J. Agr. Sci. Tech. (2017) Vol. 19: 693-705

Radiation Use Efficiency and Yield of Pepper (*Capsicum annuum* L. cv. California Wonder) under Different Irrigation Treatments

M. Yildirim[1*], K. Demirel[2], and E. Bahar[3]

ABSTRACT

This study assessed the optimum water need of pepper (*Capsicum annuum* L. cv. California Wonder) and the critical irrigation level to be applied in order to achieve a reasonable economic yield in water shortage conditions. In a controlled field experiment involving five different treatments, seasonal evapotranspiration for pepper fluctuated from 89 mm in the severe stress treatment ($I_{0.00}$) to 1,018 mm in the excess water application ($I_{1.25}$). The highest yield was obtained in the full treatment where water in the root zone was refilled up to field capacity. In cases of water shortage, applying water of 690 mm ensures an economical yield. Maximum leaf area index was recorded in the full treatment ($I_{1.00}$), which enabled the pepper to receive more benefit from total incoming solar radiation (average, 2,387 MJ m^{-2}). An average of 555.45 MJ m^{-2} was held by the pepper canopy throughout the whole growing season. Radiation use efficiency values on a dry yield basis were 0.69 g MJ^{-1} in 2011 and reached 1.07 g MJ^{-1} in 2012, since the leaf area index increased from 1.46 to 2.44. Therefore, averaged over two years, the peppers in the full treatment converted irrigation water of 888 mm and intercepted photosynthetically active radiation into the highest yield of 75.5 t ha^{-1}, which was more efficient than the excess and deficit water application treatments.

Keywords: Intercepted photosynthetically active radiation, Pepper, Photosynthetically active radiation, Radiation use efficiency, Solar radiation.

INTRODUCTION

A reduction in freshwater resources forces agricultural producers to use second quality or contaminated water (Bustan *et al.*, 2005, Alomran *et al.,* 2012, Bijani and Hayati, 2015). The required amount of water necessary for agricultural crops could not be met due to erratic rainfall and water shortages in recent years during the summer, especially in arid and semi-arid regions, which caused significant loss of crops. For this reason, identification of drought-resistant varieties of all crops has become an important issue (Kusvuran and Abak, 2012). Climatic conditions such as temperature and radiation affect the water requirement of crops (Young *et al.,* 1985). Giorgi (2006) reported that according to climate models, the Mediterranean area will become one of the hottest regions in future climate change projections. Saadi *et al.* (2014) tried to predict the effects of climate change on plant evapotranspiration. According to their forecast, the overall reduction in annual precipitation and increase in air temperature will be 39.1±55.1 mm and 1.57±0.27°C,

[1] Department of Agricultural Structures and Irrigation, Canakkale Onsekiz Mart University, Faculty of Agriculture and Design, 17020, Canakkale, Turkey.

[*] Corresponding author; e-mail: myildirim@comu.edu.tr

[2] Canakkale Onsekiz Mart University, Faculty of Architecture and Design, 17020, Canakkale, Turkey.

[3] Ataturk Soil, Water and Agricultural Meteorology Research Station Directorate, 39010 Kırklareli, Turkey.

respectively between the years 2000 and 2050. The consequent increase of annual reference evapotranspiration will be 92.3± 42.1 mm and the average length of the growing season for wheat and tomato will be shorter in 2050 by 15 and 12 days, respectively. The world population is now around 6 billion and is expected to reach 8.3 billion in 2030 (Anonymous, 2009). It is clear that agricultural productivity must increase in order to feed the growing world population (Howell, 2001). An increment in crop production is possible only by knowing the pushing effect of irrigation and radiation on plant growth and yield. One of the most important factors affecting crop growth and yield is water.

The interception of solar radiation and utilization of radiant energy for plant biomass is essential for plant growth and yield (Purcell *et al.,* 2002). Under optimum plant growth condition, crop biomass accumulation depends on the quantity of Photosynthetically Active Radiation (PAR) intercepted by the canopy (Monteith, 1977, Kiniry *et al.,* 2005). Plant growth models require information related to each plant on Leaf Area Index (LAI), light extinction coefficient for *PAR*, and Radiation Use Efficiency (RUE) (Monteith, 1965). Recently, solar radiation has been used both to estimate crop yield and also to activate automatic irrigation systems. Higashide (2009) estimated weekly tomato yield in a greenhouse by using cumulative solar radiation before harvesting. Jovicich and Cantliffe (2007) used the amount of solar radiation as a parameter to schedule irrigation events. Plant water, nutrient uptake and transpiration rate are closely related to solar radiation (Adams, 1992). There is a strong relationship between transpiration and the amount of radiation intercepted by the canopy. Hence, the intercepted radiation by the canopy was used in development of an automated irrigation system (Casadesus *et al.,* 2011). There has been much research about the effect of different irrigation levels or light intensity on plant growth, but there has been little research combining light intensity with soil water stress (Dong *et al.,* 2015).

An evaporation pan provides a measurement of the integrated effect of radiation, wind, temperature and humidity on evaporation from an open water surface. Therefore, evapotranspiration of grown plants can be predicted by pan evaporation with the help of empirically derived coefficients taking into account the climate and pan's environment (Doorenbos *et al.,* 1984). A Class-A pan is commonly preferred both in irrigation scheduling for farmers and also in research, since it is the most suitable system for showing the plant, water and climate interrelationship (Ertek *et al.,* 2006).

The objectives of this research were to determine both the effects of different irrigation levels and pan coefficients (K_{cp}) and also the Intercepted Photosynthetically Active Radiation (IPAR) of pepper at different irrigation levels.

MATERIALS AND METHODS

Experimental Site and Soil Description

The field experiment was carried out at Dardanos Agricultural Research Station of Canakkale Onsekiz Mart University during 2011 and 2012 near the Dardanelles straits in Canakkale province, Turkey. The location of the experimental area was 40^0 08' N, 28^0 20' E at an elevation of 3 meters. Dates of transplantation for the peppers (*Capsicum annuum* L. cv. California Wonder) were June 10^{th}, 2011 and June 1^{st}, 2012, at spacing's of 0.33×1 m in both years. The chemical characteristics of the soil are given in Table 1.

Each plot had dimensions of 10 m in length and 4 m in width, including 4 rows and 120 plants. The experiment was laid out using a randomized complete block design. In total there were 15 plots (5 treatments×3 replications). The climate parameters of solar radiation (W m^{-2}), temperature (^{0}C) and relative humidity (%) at the site were measured above the canopy of the plants while the solar radiation was measured above and inside the canopy. All data were measured by a HOBO U12 data logger

Table 1. Physical and chemical properties of soil in experiment.

Depth (cm)	Field capacity (%)	Wilting point (%)	Bulk density (g cm^{-3})	pH[a]	Total changeable sodium (mg l^{-1})[a]	Cation exchange capacity (me $100g^{-1}$)[a]	$CaCO_3$ (%)[a]	Organic matter (%)[a]
0-30	21	10	1.30	7.69	135	22.3	13.5	2.29
30-60	25	13	1.57	8.00	195	26.2	12.0	1.26
60-90	25	14	1.63	8.08	98.5	24.3	10.4	1.41

[a] Taken from Ozcan *et al.* (2004).

(MicroDAQ com Inc.), including sensors. Data were saved into the data logger at 1-hour intervals throughout the experiment. The Electrical Conductivity of the irrigation water (EC_w), measured with an EC59 pyranometer (Milwaukee Instruments, Inc.), was 0.410 ds m^{-1}, which was reported as having no harmful effect according to Ayers and Westcot (1989).

Irrigation Practice

Each plot in the experiment took the same amount of fertilizer; namely, urea (280 kg ha^{-1}), triple super phosphate (140 kg ha^{-1}) and potassium sulfate (140 kg ha^{-1}) in 2011 and 420 kg ha^{-1} (NPK; 18:18:18) in 2012. The total amount of urea in 2011 and NPK in 2012 was applied three times, first at planting then on the 15th and 20th day following. The irrigation program was run for full irrigation (Ik_{cp2}). Hence, the irrigation treatments included five irrigation levels from excess water to severe water stress. Only in the full irrigation treatment, the water was refilled in the root zone up to field capacity at 7-day intervals.

Irrigation regimes consisted of five different irrigation levels of cumulative pan Evaporation (E_{pan}) values. These irrigation treatments were applied based on different plant-pan coefficients (Ik_{cp1}= 1.25, Ik_{cp2}= 1.00, Ik_{cp3}= 0.66, Ik_{cp4}= 0.33 and Ik_{cp5}= 0.00). In both years, however, for the first 4 weeks after transplanting, all treatments were irrigated equally twice a week in order for the transplanted peppers to develop. Following this, they were then irrigated according to the irrigation treatments; however, plants in the treatment of Ik_{cp5} did not receive any water after the establishment of root development. All amounts of evaporation from the Class-A pan one month after transplanting were measured every 7 days for both years, since Doorenbos *et al.* (1984) reported that predicting crop water requirements for periods of 10 days or longer by using a Class-A pan is still warranted.

In the deficit treatments, water was applied at 66% (Ik_{cp3}), at 33% (Ik_{cp4}), and at 0% (Ik_{cp5}) of full irrigation. A Class-A Evaporation Pan was located next to the experimental plot. In calculation of the applied water in the full irrigation treatment, class-A pan evaporation was used for each equation given by Kanber (1984):

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

Where, I is the amount of irrigation water applied (mm), A is the plot area, E_{pan} is the cumulative evaporation at irrigation interval (mm) and k_{cp} is the plant-pan coefficient. Sezen *et al.* (2006) obtained the highest bell pepper yield at 6-day irrigation intervals with k_{cp}=1.00. The actual Evapotranspiration (ET) of the pepper (*Capsicum annuum* L. cv. California Wonder) was estimated using the soil water balance method, as;

$$ET= I+P+C_r-D_p-R_f\pm\Delta SW \quad (2)$$

Where, ET is the actual crop evapotranspiration (mm), I is the irrigation depth (mm) and P is rainfall (mm). The Capillary rise water (C_r, mm) is negligible considering a ground water level of 40-50 m below the soil surface (Li *et al.,* 2008), the Deep percolation (D_p, mm) below the root zone was also ignored because irrigation depths were small and water applied to each treatment was only sufficient to compensate for the soil moisture deficit caused by crop evapotranspiration and thus not enough to percolate through the bottom of the root zone. Surface Runoff (R_f, mm) was also ignored because no runoff was observed during the periods of irrigation and precipitation. *ΔSW* is the change in soil water content (mm) at a depth of 90 cm from the soil surface. Soil water content was determined by the gravimetric method at 30 cm intervals and 7-day intervals.

Water Use Efficiency (WUE) (kg m $^{-3}$) was calculated according to Hillel and Guron (1975) as:

$$WUE = Y/ET \quad (3)$$

Where, *Y* is yield (t ha^{-1}), and *ET* is the same as described above.

Leaf Area Index (LAI)

Three plant samples from each plot were selected randomly for leaf area measurement. The green leaf portions were separated and leaf area was determined using a CI-202 Portable Laser area meter (CID, Inc., USA) in cm^2. All leaves of each plant were collected in all treatments, and the Leaf Area Index (LAI) was determined by the following equation (Kar and Kumar, 2007):

$$LAI = \frac{\text{Measured leaf area of 3 plants}}{\text{Ground area covered by 3 plants}} \quad (4)$$

Light Attenuation and Radiation Use Efficiency

Two pyranometer sensors were placed in the center of the plot. One was placed above the canopy of a reference plant at a height of about 1.5 m to determine the incident *PAR*. The other measurement was taken at soil surface level by placing the sensor below the canopy in order to determine the transmitted *PAR*, as indicated by Charles-Edwards and Lawn (1984), and these sensors were connected to the HOBO U12 data logger, which had 2 inputs to measure total solar radiation (W m^{-2}), and also registering the time and date at 1-hour intervals. Daily solar radiation of MJ m^{-2} d^{-1} was estimated as recommended by Monteith (1977).

The light extinction coefficient (k) could be calculated by Transmitted *PAR* (TPAR as MJ m^{-2} d^{-1}) and incident *PAR* (MJ m^{-2} d^{-1}) (Kiniry *et al.,* 2005; Lindquist *et al.,* 2005) as:

$$k = \frac{[-\ln(TPAR/PAR)]}{LAI} \quad (5)$$

We estimated *k* as 0.75 in 2011 and 0.78 in 2012 for the pepper (*Capsicum annuum* L. cv. California Wonder). They were very close to the value of *k* estimated by Sarlikioti *et al.* (2011), who found the light extinction coefficient (k) to be 0.8 for sweet pepper. In this study, an exponential function was fitted for the period analysis and the fraction of *PAR* intercepted (F) was calculated according to Trapani *et al.* (1992) as:

$$F = 1-exp(-k.LAI) \quad (6)$$

Multiplying the daily fraction of *PAR* intercepted (F) with *PAR* gives an estimate of the amount of radiation intercepted by a crop canopy (IPAR, MJ m^{-2}). The Radiation Use Efficiency (RUE) on a fresh and dry yield basis was calculated as defined by Ahmad *et al.* (2008):

$$IPAR = F \times PAR \quad (7)$$

$$RUE_{Yield} = \frac{Yield}{\sum IPAR} \quad (8)$$

$$RUE_{TDM} = \frac{TDM}{\sum IPAR} \quad (9)$$

Where, *TDM* is the total dry matter (leaves and stem) (g).

Plant and Fruit Quality Parameters

Plots were harvested 134 Days After Transplanting (DAT) in 2011 and 110 DAT in 2012. One representative plant was also harvested in all plots in each individual growth period (vegetative, flowering, ripening and yield formation) and used for growth analysis. Shoot and fruit tissues were dried at 70^0C for subsequent dry weight determination. All plant weights (stem, leaf and fruit) were determined using a digital balance (±0.01 g) and diameters were measured with a digital clipper (±0.01 mm). Soluble solids were determined on a blended composite using a portable hand-held refractometer (SERICO, Shanghai E-Reliance International Co., Ltd., China). pH was determined for 100 ml fruit juice by a handheld pH meter (Milwaukee Instruments, Inc., USA.). Fresh weights (stem, leaf and fruit) were determined separately by weighing. After that, they were all oven-dried to a constant weight at about 70°C for two days to determine the dry weight of whole plants in each treatment.

Yield and quality parameters were analyzed using ANOVA. Means were separated by Duncan's Multiple Range Test at the probability level of 1 and 5% ($P< 0.01$, $P< 0.05$).

RESULTS AND DISCUSSION

Irrigation Water, Evapotranspiration (ET) and Yield

Different irrigation treatments in both experiment years had a significant effect on the yield and vegetative development of the California Wonder pepper. The Irrigation amounts (I), Evapotranspiration (ET) and yield values for both years of the experiment are given in Table 2.

The amount of water applied in both years fluctuated on average from 89 mm in the severe stress treatment ($Ik_{cp0.00}$) to 1018 mm in the excess water application ($Ik_{cp1.25}$). The amount of applied irrigation water increased the crop water consumption (ET) for all treatments. Even though the applied water and *ET* were higher in the excessive water treatment ($Ik_{cp1.25}$), the highest yield was obtained in the treatment where the full water requirement of pepper was fully covered (Table 2). The yield results, especially for the treatments of Ik_{cp1}, Ik_{cp2}, and Ik_{cp3} in the present study, were almost twice the findings given in the literature.

Sezen *et al.* (2006) obtained the highest values for bell pepper yield (35.3 t ha^{-1}) by applying 570.4 mm of irrigation water. Yıldırım *et al.* (2012) obtained the highest bell pepper yield with an application of 400 mm irrigation water, and Karam *et al.* (2009) obtained the highest marketable pepper yield with 31.9 t ha^{-1}. The yield and plant development parameters of the present study, however, are in good agreement with the findings of Sener and Erken (2004), who obtained the highest pepper (*Capsicum annuum* L. cv. California Wonder) yield with 65.64 t ha^{-1} by applying 915 mm of irrigation water according to the Class-A pan method. The reason for their high yield depended to a large extent on genotype, since the California Wonder's fruit size, weight and flesh thickness are higher than those of other pepper types. This shows that pepper requires at least 887 mm (average of

Table 2. Irrigation water amount (I), Evapotranspiration (ET), yield.

Treatment	2011				Treatment	2012			
	Irrigation water amount (I) (mm)	*ET* (mm)	Yield [a] (t ha^{-1})	*WUE* (kg m^{-3})		Irrigation water amount (I) (mm)	*ET* (mm)	Yield [a] (t ha^{-1})	*WUE* (kg m^{-3})
$I_{1.25}$	951	1047	71.36[ab]	6.82	$I_{1.25}$	1115	1085	65.11[a]	6.41
$I_{1.00}$	801	837.6	84.16[a]	10.1	$I_{1.00}$	974	965	66.93[a]	8.52
$I_{0.66}$	598	553	65.67[b]	11.9	$I_{0.66}$	782	791	53.74[b]	9.35
$I_{0.33}$	400	400	37.09[c]	9.30	$I_{0.33}$	596	643	37.88[c]	7.60
$I_{0.00}$	72	72	20.25[d]	28.1	$I_{0.00}$	106	106	12.22[d]	19.8

[a] $P< 0.01$, lower case letters show the significant differences between irrigation treatments.

both years) irrigation water in order to obtain high yields.

Water stress is increasing in a number of countries and regions are moving into increasingly water-stressed conditions (Kijne *et al.,* 2009). In a global climatic change scenario, where the sustainable use of the water has become a priority, water has to be preserved. That is why, by limiting water application water use efficiency can be increased in the treatment of $Ik_{cp0.66}$ (Table 2), and also this water management causes the pepper to produce a reasonable economical yield. Therefore, the treatment of $Ik_{cp0.66}$ should be preferred with minimal yield loss by averaging 690 mm irrigation water. Sener and Erken (2004) reported that when the amount of irrigation water dropped from 732 mm to 549 mm, water use efficiencies and yields were reduced from 6.5 kg da^{-1} mm^{-1} and 47.32 t ha^{-1} to 4.1 kg da^{-1} mm^{-1} and 30.25 t ha^{-1}, respectively. Therefore, 700 mm of water application constitutes the break point in yield reduction for our pepper (*Capsicum annuum* L. cv. California Wonder). In the non-irrigated treatment ($Ik_{cp0.0}$) in both years, dry conditions from flowering onwards resulted in a significant reduction in yield; therefore, severe water stress led to the pepper producing a very uneconomical yield. The ratio between yield and evapotranspiration increased from full water application through to severe stress treatment. This event resulted in an increment of *WUE* to the severe stress treatment. These findings agree well with Sezen *et al.* (2006), who obtained the highest *WUE* from the stress treatment.

Intercepted Radiation and Radiation Use Efficiency

For the whole growing season, the total amount of solar radiation was 2,452 MJ m^{-2} in 2011 for a growing cycle of 134 days and 2,322 MJ m^{-2} in 2012 for a cycle of 110 days. Different irrigation treatments caused the pepper to have different leaf areas; hence the maximum value of *LAI* was recorded in the full irrigation treatment. Even though the amount of water applied was over 25% in the excess water application compared with the full irrigation treatment, good plant development in terms of plant weight and yield was observed with irrigation water of 887 mm (average of both years) in the full treatment. Therefore, the excess water application of almost 130 mm in the $Ik_{cp1.25}$ treatment was found not to have a significant effect on the yield and quality parameters of pepper (*Capsicum annuum* L. cv. California Wonder). However, in all treatments, *LAI* increased faster after the 26^{th} day of the growing cycle and continued until the 100^{th} growing day, then started decreasing due to senescence of the old leaves [Figure 1 (a, b)]. This clearly indicates that meeting the full water demand of pepper is a key factor, especially 26 days after planting, for efficiently converting radiation and plant nutrients into yield.

On the other hand, parameters related to development such as plant weight, *LAI*, yield and *RUE* indicated that plant development was negatively affected as the amount of water fell below 800 mm. The value of *LAI* in the $Ik_{cp1.00}$ treatment, in which irrigation water of 800 mm was applied, was higher; with 1.46 and 2.44 in the two consecutive years in comparison with the over- and deficit irrigations. Lindquist *et al.* (2005) reported that a reduction in *LAI* resulted in reduced *PAR* interception and contributed to consistently lower biomass. Jonckheere *et al.* (2004) reported that leaf area has a significant impact on photosynthesis and *PAR* interception. In the full irrigation treatment of the present study, peppers that were not under stress at all converted the irrigation water, nutrients and Intercepted PAR (IPAR) into a marketable yield more efficiently than the over- and deficit irrigation treatments. If limited use of irrigation water is a necessity, then the amount of 690 mm, as in the $Ik_{cp0.66}$

treatment, is the critical level for converting irrigation water and intercepted *PAR* into a reasonable economic yield.

Extreme water stress applications ($Ik_{cp0.33}$ and $Ik_{cp0.00}$) have a significant negative effect on both vegetative development and yield. When *LAI* is greater than 3, almost 90% of *PAR* is intercepted by the canopy (Sarlikioti *et al.*, 2011). In the present study, even though the total incoming solar radiation

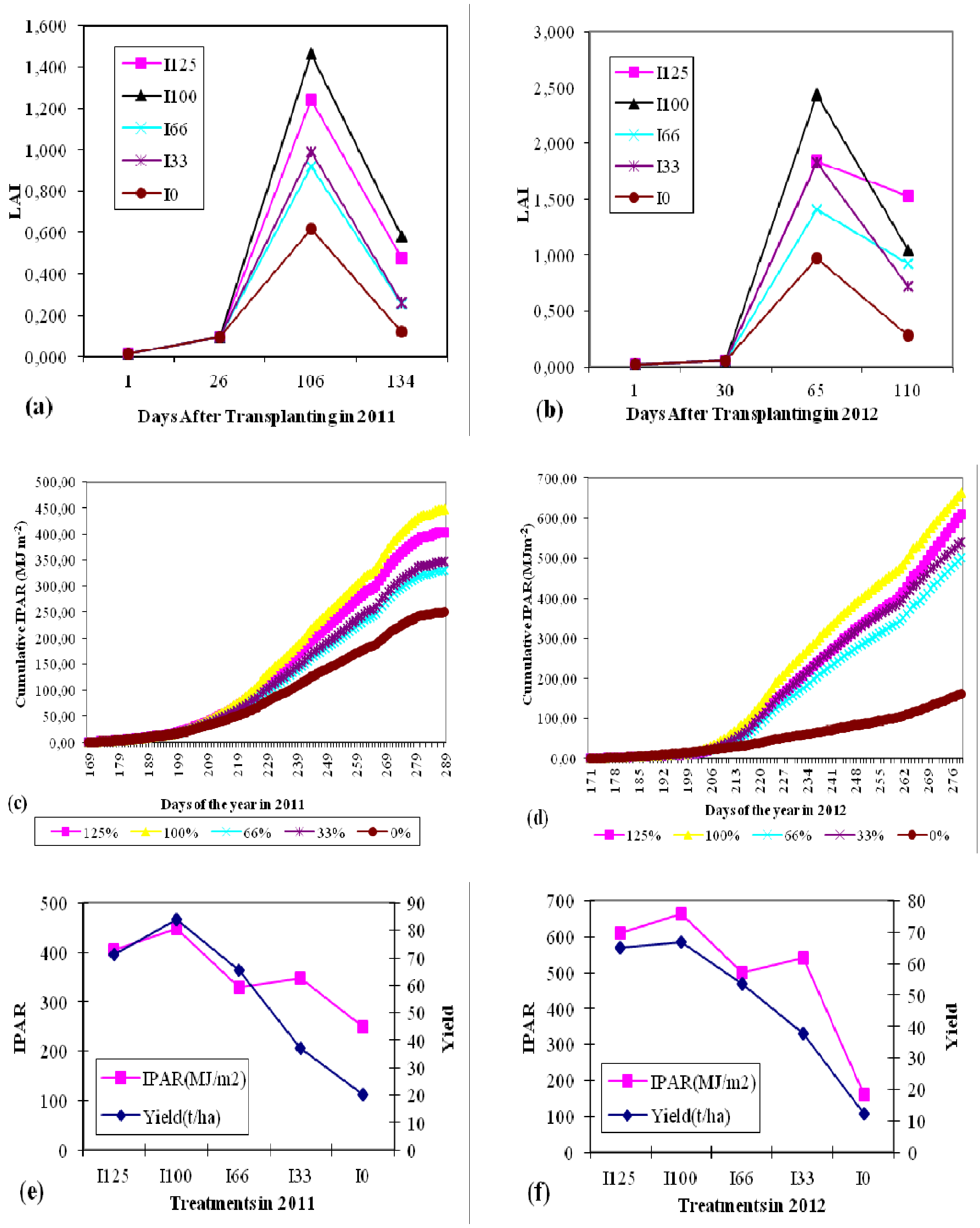

Figure 1. Changes in *LAI* and cumulative *IPAR* in growing cycle.

during the growing period was 2452 MJ m^{-2} in 2011, the intercepted *PAR* by the canopy was 447.82 MJ m^{-2} (Figure 1-c.), since *LAI* had the highest value (1.46) in the $Ik_{cp1.00}$ treatment. In 2012, that *LAI* reached 2.44 and caused the intercepted PAR to increase to 662.99 MJ m^{-2} (Figure 1-d). In both seasons, the highest yield was obtained from full irrigation in which the highest *PAR* was intercepted by the pepper canopy [Figure 1 (e, f)]. Karam *et al.* (2009) reported that water stress reduces the *IPAR* and radiation use efficiency of the crop. Therefore, the amount of intercepted *PAR* has a significant effect on yield due to its influence on the photosynthesis of the leaf area. Consequently, the highest yield was obtained from the treatment in which the full water demand of the pepper was met, as seen in Figure 1 (e, f).

Changes in the fresh and dry weight of stem, leaf and fruit against *IPAR* obtained from each irrigation treatment are given in Figure 2. In all treatments, full water irrigation had significant effects on plant development parameters (stem, leaf, fruit weight) and also radiation use efficiency. Meeting the full water demand of pepper in the $I_{1.00}$ treatment resulted in total fresh weight (stem, leaf, fruit) increasing to 107.46 and 79.03 t ha^{-1} in consecutive years. In the deficit treatments of $Ik_{cp0.66}$, $Ik_{cp0.33}$, and $Ik_{cp\ 0.00}$, total fresh weight (stem, leaf, fruit) as the average of two years compared to full irrigation was reduced by 25, 49, and 78% [Figure 2 (a, b)], respectively. According to ANOVA, the treatments had a significant effect on fresh leaf weight in 2011, but were not significant in 2012. Fresh stem weight and fruit weight (yield) in 2011 and in 2012 showed significant differences at 0.01 levels in both years. The results of ANOVA for stem and leaf weight were statistically significant in 2012, while they were not significant in 2011.

The dry weight including only stem and leaf in 2011 was the highest with 3.11 t ha^{-1} in the $I_{1.00}$ treatment; this reduced to 1.29 t ha^{-1} in the non-irrigated treatment ($Ik_{cp\ 0.0}$) [Figure 2 (c, d)]. Plants produce less dry matter if they are under water stress because this reduces the amount of *IPAR* and radiation use efficiency of a crop canopy (Karam *et al.,* 2009). Total dry weight including stem, leaf and fruit increased in 2012 up to 7.11 t ha^{-1} in the $Ik_{cp1.00}$ treatment and decreased to 2.81 t ha^{-1} in the severe stress treatment. As seen in the figures, the amount of water applied primarily affected the development of plant leaf area, and its effect on the intercepted *PAR*.

Therefore, these parameters have a significant effect on yield. *RUE* on a fresh and dry yield basis in the $Ik_{cp\ 1.00}$ treatment were 18.8 and 0.69 g MJ^{-1} in 2011 and the equivalent values were 10.1 and 1.07 g MJ^{-1} in 2012, respectively [Figure 2 (e,f)]. Radiation use efficiency on a dry yield basis was higher at 0.69 g MJ^{-1} in the $Ik_{cp1.00}$ treatment in 2011 and the equivalent value increased to 1.07 g MJ^{-1} in 2012, since *LAI* increased from 1.46 to 2.44. These results clearly indicate that the amount of irrigation water has a significant effect primarily on vegetative developments, such as the stem and leaf area, in which changes in the amount of photosynthesis and carbon dioxide uptake affects the subsequent crop yield. *RUE* on a fresh yield basis was reasonable for economic yield in the treatments of $Ik_{cp1.25}$, $Ik_{cp1.00}$, and $Ik_{cp0.66}$ in both seasons. Therefore, the critical level for irrigation water is 690 mm for pepper in terms of radiation use efficiency on both a fresh yield and dry yield basis. *RUE* on a dry yield basis as compared with full irrigation treatment was lower by 5, 15, 19, and 25% in the $Ik_{cp1.25}$, $Ik_{cp0.66}$, $Ik_{cp0.33}$, and $Ik_{cp0.00}$ treatments, respectively in 2011. A similar trend was seen in 2012. *RUE* clearly indicated a significant reduction in deficit treatments. In particular, it decreased by 43 and 57% in the $Ik_{cp0.33}$ and $Ik_{cp0.00}$ treatments, respectively.

In the present study, peppers in the $Ik_{cp1.00}$ treatment converted irrigation water of 888 mm and intercepted *PAR* into yield rather more efficiently than the other treatments. Also, the treatment of $Ik_{cp0.66}$ indicated that applied water of 690 mm was the critical

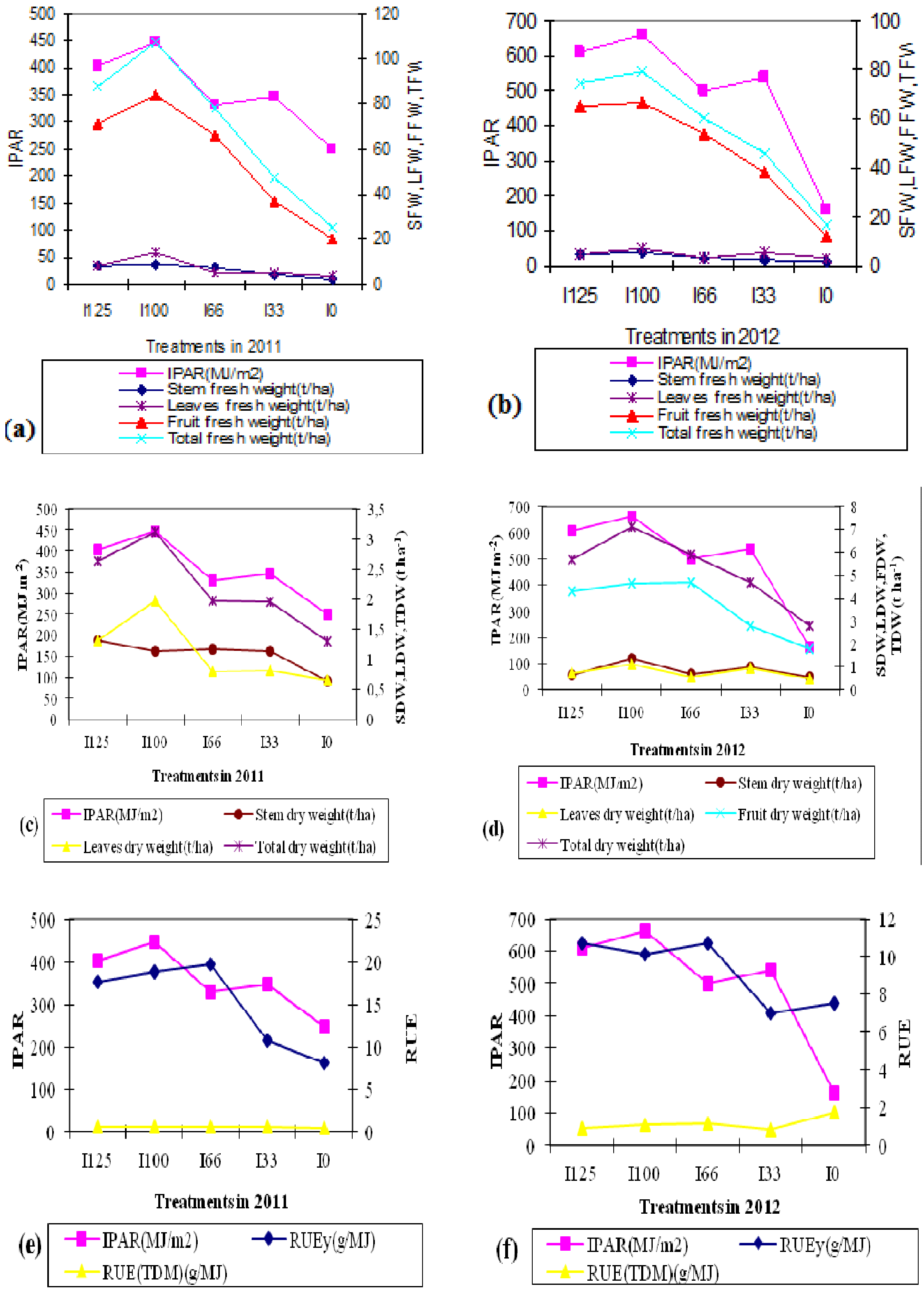

Figure 2. Relationship between *IPAR*, vegetative growth and *RUE*.

level for pepper yield since a level lower than this significantly decreased the yield and other quality parameters of the pepper (*Capsicum annuum* L. cv. California Wonder).

Different irrigation levels also have a significant effect on the fruit quality parameters of pepper. In the excess and full water applications, fruit quality parameters (fruit weight, length, and diameter) were very close to each other, but in the higher-than-deficit treatments (i.e. where irrigation water is added to the pepper root area) will give both a higher yield and higher quality per unit increment of water. ANOVA test results for 2011 revealed mean fruit weight to be F= 9.95, n= 30, P= 0.00< 0.01, mean fruit length of F= 10.7, n= 30, P= 0.00< 0.01, and the mean fruit diameter to be F=10.46, n= 30, P= 0.00<0.01. The equivalent values respectively, were F= 19.02, n= 18, P= 0.00< 0.01, F= 29.7, n= 18, P= 0.00< 0.01 and F= 53.5, n= 18, P= 0.00< 0.01 in 2012. One of the most important factors affecting sterilization time and temperature is the actual pH value of the food (Wilbur, 1983). The response of peppers to different water applications indicated that the values of pH were relatively constant at 4.50 for all treatments, but total soluble solids were higher in the deficit treatments. This agrees well with the findings of Shishido *et al.* (1992) and differences were significant at 0.01 level for both years, as given in Table 3.

CONCLUSIONS

Our results indicate the importance of irrigation on the development of pepper (*Capsicum annuum* L. cv. California Wonder) canopies and the converting of radiation and plant nutrients into yield. In particular, 26 days after planting can be considered important since flowering has begun and leaf development accelerated after that day. Leaf area has a significant impact on *PAR* interception. Therefore, intercepted *PAR* increased as *LAI* reached 2.44. Water deficit increased the dry matter; but the peppers experienced significant yield reduction. Water deficit reduces the vegetative development of pepper; hence it reduced the ability of the plant to convert intercepted energy into biomass. Therefore, providing more benefit from solar radiation and plant nutrients in the soil, the full water demand of pepper (on average 888 mm in the $Ikcp_{1.00}$) should be met. In a global climatic change scenario, where the sustainable use of water has become a priority, the treatment of $Ik_{cp0.66,}$ in which irrigation water of 690 mm was applied as an average of both years, should be considered as a water management strategy, since this level of irrigation water is the critical level for converting water and intercepted *PAR* into a reasonable economic yield. A water application of 690 mm is the break point in yield reduction of pepper. In conclusion, full water application (888 mm on average) is recommended for drip-irrigated peppers

Table 3. Fruit quality parameters.

Treatment	2011					Treatment	2012				
	Mean[a] fruit weight (g)	Mean[a] fruit length (mm)	Mean[a] fruit diameter (mm)	pH	TSS[a] (%)		Mean[a] fruit weight (g)	Mean[a] fruit length (mm)	Mean[a] fruit diameter (mm)	pH	TSS[a] (%)
$I_{1.25}$	84.77[a]	56[a]	67[a]	4.34	7.72[c]	$I_{1.25}$	145.4[b]	82[a]	71[a]	4.4	7.67[d]
$I_{1.00}$	81.16[ab]	55[ab]	66[ab]	4.40	7.94[c]	$I_{1.00}$	163.4[a]	89[a]	75[a]	4.4	7.80[d]
$I_{0.66}$	79.68[b]	51[ab]	64[ab]	4.50	8.94[c]	$I_{0.66}$	140.8[b]	80[a]	75[a]	4.3	8.08[c]
$I_{0.33}$	57.60[b]	43[b]	58[b]	4.61	10.1[b]	$I_{0.33}$	100.9[b]	74[b]	65[b]	4.4	9.38[b]
$I_{0.00}$	31.90[c]	35[c]	48[c]	5.05	11.1[a]	$I_{0.00}$	65[c]	62[c]	54[c]	4.5	10.3[a]

[a] P< 0.01.

grown in field conditions to obtain a higher yield. These results may be considered as an effective strategy for water management in peppers (*Capsicum annuum* L. cv. California Wonder).

ACKNOWLEDGEMENTS

The authors wish to thank Canakkale Onsekiz Mart University Agricultural Research Station for their assistance in this research. We are also grateful to Mr. G. H. Lee for proof-reading the manuscript and the valuable comments by reviewers.

REFERENCES

1. Adams, P. 1992. Crop Nutrition in Hydroponics. *Acta Horticulturae*, **323**: 289-305.
2. Ahmad, S., Zia-Ul-Haq, M., Ali, H., Shad, S. A., Ahmad, A., Maqsood, M., Khan, M. B., Mehmood, S. and Hussain, A. 2008. Water and Radiation Use Efficiencies of Transplanted Rice. *Pak. J. Bot.*, **40**: 199-209.
3. Alomran, A. M., Al-Harbi, A. A. R., Wahb-Allah, M. A., Alwabel, M. A., Nadeem, M. E. A. and Al-Eter, A. 2012. Management of Irrigation Water Salinity in Greenhouse Tomato Production under Calcareous Sandy Soil and Drip Irrigation. *J. Agr. Sci. Tech.*, **14**: 939-950.
4. Anonymous. 2009. *World Agriculture 2030, Main Findings*. http://www.fao.org
5. Ayers, R. S. and Westcot, D. W. 1989. *Water Quality for Agriculture*. Revision 1, FAO Irrigation and Drainage Paper, 20, Rome.
6. Bijani, M. and Hayati, D. 2015, Farmers' Perceptions toward Agricultural Water Conflict: The Case of Doroodzan Dam Irrigation Network, Iran. *J. Agr. Sci. Tech.*, **17**: 561-575.
7. Bustan, A., Cohen, S., Malach, De Y., Zimmermann, P., Golan, R., Sagi, M. and Pasternak, D. 2005. Effects of Timing and Duration of Brackish Irrigation Water on Fruit Yield and Quality Of Late Summer Melons. *Agri. Water Manage.*, **74**: 123-134.
8. Casadesus, J., Mata, M., Marsal, J. and Girona, J. 2011. Automated Irrigation of Apple Trees Based on Measurements of Light Interception by The Canopy. *Biosys. Engin.*, **108**: 220-226.
9. Charles-Edwards, D. A. and Lawn, R. J. 1984. Light Interception by Grain Legume Row Crops. *Plant Cell Environ.*, **7**: 241-251.
10. Dong, M., Luo, H., Qin, J. and He, K. 2015. Light Response of Shepherdiaargentea Rhamnoides Seedlings Under Different Soil Moisture Conditions. *J. Anim. Plant Sci.*, **25(6):** 1549-1554.
11. Doorenbos, J., Pruitt, W. O., Aboukhaled, A., Damagnez, J., Dastane, N. G., Van Den Berg, C., Rijtema, P. E., Ashford, O. M. and Frere, M. 1984. *Guidelines for Predicting Crop Water Requirements*. FAO Irrigation and Drainage Paper 24, Rome, 30 PP.
12. Ertek, A., Sensoy, S., Gedik, I. and Kucukyumuk, C. 2006. Irrigation Scheduling Based on Pan Evaporation Values for Cucumber (*Cucumis Sativus* L.) Grown Under Field Conditions. *Agri. Water Manage.*, **81**: 159-172.
13. Giorgi, F. 2006. *Climate Change Hot Spots: L08707*. Geophysical Research Letters 33. http://dx.doi.org/10.1029/2006GL025734.
14. Higashide, T. 2009. Prediction of Tomato Yield on The Basis of Solar Radiation before Anthesis Under Warm Greenhouse Conditions. *HortSci.*, **44(7):** 1874-1878.
15. Hillel, D. and Guron, Y. 1975. Relation between Evapotranspiration Rate and Maize Yield. *Water Res.*, **9**: 743-748.
16. Howell, T. 2001. Enhancing Water Use Efficiency in Irrigated Agriculture. *Argon. J.*, **93**: 281-289.
17. Jonckheere, I., Fleck, S., Nackaerts, K., Muys, B., Coppin, P., Weiss, M. and Baret, F. 2004. Review of Methods for In situ Leaf Area Index Determination. Part I. Theories, Sensors and Hemispherical Photography. *Agric. For. Meteor.*,**121**: 19-35.
18. Jovicich, E. and Cantliffe, D. J. 2007. Bell Pepper Fruit Yield and Quality as Influenced by Solar Radiation-Based Irrigation and Container Media in a Passively Ventilated Greenhouse. *HortSci.*, **42(3):** 642-652.
19. Kanber, R. 1984. *Irrigation of First and Second Crop Peanut at Cukurova Plain Using Class-A Pan*. Publication No. 114, Research Institute of Tarsus, Tarsus. (in Turkish)

20. Kar, G. and Kumar, A. 2007. Effect of Irrigation and Straw Mulch on Water Use and Tuber Yield of Potato in Eastern India. *Agric. Water Manage.*, **94**: 109-116.
21. Karam, F., Masaad, R., Bachour, R., Rhayem, C. and Rouphael, Y. 2009. Water and Radiation Use Efficiencies in Drip-Irrigated Pepper (*Capsicum annuum* L.): Response to Full and Deficit Irrigation Regimes. *Eur. J. Horti. Sci.*, **74(2)**: 79-85.
22. Kijne, J., Barron, J., Hoff, H., Rockstrom, J., Karlberg, L., Gowing, J., Wani, S. P. and Wichels, D. 2009. *Opportunities to Increase Water Productivity in Agriculture with Special Reference to Africa and South Asia*. Project Report, Stockholm Environment Institute, 3 PP.
23. Kiniry, J. R., Simpson, C. E., Schubert, A. M. and Reed, J. D. 2005. Peanut Leaf Area Index, Light Interception, Radiation Use Efficiency and Harvest Index at Three Sites in Texas. *Field Crop Res.*, **9(48)**: 81-87.
24. Kusvuran, S. and Abak, K. 2012. Kavun Genotiplerinin Kuraklık Stresine Tepkileri. *Ç.Ü. Fen ve Mühendislik Bilimleri Dergisi*, **28(5)**: 79-87. (in Turkish)
25. Li, S. E., Kang, S. Z., Li, F. S. and Zhang, L. 2008. Evapotranspiration and Crop Coefficient of Spring Maize with Plastic Mulch Using Eddy Covariance in Northwest China. *Agric. Water Manage.*, **95(11)**: 1214-1222.
26. Lindquist, J. L., Arkebauer, T. J., Walters, D. T., Cassmani, K. G. and Dobermann, A. 2005. Maize Radiation Use Efficiency under Optimum Growth Conditions. Paper 92, Agronomy-Faculty Publications, University of Nebraska-Lincoln, (http://digitalcommands.unl.edu/agronomyfacpub/92)
27. Monteith, J. L. 1965. Light Distribution and Photosynthesis in Field Crops. *Annal.Bot.*, **29**: 17-37.
28. Monteith, J. L. 1977. Climate and Efficiency of Crop Production in Britain. *Philosophical Trans. Royal Soc. London B*, **281**: 277-297.
29. Ozcan, H., Ekinci, H., Yüksel, O., Kavdır, Y. and Kaptan, H. 2004. Canakkale Onsekiz Mart Universitesi, Dardanos Yerleşkesi Toprakları, Universite Yayın No: 39 Canakkale. (in Turkish)
30. Purcell, L. C., Ball, R. A., Reaper, J. D. and Vories, E. D. 2002. Radiation Use Efficiency and Biomass Production in Soybean at Different Plant Population Densities. *Crop Sci.,* **42**: 172-177.
31. Saadi, S., Todorovic, M., Tanasijevic, L. S., Pizzigalli, C. and Lionello, P. 2014. Climate Change and Mediterranean Agriculture: Impacts on Winter Wheat and Tomato Crop Evapotranspiration, Irrigation Requirements and Yield. *Agric. Water Manage.*, DOI 10.1016/j.agwat.2014.05.008.
32. Sarlikioti, V., Meinen, E. and Marcelis, L. F. M. 2011. Crop Reflectance as a Tool for the Online Monitoring Of *LAI* and *PAR* Interception in Two Different Greenhouse Crops. *Biosys. Engin.*, **108**: 114-120.
33. Sener, S. and Erken, O. 2004. The Most Efficient Drip Irrigation Program for Pepper (*Capsicum annuum*) in Canakkale Region. *V. Sebze Tarımı Sempozyumu*, Çanakkale Ziraat Fakültesi, Onsekiz Mart Üniversitesi, 21-24 Eylül 2004, PP.327-331. (in Turkish)
34. Sezen, S. M., Yazar, A. and Eker, S. 2006. Effect of Drip Irrigation Regimes on Yield and Quality of Field Grown Bell Pepper. *Agric. Water Manage.*, **81**: 115-131.
35. Shishido, Y., Yahashi, T., Seyama, N. and Imada, S. 1992. Effects of Leaf Position and Water Management on Translocation and Distribution of 14C Assimilates in Fruiting Muskmelons. *J. Jpn Soc. Horti. Sci.*, **60**: 897-903.
36. Trapani, N., Hall, A. J., Sadras, V. O. and Vilella, F. 1992. Ontogenic Changes in Radiation-Use Efficiency of Sunflower (*Helianthus annuus* L.). *Field Crop. Res.*, **29**: 301-316.
37. Wilbur, A. G. 1983. *Tomato Production Processing and Quality Evaluation*, Avi Publishing Compony, Inc.Westport, Connecticut, 272 PP.
38. Yildirim, M., Demirel, K. and Bahar, E. 2012. Effect of Restricted Water Supply and Stress Development on Growth of Bell Pepper (*Capsicum annuum* L.) under Drought Conditions. *J. Agro. Crop Sci.*, **3(1)**: 1-9.
39. Young, S., Sammis, T. W. and Wu, I. P. 1985. Banana Yield as Affected by Deficit Irrigation and Patterns of Lateral Layouts. *Trans. ASAE*, **28(2)**: 507-518.

راندمان مصرف تشعشع و عملکرد فلفل (*Capsicum annuum* L. cv. California Wonder) تحت تیمار های مختلف آبیاری

م. ایلدیریم، ک. دمیرل، و ا. بهار

چکیده

این مطالعه به بررسی نیاز بهینه فلفل به آب (Capsicum annuum L. cv. California Wonder) و سطح انتقادی آبیاری به منظور دستیابی به عملکرد اقتصادی معقول در شرایط کمبود آب پرداخته است. در یک آزمایش کنترل شده مزرعه ای، شامل ۵ تیمار مختلف، تبخیر و تعرق فصلی برای فلفل از ۸۹ میلی متر در تیمار استرس شدید (I0.00) به ۱۰۱۸ میلی متر در کاربرد آب اضافی (I1.25) در نوسان بود. بیشترین عملکرد در تیمار کامل که در آن آب در منطقه ریشه تا ظرفیت مزرعه پر شده بود، به دست آمد. در موارد کمبود آب، استفاده از آب ۶۹۰ میلی متر عملکرد مقرون به صرفه را تضمین می کند. ماکسیمم شاخص سطح برگ در تیمار کامل (I1.00)، که در آن فلفل را قادر به استفاده حداکثری از کل تابش ورودی خورشید (میانگین 2387 MJ m-2) میکند دیده شد. میانگین 555.45 MJ m-2 توسط تاج فلفل در سراسر فصل رشد انجام شد. مقدار راندمان مصرف تشعشع بر اساس عملکرد خشک ۰.۶۹ g MJ-1 در سال ۲۰۱۱ بود که با بزرگ شدن شاخص سطح برگ از ۱.۴۶ به ۲.۴۴، به ۱.۰۷ g MJ-1 در سال ۲۰۱۲ رسید. بنابراین میانگین دو سال، تبدیل شدن آب ابیاری به Mm۸۸۸ و رسیدن به بالاترین حد دریافت تشعشع به ۷۵.۵ t ha-1 بود که از تیمار کاربرد آب اضافی یا کمبود آب راندمان بالاتری داشت.