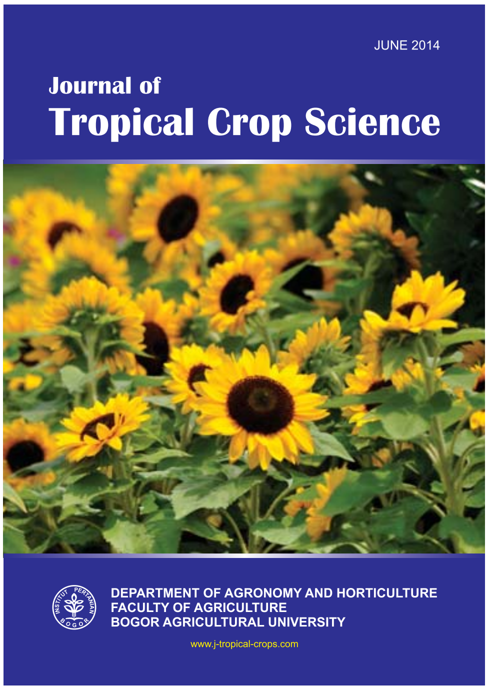

Journal of Tropical Crop Science

(ISSN 2356-0169; e-ISSN 2356-0177) is published four-monthly by Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University, INDONESIA.

9 772356 017001

Publication details, including instructions for authors and subscription information:
www.j-tropical-crops.com

Journal of Tropical Crop Science

Volume 1 Number 1 June 2014

ON THE COVER

The cover image shows sunflowers by Darda Effendi

Journal of Tropical Crop Science (ISSN 2356-0169; *e*-ISSN 2356-0177) is published four-monthly (one volume per year) by Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University, IPB Darmaga Campus, Bogor, Indonesia 16680. Send all inquiries regarding printed copies and display advertising to info@j-tropical-crops.com or to Secretary, Department of Agronomy and Horticulture; telephone/fax 62-251-8629353.

Irrigation Volume Based on Pan Evaporation and Their Effects on Water Use Efficiency and Yield of Hydroponically Grown Chilli

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Abstract This study was conducted to determine irrigation volume based on pan evaporation and their effects on growth, yield, irrigation water use efficency (IWUE) of chilli grown in sandponic system in the greenhouse. The amount of water used was based on pan evaporation. Irrigation treatments consisted of four coefficients, i.e. 0.5, 1, 1.5, 2 Epan. Plants were watered daily until soil reached field capacity during the first week. Irrigation treatments were applied on the second week until four months later. Total irrigation quantities varied from 9.4 to 37.8 L. plant^{-1}. Chilli fruit yield varied from 3.98 to 90.51 g.plant^{-1}. The highest total fruit yield and IWUE was obtained from 2 Epan treatment. Irrigation treatment had significant effects (P<0.01) on yield and there were positive linear relations between the yield and the amount of irrigation water applied. Irrigation volume significantly increased plant height, number of lateral branches, and number of leaves (P<0.01).

Key words: *plant height, lateral branches, fruit*

Introduction

Water is a basic requirement for crop growth and production. Water requirement for the plant is equal to evapotranspiration. Crop evapotranspiration can be determined based on Class A pan evaporation. Previous studies reported positive correlation between crop water requirements and Class A pan evaporation (Ertek et al., 2006). Therefore the evaporation pan can be used to determine the volume of irrigation (Ertek et al., 2006).

Previous studies have demonstrated that the quantity of irrigation water influenced chili yield and water use efficiency (Liu et al., 2012). Reducing irrigation by 22–43% reduced crop evapotranspiration by 11–25% (Liu et al., 2012). Total dry mass was reduced by 1.17–38.66% in time-space deficit irrigation treatments compared to optimum irrigation. The root to shoot ratio of the optimally irrigated plants was lower than other treatments and had the highest total fresh fruit yield (19.57 t.ha^{-1}). Deficit irrigations increased water use efficiency (i.e. yield/evapotranspiration) of hot pepper from a minimum of 1.33% to a maximum of 54.49% (Cheng et al., 2010). Water stress reduced photosynthesis through stomatal closure and impaired mesophyll conductance (Pascual et al., 2010). The maximum and minimum values of the yield and yield components were recorded from treatment full irrigation level with paired-row planting method and 0% of ET_c irrigation level with paired-row planting method, respectively, with the exception of plant height (Gadissa and Chemeda, 2009). Water use efficiency (WUE) and irrigation water use efficiency (IWUE) values significantly increased with the application of 11- day-interval irrigation (P < 0.05). The highest WUE and IWUE values obtained from 11-day- interval irrigation (Gercek et al., 2009). Total dry mass of fruit was reduced by 34.7% in drought treatments compared to full watered treatment. At harvest, water-stressed plants had 21% lower root dry weight mass but higher root/shoot ratio other than full watered treatment (Kulkarni and Phalke, 2009).

Chili plants had almost double productivity and higher water use efficiency under high soil temperature and high soil moisture (Yaghi et al., 2013). During severe water stress, photosynthesis decreased due to stomatal closure, and slower maximum carboxylation rate (V_{cmax}) and ribulose 1,5-bisphosphate (RuBP) regeneration capacity mediated by maximum electron transport rate (J_{max}) (Campos et al., 2013). Fruit yield increased gradually as soil water content levels increased from 40–55% to 70–85% field capacity, but decreased when soil water content increased above 70–85% field capacity. The water consumption increased progressively with the increase in soil water levels, but water-use efficiency was the highest when soil moisture was 55–70% field capacity (Zhu et al., 2012).

Irrigation is also important for controlling plant disease. Soil moisture and relative humidity in the atmosphere are critical in determining survival of mycelium and other propagules in the soil and on the plant. Plant infections by *P. capsici* and disease development were favored by rainfall and high soil moisture, and periodic flooding contributes to a more severe disease (Sanogo and Ji, 2013). Chemical compounds in chili fruits are affected by genetic, harvest time and irrigation control. The capsaicin contents of different *Capsicum* species and lines were affected by harvest time and drying parameters. Capsaicin contents were within the range 0.50–4.20%. The highest capsaicin content was obtained from the solar tunnel drying at the second harvest in the local *Capsicum* line Acı Çiçek 52 (Yaldiz et al., 2010). Concentration of antioxidant components and taste-related properties varied among the pepper cultivars at both the mature and whole colored ripened stages

(Ghasemnezhad et al., 2011).

Irrigation volumes are determined based on pan evaporation. Pan coefficient is defined as the ratio of evapotranspiration references (ETo) to the pan evaporation. Pan coefficients varied from 0.35-0.85 with an average of 0.7 (FAO, 1986). Crop evapotranspiration (Et) is defined as Kc x ETo, where ETo = K pan x E pan. Therefore Et = Kc x K pan x E pan. This study aimed to obtain the value of Kc x K pan or the so-called crop and pan coefficients (K_{CP}). K_{CP} value of this research can be used as a basis for determining the irrigation volume of hydroponically grown chili. This study was also aimed at studying the effects of irrigation volume on chili growth and yield, and to determine the best irrigation methods to improve chili water use efficiency.

Materials and Methods

The experiment was conducted in greenhouse at Darmaga experimental station (6° 24'S, 106° 33E; elevation 240 m), Bogor Agricultural University, Bogor, West Java, Indonesia. Chili plants were grown hydroponically using sand media. Plants were fertilized with 32N:10P: $10K_2O$ and supplied with micronutrients during vegetative growth, followed by 10N:55P:10 K_2O plus micronutrients during generative growth.

The treatments were four irrigation volumes based on pan evaporation (EoA), i.e. 0.5, 1, 1.5, and 2 Eo. Pan evaporation values were obtained by measuring the decrease in water height in the evaporation pan. Irrigation volume was calculated by multiplying surface area of the pot by 0.5, 1, 1.5, and 2 Eo, respectively. The experiment was arranged in a randomized block design and replicated three times, with five plants for each experimental unit.

Seeds were sown in a plastic tray and were grown for six weeks before transplanting into 28-cm pots. Percolation holes were made on the pot sides with a height of a third height measured from the bottom of the pot. Seedlings were fertilized using foliar fertilizer at $1g.L^{-1}$ weekly. Hydroponics fertilizer was dissolved in irrigation at a concentration of $2g.L^{-1}$ and applied twice a week.

Observations included plant height, number of branches, number of leaves and fruit weight at harvest. The dry matter of root and canopy was weighed on 1, 2 and 3 months after planting, respectively. Irrigation water use efficiency (IWUE) was calculated based on the ratio of fruit weight and irrigation volume.

Results

Irrigation volume treatment of 2 Eo (twice pan evaporation) resulted in the highest plant height, the greatest leaf number and branches at 8 and 12 weeks after planting (WAP) (Table 1).

Irrigation volume of 1.5 Eo increased plant dry matter by 99 % compared with 0.5 Eo irrigation volume at 4 weeks after planting. On 8 and 12 WAP irrigation volume of 2 Eo increased plant dry matter as much as 23%, 102% and 374% compared with 1.5, 1.0 and 0.5 Eo, respectively (Table 2).

Fruit yield increased gradually as irrigation volume increased from 0.5 Eo to 1.0 Eo, 1.5 Eo and 2.0 Eo. The highest fresh fruit yield was obtained from the irrigation volume of 2.0 Eo (Table 3). Water use efficiency of 2.0 Eo irrigation volume was significantly higher compared with 0.5 Eo and 1.0 Eo irrigation volume, respectively (Table 3).

Discussion

Irrigation volume treatment of 2 Eo (twice pan evaporation) resulted in the highest plant height, the greatest leaf number and branches at 8 and 12 WAP (Table 1).

Table 1. Plant height, leaf number, and branch number in each irrigation volume

Irrigation volume	Plant height (cm)	Leaf number	Branch number
4 WAP-old plants			
0.5 Eo	47.89c	22.33b	2.67a
1.0 Eo	57.48b	27.60ab	4.93a
1.5 Eo	61.49ab	35.53a	7.00a
2.0 Eo	62.23a	32.20ab	8.27a
8 WAP-old plants			
0.5.Eo	63.77c	29.83d	9.42d
1.0 Eo	96.95b	95.33c	43.67c
1.5 Eo	108.78ab	178.17b	84.42b
2.0 Eo	117.91a	250.33a	101.00a
12 WAP-old plants			
0.5 Eo	80.73c	79.78d	71.22d
1.0 Eo	118.23b	257.78c	223.56c
1.5 Eo	123.04ab	366.22b	351.00b
2.0 Eo	135.02a	556.22a	503.22a

Note: Data at the same column followed by the same letter was not significant based on LSD (0.05); WAP = weeks after planting

These effects were not observed earlier. Water requirement at the early growth was normally lower than that in the mid and late growth as young plants have fewer numbers of leaves. Gadisa and Chemeda (2009) showed that plant height increased significantly with increasing levels of irrigation. Shongwe et al. (2010) reported that there were significant ($P < 0.05$) increases in leaf number, plant height, chlorophyll content, canopy size, fresh and dry mass tops and fruit length at the highest moisture level (1.00 × field capacity), whereas at (0.80 × field capacity) resulted in smaller increases in each of the parameters.

Irrigation volume of 1.5 Eo increased plant dry matter by 99 % compared with 0.5 Eo irrigation volume at 4 weeks after planting. Otherwise, on 8 and 12 weeks after planting (WAP), irrigation volume of 2 Eo increased plant dry matter as much as 23%, 102% and 374% compared with 1.5, 1.0 and 0.5 Eo irrigation volume, respectively (Table 2). This shows that the crop and pan coefficient (K_{CP}) value for the initial growth phase was 1.5 but increased to 2.0 at the middle and late growth. The greatest dry matter allocation was in the leaves in all treatments. At four weeks after planting root and shoot ratio were similar in all treatments. In times of drought, carbon was mostly allocated for root development (Ehlers and Goss, 2003). Kulkarni and Phalke (2009) reported that water-stressed plants had 21% lower root dry weight mass but higher root to shoot ratio other than full water-treated plants.

Fruit yield increased gradually as irrigation volume increased from 0.5 Eo to 1.0 Eo, 1.5 Eo and 2.0 Eo. The highest fresh fruit yield was obtained from the irrigation volume of 2.0 Eo (Table 3). The similar results was reported by Zhu et al. (2012) that fruit yield increased gradually as soil water content levels increased from 40–55% to 70–85% field capacity, but decreased when soil water content was higher than 70–85% field capacity. The water consumption increased progressively with the increase in soil water content levels, but water-use efficiency was the highest when soil moisture was at 55–70% field capacity. Cheng et al. (2010) also reported that the highest total fresh fruit yield (19.57 $t.ha^{-1}$) was obtained in the optimum irrigation treatment. Irrigation water use efficiency of 2.0 Eo irrigation volume was significantly higher compared with 0.5 Eo and 1.0 Eo irrigation volume, respectively (Table 3).

Table 2. Plant dry matter at each irrigation volume

Irrigation volume	Root (g)	Stem (g)	Leaf (g)	Plant (g)	Root/shoot
4 WAP-old					
0.5 Eo	0.50b	1.25b	1.49b	3.25b	0.18ns
1.0 Eo	0.69ab	1.67ab	1.89ab	4.26ab	0.20ns
1.5 Eo	0.84ab	2.35a	3.37a	6.47a	0.15ns
2.0 Eo	1.09a	1.95ab	2.68ab	5.73ab	0.23ns
8 WAP-old					
0.5.Eo	1.38a	2.46b	1.25c	5.15d	0.37a
1.0 Eo	1.91a	5.23b	4.36b	12.03c	0.20b
1.5 Eo	2.57a	10.27a	6.27ab	19.75b	0.16b
2.0 Eo	2.59a	12.69a	8.20a	24.38a	0.12b
12 WAP-old					
0.5 Eo	1.79c	3.11d	1.94d	7.14d	0.35a
1.0 Eo	3.84cb	7.87c	4.72c	17.16c	0.30ab
1.5 Eo	5.38ab	13.24b	7.89b	30.25b	0.25ab
2.0 Eo	6.89a	21.65a	10.91a	41.88a	0.21b

Note: Data at the same column followed by the same letter was not significant (ns) based on LSD (0.05); WAP = weeks after planting.

Table 3. Fruit weight and irrigation water use efficiency in each irrigation volume

Irrigation volume	Fruit weight ($g\ plant^{-1}$)	Irrigation water use efficiency ($g.\ L^{-1}$)
0.5 Eo	3.98c	0.42c
1.0 Eo	21.84c	1.15c
1.5 Eo	57.69b	2.03ab
2.0 Eo	90.51a	2.39a

Note: Data at the same column followed by the same letter was not significant based on LSD (0.05).

Conclusion

The highest total fruit yield and IWUE was obtained from the 2 Epan treatment. Irrigation treatment had significant effects ($P<0.01$) on yield and there were positive linear correlations between the yield and the amount of irrigation water. Plant height, number of lateral branches, number of leaves increased with increasing volumes of irrigation and these effects were significant (P<0.01) since the second weeks after planting.

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