

Irrigation Regimes Affect Yield and Water Use by Bell Pepper

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Abstract. 'Keystone Resistant Giant' bell pepper (*Capsicum annuum* L.) was grown in drainage lysimeters under controlled soil water regimes during 1982, 1984, and 1985. Three irrigation regimes were imposed on bell pepper grown on two soil types during spring and fall growing seasons. Irrigation regimes consisted of applying water when the soil water tension at 10 cm exceeded 25, 50, or 75 kPa during crop growth. Yields and water use were greatest when irrigation was applied at 25 kPa. Regression equations are presented to describe the relationships of water use to plant age and to compute the ratios of daily evapotranspiration to pan evaporation (crop factors) for bell pepper grown under the three irrigation regimes.

Bell pepper has been classified as susceptible to very susceptible to water stress, with blossom stage being the most sensitive period (Bruce et al., 1980). Sprinkler irrigation to maintain the available soil moisture (ASM) >50% increased pepper yields under cool, humid conditions in Canada only during years when rainfall was below normal (O'Sullivan, 1979). Bell pepper yields in India were similar when irrigated at 40% and 60% ASM, but yields were reduced when irrigation was applied at either 20% or 80% ASM (Hedge, 1987). Marketable yields of 'Bell Boy' pepper grown on a silt loam in Arkansas were increased by trickle irrigation, but yields were similar when irrigation was applied at 30, 50, and 70 kPa soil water tension (Haynes and Herring, 1981). Yields of trickle-irrigated pepper grown under arid conditions in Israel were greater at water applications of 1.33 than 0.83, 0.95, or 1.75 times pan evaporation (Shmueli and Goldberg, 1972). Applying either trickle or sprinkler irrigation when the soil water tension exceeded 75 kPa increased 'Calwonder' pepper yields compared to nonirrigated pepper in New York, but yields of pepper irrigated at 25 and 75 kPa were similar (VanDerwerken and Wilcox-Lee, 1988). When evaporative demand was high, yields of sprinkler-irrigated pepper grown on sandy soils in Georgia were greater when irrigated at 25 than at 50 kPa (Batal and Smittle, 1981). Yields of many drought-sensitive vegetable crops have been reduced substantially when the soil water tension was >25 kPa at irrigation (Bruce et al., 1980; Smittle et al., 1992b; Stansell and Smittle, 1980, 1989). However, pepper yields were less with daily sprinkler irrigation than with irrigation at 5-day intervals (Goldberg and Shmueli, 1971), a result indicating a need to match irrigation to evapotranspiration (ET) to produce maximum pepper yields.

Pan evaporation (E_p) incorporates the climatic factors influencing ET into a single measurement (Hansen et al., 1980) and has been used to schedule irrigation for several crops (Jensen and Middleton, 1970). The single crop factor (ET/E_p) value used by Jensen and Middleton (1970) usually resulted in excessive water during some growth periods and water deficits during others. Hansen et al. (1980) present a generalized curve to describe ET/E_p changes during crop development, but the generalized curve lacks precision. We have developed regression equations to calculate

ET/E_p values used to estimate ET during the growth of several vegetables (Stansell and Smittle, 1980, 1989; Smittle et al., 1990a, 1992b) and have incorporated these equations into irrigation scheduling models (Smittle and Dickens, 1992; Smittle et al., 1990b, 1992a).

In this research, we determined the yield and water use responses of bell pepper to different irrigation regimes. We also developed regression equations to calculate ET/E_p during the growth of bell pepper grown under the different irrigation regimes.

Materials and Methods

During Spring 1982 and 1984 and Fall 1984 and 1985, 'Keystone Resistant Giant' bell pepper was grown in lysimeters containing a Tifton loamy sand soil and a Bonifay sand soil. The Bonifay sand was composed of 92.1% sand, 2.0% silt, 4.1% clay, and 1.8% organic matter. The Tifton loamy sand was composed of 80.4% sand, 9.0% silt, 7.0% clay, and 3.6% organic matter. The lysimeter plots were equipped with automatic rainout shelters activated by rainfall (Stansell and Smittle, 1980). Between-plot moisture barriers (1.2 m deep) and subsurface drains were used to isolate the plots from each other and from groundwater intrusion. Each shelter protected 24 plots of a single soil type that were 1.5 × 1.8 m. Each plot contained six resistance block soil moisture sensors placed 10, 23, 38, 53, 81, and 107 cm deep. The sensors were read daily beginning at 0800 HR by a data collection system controlled by an on-site computer. The data were processed by the computer and a daily report was printed that included the soil water content at each sensor depth and the irrigation requirements for the day. Soil water data were stored for future analyses. A shelter contained 12 plots of bell pepper. Irrigation treatments within the eight year-season-soil type combinations were arranged in a randomized complete-block design with four replications.

For 10 days after transplanting, water was applied at 2- to 3-day intervals with a hand-held sprinkler nozzle. After this time, irrigations were scheduled by measured soil water deficits. Treatments consisted of irrigating at soil water tensions of 25, 50, or 75 kPa. When sensors 10 cm deep showed soil water deficits corresponding to the treatment requirements, water was applied to refill the surface 30 cm of the soil profile to field capacity (8 kPa). The amount of water applied represented the average of the four replications and was determined from water retention curves for the soil (Stansell and Smittle, 1980).

Climatological data, including rainfall, open pan evaporation, wind movement, relative humidity, and maximum and minimum

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air temperatures were collected daily at the research site.

Plots were hand-tilled to incorporate fertilizers applied at 40N–35P–100K (kg·ha⁻¹). Transplants were planted by hand on 15 Mar. 1982, 16 Mar. 1984, 8 Sept. 1984, and 29 Mar. 1985. Plants were spaced 30 cm apart in 91-cm rows. Nitrogen was broadcast-applied at 34 kg N/ha as Ca(NO₃)₂ 3, 5, and 7 weeks after transplanting.

Plots were harvested at weekly intervals for 4 weeks beginning on 17 May 1982, 28 May 1984, 17 Oct. 1984, and 7 June 1985. The fruit were graded and the number and weight of total, marketable, US fancy, US no. 1, US no. 2, and culls were determined. Yield data for the irrigation regimes were subjected to regression analyses, wherein the eight year–season–soil type combinations were considered as separate experiments.

Water applied should be a valid estimate of ET since the plots were protected from rainfall and groundwater intrusion and water was added based on water content at various depths in the soil profile. Sufficient water (55 to 75 mm) was applied during the first 10 days after transplanting to ensure recharge of the soil profile. Data for water applications and E_p during these periods were not included in the calculation of ET and E_p rates since the amount of water applied at the last irrigation would also recharge the soil profile. Daily ET rates were determined by dividing the depth of water applied to each plot at each irrigation by the number of days since the last irrigation. Daily E_p rates were measured from a U.S. Weather Bureau class A pan. Data for ET and E_p rates on the date

of irrigation were used to calculate ET/E_p values. Regression equations were developed to describe changes in ET, E_p, and ET/E_p with age using SAS's general linear models procedure (SAS Institute, 1982).

Results and Discussion

E_p was 39% greater when bell pepper was grown during the spring than the fall (Table 1). Also, more water was applied when bell pepper was grown during the spring than the fall. During the period when irrigations were determined by soil water tension 10 cm deep, 11 to 29 irrigations were required to maintain the maximum soil water tensions below the desired level. Although the amount of water applied at each irrigation decreased as the soil water tensions at the time of irrigation decreased from 75 to 25 kPa, less total water was usually applied to bell pepper that was subjected to water stress levels of 50 and 75 than to 25 kPa. These results follow the general trend that crops receiving more frequent irrigations have had greater water use than crops receiving less frequent irrigations under similar climatic conditions (Bruce et al., 1980; Stansell and Smittle, 1980, 1989).

All of the crops showed significant marketable fruit yield responses to the irrigation regimes (Table 2). Average marketable fruit yields were 30.5, 26.5, and 21.8 t·ha⁻¹ when bell pepper was irrigated at 25, 50, and 75 kPa, respectively. The yield increase with irrigation at 25 kPa compared to 50 kPa was greater for this

Table 1. Effect of production seasons and soil types on pan evaporation and water use by 'Keystone Resistant Giant' bell peppers grown under three irrigation regimes.^z

Year–season–soil	Pan evaporation (mm)	Irrigation regime (kPa)		
		25	50	75
		Water applied (mm) ^y		
1982–Spring–Tifton	463	311 (27)	255 (16)	207 (11)
1984–Spring–Tifton	587	269 (19)	264 (15)	258 (13)
1984–Spring–Bonifay	587	280 (17)	275 (14)	225 (11)
1984–Fall–Tifton	425	221 (22)	213 (17)	200 (12)
1984–Fall–Bonifay	425	251 (16)	237 (14)	245 (12)
1984–Fall–Bonifay	425	242 (17)	228 (13)	218 (12)
1985–Spring–Tifton	656	396 (25)	387 (18)	380 (17)
1985–Spring–Tifton	656	380 (29)	349 (21)	295 (18)

^zPlots were irrigated when soil water tension at 10 cm was 25, 50, or 75 kPa.

^yNumbers in parentheses are the number of irrigations applied to each irrigation regime.

Table 2. Effect of irrigation regime^z on marketable yield of 'Keystone Resistant Giant' bell peppers.

Crop	Irrigation regime (kPa)			Significance
	25	50	75	
	Fruit yield (t·ha ⁻¹)			
1982–Spring–Tifton	33.2	31.0	23.4	L ^{**} , Q [*]
1984–Spring–Tifton	25.8	21.9	16.3	L [*]
1984–Spring–Bonifay	18.4	17.2	11.8	L [*] , Q ^{**}
1984–Fall–Tifton	26.9	23.7	19.5	L ^{**}
1984–Fall–Bonifay	24.2	26.2	20.0	Q ^{**}
1984–Fall–Bonifay	26.3	25.0	19.0	L ^{**} , Q [*]
1985–Spring–Tifton	43.3	32.9	34.8	Q [*]
1985–Spring–Tifton	46.1	34.0	29.9	L ^{**} , Q [*]

^zPlots were irrigated when soil water tension at 10 cm was 25, 50, or 75 kPa.

^{*},^{**}Significant at *P* = 0.05 or 0.01; L = linear, Q = quadratic effects of irrigation regimes.

experiment than reported earlier for the same soil type (Batal and Smittle, 1981). Bell pepper in this experiment received only the water applied by irrigation; whereas, bell pepper of the earlier field test received 122 mm of water as rainfall during the period from week 4 through 12 after transplanting.

Yields of fancy peppers showed significant linear responses to irrigation regimes for seven of the eight crops (Table 3). Fancy fruit yields were greater with irrigation at 25 than at 50 or 75 kPa for all crops. Average fancy fruit yields were 10.3, 6.7, and 4.1 t·ha⁻¹ when irrigated at 25, 50, and 75 kPa, respectively. Fancy fruit yields represent 34%, 25%, and 19% of the marketable yield of pepper irrigated at 25, 50, and 75 kPa, respectively.

The large, well-shaped fruit of the US fancy grade generally command a price of about \$675/t (Mizelle, 1991). Using this price, returns from US fancy grade bell pepper would be \$6950, \$4220, and \$2770/ha when irrigated at 25, 50, and 75 kPa, respectively. Average water application rates of 294, 276, and 253 mm, for the 25, 50, and 75 kPa irrigation treatments reflect irrigation cost reductions of about \$10/ha for the 50 kPa and \$20/ha for the 75 kPa irrigation treatments. These results show that more frequent irrigations with less water per irrigation increased marketable yield, grade, and returns of 'Keystone Resistant Giant' bell pepper.

ET and E_p data for the growth period from 10 to 14 days after transplanting until the last irrigation were used to develop regres-

sion equations to describe ET and ET/E_p values. Daily E_p rates varied from 0 mm to 8 mm during the 2- to 9-day periods of water use between irrigations; however, the E_p rates generally increased during the spring and decreased during the fall.

The regression equations for ET accurately estimate the amount of water used by bell pepper only if the evaporative demand conditions were similar to those of these tests and are not presented. However, the ET/E_p values provide a method of adjusting the water-use rates to compensate for variations in climatic conditions that influence evaporative demand.

The regression equations to describe ET/E_p values accounted for 96% to 99% of the variations of ET/E_p for the three irrigation regimes of the eight bell pepper crops (Table 4). The similarity of regression equations for the crop-irrigation regime combinations indicate that much of the variation in water-use estimation due to climatic differences could be eliminated by calculating ET/E_p values. ET/E_p values produced by these regression equations were slightly lower when bell pepper plants were irrigated at soil water tensions of 50 and 75 rather than 25 kPa. For example, ET/E_p values with all crops combined were 0.80, 0.77, and 0.73 when 75-day old bell pepper was irrigated at 25, 50, and 75 kPa, respectively. These results agree with our earlier research (Bruce et al., 1980; Stansell and Smittle, 1980, 1989) that more water is required when crops are irrigated more frequently. Stegman et al. (1980)

Table 3. Effect of irrigation regime^z on yield of fancy 'Keystone Resistant Giant' bell peppers.

Crop	Irrigation regime (kPa)			Significance
	25	50	75	
	Fruit yield (t·ha ⁻¹)			
1982-Spring-Tifton	7.5	4.9	2.5	L**
1984-Spring-Tifton	8.8	4.0	3.0	Q**
1984-Spring-Bonifay	7.4	4.7	2.4	L**, Q*
1984-Fall-Tifton	11.2	6.8	2.4	L**
1984-Fall-Bonifay	10.4	6.9	4.2	L**
1984-Fall-Bonifay	11.7	8.2	4.2	L**
1985-Spring-Tifton	13.0	8.9	7.7	L**, Q**
1985-Spring-Tifton	12.2	9.0	6.3	L**

^zPlots were irrigated when soil water tension at 10 cm was 25, 50, or 75 kPa.

*,** Significant at $P = 0.05$ or 0.01 ; L = linear, Q = quadratic effects of irrigation regimes.

Table 4. Effect of production seasons and soil types on regression equations to describe crop factors (ET/E_p) change with age^z (A) of 'Keystone Resistant Giant' bell peppers grown under three irrigation regimes.^y

Year-season-soil	Irrigation regime (kPa)		
	25	50	75
	Regression		
1982-Spring-Tifton	0.0178A - 0.00009A ²	0.0171A - 0.00008A ²	0.0169A - 0.00010A ²
1984-Spring-Tifton	0.0138A - 0.00006A ²	0.0137A - 0.00006A ²	0.0164A - 0.00010A ²
1984-Spring-Bonifay	0.0131A - 0.00005A ²	0.0150A - 0.00007A ²	0.0138A - 0.00007A ²
1984-Fall-Tifton	0.0254A - 0.00021A ²	0.0228A - 0.00016A ²	0.0226A - 0.00017A ²
1984-Fall-Bonifay	0.0207A - 0.00012A ²	0.0235A - 0.00017A ²	0.0220A - 0.00015A ²
1984-Fall-Bonifay	0.0236A - 0.00017A ²	0.0194A - 0.00012A ²	0.0202A - 0.00014A ²
1985-Spring-Tifton	0.0201A - 0.00012A ²	0.0186A - 0.00011A ²	0.0185A - 0.00011A ²
1985-Spring-Tifton	0.0204A - 0.00012A ²	0.0160A - 0.00008A ²	0.0177A - 0.00010A ²
Spring crops	0.0180A - 0.00010A ²	0.0167A - 0.00009A ²	0.0161A - 0.00009A ²
Fall crops	0.0252A - 0.00020A ²	0.0222A - 0.00016A ²	0.0220A - 0.00016A ²
All crops	0.0196A - 0.00012A ²	0.0186A - 0.00011A ²	0.0184A - 0.00012A ²

^zAge expressed as days after transplanting.

^yPlots were irrigated when soil water tension at 10 cm was 25, 50, or 75 kPa.

showed that the ET rate was elevated for a short period after irrigation due to evaporation of water from soil and plant surfaces.

The ET for a specific age of bell pepper can be estimated by multiplying the E_p value, measured from an evaporation pan, by the ET/E_p value calculated from the regression equations of Table 4. For example, 50 days after transplanting, the ET/E_p value for a spring crop of bell peppers would be 0.65 ($0.018A - 0.0001A^2$) if irrigation were applied at 25 kPa. The ET of these bell peppers on this date would be 2.6 mm (4×0.65) if E_p were 4 mm and 5.2 mm (8×0.65) if E_p were 8 mm.

The maximum ET/E_p values calculated from these regression equations were similar for all crops. At 75 days after transplanting, ET/E_p values were 0.79, 0.77, and 0.80, respectively, for spring crops, fall crops, and all crops irrigated at 25 kPa. The pattern of ET/E_p change with age varied slightly for bell pepper grown during the spring and fall (Fig. 1). Using ET/E_p values where all data were combined would not greatly affect the accuracy of estimating daily ET for bell pepper grown during the spring, but using the equation having all data combined for fall-grown bell pepper would underestimate ET during early growth and overestimate ET during late growth. For example, when data for all crops were combined, the ET/E_p values for 45- and 90-day old bell pepper irrigated at 25 kPa were 0.64 and 0.79, respectively. On the other hand, when data for only the fall crops were used, ET/E_p values for 45- and 90-day old bell pepper irrigated at 25 kPa crops were 0.73 and 0.65, respectively.

If E_p were 5 mm/day, using the regressions for all crops to calculate the ET/E_p for 45-day old bell pepper grown during the fall would introduce an error in estimating an ET of ≈ 0.45 mm/day. This magnitude of error in estimating ET may not greatly affect an irrigation scheduling model (Smittle et al., 1990b, 1992b) in the humid southeastern United States because the soil water reservoir within the root system is small and rainfall in excess of accumulated ET is relatively common. However, an accumulation of this magnitude of ET estimation error in arid areas could introduce a serious water stress near blossom stage if the regression equation for all crops was used to schedule irrigations for a fall crop.

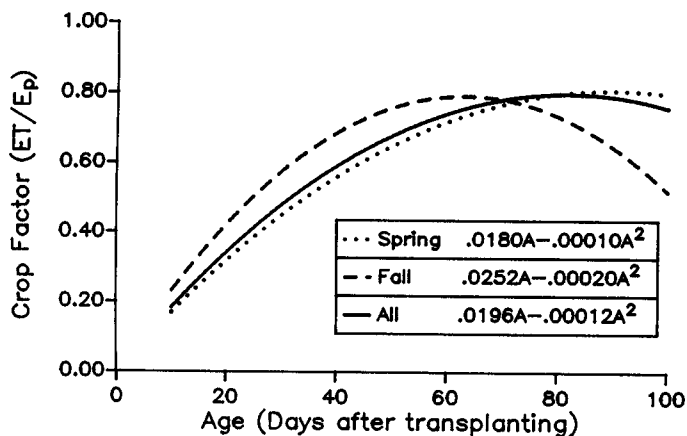


Fig. 1. Daily crop factor values for 'Keystone Resistant Giant' bell peppers grown as a spring or fall crop or when all crops were included in the regression.

We have shown that marketable and fancy yield of bell pepper was greatest with irrigation applications when the soil water tension at 10 cm was <25 kPa. This irrigation regime also resulted in more frequent applications and required more water than irrigation applications at soil water tensions of 50 and 75 kPa. Regression equations were developed to compute ET/E_p values during bell pepper growth. These equations provide a daily adjustment for E_p that allows E_p to be used to develop irrigation scheduling models (Smittle and Dickens, 1992; Smittle et al., 1990b, 1992b).

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