WFL Publisher
Science and Technology
Meri-Rastilantie 3 B, FI-00980
Helsinki, Finland
e-mail: info@world-food.net

Journal of Food, Agriculture & Environment Vol.7 (3&4) : 989-993. 2009
www.world-food.net

Deficit irrigation effects on pepper (*Capsicum annuum* L. Demre) yield in unheated greenhouse condition

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Received 3 July 2009, accepted 4 October 2009.

Abstract

The aim of this study was to determine the effect of deficit irrigation on yield for pepper grown under unheated greenhouse condition. The research was carried out at the Agricultural Research Station of Yenişehir High School of Uludag University in Bursa, Turkey, in 2007. In the study, water was applied to pepper as 100, 75, 50, 25 and 0% (as control) of evaporation from a Class A pan ($K1_{cp}$ 1.00, $K2_{cp}$ 0.75, $K3_{cp}$ 0.50, $K4_{cp}$ 0.25, $K5_{cp}$ 0.00-control) corresponding to 2-day irrigation frequency. Irrigation water applied to crops ranged from 65 to 724 mm, and water consumption ranged from 115 to 740 mm. The effect of irrigation water level on the yield, fruit heigth, diameter and weight and dry matter ratio were significant. The highest yields were 24 and 19 t ha^{-1} for the $K1_{cp}$ and $K2_{cp}$ treatments, respectively. Crop yield response factor (k_y) was 1.07. The highest values for water use efficiency (WUE) and irrigation water use efficiency (IWUE) were 3.13 and 3.39 kg mm^{-1} for the $K2_{cp}$ treatment. Under the conditions that water resources are scarce, it can be recommended that $K2_{cp}$ treatment is most suitable as a water application level for pepper irrigation by drip irrigation under unheated greenhouse condition.

Key words: Pepper, deficit irrigation, irrigation water use efficiency.

Introduction

Greenhouse cultivation, also known as protected cultivation, is one of the farming systems widely used to provide and maintain a controlled environment suitable for optimum crop production leading to maximum profits. This includes creating an environment suitable for working efficiency as well as for better crop growth [1]. Greenhouse cultivation is a steadily growing agricultural sector all over the world [9, 20]. The type of structure primarily used in Turkey is the so-called Mediterranean greenhouse; low-cost, unheated plastic-covered structures and with soil-grown crops.

Irrigation scheduling involves preventing the soil water deficit from falling below some threshold level for a particular crop and soil condition. This may involve estimating the earliest date to permit efficient irrigation or the latest date to avoid the detrimental effects of water stress on the crop [17]. Scheduling water application is very critical to make the most efficient use of drip irrigation system, as excessive irrigation reduces yield, while inadequate irrigation causes water stress and reduces production.

Approaches used to establish schedules for drip irrigation include estimates based on evapotranspiration [3, 6, 10, 14], allowable soil-water depletion [4]. A widely adopted method for estimating crop consumptive water use (CWU) is the evaporation pan method, which relates evaporation from a Class A evaporation pan to CWU. These two quantities are related by what is called the crop coefficient *K*. Irrigation scheduling based on the crop coefficient *K* is one of the simplest methods where no sophisticated instrument is required. Precise values for *K* are often difficult to establish, given regional and site-specification, soil characteristics, crop physiology and cultural practices. Any recommended value of *K* for regional irrigation scheduling program must be high enough to prevent water stress arising from emergencies and specialized local situations, while remaining low enough for efficient water management [22]. Based on the US Weather Bureau Class A pan evaporation, many studies have been completed on the irrigation of cucumber [8, 16], tomato [12], potato [10, 15], lettuce [21] and gren bean [5].

The objective of this study was to determine the effect of irrigation water level on the yield, fruit heigth, diameter and weight and dry matter ratio, daily and seasonal evapotranspiration, yield response factor (ky), irrigation water use efficiency (IWUE) and water use efficiency (WUE) of pepper grown in grown under unheated greenhouse condition.

Materials and Methods

Field experiment was carried out under unheated greenhouse condition in Yenişehir-Bursa (40°15'09"N latitude, 29°38'43"E longitude and altitude of 225 m above mean sea level). A high tunnel with the size of 8 m x 40 m using plastic coverage placed in north-south direction was used for the experiment. Summers are hot and dry; winters are cold and rainy in the region. Annual mean rainfall and temperature are 482.9 mm and 13.6°C, respectively. Average minimum temperature is 3.6°C in December; maximum temperature is 23.3°C in August [2]. The soil of the experimental plot can be classified as sandy loam, and the soil pH was 7.99-8.04. Some physical and chemical soil properties are given in Table 1. N 150 kg ha^{-1}, DAP (18% N and 46% P_2O_5) 100 kg ha^{-1} and 200 kg ha^{-1} KNO_3 (13% N and 46% K_2O) as granular fertilizer were applied prior to planting, and pest control chemicals were added as required.

Table 1. Some of chemical and physical properties of experimental field soil.

Soil depth (cm)	γ ($g\ cm^{-3}$)	Soil type	Field capacity (%)	Wilting point (%)	pH	Total salt (%)	$CaCO_3$ (%)	Organic matter (%)	Available ($kg\ da^{-1}$) P	Available ($kg\ da^{-1}$) K
0-30	1.34	SL	19.66	11.94	7.99	0.058	5.67	2.94	1.53	38.35
30-60	1.37	SL	17.26	9.98	8.04	0.051	8.49	1.39	1.24	19.52

γ Unit weight of soil, SL Sandy loam, P Phosphorus, K Potassium.

The seeds were sown in small pot on 8 May, 2007 and seedlings were transplanted to the plots (17 June, 2007). The plants were grown 0.20 m apart between the rows with 0.10 m spacing in each row. Each plot contained 600 plants. In order to prevent the water in any one plot from affecting its neighboring plots, only 50 plants of middle row were harvested. Fruits were weighed (g), fruit length (cm) and diameter (cm) were measured by caliper rule and average of measured values were calculated. The dry matter amount was found after drying at 85°C in 48 hours.

The layout of the experiment was a completely randomized block design with three replications for each of the five irrigation treatments tested. However, replications were distributed to the random blocks in such a way that following same range in three blocks not to disturb the existing irrigation system. Irrigation treatments consisted of five different plant-pan coefficients ($K1_{cp}$ 1.00, $K2_{cp}$ 0.75, $K3_{cp}$ 0.50, $K4_{cp}$ 0.25, $K5_{cp}$ 0.00-control). Pan evaporation method was used for calculation of applied water amount:

$$IW = E_{pan} \times K_{cp}$$

where IW is the amount of applied irrigation water (mm), E_{pan} the cumulative evaporation between each irrigation interval (mm) and K_{cp} is the plant-pan coefficient. Evaporation between the irrigation intervals was measured with US Weather Bureau Class A pan located in the center of greenhouse. Irrigation water was applied in 2-day frequency, and drip irrigation method was used. Required irrigation water was measured by flow meter device at the head of each plot.

Irrigation water ($3\ L\ s^{-1}$) was supplied from a deep well drilled in the area. Quality properties of irrigation water are given in Table 2. The water is placed in C_2S_1 class with low sodium risk, medium EC value. Since there is no recorded problem with water quality, it is well suited for irrigation.

Crop evapotranspiration (ET_c) was estimated using the following form of the water balance equation;

$$ET_c = (SWC_{t0} - SWC_{t1}) + IW - D$$

where ($SWC_{t0} - SWC_{t1}$) is the change in volumetric soil water content between two measurement dates; IW and D are respectively the total volumes of applied irrigation water and collected drainage for the period under consideration. The water content of plant root depth (0.60 m) was determined by gravimetric method before irrigation water application [13] and monitored in 30 cm depth increments to 0.90 m after irrigation for each irrigation treatments. Monitoring the soil water content in the plots revealed that deep percolation below 0.60 m depth was negligible.

In this study, the Stewart model has contributed to define the relationships between yield and ET [7]:

$$(1-Y_a.Y_m^{-1}) = k_y(1-ET_a.ET_m^{-1})$$

where Y_a is the actual yield ($t\ ha^{-1}$), Y_m is the maximum yield ($t\ ha^{-1}$), ET_a is the actual evapotranspiration (mm) and ET_m is the maximum evapotranspiration (mm). Values of k_y indicate the response factor of pepper to deficit irrigation. The water use efficiency (*WUE*) was determined to evaluate the productivity of irrigation in the treatments. *WUE* and irrigation water use efficiency (*IWUE*) are two terms used to promote the efficient use of irrigation water at the crop production level.

WUE was calculated as the ratio of yield (*YLD)* to ET_a , given as $WUE = YLD/ET_a$ ($t\ ha^{-1}\ mm^{-1}$). *IWUE* was estimated by following equation.

$$IWUE(t\ ha^{-1}\ mm^{-1}) = \frac{YLD - YLD_{rainfed}}{IRGA}$$

where $YLD_{rainfed}$ is the yield obtained from the rainfed treatment or dryland yield and IRGA is the seasonal irrigation amount used in millimeter.

In the harvesting time, 104 days after the pepper seeds were transplanted the pepper plants were fully developed and had the diameter, length, weight, colour and the flavour characteristics of the species. Harvested fruits from each plot were evaluated immediately according to yield, fruit heigth, diameter and weight and dry matter ratio.

Analysis of variance was performed on yield and yield component data using the MSTAT-C (Version 2.1,Michigan State University 1991) and MINITAB (University of Texas at Austin) software. The significance of irrigation treatments were determined at the 0.05 and 0.01 probability levels, by the F-test [18].

Results and Discussion

Water applied and water used: After planting 65 mm irrigation water was applied to some treatments to bring the soil water content in 0-60 cm soil depth up to level of field capacity. Irrigation treatments were started measuring of evaporation from Class A pan after the first irrigation application. The maximum amount of water applied to the crop was 724 mm in the $K1_{cp}$ treatments while the minimum amount was 65 mm in the $K5_{cp}$ treatment during the experimental year. The amount of water applied to other treatments ranged between 543 and 181 mm. Seasonal evapotranspiration (ET_a) increased with the applied irrigation water and ranged from

Table 2. Chemical composition of irrigation water used in the experiment.

Water source	$EC_{25}x(10^6)$	Na^+ (me L^{-1})	K^+ (me L^{-1})	Ca^{2+} (me L^{-1})	Mg^{2+} (me L^{-1})	pH	Class	SAR
Deep well	715	2.3	2.56	9.25	5.7	7.12	C_2S_1	0.85

Table 3. Relationship between the decrease in relative water use and decrease in relative yield and yield response factor for pepper irrigated by a drip system.

Irrigation treatment	Yield ($t\ ha^{-1}$)	Applied water (mm)	*ETa* (mm)	ET_a/ET_m	Y_a/Y_m	$1-(ET_a/ET_m)$	$1-(Y_a/Y_m)$	k_y
$K1_{cp}$	24	724	740	1.000	1.000	0.000	0.000	0.000
$K2_{cp}$	19	543	560	0.757	0.892	0.243	0.208	0.856
$K3_{cp}$	11	362	367	0.496	0.703	0.504	0.542	1.075
$K4_{cp}$	4	181	188	0.254	0.595	0.746	0.833	1.117
$K5_{cp}$	2	65	115	0.155	0.459	0.845	0.917	1.085

115 to 740 mm for $K5_{cp}$ and $K1_{cp}$ treatments, respectively (Table 3).

Linear relationships were observed between the crop evapotranspiration (ET_c) with yield (Y_a) and irrigation water (*IW*) with yield (Y_a). The equation for the relationship was $Y_a = 0.0365ET_c - 2.3617$ with $R^2 = 0.99$ and $Y_a = 0.0353IW - 1.2458$ with $R^2 = 99$ (Fig. 1).

In our study, treatment $K1_{cp}$ had the highest yield (24 $t\ ha^{-1}$) followed by $K2_{cp}$, $K3_{cp}$ and $K4_{cp}$ irrigation treatments with 19, 11 and 4 $t\ ha^{-1}$, respectively. As expected, non-irrigated control $K5_{cp}$ had the lowest yield (2 $t\ ha^{-1}$). The non-irrigated treatment ($K5_{cp}$) produced 1100% lower yield than the $K1_{cp}$ treatment. However, $K2_{cp}$, $K3_{cp}$ and $K4_{cp}$ had 26.3, 118.2, 500.0 % less yield compared with treatment $K1_{cp}$ (Table 4).

Deficit irrigation had a significant effect on fruit height, while the values of $K1_{cp}$ was in the first group, $K2_{cp}$, $K3_{cp}$ and $K4_{cp}$ treatments were in the second group and $K5_{cp}$ was placed in the last group. It can be concluded that the deficit of applied irrigation water (25%) is not compatible with the reduction in bulb height. According to results, there was no effect of deficit irrigation fruit height in terms of marketable value. This results are in agreement with those of other authors [23-27]. The fruit diameter and fruit weigth had a similar response to deficit irrigation like yield. All irrigation treatments had higher values than the non-irrigated ($K5_{cp}$) treatment.

The significant increases in dry matter were found as parallel to irrigation water deficit and the highest and lowest dry matter were found at $K5_{cp}$ and $K1_{cp}$, respectively. This may be attributed to higher fruit weight observed from $K1_{cp}$ treatment than those of deficit irrigation treatments. These results are similar to those of other authors [23, 24, 28].

Positive linear relation was found among fruit length, diameter and weight and negative linear relation between dry matter ratio and amount of water applied (IW). The equations for the relationships were *Fruit length* = $0.0151IW + 7.8333$ with $R^2 = 0.99$ (Fig. 2a), *Fruit diameter* = $0.0028IW + 0.8818$ with $R^2 = 0.97$ (Fig. 2b), *Fruit weight* = $0.0066IW + 5.82$ with $R^2 = 0.96$ (Fig. 2c) and *Dry matter ratio* = $-0.011IW + 15.013$ with $R^2 = 0.98$ (Fig. 2d).

Crop yield response factor (k_y): Crop yield response factor (k_y) indicates a linear relationship between the decrease in relative water consumption and the decrease in relative yield. It shows the response of yield with respect to the decrease in water consumption. In other words, it explains the decrease in yield caused by the per unit decrease in water consumption [7, 19]. Seasonal crop response factor was determined as 1.07 for irrigation treatments (Fig. 3). Values of k_y increased with increasing water deficit except in $K5_{cp}$.

Water use efficiencies: *WUE* and *IWUE* values decreased when irrigation water amount decreased. The highest *WUE* and *IWUE* was obtained from treatment $K2_{cp}$, 3.39 and 3.13 $kg\ mm^{-1}$, respectively. When considering IWUE values of $K1_{cp}$, $K3_{cp}$ and $K4_{cp}$ treatments, IWUE values of $K2_{cp}$ treatment were higher than that of $K1_{cp}$ treatment and followed by $K3_{cp}$ (Table 5).

Table 5. Total water use efficiency (*WUE*) and irrigation water use efficiency (*IWUE*) values for pepper irrigated by a drip system at different irrigation treatments.

Irrigation treatment	Yield ($t\ ha^{-1}$)	*WUE* ($kg\ mm^{-1}$)	*IWUE* ($kg\ mm^{-1}$)
$K1_{cp}$	24	3.24	3.04
$K2_{cp}$	19	3.39	3.13
$K3_{cp}$	11	3.00	2.49
$K4_{cp}$	4	2.13	1.10
$K5_{cp}$	2	1.74	0.00

Table 4. Effects of irrigation treatments on pepper marketable parameters.

Irrigation treatment	Fruit lenght (cm)	Fruit diameter (cm)	Fruit weight (g)	Dry matter (%)	Yield ($t\ ha^{-1}$)
$K1_{CP}$	18.5 a	2.8 a	10.2 a	7.5 d	24 a
$K2_{CP}$	16.5 a	2.5 ab	9.8 a	8.5 cd	19 b
$K3_{CP}$	13.0 b	2.0 bc	8.5 b	11.0 bc	11 c
$K4_{CP}$	11.0 bc	1.5 c	7.0 c	13.0 ab	4 d
$K5_{CP}$	8.5 c	0.9 d	6.0 c	14.5 a	2 d
Treatments	**	**	**	**	**
Blocks	ns	ns	ns	ns	ns

** Correlation is significant at the 0.01 level, * correlation is significant at the 0.05 level, ns non-significant

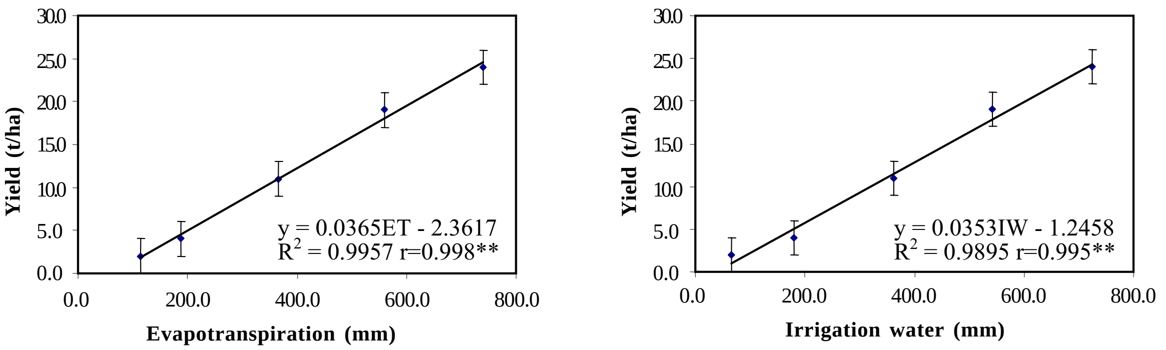

Figure 1. The relationship between crop evapotranspiration with yield and water irrigation with yield. (The error bars are SE of 50 plants.)

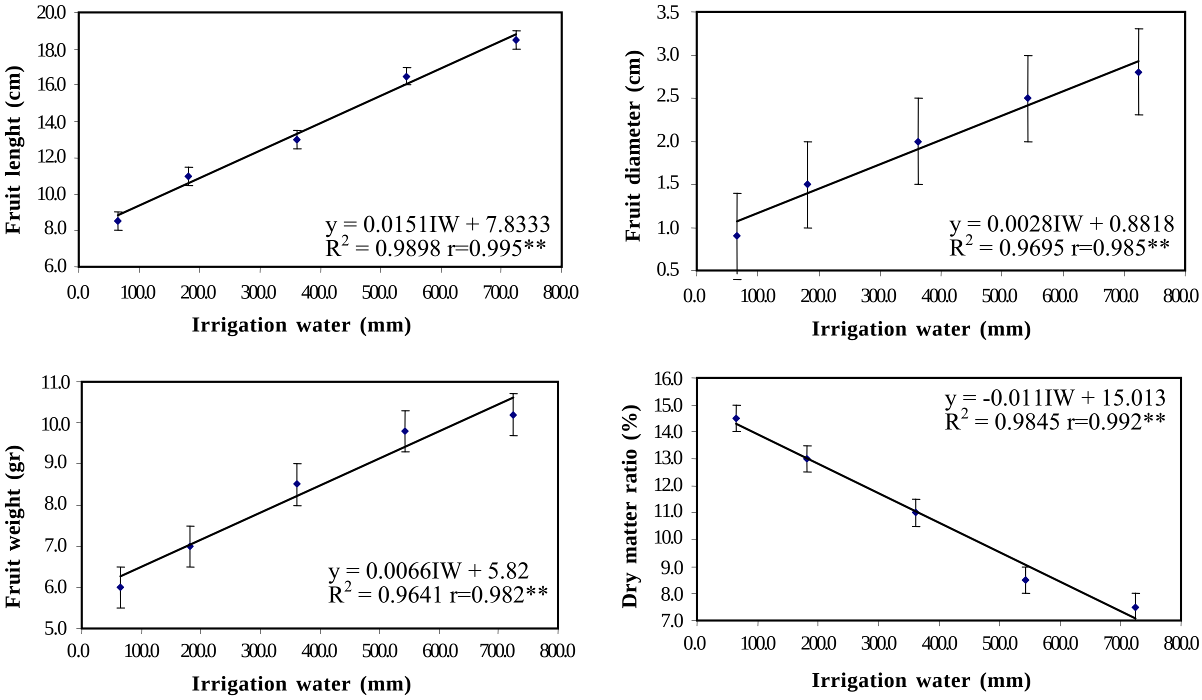

Figure 2. Relationship between applied of irrigation water and fruit lenght, fruit diameter, fruit weight and dry matter ratio. (The errors bars are SE of 50 plants.)

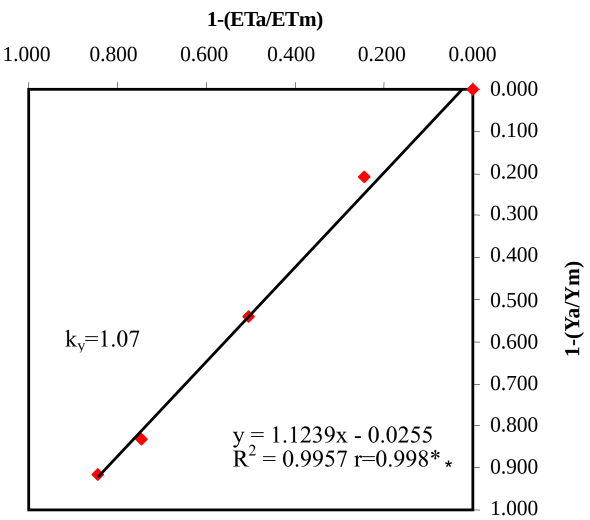

Figure 3. Relationship between relative yield decrease and relative crop evapotranspiration for pepper throughout the total growing season.

Conclusions

In this study, irrigation treatments significantly affected yield, fruit lenght, diameter and weight and dry matter ratio. The highest yield was obtained from the $K1_{cp}$ treatment as 24 t ha^{-1} and the minimum yield was obtained from the $K5_{cp}$ treatment as 2 t ha^{-1}. Yield was significantly reduced as the amount of irrigation water decreased. The rates of reduction in relative yield were 26.3, 118.2, 500.0 and 1100.0% at the irrigation treatments, respectively. *IWUE* value in the $K2_{cp}$ treatment was higher than in the $K1_{cp}$ and $K3_{cp}$ treatments. Under the conditions that water resources are scarce, it can be recommended that $K2_{cp}$ treatment is most suitable as a water application level for pepper irrigation by drip irrigation under the unheated greenhouse condition.

References

[1]Aldrich, R.A. and Barto, J.W. 1989. Greenhouse Engineering. NRAES-33, 203 p.

[2]Anonymous 2003. Meteoroloji Bülteni (in Turkish). Devlet Meteoroloji İşleri Genel Müdürlüğü, Başbakanlık Basımevi, Ankara, pp. 111–112 (In Turkish).

[3]Bar-Yosef, B. and Sagiv, B. 1982. Response of tomatoes to N and water applied via a trickle irrigation system. II Water. Agron. J. **74**:637-639.

[4]Bogle, C.R., Hartz, T.K. and Nuntoez, C. 1989. Comparison of subsurface trickle and furrow irrigation on plastic mulched and bare soil for tomato production. J. Am. Soc. Hortic. Sci. **114**:40-43.

[5]Büyükcangaz, H., Yazgan, S., Ayas, S., Candoğan, B.N. and Ayas, F. 2008. Effects of deficit irrigation on yield and quality of unheated greenhouse grown green bean. Journal of Food, Agriculture & Environment **6**(2):168-172.

[6]Clough, G.H., Locasio, S.J. and Olsen, S.M. 1990. The yield of successively cropped polyethylene-mulched vegetables as affected by irrigation method and fertilization management. J. Am.Soc. Hortic. Sci. **115**:884-887.

[7]Doorenbos, J. and Kassam, A.H. 1979. Yield Response to Water. FAO Irrigation and Drainage Paper No. 33, Rome.

[8]Eliades, G. 1988. Irrigation of greenhouse-grown cucumbers. Journal of Horticultural Science **63**(2):235-239.

[9]Enoch, H.Z. and Enoch, Y. 1999. The history and geography of greenhouse. In Stanhil, G. and Enoch, H.Z. (eds). Greenhouse Ecosystems. Ecosystems of the World 20. Elsevier, Amsterdam, pp. 1-15.

[10]Ferreira, T.C. and Carr, M.K.V. 2002. Response of potatoes to irrigation and nitrogen in a hot, dry climate. I. Water use. Field Crops Research **78**:51-64.

[11]Hartz, T.K. 1993. Drip irrigation scheduling for fresh market tomato production. HortScience **28**:35-37.

[12]Locascio, S.J. and Smajstrla, A.G. 1996. Water application scheduling by pan evaporation for drip-irrigated tomato. Journal of the American Society for Horticulture Science **121**(1):63-68.

[13]Lorenz, O.A. and Maynard, D.N. 1980. Knott's Hand Book for Vegetable Growers. 2nd edn. John Wiley Sons, New York.

[14]McNeish, C.M., Welch, N.C. and Nelson, R.D. 1985. Trickle irrigation requirements for stawberries in coastal California. J. Am. Soc. Hortic. Sci. **110**:714-718.

[15]Panigrahi, B., Panda, S.N. and Raghuwanshi, N.S. 2001. Potato water use and yield under furrow irrigation. Irrigation Science **20**:155-163.

[16]Randal, H.C. and Locascio, S.J. 1988. Root growth and water status of trickle-irrigated cucumber and tomato. Journal of the American Society for Horticulture Science **113**(6):830-835.

[17]Ritchie, J.T. and Johnson, B.S. 1990. Irrigation of Agricultural Crops. Agronomy Monograph No. 30, pp. 363-390.

[18]Steel, R.G.D. and Torrie, J.H. 1980. Principles and Procedures of Statistics. A Biometrical Approach. McGraw-Hill, NewYork, pp.186-187.

[19]Stewart, J.I., Misra, R.D., Pruitt, W.O. and Hagan, R.M. 1975. Irrigating corn and sorghum with a deficient water supply. Trans. ASAE **18**:270-280.

[20]Von Elsner, B., Briassoulis, D., Waaijenberg, D., Mistriotis, A., von Zabeltizt, Chr. and Gratraud, J. 2000. Mechanical properties of covering materials for greenhouses. Part I. General overview. J. Agric. Eng. Res. **67**:81-96.

[21]Yazgan, S., Ayas, S., Demirtas, C., Büyükcangaz, H. and Candoğan, B.N. 2008. Deficit irrigation effects on lettuce (*Lactuca sativa* var. Olenka) yield in unheated greenhouse condition. Journal of Food, Agriculture & Environment **6**(2):168-172.

[22]Yuan, B.Z., Sun, J. and Nishiyama, S. 2003. Effect of drip irrigation on strawberry growth inside a plastic greenhouse. Biosystems Engineering **87**(2):237-245.

[23]Orta, A.H. and Sener, M. 2001. A study on irrigation scheduling of onion (*Allium cepa* L.) in Turkey. Journal of Biological Science **1**(8):735-736.

[24]Imtiyaz, M., Mgadla, N.P., Manase, S.K., Chendo, K. and Mothobi, E.O. 1999. Yield and economic return of vegetable crops under variable irrigation. Irrig. Sci. **19**:87-93.

[25]Martin de Santa Olalla, F., Dominguez-Padilla, A. and Lopez, R. 2004. Production and quality of the onion (*Allium cepa* L.) cultivated under controlled deficit irrigation conditions in a semi-arid climate. Agr. Wat. Manag. **68**:77-79.

[26]Kadayifci, A., Tuylu, G.İ., Ucar, Y. and Cakmak, B. 2005. Crop water use of onion (*Allium cepa* L.) in Turkey. Agr. Wat. Manag. **72**:59-68.

[27]Kumar, S., Imtiyaz, M., Kumar, A. and Singh, R. 2007. Response of onion (*Allium cepa* L.) to different levels of irrigation water. Agr. Wat. Manag. **89**:161-166.

[28]Pelter, G.Q., Mittelstandt, R., Leib, B.G. and Redulla, A.C. 2004. Effects of water stress at specific growth stages on onion bulb yield and quality. Agr. Wat. Manag. **68**:107-115.