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Water and Radiation Use Efficiencies of Pepper (*Capsicum annuum* L. cv. Carliston)

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Abstract: This study assessed the effect of different irrigation regimes for pepper plants (*Capsicum annuum* L. cv. Carliston) on vegetative growth, the intercepted photosynthetically active radiation (IPAR), water use efficiency (WUE), radiation use efficiency (RUE) for yield and total dry matter (TDM). The incoming amount of PAR was 1424.7 MJ m^{-2}, of which 285.2 Mj m^{-2} intercepted in the $I_{0.2}$, 336.3 Mj m^{-2} intercepted in the $I_{0.5}$, 352.8 Mj m^{-2} intercepted in the $I_{0.8}$, 446.8 Mj m^{-2} intercepted in the $I_{1.0}$, 407.2 Mj m^{-2} intercepted in the $I_{1.2}$ treatments. The highest yields as 20.6 Mg ha^{-1} and 21.57 Mg ha^{-1} were obtained from the $I_{1.0}$ and $I_{0.8}$ in which the applied water was 646 mm and 518 mm, respectively. Being a strong relation between IPAR and applied water (I) and evapotranspiration (ET), IPAR is thought to be used to activate the irrigation system automatically.
Keywords: Pepper (*Capsicum annuum* L. cv. Carliston), solar radiation, PAR, drip, irrigation

INTRODUCTION

The world population is now around 6 billion and is expected to reach 8.3 billion in 2030[1]. Productivty must increase to feed the growing world population [2]. Water is genarally the most important natural factor for the development of plants and the key factor for the productivity of any plant[3].

The production area of vegetables in Canakkale is 20372.4 ha, and pepper (Kaphia + Charleston + Bell pepper) covered only 27.7 % out of the whole area in 2011. In the area, pepper (*Capsicum annuum* L.) is the second largest agricultural product after tomato among all vegetable crops[4]. Understanding the water requirements of plants has become increasingly important for sustainable agriculture, especially for areas using low quality irrigation water. That water stress affects plant growth, phenology, and also leaf area development are the causes of the low productivity of plants[5]. Evapotranspiration or its components can be affected by factors such as leaf area

Irrigation activities cause pollution when an unsuitable irrigation technique is used or poor irrigation water management decisions are made[3]. Sustainable agricultural development depends on sound irrigation and water management, the main reason of which is, firstly, to satisfy crop water needs, and secondly, to maintain good soil aeration[6]. The quality of water and timing of irrigation affects primarily plant development and secondly the yield of peppers[7]. Irrigation and fertilization are considerably related factors with minimizing the occurance of fruit disorders and maximizing the marketability of the product[8]. Pepper requires relatively moist soils and adequite water supply[9]. For irrigation management purposes, it is important to determine whether high frequency of irrigation with low nutrient concentration or low frequency of that with high nutrient concentration[8]. Irrigation frequencies or different irrigation intervals can have a different effect on yield and fruit quality. Stressed conditions of any kind cause a shortening of the plants' life span[10].

The increment in crop production is able to be possible only knowing the pushing effects of irrigation and radiation on plant growth and yield. The amount of photosynthetically active radiation (PAR) intercepted by a crop is dependent on leaf area and its coverage percent of soil media [11]. The amount of solar radiation intercepted by plants is a major determinant for the total dry matter produced by a crop[12]. The most effective development forces on plants are "Carbon", "Water", and "Radiation" and energy supply of plants' comes from radiation also[13]. Plant development depends on the amount of radiation, duration of light in a day, relative humidity, wind speed and temperature[14].

Solar radiation can be used as a parameter to schedule irrigation events[8]. Plant water, nutrient uptake and transpiration rate are closely related with solar radiation[15]. There is a strong relationship between transpiration and the amount of radiation intercepted by the canopy. Therefore, the intercepted radiation by the canopy was used for automated irrigation system[16].

This study was conducted (i) to investigate the relationships among IPAR, irrigation water through different irrigation regimes and evapotranspiration (ET) whether IPAR can be used to schedule irrigation timing automatically or not, and also (ii) to determine the response of pepper (*Capsicum annuum* L.) to different irrigation regimes in terms of yield, total dry matter (TDM), and radiation use effiency (RUE) for pepper.

MATERIALS AND METHODS

Experimental design and irrigation

The field experiment was carried out at the agricultural experiment station of Canakkale Onsekiz Mart University in Canakkale (Dardanelles), Turkey. The geographical location of the experimental area was 40.08^0 N, 28.20^0E and at an elevation of 3 meters. The peppers (*Capsicum annuum* L.) were transplanted to the field on May 5, 2010 at spacings of 1.0 x 0.66 m in clay loam with 2.67 % organic matter, pH of 7.07 and EC_e of 0.62 mS/cm at the site. Each plot was arranged in 3 rows and one of it was including 30 plants. The experiment was laid out using randomized complete block design with 3 replications. Each replicate included 30 plants in the plot. Climate parameters; solar radiation (W/m^2), temperature (^0C) and relative humidity (%) at the site were measured 1.5 m above the canopy of the plants by using a HOBO U12 instrument and measurement range is from -20 ^0C to 70 ^0C for temperature, 5% to 95% for humidity, solar radiation 0 to 1750 W/m^2.

The irrigation scheduling programme for the full irrigation treatment ($I_{1.0}$) was determined by using standard programme of IRSIS (Irrigation Scheduling Information System) using Penman-Monteith equation. The programme uses the climatic data (daily solar radiation, temperature, relative humudity , coefficients of k_c for each growing period and etc.), all entered into the programme to estimate the actual evapotranspiration (ET_a). The program was ran for the treatment of $I_{1.0}$. Hence, the irrigation treatments included five gradient irrigation levels from excess water to severe drought. Only in the full irrigation was water refilled in the root zone up to field capacity, 20 % more water than the full treatment was applied in the excess water application ($I_{1.2}$). In the deficit treatments, water was applied at 80 % ($I_{0.8}$), 50 % ($I_{0.5}$) and 20 % ($I_{0.2}$) of full irrigation.

Water use efficiency (WUE) (kg m^{-3}) was defined according to Tanner and Sinclair [17].

$$WUE = Y / ET$$

Where; Y is yield (kg ha^{-1}), ET is evapotranspiration (mm).

Radiation and Radiation use efficiency

A pyranometer sensor (Hobo U12 instrument) was placed in the middle row and above a reference plant at a height of about 1.5 m and connected to a hobo data logger processer input to measure total solar radiation (W m^{-2}) as registered time and date at 1-hour intervals. Daily solar radiation as MJ m^{-2} was estimated as recommended by Monteith [18]. An exponential function is used to estimate intercepted radiation (F) by using LAI [19, 20].

$$F = 1 - \exp(-k\, LAI)$$

Where; the extinction coeeficient (k) for total solar radiation is equal to 0.306 [21]. The PAR (Photosynthetically active radiation) (Si) was assumed to be equal one half of the total incident radiation [18]. Multiplying intercepted radiation with PAR gives an estimate of the amount of radiation intercepted by a crop canopy (IPAR), The radiation utilization efficiency (RUE) for total dry matter (TDM) and for total yield of pepper (Y) also water use efficiency (WUE) for TDM were calculated as defined by Ahmad et al. [21].

$$IPAR = F \cdot Si$$
$$RUE_{TDM} = TDM / \sum IPAR$$
$$RUE_Y = Y / \sum IPAR$$
$$WUE_{TDM} = TDM / \sum ET$$

Where; TDM is total dry matter (leaves and stem) (g), IPAR is the intercepted radiation by a crop canopy (MJ / m^2).

All plant weights (stem and leaves) were determined using a sensitive weighing (0.01 g). Leaf area was determined in cm^2 using a CI 202 area meter (CID, ınc). All leaves of each plant were collected in all treatments and the leaf area index (LAI) was measured as the ratio of total leaf area of a plant to the unit area. Ten nurseries were randomly chosen at planting and the parameters such as leaf number, stem diameter, LAI etc. were measured and avaraged. Fresh weights (stem and leaves) were determined separetely by weighing. After that, they all were oven dried to a constant weight at about 70 ^0C through two days for determining dry weight of whole plants in each treatment.

Data were analyzed using SPSS statistical package software. Means were separated by Duncan's multiple range test at the probability level of 5%, 1% and also 1 ‰.

RESULTS AND DISCUSSION

The irrigation amounts (I), evapotranspiration (ET), leaf area index (LAI), intercepted PAR (IPAR), water use efficiency (WUE) and radiation use efficiency (RUE) for both yield and TDM are given in Table 1 and 2. Evapotranspiration increased as the amount of applied water increased. The peaks of yield, 20.6 Mg ha^{-1} and 21.57 Mg ha^{-1}, were obtained from the $I_{1.0}$ and $I_{0.8}$ treatments respectively, although the highest level of irrigation water was in the $I_{1.2}$ treatment. Very close values of yield in pepper (20.65-26.56 Mg ha^{-1}) were reported[22]. Sonnenveld[23] reported that low irrigation frequency for peppers can reduce plant growth and total yield and also increase the salinity in the root area due to salt accumulation. Yildirim [3] observed the specific toxicity effects of chloride and sodium in the root area of the pepper, which was because of the deposition of these soluble ions if percolation does not exist and this event directly influences the plant growth rate and then reduces the yield. The lowest yield of 15.16 Mg ha^{-1} was obtained from the $I_{0.2}$ treatment since having the lowest amount of irrigation water. Actually, this yield was higher than expected since the rainfall during the summer time higher than usual and it caused evapotranspiration to reach up to 252 mm in the $I_{0.2}$. In the treatments of $I_{1.0}$ and $I_{0.8}$ the yield of pepper was in the first group, and the treatment of $I_{0.5}$ was one of the first and second group and also can be accepted as the threshold level , since more than 50% moisture deficiency resulted in statistically significant decline in yield and retarded growth, also turgidity in fruits (Table 1). Therefore, the applied water of 324 mm in the $I_{0.5}$ produced the yield up to 18.90 Mg ha^{-1},which can be considered as the critical level for pepper production (Table 1). Also, it may be considered a reasanable yield value if water source is scarce. The amount of rainfall had a significant positive effect on the yield, even it made the yield to be very close to the full treatment. This event resulted in an increment of WUE from full water application through severe stres treatment. Yields in the stres treatments ($I_{0.5}$ and $I_{0.2}$) were high than expected, while applied water for both were low, which case provided an inverse relationship for WUE. The changes in WUE were well agree with Sezen et al.[24] obtained the highest WUE (7.6 kg m^{-3}) from the stres treatment. Good plant developments in terms of leaf area (8150 cm^2), LAI (1.23) for the pepper planted at spacings of 100x66 cm in the full irrigation ($I_{1.0}$). Yıldırım et al. [7] obtained very close values for those parameters; yield (27.6 Mg ha^{-1}), leaf area (4012.9 cm^2) and LAI (1.22) for pepper planted at spacings of 100x33 cm. Lindquist[25] reported the reduction in LAI resulted in reduced PAR interception and contributed to the consistently lower biomass. Differences in total plant leaf area (m^2 $plant^{-1}$) in quinoa are related with the density of plants[26].

Radiation use efficiency increases for sunflower since increasing the respiratory load during the grain-filling stage [27-28]. To be almost two-fold of leaf area in the present study may be attributed to the plant densities since having an effect on the use of radiation.

The intercepted radiation and radiation use efficiency

During the whole growing season (from May 5 through September 3) in 2010, the total amount of incident PAR was 1424.7 Mj m^{-2}, of which 20% (285.2 Mj m^{-2}) held in the $I_{0.2}$, 23.6 % (336.3 Mj m^{-2}) held in the $I_{0.5}$, 24.8 % (352.8 Mj m^{-2}) held in the $I_{0.8}$, 31.4 % (446.8 Mj m^{-2}) held in the $I_{1.0}$, 28.6 % (407.2 Mj m^{-2}) held in the $I_{1.2}$ treatments (Table 2). The amount of intercepted PAR between treatments differed significantly. The reason of differences in the intercepted PAR was mainly because of the leaf area, since the intercepted PAR was estimated according to the leaf area. Hence, the level of irrigation had a considerable effect on the development of plant canopy. As a result, it is evident that full watering plants in the field intercepted very high amount of PAR than the treatments that less irrigation water was applied. Pepper plants absorbed 24.8 % in the $I_{0.8}$, and 31.4 % in the $I_{1.0}$ of PAR, and consumed irrigation water of 518 mm and 646 mm respectively, and produced the highest yield of 20.6 Mg ha^{-1} in the $I_{1.0}$, 21.57 Mg ha^{-1} in the $I_{0.8}$. Therefore, plants under the excess and full irrigation treatments ($I_{1.2}$, $I_{1.0}$ and also $I_{0.8}$) if having enough amount of water in the root area, and taking carbon dioxide and solar radiation from the air under different climatic conditions for whole growing season produced more higher yield as compared with the stres treatments ($I_{0.5}$ and $I_{0.2}$). RUE increased as the yield increased in the treatment of $I_{0.8}$. It may be attributed to both proper irrigation through the whole growing season and the amount of irrigation water of 518 mm. The reduction in LAI (0.93) resulted in reduced PAR interception but may resulted in forced the plants to produce more yield rather than biomass production. Even though the applied water was high in the treatment of $I_{1.2}$, peppers in the $I_{1.0}$ and $I_{0.8}$ treatments converted the irrigation water and intercepted PAR to the yield more efficiently than other treatments, also the treatment of $I_{0.5}$ indicated that the applied water of 324 mm and IPAR of 336.3 MJ m^{-2} were the more critical levels for pepper yield since lower than that of 324 mm significantly decreased the yield and other quality parameters(not given data). Irrigation regimes significantly affected TDM and increased from severe stress treatment to excess water application. In addition, there was a significant difference between the $I_{1.2}$ and the $I_{1.0}$ treatments it was almost stable after the full irrigation. This events may be attributed to pepper plants' physiological characteristics. In other words, it is possible to say that more than 646 mm of irrigation water applied and 753 mm did not have a significant effect on the yield, TDM and other quality parameters.

The differences in the values of WUE for TDM were significant. While expecting WUE to increase from stres treatment to excess water application we obtained an inverse relation between the amount of irrigation water applied and WUE for TDM as seen in Table 2. Although there was no significant differences between treatments in the values of RUE for TDM the highest value was obtained from the treatment of $I_{0.8}$ (Table 2).

Table 1. Measured irrigation depth (I), Evapotranspiration (ET), Yield, Water Use Efficiency (WUE) and Radiation Use Efficiency (RUE) for Yield.

Treatments	Applied water (mm)	ET (mm)	Yield* (Mg ha^{-1})	WUE_Y*** (kg m^{-3})	RUE_Y*** (g MJ^{-1})
$I_{1.2}$	776	904	18.78^{ab}	2.1^{c}	4.61^{bc}
$I_{1.0}$	646	753	20.60^{a}	2.7^{bc}	4.61^{bc}
$I_{0.8}$	518	603	21.57^{a}	3.6^{bc}	6.11^{a}
$I_{0.5}$	324	465	18.90^{ab}	4.1^{b}	5.62^{ab}
$I_{0.2}$	130	252	15.16^{b}	6.0^{a}	5.32^{b}

*P<0.05, **P<0.01, ***P<0.001

Table 2. Measured leaf area index (LAI), Intercepted PAR (IPAR), Water Use Efficiency and Radiation Use Efficiency for TDM.

Treatments	LAI	IPAR (MJ m^{-2})	TDM* (Mg ha^{-1})	WUE_{TDM}*** (kg m^{-3})	RUE_{TDM} (g MJ^{-1})
$I_{1.2}$	1.10^{ab}	407.2	1.53^{a}	1.70^{c}	0.38
$I_{1.0}$	1.23^{a}	446.8	1.54^{a}	2.05^{bc}	0.34
$I_{0.8}$	0.93^{bc}	352.8	1.39^{ab}	2.30^{bc}	0.39
$I_{0.5}$	0.88^{cd}	336.3	1.22^{bc}	2.62^{b}	0.36
$I_{0.2}$	0.73^{d}	285.2	0.83^{c}	3.30^{a}	0.29

*P<0.05, **P<0.01, ***P<0.001

The relationships among yield, TDM, RUE, I and ET, IPAR for all irrigation treatments throughout the entire growing season were compiled and are shown in fig.1. There is a considerable quadratic relationship between yield and ET in fig.1-a. In graph a, the best response of pepper to water was obtained from the treatments of $I_{1.0}$ and $I_{0.8}$, then yield started decreasing after full irrigation ($I_{1.0}$), even there was an excess water application in the $I_{1.2}$ than plants need. TDM increased up to the applied water of 646 mm in the $I_{1.0}$, then it was almost stable in the $I_{1.2}$ as shown in fig.1-b. Although RUE for both yield and TDM fluctuated between irrigation treatments, the highest RUE for both was from the $I_{0.8}$ (fig.1-c,d). The relationships of yield and TDM with IPAR (fig.1-e,f) exhibited almost a similar result with ET and TDM in fig.1-a,b, that is, the highest yield was provided with the intercepted PAR of 352.8 MJ m^{-2} from the $I_{0.8}$ treatment eventough the value of LAI was 0.93, lower than 1.0. Therefore, the applied irrigation water of 518 mm and intercepted PAR of pepper in the $I_{0.8}$ treatment provided an optimal irrigation water management in terms of pepper yield.

There is an considerable lineer relationship between IPAR and applied water (I) and evapotranspiration (ET) (fig.1-g,h). To increase irrigation efficiency in a group of homogeneous plants in a nursery Caceres et al. [29] reported that it is necessary to determine the dosage of water to be applied and the criteria for activating the irrigation system automatically. Casadesus et al. [16] reported that the intercepted radiation by the canopy was used for automated irrigation. The strong relationship was found between transpiration and the amount of radiation intercepted by the canopy. The relation in fig.1-g-h clearly indicates that the irrigation management for pepper (*Capsicum Annuum* L.) can be performed according to IPAR, and even the management if arranged to the intercepted PAR in the treatments of $I_{1.0}$ or $I_{0.8}$ can give an optimal yield value for pepper (*Capsicum annuum* L.). Jovicich and Cantliffe [8] established an automated irrigation system for pepper (*Capsicum annuum* L.). The system performed for the whole growing season according to the determined cumulative solar radiation. This results clearly indicates the pressurized drip irrigation systems for pepper growth can be controlled automatically according to the values of IPAR.

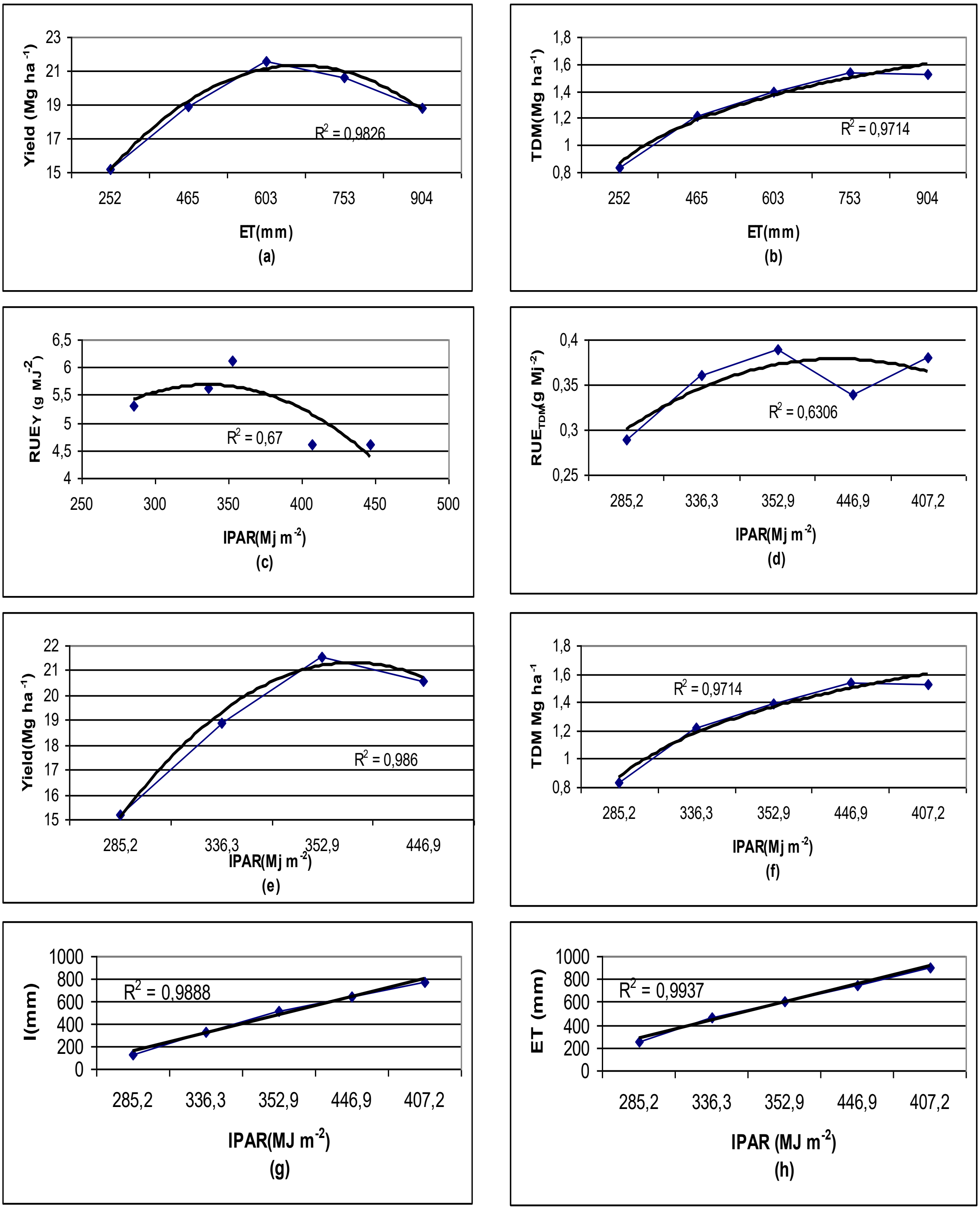

Fig-1: The relationships among Yield, TDM, RUE, I, ET and IPAR

CONCLUSION

Careful attention in irrigation must be paid to get an acceptable yield. Southwest western Australia (SWWA) has experienced a significant decrease in winter rainfall since the late 1960s [30]. Climate change is already occuring and represents one of the greatest enviromental threats facing our planet [31]. In the world, the use of irrigation water in agriculture has been gaining more importance in arid and sami arid regions. In the experiment, pepper (*Capsicum annuum* L.) plants produced the highest yields in $I_{0.8}$ and $I_{1.0}$ treatments as the amount of water applied were 518 mm and 646 mm, respectively. Those irrigation amount provided pepper plants to intercept 24.8% of PAR in the $I_{0.8}$ and 31.4% of PAR in the $I_{1.0}$ out of 1424.7 MJ m^{-2}. Therefore applying irrigation water for pepper between 518 mm and 646 mm seems to be more appropriate level for getting higher yield and for using solar radiation more efficiently. Also, to schedule the irrigation according to the intercepted PAR either in the $I_{0.8}$ or in the $I_{1.0}$ treatment will ensure optimum yield. This result may be considered as an effective strategy for water management in peppers.

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