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**ORIGINAL ARTICLE**

# Water Productivity in Pistachio Orchards of Iran

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K E Y W O R D S

Applied irrigation water;
Climate change;
Irrigation requirement

A B S T R A C T

Pistachio has a long history in Iran, where it has existed for approximately 3,000 to 4,000 years, and has spread from Iran to other parts of the world. The importance of pistachio production on one hand and the lack of water and climate changes in Iran on the other hand have made it necessary to improve water productivity for this product. This research was conducted in the production hubs of pistachio in Iran. The purpose of the research was to measure the amount of applied water used in orchards' conditions (without interfering in irrigation management) and compare it with the actual requirement. It was also to determine water productivity of pistachio. In the studied hubs which have more than 85% of Iran's pistachio production, 88 orchards were selected and applied irrigation water, yield and some other parameters were measured. Water productivity was also determined. Analysis of variance was applied to investigate the difference in yield, applied irrigation water, and water productivity in pistachio production. The results showed that there was a significant difference in applied irrigation water used and water productivity in the selected orchards. There was no significant difference between yields. The average yield, applied irrigation water, and water productivity were 1764 kg $ha^{-1}$, 8057 $m^3$ $ha^{-1}$, and 0.26 kg $m^3$, respectively. Applied irrigation water in almost all pistachio orchards in Iran was less than the net irrigation requirement. The most important causes of low yields are forced deficit-irrigation, poor orchard management, and small ownership among the others.

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**Introduction**

Pistachio cultivation has a long history in Iran. About 70 years ago, pistachio found a special economic and commercial value in Iran's economy, and its position as the third source of foreign exchange (after oil and carpet) was established (Abdollahi Ezatabadi, 2008). Iran is ranked first among the major pistachio-exporting countries globally, followed by the United States, Turkey, and other nations (Pakravan *et al*. 2019). Iran is one of the largest pistachio producers in the world with more than 518 thousand hectares of pistachio cultivation area. The largest pistachio-producing provinces of Iran are Kerman, Khorasan Razavi, Yazd, Fars, South Khorasan, Semnan, Central Province, Qom, Baluchistan, and Isfahan Provinces (Ahmadi *et al*., 2023).

Pistachio is a drought-resistant plant that can survive with small amounts of water and even produce a small amount (Goldhamer, 2005; Sanden, 2016). The pistachio tree can develop its roots up to a depth of 2.5 meters from the soil surface to absorb the moisture of the lower layers during dry periods of the year (Goldhamer, 2005). It has also been said that when soil moisture decreases to the point of permanent wilting (PWP), pistachio roots in all soil depths can completely stop their activity for 4 to 5 weeks (Kanber *et al*., 1993). At the same time, it should be accepted that the pistachio tree needs sufficient water to achieve proper function and production (Goldhamer, 2005). If the pistachio tree faces under water stress conditions in sensitive periods, it will negatively affect the internal processes of the tree (Goldhamer, 2005). On the other hand, pistachio is a salinity-tolerant plant, but its performance is strongly affected by high salinity (Abtahi, 2001).

The evapotranspiration of pistachio trees (ETc) can be calculated using the crop coefficient (Kc), developed in California by Goldhammer *et al*., (2005). These plant coefficients reach high values of 1.19 in July and August, which results in an annual water consumption of about 12,000 $m^3$ $ha^{-1}$.

In Sicily, the calculated water requirement of pistachios is about 6000 $m^3$ $ha^{-1}$. This volume of water is not available for pistachio orchards in the dry areas of Sicily where pistachios are traditionally grown (Marino *et al*., 2018). Phene *et al*. (1985) mentioned the applied irrigation water in California for pistachio orchards was 11,500 $m^3$ $ha^{-1}$ (Mohammadi Mohammadabadi *et al*., 2020). Marino *et al*. (2018) in a research conducted under Mediterranean weather conditions with supplementary irrigation for rainfed pistachio orchards concluded that by supplying 10 to 15% of the pistachio tree's water requirement, the yield and water productivity can be significantly improved. In this condition, pistachio yield increases by 30%. Supplementary irrigation reduces the shedding of flower buds and leaves. Their results showed that with supplemental irrigation of 100 mm in Mediterranean regions where the annual rainfall is about 500 mm, it is possible to achieve sustainable production in pistachio orchards. Sanden (2016) reported the water requirement of mature pistachio trees between 762 and 1270 mm depending on the soil texture, salinity, irrigation method, and management.

In Iran, different amounts of irrigation water are used for pistachio orchards in different irrigation methods (basin, drip, or bubbler). These values vary between 4000 to 9000 $m^3$ $ha^{-1}$ annually. In the saline conditions of the central plateau of Iran, such as Yazd, the water depth used in pistachio orchards is higher than these values, such that it sometimes reaches 1700 to 4500 mm in flooded methods (Rahimian, 2012). Studies conducted on the water balance of pistachio orchards in Kerman province show that 8000 to 15000

$m^3$ $ha^{-1}$ are used for pistachio orchards in each cropping season (Moazenpourkermani *et al*., 2018).

The average global temperature has increased approximately 0.85 °C from 1880 to 2012 (Stocker *et al*., 2014). Based on the conducted researches, it is predicted that it will increase between 1.4 and 5.8 °C by 2050 (Ahmadi *et al*., 2021). Mianabadi and Davari (2023) investigated the changes in precipitation and temperature in Iran. In this research changes in precipitation and average monthly and annual temperatures of 12 synoptic meteorological stations in different climates of Iran were investigated (period 1991-2020). The results showed that the average annual precipitation decreased in most of the selected stations and the average annual air temperature increased in all stations. This trend of decreasing precipitation and increasing temperature is expected to continue. Climatic changes such as increase in temperature, decrease in rainfall, change of rainfall pattern have caused pistachio yield to be affected. Nowadays, according to the climate changes in the world, the question is whether it is possible to cool the trees by a few degrees in orchards using existing technologies and creating limited environmental conditions (Microclimate Engineering). Cooling trees reduces the effects of high temperatures. This approach is called microclimate engineering (Trilnick and Zilberman, 2021). Trilnick and Zilberman (2021) conducted a research to reduce the risks caused by the increase in winter temperature and its effects on the performance of pistachio orchards. They stated that due to the advancement of technologies, methods and tools can be used to reduce the temperature of the orchard. Although these methods increase production costs, they can contribute to production stability.

Weather conditions such as drought can affect the physiology and growth characteristics of pistachio trees and its yield. In the conditions of proper rainfall and humid climate, compared to severe dry conditions, pistachio photosynthetic activity increases significantly (Mehm*et al*i *et al*., 2018). Deciduous trees such as pistachio are very sensitive to climate changes and temperature increase (Benmoussa *et al*., 2018). Pistachio trees need a period of winter dormancy for flowering (Lee and Sumner, 2016). High temperature may delay the sleeping period of pistachio trees or prevent it (Pakdaman *et al*., 2023). The pistachio tree needs a relatively long period of winter dormancy and relatively high heat during the growing season to produce a quality and smiling product (Ferguson *et al*., 2016). Climate, especially temperature, has a significant effect on pistachio yield in hot and dry regions. An increase in air temperature causes an early start of phonological stages, including the flowering of pistachio trees. Early flowering increases the risk of spring frost and reduces yield (Ahmadi *et al*., 2021). Mehm*et al*i *et al*. (2018) in a study investigated the effect of climate change on pistachio yield in a region in southeastern Turkey. They concluded that pistachio yield is significantly affected by extreme climatic conditions.

Climate changes, droughts, urban activities, industry and growing population in hot and dry regions of the world will intensify the problems related to water scarcity. Iran is also one of the regions that will be strongly affected by these conditions (Galindo *et al*., 2018). Considering that many regions of Iran have a hot and dry climate, the water requirement of agricultural products (including pistachios) is high. These areas often have salty water and soil. Therefore, the development of modern irrigation methods and increasing the water productivity are ways of optimal use of water in these areas (El Jaouhari *et al*., 2018).

For the applied irrigation water and water productivity of pistachio orchards in Iran, various figures have been mentioned by researchers and experts. Some of these recommendations are based on

calculations, and others are based on measuring. Therefore, there are no exact figures for the applied water used by pistachio orchards in Iran. This research was conducted to measure the amount of applied water used in orchard conditions (without interfering in irrigation management) and evaluating the water productivity of pistachio in the production hubs of pistachio in Iran.

## Material and Methods

Iran's pistachio cultivation area is more than 450 thousand hectares. Of this cultivated area, 74.2% are mature trees and 25.8% are Young orchards. Kerman province has the first place (with more than 60%), and the three provinces of Khorasan Razavi, Yazd, and Semnan have taken the second, third, and fourth place, respectively. Together, these four provinces have about 85% of the area of mature orchards and 18 other provinces have only 15% of mature pistachio orchards. Pistachio production in Iran is about 150-305 thousand tons per year. Table 1 shows area cultivation and production of pistachios of Iran (Ahmadi *et al*., 2023).

**Table 1.** Area cultivation and yield in the production hubs of pistachio (irrigated) in Iran

| Province | Area of orchards (ha) | | Yield average (kg ha$^{-1}$) | Total yield (ton) |
|---|---|---|---|---|
| | Mature orchards | Young orchards (Non-Fruiting) | | |
| **Kerman** | 203220 | 9355 | 552 | 112287 |
| **Khorasan Razavi** | 52083 | 34918 | 1170 | 60904 |
| **Semnan** | 11259 | 7824 | 1155 | 13012 |
| **Yazd** | 31950 | 12869 | 1498 | 47860 |
| **Other provinces** | 60566 | 33292 | - | 70357 |
| **Total sum/average** | 359078 | 98258 | 848 | 304420 |

In this research, 88 orchards were selected from Khorasan Razavi, Semnan, Kerman, and Yazd provinces and applied irrigation water was monitored from October 2015 to October 2016 (for one year). Table 2 shows the mean and standard deviation of some measured parameters in selected orchards. In this research, the amount of water used in the orchards (without interfering with the irrigation program of orcharders) was measured and determined. The applied irrigation water, yield, and other quantities related were measured in surface and drip irrigation systems and orchards in different soil textures. The measured quantities included the salinity of irrigation water, the production amount of each orchard, soil texture, and the number of irrigation cycles, pistachio yield, and applied irrigation water. Other information such as the type of irrigation network, irrigation method, and height above sea level were recorded. In the selection of orchards, it was tried to choose different management levels (weak, medium, and good) and traditional and drip irrigation systems. Measurements to determine applied irrigation water were conducted by considering various factors such as irrigation method, orchard area, Age of trees, soil and water quality, network type, and climate. In each orchard, the irrigation water flow was measured and recorded several times during the cropping season using appropriate tools (WSC flume and ultrasonic flowmeters). The number and time of irrigation were also recorded.

**Table 2.** Range of changes in some parameters measured in the selected orchards pistachio

| Province | Number of selected orchards | Irrigation water EC (dS $m^{-1}$) | Soil EC (dS $m^{-1}$) | Orchard area (ha) | Crop growth period (days) | Irrig. depth (mm) | Rainfall (mm) | Effective Rainfall (mm) |
|---|---|---|---|---|---|---|---|---|
| **Kerman** | 29 | 3.55±0.78 | 4.3 ± 1.72 | 85.3 ± 3.35 | 230 ± 5 | 65.7 ± 2.28 | 118 ± 6 | 56 ± 2 |
| **Khorasan Razavi** | 9 | 6.1 ± 1.08 | 8.5 ± 2.18 | 110.3 ± 5.18 | 210 ± 7 | 66.3 ± 3.58 | 205 ± 8 | 63 ± 4 |
| **Semnan** | 18 | 2.2 ± 0.18 | 3.8 ± 1.78 | 41.2 ± 2 | 210 ± 4 | 74.7 ± 5.18 | 135 ± 6 | 79 ± 1.6 |
| **Yazd** | 32 | 6.9 ± 1.28 | 8.1 ± 2.08 | 29.3 ± 4.5 | 235 ± 2 | 131 ± 9.48 | 95 ± 11 | 49 ± 6 |

Evapotranspiration for irrigation planning of agricultural and orchards in each region is affected by the climatic conditions prevailing in that region and the characteristics of the desired plant, which are summarized in two parameters $ET_0$ and $K_c$, respectively:

$$ET_c = K_c \times ET_0 \qquad (1)$$

Where, $ET_0$ is the reference evapotranspiration (mm $day^{-1}$), $K_c$ is the vegetation coefficient (without units), $ET_c$ is the evapotranspiration of the desired crop in standard conditions, that is, the potential evaporation and transpiration of the desired plant (mm $day^{-1}$). $ET_0$ means the evaporation requirement of the atmosphere, which is equivalent to the amount of evaporation from a reference surface (such as grass or alfalfa). Therefore, $ET_0$ has a maximum value and is solely subject to the atmospheric conditions of the region. $ET_c$ also means maximum evaporation and transpiration that the plant can do under standard conditions and free from any environmental and management stress (Goldhammer, 2005). The net water requirement of pistachio trees was calculated based on the data of the nearest meteorological station for the year of the research and the last ten years using the FAO Penman-Monteith method, and compared with the water requirement values provided in the national document. Then, the water productivity of pistachios was calculated by estimating the effective rainfall during the growing season, taking into account the amount of applied irrigation water, and measuring the crop yield in the orchards different provinces.

***Water productivity***

Water productivity is considered as an accurate and scientific indicator for measuring the optimal use of irrigation water and agricultural production. According to the definition, water productivity is a ratio in which the denominator is the applied irrigation water (irrigation water and rainfall) and in that case significant cases of quantitative concepts such as product performance are included. Generally, the two concepts of physical and economic productivity of water are more useful and are used in analyzes and decisions. The physical productivity of water is the amount of product produced per unit volume of applied irrigation water, which is expressed in kg $m^{3-1}$ (Abassi *et al*., 2016), calculated as follows:

$$WP = \frac{\mathrm{CY}}{(\mathrm{CW}+\mathrm{Re})} \qquad (2)$$

WP water productivity (kg/$m^3$), CY yield (kg/ha), CW volume of applied irrigation water in pistachio production and $R_e$ effective rainfall during the cropping season ($m^3$ $ha^{-1}$). Applied irrigation water refers to the water requirements and leaching needs of pistachio orchards.

***Data variance analysis***

Variance analysis was used to investigate yield changes, applied irrigation water and water

productivity index in pistachio production in the selected orchards. Due to the nature of the measurements, each pistachio orchard was considered as a replicate. Equation (3) was used to check the adequacy of the number of orchards to measure the volume of applied irrigation water and pistachio yield (Sarmad *et al*., 2001).

$$n = \frac{Z^2\sigma^2}{(X-\sigma)^2} \quad (3)$$

In this equation, n is the number of measurements required to analyze the variance of yield and volume of water used in pistachio production, z is 1.96 at the 95% confidence level, $\sigma^2$ is the variance, $\overline{X}$ is average of the measurements and μ is the value of each measurement. Measurements related to irrigation water, crop yield, and other variables were taken in this research.

**Results**

For statistical analysis to be valid, the basis for checking data adequacy is normal distribution. The standard normal variable (Z) in agricultural data analysis is independent of the cultivated area, irrigation systems, soil physicochemical characteristics, etc. The greater variance of the data, more data will be needed for analysis. In other words, the dispersion and non-uniformity of the data are high, and there is a need to collect more data to increase accuracy. Therefore, based on statistical analysis, the minimum number of necessary measurements in each province was determined. Table 3 shows the statistical parameters and the minimum number of orchards required for data collection. The preliminary results showed that the variance of the data in Yazd province is higher than the other three provinces. For this reason, at least 30 measurements should have been made in this province. To ensure the validity of the data collection, the number of selected orchards in each province was more than the minimum required. It should be noted that in Kerman province, despite the fact that the pistachio cultivated area was more than the total cultivated area of the other three provinces, the variance of the measured data was not significant and there was no need to increase the measurements. Given that climate variability, orchard management, soil texture, water requirements, and variations in soil, plant, and climatic factors contribute to increased variance in the measured data, In this research anticipated a high coefficient of variation and variance. In agricultural experimental designs, factors other than the experimental treatments are controlled by the researcher. Therefore, the number of measurements for applied irrigation water and yield in pistachio orchards was significantly higher than the minimum required for data adequacy. This approach ensures that the research conclusions are statistically reliable.

**Table 3.** Average, standard deviation and adequacy of measurements in Pistachio orchards

| Row | Province | Applied irrigation water average ($m^3$ $ha^{-1}$) | Standard deviation | Minimum amount of data required | Number of measurements |
|---|---|---|---|---|---|
| **1** | Kerman | 6713 | 1356 | 16 | 29 |
| **2** | Khorasan Razavi | 5579 | 852 | 9 | 9 |
| **3** | Semnan | 7394 | 1468 | 15 | 18 |
| **4** | Yazd | 11177 | 3125 | 30 | 32 |

The number of measurements was also calculated to ensure adequacy for all selected orchards. The summary of statistical indicators is presented in Table 4. The number of measurements of applied irrigation water and pistachio yield in the present study was

considered more than the number of necessary measurements.

**Table 4.** Average, standard deviation and adequacy of measurements in selected orchards

| Statistical index | Yield (kg $ha^{-1}$) | Applied irrigation water ($m^3$ $ha^{-1}$) |
|---|---|---|
| **Average** | 1678 | 8660 |
| **Standard deviation** | 719 | 3251 |
| **Number of measurements required** | 71 | 54 |
| **Number of measurements done** | 88 | 88 |

***Number of irrigation***

The pistachio tree needs a certain amount of water in each stage of its growing season. In Iran, pistachio trees are irrigated once after harvest (end of October). After that, in November, an irrigation is done for the orchards. Between February and March, the second winter water is given to the pistachio orchards. After winter, irrigation of pistachio orchards usually starts at the end of May. In surface irrigation methods, the irrigation period in each area (depending on the amount of water available) varies from 30 to 60 days. Table 5 shows the average number of irrigations in the studied provinces.

**Table 5.** The average number of irrigation of pistachio orchards in selected provinces

| Row | Province | Number of irrigation | |
|---|---|---|---|
| | | Surface | Drip |
| **1** | Kerman | 7 | 21 |
| **2** | Khorasan Razavi | 9 | 8 |
| **3** | Semnan | 8 | 22 |
| **4** | Yazd | 8 | 12 |

***Comparison applied irrigation water***

In this research, applied irrigation water (plus leaching requirement) in the orchards of Khorasan, Semnan, Kerman, and Yazd in one year was measured. The net irrigation requirement was calculated based on the irrigation method (surface and drip). Figure 1 shows the average volume of water applied. The average applied irrigation water in the surveyed provinces in surface and drip irrigation methods was 8317 and 6566 ($m^3$ $ha^{-1}$), respectively. Applied irrigation water in Khorasan Razavi, Kerman, and Semnan was close to each other, but there was a greater difference in Yazd.

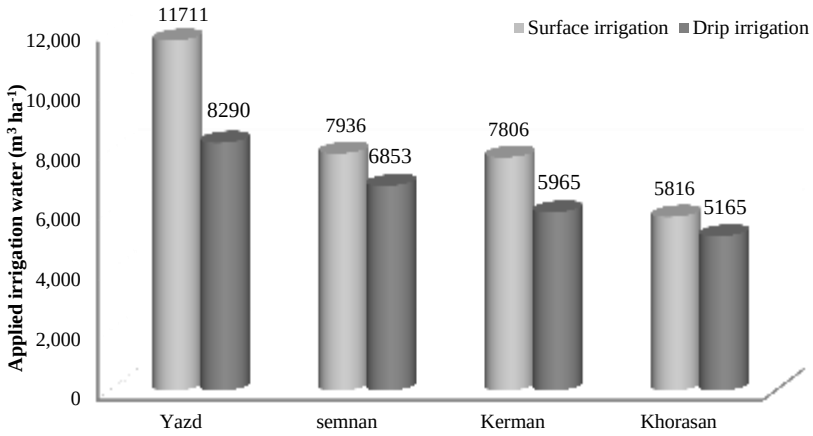


**Fig. 1.** Average volume of applied irrigation water in surface and drip irrigation systems

Abdullahi Ezatabadi *et al*. (2014) in a research conducted to determine the irrigation efficiency in 286 pistachio orchards in Anar and Rafsanjan cities obtained the volume of water used throughout the year from 970 to 27000 and an average of 9730 cubic meters per hectare. In another research regarding pistachio subsurface drip irrigation systems in Sirjan (Kerman, Iran), the volume of applied irrigation water was obtained from 4600 to 10500 cubic meters per hectare (Kohi, 2014). Moazenpour *et al*. (2018) in a lysimetry research determined the water consumption of pistachio trees at the age of 4, 5, 6, 7, 8 and 9 years as 2290, 2500, 2740, 4520, 4600 and 5620, respectively. In a research, the amount of applied irrigation water for pistachio orchards in California (from 1998 to 2010) was reported as about 12000 $m^3$ $ha^{-1}$ (California Department of Water Resources, 2014).

Based on the results of this research, in all provinces, the amount of applied irrigation water in drip irrigation systems have decreased compared to surface irrigation system. On the other hand, in almost all pistachio orchards, the volume of applied irrigation water (during the growth period along with winter washing) was less than the net required irrigation of the orchards, and forced deficit-irrigation was observed in all the orchards. This was an undeniable fact. Therefore, the conversion of surface irrigation system to drip irrigation in pistachio orchards is essential and can compensate for a relatively large part of the forced irrigation shortages. In addition, if drip irrigation systems are well implemented and managed and pistachio orchards are equipped with soil moisture measurement and monitoring systems, it can help to preserve and stabilize underground water tables.

Irrigation during the growing season is one of the most important operations for pistachio, like other plants (Hosseini Fard *et al*., 2016).

***Analysis of pistachio applied irrigation water***

By using variance analysis, the possible difference in the amount of applied irrigation water in pistachio production in Khorasan Razavi, Semnan, Kerman and Yazd provinces was investigated. The results showed that the difference in the amount of applied irrigation water in pistachio production in the selected provinces is significant at the level of less than one percent (Table 6).

**Table 6.** Variance analysis of applied irrigation water in selected orchards

| Source of changes | Sum of squares | Degree of freedom | Mean square | Ratio F | P-value |
|---|---|---|---|---|---|
| **Between provinces** | $3.721 \times 10^8$ | 3 | $1.24 \times 10^8$ | 21.46 | Less than one percent (<1%) |
| **Within provinces** | $4.10 \times 10^8$ | 71 | $5.78 \times 10^8$ | | |
| **Whole country** | $7.82 \times 10^8$ | 74 | | | |

The amount of applied irrigation water in the studied provinces can be divided into two main clusters. In the first cluster, the amount of applied irrigation water in the pistachio orchards of Yazd province with an average of 11177 $m^3$ $ha^{-1}$, in the second cluster, the amount of water used in the provinces of Semnan (7394 $m^3$/ha), Khorasan Razavi (5579 $m^3$ $ha^{-1}$), and Kerman (6713 $m^3$ $ha^{-1}$) are located. The weighted average (relative to the cultivated area) and arithmetical volume of water used in pistachio production in selected provinces for both surface and drip irrigation methods are calculated and presented in Table 7.

**Table 7.** Weighted and arithmetic average of applied irrigation water in selected orchards.

| Irrigation method | Weighted average | Arithmetic average |
|---|---|---|
| **Surface** | 8350 | 9549 |
| **Drip** | 5900 | 6566 |
| **Regardless of the irrigation method** | 7125 | 8057 |

***Water requirement of pistachio***

To calculate evapotranspiration of the reference plant ($ET_o$), the statistical data (ten years) of the nearest weather station (2007-2016) were used and the calculations were done with the help of $ET_0$ Calculator software. The net irrigation requirement was determined based on evaporation and transpiration of the reference plant and pistachio plant coefficient for each region. In calculating the net irrigation requirement, the wetted soil surface was considered 100% in surface irrigation method and 67% maximum in the drip irrigation method (Alizadeh, 2016). In calculating water requirement of pistachio trees over 15 years old, the minimum plant coefficient during the growth period was 0.40 and the maximum was 0.60. In Iran, the plant factor of pistachio ($K_c$) is set from 0.40 to 0.60 as the standard of action (Mozenpour Kermani *et al*., 2018). Figure 2 shows the comparison of applied irrigation water, water demand calculated based on 10-year meteorological data and the national water document.

The results of this research showed that applied irrigation water for pistachio orchards in selected provinces is lower than the actual water requirement (calculated) of pistachio trees (Fig. 2). In other words, in Iran, due to the limitations of water resources, pistachio orchards are under forced deficit irrigation. Therefore, forced deficit irrigation is one of the important factors in reducing the yield of pistachio orchards in Iran.

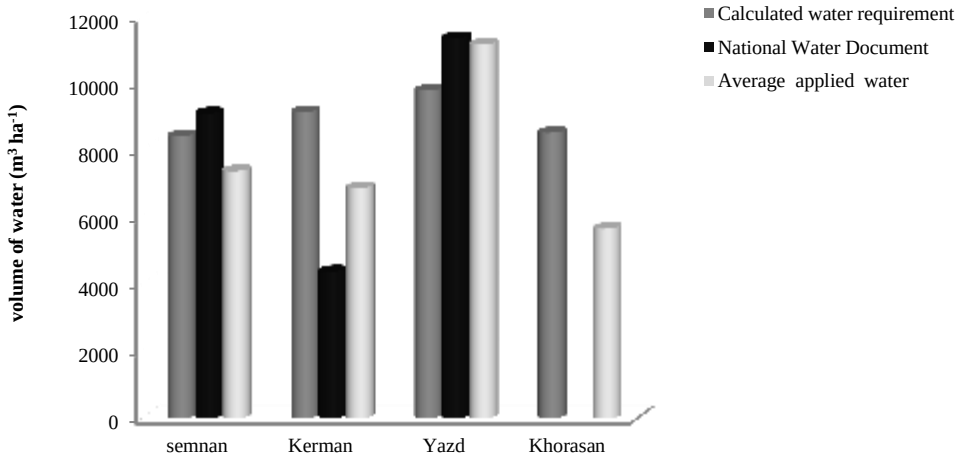


**Fig 2.** Comparison of applied irrigation water with the net irrigation requirement and Iran's national water document ($m^3$ $ha^{-1}$)

***Yield***

The non-uniformity of pistachio tree yield in two consecutive years is called alternate bearing or biennial bearing (on- off year). Alternate bearing can be related to internal physiological factors. Climatic factors such as season first frostbite, hot and dry winds, the need for winter cold and pests and diseases also play an important role in pistachio alternate bearing (Seyedi and Ismailpour, 2015). In order to avoid such errors, several years of crop yield (the year of the research implementation and the two years before that) were set as criteria for the selected orchards. The yield measured in Khorasan Razavi, Yazd, Semnan and Kerman provinces was 2506, 1750, 1708 and 1511 dried pistachios, respectively (Fig. 3). The average yields based on provincial statistics were lower than the average yield measured in this research. The average yield of pistachio in Iran was 848 kg $ha^{-1}$.

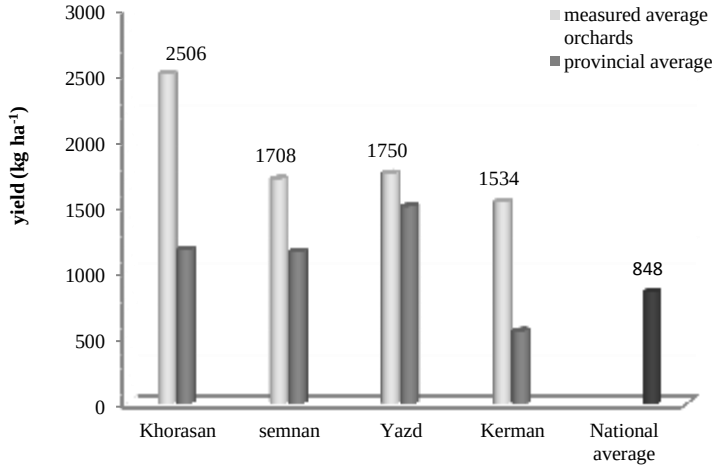


**Fig .3.** Comparison of the measured average yield of pistachio orchards with the provincial and national average (kg $ha^{-1}$)

***Analysis of pistachio yield***

Variance analysis was used to investigate changes in pistachio yield in Semnan, Khorasan Razavi, Kerman and Yazd provinces. The results showed that the yield difference is not significant at the one percent probability level (Table 8).

**Table 8.** Variance analysis of pistachio dry yield in selected orchards.

| Source of changes | Sum of squares | Degree of freedom | Mean square | Ratio f | P value |
|---|---|---|---|---|---|
| **Between provinces** | $3.089 \times 10^6$ | 3 | $1.029 \times 10^6$ | 2.08 | 0.11 |
| **Within the provinces** | $35.14 \times 10^6$ | 71 | $0.495 \times 10^6$ | | |
| **Whole data** | $38.23 \times 10^6$ | 74 | | | |

The average dry pistachio yield in selected provinces was 1742 kg $ha^{-1}$. The highest yield was obtained from the orchards of Khorasan Razavi province with an average of 2506 kg $ha^{-1}$ and the lowest from the orchards of Kerman province with an average of 1516 kg $ha^{-1}$. The yield of pistachios from the orchards of Semnan and Yazd provinces was 1708 and 1750 (kg $ha^{-1}$), respectively. Figure 3 shows the comparison of the average yield of the product measured in the selected orchards of the provinces with the average yield of pistachio based on statistics (Ahmadi *et al*., 2023). Figure 3 shows that the average yield measured in the selected orchards is higher than the average yield of the statistics. The reason for that is the participation of the entire statistical community in calculating the average in the statistics. In other words, because in the calculation of the average in the statistics, all the levels of the orchards in the whole province are considered, it is natural that the average yield is lower than when a smaller number of the statistical population is involved in the calculation of the average. It can be seen carefully in the numbers in the above figure that the average yield in Kerman province based on the statistics is much lower than the values measured in this research and this difference is significant. The reason for that is the abandonment many of the province's orchards due to the reduction of water resources, while these levels are included in the calculation of the province's yield. On the other hand, in Khorasan Razavi province, the average yield measured is higher than the average yield of the statistics. Yield of pistachio orchards depends on various factors such as weather conditions, water and soil quality, age and level of orchards, type of irrigation system, orchards management and even the level of literacy of orcharders (Faiz Abad). Therefore, the difference in yield of the studied provinces is natural, although this difference was not very large. In general, the data obtained from a research project are more accurate and more reliable than the estimates and opinions of experts obtained through non-research methods. The average pistachio yield in America is 4190 kg $ha^{-1}$. The average pistachio yield in Turkey is 3424 kg $ha^{-1}$ (U.S. Department of Agriculture, 2024).These numbers show that the average pistachio yield is far from that of the leading countries in the world (the average pistachio yield in Iran is 848 kg per hectare). Improving the management of pistachio orchards in Iran is one of the ways to increase pistachio yield.

***Water productivity in pistachio orchards***

The physical productivity of water in different provinces and in both surface and drip irrigation systems was determined and compared. Water

productivity in the surface irrigation system in Khorasan Razavi, Semnan, Kerman and Yazd provinces were 0.44, 0.24, 0.24 and 0.16 (kg $m^{3-1}$) and in drip irrigation system in provinces of Khorasan Razavi, Semnan, Kerman and Yazd were 0.25, 0.22, 0.21 and 0.16 (kg $m^{3-1}$), respectively (Fig. 4). The average water productivity in the studied provinces in surface and drip irrigation methods was equal to 0.22 and 0.25 (kg $m^{3-1}$), respectively. Water productivity in drip and surface irrigation systems (except Khorasan Razavi) did not differ much from each other due to deficit-irrigation. In Khorasan Razavi, the difference in water productivity was significant, which was probably due to the small number of orchards with drip irrigation systems. But why is the water productivity of pistachio low in all provinces and relatively large difference from the average water productivity among pistachio producing countries? According to the productivity relationship, what causes the smallness of the productivity values is the smallness of the numerator of the fraction or the largeness of the denominator of the fraction. That is, the largeness of the denominator of the fraction (volume of applied irrigation water for pistachio production), the smallness of the fraction also causes the reduction of the productivity number. The fact is that the average yield of pistachio in Iran is far from the world average, and this yield in Iran is far from the potential in the orchards and conditions of the Iran, which can be achieved with management planning. Therefore, in order to increase pistachio water productivity, in addition to managing water consumption to increase irrigation efficiency, it is necessary to improve the management of pistachio orchards and increase the yield of the product. Lai (2017) identified the most important challenges and low yield of pistachio orchards in Iran as farmers' lack of knowledge about commercial cultivars and the compatibility of their characteristics with climatic conditions, the lack of coordination between the number of pollinator bases and mother bases (1 to 8 in America, but 1 to 190 in Iran). Non-simultaneity of pollination of the maternal and paternal foundations, non-uniformity of the bases due to genetic differences, failure to select the appropriate base, failure to observe the principles of nutrition in orchards, failure to observe the appropriate time for irrigation, failure to observe the appropriate time for harvesting, compliance not following the principles of fighting against pests and diseases, improper plowing of trees, not following the correct principles of pruning, and not following the principles of mechanization.

In addition to what was mentioned, climate change is also one of the most important factors affecting the reduction of pistachio yield in Iran. Based on the meteorological data of the studied regions, the annual rainfall has decreased, and the average maximum and minimum temperatures have increased (Mianabadi and Davary, 2023). Also, the rainfall pattern has changed from snow to rain and rainfall has moved from autumn and winter to spring and early summer (change in rainfall pattern). The decrease in rainfall has increased the need for irrigation water in the regions. The increase in the average minimum temperature in the pistachio orchards has caused the lack of winter cold supply and the delay in hibernation of the pistachio trees (which results in spring frosts) and the increase in pests and diseases in the pistachio orchards. The increase in the average maximum temperature in these areas has also increased the risk of hail and heavy showers. Therefore, all these changes in the climate of these regions have caused a decrease in pistachio yield. According to scientific sources and reports, these climate changes are happening in all regions of the world and threaten pistachio orchards and other horticultural and agricultural products.

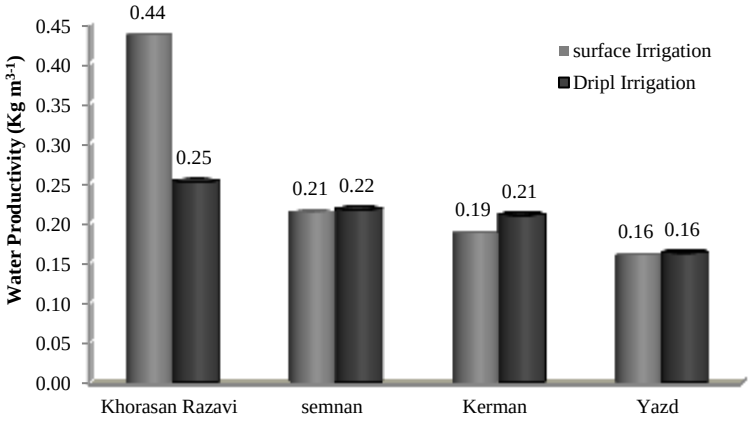


**Fig. 4.** Average water productivity (irrigation and effective rainfall) of pistachio orchards in irrigation methods (kg $m^{3-1}$)

***Analysis of pistachio water productivity***

The variance analysis of water productivity in the studied provinces is presented in Table 9. The results showed that the difference in water productivity in the mentioned provinces was very significant. The main reason for this difference is associated to the difference in yield and the volume of applied irrigation water. The average water productivity index in pistachio production from the orchards of Khorasan-Razavi, Semnan, Kerman and Yazd provinces is 0.37, 0.25, 0.27 and 0.16, respectively and the average water productivity of the studied areas, being 0.26 kg $m^{3-1}$. The higher productivity of water in Khorasan-Razavi province was due to relatively more suitable weather conditions compared to other three provinces, better quality of water, soil and also better management in the pistachio orchards of this province. Harsh weather conditions in Yazd province, relatively high salinity of water and soil resources was the main reason for the decrease in water productivity in this province.

**Table 9.** Variance analysis of pistachio water productivity of selected orchards

| Source of changes | Sum of squares | Degree of freedom | Mean square | Ratio f | P-value |
|---|---|---|---|---|---|
| **Between provinces** | 0.295 | 3 | 0.098 | 11.7 | Less than one percent |
| **Within the provinces** | 0.596 | 71 | 0.008 | | |
| **Whole country** | 0.891 | 74 | | | |

**Conclusions and Suggestion**

The results of this research showed that the amount of applied irrigation water in most pistachio orchards in Iran is less than the net irrigation requirement (without considering the irrigation efficiency). This shows that there is deficit irrigation in pistachio orchards. Because these deficit irrigations occur uniformly throughout the growing season, both sensitive and non-sensitive stages, it strongly affects pistachio yield and is one of the important factors in creating a large gap with the global average pistachio yield. On the other hand, due to the fact that pistachio orchards are a single crop, it is not possible to supply

and move water from other crops for the benefit of pistachios in sensitive stages of growth. Therefore, the conversion of surface irrigation systems to drip irrigation systems (surface or subsurface) is one of the solutions to solve the lack of water in pistachio orchards and compensate part of the deficit irrigation. The reduction of water resources (especially underground water resources) and the disproportion of the area of the orchards with the available water resources is also a factor that will cause the removal of parts of the pistachio orchards in Iran.

In recent years, all climatic parameters have changed (average annual rainfall, average maximum and minimum temperatures). Also, the rainfall pattern has changed from snow to rain and rainfall has moved from autumn and winter to spring and early summer (change in rainfall pattern). The decrease in rainfall has increased the need for irrigation water in the regions. The increase in the average minimum temperature in the pistachio orchards has caused the lack of winter cold supply and the delay in hibernation of the pistachio trees (Mehm*et al*i *et al*., 2018) and the increase in pests and diseases in the pistachio orchards. In general, climate changes are happening in all regions of the world and threaten pistachio orchards and other horticultural and agricultural products (Mianabadi and Davari, 2023).

The average pistachio yield in Iran (in well-managed 18-20-year-old orchards) is about 848 kg $ha^{-1}$. Meanwhile, the average pistachio in America (12-year-old trees) is 4190 kg $ha^{-1}$ (Seifi and Mirlatifi, 2020). This difference in the average pistachio yield is related to the use of modern techniques, proper management of irrigation and nutrition in American orchards, while the management of pistachio orchards in Iran is weak.

The water productivity of pistachio in Iran is low and has a relatively large difference with the average productivity among pistachio producing countries. According to the productivity formula, what causes the productivity index to decrease is the smallness of the numerator or the largeness of the denominator. If irrigation efficiency and irrigation needs of pistachio orchards are also calculated and taken into account, the amount of irrigation needs of pistachio orchards (gross need) will be much higher than the current volume of water used. Therefore, it can be said that in relation to the water productivity of pistachio, the denominator of the fraction is not large and it is almost impossible to reduce it. On the other hand, the smallness of the numerator in the physical productivity formula can also cause the productivity number to decrease. Because the yield of pistachio in Iran is low, as a result, the amount of water productivity is low.

The most important reasons for the low yield orchards in the Iran include: small ownership, allocation of low-quality and poor land for pistachio cultivation, weakness in orchard management, inadequate water quality, climate change and consecutive droughts, severe drop in groundwater levels, severe climate changes, improper quality of pesticides, poor mechanization in pistachio orchards, poor varieties and improper nutrition of pistachio orchards. Therefore, increasing the yield of pistachio in Iran by improving agricultural and orchard management, carrying out educational programs, improving water consumption management, teaching the correct use of pressurized irrigation systems, correct nutrition of orchards and using the opinions of experts is easily possible.

**Conflict of interests**

No conflict.

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