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**ORIGINAL ARTICLE**

# Irrigation Water Volume and Water Efficiency of Walnut Orchards in As-Suwayda, Syria

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A R T I C L E I N F O

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A B S T R A C T

In recent years, the demand for walnuts has increased due to their recognition as a nutritious food and a versatile ingredient in cooking and baking. As a result, walnut production has become a significant industry in many countries, providing income and employment opportunities for growers and processors. Despite the fact that one of the most important products in the world and Syria is walnuts, there has been little research on irrigation and, in particular, water productivity. Therefore, the purpose of this study is to examine the irrigation status and water productivity in several walnut orchards in As-Suwayda province, which is a significant production area for this product. In the course of this research, water productivity, irrigation water volume, and the crop performance of walnut orchards in three of the most important producing locations of this commodity in the province of As-Suwayda (Sweida) were evaluated and compared. Drip irrigation and surface irrigation methods were investigated. The t-test was used to compare irrigation water levels in orchards with gross water requirements. Drip irrigation systems in orchards save around 1700 $m^3$ $ha^{-1}$ of irrigation water, reduce yields by an average of 145 kg $ha^{-1}$, and boost water productivity by roughly 0.02 kg $m^3$, according to the findings, but none of these differences were statistically significant at the 5% level. In general, there was not a discernible difference found between drip and surface irrigation systems in terms of performance values, amount of water applied, or water productivity.

## Introduction

Agriculture is a critical economic sector in developing countries, which are grappling with low water resource usage efficiency and dwindling water supplies (Cullis *et al.*, 2018; Riaz *et al.*, 2020). Agriculture land expansion, which accounts for 70% of the current global freshwater extraction, has boosted

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global water demand and consumption in recent years (Rosa *et al*., 2019; Dehghanipour *et al*., 2020). Concerns about freshwater resource scarcity and overexploitation have arisen due to global economic expansion and the rising need for fuels, feed, and food (Molajou *et al*., 2021b). Over the last five years, water problems have risen to one of the top five global hazards (Di Baldassarre *et al*., 2018; Molajou *et al*., 2021a). Increased agricultural water usage puts pressure on natural ecosystems, especially in semi-arid and arid climates, leading to ecosystem degradation (Chartres and Noble, 2015). Water allocation and consumption management in the agriculture sector, which accounts for a large portion of Syria's and the world's water resources, can help to alleviate the challenges connected with water scarcity (Lotfi *et al*., 2009; Roointan *et al*., 2018). Water is a vital component of agricultural productivity and is crucial to food security. Irrigated agriculture accounts for 20% of all farmed land and 40% of all food produced worldwide (Shah and Wu, 2019; Serazul-Islam, 2023). There are many advantages to using irrigation for agricultural purposes, including increased productivity and crop diversification, compared to farming with rain water (De Pascale *et al*., 2011). Competition for water resources is predicted to increase due to population expansion, urbanization, and climate change, with agriculture bearing the brunt of the impact. In this study, the volume of irrigation water given by growers to produce walnuts during the year in three cities of Shahba, Al-Suwayda, and Salkhad in As-Suwayda province was measured (Fig. 1).


**Fig. 1.** Map of As-Suwayda Governorate showing sub-district boundaries, Syria (Source: Wikimedia).

One of the most important measures for macro-planning related to the supply, allocation, and principled use of water in each country is determining water consumption management indicators such as irrigation water quantity, crop performance, and water productivity of various crops (Wallace, 2000). The volume of water consumed in the country's agricultural sector has never been precisely measured, and this has long been a source of concern and controversy among managers and planners in the country's water industry (Abou Zakhem *et al*., 2019; Baba *et al*., 2021). Due to the importance and special characteristics of walnuts in human culture and nutrition and their high price, this product can bring significant value to the country's economy and serve domestic demands (Hassankhah *et al*., 2017; Juranović Cindrić *et al*., 2018; Sangirova *et al*., 2020; Sarikhani *et al.*, 2021; Thapa *et al.*, 2021; Akca and Sahin, 2022). According to the World Food and Agriculture Organization, China, the United States, Iran, Turkey, and Mexico, are the top walnut-producing countries (Table 1) (Banaeian and Zangeneh, 2011). Also according to FAO, in 2014, Iran was ranked third in the world with production of 445,829 tons of walnuts (Farsi *et al.*, 2018).

**Table 1.** List of Countries by Walnut Production.

| | Country | Production (tons) | Production per Person (kg) | Acreage (ha) | Yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|
|  | China | 2,521,504 | 1.809 | 631,330 | 3,994 |
|  | United States of America | 592,390 | 1.807 | 147,710 | 4,010.5 |
|  | Iran | 321,074 | 3.927 | 44,780 | 7,170 |
|  | Turkey | 225,000 | 2.784 | 124,553 | 1,806.5 |
|  | Mexico | 171,368 | 1.374 | 102,068 | 1,679 |

During the growing season, walnut requires between 950 and 1450 mm water (Kamran *et al*., 2011). To meet the watering needs of walnuts during the warmer months of the year, gardeners should begin deep watering early in the growing season. Depending on the conditions, the effective depth of walnut tree roots ranges from 85 to 295 cm (Zhang *et al*., 2015). The maximum permissible soil moisture for walnuts is roughly 45%, and a lack of irrigation water results in a significant production drop to about 35% (Yun *et al*., 2012). According to Sadeghi-Majd *et al*. (2022), the amount of drip irrigation water for walnuts in Xinjiang was 7000 m$^3$ ha$^{-1}$. According to a study conducted in Yunnan, China, the best yield of walnuts is produced when 100% of water needs are met. Increased irrigation by 25% will merely enhance plant development and growth unnecessarily. Also, based on the findings, a 20% reduction in irrigation reduces yield marginally but increases crop quality. The net water requirement of walnut trees was calculated to be 4130 m$^3$ ha$^{-1}$ (Xue *et al*., 2021). According to a study conducted by Jiyuan *et al*. (2022), walnut trees' ideal growth and development can be achieved with irrigation techniques such as drip and sprinkler systems, but not with flood or rainfed systems. In California, one study examined the impact of managed irrigation on two walnut varieties. The amount of irrigation water utilized in the mild, medium, and high irrigation treatments was calculated to be 6050, 6990, and 11100 m$^3$ ha$^{-1}$, respectively, based on the results. Low irrigation was also discovered to be unsuitable for walnut trees, reducing the quantity and quality of the crop (Dhillon *et al*., 2019). In another study, Lampinen *et al*. (2004) administered irrigation management of walnut trees using evapotranspiration, soil, and plant data in California, USA. The results showed that the effects of poor irrigation on the quantitative and qualitative yield of walnuts were different and depended on the tree's age, soil conditions, and so on. The control treatment received 11050 m$^3$ ha$^{-1}$ of irrigation, mild irrigation received 8100 m$^3$ ha$^{-1}$, and ordinary irrigation received 6635 m$^3$ ha$^{-1}$. However, in the research region, the plant's real evapotranspiration was equal to 10590 m$^3$ ha$^{-1}$ (Lampinen *et al*., 2004). Fulton (2013), calculated plant coefficients and water requirements for walnut trees in California, USA. The findings of this study revealed that the plant coefficient in the starting stage was 0.59, in the middle stage was 1.31, and in the final stage was 0.5, and the plant's seasonal water need was 10620 m$^3$ ha$^{-1}$. In a study, Apáti *et al*. (2018) demonstrated that the yield of dried walnuts was around 2210 kg ha$^{-1}$ when irrigated with a sprinkler system, 2150 kg ha$^{-1}$ when irrigated with a drip system, and 1620 kg ha$^{-1}$ when irrigated with surface water. Surface irrigation had a vegetative growth rate of 11% and 18% less than drip and sprinkler irrigation. Previous research show that estimating the amount of irrigation water and water productivity in orchards and farms is important for several reasons (Gharaghani *et al*., 2018; Valleser *et al*., 2023):

-Efficient water management: Accurately estimating the amount of irrigation water required for crops can help growers make informed decisions about water use and conserve this precious resource.

-Improved crop yields: By monitoring water productivity, growers can identify ways to optimize irrigation and maximize crop yields.

-Better economic outcomes: Irrigation efficiency and improved crop yields can lead to cost savings and increased profitability for growers.

-Sustainability: Proper irrigation management is crucial for the long-term sustainability of agriculture and the preservation of natural resources.

-Food security: Efficient use of water in agriculture is important for ensuring food security and meeting the growing demand for food as the global population continues to increase.

Despite the importance of walnuts, there is little information about the irrigation condition of walnut orchards in the Syria. The present study was inspired by the work of Shahrokhnia *et al*. (2022). The same methodology was followed to expand the existing knowledge on this subject. Therefore, the purpose of this study is to examine the irrigation status and water productivity in several walnut orchards in As-Suwayda province.

## Material and Methods

As-Suwayda, located at latitude 32.70896 and longitude 36.56951, is one of the 14 Syrian provinces, bordering Rif Dimashq province in the north and east, Daraa province in the west, and Jordan in the south. Meteorological parameters measured at benchmark stations located in As-Suwayda are presented in Table 2.

**Table 2.** Meteorological parameters for As-Suwayda.

| Site | Average low (°C) | Average high (°C) | Annual average humidity (%) | Annual average rainfall [mm] | Altitude [m] |
|---|---|---|---|---|---|
| **As-Suwayda** | 9.4 | 21.7 | 40-80 | 350 | 1100 |

The cities of Salkhad, Al-Suwayda and Shahba have cold and dry, cold and humid, and temperate climates, respectively. The average water consumption of walnuts in 12 orchards was measured in each city. Experimental walnut orchards were selected to cover various factors, including irrigation method, soil texture, and water quality. Selected orchards were monitored during one crop year. Some other general characteristics of orchards such as area, exact location with GPS, irrigation method, irrigation water source (surface, underground), etc. were documented. In each of the orchards, the amount of water flow from each water source (canal, well, aqueduct or spring) was measured with appropriate equipment (flume, meter, overflow, micro-Molina, etc.). The volume of water consumed by the walnut crop was estimated for each selected orchard after determining the water inflow by carefully monitoring the orchard irrigation program (irrigation time, irrigation cycle, number of irrigations during the growing season) and measuring the area under cultivation. The soil conductivity, irrigation water volume, and soil texture were all measured in each of the orchards that underwent screening. Finally, the values of irrigation water efficiency and total water productivity (irrigation + effective rainfall) of walnuts in selected orchards were determined after harvest. The required water by rain and surface irrigation and drip irrigation for leaching the orchards was estimated based on FAO (Ben-Gal *et al*., 2008). The Leaching Requirement (LR) equation is used to determine the amount of water that is necessary to leach salts from the soil and prevent them from accumulating in the root zone of crops. The equation is based on the balance between the amount of water that is added to the soil through irrigation (ECw) and the amount of water that is lost from the soil through evapotranspiration (ECe). The LR for rain and surface irrigation is calculated as the ratio of the electrical conductivity of the irrigation water

(ECw) to the difference between the electrical conductivity of the irrigation water and the saturation extract electrical conductivity (5 * ECe - ECw). However, for the case of drip irrigation is calculated as the ratio of ECw to 2*MaxECe. This equation helps to determine the amount of water that is necessary to maintain the soil's salt balance and prevent salt buildup, which can be harmful to the crops. The average efficiencies of surface and drip irrigation systems were considered to be 60% and 90%, respectively (Vahdati *et al*., 2021). The t-test was used to compare irrigation water levels in orchards with gross water requirements. The quantity of orchard water flow in surface systems was measured using a WSC type four flume, and in the drip systems by using water flow meter calibration. Volume of water applied (Vi) to a field during a given time period is expressed as Q×t×m, where Q is the flow rate of water ($m^3$ $s^{-1}$), t is the time of water application (s), and m is the area of the field (hectare). Water productivity (WPi) is a measure of the amount of crop yield produced per unit of water applied. It is used to calculate the water productivity of an irrigation system and is expressed as y/Vi where y is the total crop yield (kg). A higher water productivity value indicates that the irrigation system is using water more efficiently and that the crops are yielding more per unit of water applied. The gross water requirement calculated from the three water requirement scenarios was compared to the amount of irrigation water used. Finally, suggestions were provided to increase water productivity in walnut orchards by summarizing the results derived from the difference between irrigation water and water productivity.

## Results

The general characteristics of the studied walnut orchards are given in Table 3.

Table 4 provides the values of the irrigation and productivity parameters that were assessed. Their statistical comparison using the t-test is displayed in Table 5.

**Table 3.** General characteristics and performance of the considered walnut orchards.

| | SHAHBA | | | AL-SUWAYDA | | | SALKHAD | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | Min | Max | Average | Min | Max | Average | Min | Max | Average | Average |
| **Water flow (liter sec$^{-1}$)** | 4.28 | 42.80 | 12.52 | 8.56 | 29.64 | 21.19 | 2.14 | 48.15 | 18.40 | 17.33 |
| **Water salinity (ds m$^{-1}$)** | 0.41 | 1.22 | 0.67 | 0.36 | 0.57 | 0.46 | 0.24 | 0.63 | 0.47 | 0.54 |
| **Soil salinity (ds m$^{-1}$)** | 0.45 | 1.95 | 0.90 | 0.57 | 0.85 | 0.67 | 0.45 | 1.21 | 1.00 | 0.85 |
| **Orchard area (ha)** | 0.86 | 16.05 | 4.49 | 0.54 | 2.14 | 1.07 | 0.21 | 4.28 | 1.61 | 2.46 |
| **Age of trees (years)** | 7 | 27 | 17 | 21 | 37 | 28 | 19 | 43 | 37 | 27 |
| **Crop performance (kg ha$^{-1}$)** | 348 | 2274 | 1112 | 292 | 3210 | 1986 | 669 | 1792 | 1004 | 1381 |

**Table 4.** Irrigation parameters and water efficiency of walnut orchards based on region

| | SHAHBA | | | AL-SUWAYDA | | | SALKHAD | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Min** | **Max** | **Average** | **Min** | **Max** | **Average** | **Min** | **Max** | **Average** | **Average** |
| **Water productivity (kg m$^{-3}$)** | 0.13 | 0.42 | 0.25 | 0.05 | 0.35 | 0.24 | 0.04 | 0.18 | 0.12 | 0.20 |
| **Leaching requirement (%)** | 3 | 11 | 6 | 3 | 6 | 5 | 2 | 7 | 5 | 5 |
| **Volume of irrigation water (kg ha$^{-1}$)** | 2274 | 7415 | 4356 | 6163 | 21273 | 9916 | 7280 | 20454 | 10299 | 8110 |
| **Number of irrigations** | 14 | 64 | 29 | 14 | 29 | 20 | 7 | 35 | 16 | 22 |
| **Irrigation depth each time (mm)** | 9 | 36 | 19 | 28 | 82 | 55 | 26 | 139 | 81 | 50 |

The difference in the number of irrigations was due to differences in the type of irrigation system. Drip irrigation systems often use more irrigations than surface irrigation systems do. Initially, it was anticipated that Shahba city would require more irrigation water than the other two cities due to its moderate climate compared to Salkhad and Al-Suwayda cities' cold climates. However, it can be noted that Shahba city had less irrigation water than Salkhad and Al-Suwayda cities since more water was available in those two cities than in Shahba.

**Table 5.** Results of statistical analysis of irrigation water and water productivity using a region-based t-test

| Parameter | Region | Mean difference | t critical | t value | Sig. |
|---|---|---|---|---|---|
| **Irrigation water** | SHAHBA/ AL-SUWAYDA | -5559 | 2.35 | -3.72 | 0.005** |
| | SHAHBA/ SALKHAD | -5943 | 2.42 | -3.94 | 0.005** |
| | AL-SUWAYDA/ SALKHAD | -384 | 2.28 | -0.19 | 0.918 |
| **Performance** | SHAHBA/ AL-SUWAYDA | -875 | 2.27 | -2.25 | 0.054* |
| | SHAHBA/ SALKHAD | 108 | 2.35 | 0.39 | 0.773 |
| | AL-SUWAYDA/ SALKHAD | 982 | 2.39 | 3.12 | 0.016* |
| **Water productivity** | SHAHBA/ AL-SUWAYDA | 0.01 | 2.27 | 0.22 | 0.893 |
| | SHAHBA/ SALKHAD | 0.13 | 2.35 | 3.78 | 0.005** |
| | AL-SUWAYDA/ SALKHAD | 0.12 | 2.39 | 3.11 | 0.017* |

* and ** are for 5% and 1% significance level, respectively.

The t-test result revealed that the volume of irrigation water in the Salkhad and Al-Suwayda regions was more than that in Shahba by roughly 6000 and 5600 $m^3$ $ha^{-1}$, respectively, and that these differences were statistically significant at 1% level. At a level of 5%, the irrigation water difference between Al-Suwayda and Salkhad was not statistically significant. The results of the crop performance analysis showed no notable variation between Shahba and Salkhad at a significance level of 5%, however, a significant difference was observed between Al-Suwayda and both Salkhad and Shahba at a 5% significance level. The results of the water productivity comparison showed no significant difference between Shahba and Al-Suwayda at a 5% significance level. However, a noticeable difference was observed between Al-Suwayda and Salkhad at a 5% significance level, and a substantial difference was seen between Shahba and Salkhad at a 1% significance level.

Table 6 shows the irrigation system, performance and water productivity in both surface and drip irrigation systems. Table 7 displays a comparison of variations in irrigation water usage, crop performance, and water productivity across different irrigation methods.

**Table 6.** Irrigation parameters and water efficiency of walnut orchards based on the type of irrigation system.

| | **Drip** | | | **Surface** | | | **Total** |
|---|---|---|---|---|---|---|---|
| **Parameter** | **Min** | **Max** | **Average** | **Min** | **Max** | **Average** | **Average** |
| **Water productivity (kg $m^{-3}$)** | 0.05 | 0.35 | 0.21 | 0.04 | 0.42 | 0.19 | 0.20 |
| **Performance (kg $ha^{-1}$)** | 348 | 3210 | 1293 | 303 | 3210 | 1437 | 1381 |
| **Leaching requirement (%)** | 2 | 9 | 4 | 4 | 11 | 6 | 5 |
| **Volume of irrigation water (kg $ha^{-1}$)** | 2274 | 21273 | 7059 | 3876 | 20454 | 8765 | 8110 |
| **Number of irrigations** | 16 | 64 | 33 | 7 | 21 | 15 | 22 |
| **Irrigation depth each time (mm)** | 9 | 82 | 25 | 30 | 139 | 66 | 50 |
| **Age of orchard trees (year)** | 7 | 37 | 20 | 7 | 43 | 26 | 27 |

**Table 7.** The difference of irrigation water, performance, water productivity based on the type of irrigation system.

| Parameter | Mean difference (drip-surface) | t critical | t value | Sig. |
|---|---|---|---|---|
| **Drip irrigation** | -1707 | 2.30 | -0.91 | 0.44 |
| **Performance** | -144 | 2.26 | -0.43 | 0.75 |
| **Water productivity** | 0.02 | 2.23 | 0.61 | 0.61 |

## Discussion

According to the results, the use of drip irrigation systems in orchards reduces irrigation water (by about 1700 $m^3$ $ha^{-1}$), reduces crop performance (by an average of 145 kg $ha^{-1}$) and increases water productivity (by about 0.02 kg $m^{-3}$). However, none of these were statistically significant at the 5% level. These results are in agreement with those of FAO (Paredes *et al*., 2018; Çetin and Kara, 2019). Therefore, it can be concluded that equipping farms with modern irrigation systems alone is not enough and in order to achieve maximum performance and water productivity, volumetric delivery of water and different irrigation planning methods should also be considered.

## Conclusions

Irrigation water is a critical factor in the growth and productivity of walnut trees. Proper irrigation management is essential to ensure that the trees receive enough water to support healthy growth, flowering, and nut production. Walnuts are a high-value crop that require a consistent supply of water to produce high-quality nuts, and water-stressed trees can suffer reduced yields and nut quality. The water productivity of walnut trees can be influenced by various factors such as soil type, climate, irrigation management, and tree age and size. Efficient irrigation management can help to improve water productivity by ensuring that the trees receive the right amount of water at the right time. This can be achieved by using appropriate irrigation methods such as micro-irrigation systems, and by implementing strategies such as scheduling irrigation based on crop water demand, monitoring soil moisture levels, and using water-saving techniques such as mulching. In this research, the amount of water productivity and walnut irrigation water were measured in cities of Shahba, Al-Suwayda and Salkhad, which have different climatic conditions. The highest water productivity was related to Shahba city, which had less irrigation water than the other two cities, but there was no significant difference in performance. The study revealed that walnut orchards utilizing drip irrigation used less water than those utilizing surface irrigation. Yet, when considering the overall water needs of the orchards, it was found that more water was necessary in drip irrigation and less in surface irrigation. The statistical analysis found that, in general, there was no considerable variation between the water productivity, irrigation water, and performance, in surface and drip irrigation systems.

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## Conflict of interests

Regarding the publication of this article, the authors declare that there are no conflicts of interest.

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