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Short communication

Optimizing irrigation water requirements of drip-irrigated spring/summer vegetable crops in Jalandhar

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Climate change is expected to considerably limit cropping intensity by reducing the availability of water resources and disrupting the agricultural water cycle (Sharma *et al.,* 2021). As temperatures rise and precipitation patterns become more erratic, the scarcity of fresh water for irrigation will constrain the number of crops that can be grown on the same land, potentially leading to decreased agricultural productivity (Mansa and Anand, 2016). Certain popular vegetable crops, such as spring onion, radish, and okra, are typically grown during the spring/summer season, between the *Rabi* and *Kharif* cropping cycles, with a short growing period from January to May. These crops offer a valuable opportunity for farmers to generate additional income during this interval. However, elevated temperatures and high evaporation rates during the mid-growth stage necessitate frequent irrigation to ensure optimal crop development. In Punjab, irrigation water availability is a key limiting factor for the productivity of spring season crops. Therefore, the implementation of modern irrigation scheduling methods is essential for enhancing crop performance (Mehta and Pandey, 2016; Satpute *et al.,* 2021; Saxena *et al.,* 2020). Despite this, the absence of comprehensive data on the irrigation needs of these drip-irrigated vegetable crops in Punjab has limited farmers' ability to cultivate them in water-scarce regions of the state. Drip and sprinkler irrigation are widely adopted techniques that promote the sustainable utilization of water resources (Sharma *et al.,* 2023). Effective irrigation management is essential, as over-irrigation can result in reduced yields, while under-irrigation can lead to water stress, negatively impacting plant growth and overall productivity. Currently, many farmers employ the water balance method for drip irrigation, irrigating when soil moisture depletes to 50% of field capacity (Sharma *et al.,* 2021). Although this method offers general guidance, it lacks the specificity required to meet precise crop water needs. In contrast, a climatological approach to irrigation scheduling presents a more tailored solution, especially in the context of climate change (Satpute *et al.,* 2021). This method estimates daily irrigation requirements by analyzing water loss from both soil and plant canopy, relying on evapotranspiration data to accurately calculate water needs (Saxena *et al.,* 2020). Reference evapotranspiration accounts for both soil evaporation and plant transpiration, with the FAO-Penman-Monteith method providing a standardized framework for consistent evapotranspiration estimates. Standardizing stage-specific irrigation scheduling for spring/summer vegetable crops as is crucial for enhancing water efficiency, maximizing yields, and promoting sustainable farming. Vegetable crops are highly sensitive to water availability, and aligning irrigation with their distinct growth stages helps prevent over- or under-irrigation, ensuring optimal plant health. During the warmer spring and summer months, increased evapotranspiration rates drive higher water demands. A tailored irrigation schedule ensures that crops receive water precisely when needed, especially during critical stages like germination, flowering, and fruiting. This reduces water stress and enhances resilience, leading to improved yields and healthier crops. Therefore, this study aims to estimate the stage-wise irrigation water requirements for selected crops under the climatic conditions of Jalandhar, Punjab.

The present study was conducted under the prevailing climatic conditions of Jalandhar, Punjab, with the objective of developing growth-stage-specific irrigation schedules for various spring-season vegetable crops, including spring onion, radish, and okra. Using a climatological approach within an irrigation scheduling model, the irrigation water requirements for drip-irrigated crops were determined to optimize irrigation events. The study area, situated at 31.25°N latitude, 75.70°E longitude, and at an elevation of 280 meters above sea level, experiences a humid subtropical climate, characterized by an average annual temperature of 23.1°C and 957 mm of precipitation. The soil in the region is predominantly silty loam with a uniform topography. Irrigation schedules for the selected crops, spring onion (Growing period: 10

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Table 1: Average daily weather parameters during different months in selected study area (Pooled data of 2023 & 2024).

Months	Maximum temperature (^{0}C)	Minimum temperature (^{0}C)	Maximum RH (%)	Minimum RH (%)	Wind speed (km hr^{-1})	Sunshine hours (Hour)
Feb	24.3	9.9	88.3	40.8	3.5	7.7
March	26.7	13.6	83.4	48.6	3.7	6.3
April	33.4	18.1	67.8	28.4	3.9	9.2
May	34.2	20.2	59.2	29.4	5.9	9.3

Table 2: Growth stage wise crop duration, crop coefficient, daily average crop evapotranspiration (ETc) and irrigation water requirement (IWR) of selected vegetable crops (Mean of two years 2023 & 2024).

Crops and variables	Growth stages			
	Initial	Development	Mid	Late
Spring Onion				
Duration (days)	25	30	10	5
Crop coefficient (Kc)	0.7	0.7 to 1	1	0.9
ETc (mmday^{-1})	2.8	4.8	7.3	6.6
IWR (l plant^{-1}day^{-1})	0.028	0.040	0.074	0.066
Radish				
Duration (days)	10	10	15	5
Crop coefficient (Kc)	0.7	0.7 to 0.9	0.9	0.85
ETc (mmday^{-1})	2.69	3.13	4.02	2.95
IWR (l plant^{-1}day^{-1})	0.193	0.225	0.289	0.212
Okra				
Duration (days)	20	20	40	10
Crop coefficient (Kc)	0.4	0.7 to 1.2	1.2	0.6
ETc (mmday^{-1})	1.63	3.68	8.15	5.77
IWR (l plant^{-1}day^{-1})	0.110	0.248	0.550	0.389

Feb. to 20 April, Spacing: 15 × 7.5 cm), radish (Growing period: 10 Feb. to 20 March, Spacing: 40 × 20 cm) and okra (Growing period: 10 Feb. to 10 May, Spacing: 50 × 15 cm)grown during February to May, were developed based on two years (2023 and 2024) of daily meteorological data, including maximum and minimum temperatures, relative humidity (RH), wind speed, and sunshine hours. This data was acquired for Jalandhar station, from the, regional KVK of Punjab Agricultural University, Ludhiana (Table 1).

The stage-specific irrigation water requirement (IWR) is primarily a function of the evapotranspiration rate, crop coefficient, and the area occupied by the plants. The reference evapotranspiration (ET_o) was calculated using the modified Penman-Monteith method as proposed by Allen *et al.,* (1998). The water demand or the volume of water required for the selected crop at various growth stages was determined using the following equation.

$$IWR = ETo \times A \times Kc \times Wp$$

Where, IWR = Irrigation water requirement of crop (liter day^{-1} plant^{-1}), ETo = Reference evapotranspiration (mm day^{-1}), A = Area of the crop (m^2) = row to row (m) × plant to plant spacing (m), Kc = Crop coefficient; Wp = Percentage wetted area, decimal.

The duration of crops, crop coefficients (Kc), crop evapotranspiration (ETc) and irrigation water requirement (IWR) during different stages of onion, radish and okra crops are presented in Table 2. The daily average crop evapotranspiration (ETc) and irrigation water requirement (IWR) for onion across various growth stages range from 2.8 to 7.3 mm day^{-1} and 0.028 to 0.074 l plant^{-1}day^{-1}, respectively. Based on pooled data from both years, the highest daily IWR for onion was recorded at the mid-growth stage at 0.074 lplant^{-1}day^{-1}, while the lowest was observed during the initial growth stage at 0.028 l plant^{-1}day^{-1}. These findings align with similar results reported by Saxena *et al.,* (2020) and Sharma and Yadav (2021), who documented variation in ETc across different growth stages of field crops. For radish, the daily average ETc and IWR across different growth stages range from 2.69 to 4.02 mm day^{-1} and 0.193 to 0.289 l plant^{-1}day^{-1}, respectively. The pooled data over two years shows that the highest daily IWR for radish was observed at the mid-growth stage, reaching 0.289 l plant^{-1}day^{-1}, while the lowest was recorded during the initial growth stage at 0.193 l plant^{-1}day^{-1}. The daily average ETc and IWR for okra across different growth stages range from 1.63 to 8.15 mmday^{-1} and 0.110 to 0.550 l plant^{-1}day^{-1}, respectively. Based on the pooled data from both years, the highest daily IWR was recorded at the mid-growth stage, reaching 0.550 l plant^{-1}day^{-1}, while the lowest IWR was observed during the initial growth stage, at 0.110 l plant^{-1}day^{-1}. The study demonstrated that crop evapotranspiration (ETc) exhibits considerable variation across different growth stages, with peak values observed during the mid-growth phase, coinciding with the period of rapid crop development and heightened transpiration rates. The similar variation in ETc was noted by Sharma *et al.,* (2021) for okra crop.

The variation in crop evapotranspiration (ETc) for onion, radish, and okra in the study area is influenced by multiple factors, mainly environmental conditions and crop-specific traits. Factors such as growth stage and canopy coverage are key determinants of ETc, with each crop exhibiting different water requirements based on its developmental phase. Okra, for example, has a larger leaf area compared to onion and radish, which leads to higher transpiration and increased ETc. Climatic variability, including changes in temperature, solar radiation, wind speed, and humidity, also plays a significant role in driving ETc fluctuations. Additionally, cultural practices, such as plant spacing and the type of irrigation method employed, significantly influence daily irrigation water requirements. These practices, in conjunction with climatic, physiological, and agronomic factors, contribute to the observed variability in ETc and, ultimately, the irrigation water needs throughout the growing period of the selected crops. These temporal variations in daily water losses highlight the need for modern irrigation scheduling approaches, particularly those based on real-time water requirements, to optimize the use of available freshwater resources in the study area. Okra, in particular, displayed a greater water demand compared to onion and radish, which can be attributed to its larger leaf surface area and extended growing period. The fluctuating irrigation depth at different growth stages of all selected drip-irrigated crops is primarily influenced by the evolving physiological demands of the plant throughout its growth cycle. Early growth stages (such as initial and development) of all selected vegetable crops, demands relatively less water as compared to later growth stages (like mid and late). Mid growth stage of require increased moisture to support vigorous growth and reproductive processes. As the root system develops and expands, the plant's ability to withdraw water from deeper soil layers improves, necessitating higher irrigation volumes to meet escalating water demands, especially during those critical reproductive stages where water stress can severely impact yield and quality. Consequently, crop & region-specific irrigation management practices tailored to the specific needs of water during each growth stage are essential to optimize irrigation water use efficiency as well as to ensure sustainable vegetable production during spring or summer season in water scare regions

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