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Water and Radiation Use Efficiency of Eggplant Under None Water Stress Condition in Semi–Arid Region

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Abstract

An experiment was conducted in an open field to determine the simultaneous relationship between radiation interception, evapotranspiration, plant development and yield. Full water demand of eggplant (*Solanum melongena* L. cv) was met througout the entire growing season by using Class–A pan in 2014. This study assessed the intercepted photosynthetically active radiation (IPAR), water use efficiency (WUE), radiation use efficiency (RUE) and total dry matter (TDM) of Eggplant (*Solanum melongena* L.) in each stages throuhout the all growing period. The incident PAR was 1120 MJ m^{-2}, of which 393 Mj m^{-2} intercepted by the eggplant canopy. The yield was 41.5 t ha^{-1}, with the applied water of 509 mm and evapotranspiration of 612.9 mm for the entire growing season, lasting 113 days. In this experiment, a strong relationship was determined between solar radiation and evaporation occuring from Class–A pan. Therefore, it is thought to be used in the activatation of micro irrigation systems automatically.

Keywords: Eggplant, PAR, RUE, Solar radiation, Irrigation, Class–A pan.

Öz

Yarı Kurak ve Su Stresssinin Olmadığı Koşullar Altında Patlıcan Bitkisinin Su ve Radyasyon Kullanım Etkinliği

Bu çalışmada; patlıcan bitkisinde, bitki yüzeyine gelen solar radyasyon, fotosentezde kullanılan aktif radyasyon (IPAR), su kullanım etkinliği (WUE), toplam kuru madde (TDM) için radyasyon kullanım etkinliği (RUE) ve bitki su tüketim değerleri belirlenmiştir. Arazi koşullarında yetiştirilen patlıcan'da bitki gelişimi ve verim arasındaki ilişki belirlenmeye çalışılmıştır. Tüm gelişim dönemi süresince patlıcanın (*Solanum melongena* L. cv) su ihtiyacı A sınıfı buharlaşma kabı yöntemine göre belirlenmiştir. Bitki gelişim dönemi olan 113 günlük periyot içerisinde bitkinin gerçekleştirdiği fotosentezde kullanılan aktif radyasyon miktarı 1120 MJ m^{-2} olmuştur, bu periyot içerisinde gelen solar radyasyonunun 393 MJ m^{-2} kısmı bitki tarafından tutulmuş ve uygulanan 509 mm sulama suyu ve 612,9 mm bitki su tüketimine karşılık 41,5 ton ha^{-1} verim 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: Patlıcan, PAR, RUE, Solar radyasyon, Sulama, A–sınıfı buharlaşma kabı.

Introduction

Knowledge of water need and radiation use of each plant are fundemental for understanding many aspects of all crops. Water is generally the most important natural factor to get an economical yield and productivity in agriculture must be increased year by year due to increasing world population. 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 freshwater users to use water efficiently (Akuzum et al., 2010).

Total production of eggplant in Turkey was 799,285 tons, hence Turkey was the fifth largest eggplant producer in the world in 2012 (Faostat, 2015). Eggplant production has been increasing day by day due to their medicinal properties and also a good source of minerals and vitamins (Goncalves et al., 2006). Irrigation activities can cause an enviromental pollution if an unsuitable irrigation technique is used or poor irrigation management decisions are made (Yildirim, 2010). Suitable 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 (McNiesh et al., 1985). Irrigation should not be seen only as a technique used to eliminate the risk of losses caused by drought, it should be seen as a key element to improve the irrigation technology. This will provide increasing food production, and also add quality and productivity (De Carvalho et al., 2012).

Excess irrigation water provides the further development of plant vegetative componenets, which usually reduces the amount and the quality of its production. Excess amount of water cause the leaching of soluble nutrients and also higher energy coasts.

The reduction in growth, yield and quality of eggplants against the water stress has been well documented (Kirnak et al., 2001a). Therefore, more studies are required to determine the relationships of evapotranspiration, radiation use efficiency, plant development, yield for all type crops.

This study, based on the previous informations, aimed to determine the water needs, radiation use efficiency of eggplants and also to establish a relationship between evaporation and solar radiation for each growing periods.

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, 2014. The geographical location of the experimental area was 40.08^0 N, 28.20^0E and at elevation of 3 meters.

The eggplant (*Solanum melongena* L. cv) were transplanted to the field on May 15, 2014 at spacings of 0.70 x 0.33 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 4 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 120 plants in the plot. Climate parameters; solar radiation (W/m^2), temperature (^{0}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 is from -20^0C to 70^0C for temperature, 5% to 95% for humidity, solar radiation 0 to 1750 W/m^2 given in fig 2-(f).

The irrigation scheduling programme for all growing season was carried out by using Class–A pan. Evaporation was measured with 4–day intervals, hence water was applied to all plots with that interval. Irrigation amounts were estimated by the following equation (Kanber, 1984).

$$I= Ep.Kcp.P$$

Where, I is applied irrigation water (mm), Ep is cumulative evaporation amount (mm), Kcp is crop-pan coefficent and taken as 1 for all growing period, P is the percentage of soil cover.

Water use efficiency (WUE) (kg m^{-3}) was defined according to Tanner and Sinclair (1983).

$$WUE = Y / ET$$

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 (1977). An exponential function is used to estimate intercepted radiation (F) by using LAI (Monteith and Elston, 1983; Trapani et al., 1992).

$$F = 1 – \exp(-k\ LAI)$$

Where; the extinction coeeficient (k) for total solar radiation was taken as 0.77 used for light interception of eggplant by Rosati et al. (2001). The PAR (Photosynthetically active radiation) (Si) was assumed to be equal one half of the total incident radiation (Monteith and Unsworth, 1973). 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) were calculated as defined by Ahmad et al. (2008).

$$IPAR = F . Si$$
$$RUE_{TDM} = TDM / \sum IPAR$$

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

All plant weights (stem and leaves and fruits) were determined using a sensitive weighing (0.01 g). Leaf area was determined in cm^2 using a CI 202 area meter (CID, inc). 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 plants for each sampling date were randomly chosen and the parameters such as fresh and dry weights,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.

Results and Discussion

The irrigation amounts (I), evapotranspiration (ET), yield, solar radiation (Rs), PAR, (intercepted PAR (IPAR), water use efficiency (WUE), radiation use efficiency (RUE_{TDM}) for total dry matter (TDM) and cumulative mean temperature from transplanting to harvesting T (^{o}C) for all plant development stages are given in Table 1.

During the whole growing season, total solar radiation coming to plant canopy surface was 2603 MJ m^{-2}, and incident PAR was 1120 MJ m^{-2}, of which 35% (393 MJ m^{-2}) held by the eggplant canopy in Table 1. The canopy of eggplant up to the begining of flowering period was exposed to climatic parameters; solar radiation, and mean cumulative temperature were 1102 MJ m^{-2} and 1010^{o}C, respectively, for 48 days period. In this period, applied water and evapotranspiration were 201 mm and 231.3 mm, respectively. In the second step that the first fruits were seen, lasting 40 days after flowering (88 Days after transplanting, DAT), the total amount of solar radiation was 2075 MJm^{-2} and incident PAR was 895 MJm^{-2} of which 28% held by eggplant canopy and also the applied water and evapotranspiration were 493 mm and 532.8 mm, respectively. Total cumulative temperature was 2025^{o}C till 88 days after transplanting. At the end of the growing season, the incident PAR was 976 MJ m^{-2}, of which 35% held by the canopy, while solar radiation reached to the plant surface was 2603 MJ m^{-2}.

Full water demand of eggplant was provided througout the entire growing season, that is, when almost 30–40% of soil moisture in total available water was depleted in the effective root depth, then soil was refilled with water up to field capacity. In this experiment, under none water stress condition eggplant consumed water of 612.9 mm during the entire gowing season by applying water of 509 mm. Eggplant canopy intercepted radient energy of 393 MJm^{-2} out of solar energy of 2603 MJm^{-2}. Full water demand of eggplant (509 mm) should be provided to get the yield of 41.5 t ha^{-1}, and to use solar radiation efficiently by plant canopy. Kirnak et al. (2001b), obtained different yield values for eggplant from 60.1 t ha^{-1} to 40.2 t ha^{-1}, by applying water of 1275 mm and 510 mm, respectively. The highest yield value was obtained by the very high irrigation level of 1275 mm, while the yield was 40.2 t ha^{-1} against the application of water of 510 mm. The reason of high irrigation water applied should be the climate since the site that experiment was carried out was in the arid region. Halitligil et al., (2015) obtained the highest marketable yield (44.3 t ha^{-1}) with the application of water of 435 mm and 100 mg N/L nitrogen rate.

Table 1. Measured irrigation depth(I), evapotranspiration(ET_c), yield, solar radiation(Rs), PAR,IPAR, RUE_{TDM}, WUE, LAI, cumulative temperatures for each growing stages

DAT*	I (mm)	ETc (mm)	Yield (kg ha^{-})	Rs (MJ m^{-})	PAR (MJm^{-})	IPAR (MJm^{-2})	RUE_{TDM} (g MJ^{-1})	WUE (kg m^{-3})	LAI	Cum.mean T (^{O}C)
27	67	78.9	-	538	231	17	0.25	-	0.21	523
48	201	231.3	-	1102	474	57	0.41	-	0.52	1010
69	361	390.1	3400	1621	700	137	0.78	0.9	1.30	1536
88	436	486.7	10400	2075	895	248	0.99	2.1	2.85	2025
96	493	532.8	12120	2264	976	302	0.94	2.3	2.60	2235
105	509	576.5	8660	2467	1063	358	0.77	1.5	2.32	2459
113	509	612.9	6930	2603	1120	393	0.56	1.1	2.07	2653

*DAT=Days after transplanting.

Leaf area decreased in all treatments after completing the development of the plant, especially 88 days after transplanting (88 DAT) due to accelaration of plant physiology and leaf senescence. The reduction in LAI resulted in a reduction in the amount of intercepted PAR, which also decreased biomass as fresh and dry weights (leaf, stem) in Table 2.

Table 2. Plant development parameters for whole growing season

Sampling dates	Leaves		Stem		Fruit	
	Fresh (g)	Dry (g)	Fresh (g)	Dry (g)	Fresh (g)	Dry (g)
11 June	4	0.7	2	0.4	-	-
3 July	18	3.4	10	2	-	-
12 August	73.6	18.6	105.5	19.2	183.1	19.21
6 September	76.1	18.0	133	19.8	145.8	13.3

LAI was recorded as 2.85 on the 88th days after transplanting and decreased due to leaf senescence. If leaf and stem developments were not good, plants should not convert radiation and water into an economical yield. Therefore, providing a good vegetative development the amount of irrigation water of 436 mm should have been supplied to the root area of eggplants with 4 day irrigation intervals for the period lasting from transplanting to 88 days after transplanting.

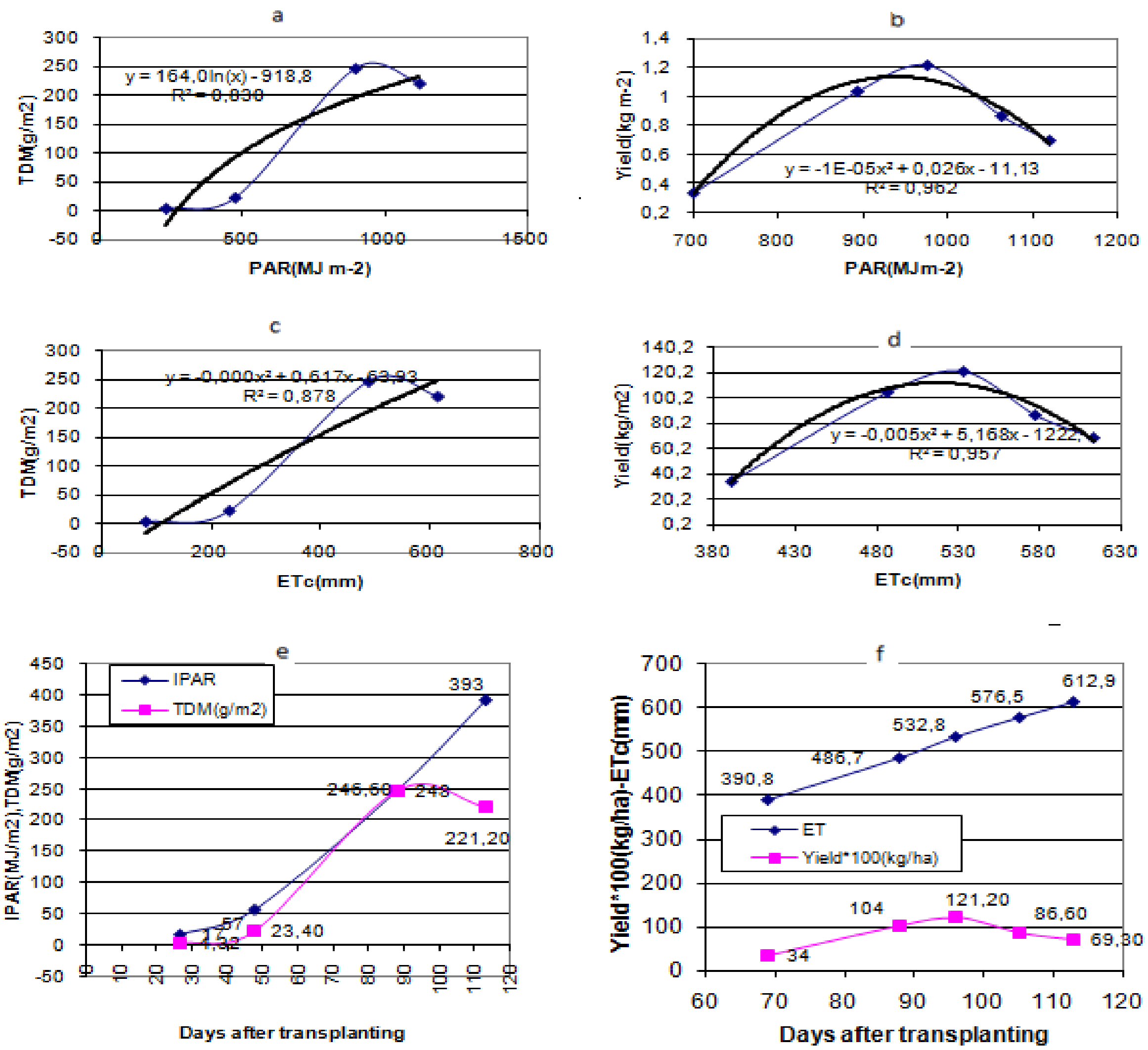

Figure 1. The relationships among TDM, ETc, and Yield under none water stress condition.

RUE increased for eggplant during the fruit development stage. This finding is supported by Gimenez et al. (1994) and Whitfield et al. (1989), who underlined that RUE increases for sunflowers after increasing respiratory load at the grain filling stage. Therefore, crop biomass production is related to the amount of photosynthetically active radiation intercepted by the canopy. RUE increased till 88 days after transplanting, based on dry weight values of 0.99 gMj^{-1}. RUE for dry weight reached that value when the water consumption of eggplant was 486.7 mm and eggplant converted radiant energy (PAR) into chemical energy.

The amount of solar radiation intercepted by plants is a major determinant of the total dry matter produced by a crop (Biscoe and Gallagher, 1978). RUE is affected by drought in arid and semi–arid areas (Patene et al., 2010). Dry matter (total weight of leaves, stem and fruits) reached to 246.6 g $plant^{-1}$ on 88 days after transplanting, but after that day it started decreasing and reached to 221.2 g $plant^{-1}$. This result may be attributed to the reduction in leaf areas due to leaf senescence after the day of 88^{th}.

The relationships among yield, TDM, PAR, IPAR, ETc for the entire growing season were compiled and are shown in fig 1.a-f. There is a quadratic relationship between TDM and PAR and ETc in fig 1 a and c. Although full water need of eggplant had been met for all growing periods, plants began to utilize water and radiation less after the day of 88^{th}. This event caused a reduction in total dry matter and yield too. In graph, evapotranspiration and yield, in turn, were 532.8 mm and 121.9 kg ha^{-1} on the 96^{th} days after transplanting in fig 1(f). In the same manner, yield began to decline after that day, even though full plant water need had been met for the entire growing period in fig 1 b and d. After that day (88 DAT), plant was put into a physiological change. This event led to the decline of many parameters such as RUE, IPAR and LAI.

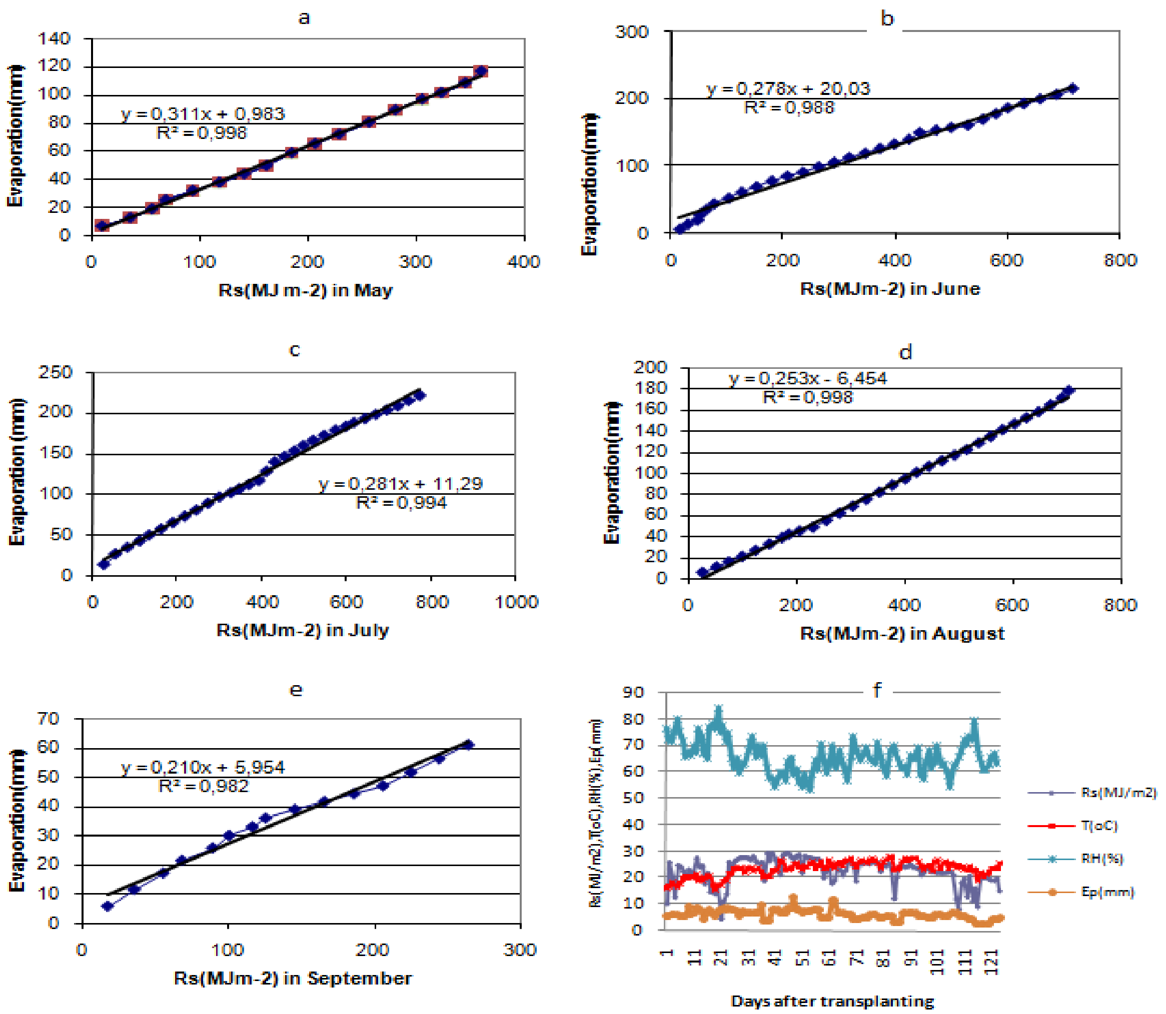

Figure 2. The relationships among evaporation and solar radiation and changes in meteorological data.

It was determined that there is a high correlation between solar radiation and evaporation occuring from Class–A pan in all months during that the trial was carried out (fig 2.). Casadesus et al.

(2011) 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 relationships in fig 2. a–e clearly indicate that the irrigation management for eggplant can be performed by estimating evaporation from the measured solar radiation.

Conclusion

Irrigation is the most important factor in increasing crop yield and water has becoming an extremely important strategic resource because of climate change since it is already occuring and represents one of the greatest enviromental threats facing our planet (Anonymous, 2010). In the world, the use of irrigation water in agriculture has been gaining more importance in arid and semi arid regions.

In this experiment, eggplants produced the yield of 41.5 t ha^{-1} with the application of 509 mm of irrigation water and evapotranspiration was 612.9 mm for the whole growing periods. However, the yield strated decreasing after 88 days so that water restrictions could be applicable after that day. Irrigation water of 509 mm provided eggplant to intercept 35% of PAR. Therefore, applying irrigation water of 509 mm in semi–arid regions for eggplant production seems to be more appropriate level for getting higher yield and for using solar radiation more efficiently. Also, being strong relationships between solar radiation and evaporation from Class–A pan, it can be used to activate the irrigation systems automatically.

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References

Ahmad, S., Zia–Ul–Haq, M., Ali, H., Shad, S., Ahmad, A., Maqsood, M., Khan, MB., Mehmood, S., Hussain, A., 2008. Water and radiation use efficiencies of transplanted rice (*Oryza sativa* L.) at different plant densities and irrigation regimes under semi–arid environment. Pak. J. Bot. 40 (1): 199–209.

Akuzum, T., Cakmak, B., Gokalp, Z., 2010. Evaluation of water resources management in Turkey.Proceedings of the 1st National Water Resources Management Symposium 20–22 October, Karaman,Turkey. 1–15.

Anonymous, 2010. Climate change, http://ee.europa.eu/enviroment/climat/home_en.htm, accessed on 6th December 2010.

Biscoe, PV., Gallagher, JN., 1978. Physical analysis of cereal yield. . Production of dry matter. Agric. Progress, 34–50.

Cai, X., Rosegrant, M.W., 2003. World water productivity: current situation and future options. In: Kijne, J.W. Barker, R., Molden, D. (Eds.), Water productivity in Agriculture: Limits and Opportunities for Improvement. International Water Management Institute (IWMI), Colombo Sri Lanka. pp. 163–178.

Casadesus, J., Mata, M., Marsal, J., Girona, J., 2011. Automated irrigation of apple trees based on measurements of light interception by the canopy. Biosystems Engineering. 108: 220–226.

De Carvalho, D.F., De Lima, M.E., De Oliveira, A.D., Da Rocha, H.S., Guerra, J.G.M., 2012. Crop coefficient and water consumption of eggplant in no–tillage system and conventional soil preparation, Eng.Agr.J. aboticabal. 32 (4): 784–793.

Faostat, Database. 2012. FAO Statistics, fresh market tomatoes. (Retrieved May 20, 2015 from: http://faostat.fao.org).

Gimenez, C., Connor, DJ., Rueda, F., 1994. Canopy development, photosynthesis and radiation–use efficiency in sunflower in response to nitrogen. Field Crops Res. 38: 15–27.

Gonçalves, M.C.R., Melo Diniz, M.F.F., Borba, J.D.C., Nunes, X.P., Barbosa–Filho, J.M., 2006. Berinjela (Solanum melongena L.) mito ou realidade no combate as dislipi demias. Revista Brasileira de Farma cognosia, Curitiba. 16 (2): 252–257.

Halitligil, M.B., Akin, A.I., Kislal, Ozturk, A., Deviren, A., 2015. Yield, nitrogen uptake and nitrogen use efficiency by tomato, pepper, cucumber, melon and eggplant as effected by nitrogen rates applied with drip–irrigation under greenhouse conditions, (accessed at ,http://www.iaea.org/inis /collection/NCLCollectionStore/_Public/33/017/33017168.pdf on August, 25, 2015).

Kanber, R., 1984. Irrigation of first and second crop peanut at Cukurova plain using Class–A pan. Research Institute of Tarsus, Publication no: 114 (6), Tarsus.

Kirnak, H., Tas, I., Kaya, C., 2001a. Effects of different irrigation levels on growth, yield and quality of eggplant under semiarid conditions, J.Agric.Fac.HR.U. 5 (3–4): 77–85.

Kirnak, H., Kaya, C., Tas, I., Higgs, D., 2001b. The influence of water deficit on vegetative growth physiology, fruit yield and quality in eggplants. Bulg.J.Plant Physiol. 27 (3–4): 34–46.

McNiesh, C.M., Welch, N.C., 1985. Trickle irrigation requirements for strawberries in coastal California, Journal of American Society for Horticultural Science. 110 (5): 714–718.

Monteith, JL., 1977. Climate and Efficiency of Crop Production in Britain. Philosophical Transactions of Royal Society London B. 281: 277–297.

Monteith, JL., Elston, JL., 1983. Performance and productivity of foliage in the field. In: The Growth and Functioning of Leaves (Eds): JE Dale and FL Miltthorpe. Camb.Univ.Press. Butterworths. London, pp. 499–518.

Monteith, J.L., Unsworth, M.H., 1973. Principle of Enviromental Physics (2 nd Edition), Oxford Auckland Boston Johannesburg Melbourne New Delhi.

Patane, C., La–Rosa, S., TringalI, S., Scandurra, S., 2010. Radiation use and irrigation water use efficiency in processing tomato at two plant densities under deficit irrigation in a Mediterranean climate. ISHS Acta Horticulture 922: XXVIII International Symposium on CLIMWATER 2010.

Rosati, A., Badeck, F.W., Dejong, T.M., 2001. Estimating canopy light interception and absorption using leaf mass per unit leaf area in Solanum melongena. Annals of Botany. 88: 101–109.

Tanner, CB., Sinclair, TR., 1983. Efficient water use in crop production: research or re–search. In: Taylor HM et al. (Eds.). Limitations to Efficient Water Use in Crop Production. ASA, Madison,WI, pp.1–27.

Trapani, N., Hall, AJ., Sadras, VO., Vilella, F., 1992. Ontogenic changes in radiation use efficiency of sunflower (Helianthus annuus L.). Field Crops Res. 29: 301–316.

Whitfield, DM., Connor, DJ., Hall, AJ., 1989. Carbon dioxide balance of sunflower subjected to water stresss during grain filling. Field Crops Res. 20: 65–80.

Yildirim, M., 2010. Water management in coastal areas with low quality irrigation water for pepper growth. Journal of Coastal Researh. 26 (5): 2010.