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Full Length Research Paper

Effect of irrigation management on yield and quality of tomatoes grown in different soilless media in a glasshouse

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Global warming and resulting drought is the most important constraint affecting plant production in the Mediterranean Region. Therefore, effective management of scarce water resources is of paramount importance in this region. This research was conducted to determine the optimal irrigation strategy for drip irrigated fresh market tomato grown in different soilless culture in a glasshouse in the Mediterranean Region of Turkey. Volcanic ash, peat and their mixture were used as growth media. Four different irrigation levels (WL_1=75%; WL_2=100%; WL_3=125% and WL_4=150% of Class A Pan evaporation) and two watering frequencies (once and twice daily applications) were evaluated. Highest yield and fruit number were obtained from the ash+peat mixture (1:1) with twice a day watering at WL_4 irrigation level. Soluble solids of tomato fruit decreased with increasing available water. The highest irrigation water use efficiency (IWUE) value of 121.4 kg m $^{-3}$ was obtained from once a day irrigation WL_1 irrigation level with peat+ash (1:1). IWUE decreased in all treatments as the amount of irrigation water increased.

Key words: Peat, volcanic ash, substrate, drip irrigation, class A Pan, irrigation water use efficiency.

INTRODUCTION

Soilless culture as a crop production system has been used around the world for centuries and is currently relied on heavily in greenhouse vegetable production in Europe, United States, the Middle East, Japan, Canada, among other countries, and the same production system might also be adoptable to outdoor culture of certain crops (Hochmuth et al., 2002). Many of these soilless systems are referred to as hydroponic culture. Soilless culture is used in greenhouse cultural systems because crop culture is practiced continually in the same site without fumigation. 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 (Olympios, 1992, Tüzel et al., 2001).

Moreover, soilless culture could lead to solve the global issues such as the shortage of water, environmental pollution and instability of ecological system in various ways. Constituting high values for agricultural crops by using low water inputs and high fertilizer efficiencies is one of the methods used in addressing the environmental and resources problems. Soilless culture could be arranged with optimum environmental medium for crop growth in dorder to gain maximum yield and high quality products. In this way, less land area is required for agriculture production system resulting in increased land productivity.

Total soilless culture production area in Turkey was only 20 ha in 2000 (Sevgican et al., 2000), and increased to more than 75 ha in 2004. This production technique is mostly directed for export purposes.

Proper irrigation management is essential for improving the productivity and quality of crops grown in the greenhouse. Exact time and amount of irrigation are two deterministic factors for efficient irrigation management. Irrigation scheduling based on Class A pan evaporation

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may improve water use efficiencies. Inside the greenhouse, crops require frequent irrigation in order to minimize water stress and achieve maximum production and high quality. Scheduling water application is very critical, as excessive irrigation reduces yield, while inadequate irrigation causes water stress and reduces production (Locascio and Smajstrla, 1996). Therefore, it is important to develop irrigation scheduling techniques under prevailing climatic condition. The meteorological-based irrigation scheduling approach, such as pan evaporation was used by many researchers due to its simplicity, data availability and higher degree of adaptability at the farmers level (Eliades and Orphanos, 1986; Locascio and Smajstrla, 1996; Sezen et al., 2006).

Irrigation scheduling methods based on pan evaporation are widely used because of their easy applications (Eliades, 1988). With available pan coefficient in hand, pan evaporation (Class-A Pan) can be used in the arrangement of irrigation programs. Pan evaporation incorporates the climatic factors influencing evapotranspiration into a single measurement (Hansen et al., 1980) and has been used to schedule irrigation intensively for several crops such as tomato (Shrivastava et al., 1994; Imtiyaz et al., 2000), eggplant (Chartzoulakis and Drosos, 1995) , green bean (Sezen et al., 2005), cucumber (Yuan et al., 2006; Wang et al., 2009), bell pepper (Sezen et al., 2006), onion (Imtiyaz et al., 2000; Kumar et al., 2007), potato (Yuan et al., 2003; Ünlü et al., 2006), spinach (Leskovar and Piccinni, 2005), muskmelon (Zeng et al., 2009).

Tüzel et al. (1994a,b) compared different irrigation interval and pan coefficients in order to determine the yield and plant growth response of glasshouse tomato. In the study, irrigation was scheduled at 1 or 3 day intervals and irrigation rates were calculated from pan evaporation within the glasshouse. Four different coefficients were used namely 0.60, 0.80, 1.00 and 1.20. There was no significant difference between the irrigation intervals, whereas, the most effective application was the use of coefficient 1.20 on early and total yields.

In soilless culture use of drip irrigation also facilitates frequent fertilizer application via injection in the irrigation system, which allows growers to improve the synchronization between nutrient application and crop nutrient uptake. Furthermore, different water regimes obtained combining amount of water and irrigation interval gave useful indications on the possibility to improve nutritional tomato quality by reducing irrigation water during tomato cultivation.

In Mediterranean area, the optimum water requirement for vegetables was still not clearly stated, but pan evaporation method within the greenhouse was used to estimate water consumption use (Abou- Hadid et al., 1994; Tüzel et al., 1994b). Increasing the irrigation rate up to 120% of pan evaporation increased crop yield but decreased total soluble solids (Tüzel et al., 1994b).

Tomato requires a constant and adequate water supply during the growing season because it is sensitive to water stress, especially during the reproductive stage (Waister and Hudson, 1970). Drought reduces fruit growth and size and excessive fluctuations in soil moisture content may induce to physiological disorders such as blossom end rot.

A study on the effect of different irrigation interval on spring season glasshouse tomato production was carried out (Tüzel et al., 1994a, 1994b). Increasing the irrigation rate up to 120% of pan evaporation increased crop yield but decreased total soluble solids. Class A pan coefficient of 1.20 resulted in highest yield and quality. The irrigation intervals did not significantly affect the crop yield, but affected other parameters, that is total soluble solid, dry matter content, pH and skin resistance were slightly changed during harvesting period.

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

Celikel (1999) conducted experiments in a plastic and a glass greenhouses to test different substrates in tomato growing. Peat + volcanic tuff + spent mushroom compost (1:1:1), volcanic tuff + spent mushroom compost (1:1), peat + volcanic tuff (1:1), and volcanic tuff were used in both trials. In addition to those, spent mushroom compost and peat in the plastichouse, and rockwool in the glasshouse were also tested. In both trials, plants grown in soil were evaluated as control. Peat + volcanic tuff + spent mushroom compost (1:1:1) gave the highest early and total yields in both greenhouses. Early and total yields were higher in all substrates compared to the yield obtained from soil grown plants. Fruit weight also increased in plants grown in substrates compared to soil and the heaviest fruits were harvested from the plants grown in peat + volcanic tuff + spent mushroom compost (1:1:1). In terms of fruit quality (TSS, TA, pH and vitamin C) there were no significant differences between the substrates and soil.

Tüzel et al. (2001) conducted a study on soilless culture using tomato cv. *Fantastic F_1* as test material to determine the effects of three irrigation scheduling and substrates (perlite, volcanic tuff, pumice, perlite (80%) + peat (20%), volcanic tuff (80%) + peat (20%), pumice (80%) + peat (20%). Among the substrates, perlite (19.20 kg m^{-2}) and perlite+peat mixture (19.66 kg m^{-2}) resulted in the highest yield.

Candido et al. (1999) found that water application positively influenced tomato productivity. The supplementary irrigation increased 284% of the marketable yield, and this value reached 578 and 1327% with the 50 and 100% maximum crop evapotranspiration replenished. The maximum irrigation supply negatively influenced the

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 ($mg\ kg^{-1}$)	K ($mg\ kg^{-1}$)
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.

quality since reductions in soluble solids and dry matter content.

In order to reduce the pollution of agricultural origin, Parra et al. (2009) studied recirculation strategies in three different substrates as an alternative to tomato soilless culture in open system in the canary island. The results indicate that the closed system saved up to 45% of water applied, and up to 69% of the water discharged, depending on the substrate. Furthermore, recycling could decrease nutrients both applied as well as discarded, reducing input by 53% and, more importantly, eventual nitrate pollution by up to 76% in relation to open system culture.

Fandi et al. (2008) mentioned that open soilless system using tuff as a substrate may be suitable for tomato production without dramatic changes in yield or fruit quality and It is concluded that open soilless culture system using tuff substrate may save about 65-70% of water applied by conventional farmers for tomato under plastic house.

Furthermore, when tomato plants were grown in different soilless substrates, fruit quality was comparable to those grown in soil culture (Celikel, 1999). However, under greenhouse conditions, tuff resulted in higher tomato yield than soil (Abak and Celikel, 1994).

Salas et al. (2005) findings, who noticed that no significant differences were observed among the nutrient solutions studied for the quality parameters of fruit diameter and fruit firmness. Additionally, Paraskevopoulou et al. (1996) found that soil and soilless cultures did not affect the fruit firmness. When we consider fruit chemical quality, Siomos et al. (2001) found that soilless culture gave higher citric acid percentage in comparison with soil culture.

The effects on yield and radial fruit cracking of 2 media (soil in beds and soilless medium in bags) and 2 drip-irrigation frequencies (once and 4 times daily) were determined for 4 greenhouse tomato (*Lycopersicum esculentum* L. Mill.) cultivars (Abbott et. al., 1986). Abbott et al. (1986) mentioned that the amount and severity of fruit cracking was least from the soilless, bag-cultured plants. Total mean fruit weight was greatest from soil-grown plants. Although no differences in cracking occurred in the fruit from soil-less, bag-cultured plants, those whose irrigation was based on soil-less medium tensiometer readings produced lower total mean fruit weight than those whose irrigation was based on soil tensiometer readings.

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 glasshouse conditions in the Mediterranean Region of Turkey.

MATERIALS AND METHODS

The research was conducted in a glasshouse at the Alata Horticulture Research Institute, southwest of Mersin in Turkey (36° 36'N, 34° 20'E) in 1998. This area has a typical Mediterrenaen climate, which is characterized by hot and dry conditions during summer and mild and rainy during winter period. The glasshouse, oriented in north- south direction, was 30 m by 40 m in size. Climate conditions inside glasshouse were adjusted via computer controller. The central heating system was used to control the greenhouse interior temperature over 12^{o}C at night and 22^{o}C at day time. Relative humidity was kept between 70-80% during the growing season of tomato.

The experiment was conducted on 3 different soilless culture materials namely ash, peat, ash+peat (1:1) in open-bag culture. Polyethylene black plastic bags with dimensions of 2.40 m x 0.50 m x 0.20 m were used for filling the culture materials. Two rows of concrete blocks were placed at the bottom of plastic bags with a slope of 5% to drain excess water and upper part of the bag was covered completely with clear plastic and prevent the contact of culture material with soil. Ash, peat and ash+peat (1:1) were put in plastic bags and tomato seedlings were planted on it. Since the drainage from the bags was negligible, no measurement on drainage water was carried out.

Inorganic ash material has a total porosity of 71.3%, and water holding capacity of 16.8%, its pH is between 7 and 8, and has low cation exchange capacity. Some physical and chemical features of these materials are displayed in the Table 1.

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 inside the glasshouse) were considered in this study. A drip irrigation system was used for irrigating the tomato plants grown in the plastic bags filled with growth materials. Each plactic bag, 3 drippers provided irrigation water. Irrigations continued until one week before the final harvest. One drip lateral served each plant row. In- line emitters with discharge rate of 2.0 Lh^{-1} at 0.40 m spacing on lateral were used.

Table 2. The amount of fertilizers and micro nutrient solutions applied in tomato cultivation in different levels of irrigation water applications in soilless culture bag system

Fertilizers	Solutions
Amonium nitrate (33%), ml	165/230
Phosphoric acid (67%), ml	90
K_2SO_4 (52%), ml	200
KNO_3 (13-0-46%), ml	200
$MgSO_4$ (10%), ml	500
Sequestren (6%), ml	16
Micro nutrient solutions, ml	150
- $MnCl_24H_2O$, mg/150ml	2.25
- H_3BO_3, mg/150ml	2.50
- $ZnSO_47H_2O$ mg/150ml	0.39
- $CuSO_45H_2O$, mg/150ml	0.12
- $Na_2MoO_4H_2O$, mg/150ml	0.05

To determine the amount of irrigation water, daily evaporation values were obtained from the Class A pan located inside the glasshouse. Two different irrigation frequency (once a day or twice a day) was used. The single daily application was made at 9:^{00} a.m.; and the twice a day applications were carried at 9:^{00} a.m. and at 15:^{00} p.m. Irrigations continued until one week before the final harvest. Irrigation water was supplied 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 replica-replications. Main plots, subplots and sub-subplots were assigned to substrate, irrigation frequency and irrigation levels, respectively. Subplot dimensions were 0.50 m by 2.40 m at planting. The tomato variety Fantastic-144 was used in this study. Three tomato seedlings were transplanted on each bag so that each plot contained a total of 6 plants. Tomato seedlings with 6 leaves were transplanted into the bags in the glasshouse on January 21, 1998 and fertilizer application together with irrigation commenced.

Water soluble fertilizers were used in this experiment. The amount of fertilizer was distributed equally among the plots by fertigation using a ventury type injection system. Fertilizer at the same concentration was applied until one week from final harvesting. The fertilizer solution was prepared using 125 mg l^{-1} N, 30 mg l^{-1} P and 200 mg l^{-1} K. The pH of the nutrient solution was 5.0-5.5 (Abak and Celikel, 1994). Nutrition of plants were done according to the Jensen and Collins (1985). Calcium-containing fertilizers are not used because irrigation water has enough calcium. All the macro-micro nutrients in the solutions were given in Table 2. 165 ml Amonium Nitrate (33%) was applied until the beginning of the flowering stage, and then 230 ml was used until harvest. The EC value of nutrient solution was kept between 1.8-2.0 dS/m until the first fruit setting, and then changed between 2.5-3.0 dS/m until the harvest period. The pH of the solution was maintained between 5-5.5 during the growing season of tomato.

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 (Anonymous, 1995). Fruits were classified by fresh weight and grouped as: 1st (> 125g), 2nd (90- 125g) and 3rd (< 90g). Early yield, total yield, first, second and third quality yield, fruit weight and fruit number per unit area were measured. The effects of quality on yield, acidity, pH, vitamin C, Total Soluble Solids (TSS) were also evaluated. TSS was determined with refractometer. Irrigation water use efficiency (IWUE) values were calculated as the ratio of yield obtained from each treatment to total irrigation applied to treatment. After the variance analysis, main factors and interactions were groupped according to the Duncan test (5%). MSTATC and SPSS statistical programs were used.

RESULTS AND DISCUSSION

Table 3 shows the interactions of the substrates, irriga-tion frequencies and irrigation levels in relation to yield and quality characteristics. Statistical analysis indicated that growth medium, pan coefficient and irrigation fre-quency interactions were significantly different at 1% level for each parameter considered. Various combina-tions of treatments produced different results for each characteristic. For example, the best result for early yield was obtained with peat material, and with once daily water application and WL_1. First and second quality yields 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 mixture (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_4 irrigation level. Highest average fruit weight was also measured in the ash+peat (1:1) culture material. However, it seems that ash produced higher fruit weight than peat. Statistical analysis of fruit weight data indicated that the effect of culture materials on fruit weight was significantly different ($P_{0.05}$). Ash+peat (1:1) 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 134.1 and 185.0 fruits m^{-2}. Average fruit weight values varied from 128.5 to 144.9 g (Table 3).

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).

The effects of substrate x irrigation frequency x irriga-tion level interactions on some fruit quality parameters are presented in Table 4. Statistical analysis indicated that growth medium x pan coefficient x irrigation fre-quency interaction was significant for TSS and ranged from 4.00 to 4.38%. Acidity was significant for each irriga-tion level, and ranged from 0.40 to 0.45 g 100 ml^{-1}. Pan coefficient x irrigation frequency interaction was signifi-cant for pH; and once a day WL4 was in the first, twice a day WL4 was in the second group, the rest of the treatments were in the third group. Growth medium x pan coefficient interaction for vitamin C was significant, and ranged from 18.00 to 18.25 mg 100 ml^{-1}.

Increasing the irrigation amounts resulted in increased total yield in general, but decreased total soluble solids. The minimum total soluble solids was obtained with WL_3 and WL_4 irrigation levels for each culture material. Similar results were obtained by Tüzel et al. (1994b). Warner et al

Table 3. Tomato yield according to irrigation frequencies, irrigation levels and culture media.

Culture materials	Irrig. freq.	Irrig. level	Yield Quality, ($kg\ m^{-2}$) Quality 1 **	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	9.95 FG	7.15 I	4.20 DE	137.0 HI	135.8 BCDEF	18.60 IJ
		WL_2	10.73DE	7.05 I	4.43 BCDE	141.9 GHI	136.3 BCDEF	19.35 HI
		WL_3	11.05 D	8.13 FG	4.38 CDE	151.9 EFG	136.6 ABCDEF	20.75 F
		WL_4	10.65 DE	8.100 FG	4.40 CDE	149.1 FG	136.1 BCDEF	20.27 FG
	Twice a day	WL_1	10.73 DE	8.225 EFG	4.43 BCDE	159.8 DE	129.6 DEF	20.73 F
		WL_2	11.93 C	8.88 CD	4.50 ABCD	161.8 DE	137.6 ABCDE	22.25 DE
		WL_3	12.20 BC	9.08 BCD	4.50 ABCD	160.0 DE	142.4 AB	22.70 D
		WL_4	11.92 C	7.875 G	4.58 ABC	155.5 DEF	139.7 ABC	21.70 E
Peat	Once a day	WL_1	8.20 I	6.93 I	4.75 A	135.0 I	128.5 F	17.35 K
		WL_2	8.95 H	7.23 HI	4.55 ABC	142.5 GHI	129.0 F	18.38 J
		WL_3	11.05 D	8.13 FG	4.38 CDE	151.9 EFG	136.6 ABCDEF	20.75 F
		WL_4	10.32 EF	6.88 I	4.23 DE	146.9 FGH	132.3 CDEF	19.42 HI
	Twice a day	WL_1	8.30 I	6.90 I	4.20 DE	134.1 I	129.3 EF	17.33 K
		WL_2	9.68 G	7.88 G	4.55 ABC	144.3 GHI	138.7 ABC	19.77 GH
		WL_3	9.48 G	7.75 GH	4.55 ABC	147.3 FGH	131.3 CDEF	19.33 HI
		WL_4	10.32 EF	6.88 I	4.18 E	146.9 FGH	132.3 CDEF	19.42 HI
Ash+Peat	Once a day	WL_1	12.60 B	8.63 DEF	4.58 ABC	165.1 CD	137.9 ABCD	22.77 D
		WL_2	13.82 A	8.65 DEF	4.58 ABC	165.1 D	144.9 A	23.88 C
		WL_3	13.88 A	8.78 CDE	4.73 AB	174.4 BC	139.1 ABC	24.27 C
		WL_4	14.18 A	9.58 AB	4.58 ABC	181.3 AB	139.9 ABC	25.35 AB
	Twice a day	WL_1	12.45 B	8.20 EFG	3.45 F	160.2 DE	138.4 ABC	22.17 DE
		WL_2	12.45 B	8.20 EFG	3.50 F	160.2 DE	138.4 ABC	22.17 DE
		WL_3	13.95 A	9.30 BC	3.63 F	177.3 AB	139.4 ABC	24.68 BC
		WL_4	14.02 A	10.10 A	3.40 F	185.0 A	138.6 ABC	25.65 A

* and ** indicate statistical significance at $P_{0.05}$ and $P_{0.01}$ level, respectively

al. (2004) studied the effect of regulated deficit drip irrigation on tomatoes and concluded that total soluble solids (%) was negatively affected by irrigation water quantity. The water applied had a significant effect on the concentration of total soluble solids. Similar observations were reported by Sanders et al. (1989) and Machado and Oliveira (2005).

The total amounts of irrigation water applied (from transplantation to harvest) in the irrigation levels in this study were 188 mm in WL_1, 250 mm in WL_2, 313 mm in WL_3 and 375 mm in WL_4 (Table 5). 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 IWUE value of 121.4 kg m^{-3} was for once a day WL_1 with peat+ash (1:1) followed by for twice a day WL_1 with peat+ash as 118.2 kg m^{-3} and the least was for twice a day WL_4 in peat as 51.8 kg m^{-3} (Table 5) IWUE 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 IWUE values for the same irrigation level. Peat and ash mixture (1:1) provided better soil water environment for tomato growth. Castilla (1996) reported IWUE values of 34 kg m^{-3} for greenhouse tomato production in soil, but in soilless culture, the IWUE value was 29 kg m^{-3}. However, in controlled greenhouses IWUE of tomato may reach 65 kg m^{-3}. Tüzel et al. (1994a) reported IWUE values ranging from 21.05 to 62.46 kg m^{-3}.

Conclusions

This work showed that optimum amount of irrigation was 1.50 times of the daily Class A pan evaporation (E_{pan}) value for twice a day irrigation for ash + peat (1:1) culture material under glasshouse conditions in the Mediterranean Region of Turkey. However, considering water savings, lower pan coefficients during the early and later growing seasons can be utilized.

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

Table 4. Some fruit quality parameters according to irrigation frequencies, irrigation levels and culture media.

Culture materials	Irrigation frequency	Irrigation level	Acidity** (g 100ml^{-1})	TSS**, (%)	pH**	Vitamin C* (mg 100g^{-1})
Ash	Once a day	WL_1	0.44 A	4.10 D	5.10 C	18.12 AB
		WL_2	0.43 AB	4.38 A	5.00 C	18.01 C
		WL_3	0.42 B	4.10 D	5.00 C	18.00 C
		WL_4	0.41 B	4.03 E	5.30 A	18.00 C
	Twice a day	WL_1	0.44 A	4.15 CD	5.00 C	18.15 AB
		WL_2	0.43 AB	4.15 CD	5.00 C	18.00 C
		WL_3	0.42 B	4.13 D	5.00 C	18.00 C
		WL_4	0.41 B	4.00 E	5.20 B	18.00 C
Peat	Once a day	WL_1	0.44 A	4.15 CD	5.00 C	18.13 A
		WL_2	0.43 AB	4.25 B	5.00 C	18.10 AB
		WL_3	0.42 B	4.10 D	5.00 C	18.01 C
		WL_4	0.42 B	4.00 E	5.30 A	18.00 C
	Twice a day	WL_1	0.44 A	4.20 BC	5.00 C	18.25 A
		WL_2	0.43 AB	4.25 B	5.00 C	18.15 AB
		WL_3	0.41 B	4.15 CD	5.00 C	18.00 C
		WL_4	0.41 B	4.00 E	5.20 B	18.00 C
Ash+Peat	Once a day	WL_1	0.45 A	4.20 BC	5.00 C	18.00 C
		WL_2	0.43 AB	4.23 B	5.00 C	18.06 BC
		WL_3	0.41 B	4.15 CD	5.00 C	18.00 C
		WL_4	0.40 B	4.00 E	5.30 A	18.00 C
	Twice a day	WL_1	0.44 A	4.25 B	5.00 C	18.00 C
		WL_2	0.43 AB	4.13 D	5.10 C	18.10 BC
		WL_3	0.41 B	4.00 E	5.00 C	18.00 C
		WL_4	0.41 B	4.10 D	5.20 B	18.00 C

* and ** indicate statistical significance at $P_{0.05}$ and $P_{0.01}$ level, respectively

Table 5. Irrigation water use efficiency values for irrigation frequencies, irrigation levels and culture media.

Culture materials	Irrigation frequency	Irrigation level	Total Yield (kg m^{-2})	Total Irrrigation (mm)	IWUE (kg m^{-3})
Ash	Once a day	WL_1	18.60	187.6	99.1
		WL_2	19.35	250.1	77.4
		WL_3	20.75	312.6	66.4
		WL_4	20.27	375.1	54.0
	Twice a day	WL_1	20.73	187.6	110.5
		WL_2	22.25	250.1	89.0
		WL_3	22.70	312.6	72.6
		WL_4	21.70	375.1	57.9
Peat	Once a day	WL_1	17.35	187.6	92.5
		WL_2	18.38	250.1	73.5
		WL_3	20.75	312.6	66.4
		WL_4	19.42	375.1	51.8
	Twice a day	WL_1	17.33	187.6	92.4
		WL_2	19.77	250.1	79.0
		WL_3	19.33	312.6	61.8
		WL_4	19.42	375.1	51.8

Table 5. Contd.

Ash+Peat	Once a day	WL_1	22.77	187.6	121.4
		WL_2	23.88	250.1	95.5
		WL_3	24.27	312.6	77.6
		WL_4	25.35	375.1	67.6
	Twice a day	WL_1	22.17	187.6	118.2
		WL_2	22.17	250.1	88.6
		WL_3	24.68	312.6	79.0
		WL_4	25.65	375.1	68.4

produced the least tomato yield. Since the cost of peat is higher than ash in the region since it is brought from a distant location (North west region of Turkey) in the country, the usage of the mixture of ash and peat (1:1) is recommended for higher tomato yield. Our results suggest that ash+peat (1:1) may decrease production cost and increase tomato yield and quality under glasshouse conditions described in this work. The development of soilless cultivation in Turkey depends on finding a suitable and cheap substrate material. 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. Soilless culture in greenhouses would expect to gain significance in the near future due to soil degradation and pollution. Therefore, qualified agricultural engineers and specialist would be required for disseminating the soilless culture production.

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