Irrigation Regimes Affect Leaf Yield and Water Use by Turnip and Mustard

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Abstract. Turnip (*Brassica rapa* L.) and mustard (*Brassica juncea* L.) were grown in drainage lysimeters under controlled soil water regimes during 2 years. Irrigation regimes consisted of water applications when the soil water tension at a 10-cm depth exceeded 25, 50, or 75 kPa throughout growth of the two crops on two soil types during spring and fall production seasons. Leaf yield and water use were highest when irrigation was applied at 25 kPa soil water tension. Regression equations are presented to describe the relationships of daily pan evaporation and water use to plant age, and to compute daily evapotranspiration : pan evaporation ratios (crop factors) during spring and fall production seasons.

Turnip and mustard greens grow rapidly, and irrigation must be applied to ensure the active foliage growth required for good yields of high-quality greens (Barber, 1983). Although short-term water deficits (Barber, 1983) or water excesses (Mullins and Swingle, 1975) may have substantial negative effects on the yield of greens, there are very few reports of irrigation research for either turnip or mustard.

Leaf yields were increased 52% to 139% when turnips were irrigated at wilting, as compared to turnips grown without irrigation (del Vane et al., 1965). Substantial yield reductions of many drought-sensitive vegetables can occur before water stress becomes severe enough to cause wilting (Bruce et al., 1980; Smittle et al., 1990; Stansell and Smittle, 1980). Therefore, we would expect yield increases from an optimum irrigation regime to be greater than those reported by del Vane et al. (1965).

Irrigation has also increased turnip root yields (Lal and De, 1972) and mustard seed yields (Joarder et al., 1979; Prihar et al., 1981); however, foliage growth has generally been more sensitive to water stress than storage root growth or seed yield (Bruce et al., 1980).

The leaf yield responses of turnip and mustard to water stress less severe than that required to induce wilting have not been reported, although Lal and De (1972) found

that turnip growth decreased long before the soil moisture reached the wilting point. Our research was conducted to 1) determine leaf yield and water use responses of turnip and mustard to irrigation regimes and 2) relate water use throughout growth to pan evaporation.

'Shogoin' turnip and 'Southern Giant Curled' mustard were grown in lysimeters containing a Tifton loamy sand soil or a Bonifay sand soil during Spring 1982 and Fall 1984. The Tifton loamy sand was composed of 80.4% sand, 9.0% silt, 7.0% clay, and 3.6% organic matter. The Bonifay sand was composed of 92.17% sand, 2.0% silt, 4.1% clay, and 1.8% organic matter. The lysimeter plots were equipped with auto-

matic rainfall shelters activated by rainfall (Stansell and Smittle, 1980). Each shelter contained 12 plots each of turnip and mustard during spring and fall production seasons. 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 twenty-four 1.5 × 1.8-m plots of a single soil type. Each plot contained six resistance blocks soil moisture sensors placed at depths of 10, 23, 38, 53, 81, and 107 cm. 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.

Irrigation treatments within the eight crop-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. For 10 days after seeding, water was applied by hand as needed. Irrigations during the 11- to 64-day growth period were scheduled by measured soil water deficits. When sensors at the 10-cm depth showed soil water tension 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 each 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 fer-

Table 1. Effect of irrigation regimes on yield and water use of 'Shogoin' turnip and 'Southern Giant Curled' mustard grown during spring and fall production seasons on Tifton loamy sand and Bonifay sand soils.¹

Crop-season-soil	Irrigation regime (kPa)			Significance ^y
	25	50	75	
Leaf yield (t·ha ⁻¹)				
Turnip-spring-Tifton	31.7	28.2	28.4	NS
Turnip-spring-Bonifay	28.2	24.0	21.0	L**, Q*
Turnip-fall-Tifton	50.3	42.9	44.5	Q*
Turnip-fall-Bonifay	44.9	43.2	40.9	Q*
Mustard-spring-Tifton	24.0	20.7	21.3	Q*
Mustard-spring-Bonifay	18.1	15.7	14.9	Q*
Mustard-fall-Tifton	42.2	36.1	29.1	L**
Mustard-fall-Bonifay	37.4	33.9	33.4	Q*
Water use (mm)				
Turnip-spring-Tifton	107	97	87	
Turnip-spring-Bonifay	114	109	96	
Turnip-fall-Tifton	127	129	124	
Turnip-fall-Bonifay	163	139	135	
Mustard-spring-Tifton	101	87	83	
Mustard-spring-Bonifay	92	97	81	
Mustard-fall-Tifton	114	97	97	
Mustard-fall-Bonifay	131	109	102	

¹Plots were harvested twice during the 64-day spring season and three times during the 65-day fall season.

²Linear (L) and quadratic (Q) effects of irrigation regimes.

NS, *, ** Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively.

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Fig. 1. Change in daily pan evaporation (E_p and evapotranspiration (ET) of greens (turnip and mustard) irrigated at 25, 50, and 75 kPa during spring and fall production seasons.

Fig. 2. Change in daily crop factors for greens (turnip and mustard) irrigated at 25, 50, and 75 kPa during spring and fall production seasons.

tilizers applied at the rates of 45N40P-112K (kg-ha⁻¹). Seeds were planted by hand on 10 Feb. 1982 for spring and 21 Aug. 1984 for fall production. The seeds were planted in four rows spaced 30 cm apart. Each row consisted of two lines spaced 5 cm apart with plants spaced 1 cm apart in each line. Broadcast nitrogen applications at the rate of 34 kg N/ha were made 3 weeks after seeding and after each harvest.

On 25 Mar. and 15 Apr. 1982 and 20 Sept., 9 Oct., and 25 Oct. 1984, leaves were cut 3 to 4 cm above the soil and weighed. Samples of the leaves were taken from each plot of the 25 Mar. 1982 harvest for quality analyses of blade : stem ratio, color, chlorophyll, and dry weight. Midribs and stems were removed from 200 g of leaves, and both petioles and blade portions were weighed, dried, and reweighed. Another 100-g sample was blended with an equal weight of water for 3 min, and the resulting slurry was used for chlorophyll, dry weight, and color determination as described by Smittle (1986).

Yield and quality data for irrigation regimes were subjected to regression analyses, wherein the eight crop-season-soil type combinations were considered as separate experiments. The relationships between water use and pan evaporation during the spring and fall production season were established

by regression analyses by use of the general linear models procedure of SAS (SAS Institute, 1982).

The combinations of growing season, crop type, and soil types of the various experiments resulted in substantial variations in leaf yields (Table 1). Average leaf yields ranged from 45.9 t ha⁻¹ for turnip grown on Tifton loamy sand during Fall 1984 to 16.2 t ha⁻¹ for mustard grown on Bonifay sand during Spring 1982. Although the duration of the tests was essentially the same, plots were harvested twice during the spring season and three times during the fall season. The additional harvest was the primary factor contributing to the 72% higher leaf yield when these greens crops were grown during the fall.

Leaf yields of most tests showed a quadratic response to the irrigation regimes (Table 1). These regimes did not produce a significant leaf yield response for turnip grown on Tifton loamy sand during Spring 1982. Strong linear leaf yield responses to irrigation occurred when turnip was grown on Bonifay sand during Spring 1982 and when mustard was grown on Tifton loamy sand during Fall 1984. When averaged over all tests, application of irrigation at 25 kPa soil water tension resulted in 13% and 18% higher yields than irrigating at 50 and 75 kPa, re-

spectively. Wilting of the foliage was observed only in the 75-kPa irrigation regime when evaporative demand was high. The 75-kPa irrigation regime represents a water stress level similar to that of the irrigated treatment of earlier research (del Vane et al., 1965). The lower leaf yields with irrigation at soil water tensions of 50 kPa as compared to irrigation at 25 kPa confirm the statement of Lal and De (1972) that plant growth decreases long before the soil moisture reaches the wilting point.

Leaf quality characteristics, petiole: blade ratio, chlorophyll content, percent dry weight, and leaf color were not affected by irrigation regimes (data not presented).

Water use was not determined during the first 10 days after seeding, but sufficient water (≈ 25 mm) was applied to ensure that the soil was at field capacity upon initiation of sensor-controlled irrigation scheduling. Water use rates ranging from 81 to 163 mm reflect water applications during the period when irrigations were scheduled from soil water measurements (Table 1). During this period, an average of nine, seven, and six irrigations were required for the 25, 50, and 75 kPa irrigation regimes, respectively. Although the amount of water applied at each irrigation decreased as the soil water tension at the time of irrigation decreased, total water applied was highest when irrigation was applied at 25 kPa. These results follow the general trend that crops that receive more frequent irrigations have higher use and often higher yields under given climatic conditions (Bruce et al., 1980; Stansell and Smittle, 1980; Stegman et al., 1980). Correlation analyses showed a highly significant positive relationship ($r = 0.81$) between water use and leaf yields in this study.

Water applied is a valid estimate of water use or evapotranspiration, since these plots were protected from rainfall and ground water intrusions and water additions were based on water content in the soil profile. Cumulative pan evaporation (E_p) and cumulative evapotranspiration (ET_c) for each crop-season-soil type combination with irrigation at 25, 50, and 75 kPa were compiled. The relationships (data for crops and soil types combined) of E_p and ET_c to plant age (days from seeding) for the spring season accounted for 99.9% of the variation of E_p and 97.9%, 98.1%, and 98.3% of the variations of ET_c for irrigation regimes of 25, 50, and 75 kPa, respectively. For the fall season, the equations accounted for 99.9% of the variation of E_p and 95.5%, 96.%, and 95.9% of the variations of ET_c for irrigation regimes of 25, 50, and 75 kPa, respectively. Cubic responses for E_p and ET_c were not statistically significant for either the spring or fall season; therefore, daily pan evaporation (E_p) and daily evapotranspiration (ET) equations, computed as the derivative of the E_p and ET_c equations, are linear.

Both E_p and ET increased with plant age during the spring season, but E_p decreased and ET increased with age during the fall season (Fig. 1). These results suggest that scheduling irrigations as a constant percent-

age of E_p , as suggested by Singh (1989), or a constant crop factor, as suggested by Jensen and Middleton (1970), would result in a much larger error for the fall season than for the spring season. The data also show that a single crop factor when multiplied by E_p would not accurately estimate ET in water balance models as outlined by Stegman et al. (1980).

Daily crop factors (CF), expressed as $CF = ET/E_p$, were computed for days 10 through 65 for each irrigation regime during the spring and fall seasons (Fig. 2). Change in CF with age was quadratic during both growing seasons. During spring, CF showed a rapid initial increase then a slower rate of increase as plants aged. However, during the fall, CF increased slowly when plants were young then increased more rapidly as the production season progressed. This difference in the change of CF with age during the spring and fall seasons may have been due to reduced relative growth rates of turnip and mustard during the spring when average daily temperatures are above 25C (Lorenz and Maynard, 1980). Crop factors were higher when irrigations were applied at lower soil water tensions. These results are in agreement with earlier reports (Bruce et al., 1980; Singh, 1989; Stansell and Smittle, 1980; Stegman et al., 1980) that state the rate of water use is increased by more frequent irrigations. The daily CF developed from the regression equations of Fig. 2, when multiplied by measured pan evaporation data, provides an accurate estimation of ET for use in water-balance irrigation models (Smittle et al., 1990; Stegman et al., 1980). For example, in water balance equations where $ET = E_p(CF)$, if E_p were 5 mm on days 20 and 60 after seeding turnip, ET would be 3.2 mm (5×0.63) on day 20 and 4.5 mm (5×0.89) on day 60.

We have shown that leaf yields of turnip and mustard were highest with irrigation applications when the soil water tension at 10 cm exceeded 25 kPa. This irrigation regime also required more water than irrigation applications at soil water tensions of 50 and 75 kPa. Regression equations were developed to compute daily water use and daily crop factors for growth during the spring and fall production seasons. These equations provide a daily adjustment of E_p to estimate daily ET for turnip and mustard for use in water-balance irrigation scheduling models.

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