Irrigation Regimes Affect Cabbage Water Use and Yield

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Additional index words. Brassica oleraceae, evaporation, evapotranspiration, irrigation scheduling, soil water tension, water-use modeling

Abstract. **Cabbage (*Brassica oleracea* L.) was grown in drainage lysimeters under controlled soil water regimes during 3 years. Three irrigation regimes were imposed on cabbage grown on two soil types during the 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 highest when irrigation was applied at 25 kPa soil water tension. 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 cabbage grown under the three irrigation regimes.**

Cabbage has been classified as intermediately susceptible to water stress, with the head formation period being more sensitive than the period before (Bruce et al., 1980; Janes, 1950; Nortje and Henrico, 1988: Singh and Alderfer, 1966). Vittum et al. (1963) reported that the most critical irrigation period occurred during the last 3 to 4 weeks before harvest. In this study, the soil was often near field capacity when the plants were set in the field in the northeastern United States, and normal rainfall usually supplied the low water-use needs of small plants. Singh and Alderfer (1966) also found that marketable yields of cabbage were similar when irrigations were applied at 100 kPa soil water tension during growth and when cabbage was irrigated at 1000 kPa before head formation and 100 kPa after head formation. However, when cabbage was irrigated at 100 kPa before head formation and at 1000 kPa after head formation, marketable yields were similar to cabbage irrigated at 1000 kPa soil water tension during growth. Yields of cabbage produced during the winter in Texas were similar when irrigated at 80 kPa and 160 kPa soil water tension, but irrigating at a soil water tension of 360 kPa reduced yields (Thomas et al., 1970).

Yields have been reduced substantially when the soil water tension was >25 kPa before many drought-sensitive vegetables were irrigated (Bruce et al., 1980; Smittle et al., 1990b, 1992b; Stansell and Smittle, 1980, 1989); therefore, cabbage yields may have been higher than reported earlier (Singh and Alderfer, 1966; Thomas et al., 1970) if the crop receiving the low-stress treatment had been irrigated at 25 rather than 80 or 100 kPa soil water tension. Drew (1966) reported higher cabbage yields with irrigation at 12.5% than at 25%, 50%, or 75% available soil moisture. He also reported that irrigation during the last 2 to 3 weeks substantially increased yields of stressed and nonstressed cabbage, while irrigation during the earlier part of the season had little effect on yields.

A consumptive use requirement of 380 mm of water for producing high cabbage yields was about the same for trickle, modified-furrow, and standard-furrow irrigation methods (Bucks et al., 1974), but applying water at less than the consumptive use rate reduced yields. Water-use rates for cabbage were further defined by Nelson and Hwang (1976) in a greenhouse growth-chamber experiment. The transpiration rate under controlled conditions varied with plant age. Daily transpiration, increased from 80g at 40 days after planting seeds (DAP) to ≈ 300 g at head formation (60 DAP), reached a peak use of ≈ 355g at 75 DAP, then decreased to 325 g at 105 DAP. The growth chambers did not circulate air; therefore, an important factor influencing evapotranspiration (ET) under field conditions was not considered.

Several methods of estimating ET from climatic data have been developed. The modified Penman and the Jensen-Haise methods use combinations of solar radiation, temperature, humidity, wind velocity, and vapor-pressure measurements to estimate the ET of a reference crop, then use a crop coefficient to adjust the ET value estimated for the reference crop to estimate the ET of the crop to be irrigated (Hansen et al., 1980), The crop coefficient values (ET of the irrigated crop/ET of reference crop) are multiplied by the ET value estimated by the specific method to estimate the ET of the irrigated crop.

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 value (ET/E_P) used by Jensen and Middleton (1970) usually resulted in applying excessive water during some growth periods and water deficits during other growth periods. A generalized curve was presented to describe crop factor value changes during crop development (Hansen et al., 1980), but the generalized curve lacks precision. We have developed regression equations to calculate daily crop factor values during the growth of several vegetables (Stansell and Smittle, 1980, 1989; Smittle et al., 1992b, 1990b) and have incorporated these equations to estimate ET from E_P data into irrigation scheduling models (Smittle and Dickens, 1992; Smittle, et al., 1990a, 1992a).

In this research, we determined the yield and water-use responses of cabbage to three irrigation regimes. We also developed regression equations to calculate crop factors during growth of cabbage grown under the various irrigation regimes.

Materials and Methods

During Spring 1982 and Fall 1983 and 1985, 'Rio Verde' cabbage 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%

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J. Amer. Soc. Hort. Sci. 119(l):20-23. 1994.

clay, and 3.6% organic matter. The lysimeter plots were equipped with automatic rainfall shelters activated by rainfall (Stansell and Smittle, 1980). A combination of between-plot moisture barriers (1.2 m deep) and subsurface drains was used to isolate the plots from each other and from groundwater intrusion. Each shelter protected 24 plots, 1.5 × 1.8-m of a single soil type. 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, which included the soil water content at each sensor depth and the irrigation requirements for the day, was printed. Soil water data were stored for future analyses. Each shelter contained 12 plots of cabbage.

For 10 to 14 days after transplanting, water was applied with a hand-held sprinkler nozzle. After this time, irrigation was scheduled by measured soil water deficits. Irrigation treatments within the 5 year–season–soil type combinations were arranged in a randomized complete-block design with four replications. Treatments consisted of irrigating at soil water tensions of 25,50, or 75 kPa. When sensors 10 cm deep showed soil water deficit 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 air temperatures were collected daily at the research site.

Plots were hand-tilled to incorporate fertilizers applied at 67N–49P–124K (in kg·ha^{-1}). Transplants were set by hand on 1 Mar. 1982, 2 Sept. 1983, and 24 Sept. 1985. Plants were spaced 30 cm apart in 91 cm rows. Nitrogen was broadcast at 34 kg·ha^{-1}, 3,5, and 7 weeks after transplanting.

Plots were harvested on 14,17, and 20 May 1982, on 16,22, and 28 Nov. 1983, and on 11 Nov. and 2 and 11 Dec. 1985. The number and weight of total and marketable cabbage heads were determined. Yield data for the irrigation regimes were subjected to regression analyses wherein the 5-year-season-soil type combinations were considered as separate experiments.

We assumed that water applied would be a valid estimate of water use or ET, since these 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 (50 to 75 mm) was applied during the first 10 days after transplanting to recharge the soil profile. Data for the initial water applications and pan evaporation during these periods were not included in the calculation of ET and evaporation rates, since the amount of water applied at the last irrigation would also recharge the soil profile. Daily water-use (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 calculated by dividing the sum of the E_p depths between irrigations by the number of days over which the age data were accumulated. Data for ET and E_p rates on the irrigation date were used to calculate daily 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

When averaged over the five crops, 99.4%, 96.2%, and 95.2% of the total yield of cabbage irrigated at 25, 50, and 75 kPa, respectively, were marketable. Therefore, only marketable yields are presented (Table 1). Marketable yields of cabbage from each of the five crops were highest when irrigation was applied at a soil water tension of 25 kPa. Marketable yield of all crops except the crop grown on the Tifton soil in spring 1982 decreased linearly with increasing water stress. Significant quadratic yield responses

Table 1. Effect of irrigation regime on marketable yields of 'Rio Verda' cabbage during spring and fall production seasons on Tifton loamy sand and Bonifay sand soils.

| | Marketable yield (t·ha^{-1}) | | | |
| | Irrigation regime (kPa)^z | | | |
Year–season–soil	25	50	75	Significance
1982–Spring–Tifton	47.6	38.6	38.6	Q**
1982–Spring–Bonifay	51.2	45.0	40.6	L**
1983–Fall–Bonifay	42.9	39.1	35.5	L*
1985–Fall–Tifton	43.7	35.4	34.0	L*Q**
1985–Fall–Bonifay	42.4	39.2	35.4	L**

^{z}Plots were irrigated when soil water tension at 10 cm was 25, 50, or 75 kPa.
*,**Significant at $P \leq 0.05$ or 0.01; L = linear, Q = quadratic.

Table 2. Effect of production season and soil type on pan evaporation and water use by 'Rio Verda' cabbage grown under three irrigation regimes.

| | Pan evaporation (mm) | Water applied (mm)^z | | |
| | | Irrigation regime (kPa)^y | | |
Year–season–soil		25	50	75
1982–Spring–Tifton	270	175 (14)	182 (11)	153 (8)
1982–Spring–Bonifay	270	177 (17)	158 (10)	142 (8)
1983–Fall–Bonifay	233	146 (13)	111 (9)	131 (8)
1985–Fall–Tifton	131	82 (12)	84 (8)	71 (8)
1985–Fall–Bonifay	131	84 (8)	75 (6)	74 (7)

^{z}Numbers in parentheses are the number of irrigations applied to each irrigation regime.
^{y}Plots were irrigated when soil water tension at 10 cm was 25, 50, or 75 kPa.

to irrigation regime for cabbage grown on Tifton loamy sand during Spring 1982 and Fall 1985 were due to a large increase in total yield with irrigation at a soil water tension of 25 kPa. These data suggest that cabbage is more sensitive to water stress than reported earlier (Janes, 1950; Singh and Alderfer, 1966) when grown on the shallow, low water-holding-capacity soils of the southeastern Coastal Plain.

In 1982 and 1985, yields of cabbage grown on the two soil types were similar. Summer squash *(Cucurbita pepo* L.) yields also were not affected by soil type when grown in these rainfall shelters (Stansell and Smittle, 1989).

E_p was 16% and 106% greater during cabbage growth in Spring 1982 than in Fall 1983 and 1985, respectively (Table 2). During the 10 to 83 days after transplanting when water applications were determined by soil water tension 10 cm deep, 7 to 14 irrigations were required to maintain the maximum soil water tensions below the desired level. Water applied to the cabbage crops varied among the years, but the amount of water applied within a growing season was similar for cabbage grown on the Tifton loamy and Bonifay sand soils in 1982 and 1985. The amount of water applied at each irrigation decreased as the soil water tensions at irrigation decreased from 75 to 25 kPa, but less total water was usually applied to cabbage that was subjected to water stress of 75 and 50 than 25 kPa soil water tension. These results follow the general trend that water use is increased by more frequent irrigation to crops grown under the same climatic conditions (Bruce et al., 1980; Stansell and Smittle, 1980, 1989). Marketable yields per millimeter of water applied were 0.34, 0.32, and 0.32 t·ha^{-1} for cabbage irrigated at soil water tensions of 25, 50, and 75 kPa, respectively.

ET and E_p data for the growth period between 10 days after transplanting until the last irrigation were used to develop regression equations to describe E_p, ET, and ET/E_p values. Daily E_p rates varied from 0 to 7 mm during the 3 to 10 days of water use between irrigations; however, the E_p rates generally decreased during growth of the fall cabbage crop. The combination of a variation in total potential ET among the five tests and the differences in growth stage at which maximum potential ET occurred contributed to the variation in ET described by the regression equations for ET per day (Table 3). The quadratic regression equations for ET accounted for 82% to 97% of the variation in daily ET with age, as seen by the r^2 values. The relationships between ET and crop age were closer for the two spring than for the three fall cabbage crops. The daily ET relationships were less close when the five cabbage crops were combined than when either the spring or fall cabbage crops were included in separate regression analyses. The high percentage (82% to 84%) of variation in ET by the five cabbage crops described by the quadratic regression equations indicate that crop age has a dominant effect on the change of cabbage ET, as indicated by Nelson and Hwang (1976). Our results suggest that using the quadratic regression equations to estimate daily cabbage ET would accurately estimate the number of days between irrigations if climatic conditions were similar to those during these tests.

ET/E_p values provide a method of adjusting these daily ET values to compensate for variations in the climatic conditions that influence ET. Jensen and Middleton (1970) expressed ET/E_p as a constant relationship between ET and E_p. Our earlier research (Smittle et al., 1990b, 1992b) shows that the relationship of ET to age changes with crop age. In this study, the regression equations to describe daily ET/E_p values accounted for 96% to 99% of the variations of ET/E_p for the three irrigation regimes of the five

Table 3. Effect of production season and soil type on regression equations to describe daily water use (millimeters per day) change with age (A) of 'Rio Verda' cabbage grown under three irrigation regimes.

	r^2	Regression	r^2	Regression	r^2	Regression
				Irrigation Regime (kPa)^z		
Year–season–soil		25		50		75
1982–Spring–Tifton	0.91	$0.133A–0.00101A^2$	0.97	$0.086A–0.00027A^2$	0.94	$0.086A–0.00052A^2$
1982–Spring–Bonifay	0.94	$0.078A–0.00024A^2$	0.85	$0.081A–0.00033A^2$	0.97	$0.066A–0.00024A^2$
1983–Fall–Bonifay	0.91	$0.107A–0.00106A^2$	0.97	$0.115A–0.00124A^2$	0.95	$0.097A–0.00092A^2$
1985–Fall–Tifton	0.91	$0.066A–0.00060A^2$	0.85	$0.088A–0.00098A^2$	0.92	$0.071A–0.00078A^2$
1985–Fall–Bonifay	0.96	$0.082A–0.00094A^2$	0.98	$0.052A–0.00044A^2$	0.98	$0.059A–0.00057A^2$
Spring crops	0.92	$0.105A–0.00061A^2$	0.92	$0.087A–0.00069A^2$	0.91	$0.076A–0.00039A^2$
Fall crops	0.87	$0.084A–0.00083A^2$	0.89	$0.090A–0.00096A^2$	0.89	$0.071A–0.00066A^2$
All crops	0.82	$0.093A–0.00068A^2$	0.84	$0.096A–0.00091A^2$	0.83	$0.075A–0.00056A^2$

^{z}Plots were irrigated when soil water tension at 10 cm was 25, 50, or 75 kPa.

Table 4. Effect of production season and soil type on regression equations to describe crop factor change with age (A) of 'Rio Verda' cabbage grown under three irrigation regimes.

	r^2	Regression	r^2	Regression	r^2	Regression
				Irrigation regime (kPa)^z		
Year–season–soil		25		50		75
1982–Spring–Tifton	0.97	$0.029A–0.00026A^2$	0.98	$0.022A–0.00016A^2$	0.96	$0.022A–0.00018A^2$
1982–Spring–Bonifay	0.98	$0.021A–0.00016A^2$	0.98	$0.019A–0.00013A^2$	0.98	$0.019A–0.00015A^2$
1983–Fall–Bonifay	0.99	$0.025A–0.00019A^2$	0.98	$0.027A–0.00023A^2$	0.99	$0.024A–0.00012A^2$
1985–Fall–Tifton	0.97	$0.024A–0.00019A^2$	0.97	$0.026A–0.00019A^2$	0.96	$0.024A–0.00016A^2$
1985–Fall–Bonifay	0.98	$0.027A–0.00028A^2$	0.98	$0.024A–0.00016A^2$	0.96	$0.021A–0.00015A^2$
Spring crops	0.97	$0.025A–0.00021A^2$	0.98	$0.021A–0.00015A^2$	0.97	$0.021A–0.00016A^2$
Fall crops	0.97	$0.025A–0.00021A^2$	0.97	$0.025A–0.00019A^2$	0.97	$0.023A–0.00017A^2$
All crops	0.97	$0.025A–0.00021A^2$	0.97	$0.023A–0.00017A^2$	0.97	$0.022A–0.00017A^2$

^{z}Plots were irrigated when soil water tension at 10 cm was 25, 50, or 75 kPa.

cabbage crops (Table 4). The similarity of regression equations for the crop irrigation regime combinations indicates that much of the variation in water-use estimates due to climatic differences was eliminated. Further, the close agreement of the equations within the 25-, 50-, and 75-kPa irrigation regimes when spring, fall, or all crops were combined suggests that daily ET/E_P values from these quadratic equations accurately estimate ET when multiplied by the measured E_P.

We have shown that total and marketable cabbage yields were highest with irrigation applications when the soil water tension at 10 cm was <25 kPa. This irrigation regime also required more water, but had a water-use efficiency rate similar to that of cabbage irrigated at soil water tensions of 50 and 75 kPa. Regression equations were developed to compute daily ET and ET/E_P values during cabbage growth. These equations allow E_P to be adjusted daily so that it can be used to develop irrigation scheduling models (Smittle and Dickens, 1992; Smittle et al., 1990a, 1992a).

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