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Comparison of the Effect of Different Irrigation Scheduling Tools on Applied Water and Citrus Fruit Quality

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ABSTRACT

Citrus is one of the most important trees in the semi-arid regions of southern Iran. Water is a limiting factor in these regions. In the present study, five irrigation scheduling tools were used and compared with conventional irrigation in Fasa region. The irrigation scheduling was based on the national document of crop water requirement (NDCW), canopy temperature measurement by an infrared thermometer, soil moisture monitoring, soil moisture tension measurement with Tensiometer and soil electrical conduction by gypsum block. Two thousand and five hundred orange trees in silty clay loam soil were irrigated by drip irrigation system during two years study periods. Applied water, fruit production and fruit quality were measured at the end of the first and second year. Results showed that irrigation scheduling treatments saved applied water from 23 to 40% and 41 to 51% in the first and second year compared to the conventional irrigation. In both irrigation seasons, the maximum fruit yield was obtained in the treatment scheduled based on canopy temperature. Irrigation scheduling increased water productivity 57 and 98% compared to conventional irrigation in the first and second year, respectively. The fruit quality characteristics and economical income were not decreased in irrigation scheduling treatments. Therefore, irrigation scheduling can be used to save applied water and cost with improving the fruit quality of the citrus orchards in a semi-arid region.

Key words : Water productivity, canopy temperature, tensiometer, gypsum block

INTRODUCTION

Water scarcity has always been a limiting factor for the agricultural activities in arid and semi-arid regions. Irregular abstraction of groundwater is one of the challenges in these regions. The development of pressurized irrigation methods with the high efficiency, is one of the ways to help the proper use of water resources. FAO stated that the water resources management should be done by the government and responsible organizations. After that, water allocation to farms to use in irrigation system should be limited and controlled to get higher water use efficiency (Perry and Steduto, 2017).

Fars province is one of the important provinces of Iran in the agricultural activities. Fars had the first or second place in the production of several products in the recent years especially in citrus production (Ahmadi *et al.*, 2017). Citrus is one of the most important perennial plants in the world with a 9.3 million hectares and an annual production of 132 million tonnes, half of which is orange (FAO, 2019). Citrus grows in tropical and sub-tropical climates in areas having fertile soil, sufficient moisture and non-frost conditions. The amount of water required per hectare of citrus orchard varies depending on the climate, crop age, number of trees per hectare, type of fruit, soil type and irrigation method. Due to salinity, citrus trees reduce vegetative growth, fruit number and quality. Depending on the climate, soil quality, irrigation scheduling, the allowable salinity of irrigation water ranged from 1200 to 1300 mmohs/cm (Sarhadi and Sharifzadeh, 2017). Increasing the yield and fruit quality of citrus is the primary economic goal of the gardeners. Saving the applied water of irrigation is another challenge in citrus production in the arid and semi-arid regions. The irrigation scheduling could be recommended to save applied water maintaining optimal yield. Bwambale *et al.* (2022) in the review of smart irrigation

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scheduling stated that closed-loop irrigation control was more efficient than open-loop systems to improve water productivity. They suggested the irrigation strategies to help farmers in improving the water use efficiency. Martinez *et al.* (2017) examined two surface and sub-surface drip irrigation systems in Spanish citrus. They reported saving of 14% applied water in the sub-surface drip irrigation system. Several studies have been done on the use of irrigation scheduling tools such as Tensiometer, gypsum block, plant stress index, soil moisture measurement and water balance in different plants. Tekelioglu *et al.* (2017) scheduled irrigation in Antalya, Turkey by measuring the canopy cover temperature technique. They reported the ability of infrared thermometer to schedule irrigation in pomegranate. In the corn irrigation scheduling in the United States, the use of soil moisture sensors was compared to soil water balance method. Irrigation scheduling based on soil moisture sensors saved applied water and was more economical than the other methods (Filho *et al.*, 2020). Soybean irrigation scheduled by installing soil moisture sensors in Stoneville, USA. Using both irrigation scheduling tools increased water productivity and economic efficiency (Wood *et al.*, 2020). Arunadevi *et al.* (2022) determined the drip irrigation scheduling of green pea by soil moisture measurements. They recommended the real-time soil moisture-based irrigation at the soil matric potential threshold level of –30 kPa with 120% of recommended dose of fertilizers to get maximum green pea pod yield and water use efficiency under semi-arid region. Tensiometer was used to manage the sub-surface irrigation of strawberries. The results showed the water productivity increased from 8 to 44% (Filho *et al.*, 2020). Tensiometer in different soil moisture tensions for tomato irrigation scheduling showed the maximum water use efficiency at -60 kPaalong with paddy straw mulching (Bahadur and Singh, 2021). Veeranna *et al.* (2016) used gypsum blocks in an irrigation automation system on farms in India and reported an average reduction of 7% in applied water. Few studies have been conducted on the effect of irrigation scheduling on fruit quality. Morianou *et al.* (2021) evaluated the quality of grape fruit in two scheduled optimal and deficit irrigation. Irrigation scheduling based on 60% of evapotranspiration improved fruit quality parameters.

There is several irrigation scheduling methods to save applied water while maintaining the fruit quality. A few studies have been accomplished to determine the effect of different irrigation scheduling tools on the yield, economics and fruit quality of citrus in Iran. The purpose of this study was to choose the optimal irrigation scheduling tool to save applied water and cost in citrus orchards.

MATERIALS AND METHODS

The study site was a 2 ha orange garden located in Fasa plain, east of Fars province (52°19′ to 54°15′ W; 28°31′ to 29°24′ N) with the semi-arid climate in southern Iran. Fasa was one of the critical regions of Iran in terms of water resources in the last 10 years. Scattered gardens, low rainfall, inadequate seasonal distribution of precipitation and recent droughts had led farmers to highly use of groundwater resources. The annual average temperature, rainfall and altitude in the study site was 18.5°C, 300 mm and 1450 m, respectively. Soil sample test showed 38% clay, 45% silt and 17% sand which classify as silty clay loam. The distance between planted trees in the garden was 4 m.

This study was accomplished in the experimental design of randomized complete block with six treatments and three repetitions with three trees in each repetition. T_1 : Conventional irrigation management (as control), T_2 : Irrigation using the national document of crop water requirements (NDCW) on the basis of Penman-Montieth method, T_3 : Managing irrigation using canopy cover temperature, T_4 : Managing irrigation using soil moisture measurement, T_5 : Managing irrigation using soil moisture tension (tensiometers) and T_6 : Managing irrigation by measuring soil electrical resistance (gypsum block). Experimental treatments were constructed under on-line drip irrigation system with 4 l/h.

Cultivation operations including fertilizing and weeding were the same in all treatments. The volume of applied irrigation water was measured by calibrated water meters. T_1 was irrigated by the gardener without any technical recommendation. Irrigation practices in T_2 (NDCW) was based on Penman-

Monteith method in every other day of the growth period. T_3 was irrigated based on upper and lower stress baselines using an infra-red thermometer. A soil moisture sensor (ECH2O) was used to monitor soil moisture in T_4 to schedule irrigation. In T_5, a 30 cm tensiometer was used to schedule irrigation. In T_6, a calibrated gypsum block (Eijkelkamp, Netherlands) was used to measure soil electrical conductivity. The start irrigation time of T_2 to T_6 was based on 25% depletion of the soil moisture. The end time of irrigation in T_2 and T_3 was to fill the 50% of moisture depletion. It was the time to reach soil moisture to field capacity in T_4, T_5 and T_6. Total applied water of the treatments was evaluated by adding applied irrigation water and effective rainfall. Quality characteristics of the orange fruit were measured including pH, dry matter, sugar, pulp, vitamin C, juice, skin, thickness and weight. Mean comparison of applied water, yield and fruit quality of the treatments was determined based on Duncan test.

The cost and income of the irrigation scheduling treatments (T_2 - T_6) were compared with control treatment (T_1). In the present study, the total cost was the sum of the initial cost, water price, worker cost, service and maintenance cost. The income of the citrus garden was considered as the total fruit selling price. Water price was considered at 1.0 dollar per 1000 liters of water. In the budgeting method, treatments were compared with control treatment (index treatment). Net benefits of the treatments were calculated as Eq. 1 :

$$B = \Delta\pi i - \Delta C_i \qquad ...(1)$$

Where, B, $\Delta\pi_i$ and ΔC_i were the net benefits, gross income and cost, respectively. Finally, the highest B introduced as the best irrigation scheduling.

RESULTS AND DISCUSSION

Table 1 indicates the average volume of applied water, the applied water reduction compared to the control treatment, yield and water productivity of treatments in the first year of the study. There was no significant difference between the yield in the conventional and scheduled irrigation. Usually, it was important for farmers, if the fruit production decreased by using scheduled irrigation. The highest fruit production was obtained in irrigation scheduling based on canopy temperature (T_3). Applied water in the control treatment (T_1) was 9979 m^3/ha which was more than other treatments. Among different irrigation scheduling treatments, T_2 and T_4 with applied water of 7688 and 6021 m^3/ha had the maximum and minimum applied water, respectively. Use of scheduled irrigation saved applied water from 23% (T_2) to 40% (T_4) compared with control.

The values of irrigation water and total water productivity were also compared in Table 1. Water productivity in all irrigation scheduling treatments was more than conventional irrigation. Water productivity in T_1 showed significant difference with T_4, T_5 and T_6. However, scheduled irrigation in T_2 had no significant difference with conventional irrigation.

The measured quality characteristics of the orange fruits have been shown in Table 2. Irrigation scheduled had no significant negative effect on dry matter, sugar, pulp, vitamin C, juice, skin and weight of the orange fruits compared to conventional irrigation. In the irrigation scheduling treatments, pH and

Table 1. Applied water, yield and water productivity of the orange irrigation scheduling treatments during the first year of the study

Treatment	Yield (kg/ha)	Applied water (m^3/ha)	Saved water compared to T_1 (%)	Irrigation water productivity (kg/m^3)	Total water productivity (kg/m^3)
T_1	27854^a	9979^a	0	2.86^c	2.35^c
T_2	24792^a	7688^b	23	3.21^{bc}	2.58^{bc}
T_3	29896^a	6958^b	30	4.38^{ab}	3.37^{ab}
T_4	23708^a	6021^b	40	4.36^{ab}	3.27^{ab}
T_5	28125^a	6271^b	37	4.51^a	3.43^a
T_6	23271^a	6375^b	36	4.32^{ab}	3.31^{ab}

The same superscripts in same col. indicate that the differences are not significant.

skin thickness showed significant differences. According to Table 3, there was no significant difference between the fruit yield in the conventional and scheduled irrigation at the second year of the study. Similar to the first year, the highest fruit yield was obtained in irrigation scheduling based on the canopy temperature. The maximum applied water was in the control treatment (12346 m^3/ha). Unlike the first year, irrigation scheduling treatments showed significant difference in applied water. T_2 and T_4 applied 7338 and 6090 m^3/ha water as the maximum and minimum values, respectively. Using irrigation scheduling saved water from 41% (T_2 and T_3) to 51% (T_4) compared T_1. Similar to the first year, irrigation scheduling based on the soil moisture measurement (T_4) saved the highest level of water. In all irrigation scheduling treatments, water productivity was higher than the conventional irrigation. The highest water productivity was obtained in the irrigation scheduling by soil moisture measurement (T_4). Irrigation water productivity ranged from 3.18 to 4.03 kg/m^3 in the irrigation scheduling treatments.

The results of comparing the quality of orange fruit in the second year of the study have been shown in Table 4. Irrigation scheduling had no significant negative effect on fruit quality compared to conventional irrigation. Among irrigation scheduling treatments, the dry matter, pulp, vitamin C, juice, skin and weight of the orange fruits had no significant change. However, the significant difference was observed in pH, sugar and skin thickness of the fruits in irrigation scheduling treatments. Irrigation scheduling increased pH, sugar and skin thickness of the fruits in the second year of the study.

The applied water and fruit yield in the average first and second year were determined and shown in Table 5. There was no significant difference between the fruit yield in the conventional and scheduled irrigation. The highest fruit yield was obtained in T_3. The maximum applied water was in T_1 (11163 m^3/ha). Irrigation scheduling showed significant difference in applied water. Among different irrigation scheduling treatments, T_2 and T_4 applied 7513 and 6055 m^3/ha water as the maximum and minimum values, respectively.

Table 2. Quality characteristics of the orange fruit in the first year of the study

Treatment	pH	Dry matter (%)	Sugar	Fruit pulp (%)	Vitamin C	Fruit juice (%)	Fruit skin (%)	Skin thickness (mm)	Fruit weight (g)
T_1	3.7^{ab}	10.7^{a}	4.4^{a}	20.3^{a}	67.0^{a}	39.5^{a}	40.1^{a}	7.7^{a}	210^{a}
T_2	3.7^{ab}	10.8^{a}	7.9^{a}	21.8^{a}	66.1^{a}	39.1^{a}	39.0^{a}	5.7^{ab}	218^{a}
T_3	3.7^{ab}	9.6^{a}	5.4^{a}	20.8^{a}	58.4^{a}	38.2^{a}	41.0^{a}	6.5^{ab}	220^{a}
T_4	3.8^{a}	11.0^{a}	7.3^{a}	17.9^{a}	56.9^{a}	44.0^{a}	38.1^{a}	5.2^{b}	214^{a}
T_5	3.7^{ab}	11.0^{a}	6.6^{a}	22.5^{a}	61.7^{a}	39.6^{a}	37.9^{a}	6.0^{ab}	208^{a}
T_6	3.6^{b}	10.7^{a}	6.2^{a}	18.8^{a}	59.8^{a}	40.8^{a}	40.4^{a}	5.7^{ab}	215^{a}

The same superscripts in same col. indicate that the differences are not significant.

Table 3. Applied water, yield and water productivity of the orange irrigation scheduling treatments during the second year of the study

Treatment	Yield (kg/ha)	Applied water (m^3/ha)	Saved water compared to T_1 (%)	Irrigation water productivity (kg/m^3)	Total water productivity (kg/m^3)
T_1	25000^{a}	12346^{a}	0	2.03^{c}	1.84^{c}
T_2	23333^{a}	7338^{b}	41	3.18^{b}	2.72^{b}
T_3	25625^{a}	7269^{b}	41	3.52^{ab}	3.02^{ab}
T_4	24375^{a}	6090^{d}	51	4.03^{a}	3.33^{a}
T_5	23542^{a}	6535^{c}	48	3.60^{ab}	3.03^{ab}
T_6	24167^{a}	6179^{d}	50	3.91^{a}	3.26^{a}

The same superscripts in the same col. indicate that the differences are not significant.

Table 4. Quality characteristics of the orange fruit in the second year of the study

Treatment	pH	Dry matter (%)	Sugar	Fruit pulp (%)	Vitamin C	Fruit juice (%)	Fruit skin (%)	Skin thickness (mm)	Fruit weight (g)
T_1	3.6^{b}	11.0^{a}	4.8^{b}	20.1^{a}	65.7^{a}	40.4^{a}	40.8^{a}	7.5^{a}	211^{a}
T_2	3.7^{ab}	11.2^{a}	8.4^{a}	20.0^{a}	66.9^{a}	41.7^{a}	41.0^{a}	6.2^{bc}	223^{a}
T_3	3.7^{ab}	10.3^{a}	6.9^{ab}	19.8^{a}	61.4^{a}	41.6^{a}	39.0^{a}	6.8^{ab}	226^{a}
T_4	3.8^{a}	11.1^{a}	7.7^{a}	19.9^{a}	59.9^{a}	42.5^{a}	40.5^{a}	5.0^{c}	219^{a}
T_5	3.8^{a}	10.8^{a}	7.1^{ab}	21.2^{a}	59.2^{a}	40.1^{a}	37.9^{a}	6.0^{bc}	211^{a}
T_6	3.6^{b}	11.1^{a}	7.4^{a}	19.0^{a}	63.5^{a}	42.9^{a}	41.1^{a}	5.3^{c}	221^{a}

The same superscripts in the same col. indicate that the differences are not significant.

Table 5. Applied water, yield and water productivity in treatments in the two years of the study

Treatment	Yield (kg/ha)	Applied water (m^3/ha)	Saved water compared to T_1 (%)	Irrigation water productivity (kg/m^3)	Total water productivity (kg/m^3)
T_1	26427^{a}	11163^{a}	0	2.45^{c}	2.11^{c}
T_2	24063^{a}	7513^{b}	33	3.20^{b}	2.65^{b}
T_3	27761^{a}	7114^{bc}	36	3.95^{a}	3.21^{a}
T_4	24042^{a}	6055^{d}	46	4.20^{a}	3.19^{a}
T_5	25833^{a}	6403^{cd}	43	4.06^{a}	3.26^{a}
T_6	23719^{a}	6277^{d}	44	4.12^{a}	3.06^{a}

The same superscripts in the same col. indicate that the differences are not significant.

Irrigation scheduling saved water from 33% (T_2) to 46% (T_4) compared to T_1. Irrigation scheduling based on the soil moisture measurement saved the highest level of water. Arunadevi *et al.* (2022) in green pea found that deficit irrigation saved applied water and increased water use efficiency without any effect on fruit yield. In all irrigation scheduling treatments of the present study, water productivity was higher than the conventional irrigation. However, water productivity in T_2 was significantly smaller than the other irrigation scheduling treatments. The highest water productivity was obtained in the irrigation scheduling by the soil moisture measurement. In the irrigation scheduling treatments, irrigation and total water productivity ranged from 3.20 to 4.20 kg/m^3 and from 2.65 to 3.19 kg/m^3, respectively. Yang *et al.* (2022) reported that water productivity increased from 1.6 to 2.4 kg m^{-3} in decreasing the irrigation water in irrigation scheduling of wheat in north China plain.

The two years' average of orange fruit quality is given in Table 6. The pulp, vitamin C, juice, and skin of the orange fruits had no significant change among irrigation scheduling treatments. However, a significant difference was observed in pH, dry matter, sugar, skin thickness and weight of the fruits in irrigation

Table 6. Quality characteristics of orange fruit in the two-year duration of the study

Treatment	pH	Dry matter (%)	Sugar	Fruit pulp (%)	Vitamin C	Fruit juice (%)	Fruit skin (%)	Skin thickness (mm)	Fruit weight (g)
T_1	3.7^{ab}	10.9^{ab}	4.6^{b}	20.2^{a}	66.3^{a}	40.0^{a}	40.4^{a}	7.6^{a}	210^{ab}
T_2	3.7^{ab}	11.0^{a}	8.1^{a}	20.9^{a}	66.5^{a}	40.4^{a}	40.0^{a}	5.9^{bc}	221^{ab}
T_3	3.7^{ab}	9.9^{b}	6.1^{ab}	20.3^{a}	59.9^{a}	39.9^{a}	40.0^{a}	6.7^{ab}	223^{a}
T_4	3.8^{a}	11.0^{a}	7.5^{a}	18.9^{a}	58.4^{a}	43.3^{a}	39.3^{a}	5.1^{c}	217^{ab}
T_5	3.7^{ab}	10.9^{ab}	6.8^{a}	21.9^{a}	60.4^{a}	39.9^{a}	37.9^{a}	6.0^{bc}	209^{b}
T_6	3.6^{b}	10.9^{ab}	6.8^{a}	18.9^{a}	61.6^{a}	41.8^{a}	40.7^{a}	5.5^{bc}	218^{ab}

The same superscripts in the same col. indicate that the differences are not significant.

Table 7. The results of economic analysis of the studied treatments (in dollars/ha)

Treatment	Irrigation cost	Applied water cost	Gross income	Tools cost	Total cost	Cost difference with T_1	Net benefits with T_1	Priority
T_1	165	160	2892	0.0	325.0	0	0	6
T_2	112	107	2892	0.1	219.1	-105.9	105.9	1
T_3	112	107	2892	1.8	220.8	-104.2	104.2	3
T_4	112	92	2892	23.2	227.2	-97.8	97.8	5
T_5	112	92	2892	19.5	223.5	-101.5	101.5	4
T_6	112	92	2892	15.8	219.8	-105.2	105.2	2

scheduling treatments. Irrigation scheduling increased the fruit quality. Morianou *et al.* (2021) concluded that irrigation scheduling based on 60% of ET increased the fruit quality of the grapefruit.

The economic cost and income of the studied treatments in the two-year period are shown in Table 7. The cost and net benefits of the irrigation scheduling treatments were less and higher than the conventional irrigation, respectively. Among all of the irrigation scheduling treatments, T_2 had the highest net benefit at 105.9 dollars/ha. Scheduling irrigation based on soil moisture measurement had the minimum net benefits among scheduled treatments due to the highest price cost of the instrument. Irrigation scheduling was more economical for gardeners than the conventional irrigation. The highest and lowest economic benefit was obtained in T_2 and T_4, respectively.

CONCLUSION AND SUGGESTIONS

Irrigation scheduling in citrus orchards under drip irrigation significantly decreased applied water and increased water productivity. Not only the applied water decreased but also fruit quality did not decrease under irrigation scheduling. Five irrigation scheduling tools were compared with conventional irrigation by the gardener. Irrigation scheduling saved applied water from 23 to 40% and 41 to 51% in the first and second year of the study period. At the highest rate, irrigation scheduling based on the soil moisture measurement saved 40 and 51% of applied water compared to conventional irrigation. In both irrigation seasons, the maximum fruit yield was obtained in irrigation scheduling based on canopy temperature. Irrigation scheduling increased water productivity about 57 and 98% compared to conventional irrigation in the first and second year, respectively. Irrigation scheduling based on Penman Montieth evapotranspiraton model (NDCW) and soil moisture monitoring were more and less economical, respectively. The conventional irrigation was not economical compared to the studied irrigation scheduling tools. Irrigation scheduling can be used to save applied water with improving the fruit quality of the citrus orchards in the semi-arid regions.

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