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Cabbage (*Brassica oleracea* L.) Response to Soil Moisture Regime under Surface and Subsurface Point and Line Applications

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ABSTRACT

Cabbage (*Brassica oleracea* var. *capitata*) head, leaf and root responses to soil moisture regimes under surface and subsurface point and line applications were determined for two seasons. Line application of water through porous pipes was compared to that of point applications of drip lines at 0, 15 and 25-cm soil depths with 4 and 6 mm/day water application rates. Results indicated that best yields were obtained with the line applications at the 15-cm depth at both rates. Porous pipes on surface resulted in more evaporation losses and depressed yield. If drip irrigation is to be used it is better to be laid at a 25 cm depth with applications of 6 mm/day. Line application of 4 mm per day at 15 cm depth gave optimum yields. Wrapper leaf number was inversely proportional to the head weight and diameter whereas the root volume and weight were directly related to it.

Key Words: Cabbage; Wrapper; Weight; Application rates

INTRODUCTION

There has been a great expansion of drip irrigation in Oman in recent years (Abdel Rahman, 1996; Al Ajmi & Abdel Rahman, 2001). This represents one of the top priority measures of water resource conservation in the Gulf where agriculture consumes about 90% of the total water use. Drip systems result in increased productivity and nutrient saving. However, the system has problems of seasonal labor requirement in spreading and collecting the laterals in addition to its deterioration because of its exposure to above soil surface condition particularly in sunny hot climates. To solve these problems, subsurface drip irrigation is being studied. This system has additional advantages over surface irrigation including placement of both water and nutrients at the center of the root system with water content being relatively high and steady with time (Phene & Howell, 1984; Thompson *et al*., 2002), and decreased evaporation of water from soil surface resulting in increased water availability to plants (Martinez Hernandez *et al*., 1991); and movement of nutrients in larger volume around the emitter in spherical volume, while in the case of surface application the movement is restricted to a semispherical volume below the drip (Phene *et al*., 1986).

Abdel Rahman *et al*. (1994) found that increasing the water application rate from 3 to 6 mm to maintain the soil moisture tension within 80 kPa significantly increased cabbage head diameter, head weight and leaf weight. Pierce (1987) reported that at least 2.5 to 3.8 cm of water per week were required for uninterrupted growth of cabbage. Depending on climate, cultivars, and growing season, water requirements of cabbage varied from 380 to 500 mm per season (Doorenbos & Kassam, 1979). Lettuce and cabbage quality, yield and head size were found to decrease as soil moisture became limiting (Sammis *et al*., 1988). In another experiment, Sammis *et al*. (1989) found that cabbage marketable yield decreased linearly with decreasing water application. El-Gindy and El-Araby (1996) found that crop yield and water use efficiency (WUE) were slightly higher when applying water through subsurface drip than through surface drip. Martinez *et al*. (1991) found that marketable and total ear yields of corn for subsurface trickler were higher than for surface tricklers. Total fresh weight, dry matter production and plant height during the growing season were greater for subsurface than for surface content at the center of the rootzone. This increased P and K uptake rates resulted in higher dry matter production and commercial yield relative to surface trickler placement. Bar Yosef *et al*. (1989) found that subsurface drip fustigation resulted in higher corn ear yield than surface drip fustigation. In comparing buried drip (point) application with seepage (line) application for tomatoes, Clark *et al*. (1991) found that maintaining the soil water tension between 5 and 10 kPa gave both methods of applications greater yields than did soil water tension of 10 to 15 kPa during the spring crop.

The objective of our study was to determine cabbage (head, leaf & root) response to soil moisture regimes under surface and subsurface point and line applications for two seasons. The combined effect of the two seasons is imperative in getting more reliable results considering the fact that these results will lead to recommendations for adapting these modern systems in Oman.

MATERIALS AND METHODS

Cabbage seeds were sown in the greenhouse during the first week of October. After four weeks the transplants were transferred to the field at the Agricultural Experiment Station at Sultan Qaboos University, Sultanate of Oman. The soil in the field was classified as sandy loam to 35-40 cm depth with bulk density of 1.4 g/cm^3 .The moisture contents at field capacity and permanent wilting point were 20.4 and 7.5%, respectively. Drip irrigation tubes and porous seepage flow tubes were placed at 0, 15, and 25 cm below the soil surface. Each replicate consisted of 3 tubes of the same type and 10 m long separated by 1.5 m between the tubes. The distance from one replicate to another was 3 m. The total number of replicates was twelve, six of which were for the drip (point application). The other six were for seepage flow (line application). The six replicates of each type were placed at three depths (0, 15, & 25 cm) with two water rates (4 & 6 mm/day). The average reference evapo-transpiration was calculated to be 4 mm/day using the Modified Penman method. The 1:5 soil water extract had an electrical conductivity (EC) and sodium adsorption ratio (SAR) of 1,560 µS cm^{-1}and 3.12, respectively. Irrigation water had an EC and SAR of 600 µS cm^{-1} and 1.78 respectively. Irrigation was carried out every three days at a rate of 12- and 18 mm each time, where previous studies indicated lack of meaningful differences existing in production among everyday and 3-day irrigation intervals (Abdel Rahman *et al.*, 1995). All the experimental units received the same cultural practices of fertilizer application and control of pests, diseases and weeds. The fertilizer was incorporated with irrigation water at a concentration of 200 mg L^{-1} urea at the beginning. This was followed by potassium nitrate at the rate of 300 mg L^{-1} and by trace elements concentration of 5 mg L^{-1} to correct any unforeseen deficiency of the nutrient elements. Cabbage head weight and diameter, wrapper leaf number and weight, and root volume and weight were then determined at the end of the experiment.

RESULTS AND DISSCUSSION

Effect of Water Application Rate

Average cabbage head weight and diameter. Table I shows the two-year combined effects on cabbage head diameter and weight for the two seasons. With irrigation of 6 mm/day the plots with drip system at 25 cm depth gave a significantly larger cabbage head diameter than at surface irrigated plots. This agrees with Abdel Rahman *et al.* (1994) who found that increasing water application rate to 6 mm significantly increased cabbage head diameter. It also agrees with Phene and Howell (1984), Martinez Hernandez *et al.* (1991) and Thompson *et al.* (2002) that the subsurface placement of both water and nutrients at the root system results in their increased availability to plants and therefore better plant growth than for surface placement of both water and nutrients. As for the head weight, the 25 cm drip-irrigated plots resulted in higher value than both the 15 cm depth and the surface-irrigated plots. The average head diameter was 17.5 cm for the 25 cm-irrigated plots while it was 14.8 cm for the surface-irrigated plots; and the average head weight was 1.9 kg for the 25 cm-irrigated plots while it was 1.2 kg for the surface and the 15 cm-irrigated plots. This could be attributed to the larger volume of soil wetted by the upward water movement from the 25-cm depth with less evaporation. The 6 mm/day rate resulted in a higher head diameter than the 4 mm/day rate with drip irrigations, in contrast to the porous pipes where the 4 mm/day at 15 cm depth-irrigated plots gave a higher head diameter and weight than the surface-irrigated or 25-cm depths. This could be explained by the fact that less evaporation occurred at 15-cm depth than the surface and that more salts moved up from the 25-cm depth into the root zone area.

Average wrapper leaf number and weight. Table II shows wrapper number and weights for the two seasons. There was no significant difference in cabbage wrapper leaf number and weight among the two irrigations, but the larger the number of wrapper leaves were, the lower was the head weight and diameter; surface plots having the largest wrapper leaf number and hence the lowest head weight and diameter. This can be illustrated by the above example where higher cabbage head diameter and weight for the 25 cm-irrigated plots as compared to the surface-irrigated plots at 6 mm/day resulted in lower wrapper leaf number of 20 in 25 cm-irrigated plots as compared to leaf number of 21 in surface-irrigated plots.

Average root volume and weight. Table III shows root volume and weight for the two seasons. There were no significant differences in both the root volume and weight among the drip-irrigated plots with 6 mm/day rate at all depths. However, the 6 mm/day rate gave a higher root weight than the 4 mm/day rate in surface drip-irrigated plots due to the extent of the semispherical wetted area. For example, the 6 mm/day surface-irrigated plots gave significantly higher root weight of 48.9 g than the 4 mm/day surface-irrigated plots with only 36.6 g root weight. The 4 mm/day rate with drip resulted in higher root volume and weight in 25 cm depth-irrigated plots than in 15 cm depth- and surface-irrigated plots, allowing roots to seek the water source deeper. However, the 15 cm depth porous-irrigated plots were consistently higher in root volume and weight than the surface-irrigated plots at both irrigation rates alleviating moisture and salt stress at the same time. This agrees with Phene and Howell (1984), Martinez Hernandez *et al.* (1991) and Thompson *et al.* (2002) that the subsurface irrigated plots have both water and nutrients placed directly at the root system and therefore their availability to the plants is increased. For example, with 6 mm/day and 4 mm/day the root volume was 83.3 mL and 86.3 mL,

Table I. Cabbage head diameter and weight in two seasons (6mm/day vs. 4mm/day)

Depth	Diameter (cm)						Weight (kg)					
(cm)	Drip			Porous			Drip			Porous		
	6 mm/day	4 mm/day	LSD	6 mm/day	4 mm/day	LSD	6 mm/day	4 mm/day	LSD	6 mm/day	4 mm/day	LSD
0	A14.8b	A15.3a	2.66	A14.8a	A12.1b	3.26	A1.2b	A1.2a	0.398	A1.3a	A0.88b	0.542
15	A15.3ab	A15.6a	4.93	A17.4a	A17.5a	3.83	A1.25b	A1.2a	0.394	A1.9a	A1.96a	0.873
25	A17.5a	B15.6a	1.15	A15.7a	A15.0ab	5.45	A1.9a	A1.5a	0.452	A1.9a	A1.4ab	1.080
LSD<0.05	2.41	3.33		4.29	3.167		0.419	0.304		0.787	0.729	

Means with the same letters are not significantly different at 5% level; Capital letters for rows, and small letters for columns

Table II. Leaf number per plant and weights in two seasons (6mm/day vs. 4mm/day)

Depth	Number						Weight (kg)					
(cm)	Drip			Porous			Drip			Porous		
	6 mm/day	4 mm/day	LSD	6mm/day	4 mm/day	LSD	6mm/day	4mm/day	LSD	6 mm/day	4 mm/day	LSD
0	A21.2a	A21.8a	1.309	A23.3a	A21.0a	3.872	A0.96b	A0.98ab	0.170	A0.97b	A0.73c	0.284
15	A20.0b	A21.0a	2.121	A21.3b	A20.8a	1.535	A1.1ab	A0.914b	0.242	A1.37a	A1.40a	0.327
25	A20.3b	A20.5a	2.314	A21.8ab	A21.3a	1.309	A1.27a	A1.1a	0.209	A1.3ab	A1.0b	0.397
LSD<0.05	0.745	2.33		1.526	2.746		0.205	0.161		0.330	0.264	

Means with the same letters are not significantly different at 5% level; Capital letters for rows, and small letters for columns

Table III. Root volume and weight in two seasons (6mm/day vs. 4mm/day)

Depth	Volume(ml)						Weight (grams)					
(cm)	Drip			Porous			Drip			Porous		
	6 mm/day	4 mm/day	LSD	6 mm/day	4 mm/day	LSD	6 mm/day	4 mm/day	LSD	6mm/day	4 mm/day	LSD
0	A62.8a	A49.7b	21.25	A48.5c	A45.3b	11.40	A48.9a	B36.6b	10.92	A40.4b	A39.7b	16.01
15	A63.7a	A56.2b	8.278	A83.3a	A86.3a	19.41	A49.7a	A43.4b	18.54	A70.6a	A72.9a	17.15
25	A59.2a	A77.2a	21.87	A67.3b	b44.0b	13.61	A57.0a	A72.2a	25.03	A66.7a	b39.3b	11.81
LSD<0.05	9.46	20.67		9.276	16.50		12.30	20.32		11.89	14.69	

Means with the same letters are not significantly different at 5% level; Capital letters for rows, and small letters for columns

respectively for 15 cm depth-irrigated plots while it was 48.5 and 45.3 mL, respectively for the surface-irrigated plots. As for the root weight, with 6 and 4 mm/day the value was 70.6 and 72.9 g, respectively for the 15 cm depth-irrigated plots while the root weight was 40.4 and 39.7 g, respectively for the surface-irrigated plots.

Effect of Point and Line Applications

Average head diameter and weight. Table IV shows that the head diameter and weight were higher for surface drip-irrigated plots than for surface porous tube-irrigated plots at 4 mm/day application rate. This indicates that there is less water available for plants in the porous tube surface-irrigated plots than for the drip surface-irrigated plots because more water is lost due to larger surface exposure through the entire porous-tube line while for the surface drip larger amount of water is available for the plants and no water loss through the line by evaporation between the drip emitters. For example, the values were 15.3 and 12.1 cm in diameter, and 1.2 and 0.88 kg in weight, respectively for drip and porous tube systems. However, at 15 cm depth with 4 mm/day rate plots that were porous tube-irrigated had higher cabbage head weight than those that were drip-irrigated. For example, the porous tube irrigated plots had 1.96 kg while the drip-irrigated plots had 1.18 kg. This indicates that more evaporation took place from the porous pipes laid on the surface whereas more moisture was conserved at subsurface depths. The 15-cm depth line application of water gave higher head diameter and weight at both water application rates.

Average wrapper leaf number and weight. Table V shows that subsurface line application of water at 15 cm depth gave significantly higher leaf number and weight. For all the three depths of irrigation with 6 mm/day, porous tube-irrigated plots had significantly higher wrapper leaf number than the drip-irrigated plots. As for wrapper weight both the irrigation rates resulted in higher wrapper weight in the porous tube-irrigated than drip-irrigated plots at 15 cm depth of application. This is an indication of better water conservation with porous tube-irrigated plots than drip-irrigated plots at this depth.

Average root volume and weight. Table VI shows that the surface drip-irrigated plots at 6 mm/day had significantly larger root volume than the surface porous tube-irrigated plots. The 25 cm depth drip-irrigated plots with 4 mm/day had higher root volume and weight than the porous tube-irrigated under same conditions. However, at 15 cm depth and with both rates of water application the porous tube-irrigated plots had higher root volume and weight than the drip-irrigated plots. This indicates that with surface and 25 cm depth drip pipes gave better root development with limited irrigation, but significant root development was obtained at the 15 cm depth with porous pipes under both rates of water application.

Table IV. Cabbage head diameter and weight in two seasons (drip vs. porous)

Depth (cm)	Diameter (cm)						Weight (kg)					
	6 (mm/day)			4 (mm/day)			6 (mm/day)			4 (mm/day)		
	Drip	Porous	LSD	Drip	Porous	LSD	Drip	Porous	LSD	Drip	Porous	LSD
0	A14.8b	A14.8a	3.80	A15.3a	B12.1b	1.80	A1.20b	A1.25a	0.612	A1.20a	B0.883b	0.278
15	A15.4ab	A17.4a	3.70	A15.6a	A17.5a	5.02	A1.25b	A1.94a	0.794	B1.18a	A1.96a	0.535
25	A17.5a	A15.7a	4.32	A15.6a	A15.0ab	3.51	A1.90a	A1.89a	0.728	A1.45a	A1.39ab	0.917
LSD<0.05	2.41	4.29		3.33	3.1674		0.419	0.7866		0.304	0.7292	

Means with the same letters are not significantly different at 5% level; Capital letters for rows, and small letters for columns

Table V. Leaf number per plant and weights in two seasons (drip vs. porous)

Depth (cm)	Number						Weight (kg)					
	6 (mm/day)			4 (mm/day)			6 (mm/day)			4 (mm/day)		
	Drip	Porous	LSD	Drip	Porous	LSD	Drip	Porous	LSD	Drip	Porous	LSD
0	B21.2a	A23.3a	1.731	A21.8a	A21.0a	3.70	A0.96b	A0.97b	0.266	A0.98ab	B0.73c	0.198
15	B20.0b	A21.3b	0.926	A21.0a	A20.8a	2.45	B1.05ab	A1.37a	0.314	B0.91b	A1.40a	0.260
25	B20.3b	A21.8ab	1.309	A20.5a	A21.3a	2.31	A1.172a	A1.29ab	0.351	A1.10a	A1.04b	0.280
LSD<0.05	0.745	1.526		2.331	2.746		0.205	0.330		0.161	0.264	

Means with the same letters are not significantly different at 5% level; Capital letters for rows, and small letters for columns

Table VI. Root volume and weight in two seasons (drip vs. porous)

Depth (cm)	Volume						Weight (grams)					
	6 (mm/day)			4 (mm/day)			6 (mm/day)			4 (mm/day)		
	Drip	Porous	LSD	Drip	Porous	LSD	Drip	Porous	LSD	Drip	Porous	LSD
0	Az62.8a	B 48.5c	10.21	A 49.7b	A 45.3b	21.84	A48.9a	A40.4b	11.14	A 36.6b	A 39.7b	15.86
15	B 63.7a	A 83.3a	4.139	B 56.2b	A 86.3a	20.69	B 49.7a	A 70.6a	15.27	B 43.4b	A 72.9a	20.11
25	A 59.2a	A 67.3b	14.75	A 77.2a	B 44.0b	21.12	A 57.0a	A 66.7a	14.42	A 72.2a	B 39.3b	23.63
LSD<0.05	9.459	9.276		20.67	16.50		12.30	11.89		20.32	14.69	

Means with the same letters are not significantly different at 5% level; Capital letters for rows, and small letters for columns

CONCLUSIONS

The average cabbage head diameter and weight in 25 cm depth drip-irrigated plots had higher values than surface- and 15 cm depth-irrigated plots when irrigation rate was 6 mm/day. For surface- and 25 cm subsurface applications, drip system should be used because it gave higher yields than porous tube system. For 15 cm subsurface irrigation, porous tube should be used for it resulted in higher yield. There was a general trend for a larger cabbage root volume and weight for subsurface- compared with surface irrigation.

The higher cabbage yield indicates the superiority of subsurface irrigation in minimizing evaporative water losses and therefore increasing water utilization by the plants. With arid conditions of Oman and with a need to minimize salinity effects on plants, subsurface irrigation will, no doubt, be beneficial to farmers.

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