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Yield, Quality, and Water Use Efficiency of Muskmelon Are Affected by Irrigation and Transplanting Versus Direct Seeding

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Abstract. **Restrictions on pumping water from underground aquifers are limiting vegetable production in Southwest Texas. To determine yield, quality, and water use efficiency (WUE) of muskmelon (*Cucumis melo* L. group Cantalupensis, 'Caravelle'), six irrigation systems with varying input levels and their interactions with stand establishment (containerized transplants vs. direct seeding) were examined. Irrigation systems were: 1) pre-irrigated followed by dryland conditions; 2) furrow/no mulch; 3) furrow/mulch (40-µm-thick black polyethylene); 4) surface drip (0 cm depth)/mulch; 5) subsurface drip (10-cm depth)/mulch; and 6) subsurface drip (30-cm depth)/mulch. Field experiments were conducted on a silty clay loam soil during four seasons (1995–98). In 1995, marketable fruit yields were greater for subsurface drip systems at 30-cm depth than for furrow systems, with or without plastic mulch. Transplants grown with surface drip irrigation produced 75% greater yield in the 9-count fruit class size during early harvest than did those grown with subsurface drip (10- or 30-cm depth), but total yield was unaffected by drip tape depth placement. In 1996, the driest season of these studies, direct-seeded plants had higher total yields than did transplants; yield was greatest for direct-seeded plants on subsurface drip placed at 10- or 30-cm soil depth, and for transplants on subsurface drip at 10-cm depth. Soluble solids content was minimally affected by irrigation method, but was higher in fruit from transplants than in those from direct-seeded plants in 3 years. Across all seasons, the average water applied for drip systems was 53% lower than that for conventional furrow systems, and WUE was 2.3-fold as great.**

Water pumping restrictions and expected reduction in the supply of high-quality irrigation water from underground aquifers (Texas Senate Bill 1477, 1993) will be detrimental to melon production in semi-arid regions of South Texas. Muskmelon provides ≈$57 million of farm income in the region. About 50% of the 5000 ha of muskmelon is still irrigated with furrow irrigation, a low efficiency method that uses large volumes of water. Excessive irrigation can impair growth of young melon seedlings early in the spring, particularly during the cooler part of the growing season, by restricting depth of rooting. Under excessive soil moisture conditions, mature vines are more prone to decline during harvest, with potential sunburn injury to the fruit and, consequently, a reduction in marketable yields and fruit soluble solids content (Pew and Gardner, 1983).

Smaller volumes of water can be applied by surface drip irrigation systems, which deliver water as needed by the crop to avoid drought or flood stress, thereby reducing water application by up to 70% compared with furrow irrigation (Goldberg et al., 1976). Additional water savings and high water use efficiency (WUE) can be obtained by subsurface drip irrigation. This system applies water through emitters positioned from between 2–5 cm to 40–50 cm below the soil surface (Bogle and Hartz, 1986; Hanson et al., 1994). Drip irrigation systems also allow fertigation and reduce the potential for leaching of contaminants such as urea, nitrates, salts, and agrochemicals that affect groundwater quality (Bar-Yosef et al., 1989; Phene et al., 1991).

In a comprehensive study of furrow, surface and subsurface drip irrigation treatments on lettuce (*Lactuca sativa* L.) in California, Hanson et al. (1997) reported that drip irrigation required between 43% and 74% of the water needed for furrow irrigation. However, in that study, furrow and subsurface drip irrigation treatments produced higher yields than did surface drip. In a 2-year study comparing furrow, sprinkler, and drip irrigation on onions (*Allium cepa* L.) established in a heavy-textured soil in Colorado, total yields of bulbs did not differ in either year and WUE among treatments was similar in one of the years (Ellis et al., 1986).

Fruit yield is also affected by stand establishment methods. Transplants produced higher late and total yields than did direct-seeded plants for one of two watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] cultivars used in a study by Hall (1989). For bell pepper (*Capsicum annuum* L.), Leskovar and Cantliffe (1993) reported that use of transplants increased basal roots, advanced maturity, improved shoot mass allocation, and improved fruit set and fruiting efficiency in comparison with direct-seeded plants. Yield and fruit quality responses of muskmelon planted as either containerized transplants or by direct seeding and irrigated by furrow and drip systems placed at various depths are unknown.

The objective of this study was to determine the effects of irrigation systems and drip tape placement, and the interaction with stand establishment method (transplant vs. direct seeding) on yield, quality, and WUE in muskmelon. Optimizing crop water use and management strategies for muskmelon production is needed to minimize risks due to uncertainties in weather and water supplies in semi-arid regions of Texas.

Materials and Methods

Transplant production. 'Caravelle' seedlings were grown in polystyrene trays (35 × 68 cm) with inverted pyramid cells of 3.2 × 4.6 cm (square side length × depth) and 128 cells per tray. Prior to seeding, a plastic insert was placed in each tray to facilitate plant pulling. Seeds were sown in a Speedling tobacco peat-lite mix (Speedling, Sun City, Fla.) and covered with 5 mL of vermiculite grade 2–3–4 (W.R. Grace and Co., Cambridge, Mass.). Trays were held in a dark room at 23 ± 2 °C and 98% relative humidity (RH) for 2 d, and then transferred to a greenhouse at 32° C day/ 18° C night temperature. After seedling emergence, plants were irrigated by an ebb-and-flow system twice a week, and a soluble fertilizer was applied by ebb-and-flow weekly for 5 weeks to provide 50N–12P–40K $mg \cdot L^{-1}$. One day prior to transplanting, seedlings were soaked for 15 min in a soluble blended fertilizer at 200N–350P–200K $mg \cdot L^{-1}$.

Field experiments. Experiments were conducted at the Texas A&M Agricultural Research and Extension Center, Uvalde. Direct seeding and transplanting plots were established in the field on 27 Apr. 1995, 11 Apr. 1996, 25 Apr. 1997, and 13 Apr. 1998. Soil

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was a Uvalde silty clay loam (fine-silty, mixed, hyperthermic Aridic Calciustoll, pH 7.7, organic matter 2.3%, with a textural analysis of 9% sand, 55% clay, and 36% silt). Elemental soil analysis before planting indicated adequate levels of macro- and micronutrients.

Main plots were allocated to transplants and direct-seeded treatments, and subplots within main plots were allocated to six irrigation systems: 1) pre-irrigated followed by dryland conditions; 2) furrow/no mulch; 3) furrow/mulch (40-µm-thick black polyethylene); 4) surface drip (0-cm depth)/mulch; 5) subsurface drip (10-cm depth)/mulch; and 6) subsurface drip (30-cm depth)/mulch. To assure that lateral movement of water would not affect treatments, subplots were separated by a blank row. The selection of these particular depths was based on observations from previous excavations of 'Caravelle' melon root systems, which were concentrated in the upper 30 cm of soil, with some laterals extending beyond 1 m from the center (data not shown). Each subplot consisted of three 15-m-long beds 1.9 m apart with plants spaced 0.3 m along the row. Preplant fertilizer (45N–45P–45K kg·ha^{-1}) was applied broadcast and incorporated into the soil. Additional fertilizer (10N–5P–13K) was applied weekly for 9 weeks using KNO_3 and H_3PO_4 as sources of N, P, and K, respectively, in the drip plots. The same rates of N–P–K were applied as a sidedressed treatment in the furrow-irrigated plots. Standard insect and disease control practices for muskmelons were followed.

Duplicate tensiometers (Irrometer Co., Riverside, Calif.) were installed in furrow and drip treatments in the middle of the row at 15- and 30-cm depth, and soil water potential was measured at 8:00 AM daily. Irrigation water in 1995 was supplied using a drip tape (0.2-mm wall thickness) with emitters spaced every 46 cm and a flow rate of 326 L·h^{-1} per 100 m of bed at 69 kPa (Netafim Irrigation, Austin, Texas), or T-Tape TSX 508 (0.2-mm wall thickness) with emitters spaced every 30 cm and a flow rate of 340 L·h^{-1} per 100 m of bed at 55 kPa (T-systems International, San Diego) in 1996–98. The irrigation water requirement (IR) for the drip-irrigated plots was applied to compensate for evapotranspiration (ET) using the method based on the class "A" pan evaporation (Doorenbos and Pruitt, 1977). The IR for each event was calculated as follows:

$$IR = [kp \times Ep \times kc - ER] / SIE$$

where kp is a tank coefficient that depends on the RH, wind speed, and ground cover (value used as kp = 0.65); Ep is the class "A" pan evaporation (mm) during the interval prior to irrigation; kc is the crop coefficient, as determined by the percentage of ground cover by foliage development; ER is the effective rainfall (mm) (value reduced to 50% on beds with polyethylene mulch); and SIE is the system irrigation efficiency (value used as SIE = 0.90). Furrow irrigation was applied to maintain the soil water tension above ≈–25 kPa at 0.3 m depth from planting to first fruit set, and above –60 kPa thereafter.

Harvests started 30 June [64 d after transplanting (DAT)] for transplants and 14 July 1995 [78 d after seeding (DAS)] for direct-seeded plants; 23 June (68 DAT) and 29 June 1996 (79 DAS); 7 July 1997 (73 DAT or DAS); and 22 June (70 DAT) and 25 June 25 1998 (73 DAS). Three to four harvests were completed in each experiment. Fruit was considered mature when the abscission zone between the fruit and peduncle was at about the half-split stage and marketable muskmelons were classed according to the U.S. commercial trade standards (23, 18, 15, 12, or 9-count per 18-kg carton). Soluble solids content (SSC) was measured with a hand-held refractometer with a range of 0% to 18% Brix (Fisher Scientific, Pittsburgh) using juice from equatorial sections of the mesocarp on five class 9-count fruit per plot at the second harvest. Fruit netting uniformity was visually scored on a 1 to 5 scale (1 = low, 5 = high), and seed cavity opening was measured transversely on cut fruits during 1996–98. The WUE was calculated by dividing total fruit yield by total water applied + rainfall received during the growing season.

Statistical design. The experiment was conducted using a split-plot experimental design with four replications. Two stand establishment methods (transplants vs. direct seeding) were the main plots and six irrigation systems, the subplots, were randomized within each main plot. Data for marketable yield, SSC, and WUE were subjected to analysis of variance (ANOVA) by PROC GLM (SAS Institute, Cary, N.C.). Significant interactions were partitioned by stand establishment and irrigation system, and means were separated by LSD, $P \leq 0.05$.

Results and Discussion

Water applied and weather. The amounts of water applied and the numbers of irrigations received by plants in each system established with containerized transplants are recorded in Table 1. The maximum number of irrigations with drip systems was higher during 1996 (14) and 1998 (12) than in 1995 (6) and 1997 (5). The seasonal class "A" pan evaporation was 490, 908, 539, and 936 mm, and rainfall throughout the growing seasons was 208, 67, 282, and 108 mm for 1995, 1996, 1997, and 1998, respectively. Daily maximum temperatures for most of the growing period after fruit set exceeded 35 °C in 1996–98 (Fig. 1). Rainfall events were well scattered throughout 1995 and 1997, but extreme events occurred during June 1997 (10 events totaling 154 mm) and June 1998 (two events totaling 108 mm).

Table 1. Frequency and amount of irrigation applied or rainfall received by 'Caravelle' muskmelon transplants, 1995–98. Uvalde, Texas.

	Frequency and amount of irrigation or rainfall					
Irrigation system[z]	April	May	June	July	Total applied	Total water received[y]
	No.–mm	No.–mm	No.–mm	No.–mm	No.–mm	mm
			1995			
Pre + dryland	1–161	---	---	---	1–161	369
Furrow	1–161	1–142	1–76	---	3–379	587
Furrow – M	1–161	1–142	1–76	---	3–379	587
Surf drip (0 cm) – M	1–23	2–15	3–65	---	6–103	311
Sub drip(10 cm) – M	1–23	2–19	3–76	---	6–118	326
Sub drip (30 cm) – M	1–26	2–17	3–95	---	6–138	346
Rain	1–13	7–86	3–77	3–32	14–208	
			1996			
Pre + dryland	1–127	---	---	---	1–127	194
Furrow	1–127	1–215	2–358	---	4–700	767
Furrow – M	1–127	1–201	2–334	---	4–662	729
Surf drip (0 cm) – M	3–67	6–68	5–139	---	14–274	341
Sub drip(10 cm) – M	3–42	6–80	5–228	---	14–350	417
Sub drip (30 cm) – M	3–69	6–66	5–194	---	14–329	396
Rain	5–13	3–14	3–40	11–67		
			1997			
Pre + dryland	1–51	---	---	---	1–51	333
Furrow	1–297	---	---	---	1–297	579
Furrow – M	1–297	---	---	---	1–297	579
Surf drip (0 cm) – M	2–53	1–22	2–40	---	5–115	397
Sub drip(10 cm) – M	2–54	1–22	2–43	---	5–119	401
Sub drip (30 cm) – M	2–70	1–24	1–17	---	4–111	393
Rain	1–31	10–97	10–154	---	21–282	
			1998			
Pre + dryland	1–101	---	---	---	1–101	209
Furrow	1–105	2–195	1–106	---	4–406	514
Furrow – M	1–105	2–195	1–106	---	4–406	514
Surf drip (0 cm) – M	5–69	5–48	2–167	---	12–284	392
Sub drip(10 cm) – M	5–67	5–48	2–157	---	12–272	380
Sub drip (30 cm) – M	5–75	5–53	2–164	---	12–292	400
Rain	---	---	2–108	---	2–108	

[z]Pre + dryland = pre-irrigated followed by dryland; M = mulch (black polyethylene 40 µm thick); Surf = surface; Sub = subsurface.
[y]Total water received = Total applied + rainfall.

Fruit yield. Yield of plants in the subsurface drip treatment at 30 cm was higher than that of those grown on both furrow systems and pre-irrigation + dryland, but similar to that of plants grown in surface and subsurface drip systems at 10 cm in 1995 (Table 2). The difference in total yield was due to more fruit in the 9-count class size, which was highest for subsurface drip (30 cm depth)/mulch and decreased progressively for furrow/mulch (60%); furrow (42%); and pre-irrigated followed by dryland (22%) (Table 3).

The advantages of drip over furrow irrigation in first harvest yield were more evident in transplants, which also differed with drip depth position. Plants irrigated with surface drip treatment produced ≈75% higher yields of total and 9-count fruit than either subsurface drip at 10 or 30 cm depth (data not shown). In contrast, direct-seeded plants irrigated with subsurface drip at 30 cm soil depth had higher total marketable fruit yield than did furrow or surface drip-irrigated plants.

In 1996, irrigation × stand establishment interactions were significant for total yield (Table 2) and 9-count fruit size (not shown). In transplants, 9-count and total yields for plants irrigated with subsurface drip at 10 cm were significantly higher than for plants in other systems (Fig. 2). Yields of transplants irrigated by furrow, with or without mulch, were similar to those irrigated by surface or subsurface drip at 30 cm. For direct-seeded plants, 9-count fruit size and total yields were highest for plants on subsurface drip at 10 or 30 cm, and furrow-irrigated plants had higher yields than those on surface drip (Fig. 2). In lettuce, Hanson et al. (1997) also reported yield advantages for furrow irrigation applied weekly over surface drip irrigation, but not with subsurface drip irrigation applied every 2–3 d. However, Hanson's study was conducted in

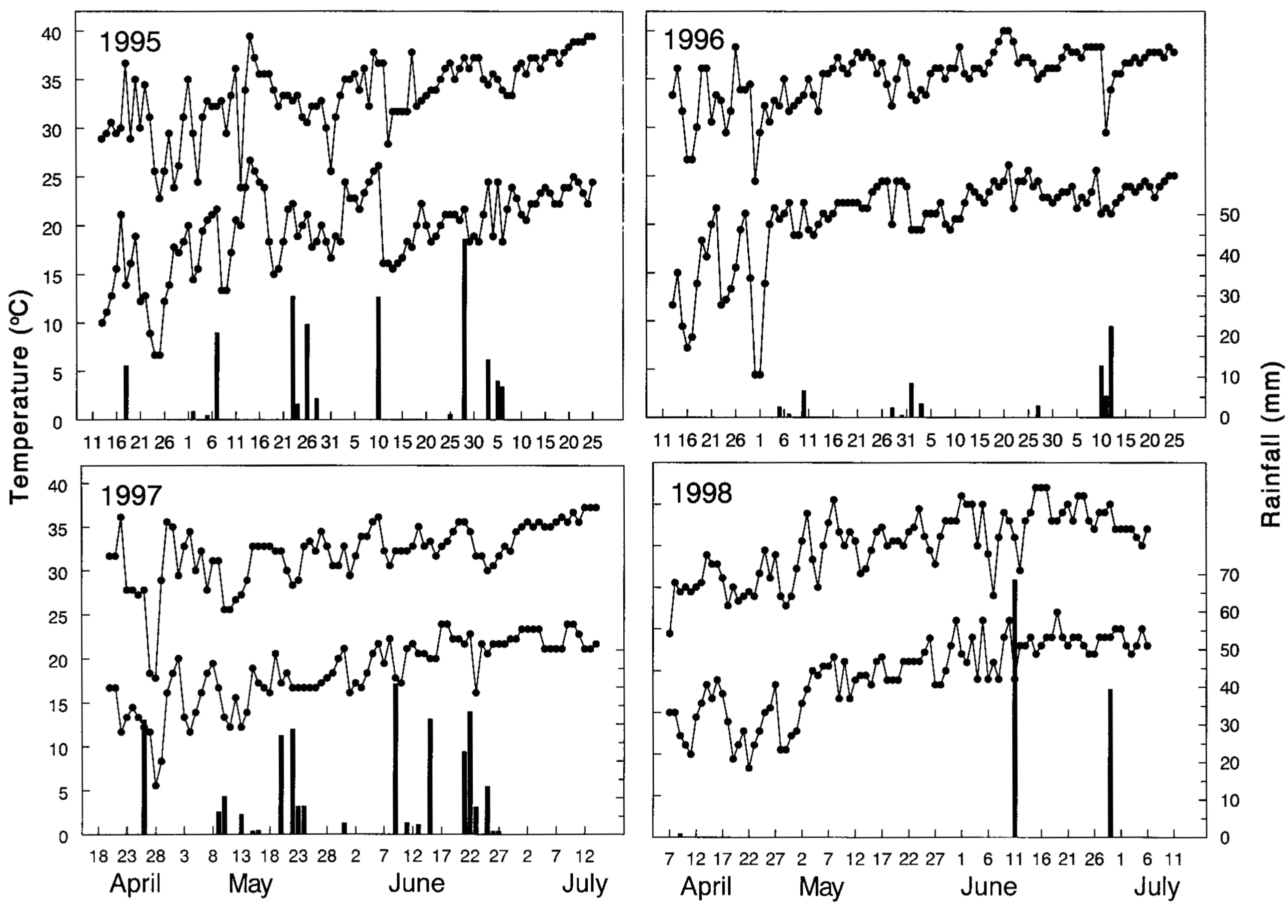

Fig. 1. Maximum and minimum air temperature, and rainfall events at the Uvalde Texas A&M Experiment Station during 1995–98.

Table 2. Effects of irrigation and stand establishment methods on total marketable fruit yield (all harvests combined), water use efficiency (WUE), and soluble solids content (SSC) of 'Caravelle' muskmelon. Uvalde, Texas.

	Yield ($t\cdot ha^{-1}$)				WUE ($kg\cdot ha^{-1}\cdot mm^{-1}$)				SSC (%)			
System	1995	1996	1997	1998	1995	1996	1997	1998	1995	1996	1997[z]	1998
Irrigation												
Pre-irrigation + dryland	22.1	7.4	5.7	14.8	60	38	17	71	11.0	11.1	2.9	10.8
Furrow	25.4	47.7	4.5	30.3	43	62	8	59	10.7	11.0	6.5	10.3
Furrow mulch	32.4	45.7	25.3	39.8	55	63	44	77	11.1	10.9	7.1	10.3
Surface drip (0 cm) – M	37.4	46.8	26.1	52.9	120	139	66	135.0	10.3	9.8	6.2	11.1
Subsurface drip (10 cm) – M	37.9	66.4	30.8	45.6	116	163	78	120	9.7	9.7	6.4	10.7
Subsurface drip (30 cm) – M	43.1	58.7	26.1	47.4	124	136	66	119	10.1	10.5	7.1	10.3
$LSD_{0.05}$	9.2	9.1	7.1	11.8	17	25	17	30	0.8	NS	0.9	NS
Stand establishment												
Transplants	30.9	39.1	27.9	50.4	73	91	65	127	11.9	10.7	6.9	10.8
Direct seeded	35.0	51.8	11.6	26.5	83	109	28	66	9.1	10.3	5.2	10.4
Significance	NS	*	*	**	*	*	*	**	*	NS	**	*
Interaction	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	**	NS

[z]Yields were not marketable since SSC <8.0%. Drip irrigation systems used black polyethylene mulch (M) 40 μm thick.

NS, *, **Nonsignificant or significant by F test at $P \leq 0.05$ or 0.01, respectively.

Table 3. Effects of irrigation and stand establishment methods[z] on total fruit yield by class size of 'Caravelle' muskmelon. Uvalde, Texas, 1995.

	Yield by size[y] ($t \cdot ha^{-1}$)				
System	9	12	15	18	23
Irrigation					
Pre-irrigation + dryland	5.1	8.4	5.3	2.6	0.7
Furrow	9.7	9.0	4.7	1.6	0.4
Furrow mulch	13.9	10.9	5.4	1.4	0.2
Surface drip (0 cm) – M	22.2	9.4	4.2	1.2	0.4
Subsurface drip (10 cm) – M	21.9	9.9	4.8	1.2	0.1
Subsurface drip (30 cm) – M	23.0	14.8	3.6	1.4	0.2
$LSD_{0.05}$	6.2	NS	NS	NS	NS
Stand establishment					
Transplants	13.8	11.1	4.3	1.4	0.2
Direct seeded	18.1	9.7	5.0	1.7	0.4
	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS

[z]Transplants were set in the field on 27 Apr. 1995 and fruits were harvested on 30 June, 6 and 14 July for transplants, and on 14, 19 and 25 July for direct-seeded plants. Drip irrigation systems used black polyethylene mulch (M) 40 µm thick.
[y]Marketable fruits were classed according to the U.S. commercial trade standards (9-, 12-, 15-, 18-, and 23-count per 18 kg carton).
[NS]Nonsignificant by F test at $P \leq 0.05$.

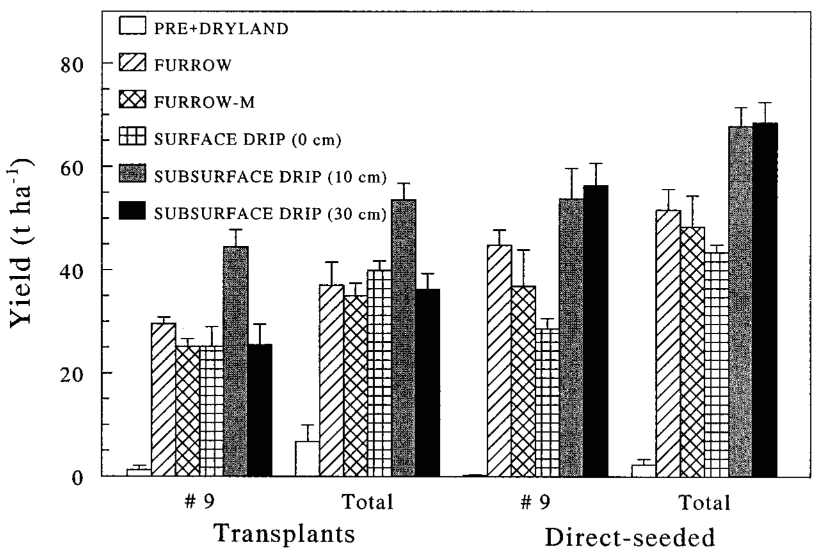

Fig. 2. Effect of irrigation method on total and 9-count (number of melons in a 18-kg carton) fruit yield of transplants and direct-seeded plants of 'Caravelle' muskmelon. Uvalde, Texas, 1996. Vertical bars represent a mean (n = 4) ± SE.

large (6288 m^2) nonreplicated plots with greater sand content in the furrow than in the drip plots.

Water tension at 15-cm soil depth, varied more when transplants were grown with drip at the 10 cm than at the 30 cm soil depth (Fig. 3). This response was probably a result of greater root activity for water uptake and root growth at the 10- to 15-cm depth. When roots in the upper 0 to 30 cm of the soil profile were manually excavated, total root weight was greater for transplants on subsurface drip at 10 cm than at 30 cm (3.13 g ± SE 0.33 vs. 1.62 g ± 0.64). The opposite trend was observed at the 30-cm depth, where water tension of the soil was ≈–10 to –25 kPa prior to fruit set (16 May) and between –25 and –60 kPa with drip at 10 cm, compared with –25 up to –80 kPa with drip at the 30-cm soil depth (Fig. 3).

Excessive rainfall late in 1997 (Fig. 1) precluded further fruit development, thereby reducing marketable yields. This effect was greater on direct-seeded plants than on transplants. As expected, this yield decrease was more pronounced for plants in the furrow systems without mulch and those under dryland conditions (Table 2). In 1998, fruit yields were higher for the surface drip treatment than for furrow systems, but not with subsurface drip systems. Fruit maturity was earlier and more synchronized for transplants than for direct seeded plants (not shown), therefore avoiding late rainfall events that reduced yields 48% in direct-seeded treatments (Table 2).

Comparing irrigation systems, the yield advantage of drip over the conventional furrow system without plastic mulch was evident in all seasons. Smaller and more frequent irrigations and fertilizer applied through drip systems provide a more efficient method to compensate for plant water and nutrient demands. Hartz (1997) reported that drip irrigation rates (from complete cut off, 20% and 50%, to normal 100% watering) and termination of applied irrigation (10 or 20 d before harvest) did not affect marketable yield and fruit size in three direct-seeded muskmelon cultivars in California. Furrow irrigations generally create cyclical water soil deficits associated with the long intervals between each irrigation; however, these cycles may be extended in silty clay soils such as those used in our study. Plastic mulch restricts soil water evaporation, allowing for greater soil moisture at shallow layers, as indicated by the lower water tension at the 15-cm but not at the 30-cm depth (Fig. 3). Interestingly, the high yields of conventional pre-irrigated dryland treatment in 1995 indicate that uniform precipitation events (Fig. 1) were adequate to raise the soil moisture profile temporarily and to allow continued plant development (data not shown). The cultivar Caravelle was able to sustain short drought periods and tolerate extreme temperatures, e.g., after fruit set (between 15 May and 15 June), when maximum air temperature was above 37 °C for 7 and 15 d in 1996 and 1998, respectively.

Direct-seeded plants produced similar or higher total marketable fruit yields than did transplants in 1995 and 1996 (Table 2). The expected delay in harvest for direct-seeded plants was compensated by higher yields during late harvests. Therefore, direct-seeded plants have a greater yield potential when grown under optimum environmental conditions for fruit development. These results contrast with those found in other crops, such as watermelons (Hall, 1989) and bell peppers (Leskovar and Cantliffe, 1993).

The first harvest yield increase from transplants established with surface drip in 1995 (not shown) or total yield increase with subsurface drip at 10 cm in 1996 (Fig. 2), suggests that early irrigations are more efficient in maintaining the depth of water necessary to recharge the soil in the upper 0- to 15-cm root zone than in deeper layers (Fig. 3). Some vegetable transplants have a restricted taproot, and develop more and early proliferation of lateral and basal roots in the upper 10 cm of the soil profile; conversely, direct-seeded plants have an unrestricted taproot development, therefore a greater potential for root proliferation and exploration at greater soil depths (Leskovar and Stoffella, 1995). Therefore, increased earliness in melons may be related to early root growth, water, and nutrient uptake.

Water use efficiency. Water use efficiency was expressed as total fruit yield divided by the total water received during the growing season; higher values indicate greater efficiency. In this study, WUE was ≈2.5, 2.4, 2.7, and 1.8-fold as great for plants on drip irrigation than for those on furrow systems throughout the 1995–98 seasons, respectively. Pooled across all years and drip depth positions, WUE for drip irrigation was 115 $kg \cdot ha^{-1} \cdot mm^{-1}$ of

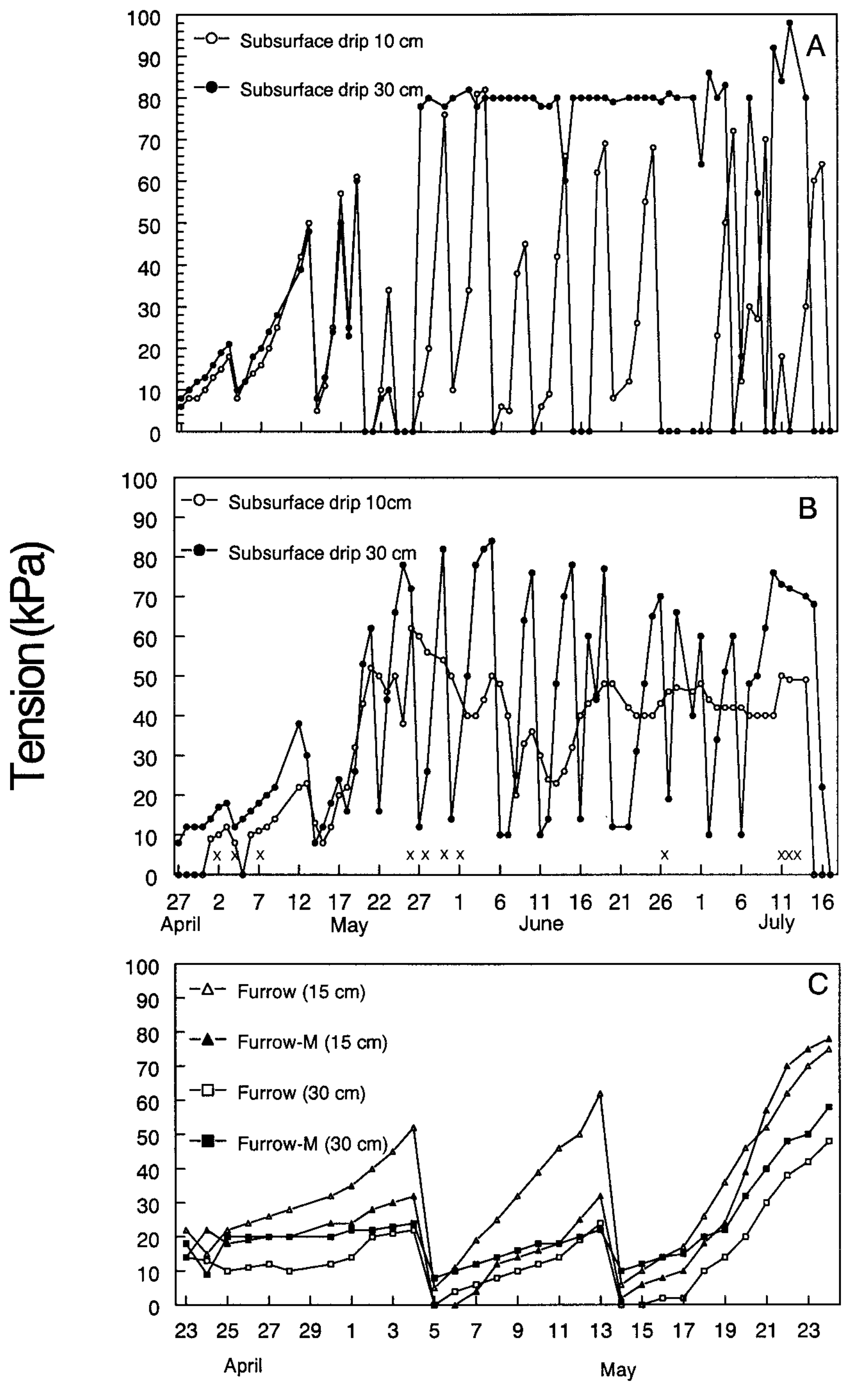

Fig. 3. Effect of irrigation method for 'Caravelle' muskmelon transplants on soil water tension measured at (**A**) 15-cm depth in 1996, (**B**) 30-cm depth in 1996, and (**C**) 15- and 30-cm depth in 1998. Uvalde, Texas. Rainfall events are indicated by an ×.

applied irrigation water + growing season precipitation vs. 51 $kg \cdot ha^{-1} \cdot mm^{-1}$ for the furrow systems. However, these data have to be taken carefully, since water management was less controlled by furrow irrigation than by drip irrigation and the volume applied may not have matched irrigation requirement.

In a study with onions, WUE for level furrow and trickle irrigation once/week was similar and in the range of 52 and 28 $kg \cdot ha^{-1} \cdot mm^{-1}$ (Ellis et al., 1986). Depth of the drip line did not affect WUE except in 1996, when WUE was greater for the drip subsurface at 10 cm than at 30 cm below soil surface (Table 2). Comparing stand establishment methods, WUE was 14% and 20% higher for direct-seeded plants than for transplants in 1995 and 1996, respectively. However, excess rainfall reduced yield in the direct-seeded crop by curtailing fruit development and maturity, reducing WUE to 43% and 52% in 1997 and 1998, respectively. The WUE for the dryland cropping system was comparable to that for furrow/no mulch in three of four seasons (Table 2), probably as a result of adequate rainfall to support crop development.

Fruit quality. Fruit SSC differences were minimal across the irrigation systems (Table 2). These results are similar to those reported by Lester et al. (1994). Fruits from the pre-irrigation + dryland system had slightly higher SSC values than those from subsurface drip irrigation systems at 10 or 30 cm in the first season. The fewer fruits per plant under pre-irrigation + dryland and furrow systems, may compete more effectively for assimilate partitioning, which is directly related with the accumulation of sucrose. A larger number of fruits per plant may increase inter-fruit competition, thus reducing the potential for sucrose accumulation per fruit. Fruit SSC was higher in transplanted than in direct-seeded melons in 1995, 1997 and 1998. Because of excess rainfall in 1997, fruit SSC was severely reduced to unmarketable levels (<8%) for both establishment systems. The effects of rainfall or late irrigations in reducing SSC and overall fruit quality have been widely recognized (Bogle and Hartz, 1987; Bouwkamp et al., 1978; Lester et al., 1994). Seed cavity measurements and netting uniformity ratings were similar among the five irrigation treatments, and lowest under the water deficit conditions of the pre-irrigation + dryland system (data not shown). Meiri et al. (1995) reported that soil water deficit resulting from saline conditions reduced the percentage of melon fruits with netted surface.

The development of medium-to-large fruits appeared to be concentrated closer to the main crown in transplants, suggesting that they may be able to maintain and partition assimilate supply more evenly among developing fruits than can direct-seeded plants, in which fruit distribution appeared to be more dispersed, with larger fruit size. Early work by Davis and Schweers (1971) showed that SSC was inversely correlated with fruit number per plant. Smaller fruits also have lower SSC, as observed in the dry-land treatment (not shown).

In summary, these experiments on methods of irrigation and stand establishment were conducted in two 'wet' (1995, 1997) and two 'dry' (1996, 1998) seasons (Fig. 1). During the wet seasons, yield improved as a result of mulch regardless of irrigation system, and in general, total yields of the combined drip systems did not differ statistically than those of furrow mulch systems. However, during the driest season (1996), yield was greatest for subsurface drip systems at 10- or 30-cm soil depth. Average yield of plants with subsurface drip at 10 cm was 40% greater than that of plants with drip surface in 1996. Comparing stand establishment across all seasons, transplant yields were higher and less variable (CV = 27%) than those of direct-seeded plants (CV =54%). In addition, SSC was consistently higher for transplants. Reduced time to fruit maturity, coupled with concentrated harvests in transplants, is critical for reducing risks associated with rainfall events. Under continuous drought conditions, such as evidenced in 1996, direct-seeded plants established with drip placed between the 10- and 30-cm depth can potentially yield more than transplants, but they have a greater risk of fruit quality loss under temperature extremes and high rainfall conditions near maturity, as in 1998. The most significant impact of the drip irrigation systems was in the amount of water applied and their WUE.

Literature Cited

Bar-Yosef, B., B. Sagiv, and T. Markovitch. 1989. Sweet corn response to surface and subsurface trickle phosphorus fertigation. Agron. J. 81:443–447.

Bogle, C.R. and T.K. Hartz. 1986. Comparison of drip and furrow irrigation for cantaloupe production. HortScience 21:242–244.

Bouwkamp, J.C., Angell, F.F. and Schales, F.D. 1978. Effects of weather conditions on soluble solids of cantaloupe. Sci. Hort. 8:265–271.

Davis, R.M. Jr. and V.H. Schweers. 1971. Association between physical soil properties and soluble solids in cantaloupes. J. Amer. Soc. Hort. Sci. 96:213–217.

Doorenbos, J. and W.O. Pruitt. 1977. Guidelines for predicting crop water requirements. Food and Agr. Organization, Rome.

Ellis, J.E., E.G. Kruse, A.E. McSay, C.M.U. Neale, and R.A. Horn. 1986. A comparison of five irrigation methods on onions. HortScience 21:1349–1351.

Goldberg, D., B. Cornat, and D. Rimon. 1976. Drip irrigation. Principles, design and agricultural practices. Drip Irr. Sci. Publ., Kfar Shmaryahu, Israel.

Hall, M.R. 1989. Cell size of seedling containers influences early vine growth and yield of transplanted watermelons. HortScience 24:771–773.

Hanson, B., L. Schwankl, S. Grattan, and T. Prichard. 1994. Drip irrigation for row crops. Water management series publication number 93–05. Univ. of Calif., Davis.

Hanson, B.R., L.J. Schwankl, K.F. Schulbach, and G.S. Pettygrove. 1997. A comparison of furrow, surface drip, and subsurface drip irrigation on lettuce yield and applied water. Agr. Water Mgt. 33:139–157.

Hartz, T.K. 1997. Effects of drip irrigation scheduling on cantaloupe yield and quality. Scientia Hort. 69:117–122.

Leskovar, D.I. and D.J. Cantliffe. 1993. Comparison of plant establishment method, transplant or direct-seeding, on growth and yield of bell pepper. J. Amer. Soc. Hort. Sci. 118:17–22.

Leskovar, D.I. and P.J. Stoffella. 1995. Vegetable seedling root system: Morphology, development, and importance. HortScience 30:1153–1159.

Lester, G.E., N.F. Oebker, and J. Coons. 1994. Preharvest furrow and drip irrigation schedule effects on post-harvest cantaloupe quality. Postharvest Biol. Technol. 4:57–63.

Meiri, A., D.J. Lauter, and N. Sharabini. 1995. Shoot growth and fruit development of cantaloupe under saline and non-saline soil water deficit. Irr. Sci. 16:15–21.

Pew, W.D. and B.R. Gardner. 1983. Effects of irrigation practices on vine growth, yield, and quality of cantaloupe. J. Amer. Soc. Hort. Sci. 108:134–137.

Phene, C.J., K.R. Davis, R.B. Hutmacher, B. Bar-Yosef, D.W. Meeks, and J. Misaki. 1991. Effects of high frequency surface and subsurface drip irrigation on root distribution of sweet corn. Irr. Sci. 12:135–140.