Irrigation & Drainage Systems Engineering

Research Article Open Access

Estimation of Crop Coefficient and Water Requirement of Dutch Roses (Rosa hybrida) under Greenhouse and Open Field Conditions

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Abstract

Precise estimation of reference evapotranspiration (ETo) and crop evapotranspiration (ETc) on a daily basis is important to apply water through drip system for crops grown in the greenhouse. Crop coefficients and crop water requirement were determined for the Dutch roses cultivated in the greenhouse and open field for the sub-humid climatic conditions of Kharagpur, India. Reference evapotranspiration (ETo) was estimated using the method suggested by FAO-56. The crop ET was determined using soil water balance approach. The soil moisture data was collected using TDR moisture meter at three depths. The maximum daily values of Crop ET were 4.99 and 5.28 mm day^{-1} for greenhouse and open field conditions respectively. Maximum values of crop coefficient were found during conjunction period of mid-season and late season stage of the crop growth period. During different growth stages of rose, crop coefficient values were found in the range from 0.48 to 0.96 and 0.59 to 1.01 for greenhouse and open field conditions. The Dutch rose planted in 200 μ diffused poly film cladded greenhouse and given 100% water requirement through drip irrigation resulted in maximum number of flowers/m^2 (212.3) annually. Total annual water requirement of rose plant was 999.51 mm and 1210.94 mm for greenhouse and open field condition respectively.

Keywords: Dutch rose; Crop coefficient; Crop evapotranspiration; Greenhouse

Introduction

Rose is a leading cut flower grown commercially all over the world. It ranks first in global cut flower trade. This flower has a worldwide consumption of more than 40 billion [1]. The various purposes for rose cultivation includes garden flowers, aesthetic value, decoration and preparation of various products such as rose oil, rose water, gulkhand rose attar, garland etc. The heavy demand of rose cut flowers in the European markets is mainly from November to March due to the shortage of local production because of severe winter. Fortunately, this is the most congenial condition for successful production of most of the cut flowers, including roses in India. It is pointed out that buyer at international market prefers a very high quality rose cut flowers. As it is difficult to obtain good quality cut flowers under open conditions throughout the year, the crops should be cultivated under the greenhouse to get good quality produce.

Greenhouse cultivation or protected cultivation is a kind of farming systems used to maintain a controlled or partially controlled environment suitable for maximum crop production. This includes creating an environment suitable for working efficiency as well as for better crop growth. The presence of a cover, characteristics of greenhouses, causes a change in the climatic conditions compares to those in open field. The property of cladding materials alters the magnitude and quality of solar radiation incidence in the greenhouse, thereby affecting the micro climate of greenhouse. UV stabilized diffused film does not allow the shadow formation of top canopy on the lower leaves. Diffused radiation penetrates deeper into plants canopy in comparison to direct radiation; thus, it is desirable to use diffused film. At high irradiation, diffused film greenhouse cover leads to better light distribution, lower plant temperature, decreased transpiration and increased photosynthesis and growth [2].

Drip irrigation has been proved as an effective water-saving irrigation method and it is important component of greenhouse cultivation system. Drip irrigation research studies carried out at Precision Farming Development Centre, IIT Kharagpur, India on several vegetable and fruit crops showed increase in yield, saving in water, higher water use efficiency and net increase in profit [3,4].

Crop evapotranspiration (ET) is required for determination of crop water requirements, irrigation scheduling and water productivity. The water balance method is a simple and easy to use as compared to several methods reported in the literature. ET is estimated using water balance method considering change in total soil water content between sampling dates plus rainfall minus any known drainage or surface runoff occurred during the period [5]. Time Domain Reflectometry (TDR) probes and capacitance-based sensors are popular devices for measuring inside soil water content directly. Advantages of these electronic sensors are in-situ measurements with continuous recording [6].

Crop coefficient is a significant parameter for estimation of crop evapotranspiration, because it accounts biological characteristics of crops, crop condition, soil texture, soil tillage conditions, crop growing environment etc. [7]. The crop coefficient Kc, is ratio of crop ET to reference ET, is needed to estimate crop evapotranspiration for irrigation planning at a regional scale. The crop coefficient value represents crop specific water use and is required for accurate estimation of irrigation requirement of single or more than one crop grown under different climatic conditions [8].

Several studies on estimation of water requirement and crop coefficient have been conducted for open field crops like Cotton (Abdelhadi et al. [9] Fisher [10]), Maize (Akinmutimi, [11] Chuanyan and Zhongren [12]), Onion and Spinach (Piccinni et al. [13]) Okra (Odofin et al. [14] Tiwari et al. [3]), Capsicum (Miranda et al. [15]), Cabbage Tiwari et al. [4] Paddy (Kuo et al. [16]), Wheat and Sorghum

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Received July 28, 2016; **Accepted** August 16, 2016; **Published** August 23, 2016

Citation: Singh VK, Tiwari KN, Santosh DT (2016) Estimation of Crop Coefficient and Water Requirement of Dutch Roses (Rosa hybrida) under Greenhouse and Open Field Conditions. Irrigat Drainage Sys Eng 5: 169. doi: 10.4172/2168-9768.1000169

Tyagi et al. [17] Teff (Araya et al. [18]), Sapota (Tiwari et al. [4]), Jujube (Hu et al. [19]), Pomegranate (Parvizi et al. [20]) and greenhouse crops like Tomato (Maldonado et al. [21] Gómez et al. [22], Wahb-Allah et al. [23] Harmanto et al. [24]), Eggplant Senyigit et al. [25] Melon, Green beans, Watermelon and Pepper (Orgaz et al. [26]), Gladiolus (Bastug et al. [27]), Cucumber (Zhang et al. [28] and Blanco and Folegatti [29]) However, limited studies are found on cultivation of rose crop under greenhouse conditions (Ehret et al. [30] Katsoulas et al. [31]) and no literature is reported for the estimation of water requirement and crop coefficient of Dutch roses under greenhouse conditions. Therefore, the present study have been undertaken to determine the crop coefficient and water requirement of Dutch rose under greenhouse and open field conditions.

Materials and Methods

Description of the experimental area

Experiment was conducted at the Field Water Management Laboratory of Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India. The experimental site is located on flat land at 22°18.5' N latitude, 87°19' E longitude and 48 m altitude above mean sea level. The local climate is sub-humid subtropical with an average annual rainfall of 1390 mm, of which about 80% is received during June to October. The mean monthly minimum temperature is 12°C in January, whereas the mean monthly maximum temperature is 41.5°C in May. The mean monthly relative humidity varies from 35% in February to 96% in July-August. The site was deep and well drained sandy loam soil. The average values of sand, silt and clay was 63%, 28% and 9% respectively in the soil depth of 1 m.

Experimental greenhouses

Two experimental sawtooth shape greenhouses (N-S oriented) one cladded with 200 μ diffused (PAR transmissivity as 90% and 42% diffusivity) film and another with 200 μ clear UV stabilized film installed at the Field Water Management Laboratory of Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, India. The total ground area of each greenhouse was 84 m^2 with central height of 4.5 m and gutter height of 4 m (Figure 1). Greenhouses had provision to vary ventilation area maximum upto 60% (60% of the floor area) to allow hot air to escape during peak summer. Ventilation was provided at ridge and both sides of the greenhouses. These ventilated openings were covered with an insect-proof net of 60 mesh size to prevent the entry of insects. These greenhouses were also equipped with fogging system (16 L h^{-1} discharge capacity) and shade net (75% shading intensity) beneath the greenhouse roof. Two exhaust fans with a capacity of 1100 m^3/min with 2.2 kW power were installed to replace hot air with ambient air in the greenhouse. Natural ventilation was maintained in both greenhouses, however fans were operated only when the air temperature in the greenhouse was high during peak summer.

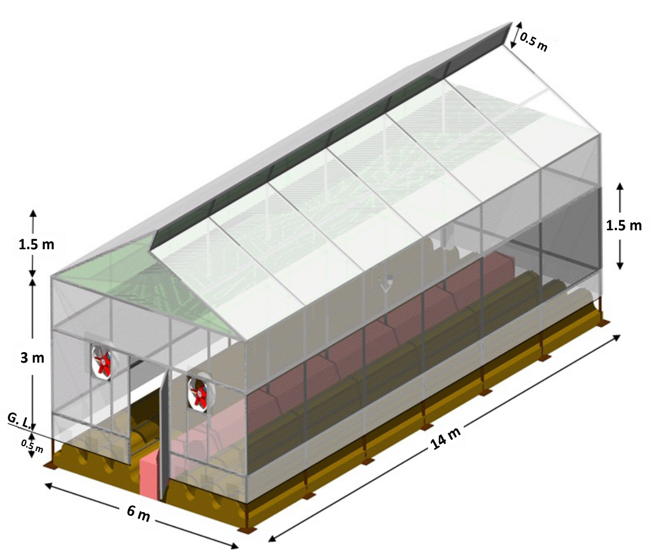

Figure 1: Isometric view of the experimental greenhouse.

The diffused film used for cladding of one of the greenhouses has inbuilt property to scatter the radiation and does not form shadow on the top of the canopy of lower leaves.

Monitoring of greenhouse microclimate: Automatic weather station of M/S Campbell Scientific, Canada comprising a data-logger (model CR1000) and sensors were installed in the greenhouse to monitor soil temperatures (models 107 BL and CS616 L), air temperatures and relative humidity (model HMP 45 C), global radiation and Photosynthetically Active Radiation (SPLITE and PARLITE of Kipp and Zonen). Outside air and soil temperatures, relative humidity and solar radiation were measured manually at 8:30 AM, 12:30 PM and 4:00 PM in a day.

Reference evapotranspiration, ET_O

Reference evapotranspiration (ET_O) was estimated using the method suggested by FAO-56 [2]. The equation used to estimate ET_O is described below [5]:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \quad (1)$$

Where,

ET_O - Reference evapotranspiration [mm day^{-1}], R_n - Net radiation at the crop surface [MJ m^{-2} day^{-1}], G - Soil heat flux density [MJ m^{-2} day^{-1}], T - Mean daily air temperature at 2 m height [°C], u_2 - Wind speed at 2 m height [m s^{-1}], e_s - Saturation vapour pressure [kPa], e_a - Actual vapour pressure [kPa], e_s-e_a - Saturation vapour pressure deficit [kPa], Δ - Slope vapour pressure curve [kPa °C^{-1}], γ - Psychrometric constant [kPa °C^{-1}].

In a greenhouse, wind speed approximately equals to zero; therefore, the Eq. (3) can be simplified written as [28]:

$$ET_o = \frac{0.408\Delta(R_n - G)}{\Delta + \gamma} \quad (2)$$

Crop details

Dutch rose plants (Variety First Red) were transplanted at a spacing of 0.5 m between rows and 0.3 m between plants in a row in both the greenhouses and also in open field on October, 2009. Rose nursery plants were planted on raised bed of 1 m wide with two rows per bed. A trench of 30 cm wide and 50 cm deep was dug in between two beds for removal of excess moisture from root zone and separation of one treatment from other. To improve the soil organic matter and nutrient (NPK) contents, manures and fertilizers were applied 1 month prior to the planting. The soils of beds were incorporated with 15 kg m^{-2} of Farm Yard Manure, 5 kg m^{-2} of vermi compost, 0.5 kg m^{-2} *Neem* cake and 0.2 kg m^{-2} of single superphosphate. The crop was drip-irrigated using one lateral per bed of two rows and one emitter of

2 L h^{-1} capacity, which met the water requirement of 4 plants of both rows. The drip irrigation system's emission uniformity was determined and maintained above 90%. Recommended dose of soluble fertilizers were applied twice in a week using a venturi injector. After 180 days of planting, plants were pruned to a height of 0.3 m above the ground. There after pruning was done once in a year to increase the number of branches for good flowering.

Measurement of crop evapotranspiration, ET_C

The actual crop evapotranspiration was estimated with the soil water balance method. The soil moisture changes in 0–90 cm soil layer during the study period were measured and used to estimate actual crop evapotranspiration with equation (1) [5]. Three circular shape drums having closed bottom, each having 0.5 m^2 cross sectional area, 1 m deep and 5 mm thick wall (Figure 2) were installed in the greenhouse. Three drums of the same size and specifications were installed outside in open field. Considering the rose plants spacing and the drum dimensions, one rose plant was planted in the each drum installed inside and outside the greenhouse. The packages of practices for the plant inside and outside the drum were maintained identical. Rose plant planted in the drum lysimeter installed outside the greenhouse is mulched with plastic film to prevent the entry of rainwater in the lysimeter during rainy season. Soil water content was measured daily using TDR moisture meter at 0-30, 30-60 and 60-90 cm depth. The root zone depth of rose plant was maximum up to 45-50 cm. The soil moisture measured at 60-90 cm was considered as vertical drainage and deducted from amount of irrigation water applied to estimate crop evapotranspiration. Appropriate amount of irrigation water was applied manually to the plant in lysimeters to replenish depleted soil moisture at field capacity. Soil-water depleted was determined by the TDR moisture meter readings and replenished by a factor of 1.1 on the same day, to meet the crop evapotranspiration in the next following day [15]. Amount of irrigation water varied according to crop water use in different growth stages. These measurements and irrigation water supply were done for the full rose crop season. Crop evapotranspiration was calculated using the change in soil moisture content and measurement of other water

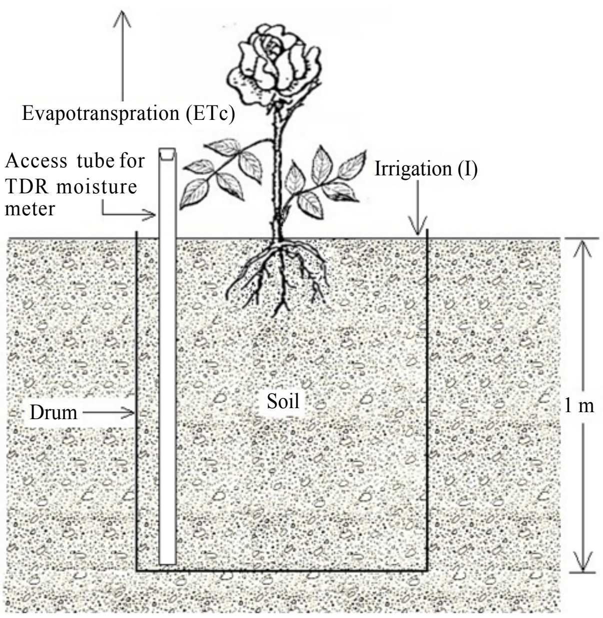

Figure 2: Cross sectional view of drum lysimeter used for determination of ET_C of rose.

balance parameters from following water balance equation

$$ET_C = P + I - R - D \pm \Delta W \quad (3)$$

Where,

ET_C: Crop evapotranspiration (mm); P: Precipitation (mm); I: Irrigation water depth (mm); R is the surface runoff (mm); D: Amount of water drained from the root zone (mm); ΔW: change in soil water storage (mm). Contribution of water due to rain in the greenhouses was zero, hence, P = 0. The contribution of lateral flow and surface runoff during irrigation events was also zero, hence R = 0.

Thus Eq. (1) can be simplified as follows

$$ET_C = I - D \pm \Delta W \quad (4)$$

The change in the amount of soil-water into the drum (ΔW) is computed by the difference between soil moisture observations of two consecutive days.

Establishment of crop coefficient (K_C) of Dutch roses for greenhouse and open field

The crop coefficient values for Dutch roses were determined for the crop grown both in greenhouse and open field conditions. The average crop coefficients for Dutch roses are estimated with an assumption that one annual cycle of crop is started after planting of crop in October and completed in next September month when pruning is done. The next annual cycle is started just after pruning and completed in next September month when pruning is done. Crop coefficient was computed on a daily basis from transplanting to pruning and pruning to pruning in next year using following equation:

$$Kc = \frac{ET_C}{ET_O} \quad (5)$$

Average crop coefficients were calculated for the initial ($Kc_{initial}$), development (Kc_{dev}), mid-season (Kc_{mid}) and late-season (Kc_{late}) growth stages. The lengths of the growth stages were determined based on the crop phenological phase and the Kc curve. $Kc_{initial}$ begins from transplanting to plant covers 10% of the plant area. The Kc_{Dev} begins after $Kc_{initial}$ (i.e., 10% canopy to 60% of canopy area). The Kc_{mid} begins after Kc_{Dev} ends (i.e., canopy attains 60% and ends in the later part of the season when the crop begins to enter in the end of the season) and the Kc_{late} starts when crops has more than 60% canopy and end when crop attains dormant stage.

Water requirement of rose plant under greenhouse and open field conditions

To optimize the water requirement of rose plants grown under two saw tooth shape greenhouses cladded with UV stabilized clear and diffused film of 200 µ thickness, an experiment was conducted for three years (January 2012 to December 2014) with four irrigation levels of 100%, 80%, 60% and 40% of estimated crop evapotranspiration (ETc) application. The experiment was designed to assess the effect of irrigation levels and greenhouse cladding materials on biometric growth and yield (No. of flowers) of rose plant. Eight treatments replicated three times were planned for the greenhouses and one treatment for open field as a control to compare the results. Statistical analysis was done for analysis of variance (ANOVA) using the Least Significant Differences (LSD) test at the 5% probability level (P = 0.05).

Treatment details are stated below:

T1 : 100% water requirement supplied through drip system to rose plants under greenhouse cladded with clear film

T2: 80% water requirement supplied through drip system to rose plants under greenhouse cladded with clear film

T3: 60% water requirement supplied through drip system to rose plants under greenhouse cladded with clear film

T4: 40% water requirement supplied through drip system to rose plants under greenhouse cladded with clear film

T5: 100% water requirement supplied through drip system to rose plants under greenhouse cladded with diffused film

T6: 80% water requirement supplied through drip system to rose plants under greenhouse cladded with diffused film

T7: 60% water requirement supplied through drip system to rose plants under greenhouse cladded with diffused film

T8: 40% water requirement supplied through drip system to rose plants under greenhouse cladded with diffused film

T9: 100% water requirement supplied through drip system to rose plants in open field conditions (Control)

Drip irrigation was installed to irrigate plants inside the greenhouse and outside (open field). The time of operation of drip system was computed using daily water requirement of four plants and emitter discharge for each irrigation. In drip system, irrigation was scheduled on alternate days and the quantity of total water applied was calculated on the basis of daily crop water requirement. The lateral lines of 16 mm diameter were laid parallel to plant rows. Online emitters of 2 L h^{-1} capacity were fitted with lateral and each emitter served the water requirement of four plants. Irrigation duration for delivery of water for different treatments was controlled with the help of gate valve provided at the inlet of each laterals. The operating pressure of about 1 kg/cm^2 was maintained to obtain design dripper discharge. The layout of the experiment and the division of beds along with the laterals are shown in Figure 3.

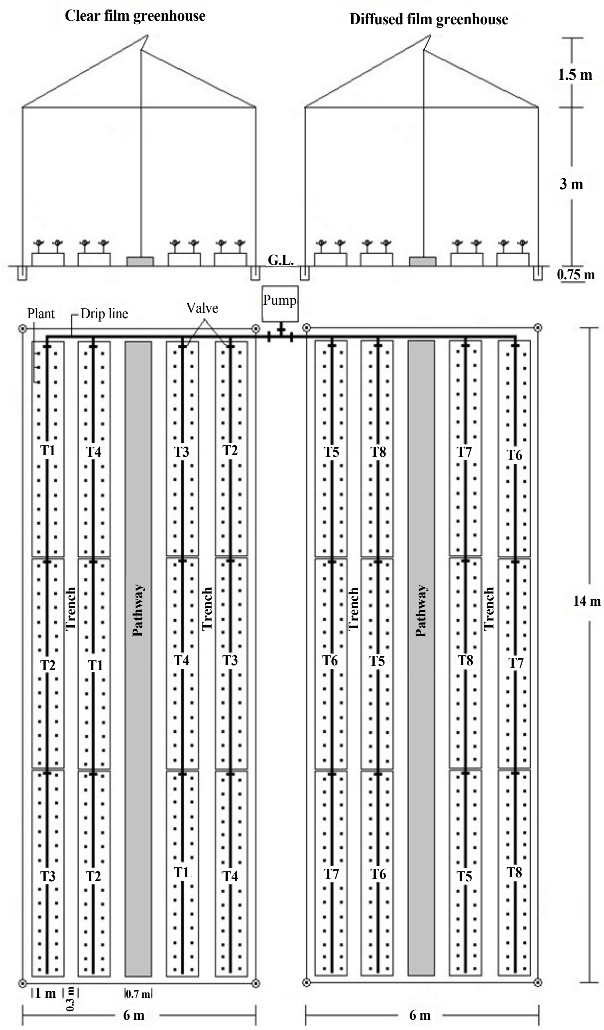

Figure 3: Experimental layout of different treatments.

Bio-metric observations and water productivity: Bio-metric observations viz. plant height, number of shoots per plant, shoot length, number of flowers/m^2/year, flower diameter and number of petals per flower were recorded at 15 days interval to evaluate the effect of irrigation levels and cladding materials on yield and yield attributes of Dutch roses inside the greenhouse and in open field (outside).

The annual water productivity (number of flowers/m^2/mm) for greenhouse and open field treatments were calculated using the following equation [5]:

$$AWP = \frac{Y}{AWU} \tag{6}$$

Where,

Y is total flower yield (number of flowers/m^2) and AWU is annual water use (mm)

Results and Discussion

Estimation of ETo for inside the greenhouse and open field

The meteorological observations collected from automatic weather stations were substituted in FAO Penman-Monteith equation to calculate daily ETo for fifteen years (January 2000 to December 2014) for inside the greenhouse and outside (open field), and the results are shown in Table 1 and Figure 3. It can be seen from Figure 3 that average ETo value inside the greenhouse and outside (open field) are relatively of greater amount from late March to October months as compared to January to early March and November – December. In April, the average daily ETo value of month is below 4 mm except a few high values occurred at the end of this month. With the increase of sunshine hours and the intensity of radiation, ETo value gradually increases. Peak value of the ETo (i.e., 5.39 mm) was observed in the month of May. June months onward average daily ETo values was reduced due to incidence of rainfall, low solar radiation, and high humidity especially during monsoon months (June to September). Further due to lowering of temperature from October months onward till March, daily ETo values reduced and reached to lowest in the month of January. ETo values get affected due to cloud cover and rains, hence fluctuating ETo values were found in the same months.

FAO Penman-Monteith equation contains two parts: one radiation and other aerodynamic components and they represent the impact of solar radiation and convection, turbulence and degree of drying above the evaporating surface respectively [32,33]. Both of these two components are dynamic processes vary with time with influenced by location and climatic conditions. Analysis of data shows that the part of solar radiation component is more than 60% of total evapotranspiration

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Month	Inside/ outside condition	Reference evapo-transpiration, ETo (mm day^{-1})	Kc	Actual evapo-transpiration*, ETc (mm day^{-1})	Area occupied by four plants (4×0.5×0.3) (m^2)	Required discharge through single emitter (L day^{-1})	Time of operation of drip system per day with 2 Lh^{-1} emitters (min)
		A	B	C=A×B	D	E=C×D	
Jan	Greenhouse	1.67	0.86	1.43	0.6	0.86	25.9
	Open field	2.40	0.89	2.14	0.6	1.28	38.5
Feb	Greenhouse	2.05	0.87	1.78	0.6	1.07	32.1
	Open field	3.12	0.90	2.81	0.6	1.69	50.6
Mar	Greenhouse	2.81	0.89	2.51	0.6	1.50	45.0
	Open field	4.18	0.93	3.89	0.6	2.33	70.0
Apr	Greenhouse	3.88	0.92	3.57	0.6	2.14	64.3
	Open field	4.99	0.96	4.79	0.6	2.87	86.2
May	Greenhouse	5.20	0.96	4.99	0.6	3.00	89.9
	Open field	5.39	0.98	5.28	0.6	3.11	93.4
Jun	Greenhouse	4.41	0.96	4.23	0.6	2.54	76.2
	Open field	4.59	1.01	4.63	0.6	2.78	83.4
Jul	Greenhouse	3.84	0.89	3.42	0.6	2.05	61.5
	Open field	4.05	0.97	3.93	0.6	2.36	70.7
Aug	Greenhouse	3.89	0.82	3.19	0.6	1.91	57.4
	Open field	4.11	0.84	3.45	0.6	2.07	62.1
Sept	Greenhouse	3.74	0.76	2.84	0.6	1.71	51.2
	Open field	4.02	0.78	3.14	0.6	1.88	56.4
Oct	Greenhouse	3.67	0.48	1.76	0.6	1.06	31.7
	Open field	3.96	0.52	2.06	0.6	1.24	37.1
Nov	Greenhouse	2.70	0.60	1.62	0.6	0.97	29.2
	Open field	2.96	0.63	1.87	0.6	1.12	33.6
Dec	Greenhouse	1.93	0.76	1.47	0.6	0.88	26.4
	Open field	2.34	0.81	1.90	0.6	1.14	34.1

* This is 100% of crop evapotranspiration estimated for Dutch rose crop with drum lysimeter in this study (treatments T1 & T5). ETc for treatment T2 & T6 is 80%, T3 & T7 is 60% and treatment T4 & T8 is 40% of this estimated value of ETc.

Table 1: Estimated water requirement and crop coefficient of Dutch rose crop and time of operation of drip system for different months.

during study period, and it is maximum in May. From May month to August month, the solar radiation decreases from the 23.5 MJ/m^2/day in May to 18.5 MJ/m^2/day in August, during which the value of each month are 23.5, 19.0, 17.4 and 18.5 MJ/m^2/day during May, June, July and August respectively. This is due to decrease in solar intensity and day length during monsoon months.

Comparison of monthly ET_O values of greenhouse and open field conditions shows that ET_O of greenhouse is always lower and this is due to the reduced evaporative demand inside the greenhouse (Figure 3). The evaporative demand is lower inside the greenhouse than outside (open field) due to the decrease in solar radiation (20% on average) and the wind speed is nearly zero. The evaporative demand inside the greenhouse is 60 percent of that of outside and the same finding is reported by Möller and Assouline [34] Fernández et al. [35]. They used lime suspension on greenhouse cover surface to cut down the entry of solar radiation to reduce air temperature that caused ETo reduction. During May to August there is very less difference between ETo of inside and outside of greenhouse, is because of high humidity with minor difference in dry bulb and wet bulb temperature of prevailing micro climate.

Soil water content at different depth in drum lysimeter

Soil moisture content at three depths (0-30, 30-60 and 60-90 cm) of drum lysimeters kept inside and outside of greenhouse was measured daily with the help of TDR moisture meter. Analysis of the soil moisture data collected from TDR moisture meter shows that moisture content in the middle layer (30-60 cm) was found maximum (15.4-9.1%) in comparison to top layer (14.6-18%) and bottom layer (14-16.1%). The top layer has high evaporation due to greater soil temperature hence lesser soil moisture content than middle layer. The top soil (up to 50 cm) of lysimeters had rich organic matter which might have increased in water holding capacity of soil, hence moisture content at bottom layer was found to retain lesser than top and middle layers (Figure 4). Similar trend of soil moisture content was observed in all the three layers of soils of lysimeters kept outside the greenhouse (open field). Within the whole growth period, the change in values of soil water content at different layers reflects crop evapotranspiration demand. In the drip irrigation water supply, the evaporation of soil water is lesser than the surface irrigation and changes of soil water content indirectly reflect characteristics of the crop water consumption [19].

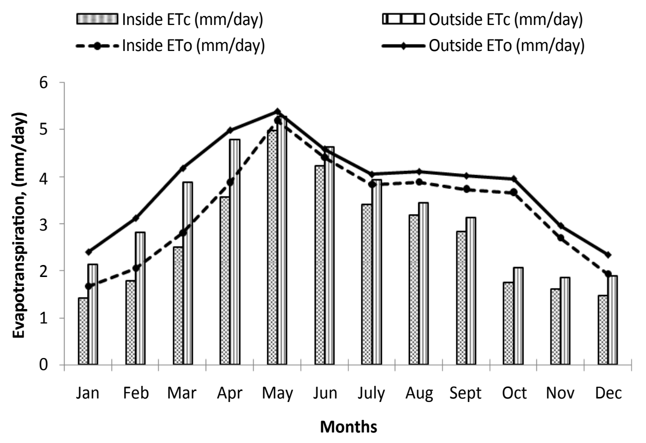

Figure 4: Relationship between ETo and ETc in greenhouse and outside conditions.

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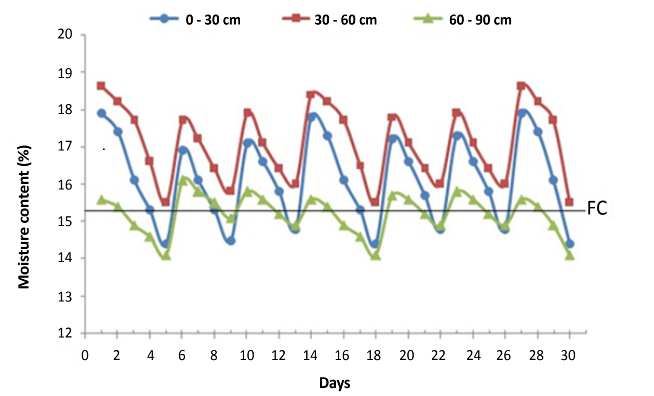

Figure 5: Soil moisture variations at different depth of lysimeter.

Crop evapotranspiration (ETc) and crop coefficient (Kc)

The evapotranspiration (ETc) of the rose crop was determined daily from the drum lysimeters kept inside and outside the greenhouse for the full crop season is presented in Table 1 and Figure 5. Daily Rose plant ET_C values varied from 1.43 to 4.99 mm day^{-1} and 1.86 to 5.28 mm day^{-1} for greenhouse and outside conditions respectively. Evapotranspiration (ETc) requirement of the plant in drum lysimeters in greenhouse is lower than the plant of drum lysimeters kept outside (open field) due to the reduced evaporative demand inside the greenhouse [34,35]. Maximum ET_C values occurred in the month of May when the crop is fully matured with greater level of ground cover [15]. ETc values reduced considerably and reached to 3.5 mm day^{-1} which coincided during the flower harvesting period. Then, during the second flowering peak, ETc values increased again rapidly, but did not reach the same level as observed during the first flowering peak.

Daily crop coefficient value was estimated for three years (October 2009 to October 2012) of experimental period and averaged on monthly basis. The daily average value of crop coefficient for one complete cycle under greenhouse and open field conditions are presented in Table 1 and Figure 6. The crop coefficient for greenhouse conditions is 0.48 to 0.6 during initial stage ($K_{C\ In}$), 0.6 to 0.86 during development stage ($K_{C\ Dev}$), 0.87 to 0.96 during middle stage ($K_{C\ Mid}$) and 0.96 to 0.76 during late season ($K_{C\ Late}$). In the same way the crop coefficient for open field conditions was estimated and found to vary from 0.50 to 0.63 during initial stage ($K_{C\ In}$), 0.63 to 0.89 during development stage ($K_{C\ Dev}$), 0.90 to 1.01 during middle stage ($K_{C\ Mid}$) and 0.97 to 0.78 during late season ($K_{C\ Late}$).

During different growth stages of rose, crop coefficient value varied from 0.48 to 0.96 and 0.59 to 1.01 for the plant under greenhouse and open field conditions. During the initial stage (30 days) of the plant crop coefficient is found lower value because of lesser ground cover and low crop water requirement whereas during the development stage (90 days) it is more than earlier [29]. During the mid-season (120 days) stage crop coefficient is found maximum for both greenhouse and open field conditions.

Crop coefficient values decreased steadily after the first harvest, reaching minimum values close to 0.75. After the pruning is done, a new cycle of vegetative growth and flowering began, that increased Kc values again. Finally, during the second harvest period Kc values decreased again. The similar trend of crop coefficient under both the conditions is found during all three years of experimental period. The behaviour of the crop coefficient curve throughout the Dutch rose growth period, with a short period of low Kc values kept between two phases of high Kc values, matched with the crop phonological behaviour observed in the lysimeter. Although the Dutch rose produced incessantly after the first harvest, it presented basically two phases when flowering was more intense.

The rose plant present more than one harvest cycle, it is important to adjust the Kc value accordingly, increasing the Kc during periods of full ground cover and decreasing the Kc when pruning is done. Since there are no published Kc values specific for Dutch rose for both the conditions, it was assumed that for irrigation management purposes one would use Kc values recommended in this study.

Micro climate behavior of greenhouse cladded with UV stabilized clear and diffused film

During summer season (May to September), the average daily variation of temperatures was found to vary between 35°C to 44°C and 34°C to 42°C in the UV stabilized clear film and diffused film respectively and during winter season (November to February), average daily air temperature in the UV stabilized clear and diffused films at 12:30 PM varied from 25°C to 31°C and 23°C to 29°C respectively against open field condition (22 to 28°C). The maximum temperature reduction in winter at 12:30 PM in the diffused film was 3°C as compared to the clear film.

The study of temperature variation in the clear and diffused covers indicated that the UV stabilized clear film maintained 3°C higher temperature than diffused film during winter and 2°C higher temperature than diffused film during summer months. Temperature reduction in the UV stabilized diffused film is more prominent than in the UV stabilized clear film due to the diffusive property. UV stabilized clear film maintained 10-15% lesser relative humidity than the diffused film whereas outside relative humidity is even lesser than diffused film. Weekly variation of solar radiation levels in the greenhouse at 12:30 PM during winter season varied from 32 to 56 Wm^{-2} and 38 to 67 W m^{-2} in the clear and diffused film respectively against the ambient solar radiation of 74 to129 W m^{-2}. Whereas in summer months, it varied from 34 to 61 W m^{-2} and 41 to 82 W m^{-2} in the clear and diffused covers, respectively against the ambient solar radiation of 86 to 170 Wm^{-2}. UV stabilized diffused film passes 20-34% more solar radiation than clear film. This solar radiation is directly related to the Photo synthetically Active Radiation (PAR) which is used in the photosynthesis of crop, hence better crop growth is found under diffused film cladded

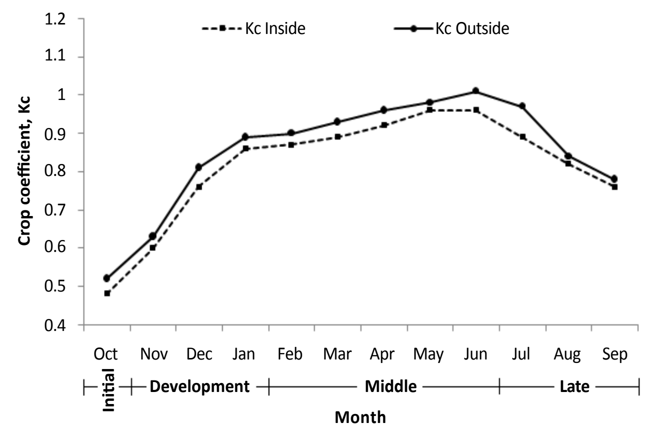

Figure 6: Crop coefficient for Dutch roses under greenhouse and open field conditions.

greenhouse. It is clear from other studies that Ultraviolet (UV), Photosynthetic Active Radiation (PAR) and Near-Infrared (NIR) is the part of solar radiation and which transmit through the greenhouse covering material. The PAR is essential for photosynthesis which is favourable to plants growth. Thus, greenhouse cladding films which diffuse the incoming solar radiation can offer several advantages and provide better micro climate (Chou and Lee [36], Kondratyev [37], Lamnatou and Chemisana [38,39], Espí et al. [40]). Soil temperature in the greenhouses cladded with clear and diffused film at 25 cm depth during winter season ranged from 19 to 21°C and 18 to 21°C respectively. During summer season, it varied from 25 to 29°C and 24 to 28°C in clear and diffused film cladded greenhouse. It was observed that no significant difference in the soil temperature was found in the greenhouses cladded with clear and diffused film.

Optimum water requirement for Dutch roses under two greenhouses of different cladding materials

To optimize the water requirement of the Rose crop under two different types of cladded film greenhouse (clear and diffused UV stabilized film of 200 µ thickness), the treatment wise biometric observations were recorded and analyzed for different irrigation levels.

The analysis of biometric data revealed that Dutch rose cultivation with 100% water requirement for the greenhouse cladded with diffused film (T_5) resulted in best performance than control plots in terms of plant height (68.8 cm), shoot length (46.2 cm), flower diameter (6.97 cm), number of petals per flower (25.1), number of shoots per plant (29.3) and number of flowers/m²/year (212.3) (Figure 7).

Time of operation of the drip irrigation system with 2 Lh^{-1} emitters for different months of growth period of rose crop planted inside and outside of greenhouse was also estimated and results are presented in Table 1. The maximum time of operation of drip system to irrigate rose plants was 89.9 minutes and 93.4 minutes required in May month under greenhouse cladded with diffused film and open field conditions respectively however, minimum time of operation is needed in January month i.e., 25.9 minutes and 38.5 minutes for inside and open field conditions respectively.

Effect of different levels of irrigation on biometric response of Dutch roses

The effect of different levels of irrigation on biometric parameters such as plant height, number of shoots per plant, shoot length, number of flowers/m²/year, flower diameter and number of petals per flower were analyzed statistically and compared with that of open field experimental treatment (T_9). The experimental results of these biometric observations for all the three years are presented in Figure 7. The analysis of variance results showed that variation among the replications for all the treatments was found to be statistically insignificant at 5% level of significance.

The plant height responded significantly with different irrigation levels of drip irrigation, however, plant height at 100% irrigation level (T_1 and T_5) was statistically at par with 80% irrigation level (T_2 and T_6). Similar trend was found for all the 3 years. The plant height was found to be highest in the year 2012 as compared to other 2 years data. Irrigation levels had no significant influence on flower diameter and number of petals per flower.

Significant increase in the number of shoots per plant was obtained due to drip irrigation treatment at all the levels of irrigation. Among various levels of water supply 100% irrigation requirement met through drip resulted in best over 60% and 40% irrigation levels in terms of number of shoots per plant and shoot length. However, biometric response at 100% and 80% of water requirement supply through drip was statistically at par. The maximum shoot length and number of flowers/m²/year were recorded for the year 2012 in comparison to other two years (2011 and 2013). It can be seen that the 100% irrigation supply has significant influence on number of flowers/m²/year over two other irrigation levels that is 60% and 40% and 100% irrigation supply in open field treatment.

In all the three years the number of shoots per plant and number of flowers/m²/year at 100%, 80% and 60% irrigation levels was significantly greater than that of open field conditions. Based on the average yield (number of flowers/m²/year) of three years, all the irrigation levels at 100%, 80% and 60% (i.e., T_5, T_6 and T_7 respectively) resulted in 55.8%, 52.9% and 29.4% higher yield respectively as compared to open field treatment (T_9). Hence, it showed that even by 60% deficit water supply through drip irrigation resulted in 29.4% higher flower yield of Dutch roses as compared to open field cultivation (T_9). The flower yield (presented in Table 2) was found to decrease as the amount of irrigation water supply was reduced from 100 % to 40 % of irrigation water requirement.

Effect of cladding materials on biometric response of Dutch roses

The plant growth and flower yield were greater in the greenhouse cladded with diffused film as compared to clear film cladded greenhouse. Among the various treatments under both the greenhouses treatment T_5 i.e., 100% irrigation water level in greenhouse cladded with diffused film responded the highest plant height in all the years considered in this study. There was significant influence of irrigation levels and

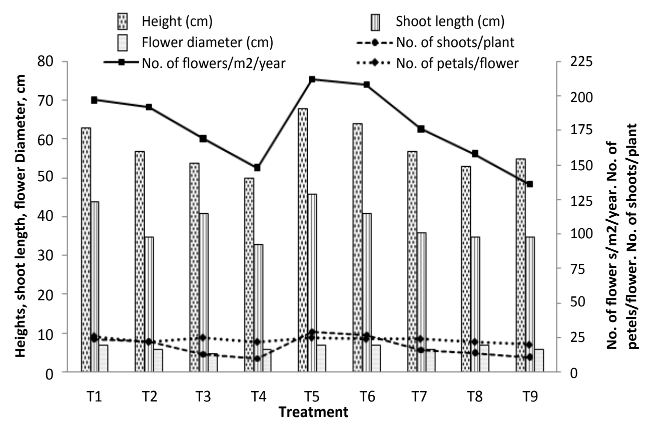

Figure 7: Biometric response of Dutch roses due to different treatments.

Treatment	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
Water applied (mm)	999.5	799.6	599.7	399.8	999.5	799.6	599.7	399.8	1210.9
Yield (No. of flowers/m²/year)	197	192	169	148	212	208	176	158	136
Annual water productivity (No. of flowers/m²/mm)	0.20	0.24	0.28	0.37	0.21	0.26	0.29	0.40	0.11

Table 2: Amount of water applied and yield response of Dutch roses for different amount of water applications under different treatments.

cladding material on plant height, number of shoots per plant, shoot length and number of flowers/m^2/year. However, there is no significant influence of irrigation level and cladding material on flower diameter and number of petals per flower. Plant height and shoot length were found to be highest in case of greenhouse cladded with diffused film as compared to greenhouse cladded with clear film at the same level of irrigation water supply.

Analysis of biometric observations revealed that flower yield of Dutch roses (number of flowers/m^2/year) was recorded greater in all the 3 years for the crop grown in the greenhouse cladded with diffused film at all the levels of irrigation. Maximum number of flowers/m^2/year was found as 212 in treatment T_5 (i.e., 100% irrigation water level under greenhouse cladded with diffused film). With the same level of irrigation water application in both the cladded materials, the flower yield was always greater for greenhouse cladded with diffused film. This may be due to fact that the diffused film has inbuilt property to disperse solar radiation which penetrate into the crop canopy that increases photosynthesis process of the crop. Diffused film does not allow the radiations to interact directly to the plant leaves hence protect plats from scorching. Moreover, the plants in the greenhouse covered with diffused film were healthy compared to the clear film greenhouse during summer season. Lamnatou and Chemisana also observed the same results that diffused light have the ability to penetrate deeper into a plant canopy in comparison to the direct light [38,39]. The seasonal variation of solar radiation, affect variations in the crop response. The temperature in diffused film greenhouse was 2-3°C lower than clear film cladded greenhouse. Higher temperature prevailing in Kharagpur sub-humid climatic condition under greenhouse cladded with clear film resulted in inferior biometric response and reduced flower yield.

Water productivity

The annual water productivity (Number of flowers/m^2/mm) values (AWP) ranged from 0.2 to 0.37 and 0.21 to 0.40 for greenhouse cladded with clear and diffused film, however it is 0.11 for open field conditions (Table 2). The AWP values are always greater for the same amount of water application under diffused film cladded greenhouse. The AWP value was found to increase as the amount of irrigation water supply was reduced from 100% to 40% of crop evapotranspiration [40-42]. From the analysis of AWP values, it is clear that for water scarce region Dutch roses can be grown under diffused film cladded greenhouse at 40% of crop evapotranspiration with the compromise in 25.5% reduction in yield [43-44].

Conclusion

The evapotranspiration requirement (ETc) of Dutch roses established under greenhouse and open field conditions is useful for the determination of the irrigation water requirement. The crop coefficient (Kc) values established on a monthly basis for both the conditions from the beginning to the end of each annual cropping period are the basic information for estimation of ETc. Four Kc values are the irreducible minimum for describing and constructing the Kc curve, namely Kc values at the initial stage ($K_{c\ Initial}$), development stage ($K_{c\ Dev}$), mid-season stage ($K_{c\ mid}$) and the end of the late season stage ($K_{c\ end}$). The optimum water requirement of Dutch rose crop estimated under both the greenhouses can be successfully used by the rose growers and irrigation planners in other parts of the sub-humid climatic conditions.

There is significant influence of cladding materials on the Dutch rose plant height, number of shoots per plant, shoot length and flower yield during winter and summer seasons. The number of shoots per plant in the clear and diffused film is almost same up to 30 days after transplanting of the crop, and thereafter plant response gradually differs up to the flowering stage. The plant height is better under the diffused film greenhouse than that in the clear film greenhouse from vegetative stage to the flowering stage in winter and summer seasons due to inbuilt property of diffused film. The values of Crop ET are more for open field conditions than greenhouse. Total annual water requirement of rose plant is 999.51 mm and 1210.94 mm for greenhouse and open field condition.

Acknowledgement

Authors are thankful to the National Committee on Plasticulture Applications in Horticulture (NCPAH), Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India for providing necessary funds and Department of Agricultural and Food Engineering, IIT Kharagpur, India for making available necessary facilities to conduct this research studies.

References

1. Singh AK (2009) Greenhouse technology for rose production. Indian Horticulture. 54: 10-14.
2. Hemming S, Mohammadkhani V, Dueck T (2008) Diffuse greenhouse covering materials-material technology, measurements and evaluation of optical properties. Acta Horticulturae 797: 469-475.
3. Tiwari KN, Singh A, Mal PK (2003) Effect of drip irrigation on yield of cabbage (*Brassica oleracea* L. var. capitata) under mulch and non-mulch conditions. Agricultural Water Management. 58: 19-28.
4. Tiwari KN, Kumar M, Santosh DT, Singh VK, Maji MK (2014) Influence of drip irrigation and plastic mulch on yield of Sapota (*Achras zapota*) and Soil Nutrients. Irrigation and Drainage Sys Eng. 3: 116.
5. Allen RG, Pereira LS, Howell TA, Jensen ME (2011) Evapotranspiration information reporting: I.Factors governing measurement accuracy. Agricultural Water Management 98: 899-920.
6. Evett SR, Tolk JA, Howell TA (2006) Soil profile water content determination: sensor accuracy, axial response, calibration, temperature dependence, and precision. Vadose Zone Journal 5: 894-907.
7. Ma HY, Jiao XY (2006) Research progress of the crop water demand calculation. Water Science Engineering Technology 16: 5-7.
8. Doorenbos J, Pruitt WO (1975) Guidelines for predicting crop water requirements. Irrigation and Drainage. Italy.
9. Abdelhadi AW, Hata T, Tanakamaru H, Tada A, Tariq MA (2000) Estimation of crop water requirements in arid region using Penman-Monteith equation with derived crop coefficients: a case study on Acala cotton in Sudan Gezira irrigated scheme. Agricultural Water Management 45: 203-214.
10. Fisher DK (2012) Simple weighing lysimeters for measuring evapotranspiration and developing crop coefficients. Int J Agric & Biol Eng 5: 35-43.
11. Akinmutimi AL (2015) Estimation of water requirements of early and late season maize in Umudike southeastern Nigeria, using Penman's equation of soil science and environmental management. J Soil Sci Environ Manage 6: 24-28.
12. Chuanyan Z, Zhongren N (2007) Estimating water needs of maize (Zea mays L.) using the dual crop coefficient method in the arid region of northwestern China. Afr J Agric Res 2: 325-333.
13. Piccinni G, Ko J, Thomas M, Daniel IL (2009) Crop Coefficients Specific to Multiple Phenological Stages for Evapotranspiration-based Irrigation Management of Onion and Spinach. Hort Science. 44: 421-425.
14. Odofin AJ, Oladiran JA, Oladipo JA, Wuya EP (2011) Determination of evapotranspiration and crop coefficients for bush okra (Corchorus olitorius) in a sub-humid area of Nigeria. Afr J Agric Res 6: 3949-3953.
15. Miranda FR, Gondim RS, Costa CAG (2006) Evapotranspiration and crop coefficients for tabasco pepper (Capsicum frutescens L.). Agricultural Water Management 82: 237-246.
16. Kuo SF, Ho SS, Liu CW (2009) Estimation of irrigation water requirements with derived crop coefficients for upland paddy crops in ChiaNan Irrigation Association, Taiwan. Agricultural Water Management 82: 433-451.
17. Tyagi NK, Sharma DK, Luthra SK (2000) Evapotranspiration and crop

coefficients of wheat and sorghum. Journal of Irrigation and Drainage Engineering. 126: 215-222.

18. Arayaa A, Stroosnijderb L, Girmayc G, Keesstrab SD (2011) Crop coefficient, yield response to water stress and water productivity of teff (Eragrostis tef Zucc.). Agricultural Water Management 98: 775-783.
19. Hu Y, Li Y, Zhang Y (2012) A study on crop coefficients of jujube under drip-irrigation in Loess Plateau of China. Afr J Agric Res 7: 2971-2977.
20. Parvizi H, Sepaskhah AR, Ahmadi SH (2014) Effect of drip irrigation and fertilizer regimes on fruit yields and water productivity of a pomegranate (*Punica granatum* (L.) cv. Rabab) orchard. Agricultural Water Management. 146: 45-56.
21. Maldonado AJ, Mendoza AB, Alba-Romenus Kd, Morales-Díaz AB (2014) Estimation of the water requirements of greenhouse tomato crop using multiple regression models. Emir J Food Agriculture 26: 885-897.
22. Gómez HV, Farías SO, Argote M (2009) Evaluation of water requirements for a greenhouse Tomato cropusing the priestley-taylor method. Chilean Journal of Agricultural Research 69: 3-11.
23. Wahb-Allah MA, Alsadon AA, Ibrahim AA (2011) Drought tolerance of several tomato genotypes under greenhouse conditions. world applied sciences journal. 15: 933-940.
24. Harmantoa, Salokhea VM, Babelb MS, Tantau HJ (2005) Water requirement of drip irrigated tomatoes grown in greenhouse in tropical environment. Agricultural Water Management 71: 225-242.
25. Senyigit U, Kadayifci A, Ozdemir FO, Hasan O, Atilgan A (2011) Effects of different irrigation programs on yield and quality parameters of eggplant (*Solanum melongena* L.) under greenhouse conditions. African Journal of Biotechnology. 10: 6497-6503.
26. Orgaz F, Ferna´ndezb MD, Bonachelac S, Gallardoc M, Fereresa E (2005) Evapotranspiration of horticultural crops in an unheated plastic greenhouse. Agricultural Water Management 72: 81-96.
27. Bastug R, Karaguzel O, Aydinsakir K, Buyuktas D (2006) The effects of drip irrigation on flowering and flower quality of glasshouse gladiolus plant. Agricultural Water Management 81: 132-144.
28. Zhang, Zi-kun, Liu, Shi-q, Su-hui L, Zhi-jun H (2010) Estimation of Cucumber Evapotranspiration in Solar Greenhouse in Northeast China. Agricultural Sciences in China. 9: 512-518.
29. Blanco FF, Folegatti MV (2003) Evapotranspiration and crop coefficient of cucumber in greenhouse. Revista Brasileira de Engenharia Agrícola e Ambiental 7: 285-291.
30. Ehret DL, Menzies JG, Helmer T (2005) Production and quality of greenhouse roses in recirculating nutrient systems. Scientia Horticulturae 106: 103-113.
31. Katsoulas N, Kittas C, Dimokas G, Lykas Ch (2006) Effect of irrigation frequency on rose flower production and quality. Biosystems Engineering 93: 237-244.
32. Qi SH, Li ZZ, Gong YS (2002) Evaluating Crop water requirements and Crop coefficients for three vegetables based on Field water budget. J China Agric Univ. 7: 71-76.
33. Zhao NN (2010) Calculation of crop coefficient and water consumption of summer maize. J Hydraulic Engine. 41: 953-959.
34. Möller M, Assouline S (2007) Effects of a shading screen on microclimate and crop water requirements. Irrigation Science 25: 171-181.
35. Fernández MD, Bonachela S, Orgaz F, Thompson RB, López JC, et al. (2010) Measurement and Estimation of plastic greenhouse reference evapotranspiration in a Mediterranean climate. Irrig Sci 28: 497-509.
36. Chou MD, Lee KT (1996) Parameterizations for the absorption of solar radiation by water vapor and ozone. American Meteorolological Society 53: 1203-1208.
37. Kondratyev KY (1969) Radiation in the atmosphere. New York.
38. Lamnatou C, Chemisana D (2013) Solar radiation manipulations and their role in greenhouse claddings: Fresnel lenses, NIR and UV-blocking materials. Renewable and Sustainable Energy Reviews 18: 271-287.
39. Lamnatou C, Chemisana D (2013) Solar radiation manipulations and their role in greenhouse claddings: Fluorescent solar concentrators, photoselective and other materials. Renewable and Sustainable Energy Reviews 27: 175-190.
40. Espí E, Salmerón A, Fontecha A, García Y, Real AI (2006) Plastic films for agricultural applications. J Plast Film Sheeting 22: 85-102.
41. Zheng J, Huang G, Jia D, Wang J, Mota M et al., (2013) Responses of drip irrigated tomato (*Solanum lycopersicum* L.) yield, quality and water productivity to various soil matric potential thresholds in an arid region of Northwest China. Agricultural Water Management. 129: 181002D193.
42. Pereira Ls, Cordery I, Iacovides I (2012) Improved indicators of water use performance and productivity for sustainable water conservation and saving. Agricultural Water Management. 108: 39-51.
43. Manohar RK, Khan MM, Shyamalamma, Kariyanna, Biradar MS (1996) Gerbera under low cost greenhouse. Published by Plasticulture Development Centre. Bangalore.
44. Sengar SH, Kothari S (2008) Economic evaluation of greenhouse for cultivation of rose nursery. African Journal of Agricultural Research. 3: 435-439.