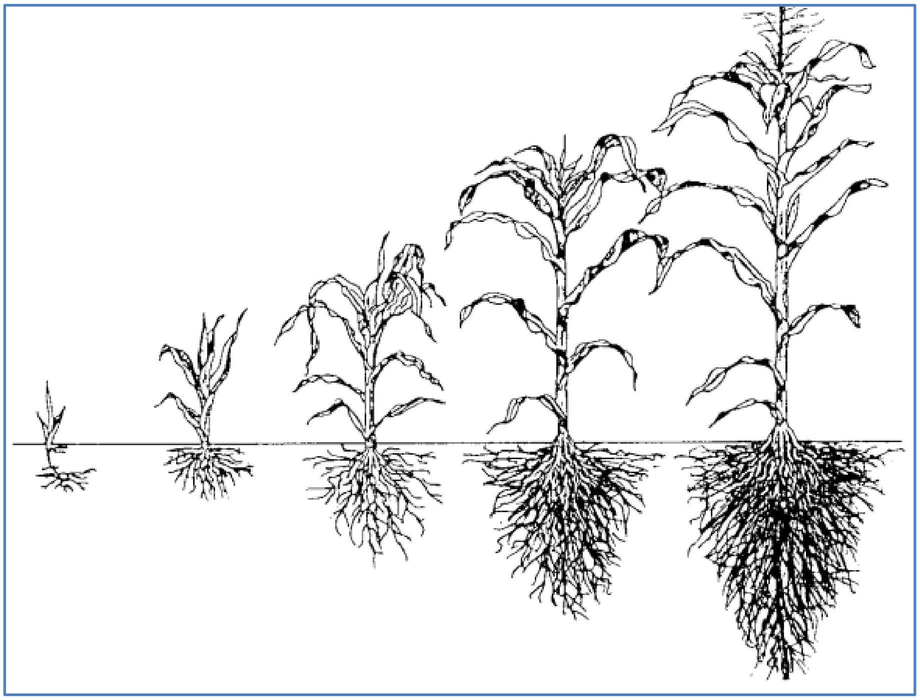


Fig. 2. Root Depth, Canopy Coverage, and Crop Growth (*Source*: https://www.canr.msu.edu/irrigation/upoads/files/E3439_Efficient-Irrigation-Management-with-Center-Pivot-Systems.pdf)

To compute Net Irrigation (*I*), we need to calculate Crop Evapotranspiration (*ETc)* and then Effective rainfall *(Pe)*.

2.3. *Soil moisture storage*

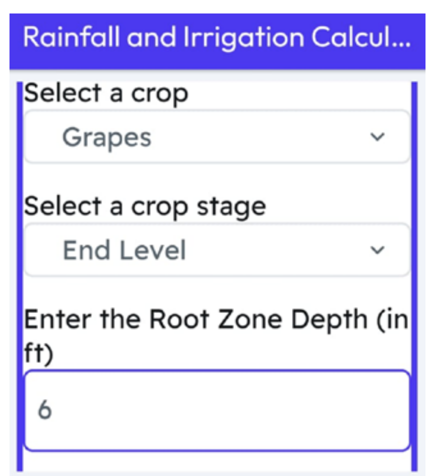
Soil Moisture Storage (Fig.1) refers to the quantity of water contained in the soil at any given moment. That quantity of water is contingent on soil characteristics such as texture and organic matter concentration. For example, fine-grain soils will retain moremoisture. In contrast, coarse-textured soils such as sand have a reduced water-holding capacity because they contain a high proportion of big holes that let the water drain freely.

2.4. *Root zone depth*

The Root Zone Depth (D_{rz}) determines how much water the crop can extract from the soil. It defines the soil areafrom which the crop retrieves water (Dukes *et al.*, 2009). The deeper the roots, the more water is accessible to the plant. Plants get the majority of their water from the uppermost soil layers. The root zone of plants grows at about the same pace as the canopy (Fig. 2) but can be shorter due to obstacles in the soil. For annual plants, full root depth typically occurs before blooming or when complete canopy coverage is achieved. Since this is not always the case for perennial plants, the app relies on the effectiveRoot Zone Depth (D_{rz}).

TheRoot Zone Depth and Crop Growth Stage are entered manually (Screenshot 1).

Screenshot 1 : Crop Type, Crop Growth Stage and Root Zone Depth



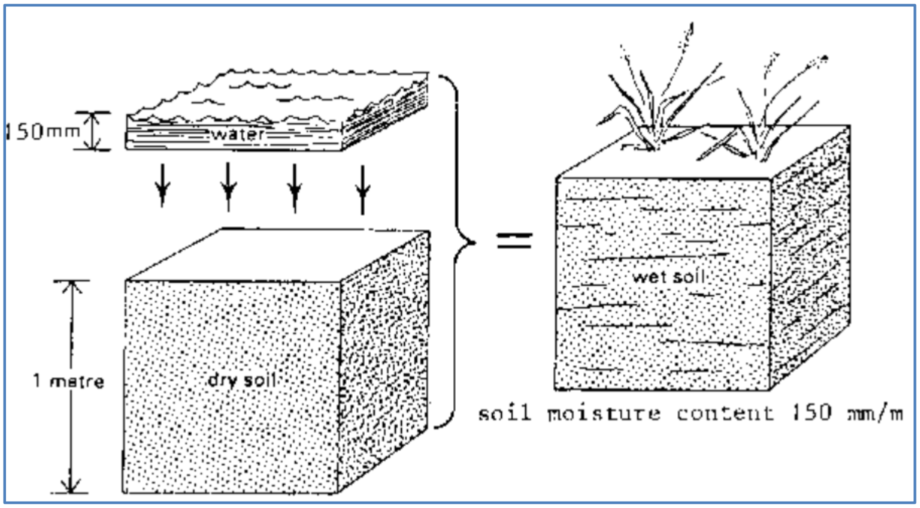


Fig. 3. SoilAvailable Water Capacity / Moisture Content per Meter of Soil (*Source*: https://www.fao.org/3/r4082e/r4082e03.htm#2.3%20soil%20moisture%20conditions)

2.5. *Root zone depth and available water capacity*

The Root Zone Depth (D_{rz}) and the soil Available Water Capacity (AWC) determines how much water is available to the plants. The soil'sAvailable Water Capacity (AWC) decreases as the soil texturebecomes coarser, as with sands. As for the root depth, shallow-rooted crops have less access to soil water than long-rooted crops. Hence, shallow-rooted plants on sandy soils are more susceptible to drought than long-rooted cropsand irrigationshould be more frequent. In contrast, fine-textured soils such as clay or clay loam,which include a larger proportion of microscopic holes that inhibit water drainage, result in a greater soil Available Water Capacity (AWC) (USDA, 2005). The soil Available Water Capacity (AWC)is commonly expressed as the amount of water (in mm of water depth) in one meter of soil. For instance, when an amount of water (in mm of water depth) of 150 mm is present in one meter of soil, the soil moisture content is 150 mm/m (Fig. 3).The app converts data from the metric system to the Imperial unit system.

The soil Available Water Capacity (AWC)depends on the soil texture class. The latter can be retrieved from the World Soils Harmonized World Soil Database (available at http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HWSD_Documentation.pdf) or the Soil SURveyGeOgraphic database (SSURGO) produced and distributed by the Natural Resources Conservation Service (NRCS) (https://sdmdataaccess.nrcs.usda.gov/) and the National Cartography and Geospatial Center (NCGC). The Soil SURveyGeOgraphic database is also available at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627. Esri also provides soil layer attributes related to soil texture (https://www.arcgis.com/home/item.html?id=aa9a3a2dc6924f46adc5a999787f7961). It also hosts theWorld Soils Harmonized World Soil Database - Hydric,which provides the Available Water storage Capacity (AWC). One can also use the SoilWeb App (https://casoilresource.lawr.ucdavis.edu/gmap/) from the UC Davis Soil Resource Laboratory to retrievethe Available Water storage Capacity (AWC) in mm/m for any selected location on a map. While the upcoming app version will automatically retrieve AWC from the mentioned database, the user provided Available Water Storage Capacity (AWC) in cm/150cm, which the app converts to inches/foot.

2.6. *Permanent Wilting Point (PWP)*

The Permanent Wilting Point (PWP) (Fig. 1) is the soil moisture content at which the plantwill wilt and not recover even when provided with enough water. Although there may still be water in the soil, the plant cannot extract enough water to satisfy its demands. As a result, the plant will wilt and die (Fig. 4).

2.7. *Field Capacity (FC)*

Field Capacity (FC) refers to the greatest quantity of water the soil can storeafter it iscompletely wet and thewater drains freely. Some sandy soils may drain within a few hours, but fine-textured soils such as clay may take days to drain as water drips slowly. Irrigation increases the soil moisture to the Field Capacity (FC).

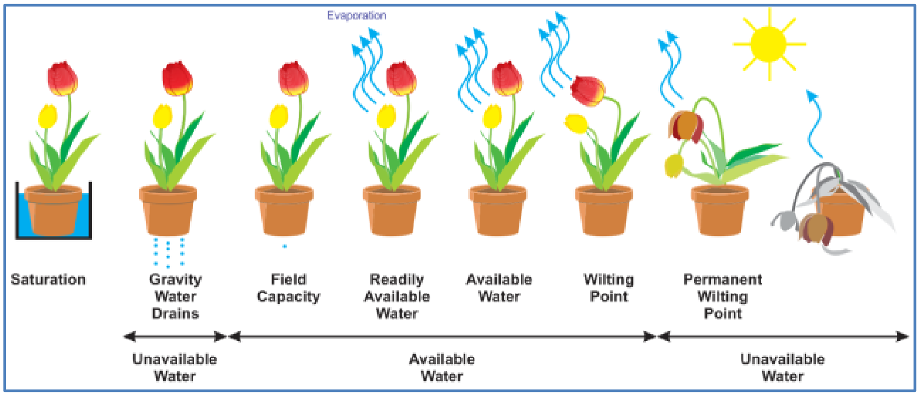


Fig. 4. Crop Growth Stage and Availability of Water (*Source* : Farsad, 2019)

2.8. *Maximum Allowable Depletion (MAD)*

A depletion factor determines the Maximum Allowable Depletion (MAD) (Fig. 1) before the plant experiences water stress. Exceeding the Maximum Allowable Depletion (MAD)will decrease the crop yield as the crop struggles to extract water from the soil.The Maximum Allowable Depletion is determined by a factor that varies with crop and soil type (clay soils retain water longer, allowing for a higher MAD) and local weather characteristics. We retrieve the local MAD factors of a range of crops in California (Tab. 1). The MAD factors are stored in the app tocompute the Readily Available Water (RAW) for the selected crop and location.

2.9. *Total Available Water (TAW)*

Total Available Water (TAW) (Fig. 1) or plant-Available Water Capacity (Fig. 1) is the amount of water that a crop can extract from its root zone. It is the volume of water in a soil profile with a known effective root depth (D_{rz}). The soil retains water and makes it available for the plant to grow. That water is stored between the Field Capacity (FC) and the Permanent Wilting Point (PWP), which defines the plant's root zone (Fig. 1).

$$\mathrm{TAW} = \mathrm{AWC} * \mathrm{D_{rz}} \quad (3)$$

where,

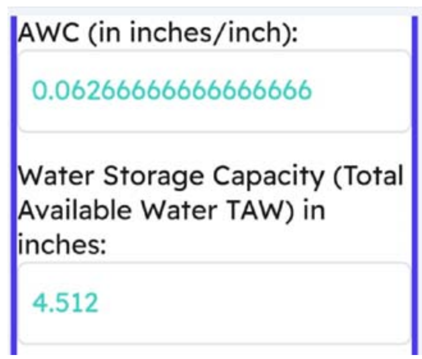
TAW is the Total Available Water (*inches*)

AWC is the Soil Available Water Capacity (*inches/foot*)

D_{rz} is the cropRoot Zone Depth (*feet*).

The app multiplies the Soil Available Water Capacity (AWC) by the crop rooting depth (Equation 3; Screenshot 2).

Screenshot 2 : TAW and AWC



2.10. *Maximum Soil Water Deficit (MSWD)*

The crop can only readily use a fraction of the available water. The Maximum Soil Water Deficit (MSWD) (Fig. 1) is the quantity of water stored in the crop root zone that is easily accessible to the plant. It is the highest volume of water that the plant can extract from the soil before irrigation becomes necessary, ideally at the Refill Point (Fig. 1).

2.11. *Readily Available Water (RAW)*

The portion of the Total Available Water (TAW) that a crop can extract from the root zone without experiencing water stress is the Readily Available Water (RAW) (Equation 4). Irrigation should occur before the water level reaches that point. The amount of water to be applied to the soil should be equal to the Maximum Soil Water Deficit (MSWD) (Fig. 1) (IIABC, 2009).

$$\mathrm{RAW} = \mathrm{MAD} * \mathrm{TAW} \quad (4)$$

where,

RAW is the Readily Available Water (*inches*)

MAD is the Maximum Allowable Depletion (*in %*),

TAW is the Total Available Water (*inches*)

3. Evapotranspiration

3.1. *Crop Evapotranspiration (ETc)*

Crop Evapotranspiration (*ETc*) is not measured directly for an individual crop but is determined from a standard reference grass, known as Reference Evapotranspiration (*ETo*) and then adjusted for the crop using a crop coefficient (*Kc*) (Allen *et al*., 1998) (Equation 5). Reference evapotranspiration (*ETo*) is the rate of evapotranspiration for a crop with a height of 0.12 m (4.72 in), a fixed surface resistance of 70 sec m^{-1} (70 sec $3.2ft^{-1}$), and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground (Allen *et al*., 1998).

$$ETc = ETo * Kc \qquad (5)$$

where,

ETc is the Crop Evapotranspiration (*inches per day*)

ETo is the Reference Evapotranspiration (*inches per day*),

Kc is the Crop Coefficient (dimensionless)

Understanding evapotranspiration patterns in California is critical for managing water resources effectively, as it is a key determinant of irrigation cycles. California experiences high evapotranspiration rates compared to other states, which can be attributed to two primary factors. Firstly, the state often encounters warm to hot temperatures during the summer months and in its interior regions. These higher temperatures can accelerate evaporation, ultimately leading to greater evapotranspiration. Secondly, California also receives significant sunlight and solar radiation throughout the year. This solar energy fuels the plant transpiration process. Different empirical models can estimate Reference Evapotranspiration (*ETo*). Depending on the ET model, these models require daily weather data such as temperatures, solar radiation, relative humidity, dew point, and wind speed. Penman-Monteith's Equation is the most widely recognized technique (1998). *ETo* data collection systems include weather sensors and telemetry. Some apps (*e.g*., evapotranspiration computation on Android) let users compute *ETo* using temperature, wind speed, and humidity rate… Although an *ET* data gathering system can deliver precise real-time *ETo* measurements, these systems are costly. Instead, the app can retrieve *ETo via* the Advanced Programming Interfaces (API) of any of the following sites.

Evapotranspiration Zones and Elevation
https://sqcwd.maps.arcgis.com/apps/Profile/index.html?appid=98947c3276f14a77b857e5a4ec4b9fff

Eto Zones in California
https://www.arcgis.com/home/webmap/viewer.html?webmap=16f12f1b224a4a1cbebf7369c21fa69c

Weather and Eto data
https://www.arcgis.com/home/webmap/viewer.html?webmap=4aead5238677470f8403baa07d6284ad

Eto_Zones
https://www.arcgis.com/home/webmap/viewer.html?layers=bfc8c49769424e1f82c1f45887851729

While *ETo* can be retrieved at a regional scale, it may fail to take into account local variations. It could overlook local topography and microclimatic conditions, which can significantly impact *ETo*.

The user selects a location on the map. Then, the app retrieves *ETo* for the corresponding area and computes the Crop Evapotranspiration (*ETc*) using a Crop Coefficient (*Kc*).

3.2. *Crop Coefficient (Kc)*

Ground cover, crop height, and leaf area changes affect the Crop Coefficient value (*Kc*). As a result,*Kc* value will vary at different stages of growth (Tab. 1). The growing period is separated into three different growth stages: the initial stage (from planting to 10 percent of the plant cover), midseason (from 80 percent ground cover to the beginning of maturity) and end season (start of maturity to harvest). We retrieved *Kc* Value for a range of crops in California (Tab. 1) and stored them in the app. In the absence of local (California) *Kc* values, one can consider Allen *et al*. (1998) valuesfor frequently cultivated crops. *Kc*canalso be determined precisely for a specific site through lysimetric measurements.

4. Effective rainfall

Farmers define the portion of the total rainfall that satisfies the crop water needs as the effective rainfall. Effective precipitation enters the soil and becomes available to the plant for its growth. SCS scientists who analyzed 50 years of rainfall records at 22 locations throughout the United States developed this formula to compute monthly effective precipitation (USDA, 1970).

TABLE 1

MAD (%) and Crop Coefficients Factor (Kc) for a selection of crops in California

Crop	MAD (%)	$K_{C,ini}$	$K_{C,mid}$	$K_{C,end}$
Alfalfa	0.67	0.6	1.10	1.10
Apples	0.75	0.4	1.10	0.85
Apricots	0.50	0.4	1.10	0.80
Avocado	0.60	0.3	0.85	0.80
Barley	0.55	0.32	1.18	0.18
Beans	0.43	0.18	1.15	0.13
Cherry	0.50	0.4	1.10	0.80
Citrus - 20% canopy	0.50	0.85	0.85	0.85
Citrus - 50% canopy	0.50	0.80	0.80	0.80
Citrus - 70% canopy	0.50	0.75	0.70	0.75
Date Palm	0.65	0.80	0.85	0.85
Grapes	0.40	0.20	0.9	0.70
Kiwifruit	0.35	0.31	1.0	1.10
Olives	0.65	0.50	0.55	0.50
Peaches	0.50	0.25	0.95	0.65
Pears	0.40	0.40	1.10	0.80
Pistachios	0.40	0.25	0.8	0.55
Rice	0.20	1.02	1.05	1.04
Strawberries	0.50	0.15	1.20	0.70
Tomatoes	0.40	0.21	1.25	0.60

Source : ITRC, 2003; Guerra *et al*., 2016

This method offers good estimates of precipitation effectiveness, particularly for project planning. The USDA-SCS approach is also widely accepted for locations with low rainfall intensity and high infiltration rates (Dastane, 1974).

$$P_e = SF\left(0.70917_t^{0.82416} - 0.11556\right)\left(10^{0.02426ETc}\right) \quad (6)$$

where,

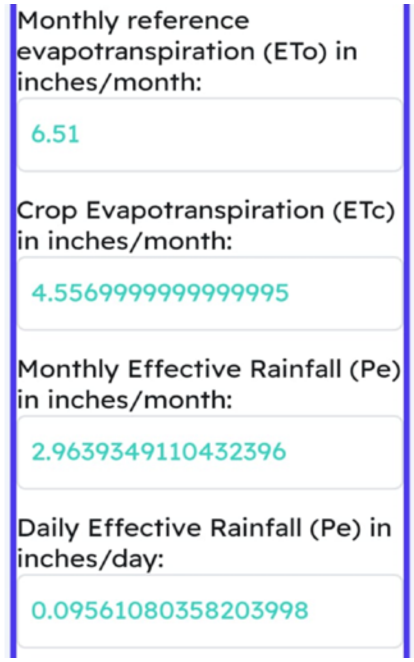
*Pe*is the average monthly effective monthly precipitation (*inches/month*)

*Pt*is the monthly mean precipitation (*inches/month*) (the app userinput *Pt*)

*Etc*isthe average monthly crop evapotranspiration (*inches/month*)

SF is the soil water Storage Factor (*SF*) defined as:

Screenshot 3 : Evapotranspiration and Effective Rainfall



The app computes the monthly effective precipitation (Screenshot 3) on the selected area using the above Equation 6:

SF = 0.531747 + 0.295164 * D – 0.057697 * D^2 + 0.003804 * D^3 (7)

where *D* is theusable soil water storage (*inches*), *i.e*., available water in storage that crops can use between irrigations (National Engineering Handbook. Chapter 2).

$$D = AWC * D_{rz} * MAD \quad (8)$$

where,

D is the usable soil water storage (*inches*)

AWC is the Available Water Capacity (AWC) (*inches/foot*)

D_{rz} is the crop Root Zone Depth (*feet*)

MAD is the Management Allowable Depletion (in %)

The app multiplies the soil Available Water-holding Capacity (AWC)by the Root Zone Depth (D_{rz}) andthe Maximum Allowable Depletion (MAD) (Trimmer, Hansen, 1994; Smajstrla *et al*., 1989) to obtain*D*(Equation 8; Screenshot 4)

Screenshot 4 : SF and D Factors

5. Results

5.1. *Gross Irrigation Water Requirement*

The quantity of water necessary for the crop to grow is the net Irrigation requirement (*I*), as determined by Equation 9. The irrigation (application) Efficiency (*E*) is the ratio of the quantity of water available for agricultural water usage to the total volume of water pumped (Werner, 1993), as water is lost before it reaches the soil.The Efficiency ratio (*E*) is expressed as a percentage or a decimal; 90 percent equals 0.90. First, the user inputs the sprinkler Efficiency (*E*). Then, the app converts thenet Irrigation water requirement (*I*)into the Gross Irrigation (*GI*) water requirement(Equation 9), which is shown on Screenshot 5.

$$GI = \frac{I}{E} \tag{9}$$

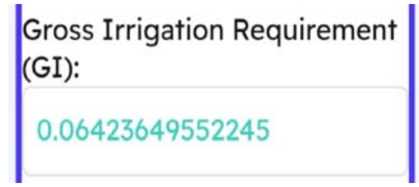
where,

GI is the Gross Irrigation requirement (*inches per day*)

*I*is the net Irrigation requirement (*inches per day*)

E is the Efficiency ratio of the irrigation system (*in %*).

Screenshot 5 : Net and Gross Irrigation Requirement



5.2. *Irrigation Runtime (IR)*

The Precipitation Rate (*PR*) is the amount of water applied to a certain area per unit of time by the irrigation system. For example, a sprinkler system may readily deliver water at a rate that exceeds the soil's capacity to absorb moisture (infiltration rate), resulting in surface Runoff (*RO*) (IIABC, 2009). The sprinkler Precipitation Rate (*PR*) determines the Irrigation Runtime (*IR*) (Equation 10) (Kisekka *et al*., 2010; Brouwer *et al*., 1989), which appearsin Screenshot 6 below.

$$IR = \frac{MAD * TAW}{PR} \tag{10}$$

where,

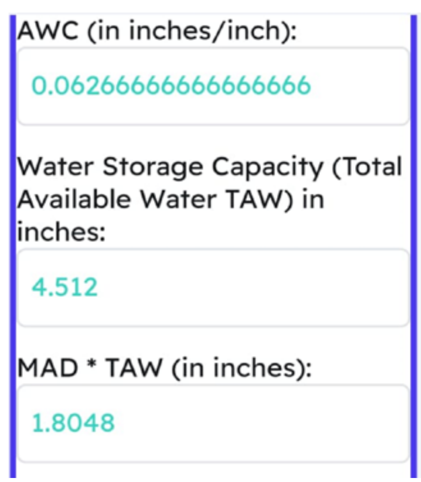
IR is the Irrigation Runtime (*hours per irrigation cycle*)

MAD is the Maximum Allowable Depletion (*in %)*

TAW is the Total Available Water (*inches*)from Equation 3

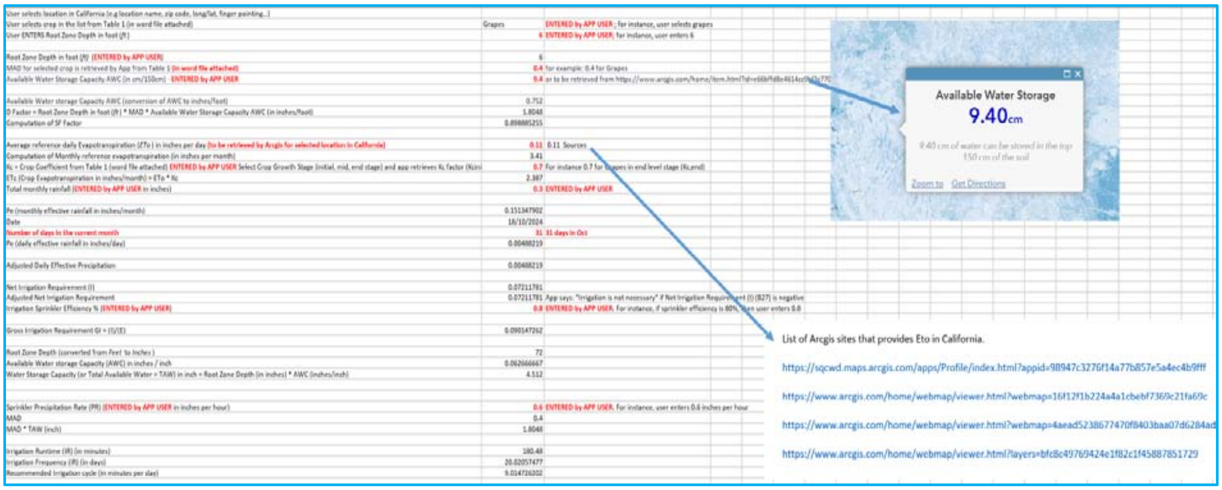
PR is the Precipitation Rate or flow rate per wetted area *(inches/hour*)

Screenshot 6 : AWC and TAW

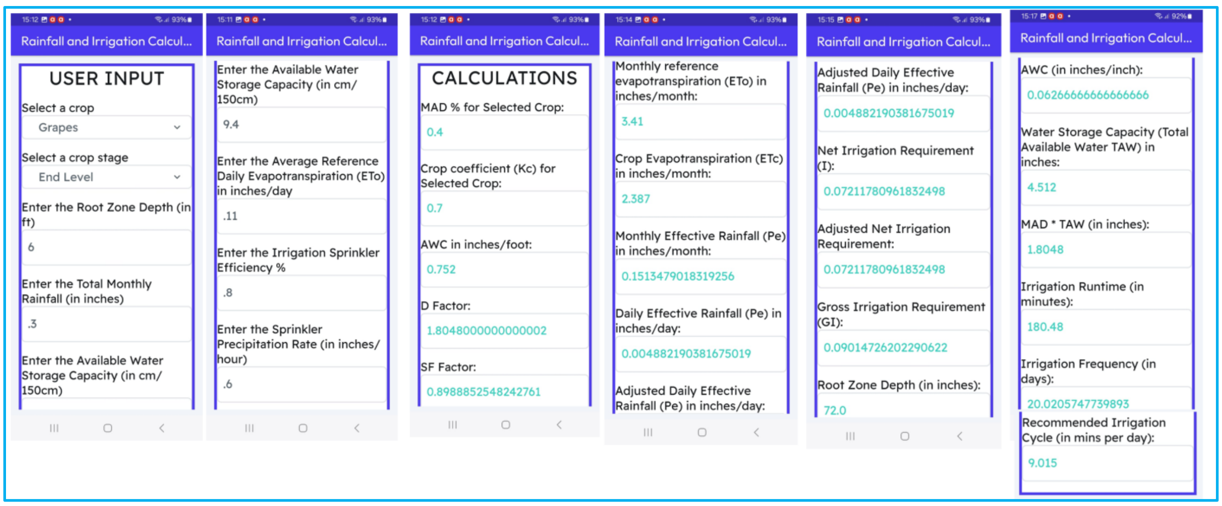


The app multiplies *IR* by 60 to convert *IR* from hours to minutes.

Tab 2. Irrigation Cycle



Screenshot 8



5.3. *Irrigation Frequency (IF)*

The Irrigation Frequency *(IF)* (*i.e.*, the number of days between irrigation events) is calculated as follows (Equation 11) (Kisekka *et al*., 2010), which appears in Screenshot 7.

$$IF = \frac{MAD * TAW}{GI} \quad (11)$$

where,

IF is the number of days between irrigation events

MAD is the Maximum Allowable Depletion (*in %)*

TAW is the Total Available Water (*inches*) from Equation 3

GI is the Gross Irrigation requirement (*inches per day*) from Equation 9

Then, we compute the Average Daily Irrigation Runtime (ADIR) or average minutes of irrigation per day in the current month by dividing *IR* (Irrigation Runtime) by *IF* (number of days between irrigation events) (Equation 12), which appearsin Screenshot 7.

ADIR = *IR*/*IF* (12)

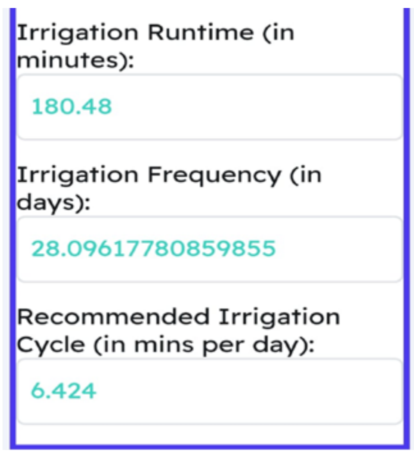
where,

ADIR is the Average Daily Irrigation Runtime (ADIR) (*minutes per day*)

IR is the Irrigation Runtime (*minutes*)

IF is the number of days between irrigation events (*days*)

Screenshot 7 : IR, IF and Recommended Irrigation Cycle



Here is a test for Grapes at end-stage growth in October with an average daily reference evapotranspiration of 0.11 inches and total monthly rainfall of 0.3 inches. The app (screenshot 8) matches the Excel sheet computations on Tab 2.

6. Conclusion

Smartphone apps called "smart irrigation apps" help customers effectively manage and control their irrigation systems by utilizing crop attributes and meteorological data. Additional enhancements encompass retrieving updated local evapotranspiration and rainfalldatarather than relying on institutional sources. The formula (USDA, 1970) to compute effective rainfall in California is valid for all US states. It is also possible to apply the same evapotranspiration-based method in States wherever evapotranspiration data and locally calibrated crop coefficients are available. Historic data for evapotranspiration across the US can be retrieved by Zip code (http://www.rainmaster.com/historicET.aspx). For constantly updated data, Agri Met provides monthly evapotranspiration(https://www.usbr.gov/pn/agrimet/monthlyet.html) and crop coefficients (https://www.usbr.gov/pn/agrimet/cropcurves/crop_curves.html) for the American Northwest. For Texas, locallycalibrated crop coefficients and local evapotranspiration data are available here (https://texaset.tamu.edu/). For the Northeast, the Northeast Regional Climate Center makes available Evapotranspiration (https://www.nrcc.cornell.edu/wxstation/pet/pet.html) and climatic data (https://www.nrcc.cornell.edu/wxstation/comparative/comparative.html. Crop coefficients for states other than California were compiled by Guerra *et al.* (2016) and can be used for a local version of the app. The crop coefficients provided by Guerra *et al.* (2016) would need to be input in Table 1.

Disclaimer : The contents and views presented in this research article/paper are the views of the authors and do not necessarily reflect the views of the organizations they belongs to.

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