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Combined Effects of Irrigation and Nitrogen on Some Quality Parameters of Processing Tomato

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Abstract: This study investigated the effects of different irrigation programs and nitrogen levels on quality parameters of tomato. The amount of water used was based on pan evaporation from a screened class-A pan. Treatments consisted of two irrigation intervals (I1: 5 day; I2: 10 day), three plant-pan coefficients ($K_{cp}1$: 0.50; $K_{cp}2$: 0.75; $K_{cp}3$: 1.00) and three N levels (N0: 0, N1: 80 kg ha^{-1} and N2: 160 kg ha^{-1}). Irrigation was started when the available water dropped in 40% in the 90 cm of the soil profile. According to the results, irrigation intervals did not affect the parameters examined. However, total solids and soluble solid concentration, titratable acidity and firmness, fruit diameter, length and weight of fruit increased with N fertilization but pH and hue values decreased. Ascorbic acid was not affected by N fertilization. While irrigation water amount did not affect dry matter content, total soluble solid concentration, pH, ascorbic acid and hue values; titratable acidity, firmness, fruit diameter, length and weight were significantly affected.

Key words: Fruit quality · irrigation · nitrogen · processing tomato

INTRODUCTION

There has been considerable research on processing tomato, yet there are clearly large gaps in the understanding of how the field environment, cultural techniques and crop management influence each of the fruit properties measured at harvest to estimate the quality of processed products. Tomato paste is the product of most interest since it is reformulated in to many other products. Its principal quality parameters are dry matter, soluble solids, titratable acidity, pH, gross viscosity and color. Since the paste values for most of these can be predicted from the same measurements on fresh fruit homogenate, also called pulp ore puree, analysis made on fruit at harvest. Fruit color is an increasingly important component of tomato product quality due to greater awareness amongst consumers of the health benefits of the red pigment lycopene. Total solids and soluble solids are closely related to each other. And these parameters are an indicator of mineral nutritional status of plant [1]. High level of solids in tomato fruit is the required parameter for tomato processing.

Among the various factors limiting the yield and quality of tomato plant, choosing a proper irrigation and fertilization programs are very important. For higher yield and quality, adequate supply of balanced fertilizer should be needed. Among the fertilizers, nitrogen, phosphorus and potassium are the main nutrients from which the plant growth and quality often affected. Of these three nutrients, nitrogen is the most required mineral for plants. Irrigation management is other crucial factor for tomato yield and quality. Tomato growth, fruit yield and quality parameter can be affected differently by irrigation programs. The differential effects of water deficits on tomato fruit yield and quality are complex and poorly defined. Regulation of fruit solids through water management appears to involve the same trade-off as occurs in plant breeding, where high-yielding cultivars have lower solids and soluble solids concentration and high solids cultivars have lower yield potential [2].

Because many factors affect the yield and quality of tomato, it is difficult to determine the optimum irrigation and fertilizer programs for tomato production. For this, a suitable program for optimal production must be determined at growth conditions [3]. Many researchers worked on the nutritional and water requirement of tomato. But their results were so diversified that it was very difficult to express the adequate requirements of

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fertilizers. This is because the fertilizer and water requirement of crops varies from soil to soil.

The objective of this study was to determine the effects of different irrigation programs and nitrogen levels on quality parameters of tomato.

MATERIALS AND METHODS

Soil and climate characteristics: The experiment was carried out at Suleyman Demirel University Experimental Station, Isparta, Turkey, during 2003 growing season. Some characteristics of soil in experimental are presented in Table 1. Soil pH, EC and lime were measured using pH meter, EC meter and calsimeter. Total N, extractable P, extractable K and CEC were determined as described by Bremnler [4], Olsen *et al.* [5], Knudsen *et al.* [6] and Jackson [7], respectively.

Mediterranean climate is dominant in the area. Based on the many years of observation data collected by the station located in the experimental farm, average temperature and annual precipitation is 12.0°C and 581.0 mm, respectively. The coldest month is February (-21.0°C) whereas the hottest month is August (37.5°C). Ninety percent of the precipitation falls during the winter. Annual average humidity and wind rate are 61% and 1.9 m s^{-1}, respectively. Precipitation is insufficient for stage in summers (24.4 mm) when plant water use is the greatest.

Design of experiment, fertilization, irrigation and harvest: Treatments consist of two different irrigation intervals (I1: 5 days and I2: 10 days); three plant-pan coefficients (K_{cp}1: 0. 50; K_{cp}2: 0.75 and K_{cp}3: 1.00) and three N rates (N0:0, N1:80 and N2:160 kg ha^{-1}). Treatments were arranged according to a split-split plot design with three replications. Tomato plants were planted at 1.4 m x 0.30 m spacing on 8th June, 2003. Distance between the plots, which consisted of 40 plants in 16.8 m^2 (3 m x 5.6 m), was 150 cm. The experiment was laid out with 54 plots.

Pre-planting fertilizer was applied at the rate of 30 kg P ha^{-1} from triple superphosphate and 50 kg K ha^{-1} from potassium sulphate. Nitrogen from ammonium sulphate was applied in equal rates at 3 periods (after planting, flowering and fruit ripening) using fertilizer tanks connected to the irrigation system.

Irrigation water having low sodium ion risk and no EC problem (8 l s^{-1}) was applied with drip irrigation system. Lateral pipes, which had inline drippers at 60 cm intervals, were 16 mm in diameter and 4 l h^{-1} with 1.8 k Pa pressure. Dripper interval was determined based on discharge rate and infiltration rate of soil. Irrigation water amount is calculated by using class-A pan evaporation and plant-pan coefficient [8].

After seedling planted, plants were irrigated several times as pre-plant irrigation. Then, when the available water in the 90 cm soil profile fell to 40%, all treatments were irrigated to the field capacity. Subsequent irrigations were initiated at 5 and 10 days intervals. Profile soil water contents were measured gravimetrically up to the 90 cm depth in every 30 cm at transplanting, before each irrigation and final harvest. E_t was estimated using the soil water balance equation given below [9].

$$E_t = I_r + P + C_r - D_p - R_f \pm \Delta s$$

Where; E_t is plant water consumption (mm), I_r is irrigation water (mm), P is precipitation (mm), $C_r$is capillar rise (mm), D_p is deep percolation losses (mm), R_f is runoff losses (mm), Δs is moisture storage in soil profile (mm).

Because irrigation was done by drip irrigation systems, R_f values were not determined. Precipitation (P) was measured daily at a nearby weather station. C_r was considered as zero because there was no high underground water problem in the area. If available water in the root zone (90 cm) and total amount of applied water by irrigation were above the field capacity, it would be assumed that mentioned water leaked and called as the deep percolation value (D_p) [10].

Sixteen plants in two mid rows from each plot were hand-harvested to avoid side effects. At the harvest, 15 fruits from each treatment were selected randomly, then fruit diameter and length measured then weighed.

Dry Matter (DM), Total Soluble Solids (TSS), Titratable Acidity (TA), pH, Ascorbic Acid (AA), Firmness (F), Color(C) and Protein analysis: For determining DM, 100 grams of newly harvested fresh fruit sample from 10 fruits was taken randomly and dried at 65°C until the stable weight was reached. Then proportion of dry matter was converted to percent basis.

Table 1: Physical and chemical characteristics of soil at the start of the experiment

Depth (cm)	γ (g cm^{-3})	FC (P_w)	WP (P_w)	pH	EC (dSm^{-1})	$CaCO_3$ (%)	Total N (%)	Extractable P (mg kg^{-1})	Extractable K (me 100 g^{-1})	CEC (me 100 g^{-1})	Texture
0-30	1.16	27.9	15.1	7.8	2.9	3.0	0.20	6.14	0.53	12.4	CL
30-60	1.18	30.7	16.6	7.8	3.1	3.0	0.13	0.88	0.46	13.2	CL
60-90	1.09	31.2	16.9	7.9	2.3	2.8	0.13	0.70	0.45	12.7	CL

γ: Bulk density, FC: Field Capacity; WP: Wilting Point: EC: Electrical Conductivity; CEC: Cation Exchange Capacity; CL: Clay-Loam

The juice of 10 fruits for per replicate was analyzed for TSS, pH and TA. Total soluble solid concentrations were measured using a digital refractometer (Palette PR-32 ATAGO).

Titratable acidity was measured by potentiometric titration to pH 8.1 using a digital burette (Jencons Digitrate -50 ml) and a digital pH meter (Hanna HI 9321 Microprocessor). Titratable acidity was expressed as percent citric acid. pH was determined by the same digital pH meter.

100 g samples from 10 fresh fruits was taken randomly from each side and homogenized in meta-phosphoric acid (6%) and titrated with 2-6 diclorophenolindophenol then calculated as described in Cemeroglu [11].

Fruit firmness was measured on 10 fruits (warmed to 20°C) from each replicate, by measuring penetration force in libre (lb) with a universal testing machine (Lloyd LF Plus Universal Test Machine) equipped with a 7.9 mm probe.

External color was measured on opposite side of 15 fruits using Minolta Chromometer (Model CR-300, Minolta) which provided CIE L*, a* and b* values. These values were also used to calculate chroma ($C^* = [a^{*2}+b^{*2}]^{1/2}$) and hue angle ($h^\circ = \tan^{-1}[b^*/a^*]$), that represent the angle in a 360° color wheel where 0, 90, 180 and 270 represent red-purple, yellow, bluish green and blue, respectively [12]. Decreases in hue angle indicate the higher redness.

To determine protein content in fruit, first N concentrations of fruit were determined according to a Kjeldahl method [4]. Then N concentration was multiplied by 6.25 factor.

Analysis of variance: Examined parameters were analysed using a Costat computer program (ANOVA). Means were separated by Duncan's multiple range test ($p< 0.01$).

RESULTS AND DISCUSSION

Dry Matter (DM) and Total Soluble Solid (TSS): Dry matter and TSS contents ranged from 6.97 to 8.05% and 4.10 to 4.83%, respectively (Table 2). While DM and TSS were not significantly affected by I, K_{cp} and I* K_{cp}, the effects of other variation sources were significant (Table 3). DM and TSS contents increased with N applications. While the lowest DM and TSS values were obtained from the zero N application, these values increased about 7 percent in DM and 11 percent in TSS with N3 level (Table 4). Dry matter and TSS contents are an indicator of mineral nutrient concentration in fruit and these values generally increases with fertilization but decreases with over irrigation [1, 13-15]. Saha [16] indicated that TSS was the highest with fruits received higher N than other levels of N. Because N is a constituent of protein and amino acids, it directly affects the DM and thus TSS. Increasing level of K_{cp} resulted in significant TSS decrease. This might be due to lower respiration rate and less dilution of TSS concentration due to lower water content in the tomato fruit [17]. Also higher TSS might be resulted from a higher conversion of starch to sugars because of deficit water [18]. Increased DM and TSS in response to soil water deficiency, have been observed from different studies as well [19-23]. On the other hand, no effect of moisture stress on solids was reported by May and Gonzales [20].

Table 2: Yield (Y), DM, TSS, TA, AA, protein, pH, F, h° FD, FL and FW values of tomato fruit grown under different N fertilization and irrigation regimes

Treatments	I_r (mm)	E_t (mm)	Y (t ha^{-1})	DM (%)	TSS (%)	TA (g l^{-1})	pH	AA (mg 100 g^{-1})	Protein (%)	F (lb)	h°	FD (mm)	FL (mm)	FW (g)
$I1K_{cp}1N0$	503.7	516.1	23.32	6.97	4.20	1.45	4.71	29.7	12.3	2.44	47.7	52.26	72.32	80.13
$I1K_{cp}1N1$		532.1	55.53	7.60	4.60	1.51	4.87	30.0	13.4	2.94	43.2	52.60	73.41	79.07
$I1K_{cp}1N2$		551.2	78.90	7.80	4.83	1.55	4.91	32.5	16.6	2.95	44.6	53.54	74.21	82.60
$I1K_{cp}2N0$	657.7	676.7	25.27	7.17	4.10	1.45	4.63	25.9	11.6	2.55	49.2	56.01	78.51	92.2
$I1K_{cp}2N1$		689.1	60.53	7.38	4.40	1.47	4.83	37.4	13.3	2.80	44.0	55.96	77.43	93.83
$I1K_{cp}2N2$		699.8	88.83	7.67	4.68	1.72	4.81	35.0	16.7	2.75	44.0	57.35	78.41	99.53
$I1K_{cp}3N0$	811.7	839.2	31.49	7.35	4.40	1.34	4.85	36.4	12.1	2.46	46.2	55.87	77.46	93.33
$I1K_{cp}3N1$		847.2	63.70	7.58	4.60	1.52	4.76	24.6	13.2	2.42	44.1	56.65	78.19	106.33
$I1K_{cp}3N2$		859.2	95.61	7.32	4.30	1.52	4.75	33.9	17.6	2.52	44.1	56.61	78.26	96.90
$I2K_{cp}1N0$	503.7	536.3	12.83	7.32	4.33	1.52	4.72	36.1	12.2	2.85	46.4	50.67	71.45	83.45
$I2K_{cp}1N1$		547.8	46.01	7.53	4.53	1.42	4.84	31.9	12.8	2.66	44.8	52.30	71.82	80.87
$I2K_{cp}1N2$		554.1	61.00	7.78	4.83	2.05	4.71	30.9	17.4	2.64	44.6	53.48	73.82	82.07
$I2K_{cp}2N0$	657.7	690.8	14.64	7.15	4.13	1.56	4.72	33.3	14.6	2.94	45.8	55.42	77.28	88.73
$I2K_{cp}2N1$		702.1	57.78	7.62	4.63	1.45	4.78	33.1	13.2	3.07	44.2	55.90	78.77	88.91
$I2K_{cp}2N2$		709.7	73.44	8.05	4.80	1.63	4.72	27.5	18.0	2.73	43.1	57.53	79.00	95.60
$I2K_{cp}3N0$	811.7	831.2	17.62	7.33	4.33	1.41	4.85	36.1	13.4	2.32	45.1	54.71	76.26	85.98
$I2K_{cp}3N1$		856.4	61.06	7.43	4.38	1.53	4.74	35.0	13.5	2.59	44.8	55.06	77.26	91.57
$I2K_{cp}3N2$		863.8	78.23	7.68	4.67	1.61	4.87	31.0	20.2	2.67	43.7	56.47	78.66	101.94

Table 3: Analysis of variance for data obtained from treatments

		F values										
Variation	Df	DM	TSS	TA	pH	AA	Protein	F	h°	FD	FL	FW
I	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K_{cp}	2	ns	ns	5.18 *	ns	ns	2.4**	8.1*	ns	28.03***	20.24 ***	17.67 ***
K_{cp}*I	2	ns	ns	ns	ns	ns	5.1	ns	ns	ns	ns	ns
N	2	124 ***	97.7 ***	16.5 ***	3.75*	ns	226.0***	4.1*	17.3 ***	5.6 *	4.96 *	4.465 *
N*I	2	5.7 **	5.5*	ns	ns	6.0 **	ns	ns	8.1**	ns	ns	ns
N*K_{cp}	4	13.9***	12.0***	ns	5.98**	12.0***	ns	ns	ns	ns	ns	ns
N*K_{cp}*I	4	9.8***	5.8**	3.13*	3.39*	10.4***	ns	3.2*	ns	ns	ns	ns
Error	24											

***p<0.001, **p<0.01, *p<0.05, ns: non significant

Table 4: Mean values of parameters compared with Duncan statistical method

Treatments	DM (%)	TSS (%)	TA (g l^{-1})	pH	AA (mg 100 g^{-1})	Protein (%)	F (lb)	h°	FD (mm)	FL (mm)	FW (g)
I1	7.42a*	4.45a	1.50a	4.79a	31.7a	14.1a	2.67a	45.2a	55.21a	76.34a	91.55a
I2	7.53a	4.52a	1.57a	4.65a	32.8a	14.9a	2.72a	45.2a	54.73a	76.03a	88.78a
K_{cp}1	7.49a	4.55a	1.58a	4.79a	31.8a	14.1b	2.74ab	45.3a	54.32b	75.55b	87.31b
K_{cp}2	7.49a	4.47ab	1.54ab	4.75a	31.3a	14.4b	2.81a	44.9a	54.74ab	76.11ab	90.08ab
K_{cp}3	7.45a	4.44b	1.49b	4.62a	32.8a	15.0a	2.53b	45.0a	55.83a	76.90a	93.11a
N0	7.21b	4.25c	1.45b	4.75a	32.9a	12.6b	2.59b	46.7a	52.64b	72.84b	81.37b
N1	7.53a	4.52b	1.48b	4.80a	31.9a	13.3b	2.78a	44.1b	56.36a	78.21a	93.13a
N2	7.69a	4.70a	1.68a	4.61b	31.8a	17.8a	2.71ab	44.6b	55.89a	77.52a	95.99a

*Means followed by the same letter are not significantly different from each other

Titratable Acidity (TA) and pH: Statistical analysis showed that K_{cp}, N and N* K_{cp} *I had significant effect on TA (Table 3). Titratable acidity decreased with K_{cp} but increased with N fertilization. While TA values decreased about 6 percent from K_{cp} 1 to K_{cp} 3, this value increased about 16 percent from N0 to N1. This indicates that N is an important factor for increasing TA. pH values were significantly affected by N fertilization and its interactions (except for N*I). While pH values were the highest (4.75) under zero N condition, it reached to the lowest value (4.61) in N3 (Table 4). And thus fruit quality increased in terms of pH [11]. Results also showed that there was reverse relation between TA and pH [24].

Ascorbic acid (AA) and protein contents: Ascorbic acid contents ranged from 24.6 to 36.4 mg 100 g^{-1} (Table 2). While mean AA content was not significantly affected by individual factors, effect of interactions (except for K_{cp}*I) on AA were significant (Table 3). In different studies, it was declared that there was not a direct effect of N on AA content. But in same cases, increasing in AA contents due to increasing N levels was attributed to the exposing of plant canopy to sun light fertilized with higher N doses [25, 26].

Protein content of fruit recorded in this study ranged from 11.6 to 20.2 (Table 2) and K_{cp} and N applications were found to be significant on these values (Table 3). While protein content of fruit was 14.1% in K_{cp}1, this increased to 15.0 with K_{cp}3. Nitrogen fertilization increased protein content. Less than zero N condition, protein content was determined as 12.6%, but this level significantly increased about 41% in N2 (Table 4). Because N is a constituent of protein, it increases with N content in tissue [27]. Also increase of protein with increased K_{cp} may be related to increase in plant available soil N with irrigation water.

Fruit Firmness (F) and Color (h°): While F values affected significantly by K_{cp}, N and N* K_{cp}*I interaction, other variation sources did not effect F value (Table 3). Firmness of fruit increased with moderately irrigation (K_{cp}2), but then decreased with K_{cp} increase. Nitrogen fertilization increased F values until N1 level, but then decreased again in N2 (Table 4). While I and K_{cp} did not affect h° values, the effects of N fertilization and N*I interactions were significant (Table 3). Under N0 condition, h° value was the highest but it decreased with both 80 and 160 kg N ha^{-1} applications. As could be seen from Table 4, the effect of N fertilization on h° value was

negative. But this negative effect showed that both N levels increased redness of fruit. Because N plays important roles in numerous physiological activities, it might have affected red color formation. Hanson and May [23] declared that fruit color was affected by environment, but irrigation levels and irrigation systems did not affect color values. This findings show well correspondence with our results.

Fruit Diameter (FD), Length (FL) and Weight (FW): Average FD, FL and FW ranged from 52.26 to 57.53 mm, 71.45 to 79.00 mm and 80.13 to 106.33 g, respectively (Table 2). Except K_{cp} and N, other variation sources had no significant effect on FD, FL and FW (Table 3). Duncan test showed that while FD, FL and FW values were the lowest in $K_{cp}1$, the highest values were obtained in $K_{cp}3$. As known water is essential constituent of plants. So plants having sufficient water, forms bigger fruits. At the same time, plants get more nutrients under water supplied conditions, thus plants grow well and fruit quality increases [28]. Under zero N conditions FD, FL and FW values were the lowest. Both N doses increased these values at similar significance level (Table 4). These findings were almost consistent with Manana [29].

CONCLUSIONS

The findings of study indicate that irrigation intervals did not significantly affect the physical and chemical properties of tomato fruit. Fruit physical properties and protein content were positively affected by K_{cp} increase. However, increasing K_{cp} levels resulted in decrease of TSS, TA and F values of fruit. Nitrogen fertilization affected all parameters (except for AA). Some properties such as FD, FL, FW, DM, TSS, TA, F and protein were increased by N applications, but pH and h° values were decreased. According to results above, because 5 and 10 day intervals did not affect all quality parameters, choosing I2 is proper for time and labor save. When N fertilization was considered, it was seen that 160 kg N ha^{-1} was the most effective rate on increasing about whole quality parameters. If irrigation levels were evaluated, $K_{cp}3$ had the most important effect on parameters (FD, Fl and FW) affecting yield directly. Also protein and pH were positively affected by $K_{cp}3$. As conclusion, to improve tomato fruit quality it might be advised that I2*K_{cp}3*N2 combination could be chosen for processing tomato production under similar condition experiment conducted.

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