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Development of crop coefficient of drip irrigated banana for semi-arid region

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Abstract

A field experiment was conducted during 2020-2023 in the experimental plots of Agricultural Research Station, Bhavanisagar, Tamil Nadu Agricultural University, Erode district, Tamil Nadu, to estimate crop water requirement of bananas (Variety: Kadhali and Red Banana) irrigated through drip irrigation system based on soil moisture availability. Water requirements include evapotranspiration of crops and losses of water from fields. Evapotranspiration is the quantity of water transpired by plants during their growth, plus moisture evaporated from the surface of the soil and the vegetation. The reference evapotranspiration was estimated from the weather parameters. Crop evapotranspiration was estimated using the soil water balance method. Tensiometers were installed at different root zone depths (0-30 cm and 30-45 cm depth) of the banana crop to measure the soil moisture tension. The soil moisture characteristics curve of the research field was estimated. Irrigation was scheduled based on the readings observed in the tensiometer. The irrigation scheduling/interval was estimated as 2 to 3 days during the crop period based on soil moisture availability. The water consumed for different crop growth stages was estimated. The total irrigation water requirement for the kadhali and red bananas was 1224 mm and 1448 mm, respectively.

Keywords

crop evapotranspiration; irrigation scheduling; soil water balance model; tensiometer

Introduction

Tamil Nadu State is classified into different agro-climatic zones, which are categorized based on the nature of the soil, rainfall pattern, irrigation, cropping system and socio-economic parameters. In each zone, the distribution of rainfall varies spatially. Rainfall in the western region of Tamil Nadu ranges from 700 to 800 mm per year. Therefore, rainfall and irrigation are the primary water sources for the crops grown in the Western Zone. The banana is one of the most significant crops grown in the western region of Tamil Nadu. In most western zones, bananas are cultivated under a drip irrigation system. Banana is grown with drip irrigation in most of the west zone locations and irrigation is typically scheduled according to weather conditions, resulting in water overuse. Numerous studies have been conducted to estimate the water savings in drip irrigation over conventional irrigation practices. Many studies have revealed increased yield, water productivity, water saving and profit for vegetable crops due to drip irrigation (1). The water requirement of bananas was less in drip-irrigated bananas with mulching practices than with mulch conditions (2).

It is necessary to understand the actual crop water requirement of the crop to save water. The water requirement of crisis is the amount required for the plants to meet requirements. Water requirements include evapotranspiration of crops and losses of water from the cropped field. To calculate water requirements, reference evapotranspiration and crop evapotranspiration must be estimated. Reference evapotranspiration is the evapotranspiration from a grass surface grown with enough water. Crop evapotranspiration is the quantity of water that transpires from the crop surface and evaporates from the soil surface.

Many studies are available on the estimation of crop evapotranspiration and irrigation water requirements. Significant variation in crop evapotranspiration between different crop growth stages affected irrigation water management (3). Many scientists also insisted on the importance of estimating crop evapotranspiration. To understand crop water requirements, scheduling irrigation and stress occurring in the plant, crop evapotranspiration needs to be estimated (4, 5). The crop evapotranspiration can be estimated by using many mathematical models. The actual evapotranspiration of different crops was calculated using conventional ET and soil water balance models to determine the total water required in an irrigation project in China (6). As the Penman-Monteith equation uses more data to estimate reference evapotranspiration, an effort was made to limit the input data to calculate reference evapotranspiration (7). Crop-related input data arrived from multispectral sensors to estimate crop evapotranspiration from 18 locations in Italy and were statistically analyzed (8). A collection of ten years of meteorological parameters was used to estimate reference evapotranspiration using FAO Penman Monteith model and trend analysis (9). The crop evapotranspiration estimated through lysimeter reference evapotranspiration derived from the FAO Penman-Monteith model was used to develop the crop coefficient of carrots for various crop growth stages (10). The crop evapotranspiration, crop water requirement, Irrigation water requirement and irrigation scheduling for groundnut were arrived at using the FAO CROPWAT model (11).

Crop evapotranspiration was estimated for all kinds of crops. The evapotranspiration of cereals, pulse, orchard and grass species was assessed. It was reported that all plant species' evapotranspiration rate was maximum during intense crop growth stages (12). The crop evapotranspiration of eggplant was estimated in three ways: FAO Penman-Monteith equation, crop coefficient approach, soil water balance method and the model performance were tested with machine learning models (13). Crop evapotranspiration of capsicum was estimated using the soil water balance method for different crop stage growth and it was found to be maximized during the middle stages of crop growth (14). The lowest value of reference evapotranspiration was recorded during winter and the highest value was recorded during summer for crops like rice, wheat and cotton (15). A study on estimating actual evapotranspiration was carried out during winter and summer wheat and reported that actual evapotranspiration was maximum during summer as wind speed and bright sunshine hours influenced the evapotranspiration rate (16).

Few studies have been done to estimate the crop water requirement of bananas. The crop water requirement for banana crops grown in Canary Island was determined and the uniformity coefficient of drippers was calculated. The net irrigation requirement was also found to be less in the treatment with mulching (17). Hydrological modelling estimated the depth of irrigation for bananas irrigated with groundwater (18). Crop modelling approach was used to assess irrigation water demand and scheduling in banana crops (19). The crop coefficient, water requirement, yield and water use efficiency were assessed for bananas when irrigation was scheduled at −20 kPa matric potential (20).

A good irrigation system is one with equal irrigation requirements and crop evapotranspiration. Only in drip irrigation does this become possible. Although many studies on water-saving aspects are available, only a few were found to estimate crop water requirements based on soil moisture availability. Accurate determination of crop water requirements for different growing stages is essential for applying the correct water quantity through the drip irrigation system. The available soil moisture needs to be measured with soil moisture sensors like tensiometers to understand whether the soil needs water. The development of crop coefficient is significant for efficient irrigation water management as it represents the physiological parameters of the crop. Hence, this study has been formulated to develop crop coefficients and estimate banana water requirements by considering soil moisture availability for irrigation scheduling.

Materials and Methods

Study area description

A field trial was conducted at the Agricultural Research Station, Bhavanisagar, Erode district, Tamil Nadu, to determine the water requirement of banana crops from 2020 to 2023. The crop was raised in two seasons with a spacing of 1.8 m × 1.8 m and observations were taken. The banana crop (Variety: Kadhali and Red Banana) was chosen for the study. The second trial was conducted from the first ratoon crop of bananas. The soil's physical and hydraulic properties at the experimental site were analyzed and given in Table 1.

Tensiometers were installed in the field at different depths (30 cm and 45 cm) and soil moisture tension was recorded to calculate crop evapotranspiration. The sensors' reading in matric potential was converted into volumetric moisture content from the soil moisture characteristic curves of the experimental field (Fig.1). Penman-Monteith equation was used to calculate reference evapotranspiration. The soil water balance model was used to estimate crop evapotranspiration. The crop coefficient was defined as the crop evapotranspiration and reference evapotranspiration ratio. Based on the above evapotranspiration data, the crop coefficient was developed for bananas under a drip irrigation system for the Western zone of Tamil Nadu.

Table 1. Soil physical and hydraulic properties

S.No	Particulars	Values
I	**Mechanical analysis**	
	Textural class	Sandy loam
II	**Soil physical properties**	
	Bulk density (g/CC)	1.48
	Field capacity (per cent)	22.0
	Permanent wilting point (per cent)	10.6
	Available water (per cent)	11.4
	Hydraulic conductivity (cm/h)	0.42
III	**Chemical analysis**	
	Organic carbon (per cent)	0.40
	Available N (kg/ha)	314.7
	Available P (kg/ha)	21.0
	Available K (kg/ha)	362.3
	pH (1:2: S: W suspension).	7.60
	EC (dS m^{-1}; 1:2: S: W suspension).	0.20

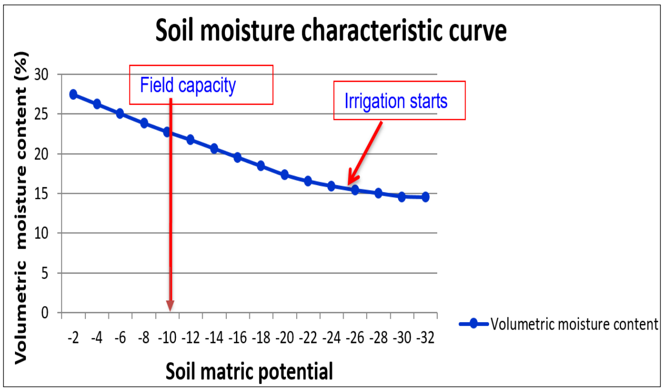

Fig. 1. Soil moisture characteristics curve of the experimental field.

Calculation of reference evapotranspiration (ET_o)

Meteorological data was collected and the Penman-Monteith method estimated the reference evapotranspiration.

Penman-Monteith method

The Penman-Monteith method is widely used to estimate evapotranspiration as it considers many climatic variables for calculation. The equation is given in Equation

$$ET_0 = \frac{0.408\Delta(R_N - G) + y\dfrac{900}{T_{mean}+273}U_2(e_2 - e_a)}{\Delta + y\,(1 + 0.34u_2)} \qquad \text{(Eqn. 1)}$$

Where,

ET_0 = reference evapotranspiration (mm/day),

R_n = net radiation on the plant surface ($MJ/m^2/day$),

G = heat flux density of soil surface ($MJ/m^2/day$),

T_{mean} = average daily air temperature at the height of 2 m (°C),

U_2 = Speed of wind at the height of 2 m from the soil surface (m s^{-1}),

e_s = saturation vapour pressure (kPa),

e_a = actual vapour pressure (kPa),

e_s- e_a = saturation vapor pressure deficit (kPa),

Δ = slope vapour pressure curve (kPa/°C),

γ = psychrometric constant (kPa/°C).

Measurement of crop evapotranspiration, ET_c - Soil water balance method

In the soil water balance method, precipitation, amount of irrigation water applied and change in moisture storage were considered for estimating crop evapotranspiration. As the irrigation was applied through drip irrigation, runoff and deep percolation were supposed to be zero. A tensiometer was installed in the research field to study the soil moisture tension at different depths (20-30 cm and 30-45 cm depth) (Fig. 2). The moisture content at different soil moisture tension was arrived at and plotted as a soil moisture characteristics curve. The change in soil water storage was estimated through tensiometer readings. The crop evapotranspiration was computed based on the change in soil moisture content and measurement of other water balance parameters in Equation 2.

Fig. 2. Tensiometer installation at the experimental field.

$$ET_C = P + I - R - D \pm \Delta W \qquad \text{(Eqn. 2)}$$

Where,

ET_c= Crop evapotranspiration (mm),

P= Precipitation (mm),

I=Irrigation water depth (mm),

R = the surface runoff (mm),

D= deep percolation from the root zone (mm),

ΔW= change in soil water storage (mm).

Development of crop coefficient (K_c)

The equation of the ratio between crop evapotranspiration and reference evapotranspiration developed the Crop coefficient in Equation 3.

$$K_C = \frac{ET_C}{ET_O} \qquad \text{(Eqn. 3)}$$

Where,

K_c = Crop coefficient .

ET_c = Crop evapotranspiration (mm).

ET_o = Reference evapotranspiration (mm).

Several studies have been done to derive site-specific crop coefficients for various crops, as the coefficient is related to plant growth parameters. Crop evapotranspiration of maize was derived from site-specific crop coefficient and FAO crop coefficient to calculate water requirement and water use efficiency of maize (21). The accumulated heat units of the maize crop were expressed with mathematical functions and this was included along with reference evapotranspiration and site-specific crop coefficient to calculate crope vapo transpiration (22). Crop evapotranspiration of cucumber was estimated for different crop growth stages using soil moisture sensors and crop coefficients were developed (23). Crop evapotranspiration was determined with Eddy correlation models for various crops like cereals and pulses with varying systems of irrigation and reported that climatic parameters, soil moisture status, adequate root zone depth and crop growth stages would influence the crop evapotranspiration rate (24). The joint probability model was used to predict seasonal reference evapotranspiration, as the conventional climate-based models could not predict more extended reference evapotranspiration (25). The crop coefficient of coriander crop for different crop growth stages was developed from the experiment through the enclosed vegetative chamber method, lysimeter method and water balance method and it was concluded that the vegetative chamber method was the best suitable way to estimate the crop coefficient of coriander crop (26). The crop coefficient of vegetable crops like tomato, eggplant, capsicum and cucumber was developed from reference evapotranspiration and crop evapotranspiration was estimated through lysimeter for different crop growth stages under greenhouse cultivation and open field cultivation (27).

Results and Discussion

Comparison of reference ET and crop ET

The estimated values of reference evapotranspiration (ETo) and crop evapotranspiration (ETc) during the banana crop seasons were compared (Fig. 3). The ETo value was found to be maximum during the initial crop growth stages as it is related to weather parameters At the same initial period of crop growth, the crop evapotranspiration rate was found less as minimum canopy coverage over the land surface. The crop evapotranspiration was observed to be at maximum during the middle and end stages of crop growth.

The crop coefficient values during the initial, developmental, middle and end stages were 0.55, 0.77, 1.1 and 0.95, respectively, for the first crop of the Kadhali banana (Fig.4). The crop coefficient values during initial, developmental, middle and end stages was 0.86, 1.00, 1.21 and 1.17 respectively for the ratoon crop of Kadhali banana. Similarly, The crop coefficient values during the initial, developmental, middle and end stages were 0.57, 0.80, 1.19 and 1.13, respectively, for the first crop of Red banana (Fig. 5). The crop coefficient values during the initial, developmental and end stages was 0.89, 1.04, 1.23 and 1.19 respectively for the ratoon crop of Red banana.

Many scientists also tried different approaches to find crop coefficient values by using empirical relations to determine banana crop Kc values using satellite images (28). The crop water requirement of bananas was measured as 1063 mm and 1145 mm for rainfed and irrigation conditions at Thrissur, Kerala. The crop water requirement was calculated using CropWat 8 software (29).

Water requirement for banana

The water consumption during different crop growth stages was estimated. The total irrigation requirement for the entire crop season was 1224 mm for kadhali banana (Fig. 6). The total irrigation requirement for the whole of the crop season was 1448 mm for red banana (Fig. 7). Irrigation interval was found to be 2 to 3 days based on soil moisture availability status. Irrigation water application to banana crops as per soil moisture status is given for different crop growth stages (Table 2). Research indicates that the water requirement of bananas was 1024 mm under drip irrigation with mulching and 1560 mm under drip irrigation without mulch (30). The banana crop water requirement was calculated as 3.9 mm, 4.0 mm and 3.3 mm during the initial, middle and end stages of the crop growth. The banana crop coefficient values ranged from 0.7 to 1.1 depending on the crop growing stages (31). Water consumption of bananas varied from 936 mm to 745 mm when irrigation was scheduled at a critical moisture depletion rate.

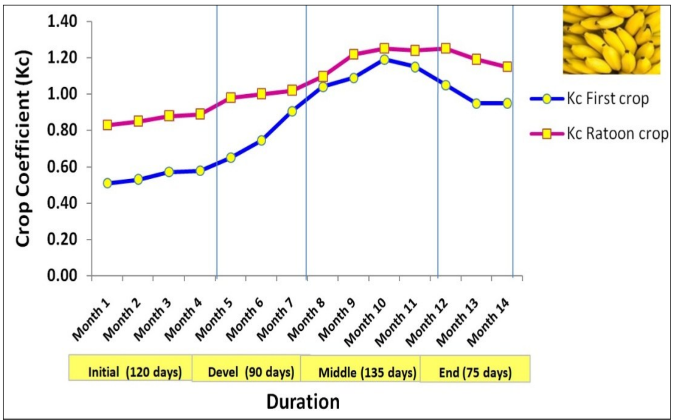

Fig. 4. Crop coefficient (Kc) value for the first crop and ratoon crop (Kadhali).

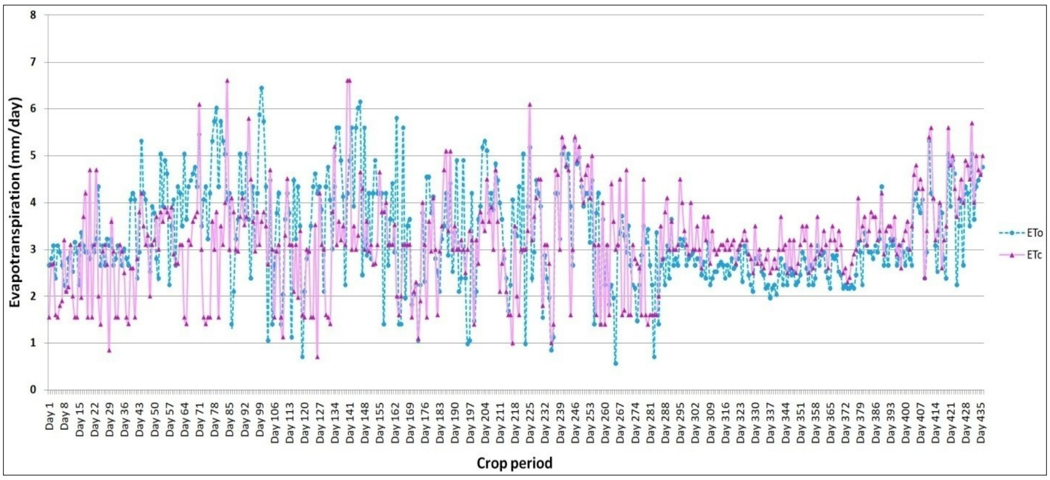

Fig. 3. Comparison of ETo value, ETc value throughout one crop growing season.

Table 2. Irrigation water application stage-wise

Water application (l/day)	Initial	Dev	Mid	End
Kadhali banana	9.6	10.4	10.5	10.3
Red Banana	9.9	11.4	11.2	11.3

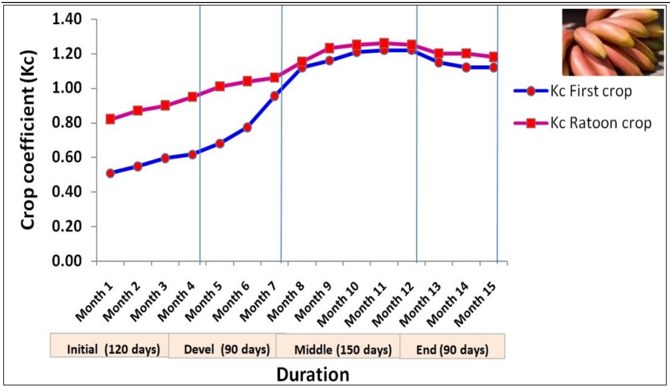

Fig. 5. Crop coefficient (Kc) value for the first crop and ratoon crop (Red Banana).

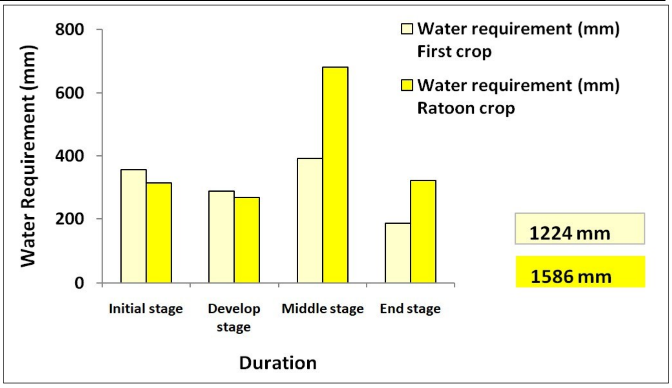

Fig. 6. Water requirement of banana (Kadhali).

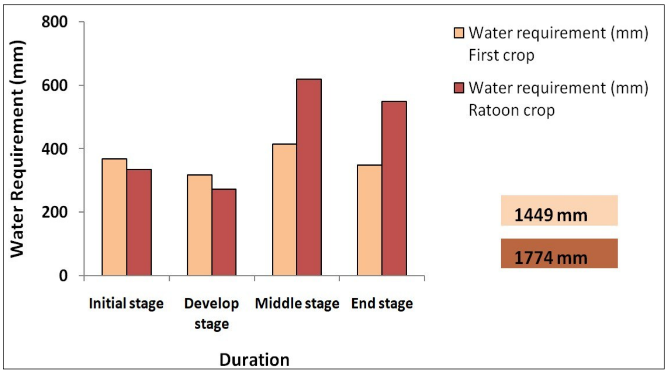

Fig. 7. Water requirement of banana (Red banana).

To maximize the yield, irrigation must be planned before the crop attained water stress condition (32). Tissue culture bananas were raised under different irrigation regimes of 100 %, 85 %, 60 % and 40 % of field capacity and reported no significant difference between the irrigation regime of 100 % and 85 % of field capacity (33). Different irrigation treatments were imposed on banana crops to study the yield water requirement and it was reported that less irrigation resulted in delayed crop growth and minimum yield. It is estimated that the water requirement of the Cavendish cultivar of banana was between 1200 mm and 1300 mm per season (34).

Conclusion

The crop coefficient value for Banana (Red banana variety) at different crop growth stages (Initial, development, mid stages) was estimated. The crop coefficient values during the initial stages ranged from 0.83 to 0.89, developmental stage Kc values were between 0.98 and 1.04, middle stage Kc values were from 1.09 to 1.25 and during end-stage Kc values ranged between 1.19 and 1.14 in kadhali banana. The crop coefficient values during the initial stages ranged from 0.82 to 0.90. Developmental stage Kc values ranged from 0.90 to 1.06, middle stage Kc values were between 1.12 and 1.22 and during end-stage Kc values were between 1.2 and 1.18 in red bananas. During the entire crop growth period, irrigation was scheduled to last between 2 and 3 days according to soil moisture availability. The water requirement of bananas for different crop growth stages was also estimated.

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Authors' contributions

KA was responsible for framing conceptualization, collecting relevant literature and drafting the original manuscript. AV developed the Methodology and offered suggestions. MN participated in the study design. NS performed overall supervision of field experiments. All authors read and approved the final 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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