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SEBAL application to estimate water use efficiency of Pistachio trees in saline condition (Case study: Bahadoran Plain, Iran)

Mohammad Hassan Rahimian[1,2], Mohammad Shayannejad*[1], Saeid Eslamian[1], Mahdi Gheysari[1], Reza Jafari[3]

[1]*Department of Water Engineering, College of Agriculture, Isfahan University of Technology, Isfahan, Iran*

[2]*National Salinity Research Center, Agricultural Research Education and Extension Organization (AREEO), Yazd, Iran*

[3]*Department of Range and Watershed Management, College of Natural Resources, Isfahan University of Technology, Isfahan, Iran*

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Key words: SEBAL, Pistachio, Water use efficiency, Leaching fraction, Landsat 8

Abstract

Annual evapotranspiration (ET) of mature pistachio tress in saline aquifer of Bahadoran plain in central Iran was first estimated on a distributed basis by running the Surface Energy Balance Algorithm for Land (SEBAL) model through Landsat 8 satellite data. Finally, the SEBAL estimate of annual water use evaluated by performing water balance analysis over the Bahadoran irrigation district. The water balance ET_a estimate was 19% larger than the SEBAL-based ET_a due to the uncertainties involved in estimation of Leaching Fraction (LF) parameter. The average LF was estimated to be 28% (with standard deviation of 19%), predominantly higher than the anticipated average leaching requirement of the Bahadoran area (23%). Assuming that SEBAL has provided accurate estimates, 64% of cumulative irrigation depth (792mm of 1242mm) was consumed by the evapotranspiration process of pistachio orchards. Moreover, the average annual released water to the Bahadoran irrigation district seems to be adequate to leach the salts down to the root zone. The latter result depends on the irrigation water salinities as well as per irrigation applied depths which may change from a field to another field and cause to over or under irrigation of pistachio orchards. Such possible under or over irrigations were demonstrated by the fluctuations of leaching fractions (3% to 65%), soil salinities (1.73 to 31.6 $dS{\cdot}m^{-1}$) and consequently, the yields (500 to 4200 $kg.ha^{-1}$). Under such a condition, averages of 0.12$kg.m^{-3}$ and 0.20 $kg.m^{-3}$ obtain for water use efficiency and evapotranspiration use efficiency of Bahadoran pistachios, respectively.

***Corresponding Author:** Mohammad Shayannejad ✉ shayannejad@cc.iut.ac.ir

Introduction

Iran is the world's largest pistachio producer, with a total harvested area of 316,780 ha in 2014 (FAOSTAT, 2016). Pistachio (*Pistacia vera* L.*)* is a sub-tropical crop belongs to the *Anacardiaceous* family (Kamali and Owji, 2016). The high tolerance of pistachio tree to the soil water and salinity (Ferguson, 2003; Sanden *et al.*, 2004; Goldhamer, 2005; Ferguson *et al.*, 2005a; Ferguson *et al.*, 2005b) along with its promising economic gains are the major reasons for development of this crop to many parts of the world.

In addition to Iran, pistachio cultivates in Middle Eastern, some European and American countries (Ozden and Alayunt, 2006; Kamali and Owji, 2016). The resistance of this crop to salinity stress may be due to its ability to retain salts in roots and limit transportation to shoot tissues (Karimi *et al.*, 2011), while its drought tolerance may be achieved by physiological changes and osmotic adjustment (Gijon *et al.*, 2011).

Most of Iranian pistachio orchards are located in central part of the country, which is identified as an arid and severe water scarce region. In addition to severe water scarcity, the agricultural sector in this part of the country is suffering from high levels of soil and water salinities (Rahimian *et al.*, 2014). In Yazd province, the second pistachio producer of Iran, the weighted average electrical conductivity of irrigation water is 5.3dS·m^{-1}. In this province, salinity of water used for pistachio production may reach 22dS·m^{-1} (Cheraghi *et al.*, 2009) and more. Annual precipitation of Yazd province is about 82 mm and evaporation exceeds to 3000mm.yr^{-1}. Groundwater table is relatively deep and is the main source of pistachio irrigation water. Furthermore, over exploiting of groundwater is declining its level and deteriorating its quality (Cheraghi *et al.*, 2009).

In order to effectively manage land and water resources of this province and minimize environmental consequences of irrigating with saline water, a comprehensive knowledge on agricultural water balance seems to be required.

Leaching of excess salts from the root zone is a requisite for the sustainability of such irrigated agricultural systems. To maintain a proper soil salt balance, some deep percolation of water is needed to transport the salts out of the tree root zone (Steduto *et al.*, 2012).

The amount ofdeep percolation required is referred to as the leaching requirement (LR) and depends on the irrigation water salinity (EC_{iw}) as well as the crop salt tolerance threshold (EC_{th}) or the anticipated soil electrical conductivity (EC_e). Methods have been established to estimate appropriate leaching requirements and can be obtained in FAO Irrigation and Drainage paper No. 29 (Ayres and Westcott, 1985).

In the manner of water balance analysis, satellite remote sensing (RS) technique can provide unbiased and near real-time information on water use of irrigated areas in arid/semi-arid regions (Taghvaeian and Neale, 2011). In addition, remotely sensed data may be the only source of data in un-gauged or poorly-gauged irrigation schemes (Poormohammadi *et al.*, 2012). An RS-based approach to estimate instantaneous, daily, seasonal or annual measurements of evapotranspiration (ET), is modeling of energy balance components at the land surface. Numerous surface energy balance models have been developed since 1970's, but a major breakthrough was the development of Surface Energy Balance Algorithm for Land (SEBAL) model (Bastiaanssen *et al.*, 1998) and the following models that are based on the SEBAL approach in estimating actual evapotranspiration.

The goal of this research was to use Landsat 8 imagery to map annual water use of mature pistachio trees under saline condition and to compare and evaluate the SEBAL results by performing a large scale water balance analysis and ground-based quantification of its different components (e.g. evapotranspiration, deep percolation and irrigation) in Bahadoran pistachio orchards, Yazd province, Iran. Comparison of the annual applied water with pistachio evapotranspiration demands and their leaching requirements were investigated and discussed, as well.

Material and methods

Study area

This study was conducted at 5728ha of Bahadoran pistachio (*Pistacia vera* L.) orchards in the Yazd province, Iran. The study area lies between 31°18' to 31°28' N latitudes and 54°48' to 55°0'E longitudes. Average elevation is 1050m above sea level (see Fig. 1). The long term annual precipitation in this area is only 72.4mm, a testament to its arid climate. The predominant soils have loam, clay-loam, and sandy-clay-loam textures. Pistachio trees in this area are 20 to 50 years old, consisting of different varieties, mainly Kalehghouchi, Akbari, Ahmadaghaei and Fandoghi. Pistachio tree row spacing ranges between 6.0 to 10.0m. The required irrigation water is pumped from the aquifer and applied mainly through surface irrigation method using 6-10m wide by 40-80m long borders. The irrigated width of each border ranges between 2.0 to 6.0m. The average irrigation interval is 30 days, but it may reach as long as 45-60 days during droughts. Based on existing statistics, the average electrical conductivity of Bahadoran irrigation waters (EC_{iw}) is about 9dS·m^{-1}, ranges between less than 1dS·m^{-1} to surprising values of 40dS·m^{-1} and more. Table 1 illustrates chemical composition of some irrigation waters used for pistachio production in Bahadoran plain. Most of these waters are classified as highly saline waters.

Despite of their high values of SAR, Bahadoran soils do not show any symptom of structural deterioration because of their high salinities (FAO, 1992). Unusual with these waters is the high ratio of Mg. Ca^{-1} which is occasionally greater than one. This has actually given a bitter taste to water and has occurred as a result of drop in groundwater level (Cheraghi *et al.*, 2009).

Table 1. Chemical composition of some irrigation wells used for pistachio production in Bahadoran plain.

Constituents	Well Number									
	1	2	3	4	5	6	7	8	9	10
EC (dS.m^{-1})	9.0	10.1	13.0	15.6	16.8	17.9	19.4	24.8	28.5	37.1
pH	7.4	7.1	7.3	7.2	7.3	7.4	7.3	7.0	6.8	6.9
Ca (meq.L^{-1})	20.0	22.8	16.0	24.0	19.2	20.8	22.4	56.8	62.4	77.2
Mg (meq.L^{-1})	14.8	14.4	20.0	18.0	17.2	26.0	22.0	50.4	42.4	55.6
Na (meq.L^{-1})	65.0	42.5	130.0	100.0	120.0	175.0	130.0	250.0	185.0	250.0
K (meq.L^{-1})	0.2	0.2	0.4	0.1	0.3	0.5	0.2	0.3	0.3	0.3
HCO_3 (meq.L^{-1})	3.3	4.3	1.8	3.5	3.8	1.3	2.8	2.8	3.5	2.5
SO_4 (meq.L^{-1})	5.8	25.6	54.6	17.1	24.5	64.5	-21.6	147.8	55.1	58.6
Cl (meq.L^{-1})	91.0	50.0	110.0	121.5	128.5	156.5	193.5	207.0	231.5	322.0
SAR	11.0	7.0	21.7	15.4	19.9	25.6	19.5	24.1	18.1	21.7
RSC	-31.6	-33.0	-34.3	-38.5	-32.7	-45.6	-41.7	-104.5	-101.3	-130.3
Mg.Ca^{-1}	0.74	0.63	1.25	0.75	0.90	1.25	0.98	0.89	0.68	0.72

Remote sensing of pistachio water use

In this study, pistachio actual evapotranspiration (ET_a) was estimated on a distributed basis, using the Surface Energy Balance Algorithm for Land (SEBAL) model. The SEBAL model (Bastiaanssen *et al.* 1998) estimates ET_a as the remainder of the surface energy balance equation in the scale of satellite image pixel:

$$ET_{inst} = 3{,}600\,\frac{(R_n - G - H)}{\lambda\,\rho_w} \quad (1).$$

Where ET_{inst} is the instantaneous (hourly) evapotranspiration at the satellite overpass time (mm·hr^{-1}), R_n is the net radiation (W·m^{-2}), G is the soil heat flux (W·m^{-2}), H is the sensible heat flux (W·m^{-2}), λ is the latent heat of vaporization (J·kg^{-1}), ρ_w is the density of water (1,000kg·m^{-3}), and multiplier 3,600 converts from second to hour. SEBAL presents an innovative approach to calculate H by interpolating between two anchor pixels (so called hot and cold pixels) for a given satellite image.

Typically, hot (dry) pixel has to be located in a fallow agricultural field with high surface temperature (T_s) as well as high albedo and low Normalized Difference Vegetation Index (NDVI). While, a well irrigated agricultural field with low T_s value, low albedo and high NDVI is a proper candidate for cold (wet) pixel of that scene. H in dry and cold pixels can be assumed equal to R_n-G and zero, respectively. Since hourly estimates of ET are less useful in water resources management, ET_{inst} was converted to daily values using the so called evaporative fraction (EF) method. The EF is the ratio of latent heat flux (LE) to the available energy (R_n-G).

$EF_{inst} = \frac{LE}{R_n - G}$ (2)

The EF method is based on the assumption that EF at the hour of satellite overpass (EF_{inst}) is equal to 24-hr EF on the day of overpass. Once the EF_{inst} is determined, daily ET (ET_d) can be calculated using the following equation:

$ET_d = 86.4\times10^6 \frac{EF_{inst} R_{nd}}{\lambda \rho_w}$ (3)

Where, R_{nd} is daily net radiation. To estimate ET_d between satellite overpass days it was assumed that the ratio of ET_d to grass-based reference evapotranspiration (ET_o) changes linearly between two consecutive overpass dates. The ET_o was estimated using weather variables measured at a nearby weather station and based on the Priestly and Taylor (1972) method. This method needs net radiation and soil heat flux (Swart, 2004). In RS-based studies, main advantage for application of this method refers the limited number of required parameters. Spatially distributed net radiation maps, those calculated for SEBAL, are the only spatial parameter used in this method (Mokhtari, 2005). In this study, the images acquired by the OLI and TIRS sensors aboard the Land sat 8 satellite platform were used as input to the SEBAL model. Sixteen images of different day of year (see Table 2.) were obtained to cover a pistachio growing season (early April 2015 to late November 2015) as well as out of this season to complete an entire experimental year (April 2015 to March 2016).

Table 2. Satellites overpass days and their corresponding meteorological data.

DOY	Date	Daily Averages*						Instantaneous (Satellite Overpass Time)	
		$T_{min.}$	$T_{max.}$	$RH_{min.}$	$RH_{max.}$	WS	SSH	$WS_{inst.}$	$T_{inst.}$
100	10-Apr-15	14.1	30.3	8.0	25.0	2.8	11.3	1.0	24.4
116	26-Apr-15	12.6	22.2	10.0	20.0	3.0	11.3	3.0	17.0
132	12-May-15	18.1	31.7	11.0	28.0	3.0	11.7	3.0	26.4
148	28-May-15	18.9	31.7	10.0	35.0	2.4	11.6	1.0	26.8
164	13-Jun-15	24.3	38.0	5.0	11.0	2.6	12.3	1.0	34.6
180	29-Jun-15	26.5	39.6	6.0	14.0	2.4	11.6	1.0	34.6
196	15-Jul-15	24.7	37.0	5.0	10.0	2.8	12.7	1.0	32.9
228	16-Aug-15	23.0	35.2	4.0	12.0	2.6	12.5	2.0	30.8
244	01-Sep-15	22.7	36.7	8.0	21.0	2.6	8.8	2.0	29.5
260	17-Sep-15	21.9	30.8	15.0	37.0	2.4	8.6	2.0	26.7
276	03-Oct-15	21.7	31.1	10.0	28.0	2.8	10.6	2.0	26.3
292	19-Oct-15	11.0	25.4	25.0	74.0	2.4	10.0	1.0	18.0
308	04-Nov-15	2.9	16.8	27.0	66.0	1.0	10.0	1.0	9.4
324	20-Nov-15	8.3	17.4	29.0	50.0	2.2	9.1	2.0	12.2
356	22-Dec-15	-0.8	7.9	36.0	74.0	1.0	9.1	1.0	3.5
007	07-Jan-16	3.3	17.2	23.0	60.0	1.0	9.4	1.0	11.6

* T is the temperature (°C), RH is the relative humidity (%), WS is the wind speed ($m.s^{-1}$), SSH is the sunshine hours (hr).

Validating SEBAL results

To validate SEBAL-ET_a results, annual water use of pistachio was estimated independently as the remainder of the water balance equation:

$ET = I + P - SR - DP - \Delta S$ (4)

Where I is irrigation, P is precipitation, SR is surface runoff, DP is deep percolation, and ΔS is the change in soil water content during the experimental year (all in mm). Irrigation depth was estimated by monitoring the hours of pump operation and measuring pump discharge (logged and measured by Yazd water resource research office 2016). Measurements at Bahadoran weather station were used for Precipitation. Due to the negligible ground slope in the region and use of border irrigation method with earthen dikes, the SR component was assumed zero. To quantify average deep percolation of Bahadoran pistachio orchards, soil electrical conductivities (EC_e) of 0 to 120cm soil profile as well as the irrigation water salinities (EC_{iw}) were measured in forty representative points (see Fig. 1). Based on a methodology described by Ayers and Westcot, (1989) in FAO irrigation and drainage paper No. 29, predicting the leaching fraction (LF) is possible through measurement of soil salinity expected after several years of irrigation (e.g. the case of Bahadoran pistachio orchards) and by calculation of a concentration factor (X) using EC_e divided by EC_{iw} in $dS.m^{-1}$, which is found by assuming a crop water use pattern of 40-30-20-10. The DP was calculated through multiplying the total irrigation depth by the LF, determined by the above mentioned procedure.

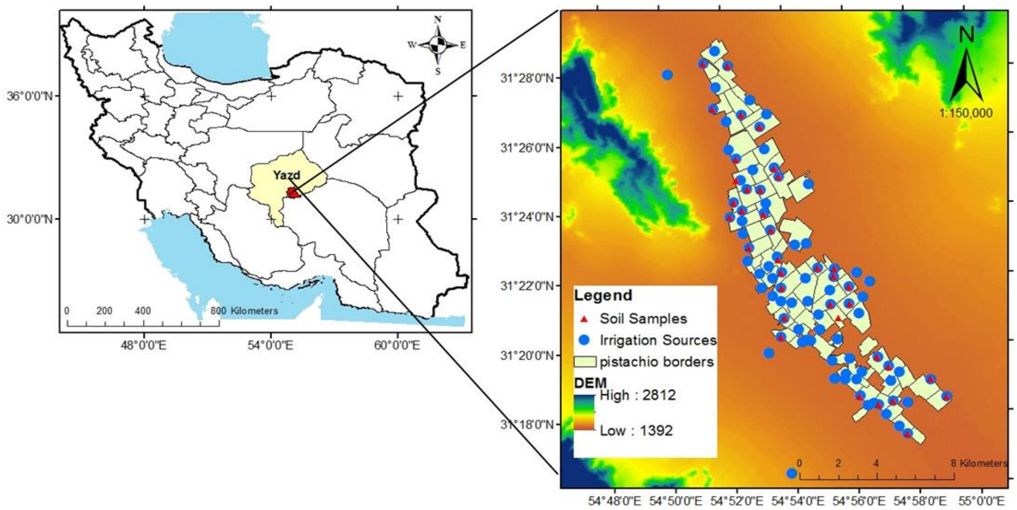


Fig. 1. Location of Bahadoran plain in central Iran along with Bahadoran pistachio orchards, its irrigation sources and representative soil sampling points.

Result and discussion

-SEBAL-based Pistachio ET_a

Fig. 2 shows maps of daily ET_a for some representative days of 2015 pistachio growing season. ET_a maps are the products of SEBAL running on Landsat 8 satellite data, as well as employment of daily and instantaneous meteorological and other ancillary data. The lower ranges of estimated ET_a belonged to marginal lands that were occasionally covered by native vegetation and had sparser canopy covers and also to the soil-vegetation combined pixels. ET_a spatiotemporal variations ranged from 0 to 10.86 $mm.day^{-1}$ with standard deviations of 0.65 to 2.47mm. day^{-1}. ET_a average and standard deviation for the entire studied region were 2.84 and 1.63mm.$day^{-1,}$ respectively and the maximum ET_a of pistachio tress (10.86mm.day^{-1}) was observed on DOY 196 (15-July-2015) map.

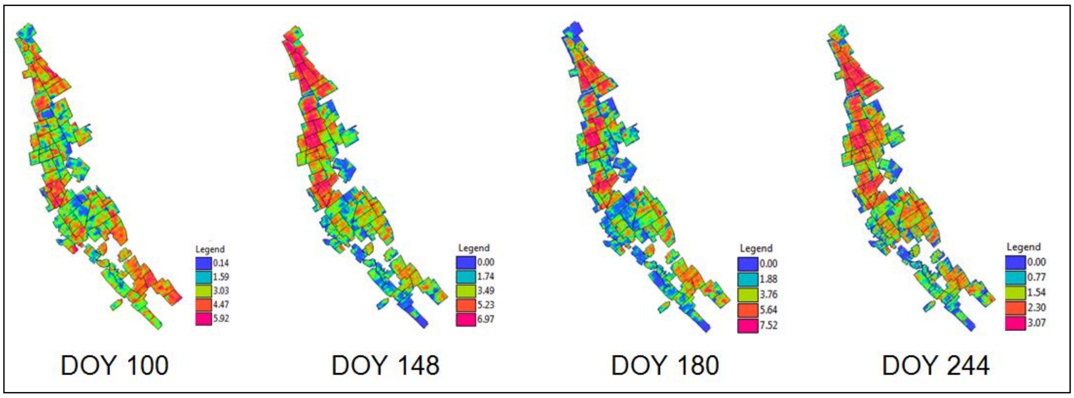


Fig. 2. Instance maps of daily ET_a, derived from SEBAL model and landsat 8 satellite data for 2015 pistachio growing season

Fig. 3 shows daily changes of SEBAL-based ET_a, the Priestly-Taylor ET_o values along with pistachio daily ET_c, derived from multiplication of traditional pistachio crop coefficients (Farshi *et al.*, 1995) by their corresponding ET_o values. In this Fig., maximum observed ET_a have been illustrated in kinds of vertical narrow lines, to show the spatial fluctuations of ET_a in Bahadoran pistachio orchards. Fig. 4. also shows cumulative seasonal and annual ET_a maps of Bahadoran pistachio orchards, along with their histograms. Annual pistachio water use ranged from 41.2 to 1605.9mm, with average and standard deviation of 791.7 and 392.6mm, respectively. Similarly, seasonal pistachio water use ranged from 32.3 to 1168.3mm, with average and standard deviation of 556.2 and 284.7mm, respectively. Based on the map histograms, more than 50% of the study areas have had annual ET_a of 680 to 1200mm, and seasonal ET_a of 430 to 830mm. Total ET_o and $ET_c$of the same period were 1688 mmand 1200mm, only 5% and %3 larger than the upper range of pistachio water use, respectively. Slight differences between ET_c and the maximum pistachio water use confirms the findings of Goldhamer *et al.* (1985) that pistachio can use large amounts of water under non-stressed conditions. On the other hand, the difference between Bahadoran pistachio ET_c (1200mm) and its average water use (556mm) can be the consequence of water or-and salinity stresses in the studied region, as further will be discussed in this paper. However, the SEBAL results reveal that an annual average of 792mm of irrigation water has been used by pistachio trees through the evapotranspiration process from the soil surface and canopy cover. It also should be noted that evaporation from soil surface may account for a significant portion of pistachio ET_a, as surface irrigation is the main irrigation method in this region. To validate the SEBAL annual results, components of the water balance equation were quantified in the large irrigation district scale of Bahadoran pistachio orchards.

Cumulative irrigation depth:

Statistics of Yazd water resource research office indicate that volume of 35.57 MCM of water pumps annually by deep irrigation wells and releases to5728 ha of Bahadoran pistachio orchards. Considering the averages of pistachio tree row spacing (8.0m) and wetted width of irrigation borders (4.0m), cumulative depth of applied water would be 1242mm.

Furthermore, annual precipitation is 84.2mm that included in the water balance analysis.

Deep percolation:

To quantify average deep percolation of Bahadoran pistachio orchards, soil electrical conductivities (EC_e) of 0 to 120 cm soil profile and the irrigation water salinities (EC_{iw}) were taken in the representative points and analyzed, as well. Fig. 5 compares the averages of soil and water salinities. In this Fig., maximum and minimum observed values have been illustrated in kinds of vertical narrow lines, to show their domains and the spatial fluctuations of salinity in sampled Bahadoran pistachio orchards.

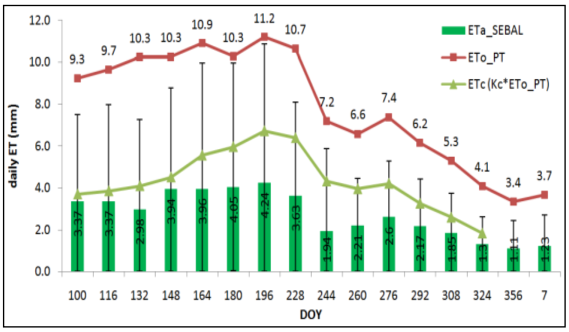
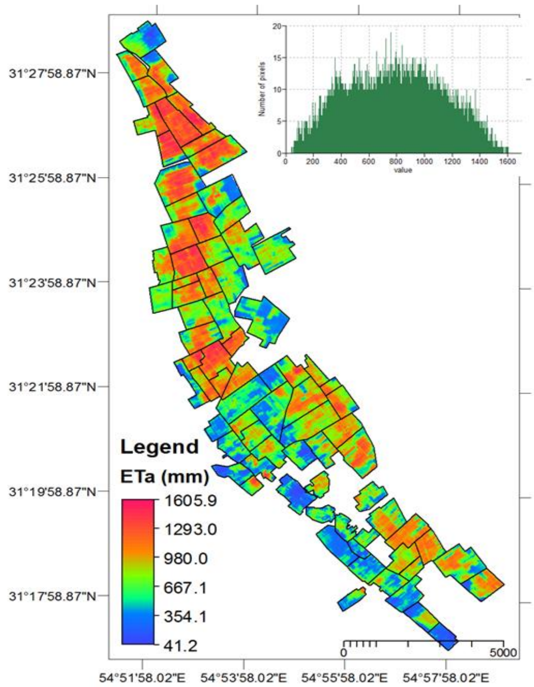
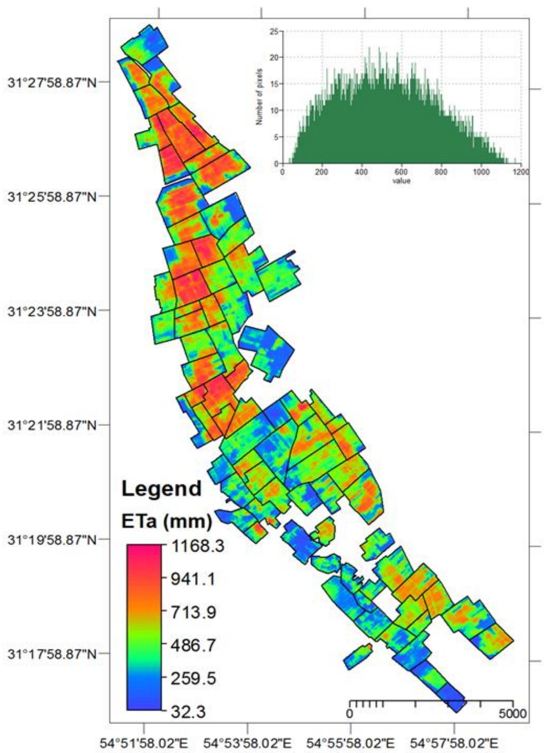


Fig. 3. Daily changes of ET_a (SEBAL results), ET_o (based on Priestly-Taylor method) and ET_c (multiplication of pistachio K_c by ET_o) for Bahadoran area.



A. Annual (April 2015 to March 2016).



B. Seasonal (April 2015 to Oct. 2015).

Fig. 4. Seasonal and annual ET_a maps of Bahadoran pistachio orchards along with their histograms.

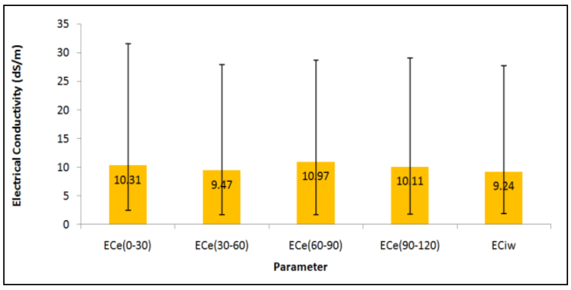


Fig. 5. Averages of soil and water salinities and their fluctuations in the representative points of Bahadoran pistachio orchards.

Measured EC_e of the 0 to 120cm soil profile ranged from 1.73 to 31.6dS·m^{-1} with the average of 10.21dS·m^{-1}. While, the electrical conductivity of irrigation water in the corresponded sampled orchards ranged from 1.87 to 27.7dS·m^{-1} with the average of 9.24dS·m^{-1}. Based on the methodology described in this paper the leaching fraction (LF) was estimated through measurements of soil and irrigation water salinities. In this approach, spatial changes of leaching fraction depend on the average root zone soil salinity, as well as their corresponding irrigation water salinities. Estimations show that LF of Bahadoran pistachio orchards ranges from 3% to 65% (standard deviation= 19%) with average of 28%. On the other hand, assuming a soil salinity threshold of 8.0dS·m-1 for pistachio (Ferguson *et al.*, 2002), the average leaching requirement estimated using equation 9 in FAO (1985) would be 23%, which is smaller than the estimated average LF of Bahadoran pistachio orchards. Generally speaking, the present amount of applied water in Bahadoran region seems to be adequate to leach the salts down to the root zone. Similar finding was previously reported by the authors in another case study, where the measured LF and estimated LR were 53% and 43%, respectively (Rahimian *et al.*, 2014). But however, this conclusion depends on the irrigation water salinity as well as per irrigation applied depths which can change from a field to another field. Considering an average LF of %28, deep percolation was predicted by multiplying the average irrigation depth (1242mm) by 0.28.

Pistachio ET_a, as the residual of water balance equation:

Hence, the change in soil moisture (ΔS) was assumed to be negligible during the pistachio growing season. Using the above mentioned information on irrigation depth, precipitation and deep percolation, annual pistachio ET_a can be estimated as 978mm, as the remainder of water balance equation (see Table 3.). Considering the SEBAL-based annual estimate of pistachio ET_a for the same region (792mm), a SEBAL under-estimation of 19% can be deduced in this case study. A possible reason for this significant difference between SEBAL results and the water balance estimates is that water balance method has over-estimated pistachio ET_a. This reason appears to be probable due to the uncertainties involved in deep percolation (DP) parameter. DP is the product of leaching fraction estimates through the methodology described by Ayers and Westcot (1989). Therefore, uncertainties involved in the DP are correlated with the leaching fraction estimates. In this method, average EC_e of the top 1.20m of soil layer (as an estimate of pistachio rooting depth) was used to calculate leaching fraction of beneath pistachio root zone.

In such a manner, root depth plays important role by altering the average soil salinity and consequently, the leaching fraction. Meanwhile, lack of soil salinity data at depths below 1.2m could cause problems for precise estimation of leaching fraction beneath the pistachio root depth. Moreover, a sensitivity analysis on the mentioned water balance equation indicate that an increase of 1% in leaching fraction parameter would yield an increase of 12mm in deep percolation and a decrease of 12mm in evapotranspiration estimate.

Assuming that SEBAL estimate is accurate, 64% of applied irrigation water was used through pistachio tree evapotranspiration process in Bahadoran region.

Moreover, averaged annual released water to the pistachio orchards seemed to be adequate to leach the salts down to the root zone. More studies need to be conducted with sensors installed at depth below 1.2 m to obtain a better understanding of deep percolation process as well as pistachio root water uptake.

Table 3. Quantification of water balance components in Bahadoran pistachio orchards (from April 2015 to March 2016).

Irrigation, I (mm)	Precipitation, P (mm)	Deep Percolation*, DP (mm)	Surface Runoff , SR (mm)	Soil moisture changes (ΔS)	Evapotranspiration** , ET (mm)
1242	84	348	0	~0	978

* Multiplication of cumulative irrigation depth and the average leaching fraction (%28)

** As the remainder of water balance equation (ET=I+P-DP-SR-ΔS).

Conclusion

This study was conducted in a 2015-2016 experimental year to estimate annual water use of mature pistachio trees in Bahadoran region in central Iran. The required irrigation water is mainly pumped by deep wells. Annual pistachio evapotranspiration was first estimated by running the Surface Energy Balance Algorithm for Land (SEBAL) model, through Landsat 8 satellite data along with climatic parameters and ground-based ancillary data. Finally, the SEBAL estimate of annual water use evaluated by performing water balance analysis over the large scale of Bahadoran plain irrigation district. The water balance ET_a estimate was 19% larger than the SEBAL-based ET_a due to the uncertainties involved in estimation of deep percolation and leaching fraction. Generally speaking, the released amount of irrigation water to the Bahadoran region seems to be adequate to leach the salts down to the pistachio root zone. Obviously, the latter result depends on the irrigation water salinity as well as per irrigation applied depths which changes from a field to another field and may cause to over or under irrigation of the pistachio trees. Such possible under or over irrigations were demonstrated through the fluctuations of leaching fraction (3% to 65%), root zone soil salinity (1.73 to 31.6dS·m^{-1}) and consequently, the pistachio yield.

Based on the latest statistics of Yazd province agricultural organization (2016) the yield of Bahadoran pistachio trees varied from 500 to more than 4200kg.ha^{-1} (average of 1550kg.ha^{-1}), mostly due to fluctuations of soil and irrigation water salinities along with depths of applied water and other practices. Considering the averages of pistachio yield, applied water and actual evapotranspiration, two averages of 0.12 and 0.20kg.m^{-3} obtain for water use efficiency and evapotranspiration use efficiency of Bahadoran pistachios, respectively. These values may satisfy most of Bahadoran pistachio growers, but it seems to be inextensible to the entire Bahadoran plain. The reason for this uncertainty can be found in high fluctuations of pistachio yields as the consequence of irrigation water salinities and leaching fractions, as demonstrated above. However, continued irrigations may worsen the condition in the future to a point when agricultural production in the region is not economically viable anymore.

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