# Comprehensive Review of Crop Water Requirement Estimation Techniques: Approaches, Challenges, and Future Directions


## ABSTRACT

In order to meet the growing demand for water, water scarcity is a significant issue that needs attention. Agriculture crops are not getting enough water because of this problem. Consequently, figuring out how much water a given crop needs requires using the right method. Accurate crop water requirements must be measured in order to schedule irrigation effectively, which in turn leads to efficient crop water management. To restore the lost moisture and promote the best possible growth for plants, irrigation is used. Water management and irrigation scheduling fundamentally depend on an accurate calculation of the crop's crop water requirements ($ET_c$). Accurate evapotranspiration measurements are necessary for effective irrigation water management. Evapotranspiration (ET), a process that measures the amount of water lost from soil and crops through transpiration and evaporation processes, respectively, is dependent on a variety of meteorological factors. A significant factor in determining crop water requirements and irrigation schedules is reference evapotranspiration. There exist multiple theories and methodologies for estimating reference evapotranspiration, ranging from empirical to physical based. Reference Evapotranspiration is referred to the idea behind ET is to calculate ET based on a reference surface that is comparable to a deep surface of green grass that is consistently growing, completely covering the surface with enough water, and looking stable. The goal of irrigation futures is to choose a suitable model for estimating reference crop evapotranspiration. In order to calculate the amount of water needed for a crop, multiply $ET_o$ by the crop coefficient ($K_c$), which is dependent on the phases and length of a crop's growth. Regression, fuzzy logic, Penman-Monteith, Blaney-Criddle, Hargreaves, ANN and WNN, and other conventional and non-traditional methods are used to estimate $ET_o$.



***Keyword:*** *Crop water requirements; Evapotranspiration; Reference Evapotranspiration; Crop coefficient*


## INTRODUCTION

Over the past few decades, irrigation has been the primary source of water usage for agriculture. To deal with the shortage of water, water-saving agriculture countermeasures must be adopted. The primary goal of irrigation is to apply water to the soil to meet crop evapotranspiration requirements when rainfall is insufficient, raising crop till harvesting (Memon & Jamsa, 2018). The process of applying the appropriate amount of water to the soil at the appropriate time to promote plant growth is known as irrigation. Therefore, determining the amount of water needed for irrigation is essential for water project design and management. The term crop water requirement refers to the amount of water needed by a crop to grow and reach maturity under optimal conditions. Accurately estimating CWR is important for ensuring food security, maximizing water use efficiency, and minimizing environmental impacts. The amount of water that crops require is provided by accessible soil moisture, irrigation water, and effective rainfall (Babu *et al.,* 2014). This review paper synthesizes the current state of knowledge on methods and approaches for estimating CWR.

## APPROACHES FOR ESTIMATING CROP WATER REQUIREMENTS

1. **Empirical approaches:** These use statistical relationships between CWR and climatic variables, such as the Blaney-Criddle and Hargreaves-Samani equations.
   - **Blaney Criddle Method:** The Blaney Criddle approach is used to find the $ET_o$ over the agricultural field under consideration. By taking the mean temperature as an input, we may calculate the $ET_o$ rate using the Blaney Criddle method, which is a temperature-based approach. The Blaney-Criddle formula for estimating $ET_0$ is given (Blaney and Criddle, 1955):

     $ET_o = p\ (0.457 \cdot T_{mean} + 8.128)$

     Where,

     $ET_o$ - Reference evapotranspiration [mm day−1 ]

     $T_{mean}$ - Mean daily temperature [°C] given as $T_{mean} = (T_{max} + T_{min}) / 2$

     p - Mean daily percentage of annual daytime hours.
   - **Hargreaves Method:** Hargreaves is one of the traditional techniques used to estimate $ET_o$. In this method of determining $ET_o$, temperature is the sole parameter that is employed. The Hargreaves formula for estimating $ET_o$ is given (Hargreaves, 1985):

     $ET_o = 0.0029\ R_a\ (TC+20)\ TR^{0.4}$

     $T_R = T_{max} – T_{min}$

     Where,

     $ET_o$ - Reference evapotranspiration

$TR$- Temperature range

$R_a$ - Extra-terrestrial radiation

TC -Temperature in degree Celsius

$T_{max}$ and $T_{min}$ - Daily maximum and minimum temperature.

2. **Analytical approaches:** These apply physical principles of water balance, energy balance, and plant physiology to model the CWR, such as the Penman-Monteith equation.

   **Penman-Monteith Method:** A common technique for predicting $ET_o$ in any place at any time of year is the Penman-Monteith approach. The Penman-Monteith method's input parameters include solar radiation, air temperature at minimum and maximum values, pressure, wind speed, and soil heat flow. The formula used for estimating $ET_o$ using Penman-Montieth method is given (Monteith, 1965):

$$ET_0 = \frac{0.4.8\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

   Where

   $ET_0$ = reference evapotranspiration (mm/day)

   $\Delta$ = slope of the saturation vapor pressure curve ($kP_a$/°C)

   $R_n$ = net radiation at the surface (MJ/$m^2$/day)

   G = soil heat flux density (MJ/m^2/day)

   $\gamma$ = psychrometric constant ($kP_a$/°C)

   T = air temperature at 2 m height (°C)

   $u_2$ = wind speed at 2 m height (m/s)

   $e_s$ = saturation vapor pressure ($kP_a$)

   $e_a$ = actual vapor pressure ($kP_a$)

3. **Remote sensing-based approaches:** These utilize satellite data on vegetation indices, soil moisture, and evapotranspiration to estimate CWR at larger spatial scales.

   - Satellite remote sensing (RS) data have been widely used for a variety of practical applications and research issues. Meteorology, soil and canopy investigations, agriculture and crop production, water, ice, and ocean research and management, geology, mapping, land use and environmental monitoring, reconnaissance and defense, etc. are among the most significant application disciplines (Ferencz *et al.*2004).

- **Crop Evapotranspiration ($ET_c$):** Crop water requirement is the total amount of water needed by the crop for the duration of the growing season. The Crop Coefficient Approach determines $ET_c$ by factoring in the crop features into the Crop Coefficient and the effect of different weather conditions into ET (Memon & Jamsa, 2018):

  $ET_c = K_c * ET_o$

  Where,

  $K_c$ is the crop coefficient, which varies according to the crop and stage of growth

  $ET_o$ is the reference crop evapotranspiration (Dadhwal and Ray, 2001).
- **Crop coefficient ($K_c$):** The crop coefficient, or $K_c$, is essentially the ratio of the crop $ET_c$ to the reference $ET_o$. It shows how the influence of the four main factors that set the crop apart from the reference grass, i.e., Height of crop. Albedo of the crop-soil surface, resistance to canopy, and soil evaporation, particularly in exposed areas . Four growth stages—initial, developmental, mid-season, and late-season—were identified within the overall crop growing cycle in order to calculate the $K_c$ values for various crops (Memon & Jamsa, 2018).
- **Reference evapotranspiration:** In irrigation engineering, the estimation of reference evapotranspiration ($ET_0$) is commonly utilized to determine crop water requirements. Both the planning process for newly designed irrigation schemes and the management of water distribution in already-existing schemes make use of these estimates. The FAO-56 application of the Penman-Monteith equation (Allen et al. 1998) is the most extensively utilized of the various $ET_0$ equations now in use and can be regarded as a kind of standard (Walter et al. 2000). Hereafter, the Penman-Monteith equation, FAO-56, will be referred to as PM. Compared to many other approaches, the PM has two advantages. Firstly, the method is primarily based on physical principles, meaning that it may be applied worldwide without requiring further parameter estimations. Second, the technique has been verified with an assortment of lysimeters and is thoroughly documented, integrated into a broad spectrum of software, and tested (Droogers and Allen, 2002).

4. **Simulation modeling:** Crop growth simulation models, such as CROPWAT and AquaCrop, integrate various biophysical processes to estimate CWR.

- **CROPWAT:** The software CROPWAT 8.0 calculates reference crop evapotranspiration using the Smith (1992), Penman (1948), and Monteith (1965) methodologies. Calculations for agricultural water requirements and irrigation schedule make use of these predictions. CROPWAT 8.0 determines how much irrigation water a cropping pattern in an irrigated area needs at different phases of crop development over the course of the growing season. This water can be needed either monthly, weekly, or as needed (Babu *et al.,* 2014).
- **Aqua Crop:** The FAO created Aqua Crop, a crop growth model, to divide the $ET_a$ into $T_r$ and non-beneficial soil evaporation $E_a$. It is a simulation model that focuses on the unique relationship between water and crop productivity. AquaCrop is widely used for many diverse applications, including assisting in irrigation management decision-making, analyzing the effects of climate change on agricultural output, and determining which crop cultivation techniques are most productive. Numerous nations across the globe have effectively used the approach to enhance sustainable agriculture productivity and water-use efficiency (Salemi *et al.,* 2011).

## CHALLENGES AND FUTURE DIRECTIONS

1. Enhancing CWR model usability and accuracy in a range of agroclimatic situations. With this method, farmers can receive customized advice that take into account their specific environmental conditions, leading to improved adaptation techniques (Lobell et al., 2014).
2. Large-scale, real-time monitoring of Crop Weather Response (CWR) is improved by integrating remote sensing data with simulation models because it provides timely information on crop status and environmental variables. Because of this synergy, agricultural forecasting and decision-making are enhanced, allowing farmers to more successfully adjust to changing climatic conditions (Zhang et al., 2019).
3. Developing resilient agricultural systems that can tolerate changing weather patterns requires addressing the effects of climate change and variability on Crop Weather Response (CWR). Researchers can more accurately forecast crop responses and guide adaptive management options by including climate projections into CWR models (Rosenzweig et al., 2014).

4. Precision agricultural technologies are essential for improving irrigation management and Crop Weather Response (CWR) estimation since they offer up-to-date information on crop health, weather, and soil moisture. According to Gebbers and Adamchuk (2010), the utilization of data in decision-making contributes to better crop yields and efficient use of resources under a variety of meteorological situations.
5. Creating decision-support tools that incorporate meteorological, hydrological, and agricultural data enables farmers and water managers to better plan and allocate water resources. These technologies allow for more informed decision-making, improving water usage while increasing crop yield and sustainability in the face of water scarcity (Zhao et al., 2024).

## RESULTS AND DISCUSSION

Allen et al. (1998) Emphasize that the FAO Penman-Monteith equation is the standard approach that the Food and Agriculture Organization recommends, consistently yielding the most accurate estimates of crop water requirements (CWRs). Trajkovic (2005) notes that although empirical methods might speed up evaluations, they frequently lack the accuracy required for a variety of climates, which could result in inaccurate estimates of water requirements. Singh and Irmak (2009) emphasize the growing significance of remote sensing technologies, which use satellite imagery to monitor crop health and moisture status and provide large-scale estimates of evapotranspiration and CWR. They also emphasize the need for rigorous calibration of these methods with ground data to ensure reliability. Steduto et al. (2009) discuss the benefits of simulation models such as AquaCrop, which provide comprehensive information on crop development and water response while simulating intricate relationships between several environmental parameters. However, they do note that these models frequently require large amounts of input data, which might be a major drawback in areas where data is scarce. The review emphasizes how important local environmental elements are for precisely predicting CWR, including soil type and particular crop characteristics. Ignoring these aspects might lead to water management measures that are unproductive. The assessment also identifies important research gaps, especially in the areas of implementing precision agriculture technologies to optimize irrigation scheduling and integrating climate change estimates into current CWR models. All of these observations highlight the necessity of continuous improvements in CWR prediction techniques in order to promote sustainable farming practices, particularly in light of growing water scarcity and climate variability.

## CONCLUSION

Water management in agriculture cannot be sustained unless crop water requirements are accurately estimated. This review emphasizes the different methods, their approaches, and the further study required to enhance CWR estimation. There are several methods for estimating CWR: analytical, empirical, remote sensing-based, and simulation modeling techniques. Comparing analytical methods with field measurements, like the FAO Penman-Monteith method, usually yields the most accurate estimations of CWR. While empirical approaches might be helpful for quick judgments, their accuracy may be compromised in areas with diverse climates. Although they need thorough calibration and validation, remote sensing-based techniques offer promise for regional-scale CWR estimation. Though they need a lot of input data and parameterization, crop growth simulation models can produce precise CWR estimates. Improving the precision and applicability of CWR models under a range of agroclimatic conditions, integrating remote sensing data and simulation models for large-scale, real-time CWR monitoring, addressing the effects of climate variability and change on CWR, evaluating the role of precision agriculture technologies in optimizing CWR estimation and irrigation management, and creating decision support tools to assist farmers and water managers in effective planning and resource allocation are some of the ongoing challenges in this field. The increasing need for sustainable agricultural water management and the need to provide food security in the face of escalating water shortages and climate change issues necessitate ongoing study and innovation in CWR estimate techniques.

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