Growth, physiology and yield responses of cabbage to deficit irrigation

C. Xu, D.I. Leskovar

Texas A&M AgriLife Research Center, Vegetable and Fruit Improvement Center, Department of Horticultural Sciences, Texas A&M University, USA

Abstract

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Field experiments were conducted in two seasons to investigate growth, physiology and yield responses of cabbage (*Brassica oleracea* L. cvs Pennant and Rio Grande) to deficit irrigation. In 2012 season, 50% of crop evapotranspiration (ETc) irrigation temporarily decreased plant size, reduced leaf area, fresh weight, relative water content, specific leaf area and gas exchange during late development, and decreased head fresh weight, size, marketable and total yield. Deficit irrigation at 75% ETc had little influence on plant growth and physiology, but it still reduced both marketable and total yield. In 2013 season, 75% ETc irrigation had little influence on plant growth, leaf characteristics, photosynthetic rate, head fresh weight and size, but it temporarily increased chlorophyll and carotenoid content, and decreased stomata conductance, transpiration, and marketable yield. Pennant, the green-head cultivar, had higher photosynthetic rate, head fresh weight, marketable and total yield than the red-head cultivar Rio Grande. In both seasons, deficit irrigations did not influence cabbage head dry weight, indicating that most yield reduction under deficit irrigations is related to water content.

Keywords: pigment; photosynthesis; relative water content; specific leaf area

The Winter Garden region of south Texas is a semiarid agricultural region with limited water resources. Cabbage is one of the most important cole crops in this region, but it was also classified as intermediately susceptible to water stress (Janes 1950; Singh, Alderfer 1966; Nortje, Henrico 1988). Cabbage production during fall and winter mainly depends on supplemental irrigation. Therefore, development of efficient and economically viable irrigation management for effective use of limited water resources is needed.

Compared with furrow and basin irrigation, drip irrigation is the most effective method to irrigate vegetable crops due to water savings and yield increases (Tiwari et al. 1998a,b; Xie et al. 1999; Tiwari et al. 2003). In addition, deficit irrigation strategy, a practice that deliberately allows crops to sustain some degree of water deficit with marginal yield loss, has the potential to increase water use efficiency and save water (Costa et al. 2007). It is expected that deficit irrigation would be adopted for a wide variety of crops and in more regions, especially in arid and semiarid climates of the world. However, leafy vegetables appear less adapted to deficit irrigation than fruit tree crops (Jones 2004; Costa et al. 2007). A previous study indicated

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that yield of cabbage was similar when irrigated at 80 kPa and 160 kPa soil water tension, but reduced at 360 kPa (Thomas et al. 1970). Smittle et al. (1994) found that cabbage yield was highest when irrigation was applied at 25 kPa soil water tension, as compared to 50 or 75 kPa. Drew (1966) reported higher cabbage yield with irrigation at 12.5% than at 25, 50, or 75% available soil moisture content. Using sprinkler irrigation system, Sanchez et al. (1994) found that cabbage production was optimized when crops were irrigated for evapotranspiration (ET) replacement while both deficit and excess irrigation reduced yield. However, Sammis and Wu (1989) reported that cabbage marketable yield increased linearly with increased water application up to 49.3 t/ha. Tiwari et al. (2003) found no significant yield difference in cabbage irrigated at 100, 80 and 60% of crop ET (ETc) during three years. Imtiyaz et al. (2000) examined the effect of irrigation scheduling using 18 mm of water in each irrigation when cumulative pan evaporation reached 11, 22, 33, 44 and 55 mm and found that irrigation at 11 mm of cumulative pan evaporation had the highest cabbage yield.

The reports on deficit irrigation for cabbage production have some discrepancies, which may be related to differences in cultivar, climate, soil conditions and irrigation method. Moreover, most research on cabbage irrigation focused mainly on yield without accounting for the effects on growth and physiology. The aim of this two-year study was to determine the influence of deficit irrigation on cabbage growth, leaf characteristics, pigment content, gas exchange, head weight, size and yield.

MATERIAL AND METHODS

Experiments were carried out in two seasons, 2011–12 and 2012–13 (herein 2012 and 2013 season, respectively) at the Texas AgriLife Research Center, Uvalde, Texas, USA (longigude 29°1'N, latitude 99°5'W, elevation 283 m a.s.l.). The soil was silty clay (fine-silty, mixed, hyperthermic Aridic Calciustolls) with an available soil moisture holding capacity of 17%. Cabbage (*Brassica oleracea* L.) was seeded with a vacuum planter (MaterMacc, San Vito al Tagliamento, Italy) on 1.02 m wide bed with double lines spaced at 0.23 m on November 24, 2011 (2012 season), and November 30, 2012 (2013 season). The cultivar Pennant (green head) was used for the 2012 season, and Pennant and Rio Grande (red head) for the 2013 season. Winter (November to February) temperatures for 2012 and 2013 seasons were generally similar with average daily temperatures in the ranges of 5 to 22°C. The main difference between the two seasons was rainfall, which was 243 and 158 mm for 2012 and 2013 season, respectively. In each season seedlings were thinned at 0.3 m between plants. Subsurface drip irrigation was installed in the centre of each bed at 10 cm depth. The irrigation rates were 100, 75, and 50% ETc for the 2012 season, and 100 and 75% ETc for the 2013 season. The adjustment of the deficit irrigation rate in 2013 was based on results obtained in 2012 season. The ETc values were estimated using weather data from a local weather station and the Penman-Monteith method, and the application of stage-specific crop coefficients (Allen et al. 1998). Total irrigation was 259, 218 and 182 mm for 100, 75 and 50% ETc irrigation in 2012 season, and 515 and 416 mm for 100 and 75% ETc irrigation in 2013 season, respectively. Total fertilizers applied as fertigation were 140 N-57 P-23 K kg/ha in 2012 season and 135 N-43 P-50 K kg/ha in 2013 season.

Growth and physiological measurements. Plant height, width and leaf chlorophyll index were periodically measured on five plants from each replication throughout development at various days after seeding (DAS). Leaf chlorophyll index was measured in the first fully-developed leaf with a SPAD-502 meter (Konica Minolta Sensing Inc., Tokyo, Japan). During early, middle and late development, leaf gas exchange (photosynthetic rate, *P*n; stomatal conductance, g_s; and transpiration, *T*r) was measured. In addition, three plants from each replication were sampled to determine leaf area, fresh and dry weight (FW and DW), relative water content (RWC), specific leaf area (SLA), and content of chlorophyll *a*, *b* and carotenoids.

Leaf area was measured with a leaf area meter (Li-3000, Licor, Inc., Lincoln, USA). For leaf chlorophyll and carotenoid content, six leaf discs were taken with a cork borer from three plants and soaked in 20 ml of 95% ethanol in the dark for 48 hours. The extraction was repeated twice with 10 ml of 95% ethanol each time. Absorbance of the extraction at 664, 649 and 470 nm was measured with a spectrophotometer (Genesys 10S, Thermo Fisher Scientific, Inc., Waltham, USA). Chlorophyll *a*, *b* and carotenoid content was calculated using the formula described by Arnon (1949). Another six leaf discs were taken to determine leaf RWC and SLA.

Leaf RWC was calculated using the formula:

100[(FW – DW)/(TW – DW)]

where:
FW – fresh weigh (g)
TW – turgid weight following soaking in water for 4 h at 4°C
DW – weight following oven-drying leaf samples for 72 h at 80°C

Gas exchange measurements were made on the largest leaf from three plants in each plot with a portable infrared gas analyser (Li-6400, Licor, Inc.). The analyser was set at 500 μmol/s flow rate (leaf temperature of 25 ± 0.4°C, 60 ± 5% relative humidity) and a light emitting diode external light source providing a photosynthetic photon flux density of 1,500 μmol/m^2/s.

Yield and yield components. Cabbage heads were harvested at peak maturity on May 17 in 2012 season and May 13 in 2013 season. Heads with defects or initial flower stalk, or too small (≤ 454 g) were defined as unmarketable. Marketable and total yield (t/ha), average head size (width and height), weight (g/head), and the ratio of head fresh and dry weight were determined.

Statistical analysis. The experiment for 2012 season was conducted using a completely randomized design with four replications. The experiment for 2013 season was conducted using a split plot design with four replications. Irrigation treatments were the main plots and cultivars the subplots. Each replication consisted of four rows with 7.6 m length. All growth and physiological variables, yield and yield characteristics data were subjected to analysis of variance (ANOVA) using SAS (SAS Institute Inc., 1993). Mean differences among irrigation and cultivar were determined according to the Tukey's Studentized range test.

RESULTS AND DISCUSSION

2012 season

Plant size was temporarily reduced by 50% ETc irrigation as compared to 100% ETc irrigation (Table 1). Plant height was 39.8, 38.0 and 38.0 cm at 105 DAS for 100, 75 and 50% ETc irrigation, respectively, and plant width was 60.7, 58.7 and 55.0 cm at 91 DAS for 100, 75 and 50% ETc irrigation, respectively. Deficit irrigation at 75% ETc had no significant effect on plant size as compared to 100% ETc irrigation. Reduced plant width at 105 DAS might result from leaf senescence and wilt under temporary heat stress. Plant size reduced at 133 DAS because the outer leaves senesced and dropped before harvesting. Chlorophyll index slightly increased under deficit irrigation at 105 (P = 0.095) and 147 (P = 0.054) DAS. The index was 64.7, 67.6 and 68.5 at 105 DAS and 80.0, 84.9 and 84.0 at 147 DAS for 100, 75 and 50% ETc irrigation, respectively. Leaf pigments content was also measured at 63, 93 and 133 DAS. Both deficit irrigation rates had no significant effect on the content of chlorophyll *a*, *b* and carotenoid based on either leaf area or dry weight (data not shown). Deficit irrigation at 75% ETc had no significant effect on chlorophyll index as compared to 100% ETc irrigation.

Leaf characteristics were not affected by deficit irrigation rates during early development (63 DAS; data not shown). At 93 DAS, 50% ETc irrigation significantly reduced leaf area per plant from 4,859 to 4,147 cm^2 while leaf FW, DW, RWC and

Table 1. Effect of irrigation rate on plant size of cabbage cv. Pennant during 2012 season

Irrigation (% ETc)	Height (cm)					Width (cm)				
	days after seeding									
	77	91	105	120	133	77	91	105	120	133
50	15.0	30.7	38.0^b	44.5	36.4	32.5	55.0^b	52.6	60.2	34.5
75	15.4	30.3	38.0^b	44.4	36.7	32.9	58.7^{ab}	53.9	60.4	35.8
100	16.1	32.4	39.8^a	45.2	37.3	32.1	60.7^a	55.0	60.9	35.7
LSD	3.27	2.91	1.58	2.69	2.60	3.41	4.66	6.36	3.63	3.97

values in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test; ETc – crop evapotranspiration; LSD – least significant difference

Table 2. Effect of irrigation rate on leaf characteristics of cabbage cv. Pennant during 2012 season

Irrigation (% ETc)	Area (cm^2)	FW (g)	DW (g)	RWC (%)	SLA (cm^2/g DW)
93 days after seeding					
50	4,147^{b}	402	36.8	87.0	0.182
75	4,345^{ab}	437	38.6	89.0	0.174
100	4,859^{a}	471	40.7	89.5	0.176
LSD	668.6	104.2	9.28	3.87	0.0172
133 days after seeding					
50c	4,797	485	54.6	93.1^{b}	0.092
75	5,278	538	57.5	93.9^{ab}	0.098
100	5,439	561	57.6	94.7^{a}	0.101
LSD	631.9	70.4	10.88	1.39	0.0084

values in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test; ETc – crop evapotranspiration; FW – fresh weight; DW – dry weight; RWC – relative water content; SLA – specific leaf area; LSD – least significant difference

SLA were not altered by both deficit irrigations (Table 2). At 133 DAS, 50% ETc irrigation slightly reduced leaf area per plant (P = 0.099), leaf FW (P = 0.085), RWC (P = 0.058) and SLA (P = 0.086), but its effect on leaf DW was not significant (Table 2). Leaf area reduction might result from leaf size and/or number, but could not be determined since they were not measured in this study. Overall, 75% ETc irrigation had no effects on leaf characteristics compared to 100% ETc irrigation.

Table 3. Effect of irrigation rate on leaf gas exchange of cabbage cv. Pennant during 2012 season

Irrigation (% ETc)	Pn	g_s	Tr
63 days after seeding			
50	29.7	0.728	12.4
75	28.3	0.746	13.4
100	28.9	0.761	13.5
LSD	2.58	0.1675	1.35
93 days after seeding			
50	17.7^{b}	0.214^{b}	7.7^{b}
75	18.7^{ab}	0.239^{b}	8.2^{ab}
100	21.8^{a}	0.323^{a}	10.1^{a}
LSD	3.47	0.0822	2.20
133 days after seeding			
50	18.6^{b}	0.357^{b}	10.0^{c}
75	21.6^{ab}	0.472^{b}	12.1^{b}
100	23.6^{a}	0.673^{a}	14.3^{a}
LSD	3.03	0.2006	1.95

values in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test; ETc – crop evapotranspiration; Pn – net photosynthetic rate (μmol CO_2 /m^2/s); g_s – stomatal conductance (mol/m^2/s); Tr – transpiration (mmol H_2O/m^2/s); LSD – least significant difference

Table 4. Effect of irrigation rate on head weight, size and yield of cabbage cv. Pennant during 2012 season

Irrigation (% ETc)	Head weight		Head size (cm)		Yield (t/ha)		
					marketable		total
	FW (kg)	DW/FW (%)	height	width	fresh	dry	
50	1.12[b]	7.83[a]	15.7[b]	15.2[b]	88[b]	6.8	90[b]
75	1.27[ab]	7.31[ab]	16.2[ab]	16.0[ab]	89[b]	6.5	98[b]
100	1.50[a]	6.97[b]	16.9[a]	16.6[a]	107[a]	7.5	112[a]
LSD	0.307	0.67	0.79	0.81	16.4	1.16	10.7

values in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test; ETc – crop evapotranspiration; FW – fresh weight; DW – dry weight; LSD – least significant difference

Leaf gas exchange was not affected by either of deficit irrigations during early development (63 DAS, Table 3). At 93 DAS, *P*n, g_s and *T*r significantly decreased at 50% ETc irrigation. *P*n was 21.8 and 17.7 μmol/m²/s, g_s was 0.323 and 0.214 mol/m²/s, and *T*r was 10.1 and 7.7 mmol/m²/s for 100 and 50% ETc irrigation, respectively. Deficit irrigation at 75% ETc reduced only g_s to 0.239 mol/m²/s. At 133 DAS, 50% ETc irrigation reduced *P*n, g_s and *T*r, while irrigation at 75% ETc only decreased g_s and *T*r. Similarly, 50% ETc irrigation reduced *P*n and g_s while 75% ETc irrigation had little effects on leaf gas exchange in watermelons (Rouphael et al. 2008).

Yield components were significantly reduced by deficit irrigation when measured at harvest. Irrigation at 50% ETc significantly reduced head fresh weight, height and width, but it increased dry biomass percentage from 6.97 to 7.83% (Table 4). Deficit irrigation at 75% ETc had no significant effects on head weight and size, but marketable and total yield decreased under both 75 and 50% ETc irrigations. Marketable yield was 107, 89 and 88 t/ha, and total yield was 112, 98 and 90 t/ha, for 100, 75 and 50% ETc irrigations, respectively. These results are consistent with previous reports by Drew (1966), Sammis and Wu (1989), Sanchez et al. (1994), and Imtiyaz et al. (2000). However, in a three-year study

Table 5. Effect of irrigation rate on plant size of cabbage during 2013 season in different days after seeding

	Height (cm)					Width (cm)				
	83	97	111	126	146	83	97	111	126	146
Irrigation (I) (% ETc)										
75	17.7	27.0	31.2	34.0	31.5[b]	40.5	48.5	53.2	58.5	60.0
100	17.8	26.3	32.3	34.2	34.9[a]	40.6	48.7	55.8	58.6	59.7
LSD	6.23	6.01	6.19	5.09	2.47	8.73	6.28	4.57	3.09	3.67
Cultivar (C)										
Pennant	19.0	25.8	29.2[b]	31.5[b]	33.3	43.5[a]	48.0	52.7	56.4	60.3
Rio Grande	16.5	27.5	34.2[a]	36.7[a]	33.1	37.6[b]	49.2	56.3	60.7	59.4
LSD	3.59	2.89	4.02	3.10	1.23	3.32	2.69	4.12	4.97	4.38
ANOVA (*P*-value)										
I	0.994	0.752	0.645	0.895	0.024	0.957	0.901	0.165	0.959	0.827
C	0.142	0.222	0.023	0.006	0.787	0.005	0.294	0.073	0.077	0.658
I × C	0.901	0.666	0.959	0.244	0.296	0.537	0.059	0.688	0.135	0.929

values in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test; ETc – crop evapotranspiration; LSD – least significant difference; ANOVA – analysis of variance

Table 6. Effect of irrigation rate on chlorophyll index during 2013 season

	Days after seeding				
	83	97	111	126	146
Irrigation (I) (% ETc)					
75	53.1	62.5	66.7[a]	66.2	77.4
100	52.5	62.3	66.0[b]	64.6	76.3
LSD	0.75	0.31	0.59	2.56	3.39
Cultivar (C)					
Pennant	51.7	59.7[b]	64.2[b]	63.1[b]	76.8
Rio Grande	53.9	65.0[a]	68.6[a]	67.7[a]	76.9
LSD	2.89	1.20	1.15	1.97	1.47
ANOVA (*P*-value)					
I	0.073	0.105	0.033	0.128	0.395
C	0.121	< 0.001	< 0.001	0.001	0.866
I × C	0.887	0.884	0.860	0.322	0.897

values in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test; ETc – crop evapotranspiration; LSD – least significant difference; ANOVA – analysis of variance

no significant yield difference in cabbage among 100, 80 and 60% ETc irrigations was detected (Tiwari et al. 2003). Also, yield of cabbage did not decrease when irrigated at 80 kPa and 160 kPa soil water tension, but it reduced at 360 kPa (Thomas et al. 1970). The inconsistency in yield response might be due to differences in climate, soil conditions and irrigation method. In this study, both marketable and total yield at 75 and 50% ETc deficit irrigation were significantly reduced as compared to 100% ETc irrigation. However, there were no significant differences detected in dry weight of marketable heads among the irrigation treatments since deficit irrigations increased the dry weight percentage, which suggests that most decreases in yield under deficit irrigation are related to water content.

2013 season

Only 75% ETc irrigation was tested but on two cultivars (Pennant, green head colour and Rio Grande, red head colour), since it had little effects on plant growth and physiology during 2012 season. The interaction between irrigation and cultivar was not significant so the data were pooled by cultivar. 75% ETc irrigation significantly reduced plant height at 146 DAS but had no significant effect on plant width (Table 5). Deficit irrigation increased chlorophyll index from 52.5 to 53.1 ($P = 0.073$) and 66.0 to 66.7 at 83 and 111 DAS, respectively (Table 6). Also leaf pigment content based on dry weight was enhanced by deficit irrigation at 106 DAS (Table 7). Chlorophyll *a*, *b*, *a* + *b* and carotenoid contents were 2.60, 0.94, 3.55 and 0.59 μg/mg DW at 100% ETc irrigation as compared to 2.97, 1.06, 4.02 and 0.64 μg/mg DW at 75% ETc irrigation. At 129 DAS chlorophyll *b* content was slightly ($P = 0.078$) reduced from 1.03 to 0.96 μg/mg DW by 75% ETc irrigation, which might result from leaf senescence under drought stress. Mäkelä et al. (2000) also reported that moderate drought stress increased tomato leaf chlorophyll content. The reduced effect of deficit irrigation on pigment content during 2012 season might be due to the low irrigation differences between 100 and 75% ETc irrigation (41 and 99 mm for 2012 and 2013 season, respectively).

Deficit irrigation affected leaf gas exchange before maturity (115 DAS), but not during development (90 DAS) and maturity (135 DAS). At 115 DAS deficit irrigation reduced g_s and *T*r at 115 DAS, but had no significant effect on *P*n (Table 8). Similarly, 75% ETc irrigation did not affect *P*n during 2012 season. Leaf characteristics (leaf area, FW, DW, RWC and SLA) were measured at 85, 106 and 129 DAS but had little difference between 100 and 75% ETc irrigations (data not shown). Marketable fresh yield significantly decreased under 75% ETc irrigation although average head fresh weight and head size (height and width) were not significantly influenced by deficit irrigation (Table 9). The reduced marketable yield mainly resulted from increased

Table 7. Effect of irrigation rate on leaf pigment content (μg/mg DW) of cabbage during 2013 season

	85 days after seeding				106 days after seeding				129 days after seeding			
	Chl *a*	Chl *b*	Chl *a* + *b*	Car	Chl *a*	Chl *b*	Chl *a* + *b*	Car	Chl *a*	Chl *b*	Chl *a* + *b*	Car
Irrigation (I) (% ETc)												
75	3.89	1.36	5.25	0.89	2.97^{a}	1.06^{a}	4.02^{a}	0.64^{a}	2.56	0.96	3.52	0.56
100	3.80	1.32	5.12	0.86	2.60^{b}	0.94^{b}	3.55^{b}	0.59^{b}	2.67	1.03	3.70	0.58
LSD	0.413	0.117	0.526	0.086	0.305	0.099	0.400	0.041	0.172	0.082	0.249	0.041
Cultivar (C)												
Pennant	3.81	1.31	5.12	0.88	2.63	0.95	3.58	0.60	2.27^{b}	0.81^{b}	3.08^{b}	0.53
Rio Grande	3.88	1.37	5.25	0.86	2.94	1.05	3.99	0.63	2.97^{a}	1.17^{a}	4.14^{a}	0.60
LSD	0.260	0.147	0.401	0.081	0.416	0.172	0.585	0.087	0.445	0.165	0.606	0.083
ANOVA (*P*-value)												
I	0.511	0.368	0.472	0.333	0.017	0.037	0.020	0.012	0.131	0.078	0.106	0.185
C	0.514	0.430	0.475	0.638	0.091	0.152	0.103	0.441	0.008	0.002	0.005	0.110
I × C	0.443	0.733	0.532	0.423	0.299	0.502	0.346	0.155	0.686	0.385	0.591	0.823

values in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test; Chl – chlorophyll; Car – carotenoid; ETc – crop evapotranspiration; LSD – least significant difference; ANOVA – analysis of variance

unmarketable head since total yield was not affected. Similarly to 2012 season, there were no significant differences detected in dry weight of marketable heads between irrigation treatments since deficit irrigations slightly ($P = 0.112$) increased dry weight percentage.

Comparing cultivars, the differences in plant size were temporary and inconsistent (Table 5). The cv. Pennant was shorter (29.2 vs 34.2 cm) at 111 DAS and initially wider (43.5 vs 37.6 cm) at 83 DAS, than cv. Rio Grande. However, cv. Rio Grande was slightly wider than cv. Pennant at 111 ($P = 0.073$) and 126

Table 8. Effect of irrigation rate on leaf gas exchange of cabbage during 2013 season

	90 days after seeding			115 days after seeding			135 days after seeding		
	*P*n	g_s	*T*r	*P*n	g_s	*T*r	*P*n	g_s	*T*r
Irrigation (I) (% ETc)									
75	24.3	0.799	9.53	24.6	0.611^{b}	7.45^{b}	22.4	0.626	6.93
100	24.1	0.755	9.49	24.0	0.732^{a}	8.56^{a}	21.3	0.606	6.94
LSD	2.60	0.2983	1.559	3.05	0.0956	0.658	1.56	0.0640	0.381
Cultivar (C)									
Pennant	25.0	0.883^{a}	10.06	25.2^{a}	0.745^{a}	8.41	22.5	0.700^{a}	7.46^{a}
Rio Grande	23.3	0.671^{b}	8.96	23.4^{b}	0.598^{b}	7.60	21.3	0.531^{b}	6.42^{b}
LSD	1.71	0.2030	1.164	1.46	0.1330	0.840	1.72	0.0976	0.527
ANOVA (*P* value)									
I	0.830	0.666	0.932	0.628	0.027	0.013	0.110	0.393	0.934
C	0.055	0.044	0.059	0.025	0.035	0.055	0.142	0.005	0.003
I × C	0.153	0.407	0.354	0.115	0.399	0.584	0.673	0.655	0.497

values in a column followed by the same letter are not significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test; *P*n – net photosynthetic rate (μmol CO_2 /m²/s); g_s – stomatal conductance (mol/m²/s); *T*r – transpiration (mmol H_2O/m²/s); ETc – crop evapotranspiration; LSD – least significant difference; ANOVA – analysis of variance

Table 9. Effect of irrigation rate on head weight, size and yield of cabbage during 2013 season

	Head weight		Head size (cm)		Marketable yield (t/ha)		Total yield (t/ha)
	FW (kg)	DW/FW (%)	height	width	fresh	dry	
Irrigation (I) (% ETc)							
75	1.48	5.59	16.4	15.9	74[b]	4.09	84
100	1.47	5.16	16.6	16.2	80[a]	4.13	87
LSD	0.209	0.61	0.94	1.67	5.3	0.559	8.6
Cultivar (C)							
Pennant	1.63[a]	5.27	16.3	16.5[a]	92[a]	4.85[a]	94[a]
Rio Grande	1.33[b]	5.48	16.6	15.7[b]	62[b]	3.37[b]	76[b]
LSD	0.103	0.48	0.52	0.61	4.9	0.436	8.0
ANOVA (*P*-value)							
I	0.928	0.112	0.533	0.604	0.031	0.837	0.353
C	< 0.001	0.334	0.128	0.023	< 0.001	< 0.001	0.002
I × C	0.331	0.482	0.655	0.516	0.183	0.545	0.542

values in a column followed by different letters are significantly different at $P \leq 0.05$ according to the Tukey's Studentized range test; DW – dry weight; FW – fresh weight; ETc – crop evapotranspiration; LSD – least significant difference; ANOVA – analysis of variance

(P = 0.077) DAS. The chlorophyll index was higher in cv. Rio Grande than in cv. Pennant during most plant development (Table 6). Also, chlorophyll *a*, *b* and total content based on dry weight were higher in cv. Rio Grande than in cv. Pennant at 129 DAS (2.97 vs 2.27, 1.17 vs 0.81, 4.14 vs 3.08 µg/mg DW, for chlorophyll *a*, *b* and total chlorophyll content, respectively) (Table 7). However, cv. Pennant had significantly higher Pn and g_s than cv. Rio Grande at 90 and 115 DAS (Table 8). High chlorophyll content does not necessarily result in high photosynthesis since it is also affected by other factors such as stomatal and metabolic limitations. There were no significant differences between cultivars in leaf area, FW, DW, RWC and SLA (data not shown). At harvesting the average head fresh weight of cv. Pennant was higher than that of cv. Rio Grande (1.63 vs. 1.33 g) and cv. Pennant had higher marketable (92 vs. 62 t/ha) and total yield (94 vs. 76 t/ha) than cv. Rio Grande (Table 9), which resulted from high photosynthetic rate in cv. Pennant.

CONCLUSION

Deficit irrigation at 75% ETc had little influence on plant size, leaf pigment content, leaf characteristics, leaf gas exchange, head weight and size, except for a moderate reduction in marketable yield. However, dry weight of marketable heads was not significantly different between 100 and 75% ETc irrigation. Since dry weight percentage increased under deficit irrigation, it suggests that most yield reduction under deficit irrigation is related to water content. Implementing deficit irrigation (75% ETc) could save water (16%) although a moderate decrease in yield (12%) and head size is expected.

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Corresponding author:

Dr. Chenping Xu, Agricultural Research Services, U. S. Department of Agriculture;
1636 E Alisal Street, Salinas, 93905 USA
phone: + 1 831 755 2860, fax: + 1 831 755 2814, e-mail: Chenping.xu@ars.usda.gov