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Effects of Drip Irrigation Management and Different Soilless Culture on Yield and Quality of Tomato Grown in a Plastic House

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Abstract: This study was carried out to determine the most suitable irrigation scheduling of fresh market tomato (Fantastic-144) grown on volcanic ash, peat and their mixture (1:1) under Plastic house conditions at Alata Horticultural Research Institute in the Mediterranean Region of Turkey in 1998. The quality and yield response of Fantastic-144 to trickle irrigation was also investigated. Four different irrigation levels (WL_1 = 75%, WL_2 = 100%, WL_3 = 125% and WL_4 = 150% of Class A Pan evaporation) and two irrigation frequencies (once and twice daily applications) were evaluated. Highest yield and fruit number were obtained from the ash+peat (1:1) with irrigation once a day at WL_4 and ash+peat (1:1) with twice a day watering at WL_3 and WL_4 irrigation levels. Soluble solids of tomato fruit decreased with increasing available water. The highest WUE value of 67.5 kg m^{-3} was obtained from WL_1 with peat+ash (1:1). WUE decreased in all treatments as the amount of irrigation water increased.

Key words: Peat, volcanic ash, bag culture, tomato, quality, Plastic house

INTRODUCTION

In Turkey, greenhouse has an important place in horticulture and encompass 44000 ha. Proper irrigation management is essential for improving the productivity and quality of crops grown in the greenhouse in which rainfall is obstructed by the cover. Exact time and amount of irrigation are two deterministic factors for the efficient irrigation management. Irrigation scheduling based on Class A pan evaporation may improve water use efficiencies.

In soilless culture, drip irrigation is used to deliver water to crops. Irrigation is an important factor for tomato production in Mediterranean climates where the growing season coincides with a period of high evaporative demand. The amount of irrigation applied and its timing throughout the crop cycle influence both yield and fruit quality (Dumas *et al*., 1994; Prieto, 1996). However, the yield and quality of marketable fruits are dependent upon local agronomic and environmental conditions.

Growers of fresh market tomatoes in Turkey commonly irrigate according to experience and convenience. Thus inappropriate irrigation might occur and have adverse effects on the yield and quality of a crop as well as irrigation inefficiencies. Irrigation scheduling based on Class A pan evaporation may improve water use efficiencies. This would be particularly useful where water availability is limited.

Soilless culture offers a valuable alternative compared to crop production in soil and has been widely adopted by specialist producers of greenhouse crops in the world, particularly for vegetable crops such as tomatoes and cucumber (Winsor and Baudoin, 1992). The problems with production factors such as soilborn pests and diseases, soil salinity, lack of arable soil, water have led to the development of substrates for soilless cultivation (Granqvist, 1981; Olympios, 1992; Tuzel *et al*., 2001).

Vegetable growing in soilless culture has been found to give higher yield and quality when compared to soil (Varis and Altay, 1992; Abak and Celikel, 1994;

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Alan *et al*., 1994). The properties of different material used as growing substrates exhibit direct and indirect effects on plant growth and production (Verdonck *et al*., 1981). The selection of a particular material depends on its availability, cost and local experience of its use (Klougart, 1983; Verdonck *et al*., 1983). Physical and chemical features of soilless culture such as degree of dispersion, pH, porosity, water holding capacity, size of soil particle, must be considered for choosing the materials (Wilson, 1983).

Candido *et al*. (1999) found that water application positively influenced tomato productivity. The supplementary irrigation increased of 284% the marketable yield and this value reached 578 and 1327% with the 50 and 100% maximum crop evapotranspiration restoration. The maximum irrigation supply negatively influenced the quality since reductions in soluble solids and dry matter content. Yuan *et al*. (2001) determined that the accumulative value of evapotranspiration of tomatoes in an unheated greenhouse in North China was approximately equal to the accumulative value of water surface evaporation measured using 20 cm pan.

The objectives of this study were to compare the effects of different water management strategies on fruit yield and quality of drip-irrigated fresh market tomatoes and to determine optimum irrigation schedule using Class A pan for tomato grown on different soilless cultures under Plastic house conditions in the Mediterranean Region of Turkey.

MATERIALS AND METHODS

The research was conducted in a Plastic house at the Alata Horticulture Research Institute, south west of Mersin in Turkey (36°36′N, 34°20′E). This area has a typical Mediterranean climate, which is characterized by hot and dry conditions during summer and mild and rainy during winter period. The Plastic house, oriented in north-south direction, was 30×40 m in size and the cover material was UV + IR added polyethylene.

The experiment was conducted on 3 different soilless culture materials namely ash, peat, ash+peat (1:1). Some physical and chemical features of these materials are displayed in the Table 1. The determination of salt, pH, organic matter, K, anions, cations and $CaCO_3$ content was carried out with the methods given by Tuzuner (1990) and Kacar (1997).

Two irrigation frequencies (once and twice a day applications) and four irrigation levels; WL_1 = 75%, WL_2 = 100%, WL_3 = 125% and WL_4 = 150% of Class A Pan evaporation were evaluated, using a Class A pan located inside the Plastic house. The irrigation water was applied with a drip system. The single daily application was made at 9:00 am and the twice daily applications were carried at 9:00 am and at 3:00 pm. Irrigations continued until one week before the final harvest. Irrigation water was obtained from a deep well and has an electrical conductivity of 0.7 dS m^{-1}. It does not contain any boron and residual sodium carbonate.

The experimental design was a split-split plot with four replications. Main plots, subplots and sub-subplots were assigned to substrate, irrigation frequency and irrigation levels, respectively. Subplot dimensions were 1.00×2.40 m at planting. Each plot consisted of two bags filled with growth medium material. Three tomato seedlings were planted in each bag so that each plot contained a total of 6 plants.

The tomato variety Fantastic-144 was used in this study. This variety is suitable for the region and is resistant to diseases and cold. Its fruit is plumply, hard and resistant to bruising. It has a strong rooting system and high in dry-matter ratio.

Polyethylene black plastic bags (1.20×0.55 m) were filled with the culture materials. Two rows of concrete blocks were placed at the bottom of the bags with a slope of 5% to drain excess water. The upper part of the bags was covered with white plastic to prevent from the contact of culture material with natural soil.

Water soluble fertilizers were used in this experiment. The amount of fertilizer was distributed equally among the plots by fertigation using a bypass system of injection. The fertilizer solution was prepared using 125 ppm N, 30 ppm P and ve 200 ppm K. The pH of the nutrient solution was 5.0-5.5 (Celikel, 1994).

Tomato seedlings with 6 leaves were transplanted into the bags in the Plastic house and fertilizer application together with irrigation commenced. Fertilizer at the same concentration was applied until one week from final harvesting. Vertical supports were used to support plants. All side shoots were removed during the cultivation period. The plants were protected against powdery and downy mildew, alternaria, botrytis, red mite and green worm according to protocols issued by the Plant Protection Institute (personnel communication).

Table 1: Physical and chemical properties of growth materials used in the study

Culture materials	FC (%)	PWP (%)	As (g cm^{-3})	Color	pH	Salt (%)	$CaCO_3$ (%)	OM (%)	P (ppm)	K (ppm)
Peat	41.7	28.1	0.44	Brown	7.4	0.13	24.0	8.3	56.0	243.0
Ash	26.7	12.1	0.69	White	7.8	0.13	27.4	0.6	40.0	248.0
Peat+ash	32.4	15.2	0.52	White +Brown	7.5	0.13	25.5	5.0	49.0	245.0

FC: Field Capacity, PWP: Permanent Wilting Point, As: Bulk Density, OM: Organic Matter

Tomatoes were hand harvested at ripening on April 3 through 10 July and classified according to TSE 794 (Turkish Standards Institute). Harvests continued until no economic yield was attained (AIB, 1995). Fruits were classified by fresh weight and grouped as: 1st (> 125 g), 2nd (90-125 g) and 3rd (< 90 g). Early yield, total yield, first, second and third quality yield, fruit weight and fruit number per unit area were measured. The effect of quality on yield, fruit diameter, vitamin C and Total Soluble Solids (TSS) were also evaluated. TSS were determined with refractometer.

After the variance analysis, main factors and interactions were groupped according to the Duncan test (5 %). MSTATC and SPSS statistical programs were used.

Water Use Efficiency (WUE) values were calculated as the ratio of yield obtained from each treatment to total irrigation applied to treatment.

RESULTS AND DISCUSSION

Harvesting started on April 03, 1998 and continued until July 10, 1998. Table 2 shows the interactions of the substrates and irrigation frequencies and irrigation levels in relation to yield and quality characteristics. Statistical analysis indicated that growth medium, pan coefficient and irrigation frequency interactions were significantly different at 5% level for each parameter considered. Different combinations gave different results for each characteristic. For example, the best result for early yield was obtained with volcanic ash material and with once daily irrigation and WL_1. First and second quality yield with ash+peat mixture was higher than that of volcanic ash and peat, separately. In general, the first and second quality yields and fruit numbers and total yield were highest with ash+peat (1:1). The reason for this can be attributed to better root-zone water environment provided by the ash+peat mixture. The highest fruit number was obtained from ash+peat (1:1) with twice a day irrigation and with WL_3 and WL_4 irrigation levels. Highest average fruit weight was also measured in the ash+peat (1:1) culture material. Statistical analysis of fruit weight data indicated that the effect of culture materials on fruit weight were significantly different. Ash + peat resulted in highest fruit weight, followed by peat and ash. Average fruit number values varied according to the substrates and applied water quantities and ranged between 134.92 and 194.50 no m^{-2}. Average fruit weight values varied from 124.39 to 141.26 g (Table 2).

Chemical characteristics of culture materials showed no significant differences in pH, $CaCO_3$, salt, P, K. Moreover, it was determined that peat contained more organic matter than ash. The research results revealed that ash+peat (1:1) resulted in higher total yields than peat and volcanic ash alone. High cation exchange capacity could be an important advantage of peat (Verdonck, 1991).

Statistical analysis indicated that growth medium × pan coefficient × irrigation frequency interaction was significant at 5% level of significance for each quality

Table 2: Tomato yield according to irrigation frequencies, irrigation levels and culture media

Culture materials	Irrig. freq.	Irrig. level	Yield Quality (kg m^{-2}) Quality 1	Yield Quality (kg m^{-2}) Quality 2	Early yield (kg m^{-2})	Fruit number (No. m^{-2})	Fruit weight (g)	Total yield (kg m^{-2})
Ash	Once a day	WL_1	8.97^{I}	5.41^{L}	4.76^{A}	134.92^{H}	126.66	17.09^{L}
		WL_2	9.71^{H}	7.10^{J}	4.56^{ABCD}	150.61^{FG}	128.92	19.42^{J}
		WL_3	11.36^{E}	4.92^{M}	4.52^{BCD}	144.29^{GH}	131.55	18.99^{JK}
		WL_4	11.08^{EF}	5.99^{K}	4.25^{EFGH}	152.19^{FG}	130.40	19.85^{I}
	Twice a day	WL_1	9.21^{IJ}	5.48^{L}	4.18^{GH}	139.69^{GH}	124.39	17.30^{L}
		WL_2	9.41^{I}	7.08^{J}	4.54^{BCD}	144.80^{GH}	130.28	18.85^{K}
		WL_3	9.27^{IJ}	7.65^{HI}	4.55^{BCD}	151.63^{FG}	128.41	19.47^{IJ}
		WL_4	10.34^{G}	6.56^{K}	4.16^{H}	148.97^{G}	130.55	19.45^{IJ}
Peat	Once a day	WL_1	11.00^{F}	8.06^{GH}	4.22^{FGH}	167.71^{DE}	129.99	21.80^{G}
		WL_2	11.19^{EF}	8.46^{FG}	4.42^{CDE}	167.83^{DE}	133.78	22.41^{F}
		WL_3	11.02^{F}	8.83^{EF}	4.36^{DEFG}	172.73^{CDE}	130.37	22.52^{F}
		WL_4	11.05^{EF}	7.26^{IJ}	4.39^{CDEF}	163.02^{EF}	129.67	21.14^{H}
	Twice a day	WL_1	11.85^{D}	9.09^{E}	4.40^{CDEF}	179.29^{BCD}	131.77	23.62^{DE}
		WL_2	11.93^{CD}	9.72^{C}	4.47^{CD}	185.55^{ABC}	131.14	24.33^{BC}
		WL_3	11.84^{D}	10.34^{B}	4.49^{CD}	184.29^{ABC}	132.60	24.44^{BC}
		WL_4	12.37^{AB}	9.20^{DE}	4.59^{ABC}	179.49^{BCD}	133.09	23.89^{CD}
Ash+Peat	Once a day	WL_1	11.10^{EF}	9.77^{C}	4.58^{ABC}	175.84^{CDE}	131.55	23.13^{E}
		WL_2	12.34^{AB}	9.35^{CDE}	4.56^{ABCD}	178.96^{BCD}	133.81	23.95^{CD}
		WL_3	12.26^{B}	8.98^{E7}	4.71^{AB}	175.83^{CDE}	133.67	23.50^{DE}
		WL_4	12.48^{AB}	10.79^{AB}	4.59^{ABC}	192.41^{AB}	133.00	25.59^{A}
	Twice a day	WL_1	12.28^{B}	9.62^{CD}	3.41^{J}	181.27^{ABCD}	133.60	24.22^{BC}
		WL_2	12.61^{A}	9.65^{CD}	3.52^{IJ}	175.30^{CDE}	141.26	24.69^{B}
		WL_3	12.19^{BC}	11.16^{A}	3.62^{I}	194.50^{A}	132.32	25.74^{A}
		WL_4	12.36^{AB}	11.06^{A}	3.40^{J}	193.56^{A}	132.84	25.71^{A}

[a]Values are means of four replicates for each treatment. Letter(s) indicate statistical significance at $p_{0.05}$ level within the same column

Table 3: Some fruit quality parameters according to and irrigation frequencies, irrigation levels and culture media

Culture materials	Irrigation frequency	Irrigation level	Fruit diameter (mm)	TSS* (%)	Vitamin C (mg 100 mL)
Ash	Once a day	WL_1	70.00^{H}	4.35^{CDEF}	17.08^{D}
		WL_2	70.00^{H}	4.25^{EFG}	17.03^{D}
		WL_3	70.00^{H}	4.20^{EFGH}	18.00^{B}
		WL_4	70.31^{DE}	4.15^{FGH}	17.70^{C}
	Twice a day	WL_1	70.00^{H}	4.60^{AB}	18.08^{B}
		WL_2	70.00^{H}	4.40^{BCDE}	17.08^{D}
		WL_3	70.05^{GH}	4.40^{BCDE}	18.03^{B}
		WL_4	70.25^{DEF}	4.20^{EFGH}	18.03^{B}
Peat	Once a day	WL_1	70.00^{H}	4.35^{CDEF}	18.05^{B}
		WL_2	70.10^{FGH}	4.25^{EFG}	18.00^{B}
		WL_3	71.00^{B}	4.20^{EFGH}	17.00^{D}
		WL_4	71.30^{A}	4.15^{FGH}	17.65^{C}
	Twice a day	WL_1	70.00^{H}	4.68^{A}	18.05^{B}
		WL_2	70.00^{H}	4.50^{ABCD}	18.03^{B}
		WL_3	70.20^{EFG}	4.40^{BCDE}	18.03^{B}
		WL_4	70.21^{DEFG}	4.10^{GH}	18.03^{B}
Ash+Peat	Once a day	WL_1	70.00^{H}	4.35^{CDEF}	18.03^{B}
		WL_2	70.00^{H}	4.28^{DEFG}	17.10^{D}
		WL_3	70.38^{CD}	4.15^{FGH}	18.08^{B}
		WL_4	70.50^{C}	4.13^{FGH}	17.78^{C}
	Twice a day	WL_1	70.00^{H}	4.53^{ABC}	18.43^{A}
		WL_2	70.00^{H}	4.55^{ABC}	18.03^{B}
		WL_3	70.08^{FGH}	4.40^{BCDE}	18.00^{B}
		WL_4	70.18^{EFG}	4.00^{H}	18.08^{B}

* TSS: Total Soluble Solids, [a]Values are means of four replicates for each treatment. Letter(s) indicate statistical significance at $p_{0.05}$ level within the same column

parameter considered (Table 3). Mean fruit diameters ranged from 70.0 to 71.3 mm, Total Soluble Solids (TSS) ranged from 4.00 to 4.68% and vitamin C ranged from 17.00 to 18.43 mg/100 mL. Increasing the irrigation amounts resulted in increased total yield and fruit diameter in general, but decreased total soluble solids. The smallest fruit diameter was obtained with WL_1 and WL_2 irrigation levels for each culture material. Similar results were obtained by Tuzel *et al.* (1994b). Warner *et al.* (2004) studied the effect of regulated deficit drip irrigation on tomatoes and concluded that total soluble solids (% Brix) and total solids (%) were both negatively affected by irrigation water quantity. As the amount of water applied through drip irrigation increased, the percent total soluble solids level decreased.

The total amounts of irrigation water applied in the irrigation levels in this study were 359 mm in WL_1, 478 mm in WL_2, 598 mm in WL_3 and 714 mm in WL_4 (Table 4). These irrigation quantities were the same for the two irrigation frequencies and culture materials. Snyder and Baurle (1985) searched the effects of three different irrigation intervals for tomato growing in greenhouse system and they found that the best irrigation interval was one time in a day to obtain high yields and yield components.

The highest WUE value of 67.5 kg m^{-3} was for WL_1 with peat+ash (1:1) followed by peat and the least was in ash as 27.3 kg m^{-3} (Table 4). WUE decreased in all culture materials as the amount of irrigation water increased. Plants used water more effectively at lower irrigation amounts than the higher water amounts applied. Irrigation frequencies resulted in similar WUE values for the same irrigation level. Peat and ash mixture provided better soil water environment for tomato growth. Castilla (1996) reported WUE values of 34 kg m^{-3} for greenhouse tomato production in soil, but in soilless culture, the WUE value was 29 kg m^{-3}. However, in controlled greenhouses WUE of tomato may reach 65 kg m^{-3}. Akat and Tuzel (2001), tested substrates (perlite, volcanic tuff, perlite+peat (4:1), volcanic tuff+peat (4:1), tuff, perlite, peat, perlite+peat (3:1)) for tomatoes in Aegean region of Turkey. Their results showed that WUE values varied according to the substrates and applied water quantities and ranged between 21.05-62.46 kg m^{-3}.

This work showed that optimum amount of irrigation was 1.25 times of the daily Class A pan evaporation (E_{pan}) value for twice a day irrigation and 1.50 for once a day irrigation for ash + peat (1:1) culture material. However, considering water savings, irrigation level of 1.25 E_{pan} was recommended for the tomato production on soilless culture in plastichouses under the Mediterranean region. Similar results were obtained by Dervis *et al.* (1992) and Tuzel *et al.* (1994a). They found that a pan coefficient of 1.20 resulted in highest yield and quality in the Mediterranean and Aegean part of Turkey. There was no significant difference between the irrigation intervals, whereas, the most effective application was the use of pan coefficient of 1.20 on early and total yields.

The tomato yield and yield components obtained from ash + peat (1:1) was higher followed by peat and ash

Table 4: Water use efficiency values for irrigation frequencies, irrigation levels and culture media

Culturematerials	Irrigation frequency	Irrigation level	Total yield (kg m^{-2})	Total irrigation (mm)	WUE (kg m^{-3})
Ash	Once a day	WL_1	17.09	359	47.6^{F}
		WL_2	19.42	478	40.6^{H}
		WL_3	18.99	598	31.8^{K}
		WL_4	19.85	714	27.8^{LM}
	Twice a day	WL_1	17.30	359	48.3^{EF}
		WL_2	18.85	478	39.9^{H}
		WL_3	19.47	598	32.6^{K}
		WL_4	19.45	714	27.3^{M}
Peat	Once a day	WL_1	21.80	359	60.8^{C}
		WL_2	22.41	478	46.9^{F}
		WL_3	22.52	598	37.7^{IJ}
		WL_4	21.14	714	29.6^{L}
	Twice a day	WL_1	23.62	359	65.9^{AB}
		WL_2	24.33	478	50.9^{D}
		WL_3	24.44	598	40.9^{H}
		WL_4	23.89	714	33.5^{K}
Ash+Peat	Once a day	WL_1	23.13	359	64.5^{B}
		WL_2	23.95	478	50.1^{DE}
		WL_3	23.50	598	39.3^{HI}
		WL_4	25.59	714	35.9^{J}
	Twice a day	WL_1	24.22	359	67.5^{A}
		WL_2	24.69	478	51.6^{D}
		WL_3	25.74	598	43.1^{G}
		WL_4	25.71	714	36.0^{J}

[a]Values are means of four replicates for each treatment. Letter(s) indicate statistical significance at $p_{0.01}$ level within the same column

produced the least tomato yield. Since the cost of peat is higher than ash in the region, the usage of the mixture of ash and peat (1:1) recommended for higher tomato yield. Our results suggest that ash+peat (1:1) may decrease production cost and increase tomato yield and quality under plastichouse conditions described in this work. In addition, soilless culture offers a valuable alternative compared to crop production in soil in the region due to soilborne disease and salinity problems. Economic analysis should be carried out in such studies in order to compare the cost of production under soilless culture with production in soil.

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