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Araştırma Makalesi - Research Article

Effects of Different Irrigation Intervals and Irrigation Levels on Yield and Quality Components of Processing Tomatoes and Economical Analysis

Farklı Sulama Aralıkları ve Düzeylerinin Salçalık Domatesin Verim ve Kalite Bileşenlerine Etkileri ve Ekonomik Analizi

İlker Elmas[1*], Ali Kaan Yetik[2], Hayrettin Kuşçu[3]

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ABSTRACT

This study was carried out to determine the effects of different irrigation intervals (II) and irrigation levels (IL) on yield, quality and net income values of processing tomato cultivation in a sub-humid climatic zone in 2019. A split-plot randomized complete block design with three replicates was used for the field experiments. The II4-days (A) and 8-days (B) were determined as main-plot factor and different IL were established according to 100% (T_1), 80% (T_2) and 60% (T_3) of the cumulative evaporation occurring in the Class A pan were determined as the sub-plot factor. Seasonal crop evapotranspiration (ET) values varied between 419 and 527 mm. The effects of different irrigation strategies on fruit yield, average fruit weight, brix and water productivity values of processing tomato were significant at the p<0.01 level. The greatest fruit yield was obtained in AT_1 treatment with 111.65 t ha^{-1}. The highest water and irrigation water productivity values were obtained from AT_2 as 22.4 kg m^{-3} and 31.4 kg m^{-3} and the lowest values from BT_3 treatment as 16.1 kg m^{-3} and 26.0 kg m^{-3} respectively. The yield response factor (ky) was determined as 1.7 for the growing season. The net income values of different treatments ranged from 213.49 to 5557.54 $ ha^{-1} and the net income increased with the augmentation inthe irrigation water applied. Based on the study results, AT_1 treatment was recommended to obtain maximum fruit yield and net income. However, in locations with limited water resources, AT_2 treatment which provides a reasonable balance between quality components and water requirements can also be evaluated.

Keywords- Water Productivity, Brix, Yield Response Factor, Net Income

ÖZ

Bu çalışma yarı nemli iklim koşulları altında salçalık domates yetiştiriciliğinde farklı sulama aralıkları ve seviyelerinin; verim, kalite ve net gelir değerleri üzerine etkisini belirlemek amacıyla 2019 yılında yürütülmüştür. Arazi denemeleri tesadüf bloklarında bölünmüş parseller deneme desenine göre gerçekleştirilmiştir. 4 günlük (A) ve 8 günlük (B) sulama aralıkları ana parselleri, A sınıfı buharlaşma kabından ölçülen buharlaşmanın %100 (T1),

[1]*Corresponding author contact: ilkerelmas16@gmail.com (https://orcid.org/0000-0002-6306-0065)
Biosystem Engineering, Faculty of Agriculture, Bursa Uludag University, Bursa, Turkey
[2]Contact: alikaanyetik@ohu.edu.tr (https://orcid.org/0000-0003-1372-8407)
Biosystem Engineering, Faculty of Agricultural Sciences and Technology, Niğde Omer Halisdemir University, Niğde, Turkey
[3]Contact: kuscu@uludag.edu.tr (https://orcid.org/0000-0001-9600-7685)
Biosystem Engineering, Faculty of Agriculture, Bursa Uludag University, Bursa, Turkey

%80 (T2) ve %60'ının (T3) uygulandığı sulama düzeyi ise alt parselleri belirlemiştir. Sezonluk bitki su tüketimi (ET) değerleri 419 ile 527 mm arasında değişmiştir. Farklı sulama programlarının salçalık domateste meyve verimi, tek meyve ağırlığı, briks ve su verimliliği değerlerine etkileri $p<0.01$ düzeyinde önemli bulunmuştur. En yüksek meyve verimi değeri 111.65 t ha^{-1} ile AT_1konusundan elde edilmiştir. En yüksek su ve sulama suyu üretkenliği değerleri sırasıyla 22.4 kg m^{-3} ve 31.4 kg m^{-3} ile AT_2'den, en düşük değerler ise 16.1 kg m^{-3} ve 26.0 kg m^{-3} ile BT_3konusundan elde edilmiştir. Sezonluk verim tepki faktörü (ky) 1.7 olarak belirlenmiştir. Farklı konulara ait net gelir değerleri 213.49 ile 5557.54 \$ ha^{-1} arasında değişmiş, uygulanan sulama suyunun artmasıyla net gelir yükselmiştir. Çalışma sonuçlarına dayanarak, maksimum meyve verimi ve net gelir elde etmek için AT_1konusuönerilmiştir. Sınırlı su kaynaklarına sahip yerlerde, kalite parametreleri ve su ihtiyacı arasında makul bir denge sağlayan AT_2konusu da değerlendirilebilir.

Anahtar Kelimeler- Su Üretkenliği, Briks, Verim Tepki Faktörü, Net Gelir

I. INTRODUCTION

Despite the fact that tomato is grown in several locations throughout the world, its homeland is Central and South America. Tomatoes hold a special place among vegetables as an essential component of human nutrition and have a wide range of uses such as frozen, bottled, sauce and pickles in the foodservice industry [1]. According to FAO, 186 million tons (Mt) of 1.1 billion tons of world fresh vegetable production was the tomato in the year of 2020 [2]. China was the leading tomato producing country in 2020 with 64.8 Mt; India was the second with 20.5 Mt and Turkey was the third with 13.2 Mt production [2]. The main reason for Turkey's being an important tomato producer is the abundance of regions with suitable climatic conditions for tomato cultivation [3]. Tomato is one of the vegetables with the highest production and consumption values in Turkey, and its importance in the food sector is growing by the day. TUIK data shows that tomatoes were cultivated in 1 652 035 da of land in Turkey in 2021, with a total yield of 13 095 258 tons [4]. Since tomato is a seasonal vegetable, keeping it fresh is very difficult and shipping expenses are considerable, it is preferable to be processed into other products such as tomato paste. Processing tomatoes are among the most important product categories in the food exports of Turkey [5]. In Turkey, processing tomatoes were cultivated in 35.2% (581 954 da) of the total tomato production area in 2021 and the total production amount was 4 514 736 tons [4].

The yield and quality components of tomato may differ under the effects of both genetic and environmental factors. One of the most essential environmental aspects of tomato production is water. Irregular and insufficient precipitation caused by the effects of climate change creates a risk in tomato farming and makes irrigation a critical input. Efforts should be made to increase productivity in agricultural production by eliminating the problems caused by climate change [6]. Irrigation and irrigation techniques are becoming increasingly important in agricultural production; however, many regions of the world are faced with a shortage of water for agricultural purposes. Water must be used as efficiently as possible in order to produce a high quality agricultural product [7]. Modern water techniques should be used to deal with the threat of water shortage [8]. The drip irrigation method is commonly used for irrigation of field crops as well as horticulture [9]. Drip irrigation methods save significant quantities of water since only a certain area is wetted [10]. In addition, due to the direct penetration of the applied water into the root zone, prevents the use of excess water and increases irrigation efficiency.

Increasing the irrigation water used in processing tomato cultivation increases the yield but remarkably decreases the brix, lycopene, and total polyphenol content [11]. In this context, optimizing the amount of irrigation water is of great importance in terms of both yield and quality parameters. In previous studies, the seasonal water requirements of processing tomatoes were reported as between 89.3-436.9 mm by [12], 503.7-811.7 mm by [13], 248-512 mm by [14] and 96.0-312.0 mm by [15]. Brix, pH, color, and fruit firmness are all key aspects to consider to determine the important quality standards of processing tomatoes [16]. Yavuz et al. stated that quality parameters such as brix, fruit firmness, titratable acidity and pH decrease with the higher irrigation water amount [17]. Favati et al. reported the highest quality values for the processing tomato in the deficit irrigation treatment under Mediterranean climatic conditions [18]. An irrigation strategy was recommended by Patanè et al. that applied 50% of the evaporation amount to increase water use efficiency and quality in processing tomatoes [19]. Kamal and El-Shazlystated that the highest fruit quality values were obtained in the treatment that least irrigation water applied under Egyptian conditions [20]. The effects of different irrigation strategies on net income and yield and quality componentsin processing tomato cultivation in sub-humid climatic zone have not been clearly explained in the literature.

The main objectives of this study are: (i) to examine the effects of different irrigation levels and intervals on the yield and quality; (ii) to determine the most suitable irrigation schedule; (iii) to assess the economic feasibility in relation to irrigation scheduling of processing tomato cultivated under sub-humid climate conditions.

II. MATERIAL AND METHODS

A. Study Site

The study was conducted at Bursa Uludag University Faculty of Agriculture (latitude 40º 11' N, longitude 29º 04' E, altitude 110 m). Table 1 summarizes the physical and chemical features of the soil of the study site. Water holding capacity of experimental soils was 163.3 mm and the soil salinity level was between 0.45-0.79 dS m^{-1}. The irrigation water utilized in the study was classified as C_2S_1 (medium salt and low sodium).

Table 1. Soil characteristic of experimental area

Soil Depth (cm)	Clay	Sand	Silt	Texture	Field Capacity (%)	Wilting Point (%)	Bulk Density (g cm^{-3})	EC (dS m^{-1})	pH	Lime (%)
0-30	49.5	24.32	26.18	Clay	38.17	27.07	1.35	0.45	6.1	0.0
30-60	50.5	23.28	26.22	Clay	40.01	27.03	1.36	0.45	6.4	0.0
60-90	53.5	21.88	24.62	Clay	43.01	26.75	1.34	0.79	7.1	1.3
90-120	40.5	21.64	37.86	Clay	40.05	23.18	1.38	0.64	8.0	43.7

[EC] electrical conductivity, [dS] deciSiemens

The sub-humid climate is dominant in the study site. The average annual precipitation of Bursa Province is 707.6 mm and the month with the most precipitation is December with 101.4 mm. The long-term annual average relative humidity is 66.2% and wind speed is 2.2 m s^{-1}. On the other hand, during the growing season of 2019 the monthly average temperature was 19.6 °C in May, it increased in the following months and the highest average temperature was seen as 24.5 °C in August. The climatic data of 2019 and long-term period are given in Table 2.

Table 2. Climatic properties of study site

Climatic factors	Years	Months				Total / Average
		May	June	July	August	
Precipitation (mm)	2019	40.4	51.2	37.9	39.1	168.6
	LT	50.1	34.1	21.4	16.3	121.9
Min. Temperature (°C)	2019	12.9	17.4	16.6	17.5	16.1
	LT	11.4	14.9	17.2	17.2	15.2
Max. Temperature (°C)	2019	26.3	29.9	30.5	31.5	29.5
	LT	23.8	28.3	30.8	31.0	28.5
Relative Humidity (%)	2019	67.3	68.2	64.9	64.7	66.2
	LT	67.3	68.6	64.6	64.3	66.2
Wind Speed[a] (m s^{-1})	2019	2.3	2.9	2.8	3.2	2.8
	LT	2.0	2.0	2.3	2.3	2.2

LT: long-term averages, [a]:Average wind speed (at 2 m height)

B. Experimental Details

A split-plot randomized complete block design with three replicates was used for the field experiments. The irrigation intervals were determined as main-plot factor and different irrigation levels as sub-plot factor. The treatments of the sub-plots were randomly distributed within the blocks. Different treatments of study are summarized in Table 3. Processing tomato variety (*Lycopersicon esculentum* Mill., cv. Heinz 1015) was used as plant material. The seedlings were planted on 3 May 2019 with 140 cm row spacing and 30 cm on-row plant spacing. Each plot was a total 21 m^2 (4.2 m wide and 5 m long) with 3 rows. The distance between all plots and blocks was set to 2 m. Plants were irrigated by drip irrigation method. A lateral line (16 mm in diameter) was located through each row and emitter spacing was 20 cm. Two days before the planting, soil samples were taken at a soil depth of 0.16, 0.45, and 0.75 m by the gravimetric method, and the difference between the field capacity and the soil moisture was determined. First half of the determined difference (30 mm) was applied as irrigation water to the experimental plots the day before planting, and the other half after planting. Experimental plots were fertilized before planting with nitrogen in the form of ammonium nitrate (33% N, 90 kg ha^{-1}) and phosphorus in the form of triple super phosphate (44% P_2O_5, 120 kg ha^{-1}) was given to all plots [21]. Afterwards, 90 kg ha^{-1} nitrogen in the form of ammonium sulfate (21% N) was applied on 11 May 2019.

Table 3. Experimental treatments of the study

Main Plots	**Sub Plots**
Irrigation interval (II)	Irrigation levels (IL)
4 days interval (A) 8 days interval (B)	K_{pc} = 1.0 (T_1) K_{pc} = 0.8 (T_2) K_{pc} = 0.6 (T_3)

Kpc: coefficients of Class A pan evaporation

C. Measurements

The amount of irrigation water applied was determined using the evaporation equation from the open water surface [22].

$$I = A \, x \, E_{pan} \, x \, K_{pc} \, x \, P \tag{1}$$

Where I is the irrigation water (L), A is plot area (m^2), E_{pan} is the amount of water evaporated from the Class A pan (mm), K_{pc} is the coefficient of Class A pan (determined as 0.6, 0.8 and 1.0 for different treatments) and P is the percentage of wetted area (was determined before each irrigation application so as to be equal to the canopy cover and was never taken below 30%).

Crop evapotranspiration (ET, mm) values of different irrigation treatments were calculated on the basis of soil water budget equation (Equation 2) [23, 24].

$$ET = I + P - R - D \pm \Delta S \tag{2}$$

Where I is the applied irrigation water amount (mm), P is the precipitation, R is the is runoff (mm), D is the drainage below the effective root depth (mm) and ΔS is the soil water content difference between two measurements (mm 90 cm^{-1}). The amount of irrigation water was measured by a water meter for each plot. The changes of soil water content between different measurements were calculated by the gravimetric method. In determining the ET, the water content in the 0-60 cm layer of the soil was taken into account [25]. A possible water content increase in the layer of 60-90 cm was considered as deep percolation and neglected. The runoff is not taken into consideration in the computation for the soil water budget since irrigation water was administered in a regulated manner using the drip irrigation method.

Processing tomato plants from each plot were harvested by hand 7^{th} of August. The fruit yield (t ha^{-1}) was determined by converting the total weight of plants harvested from each treatment to hectare yield. Average fruit weight (g) was determined in fruit samples taken from 10 randomly selected plants in each plot. Afterwards, the quality components of processing tomato were determined on three randomly selected healthy fruits for each plot. The degree of brix, pH value, the color values (L, a, b, C and h) and the fruit firmness (kg cm^{-2}) of tomato fruits were determined by using a digital refractometer (HI 96800, Hanna Instruments), pH-meter (Mettler Toledo), colorimeter (CR-10 Plus model, KONICA MINOLTA) and penetrometer, respectively.

D. Water and Irrigation Water Productivity

Water productivity (WP, kg m^{-3}) and irrigation water productivity (IWP, kg m^{-3}) values of different treatments were calculated by the Equation 3 and Equation 4 [26, 27].

$$WP = \frac{YLD}{ET_a} \tag{3}$$

$$IWP = \frac{YLD}{I} \tag{4}$$

Where YLD is yield of treatments (kg ha^{-1}), ET_a is the seasonal crop evapotranspiration of treatment (mm), I is the seasonal irrigation water amount of treatment (mm).

E. Yield Response Factor

The yield response factor (ky) determined by the Stewart equation [28, 29]. The Stewart equation (Equation 5) was developed to determine the relationship between relative yield decrease ($1-Y_a/Y_m$) and relative crop evapotranspiration deficit ($1-ET_a/ET_m$).

$$\left(1 - \frac{Y_a}{Y_m}\right) = k_y\left(1 - \frac{ET_a}{ET_m}\right) \tag{5}$$

Where *ky* is the yield response factor, Y_a is the yield obtained from treatment, Y_m is the maximum yield, ET_a is the seasonal crop evapotranspiration of treatment and ET_m is the maximum seasonal crop evapotranspiration.

F. Economic Analysis

The partial budgeting method was used in the economic evaluation of study results [30, 31]. The method is based on comparing the additional benefits and additional costs that will result from different techniques. In this method, net income per unit area ($ ha^{-1} year^{-1}) and gross income per unit area ($ ha^{-1} year^{-1}) values were calculated by using irrigation time (h), labor cost per irrigation application ($ h^{-1}), total irrigation labor cost (assumed that irrigation applications were carried out with drip irrigation system, in 1 ha land and by one worker, $), water fee ($), tomato production expenses (fertilizer, pesticide, seeds, labor cost, fuel oil etc. $ ha^{-1}), yield (t ha^{-1}) and tomato price ($ t^{-1}). The prices of labor cost, water fee, tomato production expenses and tomato sales are obtained from Karacabey Tomato Producers Association, Bursa. Financial information provided in TL (Turkish liras) was converted to USD (US dollars) at the current exchange rate of 14 August 2019 (TL 5.59 = USD 1.00).

G. Statistical Analysis

Variance analysis was conducted different probability levels (0.05 and 0.01) to investigate the impacts of different irrigation intervals and levels on the yield and quality components and Duncan test was performed to compare the averages. All statistical values were calculated with the statistical package program IBM SPSS 23 (IBM Statistics for Windows, Version 23). In addition, water-yield relations were determined by regression analysis.

III. RESULTS AND DISCUSSION

A. Irrigation Water Amount and Crop Evapotranspiration

The total irrigation water to the different experimental treatments and determined crop evapotranspiration values are given in Table 4. During the cultivation period, a total of 17 irrigation application were made in the treatments that were irrigated with 4-day intervals (A), and a total of 9 irrigation applications made in the treatments that were irrigated at 8-day intervals (B). Seasonal irrigation water amounts varied between 259 and 412 mm. The total amount of precipitation received was measured as 130 mm and differences were observed in crop evapotranspiration values of different treatments. The highest ET was calculated as 527 mm from AT_1, while the lowest ET was calculated as 419 mm from BT_3 (Table 4). [19] reported that the irrigation water requirements of processing tomato ranged between 325-464 mm and 254-386 mm for the first and second year of the study, respectively under Mediterranean climatic conditions. In another study conducted in Mediterranean climatic zone [27], reported irrigation water quantities applied of processing tomato as between 242-404 mm, and seasonal ET values as between 276-406 mm. [32] stated that seasonal irrigation amounts of processing tomato cultivated under semi-arid climatic conditions as between 167.8 mm and 507.12 mm. Seasonal ET values of processing tomato plant cultivated under sub-humid climatic conditions varied between 375 and 596 mm under the effects of different water regimes [14]. [33] reported that the ET values of tomato plant varied between 384 mm and 869 mm. The values of seasonal ET and I of the mentioned studies are similar to our findings. [13] reported highest irrigation water quantities and ET values of processing tomato respectively as 811.7 mm and 863.3mm, while the lowest as 503.7 mm and 516.1 mm, respectively in a semi-arid environment. [34] reported that the amount of irrigation water applied to processing tomato was between 151-208 mm, under greenhouse conditions. [15] stated thatseasonal irrigation water amount of tomato ranged from 96 mm to 302 mm in arid climatic zone. The differences between the mentioned studies and current study were attributed to different climatic conditions, irrigation scheduling, soil characteristics and variety of plant material.

Table 4. Seasonal irrigation water amount (I), crop evapotranspiration (ET) and precipitation values (P)

Treatments		I (mm)	ET (mm)	P (mm)
A	T_1	412	527	130
	T_2	336	470	
	T_3	259	422	
B	T_1	412	524	
	T_2	336	476	
	T_3	259	419	

A, B: Irrigation intervals, T_1, T_2, T_3: Irrigation levels

B. Fruit Yield, Water and Irrigation Water Productivity

The mean values and results of ANOVA tests of fruit yield, water productivity (WP) and irrigation water productivity (IWP) are summarized in Table 5. For all parameters, the differences between the experimental treatments were determined to be statistically significant at the 0.01 level (Table 5).

Table 5 shows that more yield was obtained by more frequent irrigation, and total yield of treatment A is 3.4% higher compared to B. In addition, fruit yield increased as the IL increased. Considering the different irrigation levels, the highest average fruit yield with 111.24 t ha^{-1} was obtained from T_1, followed by T_2 and T_3, respectively. The highest average fruit yields were obtained from treatments AT_1 and BT_1, while the lowest were obtained from AT_3 and BT_3. Besides, the effect of II was found to be statistically significant and higher fruit yield was obtained from the AT_2 than BT_2. [14] reported the similar findings for the highest fruit yield of processing tomato (obtained from the full irrigated treatments) as 100 t ha^{-1} for the first and as 110 t ha^{-1}, for the second year of study. [27] stated that the highest fruit yield was achieved in full irrigation treatment with 128.7 t ha^{-1}. [33] reported a range between 22.7-72.2 t ha^{-1} for the yield of tomato plant. In another study conducted in semi-arid climatic zone by [35], the highest yields reported as 72.56 t ha^{-1} and 68.95 t ha^{-1} for the first and second year of study.

The determined mean WP and IWP values of treatments are given in Table 5. Effects of irrigation intervals, irrigation levels and II*IL interaction on WP and IWP values were found to be significant at 0.01 level. WP values ranged from 16.1 to 22.4 kg m^{-3}, while the highest WP value was seen in AT_2, and the lowest WP value was obtained from the BT_3. IWP values were varied between 26.0-31.4 kg m^{-3}, and the highest IWP value determined was in AT_2 treatment, while the lowest IWP value was in treatment BT_3. It can be said that the WP and IWP values were increased with by more frequent irrigation applications. A similar range of WP and IWP values of processing tomato was reported by [36] as 13.1-21.6 kg m^{-3} (WP) and 19.6-30.3 kg m^{-3} (IWP) and by [35] as 12.0-25.7 kg m^{-3} (WP) and 13.5-30.6 kg m^{-3} (IWP). On the contrary, different ranges were determined for the WP and IWP respectively by [37] as 9.9-12.7 kg m^{-3} and 11.4-33 kg m^{-3}, by [38] as 3.53-7.17 kg m^{-3} and 3.61-6.87 kg m^{-3} and by [39] as 28.0-29.4 kg m^{-3} (WP).

Table 5. Effects of treatments on fruit yield and water and water productivity

Treatments	Fruit Yield (t ha^{-1})	WP (kg m^{-3})	IWP (kg m^{-3})
AT_1	111.65 a[1]	21.2 b	27.1 c
AT_2	105.50 b	22.4 a	31.4 a
AT_3	68.34 d	16.3 d	26.4 d
BT_1	110.84 a	21.2 b	26.9 c
BT_2	97.89 c	20.6 c	29.2 b
BT_3	67.36 d	16.1 d	26.0 d
F-test	**	**	**
T_1	111.24 A	21.2 A	27.0 B
T_2	101.70 B	21.5 A	30.3 A
T_3	67.85 C	16.2 B	26.2 C
F-test	**	**	**
A	95.16 *a*	20.0 *a*	28.2 *a*
B	92.03 *b*	19.3 *b*	27.3 *b*
F-test	**	**	**

A, B: Irrigation intervals, T_1, T_2, T_3: Irrigation levels
** Significant at the 1% probability level (P<0.01).
[1] Indicate significant differences at P<0.05 using least significant difference (LSD) test

C. Quality Components

The effects of II*IL interaction on the parameters of average fruit weight, brix, pH, fruit firmness and color were insignificant. On the other hand, both different irrigation levels and intervals had significant effects (p<0.01) on average fruit weight, and different irrigation levels had significant effects on brix values at p<0.01 level (Table 6). The average fruit weight was increased by decreasing water stress; and higher average fruit weight values (80.41 g, mean) were obtained from T_1 treatments. Average fruit weight values with respect to irrigation intervals varied from 71.76 to 73.80 g (Table 6). Present values on average fruit weight comply with the values found by [36] as a range between 56.62 and 71.71 g. The highest value of average fruit weight obtained from AT_1 treatment (81.89 g), while the lowest was from BT_3 (64.66 g). [19] found the highest fruit weight value in full-irrigated treatment as 72.6 g under Mediterranean climatic conditions. [40] obtained a fruit weight value of a maximum 118.32 from their study conducted in subtropical climatic zone. Soil characteristics, climatic factors and irrigation techniques can be shown as the reason for the differences in average fruit weight.

One of the most important quality parameters in processing tomato is brix. The highest brix values were obtained in least irrigated treatments. The brix values increased as water stress increased but did not significantly change with the frequency of irrigation applications (Table 6). [41] and [42] stated that brix values of tomato increase as the applied irrigation water decreases. [35] reported that irrigation levels*mulch interactions had significant effects on brix value at $p<0.01$ level and determined the maximum brix value as 7.66, while the lowest value as 6.45. [43] found a range between 5.57 and 6.78 for the brix value of tomato under Mediterranean climate conditions.

The effect of both II and irrigation levels on pH was not found to be statistically significant. The highest pH value was obtained as 4.73 from the treatment BT_3, while the lowest pH value was obtained as 4.57 from AT1 (Table 6). In another study with similar findings conducted by [44] was stated that the effect of trial subjects on pH value was not significant and reported that pH values varied between 4.12 and 4.15. The amount of irrigation water applied to the processing tomato had no significant effects on the pH value [36].

The fruit firmness values of processing tomato were not affected by II and IL (Table 6). Fruit firmness values varied between 1.38-1.13 kg cm^{-2} and however, no statistical difference was determined between the applications. [37] stated that the different emitter spacing was not statistically significant on fruit firmness, while authors reported the highest fruit firmness values as 1.25-1.22 kg cm^{-2} in full-irrigated treatment for both years, respectively. [36] reported that the effect of cutting time of irrigation on fruit firmness was statistically significant at $p<0.05$ level and stated that the fruit firmness values of processing tomato varied between 0.86 and 1.13 kg cm^{-2} under sub-humid climatic conditions. [25] reported two highest fruit yields as 4.64 kg cm^{-2} and 4.03 kg cm^{-2} for different locations in Mediterranean climatic zone. The fact that fruit firmness is found to be variable according to the applications in different studies may be due to the genetic characteristics of the variety being more dominant than the irrigation levels applied.

Another important quality parameter of processing tomato is color. According to the Table 6 the L (lightness) values ranged from 36.26 to 36.00, a (redness-greenness) values varied between 38.90 to 35.13, and b (yellowness-blueness) values were between 27.86 to 25.29. The ranges of Chroma (C) and hue angle (h) values were determined as 45.7 to 42.34and 36.00 to 33.00, respectively. The fact that there is no statistical difference between the results obtained shows that the difference between II and IL have no effect on the color parameters in question. [35] stated that there are no statistically significant differences between L, a and b parameters under the effects of different irrigation level and reported a range of 40.61 to 38.47for L, 37.39 to 32.16for a and 30.36 to 27.29for b. [18] stated that L values were measured between 40.40 to 40.11, a values between 29.94 to 29.62and b values between 24.91 to 24.01and reported that the effects of different water stress levels were not found to be statistically significant on tomato color parameters under Mediterranean climatic conditions. [45] reported that L values ranged from 43.58 to 42.99, a values ranged from 29.08 to 27.80, and b values ranged from 30.36 to 29.33, under humid climatic conditions.

Table 6. Effects of treatments on quality parameters

Treatments	Average fruit weight (g)	Brix	pH	Fruit firmness	Colorparameters				
					L	a	b	C	h
AT_1	81.89	5.54	4.57	1.13	36.00	35.13	25.38	44.00	35.83
AT_2	73.17	6.04	4.64	1.24	36.00	38.90	25.55	42.34	33.00
AT_3	66.34	6.28	4.63	1.38	36.21	37.00	26.46	45.51	35.49
BT_1	78.92	5.63	4.67	1.20	36.26	35.71	25.95	44.14	36.00
BT_2	71.71	6.04	4.66	1.23	36.07	36.49	25.29	44.31	34.81
BT_3	64.66	6.33	4.73	1.26	36.05	36.80	27.89	45.75	35.71
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns
T_1	80.41 A[1]	5.58 C	4.62	1.16	36.13	35.42	25.66	4402	35.88
T_2	72.44 B	6.03 B	4.64	1.24	36.03	37.65	27.92	4332	33.85
T_3	65.50 C	6.30 A	4.68	1.32	36.13	36.90	27.16	45.63	35.60
F-test	**	**	ns	ns	ns	ns	ns	ns	ns
A	73.80 *a*	5.95	4.61	1.25	36.06	37.00	27.46	44.00	34.74
B	71.76 *b*	6.00	4.69	1.23	36.13	36.33	26.36	44.73	35.47
F-test	**	ns	ns	ns	ns	ns	ns	ns	ns

A, B: Irrigation intervals, T_1, T_2, T_3: Irrigation levels
ns Non-significant
** Significant at the 1% probability level (P<0.01).
[1] Indicate significant differences at P<0.05 using least significant difference (LSD) test

D. Water-yield Relationships

The relationship between processing tomato fruit yield and the total irrigation water applied and crop evapotranspiration are given in Figure 1. It was observed that fruit yield increased in parallel with the increase in both parameters. Polynomial relationship ($R^2=0.9859$, $p<0.01$) was found between the seasonal irrigation water and the fruit yield values obtained and a linear relationship (R^2= 0.8826, p<0.01) was found between seasonal crop evapotranspiration and fruit yield.

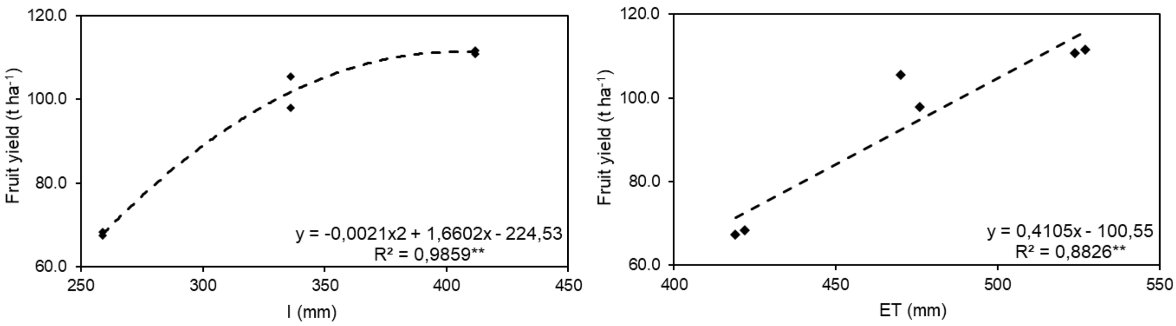

Figure 1. The relations of fruit yield and seasonal irrigation water amount applied (I) and seasonal crop evapotranspiration (ET)

When the results obtained were evaluated, since a linear relationship between fruit yield of processing tomato and seasonal ET values was observed, the yield response factor (ky) was determined. The relationship of seasonal yield response factors of treatments is given in Figure 2. Seasonal ky value was determined as 1.71. This value shows that processing tomato fruit yield will decrease by 1.7 units against a 1-unit decrease in ET. In previous studies with the similar findings, [14] reported the 2-yr average ky value as 1.59 and [21] reported the 2-yr average ky value as 1.65. In other studies, conducted under different climatic conditions ky values reported as 1.05 by [29], as 0.55 by [46] and as 0.46 by [13].The effect here does not only develop depending on the amount of irrigation, but can also change according to the soil structure, cultivation period and other cultural processes except irrigation.

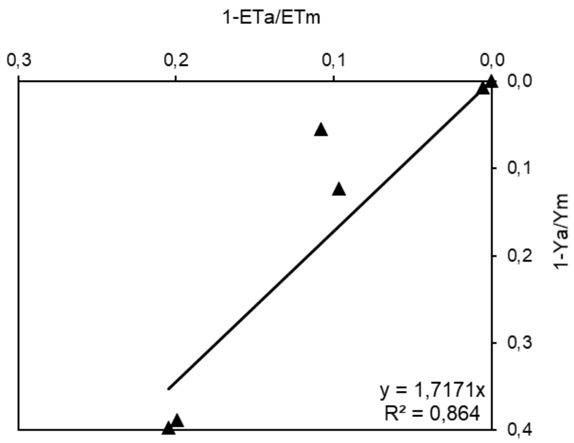

Figure 2. Yield response factor (ky) of deficit irrigated processing tomato plant

E. Economic Analysis

The economic analysis of the different treatments is given in Table 7 in detail. The gross incomes determined with evaluating investment, operating and production expenses in the study ranged between 8487.36 and 14067.19 \$ ha^{-1}. The highest net income was calculated in AT_1 treatment with 5557.54 \$ ha^{-1}, followed by BT_1 with 5455.48 \$ ha^{-1}. The lowest net income values were determined in least irrigated treatments (AT_3 and BT_3). The net income values decreased with the decreasing of irrigation water amount applied. When the irrigation intervals are compared, lower net income was obtained in 8-day interval treatments (Table 7). [47] stated that net profits varied between 867 to 1493 \$ ha^{-1}. [48] reported the net profits of tomatoes as 1804 and 2513 \$ ha^{-1} for different agricultural lands. [49] reported that the net income in tomato farming is 7710 \$ ha^{-1} in Iğdır Province. [50] stated that tomato producers in Nigeria cultivate the tomatoes profitably but the farmers must constantly create different efficiency methods and future studies must be conducted about sustainable production.

Table 7. Economic analysis of different treatments

Trt.	I (m^3 ha^{-1}) *(1)*	Irrigation duration (h) *(2)*	Labor cost per irrigation application (\$ h^{-1}) *(3)*	Total irrigation labor cost (\$, *2x3*) *(4)*
AT_1	4120	35.6	4.1	145.96
AT_2	3360	29.1	4.1	119.31
AT_3	2590	22.7	4.1	93.07
BT_1	4120	35.6	4.1	145.96
BT_2	3360	29.1	4.1	119.31
BT_3	2590	22.7	4.1	93.07
	Water fee (\$ m^{-3}) *(5)*	**Water fee (\$ ha^{-1}, *1x5*) *(6)***	**Tomato production expenses (\$ ha^{-1}) *(7)***	**Total cost of production (\$ ha^{-1}, *4+6+7*) *(8)***
AT_1	0.12	494.4	7870	8510.36
AT_2	0.12	403.2	7870	8392.51
AT_3	0.12	310.8	7870	8273.87
BT_1	0.12	494.4	7870	8510.36
BT_2	0.12	403.2	7870	8392.51
BT_3	0.12	310.8	7870	8273.87
	Yield (t ha^{-1}) *(9)*	**Processing tomato price (\$ t^{-1}) *(10)***	**Gross income (\$ ha^{-1}, *9x10*) *(11)***	**Net income (\$ ha^{-1}, *11-8*) *(12)***
AT_1	111.65	126	14067.9	5557.54
AT_2	105.5	126	13293	4900.49
AT_3	68.34	126	8610.84	336.97
BT_1	110.84	126	13965.84	5455.48
BT_2	97.89	126	12334.14	3941.63
BT_3	67.36	126	8487.36	213.49

A, B: Irrigation intervals, T_1, T_2, T_3: Irrigation levels

IV. CONCLUSIONS

The seasonal irrigation water requirements and crop evapotranspiration values of the processing tomato varied between 259-412 mm and 527-419 mm, respectively. The effects of different irrigation intervals, irrigation levels and their interactions on fruit yield and water and water productivity values of processing tomato was significant at the $p<0.01$ level. As for the quality parameters of processing tomatoes, while the significant effects of different irrigation levels were determined on average fruit weight and brix value ($p<0.01$) and different irrigation intervals on average fruit weight ($p<0.01$), the effects of their interactions were insignificant. Fruit yield values determined in the study ranged from 67.36 t ha^{-1} (BT_3) to 111.65 t ha^{-1} (AT_1). Fruit yield values decreased as a result of water deficiencies used in processing tomato farming in sub-humid climate conditions. The seasonal yield response factor (ky) was calculated as 1.71. The highest water and irrigation water productivity values were obtained from AT_2 as 22.4 kg m^{-3} and 31.4 kg m^{-3}, respectively and the lowest values from BT_3 treatment as 16.1 kg m^{-3} and 26.0 kg m^{-3}, respectively. As a result of the economic analysis, the highest net incomes were obtained from the full irrigation treatments for both irrigation intervals. Net income values varied between 156.38 \$ ha^{-1} and 4394.50 \$ ha^{-1} and decreased due to the decreasing amount of irrigation water applied.

As a result, since irrigation scheduling has significant effects on fruit yield, quality and net income, it should be planned very carefully. Full irrigation treatment with 4-day interval (AT_1) can be recommended to obtain the highest fruit yield and net income in drip-irrigated processing tomato farming in sub-humid climatic zone. For the locations of limited water resources, taking into account the brix, water and irrigation productivity values AT_2 treatment which provides an appropriate balance between yield, quality and water need can be suggested.

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