Study on the Crop Irrigation Water Requirement Based on Cropwat in Jinghuiqu Irrigation Area

Qiguang Dong\textsuperscript{1,2,3,4,*}

\textsuperscript{1}Shaanxi Land Construction Group Co., Ltd., Xi'an 710075, China.
\textsuperscript{2}Shaanxi Geotechnical Engineering Institute of Land and Construction Co., Ltd., Xi'an 710075, China.
\textsuperscript{3}Key Laboratory of Degenerated and Unutilized Land Remediation, Ministry of Land and Resources, Xi'an 710075, China.
\textsuperscript{4}Shaanxi Province Land Renovation Engineering Technology Research Center, Xi'an 710075, China.

*Corresponding author e-mail: dq-guang@163.com

Abstract. According to the meteorological data of the Jinghuiqu Irrigation Area in the past 30 years, the evapotranspiration of winter wheat and corn and the effective precipitation in the growing period were calculated using FAO's CROPWAT model to obtain irrigation water requirements such as winter wheat and corn irrigation. It provides reference for the irrigation of winter wheat and corn in irrigation areas and the distribution of irrigation water.

1. Introduction
The crop water requirement refers to the sum of plant transpiration and interplant evapotranspiration at high yields under appropriate soil moisture and fertility levels during normal crop growth and development. Crop water demand is the main component of agricultural water use, and it is also the largest water-consuming part of the entire national economy. Therefore, the crop water requirement is an essential data for planning of water resources, and it is also one of the basic data required for the planning, design, management, and operation of irrigation and drainage engineering [1].

The method for calculating the crop water requirement can be generally divided into two categories: (1) Direct method

The principle of the direct method is to select several major factors (such as temperature, temperature, relative humidity, sunshine hours, solar radiation, etc.) from various factors affecting crop evapotranspiration, according to crop evapotranspiration and major impacts. Based on the measured data of the factors, empirical formulas between crop evapotranspiration and influencing factors were established through regression analysis and other methods. The direct methods mainly include: 1) The water demand coefficient method (a-value method) with water surface evaporation as the parameter, and this method is applicable to paddy fields due to the large influence of non-meteorological conditions. 2) The water demand coefficient method (K value method) with the output as the parameter, this method makes the correlation between the crop evapotranspiration and the yield, so it is convenient for the analysis of irrigation economy, because the water demand is mainly...
controlled by the meteorological conditions, and the output is The relationship between water demand is not clear, so the error of this method is larger [2-3].

(2) Indirect method

Because the size of crop evapotranspiration is influenced by the liquid diffusion rate of the evaporating surface and the turbulence of the air above it, it is also affected by factors such as the water uptake rate of the plant roots, water transport in the body, and the stomatal opening of the leaves. Therefore, the reference crop evapotranspiration can be calculated by using the meteorological factors first, and then the crop coefficient and the soil moisture correction coefficient can be used for correction to obtain a specific crop water requirement. At present, the calculation method of crop evapotranspiration more commonly used in the world is based on the indirect method of reference crop evapotranspiration. The reference crop evapotranspiration concept was first proposed by British scholar Penman in 1948 [4]. In 1977, the United Nations Food and Agriculture Organization (FAO) recommended Penman's improved formula to calculate reference crop evapotranspiration, and for the first time used the concept of crop coefficients. Since then, FAO has proposed the Penman correction formula in 1979. Although the formula is slightly less accurate, it is widely used due to its ease of use in practice. In 1993, at the workshop on calculating crop evapotranspiration in Rome, FAO experts considered that it was necessary to regulate the calculation method of crop evapotranspiration, and according to the requirements of the Penman-Monteith formula, reference crop evapotranspiration, then a new definition was made [5]. Because the Penman–Monteith formula can be calculated using general meteorological data, and its practical value and calculation accuracy are relatively high, it is widely used worldwide [6-7].

2. Crop Water Demand Calculation

2.1. Data and Model Introduction

2.1.1. Data. The data used in this paper includes Weihui Canal meteorological data, spatial data and crop parameters. The meteorological data includes meteorological data for the recent 30 years in the Huihui Canal, including: (1) the monthly mean maximum and minimum temperatures of the crop growth period; (2) monthly precipitation; (3) wind speed; (4) hours of sunshine; (5) Relative humidity; (6) Solar radiation. The spatial data is a plan of the Jinghuiqu Irrigation District in Shaanxi Province.

2.1.2. Introduction of the CROPWAT Models. The CROPWAT model was developed by the FAO Land and Water Development Division in 1992. It is designed to help agricultural meteorologists, agronomists, and irrigation engineers calculate the reference crop evapotranspiration and crop evapotranspiration. In addition, the CROPWAT model can also provide suggestions on how to improve irrigation methods, plan irrigation schedules under different irrigation conditions, and evaluate the effects of rainwater conditions or under adequate irrigation conditions on crop yield. Input parameters required for the CROPWAT model include meteorological parameters, crop parameters, and soil parameters. The meteorological parameters include: temperature, precipitation, wind speed, sunshine hours, relative humidity and so on. Crop parameters include crop sowing date, crop coefficient, root zone range, and crop water deficit sensitivity factor. Soil parameters include: soil texture, soil available water, infiltration rate, and initial water content. The basic functions of the CROPWAT model include calculations: (1) reference crop evapotranspiration; (2) crop evapotranspiration; (3) crop irrigation water requirements; (4) development of an irrigation system; (5) evaluation of the impact of rain or insufficient irrigation on yield. In addition, daily water balance analysis can be performed using the CROPWAT model.

2.2. Calculation Methods

2.2.1. Reference crop evapotranspiration. The CROPWAT model uses the Penman–Monteith formula to calculate reference crop evapotranspiration based on local meteorological data:
\[ ET_0 = \frac{0.408\Delta(R_n - G) + 900\gamma(T_a + 273) \cdot \mu(e_a - e_d)}{\Delta + \gamma(1+0.34\mu)} \] (1)

Where, \( ET_0 \) is the reference crop evapotranspiration, mm/d; \( \Delta \) is the slope of the saturated water pressure \( e_a \) and temperature curve, kPa/°C; \( R_n \) is the reference crop canopy surface net radiation, MJ/(m²/d); \( \gamma \) is constant for dry and wet tables , kPa / °C; \( G \) is for soil heat flux, MJ/(m²/d); \( T_a \) is daily average temperature at 2m height, °C; \( \mu \) is wind speed at 2m height, m/s; \( e_a \) is saturation vapour pressure, kPa; \( e_d \) is vapor pressure, kPa.

2.2.2. Crop Evapotranspiration. The model obtains crop evapotranspiration by reference to crop evapotranspiration and crop coefficient at different stages [8]:

\[ ET_c = K_c \times ET_0 \] (2)

Where, \( ET_c \) is the crop evapotranspiration, mm; \( K_c \) is crop coefficient; \( ET_0 \) is referable crop evapotranspiration, mm.

According to the crop attributes database of the CROPWAT model, the early, middle, and late growth periods of winter wheat and maize were 0.7, 1.15, 0.25, and 0.30, 1.20, and 0.50, respectively. Crop growth parameters are set as follows:

| Table 1. Crop growth parameters of Growth Period |
|-----------------------------------------------|
| Crop Name          | parameters | Stage                                           |               |
|                   |            | initial | development | mid-season | late-season |
| MAIZE (Corn)       | Stage(days) | 20      | 35          | 40         | 30          |
|                    | Kc         | 0.30    | -           | 1.20       | 0.35        |
|                    | Rooting depth(m) | 0.3   | -           | -          | 1.0         |
|                    | Critical depletion | 0.55 | -           | 0.55       | 0.80        |
|                    | Yield response | 0.4   | 0.4         | 1.3        | 0.5         |
|                    | Croheight(m) | -      | -           | 2          | -           |
| Winter Wheat       | Stage(days) | 30      | 140         | 40         | 30          |
|                    | Kc         | 0.70    | -           | 1.15       | 0.25        |
|                    | Rooting depth(m) | 0.3   | -           | 1.5        | -           |
|                    | Critical depletion | 0.55 | -           | 0.55       | 0.90        |
|                    | Yield response | 0.2   | 0.6         | 0.5        | 0.4         |
|                    | Croheight(m) | -      | -           | 1          | -           |

2.2.3. Effective precipitation. The model uses the method provided by the United States Department of Agriculture (USDA) to calculate effective precipitation:

\[ P_e = \begin{cases} 
  \frac{P(125 - 0.2P)}{125} & (P \leq 250 \text{mm}) \\
  125 + 0.1P & (P > 250 \text{mm}) 
\end{cases} \] (3)

Where, \( P_e \) is the monthly average effective precipitation, mm; \( P \) is the average monthly precipitation, mm.

2.2.4. Irrigation Water Requirements. Because Jinghuiqiu Irrigation is located in the northwestern arid region, the annual precipitation is less and the groundwater level is lower. Therefore, when calculating the irrigation water demand of winter wheat and corn, the amount of groundwater recharge and the depth of soil leakage are ignored. The model calculates the irrigation water requirement of corn and
winter wheat based on the crop evapotranspiration and the effective precipitation during the growth period:

\[ I = ET_c - P_e \]  

(4)

Where, \( I \) is Irrigation water requirement, mm; \( P_e \) is effective rainfall of crop growth period, mm.

3. **Calculation results**

The above formula was used to calculate the evapotranspiration of corn and winter wheat at each stage of its growth. See Figure 3 and Figure 4. As can be seen from Figure 3, the peak evapotranspiration of corn in the Jinghuiqu Irrigation District appears from mid-July to late August, and the peak appears in late July. The water requirement is 68mm. The water requirement for the entire growth period is 517.8 mm. From Figure 4 it can be seen that the highest peak of the evapotranspiration of winter wheat occurs from mid-April to mid-May, ie heading-maturity stage, the peak appears in mid-April, the water requirement is 53 mm, and the water storage capacity is 552.9 mm throughout the growth period. According to Equation (4), the irrigated crop water requirement at different rainfall frequency years is calculated. The results are shown in Table 2.

![Crop evapotranspiration](image)

**Figure 1.** Evapotranspiration during corn growth
Figure 2. Evapotranspiration during wheat growth

Table 2. Irrigation water requirement of major crops in different hydrological years (mm)

| Months    | 50% flat water year | 75% drought year |
|-----------|----------------------|-------------------|
|           | Wheat                | MAIZE             | Wheat            | MAIZE            |
| January   | 20.4 -               | -                 | 21 -             | -                |
| February  | 51.8 -               | -                 | 52.9 -           | -                |
| March     | 99.2 -               | -                 | 101.8 -          | -                |
| April     | 143.9 -              | -                 | 148.1 -          | -                |
| May       | 48.8 2.5             | -                 | 54.2 3           | -                |
| June      | - 19.9              | -                 | - 25.4           | -                |
| July      | - 109.4             | -                 | - 117.3          | -                |
| August    | - 124.4             | -                 | - 132.2          | -                |
| September | - 8.1               | -                 | - 16.3           | -                |
| October   | 19.1 -               | -                 | 24.5 -           | -                |
| November  | 20.7 -               | -                 | 23.5 -           | -                |
| December  | 16.2 -               | -                 | 16.9 -           | -                |
| Total     | 420.1 264.3          | 442.9 294.2       |                  |                  |

4. Conclusion
The CROPWAT model was used to analyze the effective precipitation and evapotranspiration of maize and winter wheat in Qihui Canal Irrigation Area, and the evapotranspiration of maize and winter wheat during the growth period was obtained. Through the calculation, the water demand process of various crops in the Huihuiqu Irrigation District can also be obtained. Combined with the calculation of the precipitation, the irrigation demand process can be analyzed.

In addition, according to the cropwat model calculation, the impact of different irrigation systems on crop yield can be further studied, providing a theoretical basis for in-depth analysis of the health allocation of water resources in the Huihui Canal irrigation area.

References
[1] Mehta R, Pandey V. Crop water requirement (ETc) of different crops of middle Gujarat [J].
Journal of Agrometeorology, 2016, 18 (1):83-87.

[2] Ren J, Shi H B, He ping L I, et al. Study on Water Dynamics of GSPAC System over Maowusu Sandland in Etuoke Banner [J]. Journal of Irrigation & Drainage, 2006, 25(3):21-24.

[3] Li Y. High-Efficiency Water Use in Irrigation District [J]. China Rural Water & Hydropower, 2003(08):19-22.

[4] Cao J F, Yu-Zhong L I, Liu X Y, et al. Comparison of Four Combination Methods for Reference Crop Evapotranspiration [J]. Chinese Journal of Agrometeorology, 2015, 36 (04):428-436.

[5] Djaman K, Irmak S, Kabenge I, et al. Evaluation of FAO-56 Penman-Monteith model with limited data and the Valiantzas models for estimating grass-reference evapotranspiration in the Sahelian conditions [J]. Journal of Irrigation & Drainage Engineering, 2016, 142 (11).

[6] Luo J, Chen D, Guo Y. A Study of Application of The Theory and The Model of comprehensive Evaluation in Water Saving Irrigation [J]. Water Saving Irrigation, 1998, (05):1-5+41.

[7] Sun J, Chen Y, Kang S, et al. Numerical Modelling of Coupled Movement of Moisture and Heat for Summer Corn Field[J]. Irrigation & Drainage, 1995, (03):24-29.

[8] Smith M, Kivumbi D, Heng L.K. Use of the FAO CROPWAT model in deficit irrigation studies [J]. Deficit Irrigation Practices, 2002, (2):17-27.