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RESEARCH ARTICLE

Estimation of crop coefficient for radish using digital lysimeter under polyhouse

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Abstract

Accurate quantification of crop water requirements of any crop is essential for irrigation scheduling and water management. The objective of this study was to estimate the crop coefficient of radish for different phenological stages under protected cultivation using digital lysimeter. The experiment was carried in the Agricultural Engineering College and Research Institute, Kumulur, Trichy. The experiment layout has been made to accommodate the three treatments (T_1 - 120 % of ETc, T_2 - 100 % of ETc and T_3- 80 % of ETc) and four replications in drip irrigated polyhouse. The actual crop evapotranspiration (mm day^{-1}) measured from digital lysimeter and ETo is the reference evapotranspiration (mm day^{-1}) measured from Hargreaves model. The crop coefficient value of radish grown under protected cultivation during initial stage (Kc_{in}), development stage (Kc_{dev}), mid-stage (Kc_{mid}) and final stage (Kc_{fin}) for T_1 was 0.72, 0.99, 1.01 and 0.81, T_2 was 0.58, 0.84, 0.85 and 0.63 and T_3 was 0.43, 0.61, 0.62 and 0.48 respectively. The study demonstrated that supplying additional water had no significant effect in radish yield under polyhouse. The crop coefficient (Kc) value obtained for treatment 100 % of ETc is suggested for optimal use of irrigation water for cultivating of radish crop in naturally ventilated greenhouse.

Keywords: crop coefficient; digital lysimeter; protected cultivation; radish

Introduction

Radish (*Raphanus sativus* L.), a herbaceous plant belonging to Brassicaceae family, is a small vegetable in which the root is the comestible part. This plant is characterized as being very sensitive to variations in soil moisture and in a situation of minimal scarcity or excess water, presents physiological disturbances that interfere with its productivity and commercial root diameter, especially due to cracks that results in tubercle. Among the irrigation systems recommended for this crop, drip irrigation with high efficiency of water use in agriculture is evidenced, because it is applying the water irrigation depth only in root zone of crops and maintaining soil moisture close to field capacity (1). However, it is very important to know the water requirements of radish crop so that an efficient management of the irrigation can be carried out and, in this way, the soil moisture conditions can be maintained so that the crop can satisfy its water needs during the different stages of development.

Globally, water is considered as a precious element for the agricultural sector. Water being a scarce resource, it is necessary to use judiciously and manage this natural resource scientifically to sustain life on earth. Irrigation is the major consumer of water in the country and therefore water used for irrigation must be prudently managed to ensure high efficiency. Proper irrigation scheduling and efficient irrigation water management are crucial for the sustainability of irrigated agriculture. In this Crop water requirement is the important key for proper planning and structure of the irrigation system of any crop. Crop water requirements is the depth of water needed to meet the water loss through evapotranspiration of a disease-free crop growing in large fields under non-restrictive soil conditions including soil water and fertility and achieving full production potential under the given growing environment. Crop Water Requirement (CWR) is based on the type of crop, stage of the crop, soil type, climatic conditions and evapotranspiration demand. Accurate quantification of crop water requirements of any crop is essential for irrigation scheduling and water management. The crop water requirement (CWR) also can be determined from reference evapotranspiration using crop coefficients (Kc). To estimate crop evapotranspiration (ET) for irrigation planning, the crop coefficient (Kc), which is the ratio of crop evapotranspiration to reference evapotranspiration, is needed. The crop coefficient value represents crop-specific water use and is required for accurate estimation of irrigation requirement of different crops grown under different climatic conditions. In this context, the objective of this study was to evaluate the real crop evapotranspiration and the crop coefficient of radish for different phenological stages under protected cultivation.

Materials and Methods

The experiment was carried in the Agricultural Engineering College and Research Institute, Kumulur, Trichy, Tamil Nadu at 10.7905 °N latitude, 78.7047 ° E longitude with an average elevation of 81 meters above the mean sea level. The experiment layout has been made to accommodate the three treatments (T_1 - 120 % of ETc, T_2 - 100 % of ETc and T_3-80 % of ETc) and four replications in drip irrigated polyhouse with the dimension of 17 m x 15 m. The area of the field is 250 m^2. The laterals were laid with the in-line drippers of 4 lph capacity at an interval of 45 cm. To estimate crop evapotranspiration in the experimental plot, reference crop of radish (KTX 726) was raised at a spacing of 30 x 15 cm of paired row system in the lysimeter bin as well as surrounded area at the row spacing of 45 cm. Sowing was done on 18th August 2023. The overall views of crop development in a lysimeter bin and a field was depicted in Fig. 1-4.

The mean maximum relative humidity (RH) was noticed during the August and September months (83 %) whereas the mean minimum RH was noticed during March month (24 %). The data of air temperature, relative humidity, wind speed, sunshine hours and solar radiation for a period of growing season were measured in the experimental plot.

The Hargreaves model

The Hargreaves model is the simplest one for practical use, since it requires only two easily accessible parameters, temperature and solar energy (2). The reference evapotranspiration (ETo) in greenhouse was calculated using The Hargreaves model. It is expressed as follows,

Fig. 1. Polyhouse.

Fig. 2. Digital lysimeter

Fig. 3. Crops in lysimeter

Fig. 4. Crops in polyhouse

$$ET_0 = 0.0135\ (T+17.78)R_s \left(\frac{238.8}{595.5-0.55T}\right)$$

Where,

ETo = Reference evapotranspiration, mm/day

T= Mean temperature, °C

R_S= Incident solar radiation, MJ/m^2/day (Measured with pyranometer).

Crop reference evapotranspiration (ETc)

To investigate actual crop evapotranspiration 500 kg capacity electronic weighing lysimeter installed at the centre of the field consisting of two steel (inner and outer) tanks of size 60 cm x 60 cm x 60 cm. The weighing arrangement was made with the help of load cells and data logger. When filled with soil, all the four load cells were calibrated. A drainpipe was installed at the corner of the inner tank. The weighing lysimeter can read correctly up to 50 g. The least count of the measurement of lysimeter is 0.13 mm. In case of polyhouse due to absences of precipitation (P) it can be taken as zero. Runoff component (RO) is assumed to be insignificant in drip irrigation. Therefore, crop evapotranspiration is taken as changes in the weight (ΔW) of lysimeter as follows,

$$ETc = (\Delta W \times CF)$$

CF = Correction factor is 2.77 to convert kg in mm (ie, 1 kg = 2.77 mm)

Crop Coefficients

The measured crop coefficients (Kc) for all the selected crops under study were calculated using the following relation,

$$K_c = \frac{ET_c}{ET_o}$$

In which ETc is the actual crop evapotranspiration (mm day^{-1}) measured from weighing lysimeter and ETo is the reference evapotranspiration (mm day^{-1}) measured from Hargreaves model.

The crop coefficient varies according to crop type, growth stages and varying local climatic conditions. Hence, stage wise crop coefficients derived from FAO 56 was modified as per the polyhouse climatic parameters of Trichy for radish crop by following the standard procedure and guidelines suggested (3) using FAO-56 curve method. Which was based on the estimated value of the crop coefficients.

The total duration of radish crop was divided into four growth stages as initial; development, mid-season and late-season and the length of days were 10, 10, 15 and 10 days respectively. The initial stage refers to the germination and early growth stage when the soil surface is not or is hardly covered by the crop (ground cover <10 %). The crop development stage is the stage from the end of the initial stage to attainment of effective full groundcover (groundcover 70-80 %). The mid-season stage is the stage from the attainment of effective full groundcover to the start of maturity, as indicated for example by discolouring or falling of leaves. At this stage, Kc will reach its maximum value. The late season stage runs from the start of maturity to harvest or full senescence. The calculation of Kc and ETo was presumed to end when the crop was harvested, dried out naturally, reached senescence or experienced leaf drop.

Water use efficiency was calculated as follows,

$$WUE = \frac{\text{Yield (kg/ha)}}{ET_c\ \text{(mm)}}$$

Results and Discussion

The study was conducted in a greenhouse located in Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur. The radish (KTX 726) seeds were sown at a spacing of 30 x 15 cm of paired row system in the lysimeter bin as well as surrounded area at the row spacing of 45 cm. The average air temperature inside the greenhouse was 33 °C with variation between 30.8 and 35.6 °C. The average of air relative humidity was 64.4 % with variation between 60.4 and 71.2 %.

Reference evapotranspiration (ETo)

The reference evapotranspiration (ETo) in greenhouse was calculated using ETo calculator and it is varied from 4.1 to 5.2 mm during the growing period. The estimated average ETo value was 44.2 mm, 45.3 mm, 71.9 mm, 47.4 mm for the initial, development, mid and final stage respectively.

The reference evapotranspiration estimated was low during initial stage and maximum in mid stage, may be due to respective growth of vegetation at the stage. However, these results are not new but give confidence in the subsequent results (4-6). Same trend was reported by several researchers for different crops.

Actual crop evapotranspiration (ETc)

The actual crop evapotranspiration, ETc (mm. day^{-1}) was calculated by soil water balance using weighing lysimeter. In this study, initial, mid, development and final stage of actual crop evapotranspiration (ETc) was observed for T_1 are 35.3 mm, 42.5 mm, 77.5 mm and 33.2 mm, for T_2 the observed values are 30.1 mm, 36.1 mm, 66 mm and 27.8 mm. Lastly, for T_3 the recorded values are 23.1 mm, 27.8 mm, 52.7 mm and 24.6 mm respectively.

The total amount of water consumed by the radish in greenhouse was 188.5 mm, 160 mm, 128.2 mm in treatment T_1, T_2 and T_3 respectively. In all three treatments the highest water consumption was observed during mid stage, it may be due to the maximum vegetative growth of crop (Fig. 5). It was observed that the highest daily values of crop evapotranspiration were recorded in stage III. The stage IV presented the lowest water consumption because the culture was in the maturation stage and fruit harvest. These results are consistent with those obtained in the present work. However, ETc for the same phenological stage was 4.4 mm day^{-1} and it was 2.5 times highest than the crop evapotranspiration was found (1). This difference can be explained by the fact that climate is one of the main factors in determining the quantity of water evapotranspirated by crops.

Development of crop coefficient (Kc)

To eliminate the effect of the meteorological factors, ratio of crop evapotranspiration (ETc) to reference evapotranspiration (ETo) value is considered. With the observed data, daily crop coefficient value was estimated throughout the complete crop cycle during the experimental period. The average crop coefficient values of each stage for three treatments were determined and depicted in Fig. 6.

The crop coefficient value of radish grown under naturally ventilated greenhouse reckoned during initial stage (Kc_{in}), development stage (Kc_{dev}), mid-stage (Kc_{mid}) and final stage (Kc_{fin}) for T_1 was 0.72, 0.99, 1.01 and 0.81, T_2 was 0.58, 0.84, 0.85 and 0.63 and T_3 was 0.43, 0.61, 0.62 and 0.48 respectively. In general, crop coefficient was found to be lower in all the treatments during the initial stage of the plant due to lesser ground coverage, whereas, in mid stage, Kc was found to be highest due to kernel development (7). The coefficients obtained in the present study differed from the values previously reported (1, 7) for all the phenological phases but presented similarity in the same trend. This fact is justified by the climatic differences of the places where the studies were conducted.

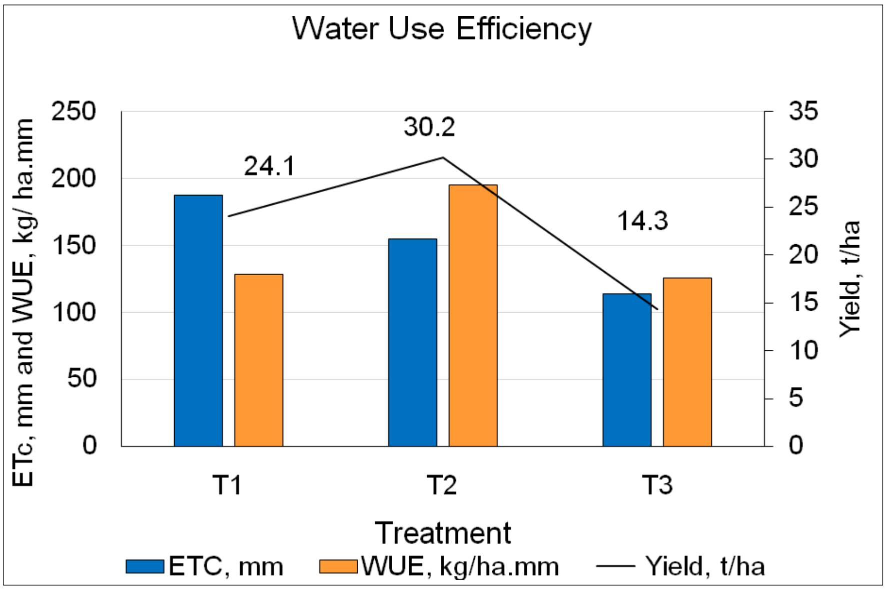

Fig. 5. Water use efficiency and yield.

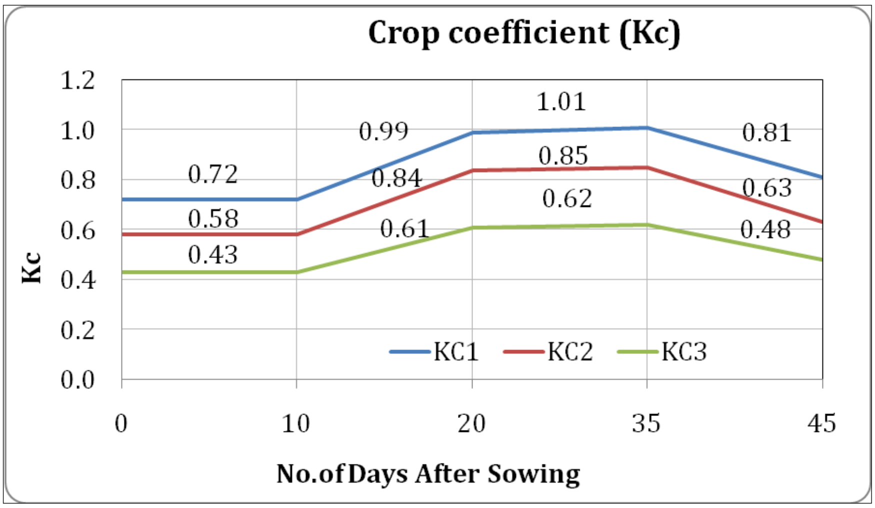

Fig. 6. Stage wise crop coefficient.

Performance of yield parameters for different irrigation levels under greenhouse

The maximum yield was observed in T_2 (30.2 t. ha^{-1}), followed by T_1 (27.5 t. ha^{-1}) and the lowest was observed in T_3 (17.1 t. ha^{-1}), which was 20.2 % and 46 % less compared to T_2 and T_1 respectively. As well as highest water use efficiency in T_2 (188.8 kg. ha^{-1}.mm^{-1}), followed by T_1 (127.9 kg. ha^{-1}. mm^{-1}) and lowest in T_3 (125.6 kg. ha^{-1}. mm^{-1}) was observed.

From the above the results, it is revealed that the treatment T_2 recorded high water use efficiency with the highest yield compared to other treatments. The present research finding indicates that WUE increased when applying 100 % of ETc in comparison with 120 % and 80 % ETc. Moreover, the 100 % ETc treatment exhibited notable 32 % and 33 % increase in WUE compared to T_1 and T_3 respectively. The similar results were previously reported (8-10). This study demonstrated that supplying additional water had no significant effect in radish yield. Instead, it resulted in water wastage, as the crop's water needs were satisfactorily fulfilled by the 100 % ETc. Therefore, the crop coefficient (Kc) value obtained for treatment $T_2$is suggested for optimal use of irrigation water for cultivating of radish crop in naturally ventilated greenhouse.

Conclusion

The present study findings clearly demonstrated that applying 100% of the estimated crop water requirement (ETc) through treatment T_2 resulted in the highest yield (30.2 t ha^{-1}) and water use efficiency (188.8 kg. ha^{-1} .mm^{-1}), outperforming both deficit (T_3 – 80% ETc) and excess (T_1 – 120% ETc) irrigation treatments. Despite T_1 receiving more water than T_2, it did not lead to any yield advantage, confirming that over-irrigation only results in water wastage without corresponding yield gains. Similarly, T_3, which received less water, exhibited significant reductions in both yield and WUE. The crop coefficient values derived for each growth stage under T_2 (Kc_{ini}: 0.58, Kc_{dev}: 0.84, Kc_{mid}: 0.85, Kc_{fin}: 0.63) are recommended for accurate irrigation scheduling of radish cultivated in similar greenhouse conditions. These values reflect the actual crop water use pattern and can serve as a practical guide for optimizing water application. In conclusion, this research establishes that 100% ETc is the most efficient irrigation level for maximizing yield and water productivity in radish under protected cultivation. The study also reinforces the importance of using stage-specific Kc values for efficient water resource management, contributing to sustainable greenhouse vegetable production.

Authors' contributions

AV conducted field research work and drafted the manuscript. ES contributed analysis part. MN contributed design of study. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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Additional information

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