Journal of AgriSearch, 10 (2): 94-98
An Open Access International Peer Reviewed Quarterly

ISSN : 2348-8808 (Print), 2348-8867 (Online)
https://doi.org/10.21921/jas.v10i02.12721

Estimating Irrigation Scheduling for Field Pea (*Pisum Sativum L.*) using the CROPWAT 8.0 Model in the Temperate Region of Kashmir

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ABSTRACT

Irrigation scheduling involves determining the appropriate timing and quantity of water to apply. In this study, CROPWAT 8.0 model was employed as a decision-making tool for irrigation scheduling. The objective was to estimate the water requirement, irrigation demand, and optimal timing of irrigation for field Pea cultivation. Inputs for the CROPWAT 8.0 model, like soil characteristics, climate conditions, crop information, and rainfall data were collected. The analysis revealed, the lowest daily crop water requirement was 0.39 mm, occurring during the second decade of December, while the highest requirement of 3.60 mm was observed during the second decade of May. The total water requirement for field Pea cultivation was estimated to be 269.8 mm, while the irrigation demand amounted to 253.7 mm. Based on these findings, which was suitable for the specific agro-ecological conditions. Ideally, it is advisable to adjust the irrigation interval based on the crop's growth stage, ensuring that soil moisture stress does not become a limiting factor in achieving maximum yield. By considering input-output parameters, this approach can help avoid over- or under-irrigation. In summary, the estimation of irrigation scheduling using the CROPWAT 8.0 model provides a valuable and efficient means of generating information for users, enabling them to make informed decisions promptly.

Keywords: CROPWAT 8.0, Irrigation scheduling, Pea, Kashmir

ARTICLE INFO

Received on	:	01.05.2023
Accepted on	:	21.06.2023
Published online	:	30.06.2023

INTRODUCTION

Water scarcity has emerged as a global challenge, significantly affecting agricultural production (Eck *et al.,* 2020). Recent reports (Anonymous, 2023) indicate that irrigation covers over 20% of cultivated lands worldwide and contributes to more than 40% of total global food production. However, agricultural irrigation consumes the highest volume of water while yielding the lowest return per unit of water compared to other economic sectors. Traditional irrigation methods, such as flood irrigation, exhibit lower water productivity (WP). To address this issue, various irrigation techniques have been developed worldwide, including furrow and drip irrigation (Zhang *et al.,* 2021). Furrow irrigation, a refined form of surface irrigation (SI), incorporates ridge tillage to facilitate root development and water infiltration, reducing deep percolation and enhancing WP (Kang *et al.,* 2000). Additionally, drip irrigation (DI) has experienced rapid advancement in recent decades. DI offers distinct advantages over conventional irrigation, such as reduced water usage, controlled salt levels, minimized evaporation, and precise water application, thus playing a pivotal role in global agricultural production (Wang *et al.,* 2011). Deficit irrigation, another water management strategy, allows for the irrigation of larger agricultural areas despite limited water resources. This technique leverages the fact that crops respond differently to water stress at various growth stages, enabling efficient irrigation scheduling with minimal impact on yield. The timing and extent of water stress applied to plants are crucial considerations when implementing deficit irrigation (Yang *et al.*, 2017). Insufficient irrigation prompts crop roots to grow deeper, accessing soil water and resulting in substantial water conservation without compromising yield. This approach improves WP and enhances net farm income (Chai *et al.*, 2016).

Pea (*Pisum sativum L.*) is an important vegetable crop grown throughout in the world. In India, it is mainly grown as winter vegetable in the plains of North India and as summer vegetable in the hills. In Kashmir valley pea is mainly grown as Rabi crop, however, in high altitudes it is grown as an offseason vegetable during summer. Pea production in Jammu and Kashmir was reported as 58.081 Tons from Mar 2012 to 2017 by Agriculture Production & Farmers Welfare Department (Anonymous, 2020). Peas are grown at higher altitudes in tropics with temperature from 7 to 30°C. As a winter crop pea is able to withstand relatively low temperature especially during the early stages of growth but may not withstand a severe continued frost. However, growers express concerns about the long-term production and yield of crops under water-stressed conditions (Pequeno *et al.*, 2021). Pea farmers, in particular, are currently grappling with challenges such as water scarcity and unpredictable

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water delivery schedules (Khuhro *et al.,* 2018). Adequate soil moisture is essential for normal growth and development of Pea at all stages, necessitating precise irrigation scheduling to minimize overwatering (Meena *et al.,* 2018). Excessive water usage can lead to waterlogging and nutrient leaching beyond the root zone. To enhance water productivity (WP), it is crucial to implement appropriate irrigation practices, as excessive flooding can reduce both WP and crop yield (Qiu *et al.,* 2008). Hence, it is of utmost importance to prioritize the development of water-saving agricultural methods that effectively lower the usage of irrigation water, while simultaneously enhancing water productivity (WP) in order to attain sustainable agricultural progress (Gao *et al.,* 2017; Memon *et al.,* 2021). Furthermore, the use of mathematical models by decision-makers to manage irrigation water and forecast production under different conditions has proven to be time-saving. These models serve as valuable tools for scientifically documenting irrigation scheduling, aiming to reduce water consumption and facilitate the expansion of agriculture by effectively utilizing limited water resources.

The use of CROPWAT as a tool for determining irrigation regimes is widely recognized as one of the most popular approaches to evaluating irrigation performance and water productivity (WP) in irrigated regions. CROPWAT is a software application for irrigation management and planning, developed by a team of experts (Smith, 1993). The calculations performed by the CROPWAT model are based on established guidelines for determining crop water requirements (Allen, 1998) and the relationship between yield and water requirements (Doorenbos & Kassam, 1979). The CROPWAT model offers a valuable means of calculating irrigation water requirements by considering crop parameters and conducting a daily soil moisture balance at the maximum root depth (Jeet *et al.*, 2016). This information can be utilized to estimate evapotranspiration and develop irrigation schedules for different crops, accounting for various environmental conditions and considering different water sources and irrigation management practices (Tsakmakis *et al.,* 2018). The aim was to estimate crop water requirement of Pea, irrigation requirement and time of irrigation or irrigation interval using CROPWAT 8.0 model.

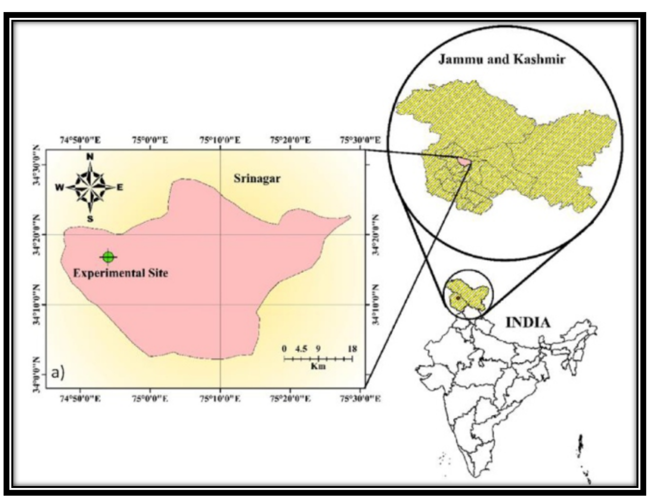

Fig. 1: Location map of the Study Area

MATERIALS AND METHODS

Study area

The experiment was conducted at the experimental fields of SKUAST-K, Shalimar, Srinagar UT of Jammu & Kashmir, India. SKUAST-K is located at 34.01° N latitude and 74.5° E longitude at an elevation of 1586 m mean sea level. The climate of the field site is of temperate type. The location map of the study area is shown in Fig. 1.

Data used

The meteorological data for the cropping season were collected from the meteorological observatory within the Division of Agronomy at SKUAST-K, Shalimar.

Climate data

Daily weather data like rainfall, air temperature (maximum and minimum), wind speed, relative humidity (RH), wind speed at two meter height (U2) and Sunshine hours were collected for crop duration from meteorological observatory.

Soil characteristics

The physical and chemical properties of the soil during experiment were analysed using standard procedures. The soil data like, texture, field capacity (FC), permanent wilting point (PWP), bulk density, water holding capacity were used to calculate irrigation scheduling.

Crop data

The variety of peas was Arkel which were sown on 20th November 2020 at an area of 84 m^2 areas at a spacing of 30 cm × 10 cm. Crop data like sowing date, harvesting time, growing day, growth stages, rooting depth, yield response factor and crop height were needed to calculate crop water requirement and irrigation scheduling.

MATERIALS AND METHODS

Description of CROPWAT 8.0 model

CROPWAT 8.0 is a computer program developed by the Food and Agricultural Organization (FAO) that serves as a decision-support tool. It is based on a set of equations and designed to calculate various parameters including reference evapotranspiration (ET_0), crop water requirement (CWR), irrigation scheduling, and irrigation water requirement (IWR). These calculations are performed using data related to rainfall, soil characteristics, crop information, and climate conditions (FAO, 2015). The program encompasses comprehensive data on crop characteristics, local climate conditions, and soil properties. By utilizing this information, CROPWAT 8.0 assists in improving irrigation schedules and facilitating the computation of water supply schemes for different crop patterns, both under irrigated and rain-fed conditions. It serves as a valuable tool for optimizing water management in agriculture, supporting decision-making processes for irrigation planning and enhancing overall water-use efficiency.

Effective rainfall

The rainfall considered by CROPWAT 8.0 is the effective rainfall, which takes into account the losses due to surface runoff and deep percolation. This effective rainfall is the portion of rainfall that is actually utilized by the crop, as it accounts for the water lost through surface runoff and the water that percolates deep into the soil beyond the reach of the crop's roots. By considering these losses, CROPWAT 8.0 provides a more accurate estimation of the rainfall available for crop water requirements and irrigation scheduling. For the determination of effective rainfall, a fixed percentage method was used.

Determination of reference evapotranspiration

The CROPWAT 8.0 model was utilized to calculate evapotranspiration, which serves as a measure of the atmosphere's evaporative demand. Reference evapotranspiration (ET_0) was estimated using the FAO Penman-Monteith equation (Allen et al., 1998) through the ET_0 calculator program included in the CROPWAT 8.0 software (FAO, 2015). Monthly meteorological data, including the geographical location of the study area, were collected.

Monthly ET_0 values were computed using the CROPWAT 8.0 for Windows software. Subsequently, the obtained monthly long-term ET_0 data from the CROPWAT 8.0 model was fitted to various standard frequency distribution models using a computer-based routine package. The distribution that provided the best fit to the data was selected by applying the chi-square statistical test of goodness-of-fit. This selected distribution was then used to determine the occurrence of monthly ET_0 values at an 80% probability level. The calculation of ET_0 was performed using equation (1) from the CROPWAT 8.0 model. ET_0 was calculated as equation (1) from CROPWAT 8.0 model.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,U_2)} \quad (1)$$

Where,

R_n = the net radiation at the crop surface ($MJm^{-2}day^{-1}$)

G = soil heat flux density ($MJm^{-2}day^{-1}$)

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

u_2 = wind speed at 2 m height (ms^{-1})

e_s = saturation vapour pressure (kPa)

$(e_s - e_a)$ = saturation vapour pressure deficit (kPa)

Δe = slope vapour pressure curve (kPa°C^{-1})

γ = psychometric constant (kPa°C^{-1}).

Crop coefficient (Kc)

The crop coefficient (Kc) is a measurement that represents the ratio of the actual evapotranspiration of a healthy crop cultivated in a well-watered and disease-free large field to the reference evapotranspiration as shown in equation 2.

$$K_c = \frac{ETc}{ETo} \quad (2)$$

Where,

ETc is crop evapotranspiration,

ET_0 is reference evapotranspiration

The crop coefficient (Kc) value was obtained from the literature. The Kc varies depending on the specific crop, the stage of development of the crop, and to some extent, factors such as wind speed and relative humidity. Typically, for most crops, the Kc value starts at a low level during crop emergence and gradually increases as the crop progresses towards full development, with the maximum value usually occurring during the period of flower initiation. As the crop matures, the Kc value then begins to decline. This pattern of variation in the Kc value reflects the changing water requirements of the crop throughout its growth stages and is essential for accurate irrigation scheduling and water management practices.

Determination of crop water requirement and irrigation requirement

CROPWAT 8.0 calculates the crop water requirement by inputting the computed monthly reference evapotranspiration (ET_0) values along with the necessary crop and soil data. The monthly rainfall data plays a crucial role in determining the irrigation requirement. The combination of monthly rainfall data, ET_0 values, crop type, cropping calendar, and the required soil characteristics is utilized to compute the irrigation requirement for the selected crops. Crop evapotranspiration (ET_c) is calculated by equation (3).

$$ET_c = K_c * ET_o \quad (3)$$

Irrigation scheduling

Irrigation scheduling was conducted using CROPWAT 8.0 for Windows by employing two specific criteria for scheduling. The first criterion involved fixing the irrigation interval and adjusting the irrigation depth to a constant value that ensures no yield reduction and minimizes water loss. The second criterion utilized the concept of 100% readily available soil moisture depletion, indicating that irrigation should be applied when the soil moisture level reaches its maximum depletion point. These scheduling criteria were selected to optimize water usage, minimize yield loss, and prevent excessive water loss. By utilizing, CROPWAT 8.0, the irrigation scheduling process was effectively guided, ensuring efficient water management and maximizing crop productivity.

RESULTS AND DISCUSSION

Reference evapotranspiration and effective rainfall

The reference evapotranspiration (ET_0) exhibited its highest value of 3.60 mm/day in the months of May, while the lowest value of 0.39 mm/day was recorded in December (Fig. 2). It is important to note that ET_0 and crop water requirement share a direct relationship, meaning that as ET_0 increases, the water requirement of the crop also increases, and vice versa. The maximum effective rainfall was observed in January, amounting to 20 mm, while the minimum effective rainfall of 1 mm was recorded in November. These variations in ET_0 and effective rainfall throughout the year have implications for irrigation scheduling and water management practices in relation to the water needs of the crop.

Fig. 2: Reference evapotranspiration and effective rainfall

Crop water and irrigation requirements

Increasing effective rainfall results in a reduction in the amount of irrigation water required. This is because the moisture available in the soil due to effective rainfall supports a portion of the crop's water requirement. Consequently, the efficient use of water is promoted, leading to savings in irrigation water applied to the soil. In this study, the determination of water requirement relied on the use of the crop coefficient (K_c). The K_c values specific to the crop stages were obtained from FAO Irrigation and Drainage Paper-33 and adapted to the study area by creating a slope graph in Microsoft Excel, allowing for customized values. As presented in Table 1, the lowest daily crop water requirement was 0.39 mm, occurring during the second decade of December, while the highest requirement of 3.60 mm was observed during the second decade of May. Throughout the growing seasons, the water requirement for Pea cultivation was estimated to be 269.8 mm, while the irrigation requirement amounted to 253.7 mm (Table 1).

Table 1: Kc, Crop water requirement and Irrigation requirement of Pea

ETo station: SKUAST-K, SHALIMAR Crop: Field Pea
Rain station: SKUAS-K, Shalimar Planting date: 18/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.50	0.47	1.4	0.0	1.4
Nov	3	Init	0.50	0.44	4.4	0.1	4.4
Dec	1	Init	0.50	0.43	4.3	0.1	4.3
Dec	2	Init	0.50	0.39	3.9	0.1	3.8
Dec	3	Deve	0.56	0.40	4.4	0.6	3.8
Jan	1	Deve	0.70	0.46	4.6	1.4	3.2
Jan	2	Deve	0.83	0.51	5.1	2.0	3.1
Jan	3	Deve	0.98	0.76	8.4	1.4	7.0
Feb	1	Mid	1.10	1.04	10.4	0.5	9.9
Feb	2	Mid	1.11	1.25	12.5	0.0	12.5
Feb	3	Mid	1.11	1.47	11.8	0.5	11.3
Mar	1	Mid	1.11	1.70	17.0	1.2	15.8
Mar	2	Mid	1.11	1.92	19.2	1.6	17.6
Mar	3	Mid	1.11	2.21	24.3	1.6	22.7
Apr	1	Mid	1.11	2.49	24.9	1.5	23.5
Apr	2	Late	1.11	2.78	27.8	1.4	26.3
Apr	3	Late	1.10	3.06	30.6	1.1	29.4
May	1	Late	1.09	3.33	33.3	0.8	32.4
May	2	Late	1.08	3.60	21.6	0.3	21.3
					269.8	16.1	253.7

Table 2: Irrigation scheduling of Pea

ETo station: SKUAST-K, SHALIMAR Crop: Field Pea Planting date: 18/11 Yield red.
Rain station: SKUAS-K, Shalimar Soil: Sandy loam Harvest date: 16/05 0.0 %

Table format
Irrigation schedule
Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
16 Feb	91	Mid	0.0	1.00	100	40	48.3	0.0	0.0	69.0	0.09
20 Mar	123	Mid	0.0	1.00	100	41	49.6	0.0	0.0	70.8	0.26
11 Apr	145	Mid	0.0	1.00	100	41	48.9	0.0	0.0	69.9	0.37
29 Apr	163	End	0.0	1.00	100	42	49.9	0.0	0.0	71.3	0.46
14 May	178	End	0.0	1.00	100	41	49.6	0.0	0.0	70.9	0.55
16 May	End	End	0.0	1.00	0	3					

Totals

Total gross irrigation	351.9	mm	Total rainfall	16.2	mm
Total net irrigation	246.4	mm	Effective rainfall	16.2	mm
Total irrigation losses	0.0	mm	Total rain loss	0.0	mm
Actual water use by crop	266.2	mm	Moist deficit at harvest	3.6	mm
Potential water use by crop	266.2	mm	Actual irrigation requirement	250.0	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	100.0	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.20	0.60	0.50	0.40	1.70	
Yield reduction	0.0	0.0	0.0	0.0		%
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0	%

Irrigation scheduling

The irrigation interval was varying depending on the growth stage of pea. According to the growth stage, the interval of irrigation for, mid-season and late season stages were 20 days, and 15 days, respectively and for initial stage no irrigation was required since crop was sown in winter season, temperature was very low. As shown in (Table 2), the total net irrigation and total gross irrigation requirements were 246.4 mm and 351.9 mm, respectively. As much as possible, it is better to use the irrigation interval depending on the growth stage of the crop in which soil moisture stress could not be a limiting factor to obtain maximum yield with considering input-outputs along with the prevailing climatic conditions.

CONCLUSIONS

The CROPWAT 8.0 model relies on climate, rainfall, soil, and

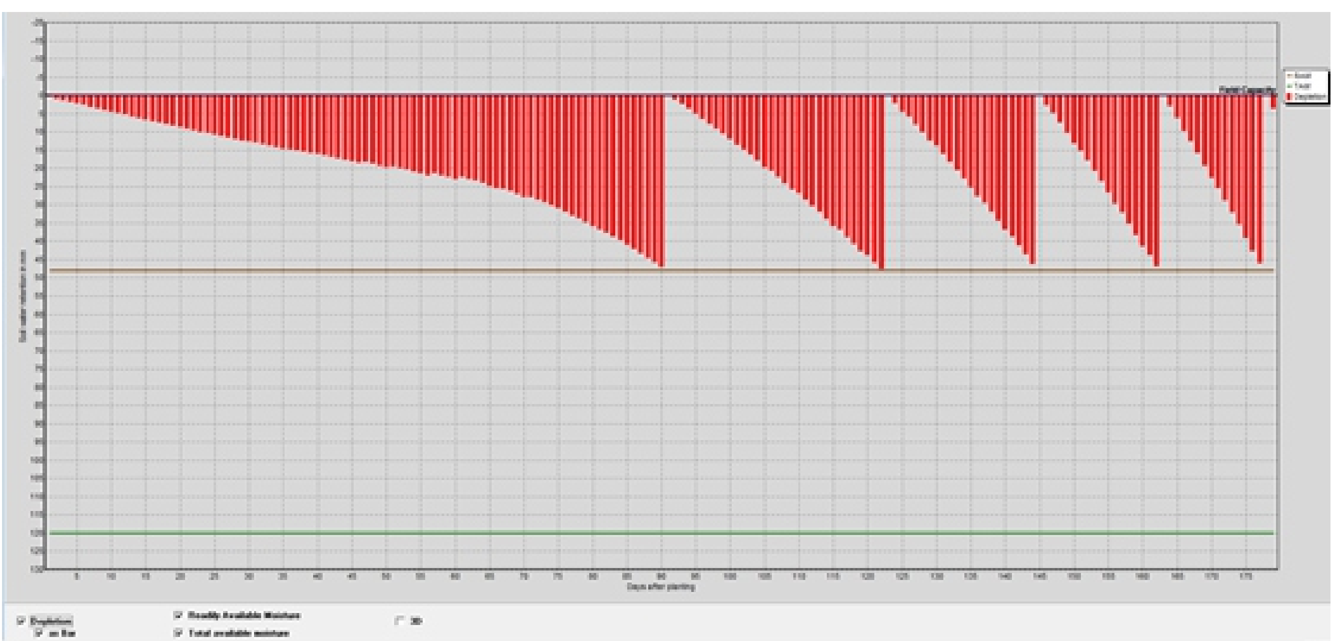

Fig. 3: Irrigation scheduling graph of Pea

crop data to create schedules for irrigation. In the case of the pea crop, the growing season required 269.8 mm of water for the crop, with an irrigation requirement of 253.7 mm. The total net irrigation needed was 246.4 mm, while the total gross irrigation requirement was also 351.9 mm as during that period the crop was under frost conditions of winter and temperature was below zero. To achieve maximum yield and minimize soil moisture stress, it is advisable to adjust the irrigation interval according to the crop's growth stage. This ensures that water availability is optimized and doesn't limit yield potential. Considering the input data and outputs, the CROPWAT 8.0 model's estimation of irrigation scheduling becomes crucial in generating timely information for users.

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Citation:

Pandey Y.2023. Estimating Irrigation Scheduling for Field Pea (*Pisum Sativum L.*) using the CROPWAT 8.0 Model in the Temperate Region of Kashmir. *Journal of AgriSearch* **10**(2):94-98