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Evaporation, Radiation use Efficiencies and Solar Radiation Relationships to be used in an Auotamated Irrigation System for Field Grown Melon (*Cucumis melo* L. cv. Ananas F1)

Murat Yıldırım[1*] Okan Erken[1]

[1]COMU Faculty of Agriculture, Department of Agricultural Structures and Irrigation, Canakkale/Turkey.
[*]Corresponding Author: myildirim@comu.edu.tr

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Abstract

This study assessed water needs of melon (*Cucumis melo* L. cv. Ananas F1) by using class–A pan and determined the effect of the irrigation management on vegetative growth, the intercepted photosynthetically active radiation (IPAR), water use efficiency (WUE), radiation use efficiency (RUE) for total dry matter (TDM). The incoming amount of solar radiation was 2174.3 MJ m^{-2} day^{-1} for 89 days period, of which 372.69 MJ m^{-2} day^{-1} intercepted by melon canopy. With the effect of the applied irrigation water of 412.1 mm and the intercepted radiation of 372.69 MJ m^{-2} by the plant canopy, Ananas melon variety produced the yield of 23.01 Mg ha–1. Being a strong relationship between evaporation from class–A pan and solar radiation and mean temperature, the equation developed in this study is thought to be used to activate the pressurized irrigation systems automatically.
Keywords: Melon (*Cucumis melo* L.), Evaporation, Solar radiation, Automation, Drip irrigation, PAR.

Öz

Arazi Koşullarında Yetiştirilen Kavun (*Cucumis melo* L. cv. Ananas F1) Bitkisinde Kullanılabilecek bir Otomatik Sulama Sisteminde Kullanılabilecek Buharlaşma, Radyasyon Kullanım Etkinliği ve Solar Radyasyon Arasındaki İlişki

Bu çalışmada, A sınıfı buharlaşma kabı yöntemi kullanarak kavunun (*Cucumis melo* L. cv. Ananas F1) su ihtiyacı, su yönetiminin kavunun vejetatif gelişimi üzerine etkileri, fotosentezde kullanılan aktif radyasyon (IPAR), su kullanım etkinliği (WUE), toplam kuru madde (TDM) için radyasyon kullanım etkinliği (RUE) değerleri belirlenmiştir. Bitki gelişim dönemi olan 89 günlük periyot içerisinde gelen toplam solar radyasyon miktarı 2174,3 MJ m^{-2} $gün^{-1}$ olmuştur, bu periyot içerisinde gelen solar radyasyonunun 372,69 MJ m^{-2} $gün^{-1}$ kısmı bitki tarafından tutulmuş ve uygulanan sulama suyuna karşılık 23,01 ton ha^{-1} kavun verimi elde edilmiştir. Bu çalışma sonucunda, A–sınıfı buharlaşma kabından meydana gelen buharlaşma, solar radyasyon ve ortalama sıcaklık arasında güçlü bir ilişki olduğu ve bu ilişkiden yararlanarak özellikle otomatik sulama sistemlerinin aktive edilebileceği düşünülmektedir.
Anahtar Kelimeler: Kavun (*Cucumis melo* L.), Buharlaşma, Solar radyasyon, Otomasyon, Damla sulama, PAR.

Introduction

The world population is now around 7 billion (Anonymous, 2014a). Productivity must be increased to feed the growing world population (Howell, 2001). Agriculture uses 72% of the world's freshwater (Cai and Rosegrant, 2003). Freshwater resources are mostly allocated to agricultural sector around 70% especially for irrigations and increasing domestic and industrial water demands enforce fresh water users to use water efficiently (Akuzum et al., 2010). World melon production totalled 31. 053.716 tons in 2009 and the most important melon producing countries are China, which accounted for 52% of total production in 2009, Turkey yielded 1.880.692 tons of melon in 2009 and Turkey is followed by Iran, the United States and Spain (Anonymous, 2014b). Understanding the water requirements of plants has become increasingly important for sustainable agriculture, especially for areas using low quality irrigation water. Therefore, sustainable agricultural development in coastal areas depends on sound irrigation and water management. Water scarcity and water quality degradation are important issues in water management (Yildirim, 2010). The reducing amount of fresh water has become a problem all around the world. The water saving in agriculture has an important key role for dealing with the water shortage, since water use in agriculture is higher than industrial and urban uses (Zeng et al., 2009). The reduction in freshwater resources enforces the agricultural producers to use the second quality or contaminated water in agriculture (Buston et al., 2005). Limited water resources, recent global warming and climate change bring optimum water use into the forefront especially in arid and semiarid regions (Cakmak et al., 2007). The quality of water and timing of irrigation affects primarily plant development and scondly the yield of peppers (Yildirim et al., 2012).

Saving water and energy in agriculture, the current trend is toward switching from a manual system to automatic operations in a pressurized system (Yildirim and Demirel, 2011). Automated irrigation systems provide high crop yield, save water compared to conventional systems (Mulas, 1986), facilitate high frequency and low volume irrigation (Abraham et al., 2000) and also reduce human error (Castanon, 1992).

The amount of solar radiation can be used as a parameter to schedule irrigation events (Jovicich and Cantliffe, 2007). Plant water, nutrient uptake and transpiration rate are closely related with solar radiation (Adams, 1992). 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 (Casadesus et al., 2011).

This study was conducted (i) to investigate the relationships between solar radiation (Rs), intercepted photosynteticly active radiation (IPAR), irrigation water (I), evaporation (Ep) and evapotranspiration (ET), (ii) to determine the response of melon to irrigation program in terms of yield and quality parameters, (iii) to determine whether Rs and temperature be used to schedule irrigation timing or not.

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 (Dardalelles), Turkey. The geographical location of the experimental area was 40.08^o N, 28.20^o E. The melon (*Cucumis melo* L. cv. Ananas) was planted as a nursery at a spacing of 100x100. The planting date was 24 May, 2013. All plants received the same amount of 260 kg ha^{-1} (NPK; 18:18:18) and 80 kg ha^{-1}(K; 0:0:51). The soil type is clay loam with 2.67% organic matter, pH of 7.7 and EC_e of 0.62 mS/cm at the site. Each plot was arranged in 3 rows of 30 plants. Climate parameters; solar radiation(W/m^2), temperature T (^{o}C) 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 was from –20 to 70^{o}C for temperature, 5% to 95% for humidity, solar radiation 0 to 1.750 W/m^2. Evaporation was measured by using a Class–A pan and irrigation interval was 4 days throughout the whole growing season for melon. The soil moisture was brought to field capacity by applying full irrigation water to the plant roots in two treatment blocks.

Irrigation amounts were estimated by the following equation (Doorenbos and Pruitt, 1992).

$$I = Ep.A.Kcp.P \tag{1}$$

Where; I is the amount of irrigation water (mm), Ep is evaporation between irrigation intervals from Class–A pan (mm), A is plot area (m^2), K_{cp} is crop–pan coefficient, and P is the crop coverage as percent (%). Crop–pan coefficient (K_{cp}) was 0.8 from tranplanting to fruit development, and then changed as 1.3 from fruit development to ripening period. Evapotranspiration (ET, mm) was estimated as follows;

$$ET = Kcp \cdot Ep \tag{2}$$

Water use efficiency (WUE, kg m^{-3}) (Taner and Sinclair, 1983) was defined as below;

$$WUE = \frac{Y}{ET} \tag{3}$$

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

Radiation and radiation use efficiency: A pyronometer 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 processor 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} d^{-1} was estimated as recommended by Monteith (1977). The fraction of PAR intercepted at midday (F) was calculated as (Charles–Edwards and Lawn, 1984),

$$F=\frac{(I_o - I_t)}{I_o} \tag{4}$$

Where; I_o and I_t are the means of the measurements; incident PAR above canopy, transmitted PAR below canopy at soil surface level, respectively. Daily fraction of PAR intercepted (Fd) was calculated by using midday values, as proposed by Charles–Edwards and Lawn, (1984) as follows;

$$F_d=\frac{(2F)}{(1+F)} \tag{5}$$

Multiplying daily fraction of PAR intercepted with PAR (S_i) gives an estimate of amount of radiation intercepted by a crop canopy (IPAR), the radiation use efficiency (RUE) for total dry matter (TDM) were calculated as defined by Ahmad et al. (2008).

$$IPAR = F_d \,.\, S_i \tag{6}$$

$$RUE_{TDM} = \frac{TDM}{\sum IPAR} \tag{7}$$

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

Plant and fruit quality parameters: All plant weights (vein and leaf) were determined using a digital balance (±0.01 g) and diameters were measured with a digital clipper (±0.01 mm). Leaf area was determined by CI–202 area meter (CID, inc.) as cm^2, all leaves of each plant were collected in all treatments, and leaf area index (LAI) was measured as the ratio of total leaf area of a plant to the unit area. Soluble solids were determined on a blended composite using Serico portable hand refractometer. pH was determined for 100 ml fruit juice by a pH meter (Milwaukee Comp.). Three nurseries were randomly chosen and the parameters such as leaf number, vein, LAI, etc. were measured and averaged, then the same values were assigned to each treatment. Carbohydrate (CH) content of the fruit flesh as a reduced and total sugar concentration (Glucose+sucrose+fructose) was determined by dinitrophenol method. Concentration of sugars (g/100g) was calculated according to Ross (1959). Fresh weights (vein and leaf) were determined separately by weighing. After that, they all were oven dried to a constant weight at about 70 ^{o}C through two days for determining dry weight of whole plants in each treatment.

Multiple linear regression analysis and ANOVA test were applied between cumulative solar radiation (Rs) and temperature and cumulative irrigation, evaporation and evapotranspiration to develop a relationship between all the data to be used or not in irrigation automation.

Results and Discussion

Applied irrigation water and evapotranspiration, solar radiation (Rs), intercepted PAR (Photosynthetically active radiation, IPAR), evaporation from class–A pan, cumulative heat from transplanting to harvesting T (^{o}C) for all plant development stages are given in Table 1.

Total seasonal irrigation water applied was 412.1 mm and evapotranspiration was 643.1 mm (Table 1.). In stage 1, covering from transplanting to the flowering, lasting 14 days, mean cumulative temperature T (^{o}C) and total solar radiation (R_s) were 302.9^{o}C, 361.4 MJ m^{-2} for 14 days period.

During this period, evaporation from Class–A pan, the applied irrigation water and evapotranspiration were 57mm, 47 mm, and 47 mm, respectively. Irrigation interval was 4–day through the whole growing season. Total amount of incident PAR was 361.4 MJ m^{-2}, of which almost 5.4% (19.65 MJ m^{-2}) held by the melon canopy and the total solar radiation was 130.3 MJ m^{-2} , the amount of irrigation water was 13.5 mm for each irrigation for 4–day period and leaf area and LAI were 92.72 cm^{2} and 0.012, respectively in stage 1. The amount of solar radiation intercepted by plants is a major determinant for the total dry matter produced by a crop (Biscoe and Gallagher, 1978). 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 PAR intercepted by a crop is dependent on leaf area and its coverage percent of soil media (Monteith, 1977). In stage 2, covering from flowering to the time that the golf–ball size melon or smaller was seen, lasting 20–days after flowering, the total amount of solar radiation was 1017.2 MJ m^{-2} , of which 10.2% (103.91 MJ m^{-2}) held by melon canopy, leaf area and LAI was developed up to 2725 cm^{2}, 0.336, respectively, and also in this stage the total solar radiation coming for 4–day period was 131.2 MJ m^{-2} and evaporation from class–A pan was 29.24 mm and the amount of irrigation water applied for this period was 21.1 mm for each irrigation. In stage 3, covering fruit development and first harvesting, lasting 14 days, the cumulative solar radiation upto the end of this period was 1476.4 MJ m^{-2}, of which 13.8% (203.28 MJ m^{-2}) held by the canopy. The leaf area and LAI reached the highest level of 859.5 cm^{2}, 1.061, respectively, and also in this stage the total solar radiation coming for 4–day period was 131.2 MJ m^{-2} and evaporation from class–A pan was 33.7 mm and the amount of irrigation water applied for this period was 47.3 mm for each irrigation. In stage 4, covering fruit ripening and last harvest, lasting 41 days, at the end of this period melon plants encountered to the cumulative solar radiation of 2174.3 MJ m^{-2}, of which 17.1% (372.69 MJ m^{-2}) held by the canopy, however, leaf area decreased to 4521 cm^{2} due to senescent of the leaves, also LAI, 0.558. Plants in this stage received the solar radiation of 118.4 MJ m^{-2} within 4–day periods and evaporation from class–A pan was 23.7 mm, also in each irrigation made at intervals of 4 days, 16.5 mm of water was applied. With this irrigation management, a successful plant development and yield of melon has been achieved.

Table 1. Irrigation depth(I), evapotranspiration (ET), evaporation (Ep), Solar radiation (Rs), IPAR, Cumulative mean heat (T)

Stages	**Days**	**I(mm)**	**ET (mm)**	**Ep (mm)**	**Rs (MJ m^{-2} day^{-1})**	**IPAR (MJ m^{-2} day^{-})**	**T (^{o}C)**
1	**14**	47	47	57	361.40	19.650	302.90
2	**20**	152.5	162.5	203.2	1017.2	103.91	787.30
3	**14**	317.9	315.9	321.2	1476.4	203.28	1136.3
4	**41**	412.1	643.1	572.9	2174.3	372.69	2207.7

Table 2. Yield, Plant and fruit fresh and dry weights, RUE, WUE, Leaf area and LAI

Stages	**Yield (Mg ha^{-1})**	**Whole plant weight (g) (veins and leaves)**		**Fruit weight (g)**		**RUE$_{TDM}$ (MJ m^{-2})**	**WUE (kgm^{-3})**	**Leaf area (cm^{2})**	**LAI**
		Fresh weight	**Dry weight**	**Fresh weight**	**Dry weight**				
1		10	1.6					92.71	0.012
2		271	41.5			0.40		2725	0.336
3	5.170	1742	121.4	1143.2	53.3	1.06	1.6	8595	1.061
4	17.84	2320	200	2264.7	120	0.86	3.6	4521	0.558

Ananas melon variety, 34 days after planting, began to form its mature fruits and leaf area to 2725 cm^{2} by both exposing to the solar radiation of 1017.2 MJ m^{-2} and receiving water of 152.5 mm. Also, by holding almost 10% of the incident radiation, dry weight of the plant (vein+leaves) raised from 1.6 g to 41.5 g (Table 2.). At the end of 48 days, plant received the radiation of 1476 MJ m^{-2} and irrigation water of 317.9 mm, which led plant to develop leaf area to 8595 cm^{2} and LAI to 1.061. At the end of the 3rd period, by holding nearly 13% of the incident radiation plant increased dry weight (vein+leaves) to 121.4 g plant^{-1}, and fruit fresh weight to 1143.2 g fruit^{-1} and dry weight to 53.3 g fruit^{-1}. In 4th period, by absorbing almost 17% of incident radiation of 2174.3 MJ m^{-2} and receiving irrigation water of 412.1 mm plants developed both its vegetative growth (vein+leaves) in fresh 2320 g plant^{-1} and in dry weight 200 g plant^{-1} and its fresh fruit weight to 2264.7 g fruit^{-1}, dry fruit weight to 120 g fruit^{-1}.

By the applied irrigation water of 412.1 mm and holding 372.69 MJ m^{-2} of the incident radiation, ananas melon variety produced the yield of 23.01 Mg ha^{-1}. Zeng et al. (2009), have developed a relationship between yield and water, which is Y(kg ha^{-1})= 42.517 I (mm)+8097.9. This water–yield relationship indicates a close relationship with the current findings. Sensoy et al. (2007) obtained the yield of 32.4 Mg ha^{-1} with Kcp=0.9, 6–day irrigation interval and the application of 548.8 mm irrigation water for *Cucumis melo* L. Bonanca F1, but Tekiner et al.(2010) increased the yield up to 49.04 Mg ha^{-1} with Kcp=0.5, 12–day interval and irrigation water of 168 mm for *Cucumis melo* L. Carna F1. These results indicate that a wide range of irrigation interval may have positive effects on both yield and quality for melon cultivars. The quality parameters of fruit were obtained as follows; fruit diameter and length were 13 cm, 18.5 cm, respectively. Seed house diameter and length were 58.8 mm, 123 mm, respectively. Flesh and peel thickness were 42.7 mm, 7 mm, respectively. In the first harvest pH of fruit juice was 5.56, but increased to 6.22 in the second (last) harvest. Also, total soluble solid became 5.2% while it was 4.1% in the first harvest. Water use efficiency increased from 1.6 kg m^{-3} to 3.6 kg m^{-3} to the last harvest. While radiation use efficiency was 0.9 g MJ^{-1}day^{-1} in the vegetative period, it increased to 1.06 g MJ^{-1}day^{-1} during fruit development. However, it decreased to 0.86 g MJ^{-1} day^{-1} because of the drying up of some branches and leaves in the 4th period. Total sugar and reduced sugar in fruits at the first harvest were 0.8435 g/100g and 2.1975 g/100 g, but those values dropped to 0.7415 g/100g, and 1.969 g/100g, respectively. Excessive amounts of water deficit decreases yield but increases quality and total soluble solids (Shishida et al., 1992; Hernandez et al., 1995). The amount of irrigation water corresponding to 75% of evapotranspiration demand of melon provided the highest yield and quality (Yildirim et al., 2009). Implementation of irrigation water in limited quantities increases yield and quality of fruit (Lei et al., 2003). This result showed that the frequent irrigation with 4 days interval during fruit ripening period reduces the sugar content of the fruit. Therefore, the irrigation management for melon production is a key role in terms of yield and quality. Irrigation interval during ripening period should be a wider range rather than 4 day intervals.

To schedule the irrigation according to the intercepted PAR will ensure optimum yield. The linear and multiple linear regression analysis indicated that there is a strong relationship between solar radiation and irrigation water, evaporation and evapotranspiration. The equations were as follows; I(mm)= –32.7+0.211Rs (MJ m^{-2} day^{-1}) R^2= 96.8% and the statistical result of the anova test was F=59.81, p= 0.016<0.05. Ep (mm)= –67.8+0.283Rs, R^2= 98.4%, F= 124.13, p= 0.008 <0.01. ET (mm)= –124+0.331Rs, R^2= 95.2%, F=20.11, p= 0.024<0.05. According to the multiple linear regression analysis, the equations were as follows; I(mm)= –50 +0.303Rs–0.089T (^{o}C), R^2= 97.6%, F= 20.11, p= 0.156>0.05. Ep(mm)= –35.9+0.113Rs + 0.164T, R^2= 100%, F= 1591.7, p= 0.018 <0.05 and ET(mm)= –61.6–0.004Rs+0.323T, R^2= 99.5%, F= 93.81, p= 0.073>0.05. Results indicate that there is a strong relationship of solar radiation and temperature, even over 95% with applied irrigation water, evaporation from class–A pan, and also evapotranspiration. Hence, an automatic irrigation system can be performed by measuring daily solar radiation and mean temperature to estimate daily evaporation as mm from class–A pan by using these equations. These results can be considered as an irrigation strategy for melon in an automated irrigation systems.

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