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Effect of Tree Age on Water Requirement of Pomegranate under Localized Irrigation System

Ali Bafkar[1]*, Mosayeb Karimi[1] and Mohammad Hadi Rad[2]

[1]*Water Engineering Department, Faculty of Agricultural Science and Engineering, Razi University, Kermanshah, Iran*

[2]*Research Center for Agriculture and Natural Resources, Yazd, Iran*

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Abstract: In this study, water requirements of pomegranate (adult and young plants), with regard to age and tree canopy, were estimated for a 2-year period for climatic conditions of Yazd province. The results showed that the amount of water use by young trees was less by about 6500 m^3 in comparison to mature trees during the growth period, which was related to the canopy of trees. During the growing months, a large difference was observed in evapotranspiration. The maximum and minimum amount of water use was in July and November, respectively. In the design of localized irrigation systems, the maximum required discharge rate for pomegranate orchards in July was estimated to be 0.71 L s^{-1} ha^{-1} for mature trees and 0.27 L s^{-1} ha^{-1} for young trees. The obtained relationships showed that it is possible to accurately estimate the irrigation requirement of pomegranate trees with respect to their age.

Key words: Pomegranate, pressurized irrigation, shadow surface, water requirement, Yazd province.

Irrigation water depth and interval is based on the amount of water use by the plants. Therefore, it is possible to develop irrigation schedules to increase water productivity when the water requirement of plants is accurately estimated. Proper irrigation management is based on the accurate estimation of water requirements of plants (Farshi *et al*., 2003). Pomegranate is one of the most important products that play an important role in the agricultural economy of Yazd province. The most important irrigation resource of pomegranate orchards in Yazd province is deep wells, followed by aqueducts and semi-deep wells. In spite of severe water constraints in many areas of Yazd province, proper measures are not taken to protect, conserve and efficiently use water. Annually, a significant amount of water extracted at high cost from the surface and underground resources is wasted (Salem, 2000). Water is still the most important and limiting factor of production in many parts of Yazd province. Grown in 758 hectares of fertile soil, pomegranate has second rank with respect to area under cultivation after pistachio; and first rank in terms of production (Shakeri, 2008b).

*E-mail: alibafkar@yahoo.com

In designing new networks, the designer has to estimate crops water requirement usually in a region that has never undergone any irrigated agriculture. Therefore, estimating the water requirement through direct measurements of soil moisture variation in the sowing season is not feasible. In such conditions, estimation of water requirement is possible using evapotranspiration estimation models based on meteorological data. Undoubtedly, if the model used to estimate the water requirement is not sufficiently precise for region's climatic condition, it will result in over- or under-estimation of project requirement, and is most likely to bring economic losses. Therefore, if the estimation of the water requirement does not have the required accuracy, the profitability of the project will be distorted (Farshi *et al*., 2003).

Further, there is little information on water management in pomegranate orchards in Iran. For example, its water requirement is not included in the FAO publication on estimation of crop water requirement (Allen *et al*., 1998) as pointed by Intrigliolo *et al*. (2011). Farshi *et al*. (1997) determined water requirement of pomegranate in Iran based on potential evapotranspiration estimation and they estimated the net water requirement of 9200 m^3 by surface irrigation method. The estimated

Table 1. Long-term (1996-2012) mean monthly meteorological data of the site for the growing months of pomegranate

Month	Maximum temperature (C°)	Minimum temperature (C°)	Mean relative humidity (%)	Mean wind speed (m s^{-1})	Mean sunshine hour (hr)	Monthly precipitation (mm)
April	25.4	11.6	30.5	3.0	8.4	11.9
May	31.7	17.4	24.1	3.2	9.8	3.8
June	36.8	22.2	16.8	3.2	11.5	4.4
July	40.3	26.0	15.9	3.2	11.2	3.8
August	38.9	23.9	15.3	3.0	11.6	0.0
September	36.5	20.8	16.1	6.2	11.1	0.0
October	30.8	15.4	21.3	4.2	10.0	8.2
November	23.0	9.0	34.9	3.2	8.2	12.0

value was 7300 m^3 by drip irrigation. Recently, two field studies have been conducted in the south eastern Spain to assess the basic plant water relationships (Intrigliolo *et al.*, 2011). Abbasi and Sanij (2013) examined the effect of crop evapotranspiration calculation methods on irrigation and water use planning of apricot trees. The results indicated that the maximum yield of apricot trees in the drip irrigation system was achieved when the water requirement was estimated based on daily weather data. Also the necessity of actual meteorological data in the irrigation management planning was recommended. Michelakis *et al*. (1997) stated that the type of irrigation system and irrigation planning can have a great effect on the water absorption by the plants as the localized or drip irrigation systems moisturize only part of the soil around the roots. Alizadeh *et al*. (2004) evaluated the evapotranspiration estimation methods in arid regions of Iran. The results of different methods of estimating the evapotranspiration of the reference plant with the lysimeter measurements showed that Penman-Monteith and Penman-FAO methods gave the best estimation. The FAO Penman-Monteith method is used widely for estimating potential evapotranspiration and has a unique global presence (Mirmosavi *et al*., 2012). Rad *et al*. (2013) conducted lysimeteric studies under Yazd climate conditions and observed that the amount of water requirement calculated by CROPWAT software showed little difference. Ian and Isa (2003) concluded that olive trees responded well to irrigation when evapotranspiration was more than 5 mm day^{-1}.

Hershfield (1964) defined the effective precipitation throughout the growing season as the part of the total rainfall that meets the water needs of plants. Smajstrla *et al*. (2001) calculated the effective precipitation by SCS method and considered the net irrigation requirement as the amount of water that was not effectively supplied by rain. Chahon *et al.* (2001) identified the effective precipitation as rainfall that is stored in the root zone of the plant and estimated effective precipitation for wet and dry land farming. They considered two factors to estimate effective precipitation, the total amount of rainfall and the amount of stored moisture in the root zone.

The purpose of this research was to estimate the potential evapotranspiration using the recommended methods for the climatic conditions of Yazd, estimation of water requirement of young and mature pomegranate trees during plant growth period for optimal irrigation management.

Materials and Methods

Potential evapotranspiration of Yazd meteorological station (31°54′ lat and 54°24′ long) was calculated using the FAO Penman-Monteith method as well as CROPWAT software using 17-year (1996-2012) meteorological data of this station. The station is 1230 m above mean sea level.

CROPWAT model of FAO was used for irrigation management and planning. Average monthly values of input data including temperature (minimum and maximum), relative humidity, sunshine and wind speed of the site are given in Table 1.

The crop evapotranspiration was obtained from the calculated potential evapotranspiration (ETo) as given in Eq. 1 (Alizadeh, 2004):

$$ETc = (Kc) \times (ETo) \qquad \text{... ...1}$$

The crop coefficient (Kc) reflects the crop characteristics in crop water requirement. The crop coefficient varies according to plant type, growth stage and general climate conditions including humidity (Jeyhoun *et al.*, 2006). In this research, Kc values were taken from Farshi *et al.* (1997).

Effective precipitation was estimated as per Eq. 2 (Emamgholizadeh, 2006).

$$P_e = P - (RO_p + DP_p) \quad \text{... ...2}$$

where, Pe is effective precipitation, P is precipitation, DP_p is the amount of depth penetration in millimeters and RO_p is surface runoff in millimeters.

The use of formula involves less cost and is easy, but this method is less accurate than soil water balance and direct measurement methods. To calculate the effective precipitation rates, four methods given in CROPWAT software including Reliable Precipitation Method (FAO), Percentage Method, Experimental Formula, and USDA Method were used. Values calculated based on two methods are given in Table 2.

In a drip system since the whole surface of the ground does not get wet in localized irrigation methods, evaporation from the soil surface is low and water use is more related to transpiration from plant leaf area. If the canopy cover percentage is P_d (from zero to 100) and the daily evapotranspiration of the vegetation is U_d, the water requirement in the drip system (Td) is obtained from equation 3 (Merkly *et al.*, 2007):

$$T_d=0.1U_d(P_d)^{0.5} \quad \text{... ...3}$$

The coefficient of 0.1√Pd is the coefficient of evapotranspiration reduction. As the canopy spread increases, this coefficient also increases and the value of 0.1√Pd reaches 1.0 when canopy cover is complete (Pd = 100). In fruit trees, the maximum canopy cover is reached when canopy is tangent to each other as shown in Fig. 1. In this situation, the percentage of canopy cover will be π/4 or 0.785. In this case, the reduction coefficient of water requirement is as much as 0.88. The value is obtained through circles area divided by squares area (Alizadeh *et al.*, 2004).

Table 2. Effective precipitation values given by two methods available in CROPWAT

Month	Effective precipitation (mm)	
	USDA method	Percentage method
April	5.6	4.6
May	1.6	1.3
June	0.5	0.4
July	0.3	0.2
August	0.0	0.0
September	0.0	0.0
October	0.2	0.2
November	3.4	2.7

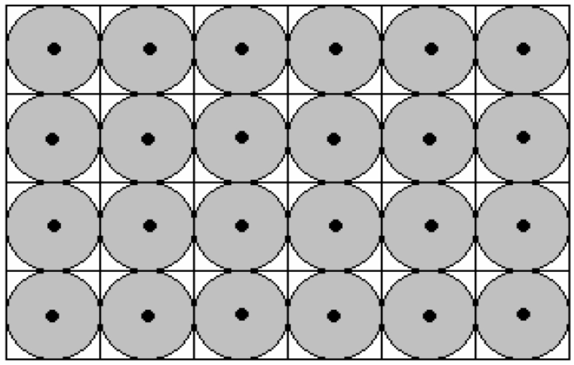

Fig. 1. Schematic representation of the canopy cover of plants in fruit orchards at maximum growth (Merkly and Allen, 2007).

In above equation, if P_d is very small (for example, 1%) then, T_d = 0.1 U_d. Therefore, it can be said that Td is always larger than 0.1 U_d. In this study, the canopy cover of the trees was determined from field observations and regional information (percentages), which was calculated for mature and young trees through test percentage method under farm condition (Fig. 2).

The required water per irrigation (maximum depth of irrigation water) was calculated using Eq. 4 (Alizadeh *et al.*, 2004):

$$dx = TAW \times MAD \times Z \times Pw \quad \text{... ...4}$$

where, d_x is maximum net depth of irrigation in millimeters; TAW is available water in soil in millimeters; MAD is allowed drainage in per cent; Z is root development in meters; P_w is percentage of wet soil area. The maximum irrigation interval was calculated using Eq. 5 (Alizadeh *et al.*, 2004):

$$fx = dx/NWR \quad \text{... ...5}$$

where, fx is maximum irrigation interval piner days; dx is maximum net irrigation depth in millimeters; NWR is crop evapotranspiration

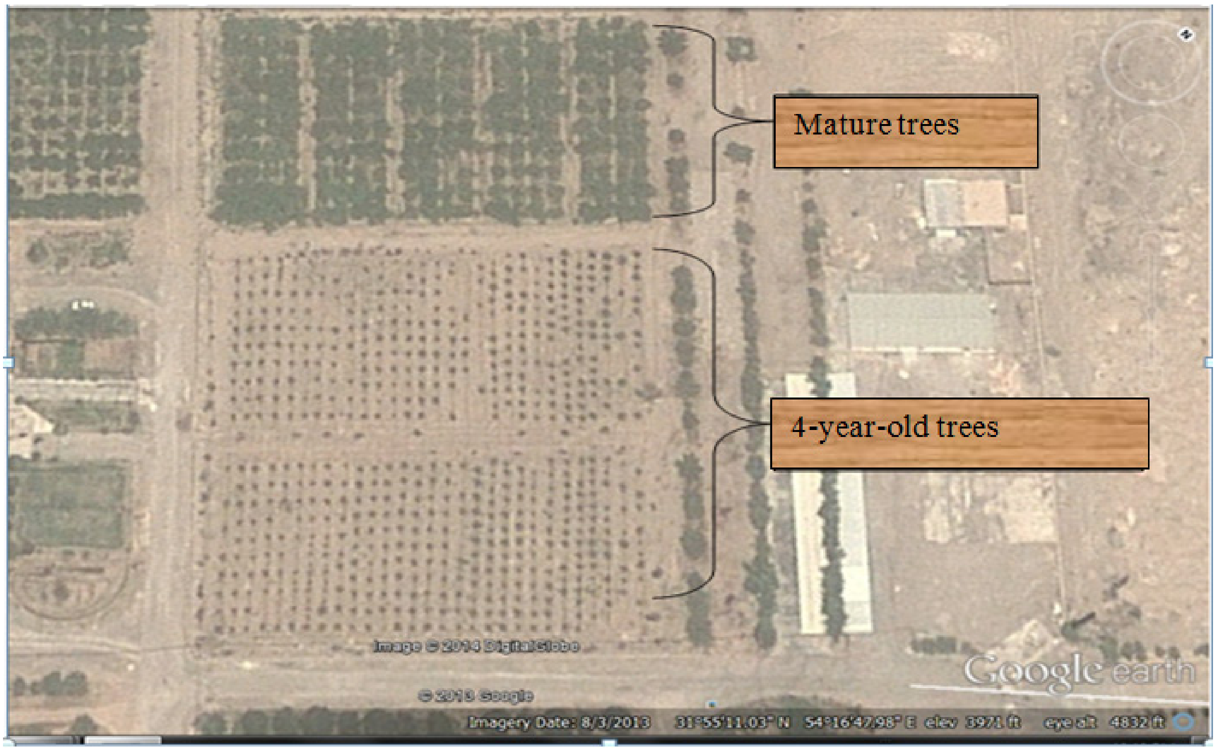

Fig. 2. The canopy cover of mature and young pomegranate trees at the time of maximum vegetation cover as seen in Google Earth image.

in mm day^{-1}. Root depth and wet area were measured in the field.

The net depth of irrigation was calculated following Eq. 6 (Farshi *et al*., 1997):

$$dn = f \times NWR \quad \text{... ...6}$$

where, dn is net irrigation depth in millimeters; f is selected irrigation interval in days; NWR is net water requirement of the trees in mm day^{-1}.

In this study, the appropriate irrigation interval was selected according to evapotranspiration, canopy cover, and potential evapotranspiration in different months between 5 and 14 days. In this study, irrigation efficiency was considered to be 90%.

The gross depth of irrigation (d), may be computed using Eq. 7 if the leaching

Fig. 3. The canopy of young trees.

Table 3. Parameters used for calculation of irrigation depth and interval in mature and young trees

	Water holding capacity of the soil (mm m^{-1})	Root depth (m)	Wet area (m^2)	Allowed depletion of moisture (%)	Canopy cover (%)
Young trees	120	1.0	25.2	50	30.0
Mature trees	120	2.1	4.0	50	78.5

requirement (LR) is less than 10%, otherwise using Eq. 8 (Alizadeh *et al*., 2004):

d = 100 (dnTr/EU) 7

d = 100 (dn/(EU(1-LR)) 8

Results and Discussion

The evapotranspiration of pomegranate crop in the Yazd climate varied from 2.08 mm day^{-1} in November to 6.26 mm day^{-1} in July (Table 4).

Table 4. Reference evapotranspiration, crop coefficient and crop evapotranspiration of pomegranate during the growth period

Month	Reference evapotranspiration, ETp (mm day^{-1})	Plant growth coefficient, Kc	Evapotranspiration of pomegranate, ETc (mm day^{-1})
April	5.72	0.50	2.86
May	7.62	0.50	3.81
June	9.14	0.57	5.21
July	9.78	0.64	6.26
August	9.11	0.65	5.92
September	7.51	0.65	4.88
October	5.61	0.62	3.48
November	3.65	0.57	2.08

If the distance between tree rows and spacing of trees in the rows are S_r and S_p, the required volume of water per tree (or plant) in liters per day (G) for specified gross irrigation depth (d) may be calculated using Eq. 9 (Alizadeh *et al*., 2004):

$G = d \times S_r \times S_p$ 9

In this equation, S_r and S_p are in meters. D is in mm day^{-1} and G is L day^{-1} for each plant. The distance between trees was 5, 5 and 6 m and row spacing was 5, 5, and 6 m in this study. This indicates a large difference in pomegranate evapotranspiration during the growth period.

The maximum irrigation water requirement was in July (191.02 mm) and the minimum in November (61.44 mm) as shown in Table 5. The maximum hydro module for mature trees was 0.71 L s^{-1} ha^{-1}. Tree pruning during the growth period maintained fixed canopy level, which saved water.

In addition, the gross irrigation requirement during the growth period of young pomegranate

Table 5. Water requirement of mature pomegranate trees during the growth period

Month	Canopy cover, Pd (%)	Crop transpiration, Td (mm)	Gross irrigation requirement, d (mm)	Water required for each tree, G (L day^{-1})	Hydro module, H (L s^{-1} ha^{-1})
April	78.5	78.55	87.28	33.79	0.33
May	78.5	104.65	116.27	45.01	0.43
June	78.5	143.09	158.99	61.55	0.59
July	78.5	171.92	191.02	73.94	0.71
August	78.5	162.64	180.71	69.95	0.67
September	78.5	134.08	148.97	57.67	0.56
October	78.5	92.45	102.72	41.09	0.40
November	78.5	55.30	61.44	24.58	0.24
Total		942.67	1047.42		

Table 6. Irrigation requirement of young pomegranate trees during the growth period

Month	Canopy cover, Pd (%)	Crop transpiration, Td (mm)	Gross irrigation requirement, d (mm)	Water required for each tree, G (L day^{-1})	Hydro module, H (L s^{-1} ha^{-1})
April	30	30.02	33.36	12.91	0.12
May	30	39.99	44.44	17.20	0.17
June	30	54.69	60.76	23.52	0.23
July	30	65.70	73.00	28.26	0.27
August	30	62.16	69.06	26.73	0.26
September	30	51.24	56.93	22.04	0.21
October	30	35.33	39.26	15.70	0.15
November	30	21.13	23.48	9.39	0.09
Total		360.26	400.29		

trees was calculated (Table 6). The maximum irrigation requirement was in July (73 mm) and the minimum in November (23.48 mm). The maximum hydro module for the young trees was 0.27 L s^{-1} ha^{-1}.

Relationship between tree age and per cent canopy cover is shown in Fig. 4 with respect to the conventional spacings followed in the studied area (5 m x 5 m, 6 m x 5 m and 6 m x 6 m).

It is evident from Fig. 4 that the slope is not the same in different age groups, but canopy cover has a high correlation with age. The irrigation requirement of the trees was observed to differ greatly depending on age of trees and tree spacing (Fig. 5).

The irrigation requirement values in the design were much higher than the required level for trees less than eight years old, while these values were much lower to meet the irrigation requirement of trees over 12 years age. For example, the irrigation requirement of 5-year-old trees grown at 5 m x 5 m spacing had requirement of 0.56 mm day^{-1} as against provision of 2.54 mm day^{-1} in design. In case of 14-year-old trees with 6 m x 6 m spacing, the irrigation requirement was 2.72 mm day^{-1}, and the design will supply 1.8 m^3 $month^{-1}$ less water to each tree during peak requirement, which is much less to meet its requirement and thus, will adversely affect crop yield.

Conclusions

The lack of proper use of irrigation water, water resource constraints, and the growing human need for more, varied, and more desirable foods require irrigation engineers to apply new management practices for reducing water consumption and increasing irrigation efficiency. This is not possible without the accurate estimation of the water requirement of the crops and understanding of seasonal water requirement of the plants

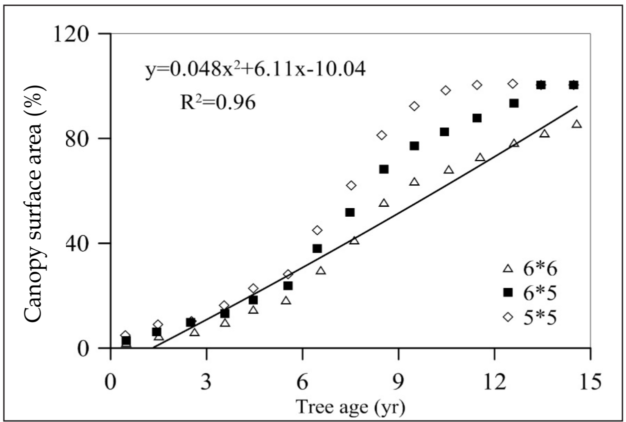

Fig. 4. Changes in per cent canopy cover with age of trees in three tree spacings.

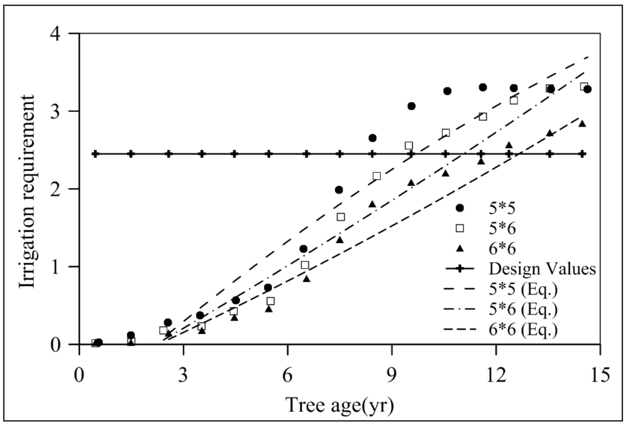

Fig. 5. The relationship between irrigation requirement (mm day^{-1}) and age of pomegranate trees in three spacings.

(Farshi *et al*., 2003). The accurate estimation of potential evapotranspiration values can enable agricultural planners to identify the water requirement and the effective amount of rainfall and perform the necessary planning for water supply (Mirmosavi *et al*., 2012).

The volume of water required for mature pomegranate trees in the Yazd region during the growing period was estimated to be as much as 10,470 m^3 ha^{-1} under localized irrigation system. The Agricultural Promotion Coordination Management estimated that the amount of water consumed per hectare of pomegranate garden is about 30,000 m^3 in the traditional way. This amount of water decreases to one-third through drip irrigation (Shakeri, 2008b). According to another study in Isfahan, the amount of water consumed in the surface irrigation (flooding) and in the drip irrigation systems were 22000-26000 m^3 ha^{-1} and 7500-13000 m^3 ha^{-1}, respectively. The results of this study and some other studies favor the use of drip irrigation method. In this method, the yields increased by 21 to 44.5% in addition to increasing irrigation efficiency resulting in 50-60% reduction in water consumption (Shakeri, 2008a).

In this study, the net and gross irrigation requirements based on effective precipitation, irrigation efficiency, and canopy cover were calculated during the growth period of the pomegranate trees. The maximum and minimum amount of water consumption was in July and November, respectively. The required flow rate for drip irrigation in pomegranate orchard given by hydro module for mature trees in July was 0.71 L s^{-1} ha^{-1} and the hydro module value for young trees was 0.27 L s^{-1} ha^{-1}.

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