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PORTABLE CANAL IRRIGATION COMPARED TO DRIP IRRIGATION FOR TOMATOES (*LYCOPERSICUM ESCULENTUM* MILL.) PRODUCTION IN GREENHOUSE CONDITION

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Abstract

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This study examined the effects of the Portable Canal Irrigation method, a new alternative method to Drip Irrigation, and of the effects of different irrigation intervals on the growth, yield and quality of tomato (*Lycopersicum esculentum* Mill.) under greenhouse conditions in the Mediterranean Region of Turkey in the 2011 growing season. In this study, the treatment types used were: (i) Portable Canal Irrigation method with a 3-day irrigation interval, (ii) Portable Canal Irrigation method with a 6-day irrigation interval, (iii) Portable Canal Irrigation method with a 9-day irrigation interval and (iv) Drip Irrigation method with a 3-day interval (control). There were no statistical differences in the growth and yield of tomato plants between Drip Irrigation and Portable Canal Irrigation 1 treatments ($P < 0.05$). The irrigation intervals of Portable Canal Irrigation methods were significant in total tomato yields and marketable yields. The Portable Canal Irrigation 1 and Portable Canal Irrigation 3 treatments produced maximum and minimum yields (mean of both autumn and spring experiments) 3.81 kg plant^{-1} and 3.10 kg plant^{-1}, respectively. By comparing Portable Canal Irrigation with Drip Irrigation, we concluded that Portable Canal Irrigation has some advantages. Those are; its prevention of weed growth, its lack of a need for energy, its maintenance of the water level in the root area by decreasing evaporative losses from the soil surface due to its mulching effect, and the fact that it produces the greater yield (3.81 kg plant^{-1}) from Drip Irrigation (3.6 kg plant^{-1}) in greenhouse tomato production.

Key words: drip irrigation, irrigation method, portable canal irrigation

Abbreviations: A – plot area in square meter; Chl – chlorophyll; DI – drip irrigation; E – east
EC – electrical conductivity; Eq. – equation; E_{pan} – cumulative evaporation in irrigation intervals in millimeter; dS – desi Siemens; F.C. – field capacity; I – the amount of irrigation water in millimeter; K_p – pan coefficient; LAI – leaf area index; LSD – least significant difference; meq l^{-1} – mili equivalent liter; mmhos – milimhos; PCI – portable canal irrigation; % Pw – soil water content on a dry weight basis in percent; SAR – sodium adsorption rate; SCL – silty clay loam; SL – silty loam; TA – titratable acidity; TARIST – statistical program developed by Ege University; TSSC – total soluble solid content; W.P. – wilting point

Introduction

Surface irrigation is the oldest and most used method of irrigation. Surface irrigation systems convey water from the source to fields in lined or unlined open channels and/or low-head pipelines (James, 1988). The most frequently used surface irrigation systems are: contour irrigation, border irrigation, and furrow irrigation. Furrow irrigation that used to irrigate row crops and orchards is the oldest and more commonly used irrigation system. Lately, it has become important because of the high cost of energy in pressurized irrigation methods and the incorporation of automation in its operation (Holzapfel et al., 2009).

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The increasing worldwide shortages of water and costs of irrigation are leading to an emphasis on developing methods of irrigation that minimize water use (maximize the water use efficiency) (Jones, 2004). Irrigation efficiency is a measure of (1) the effectiveness of an irrigation system in delivering water to plants or (2) the effectiveness of irrigation in increasing plant production. From definition (1), irrigation efficiency may be expressed as the ratio of the volume of water used or available for use in plant production to the volume pumped or delivered for use. From definition (2), irrigation efficiency may be expressed as the ratio of crop yield or increase in yield over no irrigated production to the volume of irrigation water used (Haman et al., 2005). In irrigation science, the term drip or trickle irrigation has become synonymous with an efficient irrigation system. Drip irrigation has attained popularity due to its ability to convey water from the water source to a plant's root zone without loss of water. Compared to furrow irrigation with its seepage losses in the canals and furrows, and sprinkler irrigation with its direct evaporation from airborne water droplets, drip irrigation has no significant conveyance losses (Meshkat et al., 2000).

Higher pumping costs, water restrictions and water shortages are all factors encouraging efficiency-improving irrigation practices. Generally, reduced application efficiency with furrow irrigation occurs because of runoff or deep percolation. Deep percolation is the loss of water below the root zone. The amount of deep percolation caused by irrigation is difficult to estimate unless irrigation application is measured or the soil water content is monitored. Deep percolation reduces irrigation efficiency and increases pumping costs (Yonts and Eisenhauer, 2007). Efficient irrigation is obtained by almost filling the crop root zone each irrigation, applying water uniformly and either minimizing or utilizing runoff (Yonts et al., 2007).

The aim of the present research work is investigate of the performance of the Portable Canal Irrigation Method (PCI) which is newly developed by Ayranci and Temizel (2012) and compared with the results of the Drip Irrigation (DI) method.

Materials and Methods

This study was carried out in the experimental plastic greenhouse at the Ortaca Vocational School of Mugla Sitki Kocman University in Turkey (36°50′48″60 N, 28°44′34″68 E) in the period of 2010–2011. The Orion F_1 and Jadelo F_1 hybrid tomato (*Lycopersicon esculentum* Mill.) varieties were used in autumn and spring, repsectively. The weather in the region is that of a typical Mediterranean climate. The greenhouse was not heated.

The texture of the soil used in the research area was sandy-clay. Some of the relevant physical and chemical characteristics of the greenhouse soils, according to the depths, are given in Table 1. 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 2.

According to the results of the analysis, the irrigation water does not have any problem except its strong alkaline, has a C1S1 classification and is safe to use for irrigation. Seedlings for the experiment were produced by a commercial company. Four-week-old seedling of tomato were transplanted by hand onto double rows, 90 cm apart between double rows, spaced 60 cm apart between row with 50 cm

Table 1
Soil analysis results in the research field

Depth (cm)	Texture	Bulk density (g cm^{-3})	F.C. (% Pw)	W.P. (% Pw)	pH	Organic matter (%)	EC (mmhos cm^{-1})	P_2O_5 (kg da^{-1})	K_2O (kg da^{-1})	$CaCO_3$ (%)
00–30	SCL	1.45	23	13	8.20		0.72			16.33
30–60	SCL	1.39	30	11	8.20	1.25	0.41	1.45	83.92	16.56
60–90	SL	1.43	23	15	8.40		0.32			14.84

F.C.: field capacity, W.P.: wilting point

Table 2
The results of the irrigation water analysis

Irrigation water classification	EC		Cations (me l^{-1})				Anions (meq l^{-1})				Na (%)	SAR	B (me l^{-1})
	(dS cm^{-1})	pH	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

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). The planting/harvest dates and plant varieties used in the experiments are presented in Table 3.

Table 3
The first and last harvest dates, and plant varieties of the planting experiments

Period	Plant variety	Planting date	First harvest date	Last harvest date
Autumn	Orient F1	02.09.2010	14.11.2010	27.12.2010
Spring	Jadelo F1	21.02.2011	26.04.2011	23.06.2011

The research studied subjects organized into three different irrigation interval plots of PCI and DI (PCI-1: 3 days, PCI-2: 6 days, PCI-3: 9 days and DI: 3 days). The experiments were arranged using a factorial randomized plot design with 3 replications. The plots' width and length were 3m and 5 m, respectively, and 4 rows were prepared in each plot. In total, 40 seedlings were planted in each plot. Following the planting, a certain amount of irrigation water was applied to the plots to bring the soil up 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 (Eq. 1).

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

In order to determine the values of evaporation in the greenhouse, a *Class A Pan* was placed in the middle of the structure. The evaporation values were measured during the irrigation intervals. The pan coefficient was taken to be 0.3, 0.9 and 1.2, according to the plant development phase. In the all of experimental subjects, 235.9 mm and 341.9 mm irrigation water was applied in the autumn and spring seasons, respectively. 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. A 0,0001 m^3 sensitivity water meter was beneficial for the purposes of plot irrigation. In order to determine the effects on plant growth in the experiments, plant height, stem thickness at harvest, the plant's fresh and dry weight and leaf area index (LAI $m^2 m^{-2}$) were measured.

Harvested fruits were weighed and counted to determine the fruit yield and the number of fruits per plant. Yield was classified as the total of marketable produce (fruit weight above the 3.5 cm fruit diameter, without physiological disorders as blossom end root). Average fruit weight (g) and fruit classification were examined in order to find out the effect on yield in the experiments. The fruit quality parameters, determined in the homogenized fruit juice samples were EC (dS m^{-1}), pH, titratable acidity (TA) (meq 100 ml^{-1}) and total soluble solids (TSS) content. TSS was determined by an Atago N-1E refract meter at 20 °C. TA 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 was performed by TARIST statistical program developed by Ege University (Acikgoz et al., 1994).

Introducing the Portable Canal Irrigation method

This method concerns a newly developed hydraulic structure "*Portable Canal Irrigation*", which is a different form of applying the furrow irrigation method i.e. another type of surface irrigation method (Figure 1).

A *portable canal* has a rectangle (or square) cross-section and holes of 2–2.5 mm diameter through both lower corners discharging water to the soil. Both ends of the *portable canal* are closed and equal in height with edges (Ayranci and Tem-

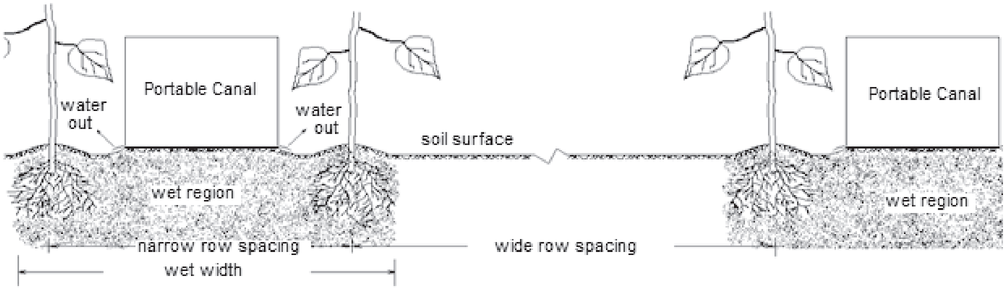


Fig. 1. Placement of Portable Canals between plant rows

izel, 2012). Distance between the holes varies depending on the plant spacing on the row and soil texture. The length of a *portable canal* is equal to the length of the plant row. In the implementation of the method, a *portable canal* is placed between two plant rows in parallel to the plant rows and leveled without slope in the transverse and longitudinal axes (Figure 2).

Fig. 2. A view from trial realized using Portable Canals

The required irrigation water depth is filled to the canal level and discharge is provided by means of the holes on both sides of the *portable canal* base. Similarly to a drip irrigation method, the water leaks with a little volume of flow and is transmitted to the plant root zone by moving horizontally and vertically in the soil. The method has many of positive features such as providing high irrigation efficiency, controlling erosion and decreasing weed growth, to a certain extent, and the need for application of liquid fertilizer, and increasing production (Ayranci and Temizel, 2012).

Results and Discussion

In the PCI method, increasing irrigation intervals negatively affected all aspects of plant growth in both autumn and spring cultivations. The prolongation of the irrigation interval further created water stress in plants. The lowest plant growth values were obtained from the PCI-3 subject. The prolongation of the irrigation interval caused water stress and negatively affected the growth of the upper part of the plant and its root development. Especially in the spring period, the plant height difference (12.5%) between the PCI-1 and PCI-3 was obvious. A number of researchers (Guzel, 2006; Ozturk et al., 2004; Sanchez-Blanco et al., 2002; Shao et al., 2008; Unyayar et al., 2005) reported that water stress reduced shoot and root development resulting in reduction of the plant height and development. Our findings are also consistent with the results of these studies (Table 4).

Measurements of leaf area are an important parameter in tracking a plant's growth. In our study, increasing the irrigation interval caused a decrease in the leaf area in both growing periods. In the autumn period, there was a difference of 15.46% in leaf area between the PCI-1 and PCI-3 subjects

Table 4
The effect of irrigation practices on some plant growth parameters

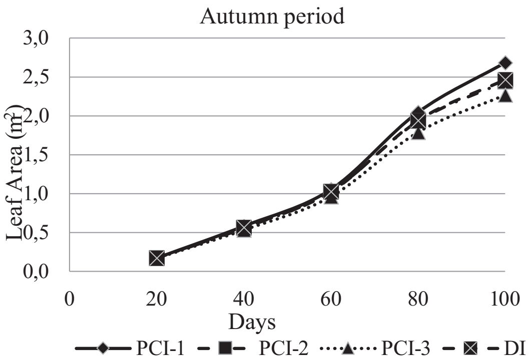
Irrigation methods	Plant height (cm)	Plant diameter (mm)	Wet weight of whole upper part (g)	Dry weight of whole upper part (g)	Dry weight of whole upper part %	Wet root weight (g)	Dry root weight (g)	Dry root weight (%)
				Autumn period				
PCI-1	**192.2** a	9.98 a	**1088.7**	**157.9** a	**14.6** a	**75.4** a	**7.6** a	**10.1** a
PCI-2	188.2 b	9.59 bc	1056.3	147.8 a	13.9 a	72.2 ab	6.9 b	9.7 ab
PCI-3	184.8 b	9.40 c	1027.6	124.9 b	12.2 b	68.7 b	5.9 c	8.7 b
DI	188.3 a	9.77 ab	1055.2	148.7 a	14.1 a	74.5 a	7.5 a	10.0 a
$LSD_{0.05}$	3.42**	0.31**	n.s.	10.47**	0.97 **	4.72 *	0.52 **	1.19*
				Spring period				
PCI-1	**184.7** a	**10.06** a	**1141.7**	**167.1**a	**14.8** a	**79.0** a	**8.1** a	**10.3** a
PCI-2	173.5 b	9.35 b	1139.2	153.4 b	13.5 a	73.1 bc	6.9 b	9.4 ab
PCI-3	160.8 c	9.12 b	1086.2	127.7 c	11.8 b	70.4 c	5.9 c	8.5 b
DI	182.0 a	9.88 a	1107.0	159.5 ab	14.4 a	77.4 ab	7.8 a	10.2 a
$LSD_{0.05}$	9.30**	0.32**	n.s.	12.44**	1.36 **	4.46**	0.62 **	1.17*

while this difference was 29.50% in the spring period. Plants reduce their leaf area development in order to prevent water loss and this negatively affects their development (Figure 3).

A number of studies (Bhatt et al., 2002; Garcia-Sanchez et al., 2004; Karam et al., 2002; Thakur and Kaur, 2001) have recently focused on a decrease in leaf area development in different plants under water stress. Our findings are also consistent with the studies mentioned above. Garcia-Sanchez et al. (2007) investigated the effect of the usage of different doses of nitrogen in tomato development under moderate drought conditions, and reported a particular decrease of nitrogen uptake with drought and that this resulted in a slowing in the development of the leaf area and a reduction in its overall size.

In both periods, the highest yield per plant was obtained from the application of the PCI-1. However, the highest unmarketable yield, in both periods, was observed at 0.41 kg and 0.49 kg in the PCI-3. The applications on the number of fruits in both periods were not statistically significant, but average fruit weight was effective on the increase of the yield. In the autumn period, the average fruit weight increased at 11.3% according to both applications PCI-1 and PCI3 while this was 17.7% in the spring period. This situation was fully reflected in the fruit classification (Table 5).

A number of findings made by researchers (Bhatti et al., 2000; Karam et al., 2002; Karipçin, 2009; Kirnak et al., 2002; Nahar and Gretzmacher, 2002) are also similar to our results. Kirda et al. (2004) reported that unmarketable yield and 2nd class fruit rate were also increased by water stress in the limited irrigation applications of their research.



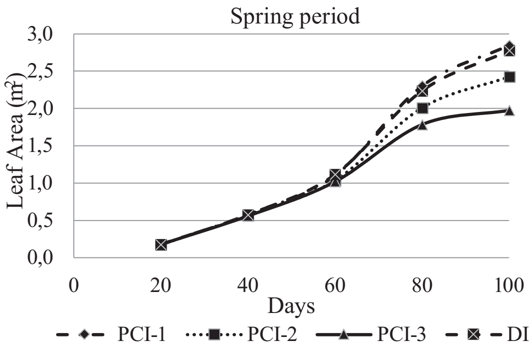


Fig. 3. 20-day intervals of leaf area measurements in plant development

Table 5
The effect of irrigation applications on some yield parameters

Irrigation Methods	Total yield (kg/plant)	Marketable yield (kg/ yield)	Unmarketable yield (kg/ plant)	Number of fruits	Average fruit weight (g)	1st class fruit rate (%)	2nd class fruit rate (%)	3rd class fruit rate (%)
				Autumn period				
PCI-1	**3.76** a	**3.35** a	0.32 bc	**26.3**	**142,8** a	**63.1** a	19.9 c	9.22
PCI-2	3.43 bc	3.13 ab	0.28 c	26.0	131.9 ab	51.0 bc	28.9 ab	10.55
PCI-3	3.16 c	2.75 b	**0.41** a	24.9	126.7 b	44.7 c	**31.3** a	**11.72**
DI	3.49 ab	3.14 a	0.35 ab	25.1	138.9 a	58.4 ab	22.0 bc	9.26
LSD $_{0.05}$	0.32*	0,38*	0,06*	n.s.	11,6**	7,76**	9.00*	n.s.
				Spring period				
PCI-1	**3.85** a	**3.53** a	0.32 c	**26.9**	**143.1** a	59.9 a	21.Mar	6.6
PCI-2	3.44 b	3.16 b	0.41 b	26.6	129.7 ab	**62.9** a	15.Mar	8.3
PCI-3	3.03 c	2.63 c	**0.49** a	25.8	117.8 b	50.2 b	**23.Haz**	**11.9**
DI	3.71 ab	3.36 ab	0.32 c	26.7	140.3 a	58.7 a	20.Şub	9.3
LSD $_{0.05}$	0.27**	0.28**	0.04**	n.s.	13.87*	8.01*	n.s.	n.s.

Table 6
The effect of irrigation applications on some fruit quality values

Irrigation methods	Dry fruit weight (%)	EC	pH	TA (meq/100 ml)	TSSC
			Autumn period		
PCI-1	4.54 b	4.55 b	**4.32**	5.30 b	4.07 b
PCI-2	4.58 b	4.65 b	4.28	5.36 b	4.10 b
PCI-3	**5.33** a	**4.92** a	4.20	**5.60** a	**4.39** a
DI	4.53 b	4.54 b	4.30	5.30 b	4.08 b
$LSD_{0.05}$	0,47*	0,20*	n.s.	0.145**	0,13**
			Spring period		
PCI-1	4.54 a	4.51 b	**4.31**	5.27 b	4.06 b
PCI-2	4.50 a	4.61 b	4.26	5.34 b	4.05 b
PCI-3	**5.17** b	**4.88** a	4.16	**5.57** a	**4.35** a
DI	4.53 a	4.53 b	4.30	5.26 b	4.03 b
$LSD_{0.05}$	0.16*	0.23*	n.s.	0.20*	0.18*

TA: titratable acidity, TSSC: total soluble solid content

Table 7
The effect of irrigation applications on leaf chlorophyll *a*, chlorophyll *b* and total chlorophyll

Irrigation methods	Chlorophyll *a*	Chlorophyll *b*	Total chlorophyll
	Autumn period		
PCI-1	1628.99 a	721.74 a	2350.74 a
PCI-2	1388.22 b	670.13 b	2058.47 b
PCI-3	1198.66 c	635.62 c	1829.30 c
DI	**1631.50** a	**722.32** a	**2353.84** a
$LSD_{0.05}$	34.46**	17.17**	47.80**
	Spring period		
PCI-1	1644.76 a	**724.94** a	2369.71 a
PCI-2	1374.47 b	667.40 b	2041.88 b
PCI-3	1190.61 c	632.72 c	1823.32 c
DI	**1647.50** a	722.29 a	**2369.79** a
$LSD_{0.05}$	50.69**	17.87**	65.63**

In this study, dry fruit weight, fruit juice EC and pH values, titratable acidity (TA) and total soluble solid content (TSSC) were the quality criteria investigated. In both periods, while the effect of irrigation applications was not significant on the fruit juice pH values, prolongation of the irrigation intervals showed an increase on dry fruit weight, fruit juice EC value and TSSC value (Table 6).

Water stress and decreasing water amount in the fruit increased dry fruit weight, TA and TSSC. The researchers, Amore and Amore (2007) and Kirda et al. (2004) also reported that their limited irrigation application with water stress on tomato increased the dry fruit weight, TA and TSSC value. The increase of the dry weight was related to an increased amount of sugar and a decrease in fruit juice content due to the result of photosynthesis.

Photosynthesis is crucial in plant growth and development. The amount of total chlorophyll, chlorophyll *a* and chlorophyll *b* is an important piece of data in determining the effectiveness of photosynthetic metabolism. In our study, the effect of increasing the irrigation interval was found to decrease the amount of chlorophyll *a* and chlorophyll *b* and total chlorophyll (Table 7).

The DI and PCI-1 were formed in the same group. Under drought stress, the first decline in photosynthesis was caused by the stomata closures and reduction of CO_2 absorption. A decrease of chlorophyll adversely affects photosynthesis as time progresses and parallel to this decrease in photosynthesis, development slows down. Many researchers (El-Tayep, 2006; Karipçin, 2009; Kirnak et al., 2002; Koskeroglu, 2006; Ohashi et al., 2006; Ozmen, 2009; Zgalli et al., 2006, 2005) have reported that chlorophyll content in various plants was decreased due to water stress.

Conclusions

In this study, a new irrigation method (Portable Canal Irrigation-PCI) which is alternative to Drip Irrigation is examined. In examination three treatment types were used: i; 3-day irrigation interval, ii; 6-day irrigation interval and iii; 9-day irrigation interval. Drip Irrigation (DI) method with a 3-day interval was used as a control.

The PCI method is an alternative form of applying furrow irrigation i.e. being another type of surface irrigation methods. A *portable canal* has a rectangle (or square) cross-section and holes of 2–2.5 mm diameter and 25–50 cm distance depending on the plant spacing on the row and soil texture through both lower corners discharging water to the plant rows. The length of a *portable canal* is equal to the length of the plant row and both ends of the *portable canal*s are closed. While implementing the method, *portable canal*s are placed between two plant rows in parallel to the plant rows and leveled without slope in the transverse and longitudinal axes and required irrigation water depth is filled to the portable canal and provided discharge by means of the holes.

The water leaks with a small volume of flow and transmitted to the plant root zone by moving horizontally and vertically in the soil.

There were no statistical differences in the growth and yield of tomato plants between DI and PCI-1 treatments (P < 0.05). Irrigation intervals of the PCI method were significant in total tomato yields and marketable yields. According to the mean of both autumn and spring experiments, PCI-1 treatments produced maximum yields 3.81 kg plant^{-1} in all treatments. By comparing PCI with DI, we conclude that PCI has some advantages such as preventing weed growth, its lack of a need for energy, it maintenance of the amount of water in the root area by decreasing evaporative losses from the soil surface due to its mulching effect, and its production of greater yield (3.81 kg plant^{-1} for PCI-1 treatment) from DI (3.6 kg plant^{-1}) in tomato production under greenhouse conditions.

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