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Evapotranspiration and crop coefficient of turmeric (*Curcuma longa* L.) under drip irrigation and Fertigation levels in Jalgaon, Maharashtra

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ABSTRACT

An attempt was made to determine the actual evapotranspiration and crop coefficient of turmeric at various growth stages under drip irrigation and fertigation scheduling during 2014-15 and 2015-16 at Jalgaon, Maharashtra. The results revealed that cured rhizome yield of turmeric increased significantly at each higher levels of drip irrigation up to 100% Epan and fertigation of 100% dose of N and K. Peak seasonal ETc (3.04 to 4.40 and 3.50 to 5.11 mm day^{-1}) of turmeric was recorded at rhizome initiation stage (91-20 DAS) and rhizome development stage (121 to 210 days). The mean seasonal ETc of turmeric ranged from 770 to 1090 mm. The highest seasonal ETc and ETc rate was recorded in surface check basin irrigation at IW/CPE 1 and lowest in deficit irrigation schedule i.e. drip irrigation at 60% Epan. Each higher level of fertigation from 50% to 125% recommended dose of N and K increased ETc and ETc rate of turmeric with increase in cured rhizomes yield of turmeric. The measured Kc values were different up to some extent from the FAO reported values; corrected crop coefficient values for Jalgaon region was recorded at 100% Epan through drip were slightly higher over the FAO Kc values.

Key words : *Crop coefficient, Crop evapotranspiration, Drip irrigation, Turmeric, Yield*

Introduction

Turmeric is a very important spice crop in India from ancient times and produces nearly the whole world's turmeric demand and consumes 80% of it. India is the largest exporter of turmeric among the spices which covers 193390 ha area and 1051160 tonnes production in 2016-17. Owing to its long duration and heavy consumer of water and nutrients in turmeric production, the water and nutrient management study is most important. The adoption of exact or correct amount of water and correct timing of application along with nutrients is very essential for optimum crop production. Drip irrigation is the most advanced and modern method of irrigation and fertilizer application which not only saves water but also supplies water and nutrients directly to the root zone there by better water and fertilizer use efficiency. In order to optimize the water requirement under drip irrigation, a comprehensive knowledge of crop evapotranspiration (ETc) and crop coefficient (Kc) are required to increase water uses efficiency in the water-limited region. Therefore, it is necessary to predict crop irrigation water demand under drip ir-

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rigation system.

Crop evapotranspiration (ETc), as the critical process of water circulation had become an important scientific issue in sustainable agricultural development and climate changing situation. Knowledge of the ETc process in the tropical region is an imperative research content in water - energy balance of the terrestrial ecosystem and promoting the reasonable utilization of limited water resources through precise irrigation systems. Several measurement researches on farmland ET was tested for different crops in different climatic conditions (Mehta and Pandey, 2015). Among all the methods Penman-Monteith method (Allen *et al.,* 1998) has been reported to yield consistently more accurate reference evapotranspiration (ETo) estimates across a wide range of climate condition. Although crop coefficient values for different crops grown under different climatic conditions as suggested by Doorenbos and Pruitt (1977) are used where locally measured data are not available. Allen *et al.* (1998) have suggested that these values need to be derived empirically for each crop based on the local conditions to determine the water requirement. Some studies revealed that Kc not only has significant differences in different types of ecological system, but also influenced by various environment factors. Since Kc values are found to be crop, location and season specific, hence, need to be corrected for each location to determine ETc.

In this paper, an attempt was made to determine continual ETc observation of turmeric crop in Jalgaon region of Maharashtra during 2014-15 and 2015-16 by water balance method, determined consumptive use of water, analyzed the dynamics of actual field ET and develop empirical region specific Kc values (corrected Kc) on the basis of reference evapotranspiration (ETo) and then compared with FAO Kc slandered values.

Materials and Methods

A Field experiment was carried out during *kharif* season of 2014-15 and 2015-16 at Jain Hi-Tech Agri. Institute, Jalgaon, Maharashtra. The site is geographically situated at 21° 01' 52'' N-Latitude, 75° 56' 38'' E-Longitude and at an altitude of 292 m above mean sea level. The soil of the experimental plot was sandy clay loam texture in surface layer and sandy loam in the reaming lower layer, neutral in reaction and non-saline. Mechanical analysis of the soil at different depths revealed sand percentage increased with increase in soil depth from 0-15 cm to 45-60 cm. Taking into the consideration of top two layers maximum percent of crop root will be distributed, the soil was low in available nitrogen, high in available P_2O_5 and medium in K_2O. The soil moisture retention capacity at field capacity and at permanent wilting point of the experimental site was 21.67% and 11.77% (0-60 cm) estimated by the standard procedures. The total plant available soil water i.e. the difference between field capacity and permanent wilting point from 0 to 60 cm soil depth amounted to 87.50 mm. Hydraulic conductivity of soil found to be moderate (1.36 to 2.53 cm h^{-1}). Bulk density found to be slightly affect the root growth (1.472 g/cm^3). The climate of Jalgaon is described as dry tropical and semi-arid with dry winter (Nov-Feb). During both the years of experiment, 888.40 and 419.30 mm rainfall was received. Mean pan evaporation ranged from 1.22 to 7.89 mm day^{-1} and 3.55 to 6.01 mm day^{-1} in 2014-15 and 2015-16, respectively. The seasonal pan evaporation during the crop period was 1140.75 mm in 2014-15 and 1201.85 mm 2015-16, respectively.

Finger rhizome of turmeric variety "Salem" @ 2000 kg ha^{-1} was planted on 10^{th} June in 2014-15 and 14^{st} June in 2015-16 in bed planting method with spacing of 45 cm X 20 cm. The recommended dose of fertilizers was 180:60:120 NPK kg/ha. The experiment was laid out in a split plot design with twenty treatment combinations and replicated four times. The main treatment comprised five irrigation levels involving four irrigation through drip (DI - 1.2, 1.0, 0.8, 0.6 Epan and one control [SI- surface check basin irrigation at IW/CPE 1 with 50 mm depth of water] as main treatments along with four fertigation levels *viz.*, 50, 75, 100 and 125% of recommended dose of nitrogen and potassium ha^{-1} through drip. Full dose of phosphorus was applied as basal dose through SSP. Nitrogen and potassium applied at weekly intervals with split application such as 40% of total nitrogen and potassium applied from 4^{th} – 12^{th} weeks, 40% of total nitrogen and potassium applied from 13^{th} – 25^{th} weeks and 20% of total nitrogen and potassium applied from 26^{th} – 30^{th} weeks. Irrigation and fertigation treatments were imposed 30 days after sowing.

The daily reference evapotranspiration was calculated following FAO56-Penman-Monteith equation and seasonal crop evapotranspiration (ETc) was estimated based on water balance equation using soil water measured by gravimetric sampling method (FAO) at weekly intervals. Crop coefficient (Kc) was calculated following Doorenbos and Pruitt (1977). For estimation of Kc values, the turmeric crop life was divided into germination and establishment (0-30 DAS), vegetative phase (31-90 DAS), rhizome initiation stage (91-120 DAS), rhizome development stage (121-210 DAS) and maturity stage (211- 260 DAS).

$$ETo = \frac{0.408\,\Delta\,(Rn - G) + \gamma\,\frac{900}{T_{mean} + 273}\,\mu_2\,(e_2 - e_a)}{\Delta + \gamma\,(1 + 0.34\,\mu_2)} \quad \text{eq.1}$$

$$Kc = \frac{\text{Crop evapotranspiration (ETc)}}{\text{Reference crop evapotranspiration (ETo)}}$$

The data obtained on total rhizome yield were analyzed statistically by the method of analysis of variance as per the procedure outlined for split plot design. Statistical significance was tested by P–value at 0.05 level of probability and critical difference was worked out where ever the effects were significant.

Results and Discussion

Cured rhizome yield and stalk yield

Cured rhizome and stalk yield was found to be higher (6421 and 3840 kg ha^{-1}) when irrigation was scheduled at DI - 1.2 Epan but it was statistically at par with DI - 1.0 Epan (6262 and 3774 kg ha^{-1}) and significantly superior to DI - 0.6 and 0.8 Epan on polled basis. On an average the crop in DI - 1.0 Epan treatment registered 13.48% and 21.35% more yield over DI - 0.6 and 0.8 Epan (Table 1). Turmeric cured rhizome yield and stalk yield under surface check basin irrigation at IW/CPE 1 (4693 and 3111 kg ha^{-1}) was also statistically inferior in comparison to drip irrigation treatments (DI - 0.8, 1.0 and 1.2 Epan) except DI - 0.6 Epan. The above trends in total rhizome yield registered under DI - 1.0 and 1.2 pan evaporation (Epan) in comparison to other treatments could be traced to the favourable soil water balance near to field capacity (applied water) as observed by variation in soil moisture during the crop growing season. Thus, favourable soil water balance under DI - 1.0 and 1.2 Epan aided the plants to put forth improved performance over other treatments, since water plays a vital role in carbohydrate metabolism, protein synthesis, cell wall synthesis, cell enlargement and partitioning of photosynthates to sink for improved development of growth traits. Therefore, crop plants in DI - 1.0 and 1.2 Epan treatments had the higher crop growth, development and yield contributing characters resulting in higher yields.

In case of fertigation levels, each higher level of nitrogen and potassium fertigation levels significantly improved the total fresh rhizome yield and stalk yield over its lower levels up to 125% of recommended dose of N and K ha^{-1}. The highest total rhizome yield and stalk yield in pooled basis was associated with 125% recommended dose of N and K ha^{-1} which statistically on par with 100% recommended dose of N and K ha^{-1}. The performance in terms of total rhizomes yield was in the decreasing trend of 125 % N and K ha^{-1} > 100 % N and K ha^{-1} > 75 % N and K ha^{-1} > 50 % N and K ha^{-1}. Fertigation with the higher levels of N and K especially in water soluble forms has definitely influenced the physiological attributes, which reflected in higher growth, dry matter production, yield and yield related traits. Better nutrient availability in these treatments could be the crucial factor as it contributed to significantly higher dry matter yield in 125 % recommended dose of N and K as compared to other lower fertigation levels. Turmeric being a long duration crop, responds more to increasing application of fertilizers. The beneficial influence of applied N and K on these parameters may be due to enhanced photosynthesis coupled with increased translocation of photosynthates towards the sink as a result of increased availability of N and K nutrients for the actively growing plants. The interaction effects between irrigation regimes and fertigation levels were found to be non-significant with respect to the total fresh rhizome yield and stalk yield on pooled basis.

Crop evapotranspiration (ETc) and evapotranspiration rate

The crop ETc and ETc rate at various crop growth periods i.e. establishment to vegetative period was linear in all the treatments in on polled year data (Table 2). However during establishment period, the difference in crop ETc and ETc rate was not varied much among treatments and recorded 86.88 mm with 2.81 mm day^{-1} on pooled basis, owing to uniform water application till 30 DAS except in surface check basin irrigation. From vegetative period until maturity due to variations in the water application levels as per the treatments, a large difference in ETc and ETc rate was observed. The higher ETc and ETc

Table 1. Cured rhizome yield, stalk yield and total seasonal crop evapotranspiration of turmeric as influenced by irrigation (drip and surface check basin) and Fertigation levels (pooled data).

Treatments	Cured rhizome yield (kg/ha)	Stalk yield (kg/ha)	Total seasonal crop evapotranspiration (mm)	Water productivity (kg m^{-3})
Irrigation levels (I)				
I_1: Drip irrigation at 120% E_{pan}	6421	3840	1071	0.60
I_2: Drip irrigation at 100% E_{pan}	6262	3774	1001	0.63
I_3: Drip irrigation at 80% E_{pan}	5518	3450	829	0.67
I_4: Drip irrigation at 60% E_{pan}	5160	3281	771	0.67
I_5: Control (surface irrigation): 1.0 IW/CPE	4693	3111	1091	0.43
S.Em. ±	77.4	46.3	-	-
CD (P=0.05)	241.0	143.2	-	-
Fertigation levels (F)				
F_1: 50% of recommended dose of N and K ha^{-1}	5212	3318	952	0.55
F_2: 75% of recommended dose of N and K ha^{-1}	5478	3420	954	0.57
F_3: 100% of recommended dose of N and K ha^{-1}	5824	3571	957	0.61
F_4: 125% of recommended dose of N and K ha^{-1}	5930	3656	960	0.62
S.Em. ±	66.6	35.6	-	-
CD (P=0.05)	190.2	101.7	-	-
Interaction				
N and K at same level of irrigation				
S.Em. ±	592.1	91.6	-	-
CD (P=0.05)	NS	NS	-	-
Irrigation at same or different levels of N and K				
S.Em. ±	571.7	82.8	-	-
CD (P=0.05)	NS	NS	-	-

rate was noticed during vegetative stage to rhizome development stage due to higher cumulative Epan values recorded than the subsequent stages. The large reduction in crop evapotranspiration and rate was observed in all the treatments at maturity stage was due to withholding of irrigation water after the crop reaching to physiological maturity for making harvesting simple and easy. The lower ETc and ETc rate values observed in the turmeric with drip irrigation at 0.6 and 0.8 Epan from 30 DAS to maturity in comparison to 1.0 and 1.2 Epan treatments were due to less water application in this treatment. Highest seasonal ETc (1090.7 mm) was observed with surface check basin irrigation at IW/CPE 1 while lowest seasonal ETc (770.7 mm) was associated with 0.6 Epan and (Table 2). In the present experiment, reduction in seasonal ETc with increasing irrigation levels was observed in the order of surface irrigation<120% E_{pan}<100% E_{pan}<80% E_{pan}<60% E_{pan} in both the years. The crop ET is a physical process taking place continuously from periodically replenished source of water and variable potential *viz.*, soil moisture reservoir to a sink of virtually unlimited capacity i.e. the atmosphere. As long as the water availability matches the rate of water loss through transpiration by the crop canopy and evaporation from soil surface the ETc continuous at potential rates as determined by the evaporation demand of atmosphere as witnessed in drip irrigation at 1.0 and 1.2 Epan. However, as the crop removes the water from the soil, the soil moisture content and soil water potential decreases leading to low soil water conductivity thereby resistance to water movement in the soil increases. This tend to decrease water flow in to the plant system causing marked reduction in ETc as could be observed in deficit irrigation levels, i.e. 0.6 Epan. In case of fertigation, crop evapotranspiration and evapotranspiration rate increasing during each crop growth sub-period with each additional dose of nitrogen and potassium fertigation levels from 50% to 125% recommended dose of N and K ha^{-1}. The seasonal ETc in fertigation from 50% to 125% recommended dose of N and K ha^{-1} varied from 770.6 mm to 1070.5 mm on pooled basis.

Crop coefficient (Kc)

In initial period of crop growth, i.e. germination and establishment stage (30 DAS) the estimated Kc val-

Table 2. Crop evapotranpiration (mm), evapotranspiration rate (mm day^{-1}) and crop coefficient (Kc) of turmeric at different growth stages as influenced by irrigation (drip and surface check basin) (pooled data)

Crop growth stages	DI-0.6 Epan			DI-0.8 Epan			DI-1.0 Epan			DI-1.2 Epan			IW/CPE = 1		
	ETc	ETc rate	Kc	ETc	ETc rate	Kc	ETc	ETc rate	Kc	ETc	ETc rate	Kc	ETc	ETc rate	Kc
0-30 DAS (Germination and establishment)	86.88	2.81	0.76	86.88	2.81	0.76	86.88	2.81	0.76	86.88	2.81	0.76	95.55	3.08	0.83
31-90 DAS (Vegetative phase)	189.49	3.16	0.92	203.54	3.39	0.99	241.17	4.02	1.17	258.96	4.32	1.26	279.37	4.66	1.36
91-120 DAS (Rhizome initiation stage)	90.99	3.04	1.04	100.29	3.34	1.15	123.36	4.11	1.42	131.77	4.40	1.50	129.75	4.33	1.49
121-210 DAS (Rhizome development stage)	314.66	3.50	1.08	344.26	3.83	1.18	425.80	4.73	1.46	459.60	5.11	1.57	448.58	4.99	1.53
211- 260 DAS (Maturity stage)	88.64	1.86	0.75	94.20	1.97	0.80	123.48	2.59	1.04	133.27	2.79	1.13	137.47	2.88	1.16
Total (mm)	770.7			829.2			1000.7			1070.5			1090.7		

ues were same in all irrigation treatment owing to uniform water application during this period. From vegetative stage until crop maturity due to variations in the applied water as per the treatments a large difference in Kc was observed. Such variations in Kc values with crop growth stages wise in wheat was also reported by (Malve *et al.*, 2017). Drip irrigation 1.0 Epan which produced significantly higher total fresh rhizome yield and stalk yield as compared to other treatments and Kc values recorded in this treatment was little more over FAO Kc values of 0.45, 0.75, 1.15 and 0.75 at initial, crop development, mid and late season (Allen *et al.*, 1998) (Fig. 1). However, drip irrigation at 0.8 Epan recorded a Kc value which was little close to FAO Kc values due to optimum rhizome yield and highest water productivity at his treatment (Fig. 2). The measured Kc values were different up to some extent from the FAO Kc values. The cause might be that FAO Kc values are generalized and recommended for a wide range of

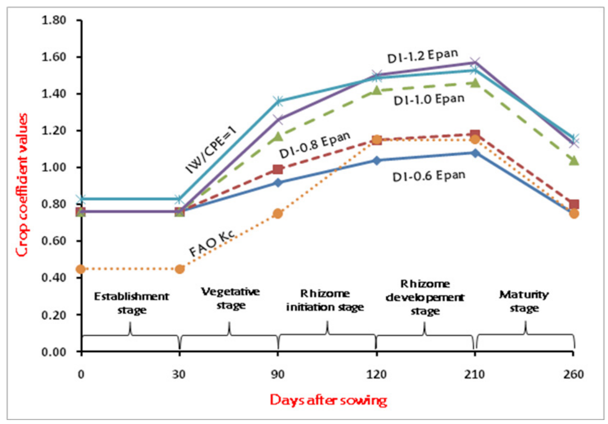

Fig. 1. Corrected crop coefficient curve under different irrigation levels and comparison with FAO Kc values

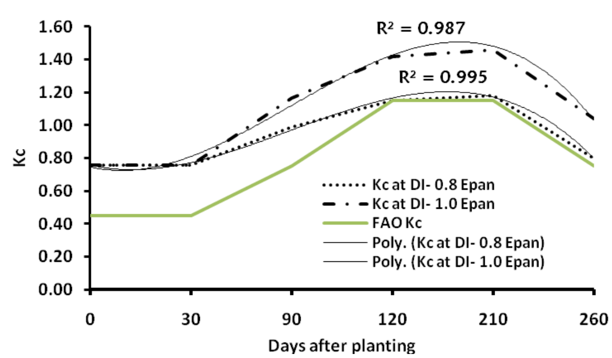

Fig. 2. Crop coefficient (Kc) of different specific growth stages of turmeric and the FAO reported Kc values

climatic conditions. Other causes might be that different turmeric varieties have different crop water use and evapotranspiration patterns. So, determination of Kc for crops in different regions and climates is important for precise water management. The result of experiment clearly indicate the calculated Kc values differ from the average Kc values of FAO and suggesting the optimum Kc value (0.76, 1.17, 1.42, 1.46 and 1.04 at germination and establishment, vegetative phase, rhizome initiation, rhizome development and maturity stage) at 100% Epan at this treatment for Jalgaon region of Maharashtra for getting higher yield. These results are in corroborating with finding of Mehta and Pandey (2016) who similarly developed corrected crop coefficient values for 10 different crops during *khairf*, *rabi* and summer season in middle Gujarat and Malve *et al.* (2017) for wheat in Jalgaon region (Maharashtra).

In case of nitrogen and potassium fertigation, each unit increase level from 50 to 120%, Kc values increased slightly over its lower levels at all crop growth stages (Table 3). In initial stage, Kc value of turmeric was low (0.78) and it increased continuously toward development stage (1.13 to 1.17) and during the mid season stage (1.22 to 1.27) and decreased during late season stage (0.77 to 0.79). Fertigation of 100% recommended dose of N and K producing significantly higher grain yield had the crop coefficients values of 0.77, 1.15, 1.34, 1.37 and 0.98 at germination and establishment, vegetative

Table 3. Crop evapotranpiration (mm), evapotranspiration rate (mm day^{-1}) and crop coefficient (Kc) of turmeric at different growth stages as influenced by fertigation levels (pooled data)

Crop growth stages	F_1- (50 % N and K ha^{-1})			F_2- (75 % N and K ha^{-1})			F_3- (100 % N and K ha^{-1})			F_4- (125 % N and K ha^{-1})		
	ETc	ETc rate	Kc	ETc	ETc rate	Kc	ETc	ETc rate	Kc	ETc	ETc rate	Kc
0-30 DAS (Germination and establishment)	86.88	2.86	0.77	86.88	2.86	0.77	86.88	2.86	0.77	86.88	2.86	0.77
31-90 DAS (Vegetative phase)	189.49	3.91	1.14	203.54	3.92	1.15	241.17	3.92	1.15	258.96	3.93	1.15
91-120 DAS (Rhizome initiation stage)	90.99	3.84	1.32	100.29	3.86	1.33	123.36	3.89	1.34	131.77	3.91	1.34
121-210 DAS (Rhizome development stage)	314.66	4.43	1.36	344.26	4.44	1.36	425.80	4.46	1.37	459.60	4.47	1.37
211- 260 DAS (Maturity stage)	88.64	2.42	0.98	94.20	2.42	0.98	123.48	2.42	0.98	133.27	2.42	0.98
Total (mm)	770.6			829.2			1000.7			1070.5		

Table 4. Net (In) and gross irrigation requirement (V) for turmeric under assumed project efficiency (Ep) and field application efficiency (Ea)

Sr. No.	Parameter	0-30 DAS (Germination & establishment)	31-90 DAS (Vegetative)	91-120 DAS (Rhizome initiation)	121-210 DAS (Rhizome development)	211-260 DAS (Maturity)	Total growing season
				Irrigation levels			
1	ETo (mm day^{-1})	3.71	3.43	2.90	3.26	2.48	15.78
2	Kc (ETa/ETo)	0.76	1.17	1.42	1.45	1.04	5.84
3	ETm (mm day^{-1})	2.80	4.02	4.11	4.73	2.58	18.25
4	In (mm period^{-1})	86.9	241.3	123.2	425.9	123.9	1001.2
5a	vat field inlet (m^3)	915.22	2540.24	1296.57	4482.99	1303.81	10538.8
5b	vat water source (m^3)	966.06	2681.37	1368.61	4732.04	1376.25	11124.3
6	Peak IR (m^3)						**4732.04**

10 (A*In) Ep (Project efficiency) = 0.90 (assumed), Area = 1 ha, Vws = 10. A. In/Ep (1-LR), Vfi = 10. A. In/Ea (1-LR), V= (——) * (—————) Ea (Application efficiency) = 0.95 (assumed), Leaching requirement (LR) = NIL, In = ETm x growth period
Ea (1-LR) ETo = Pooled values of both the years, Kc = Pooled values of 100% Epan which is optimum treatment.

phase, rhizome initiation, rhizome development and maturity stage on pooled year basis, respectively.

Water productivity

Drip irrigation scheduled at 60% and 80% Epan registered significantly higher water productivity on cured rhizome yield basis (0.67 kg m^{-3} on pooled basis) over 100% and 120% Epan and surface irrigation at 1.0 IW/CPE ratio (Table 1). The decrease in water productivity at higher irrigation regimes might be due to the incremental yield increase at high irrigation levels could not compensate for the crop evapotranspiration. These results are in corroborated with Kaur and Brar, (2016) in turmeric. However, lowest water productivity was registered in surface irrigation at 1.0 IW/CPE ratio in both the years. In case of fertigation levels, each incremental increase level of nitrogen and potassium from 50% to 125% N and K ha^{-1} increased the water productivity. Highest water productivity on was registered at 125% N and K ha^{-1} over 50%, 75% and 100% N and K ha^{-1} treatments.

Net (In) and gross irrigation requirement (V)

Net (In) and gross irrigation requirement (V) at field inlet and at water source under assumed project efficiency (Ep) and field application efficiency varied widely with crop growth stages (Table 4). The net irrigation requirement for turmeric crop ranged from 86.9 to 425.9 mm at different phonological stages with seasonal requirement of 1001.19 mm for the total crop growing season. On the other hand the gross irrigation requirement (V) at field inlet and at water source varied from 915.22 m^3 to 4482.99 m^3 and 966.06 m^3 to 4732.04 m^3 with a seasonal total of 10538.83 m^3 and 11124.32 m^3 respectively. The peak irrigation requirement is 4732.04 m^3.

Conclusion

The present research aimed to determine the exact plant water usage or ETc and Kc for turmeric in Jalgaon region of Maharashtra, India. Drip irrigation with fertigation of nitrogen and potassium is an advantageous technique for getting higher yield of turmeric. The study established precise information on ETc and ETc rate at different crop stage wise for turmeric crop. The result showed that Kc values vary from one region to another. Drip irrigation at 1.0 Epan recorded significantly higher total fresh rhizome yield and Kc values in this treatment was higher than FAO Kc values which will be useful to estimate actual crop water requirements for turmeric in Jalgaon region and further developing precise irrigation schedules. The corrected Kc values for turmeric in the Jalgaon region of Maharashtra are obtained and these values offers a scientific reference for irrigation planning for scientist, farmers, stakeholders and policy makers for profit maximization and resource conservation.

Conflict of interest: Hereby all the authors declare that there is no conflict of interest among us on submitted manuscript.

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