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COMPARISON OF WATER PILLOW AND DRIP IRRIGATION SYSTEMS FOR TOMATO (*LYCOPERSICON ESCULENTUM* MILL.) PRODUCTION UNDER GREENHOUSE CONDITIONS IN THE MEDITERRANEAN REGION OF TURKEY

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Abstract

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This study compared the effects of the Water Pillow (WP) irrigation method, a new alternative method to Drip Irrigation (DI), and of different irrigation interval on growth, yield and quality of tomato (*Lycopersicon esculentum* Mill.) under greenhouse conditions in the Mediterranean Region of Turkey in 2011 growing season. The treatments were as follows: (i) WP method with a 3-day irrigation interval (WP1), (ii) WP method with a 6-day irrigation interval (WP2), (iii) WP method with a 9-day irrigation interval (WP3) and (iv) Drip Irrigation (DI) method with a 3-day interval (control). There were no statistical differences in growth and yield of tomato plants between DI and WP1 treatments ($P<0.05$). Irrigation intervals of WP method had significantly different effect in total yields and marketable yields. Maximum and minimum total yields were obtained from WP1 and WP3 treatments; 3.70 kg plant^{-1} and 2.8 kg plant^{-1}, respectively. By comparing WP with DI, we concluded that the advantages of WP were maintaining the water amount in the root area by decreasing evaporative losses from the soil surface due to its mulching effect, and it also produced the same yield as DI in the greenhouse tomato production.

Keywords: water pillow; drip irrigation; tomato; greenhouse; Mediterranean Region
List of abbreviations: WP – Water Pillow; DI – drip irrigation; WP1 – the subject of Water Pillow with 3 day irrigation interval; WP2 – the subject of Water Pillow with 6 day irrigation interval; WP3 – the subject of Water Pillow with 9 day irrigation interval; I – the amount of irrigation water, mm; FC – the field capacity, P_w%; PWP – the permanent wilting point, P_w%; E.C. – the electricity conductivity, dS m^{-1}; OM – the organic matter, %; SAR – the sodium adsorption ratio, %; A – the plot area, m^2; E_{pan} – the cumulative evaporation in irrigation intervals, mm; K_p – the pan coefficient; LAI – the leaf area index, m^2 m$^{2\ -1}$; Ir. int. – the irrigation interval, days; PH – the plant height, cm; SD – the stem diameter, mm; VPFW – vegetative part fresh weight, g; VPDW – vegetative part dry weight, g; VPDR – vegetative part dry ratio, %; RFW – the root fresh weight, g; RDW – root dry weight, g; RDR – root dry ratio, %; TY – the total yield, kg plant^{-1}; MY – the marketable yield, kg plant^{-1}; UMY – the unmarketable yield, kg plant^{-1}; FN – the fruit number; AFW – the average fruit weight, g; 1CFR – the 1st class fruit ratio, %; 2CFR – the 2nd class fruit ratio, %; 3CFR – the 3rd class fruit ratio, %; DFW – the dry fruit weight, %; TA – the titratable acidity, mval 100^{-1} ml^{-1}; TSS – the total soluble solids, %; *chl a* – the chlorophyll a; *chl b* – the chlorophyll b; Total *chl* – the total chlorophyll; *ns* – not significant

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Introduction

The world is facing a serious global warming that significantly increases the evaporative demand and the irrigation requirement for crops (Gercek et al., 2009a). For this reason, in agriculture, concern of newer and more efficient irrigation methods is in demand (Gercek et al., 2009b). Therefore, it is necessary to adopt specialized and efficient methods of irrigation, such as drip irrigation, partial root drying (PRD) technique (Kirda et al., 2004) and subsurface drip irrigation (Amore and Amore, 2007), in order to achieve the twin objectives of higher productivity and optimum use of water. Along with drip irrigation, use of mulching provides many advantages, such as increasing yield and quality, decreasing water lost from the soil surface, increasing soil temperature and reduction of weed growth (Antony and Singandhupe, 2004). Ironically, in semi-arid climatic regions, farmers tend to prefer traditional irrigation methods (uncontrolled flooding, border strip method, check method etc.) which require more water to modern irrigation methods such as drip irrigation or Water Pillow. Expensive initial investment costs of modern irrigation methods, and lack of skilled irrigators, and so many other reasons put the farmers off using more efficient irrigation systems (Gercek et al., 2009b).

Some studies have shown that higher tomatoes yields are obtained by drip irrigation compared to other irrigation methods. Tekinel et al. (1989) compared drip irrigation and conventional irrigation methods for tomatoes in the Cukurova Region in Turkey and obtained the highest yield and water use efficiency (WUE) with drip irrigation. Jadhaw et al. (1990) tested drip and furrow methods for tomatoes. Tomatoes yields were 48 t ha^{-1} for drip irrigation systems with pressure-compensating emitters and 32 t ha^{-1} when furrow irrigation was used. Kadam (1993) compared the effects of furrow, sprinkler and drip irrigation methods on the growth of tomatoes and drip irrigation resulted in the highest plant leaf area and fruit yields.

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; Tuzel et al., 1994). 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 physiological disorders such as blossom end rot of tomato fruit (Sezen et al., 2010).

Many researchers stated that drip irrigation accompanying with black plastic mulches in vegetable production have many beneficial effects such as conserving the soil moisture, suppressing weed growth, moderating soil temperature, and increasing yields (Singh et al., 2009).

The Water Pillow (WP) is a new irrigation method that combines drip irrigation and mulch, and offers a number of unique opportunities to save water as well as alleviating some problems, such as low irrigation efficiency, erosion and weed control and benefits including saving water from evaporation (Gercek, 2005). WP irrigation can be used to irrigate crops grown in rows, such as soybean (*Glycine max*) and corn (*Zea mays*) (Gercek et al., 2009a). The main components of WP are portable black polyethylene pipes, and laterals. The pipe is elastic, and should be usable for at least 2 years. The diameter of the pipe should almost cover the row spacing; in this way, the water content in the root zone in the intervals between irrigation and the maximum mulching effect throughout the growing season can be sustained (Gercek et al., 2009b). The method is new, and detailed studies would be required to refine the system.

The objective of this work was to examine the efficiency of this newly developed method, WP, with different irrigation intervals and to compare with drip irrigation (DI) on growth, yield, and quality of tomatoes grown under plastic greenhouse in Mediterranean climatic conditions of Turkey.

Materials and Methods

This study was carried out in experimental plastic greenhouse at the Ortaca Polytechnic of Mugla Sitki Kocman University ($36^0 50^/ 48^{//} 60$ N, $28^0 44^/ 34^{//} 68$ E) in period of 2010-2011. Jadelo F1 (Vilmorin, France) hybrid tomato (*Lycopersicon esculentum* Mill.) variety was used. The climate in the region is a typical Mediterranean climate. The greenhouse was not heated. The Dalaman Meteorological Station climate data, very close to the research field, are given in Table 1.

Texture of the soil of research area was sandy-clay. Some of the relevant physical and chemical characteristics of the greenhouse are given in Table 2. The amount of irrigation water, measured by a water meter with 0.0001 m^3 sensitivity connected to the output of the pipe, was channeled to each required row. The results of the irrigation water analysis are provided in Table 3. According to the results of the analysis, the irrigation water, does not have any problem except the strong alkaline, is C1S1 classification and safe to use for irrigation.

Tomato seedlings for the experiment were produced by a commercial company (Histhil-Toros Fidecilik AŞ, Antalya). Four weeks old seedling of tomato were transplanted by

Table 1
The climatic values of the Dalaman Meteorological Station

Months	Rain, mm	Temperature, °C	Relative Humidity, %	Wind speed, m s^{-1}	Sunshine duration hr, min.
January	204.1	10.1	72	2.2	05:03
February	127.3	10.4	70	2.4	05:44
March	99.0	12.2	73	2.4	06:56
April	53.9	15.4	74	2.3	07:52
May	25.8	20.0	71	2.3	09:34
June	5.9	24.8	63	2.7	11:22
July	1.3	27.4	64	2.6	11:43
August	0.7	27.1	67	2.3	11:15
September	4.6	23.6	68	2.1	10:02
October	61.6	19.2	71	1.9	07:57
November	160.6	14.5	74	1.9	06:03
December	232.9	11.4	74	2.0	04:45
Average	977.7	18.0	70	2.3	08:12

Table 2
Soil analysis results of the research area

Depth (cm)	Texture	Weight, g/cm^3	FC	PWP	pH	OM	E.C.	P_2O_5, kg da^{-1}	K_2O, kg da^{-1}	$CaCO_3$, %
0-30	SCL	1.45	23	13	8.2		0.72			16.33
30-60	SCL	1.39	30	11	8.2	1.25	0.41	11.45	83.92	16.56
60-90	SL	1.43	23	15	8.4		0.32			14.84

Table 3
The results of the irrigation water analysis

Irrigation water classification	E.C.	pH	Cations, me l^{-1}				Anions, me l^{-1}				Na %	SAR %	B me l^{-1}
			Na^+	K^+	Ca^{++}	Mg^{++}	$CO_3^=$	HCO_3^-	Cl^-	$SO_4^=$			
C1S1	0.62	8.31	0.32	0.00	0.75	6.13	0.00	0.42	0.53	1.70	4.59	0.17	0.13

Table 4
The first and last harvest dates, and plant varieties of the planting experiments

Period	Plant Variety	Planting date	First harvest date	Last harvest date
Spring	Jadelo F1	21/02/2011	26/04/2011	23/06/2011

hand on double rows, 90 cm apart between double rows, 60 cm apart between row and with 50 cm apart between plants, corresponding to (90*60*50 cm) 3704 plants ha^{-1}. Fertilizers were applied as recommended by Sefa and Oruc (1990). Thirty percent of the macro-nutrient requirements and 100% of the micro-nutrient requirements were supplied at planting. The remaining fertilizer, which contained nitrogen, phosphorus, potassium was applied by fertigation 3 or 4 times. The plant maintenance work in the study was carried out according to Sevgican (2002). Planting/harvest dates and plant varieties used in the experiments are presented in Table 4.

The research has the subjects that three different irrigation interval plots of WP and DI (WP1: 3 days, WP2: 6 days, WP3: 9 days and DI: 3 days). The experiments were arranged using a factorial randomized plot design with 3 replications. The width and length of the plots were 3 m by 5 m and in each plot 4 rows were prepared. In total, 40 seedlings were planted in each plot. Following the planting, an amount of irrigation water was applied to the plots to bring the soil to the normal soil capacity; Kanber's (1984) principles were used in the calculation of the irrigation water amount by including the issue of open surface water evaporation pan (Equation 1).

$$I = A \times E_{pan} \times K_p \quad (1)$$

In order to determine the values of evaporation in the greenhouse, a class A evaporation pan was placed in the middle of the greenhouse. The evaporation values were measured in the irrigation intervals. Pan coefficient was taken as 0.3, 0.9 and 1.2 according to the plant development phase. In the all of experimental subjects, 341.9 mm irrigation water was applied. In the plots where the drip irrigation method was applied, 25 cm dripper distance and 4 l/h fixed flow rate lateral line in each seedlings row were applied. In order to determine the effects on plant growth in the experiments, plant height, stem thickness in harvest, plant's fresh and dry weight and leaf area index (LAI m^2leaves m^{-2} ground) were measured. Leaf area index (LAI) was measured on cut-plant samples.

Harvested fruits were weighed and counted to determine the fruit yield and the number of fruits per plant. Yield has been classified as total and marketable (fruit weight above the 3.5 cm fruit diameter, without physiological disorders as blossom end rot). Average fruit weight (g) and fruit classification were examined in order to find out the effect on yield in the experiments. Fruit quality parameters determined in the homogenized fruit juice samples were EC (dS m^{-1}), pH, titratable acidity (TA) (mval 100^{-1} ml^{-1}) and total soluble solids (TSS) content. TSS was determined by an Atago N-1E refract meter at 20°C. Titratable acidity was analyzed by potentiometric titration with 0.1 N NaOH to pH 8.5, using 10 ml of fruit juice. Fruit dry matter (%) was determined after drying for 72 h at 65°C in an oven. After 45 days at the start of irrigation practices, leaf *chlorophyll* (*chl a*, *chl b*) was determined according to Strain and Svec (1966). Statistical analysis (like LSD, SD etc.) was performed by TARIST statistical program developed by Ege University (Acikgoz et al., 1994).

Results and Discussion

Increasing the irrigation interval had a negative impact on the plant growth. Decreases in values were determined in the plant height and stem diameter, fresh and dry stem weights, fresh and dry root weights. The maximum plant growth was obtained from DP and WP1 treatment, followed by WP2 and WP3. In drip irrigation and WP1 treatment produced the highest plant and stem diameter, however, in WP3 treatment produced the lowest value.

WP1 treatment presented the highest values not only in dry stem weight (14.44%) but also in dry root weight (10.35%). WP3, however, presented the lowest values as in dry weight of stem (11.60%) and root (8.68%) (Table 5).

Increasing the irrigation interval, created a water stress to the plant and moreover this negatively affected the vegetative parts as well as the root development of the plant. The first signs of water stress in plants are insufficient shoot development, less elongation and root development, and reduction in fresh and dry stem weight (Shao et al., 2008). Sanchez-Blanco et al. (2002), Ozturk et al. (2004), Unyayar et al. (2005) and Guzel (2006) reported that water stress reduces plant height and development. These researchers also reported that the water stress may slow the growth by inhibiting cell development. Behnamnia et al. (2009), in their research, also highlighted a decrease in length of plant stem and cell, and weight of fresh and dry root and stem in open-field tomato plantations with dry conditions.

Under water stress conditions, root development is more important than stem for the plant. Plants, when exposed to water stress conditions during vegetation, display an underperformed potential in cell mechanisms and growth (yield, shoot length, etc.) (Osmond et al., 1987).

Leaf area index is an important criterion in plant growth. The difference in the dry matter production due to different treatments can be ascribed to the leaf area production. From 40 days after planting, leaf areas began to differ according to the applications and in 60 days it became increasingly more evident. Hundred days after planting, the highest value of leaf area 2.85 m^2 m^{-2} was achieved with the WP1 treatment and this was followed by DI treatment value, 2.78 m^2 m^{-2}. The lowest value was obtained as 1.98 m^2 m^{-2} from WP3 treatment. The difference in leaf area between WP1 treatment and WP3 treatment was about 30.64% (Figure 1). Increasing of irrigation intervals created stress to the plants. There are several studies (Thakur and Kaur 2001, Bhatt et al. 2002, Karam et al., 2002, Garcia-Sanchez et al., 2004) emphasizing a decrease in leaf area of different plants under

Table 5
The effect of irrigation practices on plant growth parameters

Experiment	Ir. int.	PH	SD	VPFW	VPDW	VPDR	RFW	RDW	RDR
WP	3	180.5 a	9.80 a	988.4 b	142.0 b	14.4 a	75.8 ab	7.8 a	10.4 a
	6	172.7ab	9.46 b	957.5 b	129.5 c	13.5 a	73.1 bc	6.9 b	9.5 b
	9	165.5 b	9.22 b	981.8 b	113.7 d	11.6 b	70.2 c	6.2 c	8.7 c
DI	3	182.0 a	9.88 a	1107.0 a	159.5 a	14.4 a	77.4 a	7.9 a	10.2 ab
$LSD_{0.05}$		9.98**	0.30**	57.38 **	9.33**	0.95 **	4.13 **	0.36**	0.82**

Different letters in each column represent significant differences at $P < 0.05$, based on LDS test. ns: not significant ; WP: Water Pillow; DI: Drip irrigation; PH: plant height; SD: stem diameter; VPFW: vegetative part fresh weight; VPDW: vegetative part dry weight; VPDR: vegetative part dry ratio; RFW: the root fresh weight; RDW: the root dry weight; RDR: root dry ratio water stress conditions and these findings are also consistent with our own results. Garcia-Sanchez et al. (2007) studied the development effect parameters of tomato due to the use of different concentrations of nitrogen under moderate water stress conditions, and concluded a decrease intake of nitrogen resulted in slow development and low leaf area. According to this result, in WP3 treatment, a decrease in plant development and leaf area may be caused by a decreased nitrogen intake.

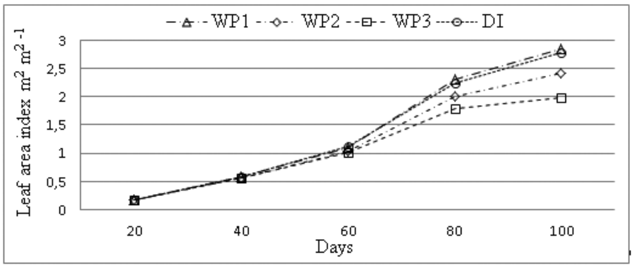

Fig. 1. Measurements of leaf area index in 20 days interval

The effect of irrigation practices on total yield, unmarketable yield, total fruit number, average fruit weight and fruit classification were found significant. In the unmarketable yield, the highest lost occurred in WP3 treatment caused by Blossom end rot and this was interpreted as a sign of some kind of stress, e.g. by soil water deficit, high salinity. WP1 and DI treatments reached the highest value in terms of total yield, total fruit number, average fruit weight and 1st class fruit ratio. In these parameters, the lowest values were obtained from WP3 treatment. As for the unmarketable yield, the highest value was reached at 0.5 kg/plant in WP3 treatment (Table 6).

Several studies (Bhatti et al., 2000; Kirnak et al., 2002; Nahar and Gretzmacher, 2002; Karam et al., 2002; Karipçin, 2009) have shown that tomato and other plant species (aubergine, lettuce and water melon) under drought and water stress conditions reduce the yield and result in an increase in the unmarketable yield. Kirda et al. (2004) reported an increase in the unmarketable yield of deficit irrigation caused by water stress and due to this water stress 2nd class fruit ratio reached a higher level.

In the study, dry weight of fruit, EC and pH values of the fruit juice, TA and TSS as fruit quality parameters were also investigated. Results related to fruit quality are portrayed in Table 7. İrrigation intervals did not cause any significant changes on EC and pH of fruit juice. However, the increase in irrigation intervals showed dry weight of fruit, TA and TSS values significantly increased.

Table 7
The effect of irrigation practices on fruit quality

Experiments	Ir. int.	DFW	EC	pH	TA	TSS
WP	3	4.53 b	4.55	4.25	5.28 b	4.07 c
	6	4.65 b	4.65	4.21	5.45 ab	4.21 b
	9	4.97 a	4.86	4.16	5.60 a	4.49 a
DI	3	4.53 b	4.51	4.30	5.29 b	4.03 c
$LSD_{0.05}$		0.25**	ns	ns	0.208*	0.08*

Different letters in each column represent significant differences at P < 0.05, based on LDS test. ns: not significant; WP: Water Pillow; DI: Drip irrigation; DFW: dry fruit weight; EC: electricity conductivity; TA: titratable acidity; TSS: total soluble solid

Amore and Amore (2007) and Kirda et al. (2004) reported that tomato in deficit irrigation applications showed an increase in water stress and also an increase in values of dry fruit weight, TA and TSS. Increase in dry matter was related to the increase in sugar as a result of photosynthesis and decrease in amount of fruit juice (Ho, 1988). Photosynthesis metabolism plays a crucial role in plants' development. The amount of total *chlorophyll*, *chlorophyll a* and *chlorophyll b* is an important data in determining the effectiveness of photosynthetic metabolism (Krause and Weis, 1991). Our study identified a reduction in the amount of *total chlorophyll, chlorophyll a and chlorophyll b* as an effect of irrigation interval (Table 8). One of the earliest responses against limited

Table 6
The effects of irrigation practices on yield values

Experiment	Ir. int.	TY	MY	UMY	FN	AFW	1CFR	2CFR	3CFR
WP	3	3.7 a	3.38 a	0.33 c	26.2 a	143.8a	54.7ab	21.3b	11.3
	6	3.5 b	3.03 b	0.42 b	25.7 a	134.4a	50.6b	24.4b	11.4
	9	2.8 c	2.29 c	0.50 a	23.7 b	118.2b	39.7c	30.2a	13.4
DI	3	3.7 a	3.39 a	0.32 c	26.5 a	140.4a	58.7a	20.2b	9.3
$LSD_{0.05}$		0.212^{**}	0.061^{**}	0.228^{**}	1.92^{**}	11.45^{**}	5.52^{**}	4.70^{**}	ns

Different letters in each column represent significant differences at P < 0.05, based on LDS test. ns: not significant; WP: Water Pillow; DI: Drip irrigation; TY: total yield; MY: marketable yield; UMY: unmarketable yield; FN: fruit number; AFW: average fruit weight; 1CFR: the 1st class fruit ratio; 2CFR: the 2nd class fruit ratio; 3CFR: the 3rd class fruit ratio water condition is stomatal closure that limits CO_2 diffusion towards chloroplasts.

Table 8

The effect of irrigation practices on leaf chlorophyll a (chl a), chlorophyll b (chl b) and total chlorophyll

Experiments	Ir. int.	*chl a*	*chl b*	Total *chl*
WP	3	1632.8 a	730.0 a	2362.6 a
	6	1448.9 b	660.2 b	2109.2 b
	9	1204.7 c	643.6 b	1848.3 c
DI	3	1647.5 a	722.3 a	2369.8 a
$LSD_{0.05}$		79.24 **	40.29**	98.03**

Different letters in each column represent significant differences at $P < 0.05$, based on LDS test. ns: not significant; WP: Water Pillow; DI: Drip irrigation; *chl a:* chlorophyll a; *chl b:* chlorophyll b: Total *chl:* total chlorophyll

Photosynthesis takes place in chloroplasts from beginning to end; a reduction in the amount of *chlorophyll a* and *chlorophyll b* and total *chlorophyll* affects photosynthesis negatively. Inhibition of photosynthetic electron chain reactions can cause forming active oxygen species, particularly singlet oxygen which can lead to photo oxidative damage (Dat et al., 2000).

These free radicals, which are the molecules with highly reactive electrons, may occur damage within the photo system II (PS II). (Kalefetoglu and Ekmekci, 2005; Shao et al., 2008). In line with the decrease in photosynthesis the plant growth slows down too. A decrease in chlorophyll content of different plants due to water stress was reported in the literature as follows: aubergine, Kirnak et al. (2002); tomato, Zgalli et al. (2005 and 2006); broad bean, El-Tayep (2006); soybean, Ohashi et al. (2006); corn, Koskeroglu (2006); water melon, Ozmen (2009) and Karipçin (2009).

Conclusions

According to the results of this study, firstly, there was no statistical difference significant between the Water Pillow (WP1) and Drip Irrigation (DI) 3 day's interval on the parameters of plant growth and yield. Further, no stress sign on the tomato plant throughout the growing season was observed. Therefore, higher and better quality tomato yield was obtained especially from WP1 and DI treatment. The new irrigation method, WP, had a number of advantages in both DI and mulching such as restricting weed growth, decreasing herbicide usage and being suitable for organic farming. On the other hand, the results showed that increasing the irrigation interval of water pillow (e.g. WP2 and WP3) method produced negative effects on the plant growth and yield. With increasing irrigation interval, the average fruit weight and the percentage of marketable fruit decreased. Moreover, the water stress resulted in the high amount of blossom end rot. Future studies on the performance of the WP method with more different types of crops should be carried out to evaluate the more beneficial sides of this method.

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