RESPONSE OF RED HOT PEPPER PLANT (*Capsicum annuum* L.) TO THE DEFICIT IRRIGATION

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Abstract

The objectives of this study were to investigate the effects of five different irrigation levels (I_1, I_2, I_3, I_4 and I_5) on fruit number (FN) of red hot pepper, fruit dry weight (FDW), dry yield (DY) using a line source sprinkler system and determine water production function of pepper in 1999 and 2000 growing season in Kahramanmaraş. The average water amounts applied to I_1 (non-stressed) and I_5 (stressed) for the two years were 913.4 and 295.7 mm. The evapotranspiration (Et) for peppers over the 2 years for I_1 and I_5 were 1056 and 446.6 mm, respectively. Mean FN, FDW and DY for I_1 and I_5 treatments were 46 and 14.5 fruit plant^{-1}, 0.9 and 0.55 g fruit^{-1} and 1358 and 284 kg ha^{-1}, respectively. Deficit irrigation significantly affected the FN and FDW and DY. The average FN increased over 3 times when comparing I_1 with I_5. The average FDW increased over 1.6 times when comparing I_3 with I_5. Linear water production functions were determined DY versus total irrigation water and Et. When irrigation water is plenty, the red hot pepper can be irrigated at the level of I_1 and I_2. When water source is scarce, pepper can be irrigated at the lower water level taking economic conditions into consideration.

Keywords: Red hot pepper, deficit irrigation, production, function, sprinkler

Kırmızı Acı Biber Bitkisinin (*Capsicum annuum* L.) Kısıntılı Sulamaya Tepkisi

Özet

Bu çalışma, çizgi kaynaklı yağmurlama sulama sistemini kullanarak beş farklı su seviyesinin (I_1, I_2, I_3, I_4 and I_5) kırmızı biber meyve sayısına (FN) meyve kuru ağırlığına (FDW), kırmızı kuru biber verimine (DY) etkisi ile su-verim ilişkisini belirlemek amacıyla 1999 ve 2000 yıllarında Kahramanmaraş'ta yürütülmüştür. Tam su alan I_1 ve en fazla su kısıntısı uygulanan I_5 sulama konularına uygulanan iki yılın ortalaması sulama suyu miktarları sırasıyla 913.4 ve 295.7 mm'dir. Anılan sulama konularında belirlenen ortalama su tüketimleri sırasıyla 1056 ve 446.6 mm'dir. I_1 ve I_5 sulama konularında belirlenen ortalama FN, FDW ve DY değerleri sırasıyla 46 ve 14.5 meyve bitki^{-1}, 0.9 ve 0.55 g bitki^{-1}, 1358 ve 284 kg ha^{-1} olarak bulunmuştur. Kısıntılı sulama FN, DFW ve DY değerlerini istatistiksel olarak önemli derecede etkilemiştir. I_1 sulama konusunda belirlenen FN değeri I_5 sulama konusunda belirlenen FN değerinden 1.6 kat daha büyük olduğu bulunmuştur. DY ile toplam uygulanan sulama suyu ve Et arasında doğrusal su üretim fonksiyonları bulunmuştur. Kımızı acı biber su kaynağının bol olduğu koşullarda I_1 ve I_2 sulama düzeylerinde, kıt olduğu koşullarda ise daha düşük su seviyelerinde sulanabilir.

Anahtar Kelimeler: Kırmızı Acı Biber, Kısıntılı Sulama, Üretim Fonksiyonu, Yağmurlama.

1. Introduction

Kahramanmaraş region is major production area of red hot pepper as spices in Turkey. However, there have been great instabilities in production of the pepper due to problems such as seed, cultivars (fruitful, susceptible to disease (*Phytophthora capsici*) and insect), poor quality, aflatoxin and inappropriate agricultural growing techniques, especially irrigation and root-crown rot.

Pepper is among the most susceptible horticultural plants to drought stress because of the wide range of transpiring leaf surface and high stomatal conductance (Alvino et al., 1994), and having a shallow root system (Dimitrov and Ovtcharrow, 1995). For high yields, an adequate water supply and relatively moist soils are required during the entire growing season. A significant yield reduction was reported by limiting the amount of water supplied during different growing periods such as vegetative, flowering or fruit settings (Doorenbos and Kassam, 1979). Low water availability prior to flowering of pepper reduced the number of flowers and retarded the occurrence of maximum flowering. The water deficit during the period between flowering and fruit development reduced final fruit production (Jaimez et al., 2000). Della Costa and Gianquinto (2002) reported that continuous water stress significantly reduced total fresh weight of fruit, and the highest marketable yield was found at irrigation of 120% ET; lowest at 40% ET, and marketable yield did not differ among 60%, 80% and 100%ET. Antony and Singandhupe (2004) resulted that total pepper yield was less at lower levels of irrigation. Kang et al. (2001) conducted a hot pepper study applying water through alternate drip irrigation on partial roots (ADIP), fixed drip irrigation on partial roots (FDIP) and even drip irrigation on whole roots (EDIP) and they concluded that ADIP maintained high yield with up to 40% reduction in irrigation compared to EDIP and FDIP, and moreover, best water use efficiency occurred in ADIP. Throughout the world, since the available water for agriculture is generally limited, the knowledge of the relationship between yield and quality of the product and irrigation regimes is an important factor to maximize the benefit of the available water supply (Pellitero et al., 1993).

It has been stated that a heavy rain and sprinkler irrigation during flowering could cause flower damage, or interfere with pollination and reduce yield. However, the negative effects of heavy rain and sprinkler irrigation would change depending on plant type, whether to be determinate or indeterminate. Indeterminate plants keep flowering and producing fruits as long as the weather allows and determinate plants flower within the certain period in the growing season (Wierenga and Hendrickx, 1985). For example, Dey Sarkar et al. (1996) reported that simulated rain (sprinkler irrigation) significantly reduced yield of a determinate wheat (*Triticum aestivum L.*) crop. Ontai and Bordovsky (2003) reported a study of irrigating indeterminate cotton (*Gossypium hirsutum L.*) plants using three different irrigation applicators. They found that lint yield and the average number of bolls per plant were not affected by the spray above canopy. These results show that sprinkler irrigation may have an effect on pollination depending on crop type.

The objectives of this study were to determine the effects of different irrigation levels applied by line source sprinkler irrigation system on FN, FDW, DY and develop water production functions for red hot pepper.

2. Material and Method

The experiment was conducted at the research area of Agricultural Facility, Kahramanmaraş Sütçü İmam University during the 1999 and 2000 growing seasons. Local red hot pepper variety of "Kahramanmaraş" was used because it is very suitable for spice.

The soil in the area was classified as *Inceptisol*, heavy textured and homogeneously structured. Soil profile of 0-30 and 30-60 cm were clay loam and clay, respectively. Field capacity (FC), wilting point (WP), bulk density, salinity and pH for 0-30 and 30-60 soil layer were 26.0 and 33.6 %, 16.4 and 26.2 %, 1.4 and 1.8 g cm^{-3}, 0.06 and 0.07 %, 7.90 and 8.03, respectively. Irrigation water used in the area was classified as C_2S_1 (Anonymous, 1954).

The local climate was semi-arid. During the growing season the average temperature and relative humidity were 17.1°C, and 59 %. Total rainfall and rainfall within the first (30 April- 5 September, 1999) and the second (9 April – 6 September, 2000) growing seasons were 442.7 and 20 mm, and 680.3 and 38 mm, respectively.

Fertilizer (50 kg N $ha^{-1}$and 50 kg P_2O_5 ha^{-1}) was applied based on soil analysis and incorporated during tillage and seedbed preparation. Seeds were sowed into the top 3 cm of soil on 30 April 1999 and 9 April 2000. Experimental area given in Figure 1 was 882 m^2. The inter-plant and inter-row spacing were 30 cm and 70 cm, respectively. At the first irrigation, an additional 115 kg N ha^{-1} was applied. Weeds were controlled by manually.

The experiment was uniformly irrigated for 2-3 h using a hand-move sprinkler irrigation system (12 x 12 m) every three days in order to provide optimum soil moisture for homogeneous emergence and stand establishment until 11 July, 1999 and

5 July, 2000. By these dates (prior to early flowering stage), the depths of 258 and 316 mm of irrigation water were applied to the experiment for 1999 and 2000, respectively. Plot was thinned to one plant per 30 cm of row. Number of the pepper plant for per hectare was about 47619. After these dates, irrigation treatment with the line source sprinkler irrigation system was started and continued until the first week of September. The first irrigation started when about 40% of the available soil water was consumed. The line source sprinkler irrigation system can be used effectively to study the effects of various amounts of water applied to crop, and minimize the amount of land required for such experiment (Bresler et al., 1982). Sprinkler heads with nozzle sizes of 4.5 x 4.8 mm and with an application rate of 6.57 mm h^{-1} were located 6.0 m apart on the line source. The system was operated at 300 kPa pressure to obtain a linearly decreasing water distribution from the line source sprinkler irrigation system to the wetted perimeter. The experimental area (30 m long and 29.4 m wide) was irrigated every week by the line source sprinkler system (Hanks et al., 1980). As seen in Figure 1. five irrigation treatments were arranged at both sides of the line source sprinkler system. Treatments were replicated three times. Irrigation treatments were named I_1, I_2, I_3, I_4 and I_5. I_1 and I_5 were non water stressed and stressed irrigation treatments. Size of each treatment was 10 m long and 2.8 m wide. The plant rows adjacent to the line source and perimeter were not included in the treatment I_1 and I_5. Plant rows were parallel to the line source.

Prior to an irrigation, available soil water content for all the treatments were measured in the third plant row at 0-30 and 30-60 cm soil depths using the gravimetric sampling method (Jury et al., 1991). The total depth of water applied to treatment I_1 was to bring the measured gravimetric soil water content to FC level in 60 cm soil profile. The depth of water applied to treatment I_1 was calculated for each of 0-30 and 30-60 cm layers using equation given by Keller and Bliesner (1990) and summed to find out total water depth.

$$d = \frac{(\theta_{fc} - \theta_w) Z \rho_b}{10} \quad (1)$$

where d is the depth of water to apply to treatment I_1 (mm), θ_{fc} is soil water content on a mass basis at the field capacity (%), θ_w is the soil water content on mass basis (%), Z is the rooting depth (cm) and ρ_b is the bulk density of soil (g cm^{-3}).

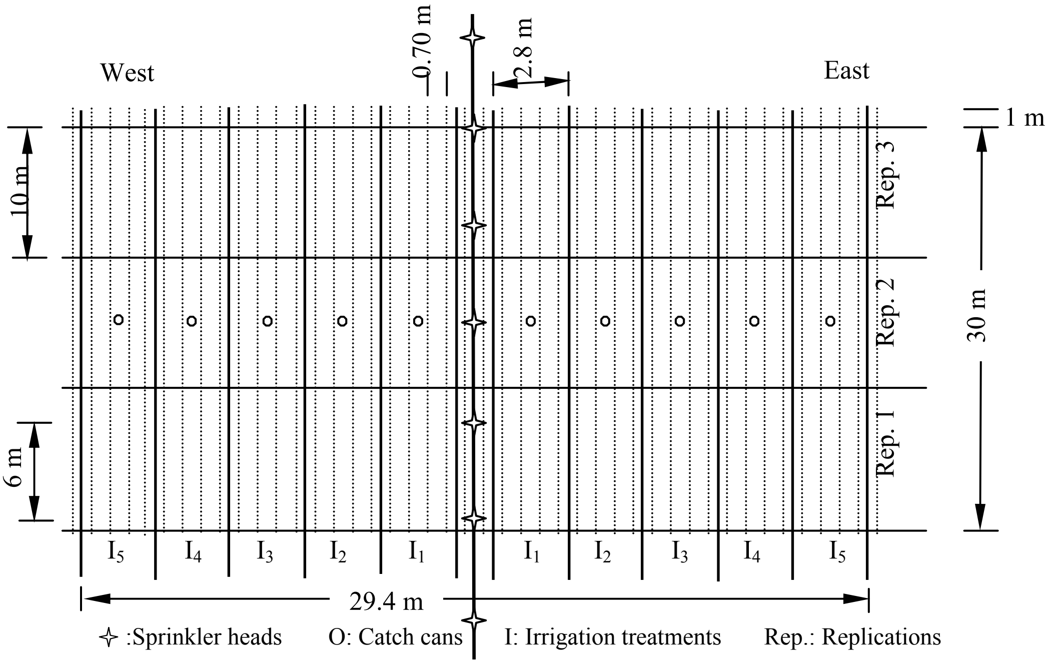

Figure 1.Experiment layout

Water application by the sprinkler line source irrigation system was applied intermittently so that runoff from the treatments would not occur. The depth of applied water decreases linearly away from the line source when using the line source sprinkler system (Hanks et al., 1980). The depth of water applied in each treatment was measured using catch can located above the canopy at the centre of each plot on both sides of the line source sprinkler system (Figure 1). Area of the catch cans was 78.85 cm^2. To determine duration of sprinkler operation, depth-time relationship was used.

The water balance approach (James et al., 1982) was used to estimate evapotranspiration for the treatments. The water balance equation is given as following,

$$Et = I + P - Rf - Dp \pm \Delta s \quad (2)$$

where Et is evapotranspiration (mm), I is the amount of irrigation water (mm), P is the effective precipitation (mm), Rf is the runoff (mm) (not occurred), Δs is the change in soil water (mm), Dp is deep percolation (mm) (not measured). Both Rf and Dp were assumed to be zero since runoff from irrigation was minimized by intermittent sprinkler application and depth of irrigation applied did not exceed FC calculations.

Red fruits were harvested from the area of 28 m^2 on 9 August, 13 September and 15 October in 1999 and on 26 July, 31 August and 4 October in 2000. The total mass from each treatment was weighted and individual fruits were counted. At the end of the experiment, green fruits were counted and added to number of red fruit. Fruits numbers (FN) per plant were determined from the counted fruits divided by total number of plants for each treatment. Fresh fruit sub-samples from each treatment was dried in the oven at 65 °C until reaching constant weight to determine fruit dry weight (FDW) and yield (DY).

Line source statistical principles (Analysis of Variance) given by Hanks et al. (1980) were used for DY, FDW and FN. These parameters were analyzed using Duncan's multiple range test. Regression analysis was used to determine production functions for DY versus I and Et. In addition, dry hot pepper yield response factor (ky), which quantifies the response of the yield to water supply was determined between relative dry hot pepper yield reduction (1-Ya/Ym) and relative evapotranspiration deficit (1-Eta/Etm) using Steward Model (Stegman et al., 1981).

$$\left(1 - \frac{DYa}{DYm}\right) = ky\left(1 - \frac{Eta}{Etm}\right) \quad (3)$$

where DYa is the actual harvested yield, DYm is the maximum harvested yield obtained from treatment I_1, ky is the yield response factor, Eta is the actual evapotranspiration and Etm is the maximum evapotranspiration.

3. Results and Discussion

3.1. Irrigation Water and Water Consumption

Table 1 shows total depth of the irrigation water applied by line source sprinkler system and water use for the irrigation treatments. The number of irrigations was 9 in 1999 and 10 in 2000. Each sprinkler irrigation operated until time of ponding on the soil surface of I_1 treatment and sprinkler application period to the ponding changed between 3-4 hours. Non-water stress treatment I_1 received as much water as red hot pepper consumed weekly. The other treatments received less water than I_1 treatment. Therefore, water deficit increased from I_2 to I_5. The most amount of water was applied to the non-water stress treatment I_1 and the least water was applied to the water stress treatment I_5. The mean total depth of irrigation applied to the treatments I_1 through I_5 ranged from 913.4 to 295.7 mm. Rainfall was 20 mm in the first and 38 mm in the second growing season. In the same region, a study conducted by Kanber et al. (1980) showed that water applied to closed-end furrow plots varied between 828 and 1096 mm. In the field and lysimeters under Las Cruces climatic conditions, Beese et al. (1982) concluded that the water applied ranged from 417 mm to 923 mm. Our results were similar to their results.

Table 1. Total applied water depth, and Et by irrigation level (IL).

IL	Years							
	1999				2000			
	I	P	Δs	Et	I	P	Δs	Et
I_1	813.4	20	104.3	957.7	1013.3	38	103.0	1154.3
I_2	727.6	20	113.4	861.0	853.5	38	98.5	990.0
I_3	602.0	20	81.5	703.5	645.1	38	72.6	755.7
I_4	378.4	20	117.0	515.4	359.1	38	97.6	494.7
I_5	267.8	20	151.9	439.1	323.5	38	92.5	454.0

Mean seasonal water use by the peppers in the treatments of I_1, I_2, I_3, I_4 and I_5 varied from 1056 to 447 mm. Water use in the sprinkler irrigation treatments changed mostly depending on the applied irrigation water.

3.2. Fruit Number

Table 2 shows measured fruit number from irrigation treatments for 1999 and 2000. Fruit number of pepper was significantly affected by deficit irrigation applied by line source sprinkler system. In both years, the highest fruit number was obtained at the I_1 treatment to which the greatest depth of water was applied. As depth of water applied decreased, there was a decrease in the number of fruit such that the lowest fruit number was obtained from treatment I_5. These data show a direct relationship between water applied and the number of fruit per plant and correspond with Pellitero et al. (1993) showed that the number of fruits per plant decreased as soil water deficit increased.

Sprinkler irrigation had higher numbers of fruit per plant (46) when compared with the mean fruit number of basin (20.5), furrow (15.5) and drip (25.5) irrigation methods given by Gençoğlan et al. (2002). The increase of the fruit number per pepper plant implies that sprinkler irrigation does not adversely affect the pollination of pepper when compared to other irrigation methods such as basin, furrow and drip. If the sprinkler method adversely affected pollination of red hot pepper, then fruit number per plant would be lower than that of the other irrigated methods. Peppers are indeterminate plants, that is, they keep flowering and producing fruits as long as the weather allows (Wierenga and Hendrickx, 1985). In both growing seasons, irrigation applications, which were made weekly and operated about 3-4 hours, may cause flower losses but not considerable.

3.2. Fruit Dry Weight and Dry Yield

The FDW and DY were significantly affected by deficit water applied by the line source sprinkler (Table 2). In the first year (1999), the highest FDW was obtained from I_2 and followed by I_1, I_3 and I_5 treatments, all of which were in the same group. The lowest FDW was in the I_4 treatment. In 2000, the highest FDWs were in treatments I_3, I_1 and I_2, and followed by I_4 and I_5 which had the lowest FDW. Generally, there was a decreasing trend in the FDW and conversely, increasing trend in the FN according to the increased water deficit. Pill and Lamberth (1980) confirmed that decreasing the soil water potential reduced fruit number set, and mean and total fruit weight of tomatoes.

Dry yield is the best indicator of the response of pepper-plant to irrigation (Bernstein and Francois, 1973). DY of pepper increased as total water applied increased. In 1999, the highest DY was obtained from I_1 and I_2 in order. The lowest DY was also obtained from treatment I_4 and I_5 in order. In 2000, the highest DY was obtained from I_1, I_2 and I_3. The lowest DY was also harvested from I_5 treatment. In both years, DY decreased as depth of water applied decreased. O'Sullivan (1979) reported that sprinkler irrigation increased pepper yields when maintained the available soil moisture (ASM) >50%.

Table 2. Yield component by irrigation level.

	Years					
	1999			2000		
IL	Fruits number per plant	Fruit dry weight (g)	Dry yield (kg ha^{-1})	Fruits number per plant	Fruit dry weight (g)	Dry yield (kg ha^{-1})
I_1	61a^z	0.6ab^z	1474a^z	31a^z	1.1b^z	1242a^z
I_2	45b	0.7a	1138ab	24ab	1.1b	1091a
I_3	44b	0.6ab	1069b	19ab	1.4a	1005ab
I_4	32b	0.4b	608c	26ab	0.7c	862b
I_5	16c	0.6ab	316c	13b	0.5c	252c
P	0.001*	0.064*	0.011*	0.069*	0.000*	0.021*

*is significant at p<0.05, ^{z}; values followed by the different letters are significantly different (P<0.05).

3.3. Production Function

Linear relationships were established between the total amount applied water (I, mm) and DY (kg ha^{-1}), and water use (Et, mm) and DY (Figures 2 and 3). Water versus yield relationships show that for each 10 mm additional water or water use will increase DY by 10 to 20 kg ha^{-1}. These production functions are established up to the maximum yield (Wierenga and Hendrickx, 1985). The slope of the red dry pepper-water production function varied between years. This slope change may be the result of differences in weather or cultural practices (Wierenga and Hendrickx, 1985).

The slopes of the relationships between relative dry hot pepper yield reduction and relative evapotranspiration deficit, termed “yield response factor” by Doorenbos and Kassam (1979) were found to be 1.33 in 1999 and 0.93 in 2000 (Figure 4). When combined values were used, a ky factor of 1.07 was obtained. Doorenbos and Kassam (1979) reported that pepper yield response factor (ky) would be greater than 1, which corresponded to ky of this study. Response of the yield to water supply is quantified through the yield response factor.. Under conditions of limited water distributed equally over the total growing season, the crop with (ky>1) would suffer a greater yield loss than the crop with (ky<1). This shows that pepper is susceptible horticultural plant to drought stress. Yield response factor (ky) is important because it allows quantification of water supply and water use in terms of crop yield and production for the project area for planning, design and operation of irrigation projects.

4. Conclusion

Plant water stress from deficit irrigation significantly affected the FN, FDW and DY of hot pepper. While

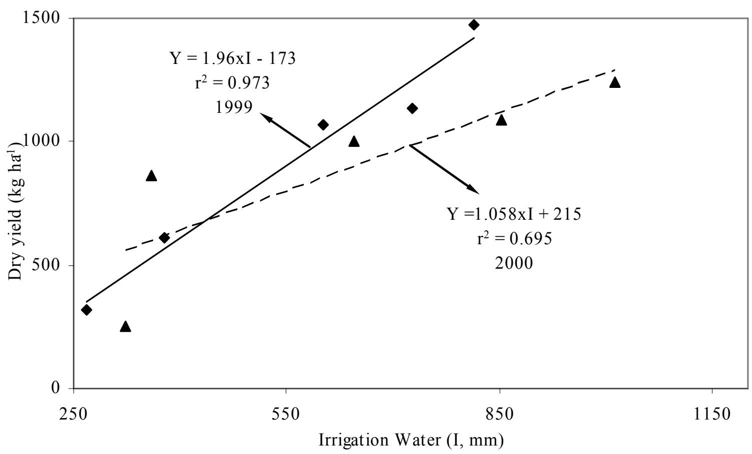

Figure 2. Irrigation water – dry yield relationship for pepper.

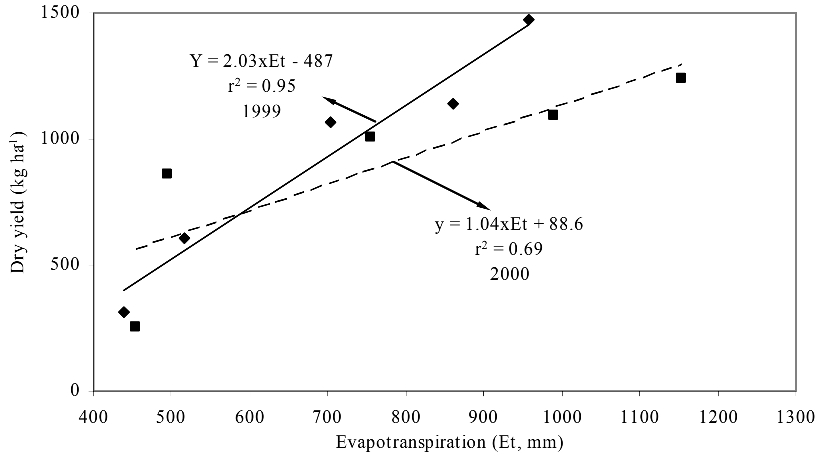

Figure 3. Evapotranspiration – dry yield relationship for pepper.

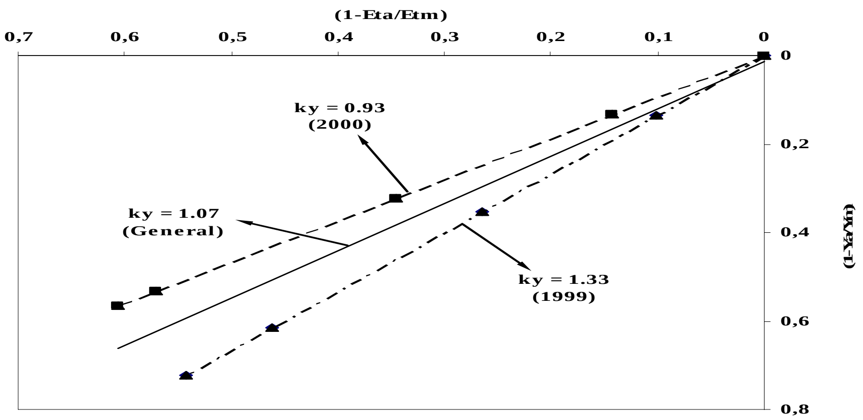

Figure 4. Relationship between relative dry yield decrease (1-Ya/Ym) and relative evapotranspiration deficit (1-Eta/Etm) for pepper.

treatment I_1 resulted in the highest yield components, treatment I_5 resulted in the lowest yield components. Linear water production functions of red hot pepper were found between DY versus water applied and evapotranspiration obtained from the line source sprinkler irrigation plots. For each 10 mm increase in water applied and Et, 10 kg ha^{-1} and 20 kg ha^{-1} of red pepper yield increased, respectively. When water is plenty, red hot pepper can be irrigated at the level of I_1 and I_2. When water source is scarce, pepper can be irrigated at the lower water level taking economic conditions into consideration.

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