Optimization of water distribution bed and its effects on water productivity, crop yield and nutritional indicators of pistachio trees

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Abstract: This research was carried out in Sarvestan city of Fars province in the southwest of Iran. Due to successive droughts, the groundwater resources of this city have decreased in terms of quantity and quality. Therefore, deficit irrigation in this area is inevitable and occurs mainly by increasing the irrigation cycle in pistachio orchards. Hence, a study was conducted in a pistachio orchard of Ahmad Aghaei cultivar in Sarvestan city during 2018-2020 with the aim of comparing irrigation water productivity, crop yield and machine farm efficiency in different water distribution substrates in the surface irrigation method with constant irrigation cycle. The experimental design was performed in the form of randomized complete blocks with 4 treatments of irrigation management in three replications. The treatments were: conventional flooding method with a strip width of 6 meters (Control treatment), the creek created on both sides of the tree row (Ditcher), reducing the strip width through the border created in the middle of the row of trees (Border) and the bed of Sine-Morghi created on both sides of the rows of trees (Kadval). The amount of irrigation water according to the inflow to each treatment and the time of cut off based on the management applied by the gardener in Control, Border, Kadval and Ditcher treatments was 8400, 4648, 4200 and 3080 cubic meters per hectare, respectively. The results showed that in both years of experiment in all treatments, irrigation water productivity increased compared to the control treatment. So that in the first year that the trees had good yield, the rate of increase in Ditcher, Kadval and Border treatments compared to the control treatment was 120%, 91% and 62%, respectively. Also, according to the results of calculating the nutritional indices of pistachio leaf nutrients, it was observed that Ditcher treatment had the highest nutritional balance in the first year (1.6) and second (26.5) compared to the control. In terms of farm efficiency, there was no significant difference between the three types of Ditcher, Border, and Kadval machines, so there is no difference between their selection in the preparation of a water distribution bed for pistachio trees. Finally, Ditcher treatment was proposed as the best irrigation treatment for pistachio trees in the tested orchard.

Keywords: irrigation management, feeding pistachio trees, machine farm efficiency, surface irrigation

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1 Introduction

Today, achieving sustainable agriculture, food safety and economic production is mainly possible by using the knowledge of agricultural engineering, and conducting agricultural engineering research provides a suitable platform for using inputs to achieve the goals of self-reliance in the production of basic products in the agricultural sector. Considering the

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quantitative and qualitative reduction of water resources and also to maintain existing agriculture, there is no solution other than increasing yield per unit area through changing the cultivation pattern, correct use of inputs and finally increasing the productivity of irrigation water.

In Fars province, where more than 80% of underground water resources are used for agriculture, due to excessive harvesting and recent droughts, these resources have been decreasing in quantity and quality. Despite this restriction, pistachio crop planting is increasing in the province. Currently, the area under cultivation of pistachio orchards in the province is about 20,000 hectares, and in Sarvestan city, which is the area of the current research, it is 4,500 hectares. About 50% of the total area under pistachio cultivation in this city is under pressure irrigation, and 50% of the orchards are still irrigated with the traditional flooding method, which causes a lot of water loss through evaporation and deep percolation in the field (Anonymous, 2017).

By reducing the width of the strip or changing the bed of water distribution, which reduces the level of irrigation, it is possible to prevent water loss and increase water productivity. Currently, in the pistachio product, the average water productivity in the country is reported as 0.26 kg m^{-3} (Mousavi Fazl et al., 2020).

As an important principle in agricultural water productivity, water stress alone will help improve water productivity when other stresses (nutrient deficiency, weeds and disease) are also reduced or eliminated (Bouman, 2007). For example, water management should be done together with nutrition management, soil management and pest management (Bindraban et al., 2000; Rockström and Barron, 2007).

The results of the research showed that various factors including: proper irrigation and drainage, soil fertility management, reducing tillage operations, maintaining soil moisture, and using varieties resistant to drought and disease are effective in improving agricultural water productivity (Fischer et al., 2009; Geerts and Raes, 2009; De Vries et al., 2010; Arora et al., 2011; Balwinder et al., 2011).

Pour Mohammadali et al. (2019) conducted research with the aim of modeling relationships between pistachio yield and soil, water and management variables in Rafsanjan region, southeast of Iran. The results showed that due to the sensitivity of the models to the characteristics of irrigation water, special attention should be paid to new irrigation methods and management practices as an effective strategy to minimize water losses and increase water use efficiency. Improving the allocation and management of irrigation water to specific orchard conditions (e.g., canopy characteristics and soil-water salinity/acidity) by pistachio growers and farm managers can potentially lead to water and energy savings through improved conditions of practices. Irrigation management (Marino et al., 2019).

In research, some of the echo-physiological characteristics of pistachio trees were studied to understand crop response to drought stress and determine the best irrigation interval. The results showed that with an increase in irrigation intervals and considering soil water holding capacity, soils were not able to provide enough moisture for the plant to carry out its normal metabolic activities. However, in the prolonged irrigation intervals, there were not many differences between treatments i.e. the pistachio tree could adapt itself to the naturally occurring environmental stress conditions (Sedaghati and Hokmabadi, 2015).

In another research, two ditchers with vertical standard and oblique standard were tested by a Universal 650 tractor in a field. This experiment was carried out by connecting the ditcher to the tractor and changing the angles of the middle standard, as well as measuring the average acceleration of the ditcher for dynamic analysis. In order to analyze the forces on the ditcher, the force transmission system is divided into three parts: 1- the ditcher, 2- the middle standard, 3- the arms, and by determining the static and dynamic equations of the ditcher in the soil and taking the help of Dalembert's theorem, the amount of forces acting on the ditcher was calculated in two static and dynamic states (Hosseinzadeh Samani et al., 2007).

Asadi and Razzaghi (2007) introduced the new border- furrow system in order to increase the performance of irrigation systems. The preparation of the seed bed in this method is similar to the method of furrow and ridge, with the difference that in this method, the plots are created in the plots at specific intervals. In this method, the plots created in the furrow act as water catchment pits during rain or irrigation. The water catchments in this method, in addition to reducing water runoff, increase water storage in the soil and also increase usable water for plants. Due to the existence of modern tools, there are no restrictions in the use of this method of seed bed preparation, and this method can be used in dry and semi-arid areas and in irrigated or rain fed fields, especially for the cultivation of plants such as cotton, sunflower, sorghum and corn.

As is the case in all type of orchards, agricultural practices should be done on regular and timely basis in Pistachio orchards to get abundant and high-quality products. The agricultural practices applied mainly in pistachio orchards include tillage, irrigation, pruning, fertilization, plant protection, harvesting and post-harvest handling and processing. In this study, the use of machinery and the problems encountered in the application of agricultural practices in pistachio orchards were evaluated in Siirt province of Turkey. Study data were collected with the structured questionnaires during the face-to-face farmer interview, which was conducted in 165 pistachio farms in 2019. It was revealed that the mechanization applications and problems encountered in pistachio production were connected with the processes from soil cultivation to harvest and post-harvest. The results showed that the use of machine power in the pistachio farms in Siirt province is very limited with tillage, spraying and transportation. It was also revealed that the orchard acreage had a statistically significant relationship with the machinery use for almost all agricultural practices except tillage and irrigation methods (Songül et al., 2021).

Restrictions in the soil environment cause the limitation of nutrients uptake from the soil (Beede et al., 2005). Decreasing water quality and its effect on soil soluble salts due to the conflicting effect of nutrients and causes nutritional imbalance in plants (Liu et al., 2023). In calcareous and saline soils, high bicarbonate, boron, magnesium and especially sodium and chlorine cause ionic imbalance and problems in the absorption of nutrients by the root systems. Under environmental stresses, high soil pH and salinity, the competition for carbohydrates and nutrition causes activating in fluorescence bud and fruit abscission and blank nuts in pistachio (Ferguson et al., 2005; Spann et al., 2008). An excessive increase of some cations causes a significant decrease in the dry weight of pistachio leaves and roots, and reduces the height of the stem, the number and surface of the leaves, the concentration of chlorophyll and total chlorophyll compared to the control (Razavi Nasab et al., 2018). Diagnosis and recommendation integrated systems (DRIS) method (Nguyen Quoc et al., 2023) provided the concept of nutritional balance and is more accurate in detecting the deficiency, excess and relationships between nutrient elements than critical and sufficient levels of leaf nutrients. DRIS norms and critical value of pistachio trees was calculated and presented by Hosseini Fard et al. (2018).

2 Materials and methods

2.1 Specifications of the study area

Sarvestan city is located in the southeast of Fars province in Iran. Its distance from the center of the province is about 80 km and its geographical position is at least 52° 43´ and maximum 53° 28´ east longitude and at least 29° 1´and maximum 29° 27´ north latitude. Its height above sea level is 1540 meters in the plain and 2300 meters in the surrounding mountains. The long-term average annual rainfall is 223 mm. The average minimum temperature of the city in the long term is 0.5 ℃ in January and the average maximum temperature is 38.3 ℃ in July. Also, the maximum humidity is 84%

in January and the minimum is 10% in July. This region has a warm Mediterranean climate, mild winters and hot and dry summers (Ghasemi et al., 2019).

This research was carried out in a plot of land with an area of 0.5 hectares in the pistachio orchard of Mr. Jalali, one of the farmers of the region, during the crop years of 1997-1998 and 1998-1999. The age of the selected trees was 20 years, and their variety was Ahmad Aghaei. The pistachio trees were planted at a distance of 1 × 6 meters in a length of 50 meters. The irrigation system of the orchard was designed and implemented in a low-pressure manner, so that the water was transported from the pool to the point of water entry into the orchard by a pipe and then entered a 6-meter-wide strip using the surface method (traditional) with a 30-day irrigation cycle.

2.2 Experimental design and treatments

The experimental design was implemented in the form of randomized complete blocks with four irrigation management treatments and in three replications (one replication for each row of trees). The first treatment (control): common flooding method with a strip width of six meters. In this treatment, a leveler machine was used to flatten the distance between trees. The second treatment (Ditcher): the stream created on both sides of the row of trees. In this treatment, a stream was created with a working width of one meter, with a distance of 1.5 meters on both sides of the row of trees. The third treatment (Border): reducing the width of the strip through the border created in the middle of the row of trees. In this treatment, a border was created in the middle of the row of trees using a border machine. The fourth treatment (Kadval): the bed created on both sides of the row of trees. In this treatment, a Sine-Morghi bed was created on both sides of the rows of trees by using a Kadval machine. In order to create a Sine-Morghi bed using a Kadval machine, its blade was adjusted in such a way that one side of the blade was raised to 28 cm and a 7.5° slope was created for the blade compared to the horizon (Figure 1). In total, including the control treatment, 12 rows of trees were considered for the experiment.

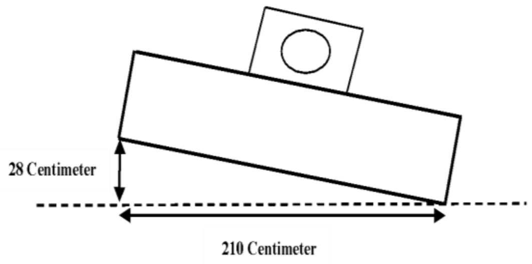

Figure 1 Adjusting the Kadval machine blade to create a Sine-Morghi bed

2.3 Parameters measurements

2.3.1 Soil properties

Soil sample was taken in March 2019 and its physico-chemical properties have shown in Table 2. Samples were analyzed at the Analytical Laboratory of the Soil and Water Research Department, Fars Agricultural and Natural Resources Research and Education Center, Zarghan, Iran (Table 1). Soil pH and Electro Conductivity (EC) were determined using water extract from saturated soil paste. Total calcium carbonate ($CaCO_3$%) was determined by calcimeter method, organic matter (OM%) by potassium dichromate, total nitrogen by Kjeldahl method, phosphorus (P) was extracted using sodium bicarbonate. Potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na) were extracted using ammonium acetate. Iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) were extracted using DTPA (Lindsay and Norvell, 1978). Soil sample salinity was measured at 0-30, 30-60 and 60-90 cm soil depths, with 0, 1 and 2 m distances from the rows of trees. The sodium adsorption ratio (SAR) was calculated in the water extract from saturated soil paste (Piper, 2019). The soil of the experimental field site was saline and calcareous with high pH that has restriction effects on micronutrients absorption, high total neutralizing value, potassium, calcium and magnesium and low amount of organic carbon, available phosphorus and manganese. The concentration of available iron, boron and copper in the soil of the experimental field site were at normal levels (Table 1). The fertilization program of trees in all experimental treatments was carried out in the same way based on the soil test.

2.3.2 Leaf properties

Leaf samples were collected randomly from the fully mature leaves on current season non fruiting branches of 30 trees, in July. The leaf samples were washed with tap water, deionized-water, 0.1 mol L^{-1} HCl, and deionized-water, forced-air oven-dried at 65℃ for 48 h to constant weight. After determining dry matter (DM), samples were grounded and sieved in 0.841 mm mesh. Nutrient compositions in the leaves were analyzed for the macro and micronutrient contents. Total leaf nitrogen (N) concentration (% dry weight) was analyzed according to the micro Kjeldahls' method (AOAC, 1990) using a Kjeltec 2300 Analyzer unit (Foss Tecator, Sweden). P was analyzed by a spectrophotometer using the vanado-molybdate phosphoric acid yellow color method (Chapman and Pratt, 1978). Total leaf K concentration was analyzed using the flame-photometric method (Helmke and Spark, 1996). Ca, Mg, Fe, Mn, Zn, and Cu were analyzed by atomic absorption spectrophotometry (Perkin- Elmer 1100B) (Isaac et al., 2015), and boron (B) concentration by using Azomethine H spectrophotometric method (Krug et al. 1981). According to the DRIS norms and critical value of pistachio trees (Hosseini Fard et al., 2018), the leaf nutrient index and their balance in different changing the shape of the irrigation water distribution bed treatments, was calculated and interpreted.

2.3.3 Product quantity and quality

In each treatment or row, the number of 6 trees that had the same conditions was selected and their dry product yield was measured. To check the effectiveness of each treatment on the quality of the pistachio product, traits such as the number of seeds per ounce, the percentage of open mouth, the percentage of closed mouth and the percentage of without seeds were measured by the usual method of counting seeds from the harvested samples.

2.3.4 Water productivity

The simplest method that can be used in farmers' fields to estimate the water productivity of a plant is to measure two factors: the yield and the amount of irrigation water during the cropping season. Having these values and according to Equation 1, the productivity of irrigation water is calculated (Abbasi et al., 2014).

$$WP_i = \frac{Y}{I_a} \qquad (1)$$

Where WP_i is productivity of irrigation water (kg m^{-3}), Y is yield (kg ha^{-1}), and I_a is depth of irrigation water (m^3 ha^{-1}).

Table 1 Soil sample characteristics in the experimental Mr. Jalali's pistachio orchard in Sarvestan city, Fars province, Iran

Soil depth (cm)	Bulk density (g cm^{-3})	Field Capacity (%)	ECe (dS m^{-1})	SAR*	pH	Total Neutralizing Value (%)	Organic carbon (%)	P (mg kg^{-1})
0-30	54.1	17	6.53	11.3	8.36	46.3	0.97	12.2
30-60	44.1	9.22	7.97	14.7	8.38	49.7	0.78	9.8
60-90	54.1	17	8.94	17.9	8.45	49.2	0.41	7.5

Soil depth (cm)	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	B (mg kg^{-1})	Cu (mg kg^{-1})	Soil texture
0-30	316.3	170.4	552	0.88	6.25	4.87	0.65	0.52	sandy loam
30-60	272.7	177.6	564	0.67	5.96	3.29	0.77	0.50	Loam
60-90	255.6	174.0	568	0.66	5.23	3.45	0.79	0.42	sandy loam

Note: *Sodium adsorption ratio

2.3.5 Irrigation water volume

Considering the lack of water compared to the cultivated area of the tested orchard, the volume of irrigation water in different treatments was calculated according to the farmer irrigation management in the first irrigation and repeated in other irrigations. The farmer management was such that after the water reached the end of the 50-meter row of trees in all treatments (advanced time), a period of time was considered as an infiltration opportunity, and then the water was transferred to the next treatment. Therefore, the sum of the advanced times and the opportunity time was considered as the cut off time of irrigation in each treatment. The inlet flow to each treatment was measured through a type 4 of WSC flume that was installed in the main water inlet channel to the treatments. The amount of flow obtained in the first irrigation was repeated in other irrigations. Considering the water output from a swimming pool and adjusting the water output with a valve, this was easily possible. Therefore, according to the difference in the cut off time of irrigation in different treatments and the constant flow rate of the input to each treatment, the volume of irrigation water for each treatment was calculated in the first irrigation and applied to each treatment during the cropping season and other irrigations. The number of irrigations in the experimental year was seven times, and one irrigation was done every month, starting from May and continuing until November.

2.3.6 Effective and theoretical field capacity and machine field efficiency

Field efficiency is equal to the percentage of ratio of the effective field capacity to the theoretical field capacity. This index is widely used in mechanization calculations, and it shows the ability of management to use the working capacity of machines and tools in production and reduce the time wasted in operations. Considering that the field efficiency of the machine was the only parameter that could be calculated for the machines used in this research and it was possible to compare the machines with that, therefore this parameter was measured.

To determine the field efficiency, it was necessary to determine the theoretical and effective field capacity of the three types of evaluated machines. For this purpose, the parameters of the working width of the machine in meters, the forward speed in kilometers per hour, the operation area in hectares, and the operation time in hours for three types of ditchers, border and Kadval machines in three replications were measured.

The theoretical field capacity was calculated according to the forward speed and working width of the machine using Equation 2 (Almasi and Kiani 2009, 4th).

$$C_{at} = \frac{w \times s}{10} \quad (2)$$

Where C_{at} is theoretical field capacity (ha hr^{-1}), W is working width of the machine (m), and S is forward speed (km hr^{-1}).

The effective field capacity is calculated according to the actual hours of doing one hectare of field operations. Therefore, using the parameters of the area and time of the operation, the effective field capacity was calculated in terms of hectares per hour.

The amount of field efficiency was obtained using Equation 3 (Almasi and Kiani, 2009).

$$F_{ef} = \frac{C_{ac}}{C_{at}} \times 100 \quad (3)$$

Where F_{ef} is field efficiency (%), C_{ae} is effective field capacity (ha hr^{-1}), and C_{at} is theoretical field capacity (ha hr^{-1}).

Soil sample was taken in March 2019 and its physico-chemical properties have shown in Table 2. Samples were analyzed at the Analytical Laboratory of the Soil and Water Research Department, Fars Agricultural and Natural Resources Research and Education Center, Zarghan, Iran (Table 1). Soil pH and EC were determined using water extract from saturated soil paste (Munk, 1992). Total calcium carbonate ($CaCO_3$%) was determined by calcimeter method, organic matter (OM%) by potassium dichromate (Chapman and Pratt, 1978), total nitrogen by Kjeldahl method (Nelson and Sommers, 1980), phosphorus (P) was extracted using sodium bicarbonate (Olsen et al., 1954). Potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na) were extracted using ammonium acetate (Jackson, 1973). Iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) were extracted using DTPA (Lindsay and Norvell, 1978). Soil sample salinity was measured at 0-30, 30-60 and 60-90 cm soil depths, with 0, 1 and 2 m distances from the rows of trees. The SAR was calculated in the water extract from saturated soil paste (Munk, 1992). The soil of the experimental field site was saline and calcareous with high pH that has restriction effects on micronutrients absorption, high total neutralizing value, potassium, calcium and magnesium and low amount of organic carbon, available phosphorus and manganese. The concentration of available iron, boron and copper in the soil of the experimental field site were at normal levels (Table 2). The fertilization program of trees in all experimental treatments was carried out in the same way based on the soil test.

2.4 Statistical analysis

One-way ANOVA analyses were applied to the data collected from the experiments using SAS 9.13 software for two years. When treatment effects were significant ($p \leq 0.05$) level of probability, treatment means were compared by Duncan's new multiple range test. Descriptive parameters (means, SD, CV and geometric mean) and DRIS indexes were calculated by Microsoft Excel 2016.

3 Results and discussion

3.1 Nutritional status of pistachio trees

Different shapes of the irrigation water distribution bed treatments changed the nutritional balance of pistachio trees.

According to DRIS indexes, there was a severe deficiency of leaf boron, magnesium, phosphorus, potassium and excess of zinc, iron, copper and manganese in 2019 "on" year, respectively (Table 2). Leaf nitrogen concentration was approximately in a balanced range. So, the results of the DRIS method showed that the priority of the nutrient's deficiency in 2019 "on" year was boron > magnesium > phosphorus > potassium.

Table 2 The nutritional status of pistachio trees based on the DRIS norms of 'Ahmad-Aghai' pistachio during 2019-2020

Nutrient Index	N	P	K	Ca	Mg	Fe	Zn	Mn	Cu	B	Nutrient balance index (NBI) = ∑ Nutrient index
2019 "on" year	0.62	-22.35	-5.05	4.49	-31.48	40.70	129.70	13.21	18.02	-120.21	27.65
2020 "off" year	-1.41	-18.75	-12.88	-18.72	-32.47	40.81	264.40	36.85	-91.38	-162.89	3.55

Note: ∑Nutrient Index closer to zero indicates more nutritional balance in pistachio trees.

Positive numbers indicate an excess and negative numbers indicate a deficiency of nutrients.

The nutrient balance index (NBI) in 2019 "on" year (27.65) was very higher than 2020 "off" year (3.55), which showed the nutritional balance of pistachio trees has improved in 2020 "off" year (Table 2). High yield in 2019 "on" year and reduction of yield in 2020 "off" year, due to fruit alternative bearing of pistachio trees, can be the reason for the greatest nutritional imbalance in the first experimental year.

The nutritional indices of pistachio in different experimental treatments in 2019 "on" year is shown in Table 3. Irrigation in the creek created on both sides of the tree row (N) had the highest nutritional balance (NBI=26.53) and Irrigation by conventional flooding method with a strip width of 6 meters (Control) had the lowest nutritional balance (NBI= 29.55).

Table 3 The nutritional status of 'Ahmad-Aghai' pistachio based on the DRIS norms in the different shape of irrigation water distribution bed treatments in 2019

Treatments	N	P	K	Ca	Mg	Fe	Zn	Mn	Cu	B	Nutrient balance index (NBI) = ∑ Nutrientindex
Control	1.81	-24.05	-5.92	5.96	-30.29	44.39	126.67	13.49	18.74	-121.25	29.55
Ditcher	1.47	-19.04	-2.63	7.13	-29.16	34.87	124.63	11.65	16.08	-118.47	26.53
Border	-3.56	-22.82	-5.63	0.99	-36.83	44.01	139.75	12.72	19.56	-121.13	27.06
Kadval	3.64	-23.67	-6.16	4.59	-30.02	39.84	127.95	15.17	17.71	-119.98	29.07

Note: ∑Nutrient Index closer to zero indicates more nutritional balance in pistachio trees.

Positive numbers indicate an excess and negative numbers indicate a deficiency of nutrients.

According to DRIS indices, there was a severe deficiency of leaf boron, copper, magnesium, phosphorus, calcium, and excessive leaf zinc, iron and manganese in 2019 “off” year, respectively (Table 3). So, the results of the DRIS method showed that the priority of the nutrient’s deficiency in the 2020 “off” year was boron > copper > magnesium > phosphorus> calcium > potassium > nitrogen.

The nutritional indices of pistachio in different experimental treatments in 2020 “off” year is shown in Table 4. Irrigation in the creek created on both sides of the tree row (N), and irrigation in the bed of Sine-Morghi using a Kadval machine created on both sides of the rows of trees (K) had the highest and lowest nutritional balance, with NBI 1.64 and 8.14, respectively, in comparison with control (C).

Table 4 The nutritional status of ‘Ahmad-Aghai’ pistachio trees based on the DRIS norms in the different shape of irrigation water distribution bed treatments in 2020

Treatments	IB	ICu	IMg	ICa	IP	IK	IN	IMn	IFe	IZn	Nutrient balance index (NBI) = ∑ Nutrient index
Control	-163.52	-90.87	-30.72	-17.69	-16.89	-11.55	-1.69	33.49	40.61	262.39	3.55
Ditcher	-159.51	-91.46	-34.55	-21.06	-20.05	-11.37	-2.62	37.54	41.32	263.38	1.64
Border	-164.24	-90.75	-31.96	-19.32	-16.52	-15.59	-0.69	34.99	40.48	267.60	4.00
Kadval	-164.40	-92.44	-32.74	-19.76	-18.79	-13.19	2.60	40.94	41.37	264.57	8.14

Note: ∑Nutrient Index closer to zero indicates more nutritional balance in pistachio trees.

Positive numbers indicate an excess and negative numbers indicate a deficiency of nutrients.

Among the experimental treatments, especially in the second year, the irrigation in the creek created on both sides of the tree row (Ditcher) had the highest nutritional balance in comparison with control. Also, the means of DRIS indices of both experimental years showed that the best condition for the nutritional balance of pistachio trees prepared in the irrigation in the creek created on both sides of the tree row (Ditcher) (Table 5).

Table 5 The nutritional status of ‘Ahmad-Aghai’ pistachio trees based on the means of DRIS indices in the different shape of irrigation water distribution bed treatments during two experimental years (2019-2020)

Treatments	IB	ICu	IMg	ICa	IP	IK	IN	IMn	IFe	IZn	Nutrient balance index (NBI) = ∑ Nutrient index
Control	-142.64	-32.02	-17.71	-11.42	-6.08	-3.76	-3.48	16.49	41.65	178.51	19.54
Ditcher	-139.33	-33.36	-17.56	-9.18	-5.79	-5.22	-3.87	17.32	37.64	177.69	18.34
Border	-142.38	-35.98	-18.74	-12.68	-6.97	-5.11	-2.17	16.82	41.89	186.76	21.43
Kadval	-142.46	-32.97	-18.76	-12.19	-6.14	-4.05	-0.35	20.75	39.93	180.08	23.85

Note: ∑Nutrient Index closer to zero indicates more nutritional balance in pistachio trees.

Positive numbers indicate an excess and negative numbers indicate a deficiency of nutrients.

Changing the water distribution bed by creek created on both sides of the tree row (N) can improve the nutrient balance of pistachio by changing the pattern of feeding roots accumulation as well as the pattern of soil moisture in the active root environment.

Productivity of the plant depends essentially on the nutrient balance; the biological activity an integrative physiological approach was suggested. There are more complex interactions between salinity prevalence and plant responses such as exclusion of saline ions, nutrient and water uptake, root architecture, or adjustment to varying pH within the root-zone. In a changing environment, soil water content will become even more important for both mass flow and diffusion components of root nutrient acquisition. Increased water content increases hydraulic conductivity, which facilitates the movement of water and dissolved ions over relatively large distances via mass flow, whereas decreased water content serves to concentrate nutrient ions and thus decrease the diffusional flux (Tinker and Nye, 2000). Optimizing the water distribution bed which could had effect on pistachio trees salt/nutrient interaction. In our experiment, the results indicated that the changing of the water distribution bed as irrigation in the creek created on both sides of the 'Ahmad-Aghai' pistachio tree rows treatment (Ditcher) had the best nutritional balance index and increased the yield and water productivity.

Every year, irrigation of the orchard started from May and continued until November. In this way, irrigation was done with a frequency of 30 days and 7 times a year. According to the measured data, the volume of water in each irrigation and during the crop year for each treatment is calculated and given in Table 6. As can be seen in the mentioned table, the minimum and maximum amount of water-irrigation during one crop year was obtained in Ditcher and Control treatments, equivalent to 3080 and 8400 cubic meters per hectare, respectively.

3.2 Applied water

Table 6 Calculation of the amount of water in one irrigation round and applied water during one agricultural year based on the input flow rate, area and irrigation duration of each treatment

Treatment	Input flow (L s^{-1})	Treatment area (ha)	Irrigation duration (hr)	Water volume (m^3)	Irrigation number	Applied water (m^3 ha^{-1})
Control	20	0.09	1.5	108	7	8400
Ditcher	20	0.09	0.55	39.6	7	3080
Border	20	0.09	0.83	59.8	7	4648
Kadval	20	0.09	0.75	54	7	4200

3.3 Product quantity and quality

Tables 7 and 8 show the quality characteristics of pistachio trees in each treatment and in the years 2018 and 2019. These characteristics have been measured in 500 grams of samples from each treatment, which include the number of open mouths, the number of closed mouths, the number of without seeds and the number of seeds per ounce. In order to calculate the quantitative characteristic (total weight), 6 trees were randomly selected from each treatment and the product was weighed in dry state. The average yield of each tree in different treatments (dry weight) is calculated and given in kilograms in Tables 7 and 8.

Table 7 Average quantitative and qualitative parameters of pistachio product in different treatments in 2018

Treatment	Product of each tree (kg)	Open mouths (%)	Closed mouths (%)	Without seeds (%)	Seeds per ounce* (%)
Control	4.73	80	15	5	22
Ditcher	3.81	83	10	7	22
Border	4.23	85	10	5	22
Kadval	4.51	85	10	5	22

Note: * each ounce is equal to 28.35 grams

Table 8 Average quantitative and qualitative parameters of pistachio product in different treatments in 2019

Treatment	Product of each tree (kg)	Open mouths (%)	Closed mouths (%)	Without seeds (%)	Seeds per ounce (%)
Control	0.74	85	10	5	24
Ditcher	0.51	83	10	7	24
Border	0.51	90	15	5	24
Kadval	0.59	90	14	6	24

3.4 Water productivity

Tables 9 and 10 show the results of yield calculation (kilogram per hectare) and water productivity index (kilogram per cubic meter) according to the amount of irrigation water in each treatment and in two consecutive years. As can be seen, according to these tables, the highest level of water productivity index in the years 2018 and 2019 is related to the treatment of the Dicher and the lowest is related to the Control treatment. The reason for the huge difference in the yield of the product is related to the On or Off of the pistachio tree and the lack of timely inoculation (pollination) of the trees in 2019.

Table 9 Amount of irrigation water, yield and water productivity index of pistachio trees in different treatments in 2018

Index	Treatment			
	Control	Ditcher	Border	Kadval
Irrigation water (m^3 ha^{-1})	8400	3080	4648	4200
Yield (kg ha^{-1})	3786	3062	3391	3617
water productivity (kg m^{-3})	0.45	0.99	0.73	0.86

Table 10 Amount of irrigation water, yield and water productivity index of pistachio trees in different treatments in 2019

Index	Treatment			
	Control	Ditcher	Border	Kadval
Irrigation water (m^3 ha^{-1})	8400	3080	4648	4200
Yield (kg ha^{-1})	444	311	311	355
water productivity (kg m^{-3})	0.05	0.1	0.07	0.08

According to the average water productivity of pistachio trees in Iran, 0.26 kg m^{-3} (Mousavi Fazl et al., 2020), the productivity values obtained in the first year of the experiment in all treatments are higher than the national average. Also, in all treatments, the amount of this index has increased significantly compared to the control treatment, so that in the same year, an increase of 120%, 91%, and 62% was obtained in Ditcher, Kadval, and Border treatments, respectively, compared to the control.

3.5 Analysis of composite variance for yield and water productivity

Tables 11 and 12 respectively show the results of the composite variance analysis of the year for the yield and water productivity of pistachio trees. As can be seen, only the effect of the year has become significant. This means that there was a significant difference in yield and water productivity in different years, but the effect of irrigation treatments on them was not significant.

Table 11 Results of variance analysis of yield of pistachio trees

Sources of changes	Degrees of freedom	Sum of squares	Mean of squares	F
Block	5	13.35	2.67	1.39 ^{ns}
Year	1	167.29	167.29	107.4 **
B*Y	5	7.77	1.55	0.81 ^{ns}
Irrigation	3	2.14	0.71	0.37 ^{ns}
I*Y	3	0.88	0.29	0.15 ^{ns}
Error	30	57.7	1.92	
Total	47	249.1		

Note: ^{ns}: Non-significant; **: significant at p<0.01.

Table 12 Results of variance analysis of water productivity of pistachio trees

Sources of changes	Degrees of freedom	Sum of squares	Mean of squares	F
Block	5	13.35	2.67	1.39 ^{ns}
Year	1	167.29	167.29	107.4 **
B*Y	5	7.77	1.55	0.81 ^{ns}
Irrigation	3	2.14	0.71	0.37 ^{ns}
I*Y	3	0.88	0.29	0.15 ^{ns}
Error	30	57.7	1.92	
Total	47	249.1		

Note: ^{ns}: Non-significant; **: significant at p<0.01.

To check the statistical difference of water productivity index in different irrigation treatments, using Duncan's test, the interaction effect of year and treatment was used simultaneously. In fact, 8 treatments were compared, and the results are shown in Figure 2. As it can be seen from this figure, there is no significant difference between Ditcher and Kadval and Border treatment in the first year, while there is a significant difference at the level of 5% between the two Ditcher and Kadval treatments and the control treatment. Also, no significant difference was observed between Border treatment and control. In this year, the highest and lowest water productivity are related to Ditcher and control treatments, respectively. In the second year of the experiment, the results of the statistical analysis showed that there was no significant difference between the irrigation treatments, although in this year the highest and lowest water productivity was related to the Ditcher and Control treatments. When the results of both years are examined together, the Ditcher and Kadval treatments in the first year have significant differences with the Control treatments of the first year and all treatments of the second year. Also, Border treatment in the first year shows a significant difference with all treatments in the second year. Therefore, it is recommended to use the results of composite analysis in such designs to correctly identify the differences.

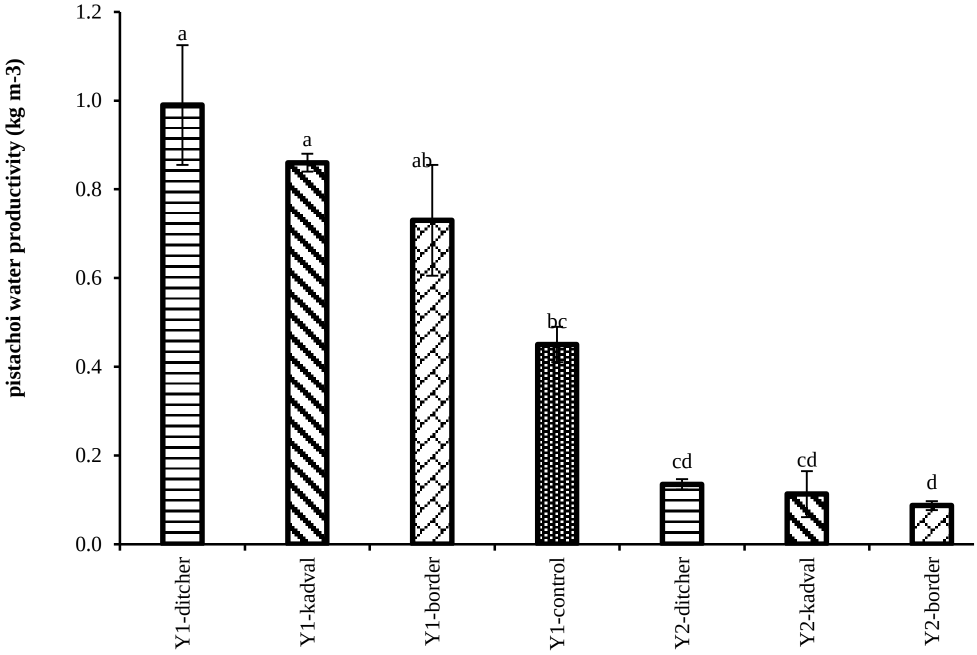

Figure 2 Comparison of the average water productivity of pistachio trees of irrigation treatments in two different years. (Different letters indicate significant differences at the 5% level of Duncan's test)

3.6 Theoretical field capacity, effective field capacity and field efficiency of three types of evaluated machines

The average of measured parameters in three types of evaluated machines are presented in Table 13. Based on these parameters, theoretical and effective field capacities and field efficiency of machines were calculated and analyzed. The results of variance analysis of theoretical field capacity, effective field capacity and field efficiency data in three types of evaluated machines are presented in Table 14. The results of this table show that the effect of replication on theoretical field capacity and effective field capacity is not significant and the effect of machine type on theoretical field capacity and effective field capacity is significant at the 1% probability level. It was also found that the effect of the replication and the effect of the type of machine on field efficiency was not significant.

Table 13 The average of measured parameters in three types of evaluated machines

Parameter	Ditcher	Border	Kadval
Working width of the machine (m)	1	1.4	2.15
Forward speed (km hr^{-1})	4.74	7.19	6.24
Operation area (ha)	0.03	0.021	0.064
Operation time (hr)	0.097	0.033	0.077

Table 14 Variance analysis of theoretical field capacity, effective field capacity and field efficiency data in three types of evaluated machines

Row	Sources change	Degrees of freedom	Mean of squares		
			Theoretical field capacity	Effective field capacity	Field efficiency
1	Replication	2	0.001 ^{ns}	0.001 ^{ns}	4.157 ^{ns}
2	Machine type	2	0.576 **	0.217 **	6.370 ^{ns}
3	Test error	4	0.001	0.000	1.038
4	Total	9			

Note: ^{ns}: Non-significant; **: significant at p<0.01.

The results of comparing the averages of the effect of machine type on theoretical field capacity, effective field capacity and field efficiency are presented in Table 15. The results of this table show that the highest amount of theoretical field capacity is in the Kadval machine with a value of 1.343 ha hr^{-1} and the lowest theoretical field capacity is in the ditcher machine with a value of 0.474 ha hr^{-1}. The highest effective field capacity is found in the Kadval machine with 0.843 ha hr-1 and the lowest effective field capacity in the ditcher machine with 0.311 ha hr^{-1}. It was also found that the ditcher machine has the highest field efficiency with 65.65%, followed by the border machine with 63.92% and the Kadval machine with 62.75%. Although there is no statistically significant difference between them.

Table 15 Comparing the averages of the effect of machine type on theoretical field capacity, effective field capacity and field efficiency

Machine type	Theoretical field capacity (ha hr^{-1})	Effective field Capacity (ha hr^{-1})	Field efficiency (%)
Ditcher	0.474 ^{c}	0.311 ^{c}	65.647 ^{a}
Border	1.007 ^{b}	0.643 ^{b}	63.920 ^{ab}
Kadval	1.343 ^{a}	0.843 ^{a}	62.750 ^{b}

Note: Similar letters indicate that there is no significant difference.

Considering that the working width of Kadval machine (2.15 m) is more than border (1.4 m) and ditcher (1 m) and the forward speed of Kadval machine (6.24 km h^{-1}) is more than ditcher machine (4.74 km h^{-1}) and is close to border machine (7.19 km h^{-1}). Therefore, the theoretical field capacity of the Kadval machine, which is the multiplication of the working width of the machine and the forward speed, is significantly more than the other two machines.

In terms of the effective field capacity, because the operation area, in the Kadval machine (0.065 ha) it is about 2 times the ditcher machine (0.03 ha) and 3 times the border machine (0.021 ha), so the effective field capacity of the Kadval machine is significantly more than the other two machines.

In general, for the overall evaluation of the three types of ditchers, border and Kadval machines, because their field efficiency during operation is important, and the results have shown that there is no significant difference between the field efficiency of these three types of machines, therefore, there is no difference between their selection in the preparation of water distribution bed in pistachio trees.

4 Conclusion

Due to the decrease in the quantity and quality of water resources in Sarvestan city, optimal irrigation management is inevitable. The results of this project determined that, in order to prevent the reduction of the yield, orchard management (timely pruning, spraying and proper fertilization) should be applied in the orchard at the same time as irrigation management. In the first year of the experiment, due to the good performance of trees in all treatments, the water productivity index of pistachio trees was much higher than the national average (0.26 kg m^{-3}). At the same time, in both years of the implementation of the project, the highest amount of water productivity was achieved in the Ditcher treatment and the lowest in the Control treatment. In the first and second year of the research, the nutritional balance index in the preparation of the water distribution bed of the Ditcher was obtained as 1.64 and 26.53, respectively, which was the highest value compared to the control and other treatments.

Finally, by examining the results, it can be said that the most suitable water distribution bed for pistachio trees in the tested orchard is the Ditcher treatment, considering the quantitative limitation of water resources. Because in the Ditcher treatment, despite a 63% decrease in the amount of applied water compared to the control treatment, no significant difference in yield was observed, and the water productivity increased by 120% compared to the Control. In this treatment, due to the reduction of the water distribution bed, the number of weeds is also significantly reduced.

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