Florida Watermelon Production Affected by Water and Nutrient Management

Gregory S. Hendricks¹, Sanjay Shukla^{1,5}, Kent E. Cushman¹, Thomas A. Obreza², Fritz M. Roka¹, Kenneth M. Portier³, and Eugene J. McAvoy⁴

ADDITIONAL INDEX WORDS. best management practices, *Citrullus lanatus*, groundwater, seepage irrigation, fertilizer recommendation, partial budgeting

SUMMARY. Watermelon (*Citrullus lanatus*) production is concentrated in southern Florida where growers often use seepage irrigation. According to a recent survey, growers believe that nitrogen (N), phosphorus (P), and potassium (K) rates recommended by the University of Florida Institute of Food and Agricultural Sciences (UF-IFAS) are low. A study was conducted during Spring 2004 and 2005 at a UF-IFAS research farm to compare three nutrient and water management systems: high rate [HR (265, 74, and 381 lb/acre N, P, and K, respectively)], recommended rate [RR (150, 44, and 125 lb/acre N, P, and K, respectively)], and recommended rate with subsurface irrigation (RR-S). Irrigation was managed to keep soil moisture content at 16% to 20% for HR and 8% to 12% for RR and RR-S. The experimental design was a randomized complete block design with two replications and three subsample areas within each 0.25-acre plot. The HR management approach produced ≈60% to 80% higher yields (cwt/acre) during 2005 than RR or RR-S. The HR treatment produced larger watermelons than RR or RR-S in 2005. Triploid watermelon prices had to be at least \$3.74/cwt to cover all costs associated with HR. The HR approach increased the grower net returns by \$590/acre and \$1764/acre under conservative and higher yield and price expectations, respectively. Soluble solids content and hollowheart ratings were unaffected by treatment. Total biomass, recorded during 2005, followed a similar trend as yield, with HR producing 105% and 125% greater total dry weight than RR and RR-S, respectively. Total N content of HR biomass was 56% higher than that of RR and RR-S. Total P content was 29% and 50% higher than that of RR and RR-S, respectively. Leaf and petiole tissue from the HR treatment exhibited consistently higher N and K leaf tissue values during 2005 than RR and RR-S. In conclusion, trends in the data consistently showed greater plant performance with higher rates of fertilizer and soil moisture content. Our ability to detect differences in 2005 was probably enhanced by higher rainfall during 2005 compared with 2004.

Florida ranks second in the United States in acreage and value of fresh market vegeta-

bles with almost 290,000 acres in production [Florida Department of Agriculture and Consumer Services (FDACS), 2006] and over \$2 billion in farm gate value. Florida is also a leader in watermelon production,

ranking first during 2005 among the top five leading states in the country along with Texas, California, Georgia, and Arizona for production and value [U.S. Department of Agriculture (USDA), 2006a]. Watermelon production is concentrated in southern Florida where many growers use seepage irrigation with or without raised beds and plastic mulch. Seepage irrigation involves raising the water table to provide moisture to the root zone through upflux. The water table is adjusted during the crop season to control moisture levels in the crop root zone. High water table conditions (e.g., 18 inches from the top of the bed) combined with rapid water movement in sandy soils in southern Florida can result in large fluctuations in water table levels in response to rainfall and irrigation. Bonczek and McNeal (1996) noted that water table fluctuations in seepage irrigation systems could result in a significant movement of fertilizer out of the root zone. Water table management has a direct and profound impact on soil moisture and nutrient concentrations in the root zone. Either wet or dry soil moisture conditions can adversely impact crop yield, but water management can also cause low or high nutrient concentrations in the root zone. Therefore, water and nutrients have to be managed simultaneously to optimize yield and minimize nutrient losses to groundwater.

Irrigation management practices used by watermelon growers vary from simple to complex. Some growers rely on experience and personal judgment to assess soil moisture for irrigation management. Other growers use sophisticated moisture monitoring devices or

Funds for this study were provided by the Florida Department of Agriculture and Consumer Services and the Southwest Florida Water Management District.

We thank Charles Obern of C&B Farms and Jason Shiveler of Six L's Packing Company Inc. for providing assistance with harvesting and other field operations. Special thanks to J. Dale Hardin and Karen Ambrester for their technical assistance.

¹Agricultural and Biological Engineering, Horticultural Sciences, and Food and Resource Economics, Southwest Florida Research and Education Center, University of Florida Institute of Food and Agricultural Sciences (UF-IFAS), 2686 State Road 29 N, Immokalee, FL 34142

²Soil and Water Science Department, UF-IFAS, Gainesville, FL 32611

³Department of Statistics, UF-IFAS, Gainesville, FL 32611

⁴Hendry County Extension Office, UF-IFAS, LaBelle, FL 33975

⁵Corresponding author. E-mail: sshukla@ufl.edu.

Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
45.3592	cwt	kg	0.0220
112.0851	cwt/acre	kg·ha ⁻¹	0.0089
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
3.7854	gal	L	0.2642
2.5400	inch(es)	cm	0.3937
25.4000	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
1	meq/100 g	cmol·kg ⁻¹	1
28.3495	oz	g	0.0353
3.0515	oz/1000 ft ²	kg·ha ⁻¹	0.3277
1	ppm	mg·L ⁻¹	1
6.8948	psi	kPa	0.1450

evapotranspiration data to schedule irrigation. Likewise, nitrogen (N), phosphorus (P), and potassium (K) applied to watermelon crops vary according to grower preference and site-specific conditions such as soil characteristics. According to a survey of southwestern Florida watermelon growers, the average N, P, and K rates were 265, 74, and 381 lb/acre, respectively (Shukla et al., 2004). Fertilizer recommendations developed by the University of Florida Institute of Food and Agricultural Sciences for watermelon are 150 lb/acre N along with P and K application rates determined by soil testing and laboratory recommendations (Maynard et al., 2001). Recommendations for managing irrigation, although less specific than for fertilizer, include managing soil water between field capacity and 50% depletion of the plant available water to avoid plant water stress (USDA, 1993).

Florida's vegetable industry is faced with environmental issues such as the development of total maximum daily load for nutrients of concern such as N and P. To achieve water quality goals, state agencies are promoting the use of best management practices (BMPs). BMPs are a practice or combination of practices based on research, field testing, and expert review deemed to be effective and practicable for producers and for improving water quality in agricultural discharges (FDACS, 2005). BMPs are required to be economical and technologically feasible. To maximize yields, fertilizer and water inputs for watermelon production in southern Florida often exceed the recommended inputs. To promote the use of recommended inputs, current production practices need to be compared with the recommended practices with special emphasis on yield performance and farm profitability.

This study evaluated three water and nutrient management systems for watermelon production in southern Florida with regard to watermelon yield, fruit quality, and farm income. The first system involved typical water and nutrient management practices encountered in southern Florida. The second and third systems involved soil moisture-based water table management systems with recommended fertilizer rates (Maynard et al., 2001).

Materials and methods

The study was conducted during the winter-to-spring growing seasons of 2004 and 2005 and was located at the Southwest Florida Research and Education Center in Immokalee. The center is located in Collier County at an elevation of 35 ft above mean sea level. The soil at the site is Immokalee fine sand (sandy, siliceous, hyperthermic, Spodic Psammaquents) with a cation exchange capacity of 12 meq/100 g and a pH of 5.6 (Carlisle et al., 1989), and 49 and 60 ppm of P and K, respectively. This soil is common in the flatwood regions of southern Florida. Immokalee fine sands are characterized by poor drainage, nearly level surfaces (slopes less than 2%) and a poorly drained spodic layer situated ≈ 3 to 4 ft below the soil surface. This soil also has a moderately rapid permeability (2.0 to 6.0 inches/h) and low available water capacity (5% to 7%). The average annual rainfall for the region is ≈ 54 inches (Fernald and Purdum, 1998). A field of ≈ 3.6 acres was divided into six main plots of 0.6 acres each. Each plot had 0.25 acres of bedded area. Crop beds were 8 to 10 inches high and spaced 6 ft apart.

This study considered three nutrient and water management systems: high rate (HR), recommended rate (RR), and recommended rate with subsurface irrigation (RR-S). The HR fertilizer rate, based on the results of a grower survey, was 265, 74, and 381 lb/acre N, P, and K, respectively, and the moisture level was held in the range of 16% to 20%. This moisture content range was based on a survey of watermelon producers in southwestern Florida (Shukla et al., 2004). The fertilizer rate for RR and RR-S treatments was 150, 44, and 125 lb/acre N, P, and K, respectively, and the moisture level was held in the range of 8% to 12%. This moisture content range was considered suitable based on the reported field capacity of this soil, which ranges from 8.5% to 12% and the wilting point, which is $\approx 4\%$ (Carlisle et al., 1989). Water tables in HR and RR were managed by water supplied to shallow irrigation ditches placed parallel to each set of three rows of plant beds. The water table in RR-S was managed by water supplied to subsurface drip tubing (UniRam RC;

Netafim Irrigation, Fresno, Calif.) that was installed ≈ 18 inches beneath the soil surface and perpendicular to the plant beds. Drip tubing was operated at 20 psi and emitter spacing was 3 ft. Each emitter had a maximum flow rate of 0.92 gal/h.

The three treatments in this study involved two levels of water table management. The water table for HR was higher than that of RR or RR-S. However, maintaining two different water table regimes in neighboring fields is difficult as a result of exchanges of groundwater among HR, RR, and RR-S. To maintain different water table depths for different treatments, main plots were separated from each other by a vertical polyethylene plastic barrier to prevent lateral flow of water and nutrients between plots. The polyethylene barrier extended from the soil surface to the average depth of the spodic layer (3 ft). An external drainage canal bordered most of the field's perimeter to convey runoff or drainage from the field. Soil samples were taken at regular intervals throughout the field to characterize the soil, especially depth to the spodic layer. Soil characterization data obtained from the samples indicated that the depth of the spodic layer, on average, was lower on the east section relative to the west section of the field (Fig. 1). To account for possible hydrologic differences introduced by a variable spodic layer, the field was divided into two statistical blocks to account for this variation. It was assumed that hydrological characteristics within each block were uniform.

Fertilizer was applied as 10N-0P-8.3K (4.1% nitrate nitrogen, 3.2% ammoniacal nitrogen, 2.7% other water-soluble N, and 10% soluble potassium as K_2O derived from potassium nitrate), 0N-20.2P-0K (triple superphosphate), and 0N-0P-49.8K (potassium chloride). Twenty percent of the N and K and 100% of the P fertilizer was incorporated into the bed. The remainder of the N and K was applied in two shallow grooves (2 to 2.5 inches deep) at the top left and right sides of the bed.

Soil moisture levels within each treatment plot were monitored on a daily basis by capacitance probes (EasyAg; Sentek Sensor Technologies, Stepney, South Australia), each having sensors at depths 10, 20, 30,

Fig. 1. Layout of experimental design for watermelon production with plastic-mulched raised beds and seepage irrigation. Total experimental area was 3.6 acres. Each plot had 0.25 acres of cropped area that contained 18 rows that were each 100 ft long. A plastic liner was installed around the perimeter of each plot from the soil surface to a depth of 3 ft to create quasi-isolated hydrologic conditions that provide independent control of water table depth. Water tables were maintained within each plot by riser boards installed at the end of a drain tile that collected drainage from each plot. Three different water and fertilizer management strategies were applied: high fertilizer rate and soil water content (HR), recommended fertilizer rate and soil water content (RR), and same as RR but with subsurface irrigation (RR-S). The field was divided into two statistical blocks (1 and 2) to account for possible differences introduced by the sloped spodic layer (1 ha = 2.4711 acre; 1 ft = 0.3048 m).

and 50 cm. Moisture content measurements were recorded as a percent [volumetric (v/v)]. The grower survey indicated that growers in southwestern Florida often maintain soil moisture levels higher than the field capacity in the top 12 cm of a raised bed. To emulate this style of water management, soil moisture in the bed was maintained at a level that was higher than field capacity.

For 2004, seedlings of 'Mardi Gras' diploid watermelon and 'Tri-X 313' triploid watermelon were obtained from a commercial transplant production facility and transplanted on 8 March. A row of diploid seedlings was transplanted between every two rows of triploid plants. For 2005, seedlings of 'Tri-X 313' were transplanted in all rows on 21 Feb. and then the dedicated pollinizer 'SP-1' was interplanted between each third

and fourth triploid plant. The study was replanted on 15 March because of poor growth of the first planting and variability in seedling uniformity. In addition, more than 4 inches of rainfall occurred during the week of 21 Feb. and additional N and K fertilizer was applied manually at the rate of 30 and 24 lb/acre, respectively, to compensate for leaching. The compensatory N and K application was based on Florida extension recommendations (Maynard et al., 2001). The second planting performed well and the study was completed. Crop yield was recorded from three subsample areas within each plot. Subsample areas were 20 ft long by six beds wide. An industry cooperator with experience in watermelon production determined when fruit were harvestable and experienced pickers selected marketable fruit at each

harvest. Fruit from each subsample area were counted and weighed, and five fruit from each subsample area were selected for internal evaluations. Soluble solids content was measured with a handheld refractometer. Hollowheart was measured at the widest point with a micrometer gauge. Watermelons located outside the subsample areas were harvested, counted, and weighed using an industrial scale. Weights were recorded by treatment, with blocks 1 and 2 combined, to provide adequate tonnage for the scale.

Samples for leaf tissue and petiole sap analyses were collected biweekly at ≈ 1000 HR at each sample date. The most recently matured leaf (MRML) was removed for leaf tissue analysis. Two sets of six to eight MRMLs were collected from each plot. Composite samples were dried, ground, and then sent to a commercial laboratory for analysis of N and K. Petioles from two sets of six to eight MRMLs were also selected from each plot. Each composite sample was chopped and mixed; a subsample was taken for petiole sap analysis using a specific ion meter (Cardy; Spectrum Technologies, Plainfield, Ill.). Each meter was calibrated biweekly according to the user manual specifications for nutrients N and K (Spectrum Technologies, Inc., 2006a, 2006b).

The experimental design was a randomized complete block design with two replications and three subsample areas within each experimental unit. Initially, the study was evaluated as a nested design accounting for block, experimental treatment, and crop season (or year) as fixed effects and estimation of replication (block-by-treatment interaction) and subsampling variability. Test for treatments, however, had low power because of low replication. Wald's test was then used to compare replication and subsampling variance component estimates and in all cases, the two estimates were not statistically different. A second analysis model was used that pooled replication and subsampling variability for the test of treatment effects. Results are reported using this second analysis model, which typically had a pooled variance estimate that was larger than the replication residual variance but also more denominator df for the statistical tests (and hence more powerful tests). Pooling variance estimates for testing

of main plot effects is typically not a valid substitute for increased main plot replication, but in this case, increasing main plot replication was infeasible. Estimation and test computations were performed using SAS (version 9; SAS Institute, Cary, N.C.), general linear model (GLM), and linear mixed model (MIXED) procedures for yield, soluble solids content, and hollowheart responses. Yields were calculated and analyzed based on watermelon fruit weights greater than or equal to 10 lb. Significance of statistical tests is indicated at *P* values less than 0.05 and means separation was performed using Tukey's test.

Economic data were collected on fertilizer and triploid watermelon prices as well as costs on fertilizer application, harvesting, and marketing costs. Fertilizer prices were estimated to be \$0.45/lb, \$0.68/lb, and \$0.18/lb for N, P, and K, respectively (USDA, 2006b). Season average prices for triploids ranged from \$8.40/cwt in 2004 to \$15.50/cwt in 2005 (Florida Agricultural Statistics Service, 2006). Fertilizer application costs were estimated to be \$25/acre (Smith and Taylor, 2005). Harvesting and marketing costs were estimated to be \$2.95/cwt (Smith and Taylor, 2005). The HR treatment incurred more fertilizer costs. An economic analysis was necessary only so long as HR produced more yield than the treatments with lower fertilizer rates. If the HR treatment produced significantly higher yields of triploid watermelons, a partial budget analysis would determine the costs of the HR treatment, the value of the yield difference, and the break-even price necessary to cover all grower costs associated with the HR treatment. Grower costs consisted of two components: 1) higher costs from using more fertilizer material, and 2) higher harvesting and marketing costs associated with higher yields from the HR plots.

Results

Despite large numerical differences, HR did not produce significantly higher yields (number and weight per acre) of diploid or triploid watermelons during 2004 compared with RR or RR-S (Table 1). In contrast, HR produced significantly higher yields (number and weight per acre) of triploid watermelons

Table 1. Yield, average weight, soluble solids content (SSC), and severity of hollowheart (HH) of watermelon grown under three different water and fertilizer management strategies during Spring 2004 and 2005.^z

Yr	Treatment	Diploid				Triploid			
		Yield		SSC		Yield		SSC	
		(melons/acre) ^y	(cwt/acre) ^y	Avg wt (lb) ^y	HH (mm) ^y	(melons/acre) ^y	(cwt/acre) ^y	Avg wt (lb) ^y	HH (mm) ^y
2004	HR	3993	758	19.0	10.7	2935	444	15.1	12.2
	RR	2995	538	18.0	9.6	1755	261	14.9	11.7
	RR-S	2662	475	17.8	11.1	2421	349	14.4	12.2
Significance		0.331	0.261	0.410	0.786	0.420	0.336	0.369	0.618
2005	HR	—	—	—	—	2460 a ^x	345 a	14.0 a	12.5
	RR	—	—	—	—	1532 b	193 b	12.7 b	12.4
	RR-S	—	—	—	—	1643 b	214 b	13.0 b	12.4
Significance		—	—	—	—	0.037	0.031	0.043	0.964
<i>P</i>		—	—	—	—	—	—	—	0.361

^zThree different water and fertilizer management strategies were applied: high fertilizer rate and soil water content (HR), recommended fertilizer rate and soil water content (RR), and same as RR but with subsurface irrigation (RR-S). Seepage irrigation was used to supply water to the watermelon plants for HR and RR.

^yOne melon/acre = 2.4711 melons/ha; 1 cwt/acre = 112.0851 kg·ha⁻¹; 1 lb = 0.4536 kg; 1 mm = 0.0394 inch. Values for yield represent the average of three subsample plots in each of two blocks. Values for average weight, SSC, and HH represent the average of five fruit per subsample, three subsamples, and two replications.

^xValues followed by the same letter are not significantly different at a level of significance, *P* ≤ 0.05. Means separation by Tukey's test.

during 2005 compared with RR or RR-S, with HR producing $\approx 60\%$ and 80% higher yields (hundredweight per acre) than RR and RR-S, respectively. Compared with RR and RR-S, watermelons from HR were larger, but this difference was significant only for triploids during 2005 (Table 1). Soluble solids content and hollowheart ratings were unaffected by treatments. Soluble solids content ranged from 9.6% to 11.1% for diploids during 2004 and from 11.7% to 12.5% for triploids during 2004 and 2005 (Table 1). Hollowheart ratings were low for diploids and ranged from 7 to 17 mm in width for triploids (Table 1).

Total plant biomass during 2005 followed a similar trend as yield with HR producing 105% and 125% greater total dry weight than RR and RR-S, respectively (Table 2). The N, P, and K uptake by plant biomass of HR was 56%, 29%, and 120% higher than that of RR, respectively. Similarly, the N, P, and K uptake by plant biomass of HR was 56%, 50%, and 108% higher than that of RR-S, respectively. Leaf tissue (N and K) and petiole sap (K only) data for 2005 exhibited declining trends beginning at or above sufficiency levels and declining steadily over time until after second harvest (Fig. 2). This is a common occurrence for seepage-irrigated crops where most of the crop's fertilizers are applied before planting (Simonne and Hochmuth, 2005). However, HR frequently exhibited higher N and K contents than RR and RR-S. Higher values for HR were clearly evident for K content, whereas differences for N content were not as large. The

N content from leaf tissue analyses was at or above sufficiency ranges for each of the three treatments throughout the study. The K content from leaf tissue analysis was at or above sufficiency ranges until week 9 for HR and week 7 for RR and RR-S. The K content from petiole sap analysis was within sufficiency ranges for HR for the duration of the study but mostly below sufficiency ranges for RR and RR-S (Fig. 2). Values for leaf petiole sap N content produced a similar trend as that of leaf tissue N content but were significantly lower than expected and thought to be too low to be accurate (data not shown).

During 2005, yields of triploid watermelon ranged between 131 and 152 cwt/acre higher for HR than RR-S and RR, respectively (Table 1). In addition, total large-plot yield data, as provided by the commercial cooperator, indicated HR produced at least 90 cwt/acre more triploids than RR or RR-S (data not shown). Therefore, partial budgeting analysis was used (Table 3) to consider a matrix of costs and benefits of HR associated with yield increases from 130 to 150 cwt/acre. The lower end of the yield range, 130 cwt/acre, represented a conservative estimate of yield gain from HR, whereas the upper end of the yield range, 150 cwt/acre, allowed more optimistic gains. Low (\$8.40/cwt) and high (\$15.50/cwt) watermelon prices were used to span a range of market conditions that existed during the 2004 and 2005 seasons.

Additional fertilizer used in HR cost \$119/acre. Accounting for higher harvesting and marketing costs associated with higher yields, total costs

of higher fertilization rates (HR) were between \$384/acre and \$561/acre, depending on the actual yield increase. At a lower yield increase (130 cwt/acre), \$3.86 was the "break-even" fruit price necessary to cover the total costs of the HR. As yield increased to 150 cwt/acre, the break-even price fell to \$3.74/cwt. During 2004 and 2005, average season prices for triploids were higher than break-even values, ranging between a low of \$8.40/cwt in 2004 to \$15.50/cwt in 2005. Under conservative yield increase expectations and low market prices, HR increased grower net returns by \$590/acre. Under higher yield and price expectations, the gain in grower net return increased by \$1764/acre.

Discussion

Values for yield (weight and number per acre), average fruit weight, and N, nitrate (NO_3)-N, and K content of leaf and petiole tissue were almost always higher for HR than for RR or RR-S. The data show a trend of increased plant performance with increased fertilization and soil moisture content, but only a few of these values were statistically significant. The combined effects of limited treatment replication and variable soil properties resulted in variability that made it difficult to detect significant differences among treatments during 2004. Leaf tissue data during 2005 indicated that all treatments were above or within the N sufficiency levels throughout the duration of the study until the second harvest. Leaf tissue and petiole sap data showed a rather steady decline from sufficient to insufficient levels of

Table 2. Biomass, nitrogen (N), phosphorus (P), and potassium (K) content and total uptake of N, P, and K of watermelon plant material harvested (i.e., roots, foliage and fruit) from a 24-ft² (2.2 m²) area within each plot during 2005 after second harvest.^z

Treatment	Biomass (g/24 ft ²) ^y	Above ground (%) ^x			Below ground (%) ^x			Fruit uptake (lb/acre) ^{y,x,w}			Total uptake (lb/acre) ^{y,x,v}		
		N	P	K	N	P	K	N	P	K	N	P	K
HR	1019	1.71	0.17	1.94	1.52	0.15	1.47	49.80	8.47	45.25	83.03	11.70	83.06
RR	498	1.36	0.24	0.67	1.30	0.22	0.79	28.13	4.79	25.57	53.07	9.05	37.84
RR-S	452	1.56	0.18	0.78	1.32	0.18	0.86	30.89	5.25	28.07	53.11	7.79	39.93

^aWatermelons were grown under three different water and fertilizer management strategies: high fertilizer rate and soil water content (HR), recommended fertilizer rate and soil water content (RR), and same as RR but with subsurface irrigation (RR-S). Seepage irrigation was used to supply water to the watermelon plants for HR and RR.

^y1 g/24 ft² = 0.4485 g·m⁻² = 1.4697 oz/1000 ft²; 1 lb/acre = 1.1209 kg·ha⁻¹; 1 ft² = 0.0929 m².

^zAverage of two replications.

^wN, P, and K analysis for fruit was performed for only one treatment; results assumed the same for all treatments (i.e., 2.41% N, 0.41% P, 2.19% K). Fruit uptake of N, P, and K was determined from the weight of fruit harvested from the 24-ft² areas; these weights were based on the estimated average number and weight of fruit from subsample plots in each plot. Associated weights (dry) were multiplied by the percent N, P, and K assumed present in each watermelon.

^vTotal uptake is the sum of the N, P, and K in above and below ground biomass and the fruit uptake.

Fig. 2. Leaf tissue analyses (nitrogen and potassium) and petiole sap concentrations (potassium) from watermelon plants during 2005. High rate (HR) treatment (solid line) is high fertilizer rate and soil water content. Recommended rate (RR) treatment (dashed line) is recommended fertilizer rate and soil water content. Recommended rate with subsurface irrigation (RR-S) treatment (dash-dot-dash line) is same as RR but with subsurface drip irrigation. Grayed areas depict sufficiency ranges (Hochmuth et al., 2004). Seepage irrigation was used for HR and RR. Values are means of six measurements (three subsample areas within each plot). NS = not significant; bars = values of least significant differences (LSD) ($1 \text{ ppm} = 1 \text{ mg} \cdot \text{L}^{-1}$).

K throughout the duration of the study.

Rainfall during the two growing seasons was another source of variation with three times more rainfall during 2005 than 2004 (Table 4). Higher than normal rainfall conditions in 2005 made maintenance of target soil water content difficult. Spring in southern Florida is normally dry compared with summer, fall, and winter seasons (Fernald and Purdum, 1998). Rainfall during Spring 2005 was above normal. Soil moisture content varied over the duration of the study, but despite these variations,

the average moisture level in HR was numerically higher than that of RR during both years. This was consistent with one of the aims of the study, to maintain greater soil moisture content in HR. Soil moisture content of RR-S was consistently higher than RR and varied higher or lower compared with HR (Table 4). Moisture levels in this study were difficult to maintain using water table management for several reasons: 1) water percolation through the soil profile was affected by unpredictable fluctuations in the regional water table; 2) spodic layer (restrictive soil

layer) depth and continuity varied in the experimental area; 3) irrigation was at times interrupted in response to actual and anticipated rainfall events; and 4) evapotranspiration varied in response to crop vigor (treatment) and variable soil characteristics in the experimental area. The thickness of the spodic layer can be highly variable and can vary in thickness from a few inches to more than 2 ft within horizontal distances of a few inches (Jaber et al., 2005). Such differences can cause variability in water table depths and result in variable soil moisture content in the root zone of the crop.

Wet soil conditions during 2005 probably enhanced NO_3^- and K leaching, especially during the early part of the season. This inference is supported by trends in plant N and K nutrient status that were above the sufficiency range at first measurement and then declined to either the lower limit of sufficiency ranges (N) or well below it (K) during the course of the experiment (Fig. 2). Plant nutrient status indicated a likely soil K deficiency for optimum plant growth and fruit production. Deficiency for N, if any, was small and occurred at the end of the study period (Fig. 2). Rainfall data showed 2.5 inches of rain fell on 17 Mar., just 2 d after transplant. Jaber et al. (2006) observed that for every 1 cm rainfall, the water table for the Immokalee fine sand can rise up to 15 to 16 cm. In response to this large rainfall, water tables in all six plots rose to the surface and likely resulted in higher rates of fertilizer dissolution. In an effort to minimize stress on the transplants resulting from excessively high moisture conditions, riser boards installed in each plot were removed to facilitate drainage that allowed the water table to drop. The falling water table may have carried some of the solubilized fertilizer (N and K) with it, thereby reducing the amount of N and K left in the plant bed. This contributes to fertilizer loss by the phenomenon called “dropout” (Bonczek and McNeal, 1996). Dropout is the downward movement of dissolved nutrients resulting from density differences in the soil solution created by high nutrient concentration in the upper regions of the soil profile relative to the lower regions.

Higher yields of HR were likely the result of higher fertilizer rates

Table 3. Partial budgeting analysis for watermelon over a range of yield and price expectations considering three different water and fertilizer [nitrogen (N), phosphorus (P), and potassium (K)] management strategies during 2004 and 2005: high fertilizer rate and soil water content (HR), recommended fertilizer rate and soil water content (RR), and same as RR but with subsurface irrigation (RR-S).^z

		Cost/cwt ^y	Low-yield gain (130 cwt/acre)	High-yield gain (150 cwt/acre)
Added cost of HR treatment	Harvest and marketing	\$2.95	\$383/acre	\$442/acre
	Higher fertilizer cost ^x		\$119/acre	\$119/acre
Total added cost			\$502/acre	\$561/acre
Break-even price ^w			\$3.86/cwt ^z	\$3.74/cwt ^z
Added benefit of HR treatment	Low watermelon price ^v	\$8.40	\$1092/acre	\$1260/acre
	High watermelon price ^v	\$15.50	\$2015/acre	\$2325/acre
Benefit-cost	Low watermelon price ^v	\$8.40	\$590/acre	\$699
	High watermelon price ^v	\$15.50	\$1513/acre	\$1764/acre

^zHigh-yield gain values, 150 cwt/acre (16,812.8 kg·ha⁻¹), and low-yield gain values, 130 cwt/acre (14,571.1 kg·ha⁻¹), represent the maximum and minimum differences, respectively, between watermelon yields of HR and RR treatments (Table 1).

^y\$1.00/cwt = \$0.0220/kg; \$1.00/acre = \$2.4711/ha.

^xHR = 265, 74, and 381 lb/acre of N, P, and K at \$0.45/lb, \$0.68/lb, and \$0.18/lb, respectively (\$1.00/lb = \$2.026/kg). RR = 150, 44, and 125 lb/acre of N, P, and K at \$0.45/lb, \$0.68/lb, and \$0.18/lb, respectively.

^wCalculated by dividing total added cost by expected yield gain.

^vFlorida Agricultural Statistics Service, 2006.

Table 4. Soil moisture content (percent by volume, biweekly average) and rainfall (depth, biweekly total) data for watermelon plants with high fertilizer rate (HR), recommended fertilizer rate (RR), and same as RR but with subsurface irrigation (RR-S) treatments during 2004 and 2005.^z

2004					2005				
Weeks	Moisture content (%)			Rainfall (cm) ^z	Weeks	Moisture content (%)			Rainfall (cm) ^y
	HR	RR	RR-S			HR	RR	RR-S	
0–2	16.0	13.5	14.8	0.2	0–2	14.9	8.4	15.8	6.9
2–4	—	—	—	0.1	2–4	22.8	14.3	20.0	4.1
4–6	15.1	8.1	9.5	3.5	4–6	20.4	14.1	17.8	0.4
6–8	22.0	9.9	12.0	2.2	6–8	17.0	14.8	14.4	4.7
8–10	16.1	8.7	13.0	1.5	8–10	15.4	13.0	15.1	0.3
10–12	12.2	5.2	11.6	0.0	10–12	10.3	12.1	18.6	14.4
12–14	7.5	6.1	7.6	6.3	12–14	16.9	14.4	20.7	15.4
Season total				13.8					46.2
Season avg	14.8	8.6	11.4			16.8	13.0	17.5	

^zSeepage irrigation was used to supply water to the watermelon plants for HR and RR. Values are means of two replications.

^y1 cm = 0.3937 inch.

and higher soil moisture content compared with RR and RR-S. However, our data support the conclusion that soil moisture for RR and RR-S was above optimum levels for each year. This suggests that differences among treatments were likely attributable to differences in fertilizer and not differences in soil moisture content. Periods of excessive moisture at times in HR did not adversely affect crop yield, which again appears to indicate that the main factor affecting crop yield in this study was fertilization. It appears that under wet conditions, the RR approach may not be sufficient to sustain the optimum yield compared with the HR attributable to excessive K (and possibly N) leaching.

A partial budget analysis of costs and benefits of the HR treatment indicates a strong economic motivation for higher fertilization rates.

Even under conservative yield and price expectations, the value of yield increases observed during 2005 covered the additional total cost for both the 2004 and 2005 seasons.

In summary, this study evaluated the performance of three nutrient and water management systems for seepage-irrigated watermelon in southern Florida. Treatments were designed to compare typical grower practices (HR) and recommended practices (RR). Trends in the data showed greater plant performance with higher rates of fertilizer and higher soil moisture content in 2005 but not in 2004. Our ability to detect significant differences was enhanced by higher rainfall in the 2005 season compared with 2004, indicating again the importance of maintaining adequate levels of nutrients in the root zone of a seepage-irrigated crop. This study suggests

that growers may need to apply higher fertilizer levels, particularly during wet years; however, because of the lack of statistical differences in 2004, more study is warranted.

Literature cited

- Bonczek, J.L. and B.L. McNeal. 1996. Specific-gravity effects on fertilizer leaching from surface sources to shallow water tables. *Soil Sci. Soc. Amer. J.* 60:978–985.
- Carlisle, V.W., F. Sodek, III, M.E. Collins, L.C. Hammond, and W.G. Harris. 1989. Characterization data for selected Florida soils. University of Florida Inst. of Food and Agr. Sci., Soil Characterization Laboratory in cooperation with U.S. Dept. Agr., Soil Conservation Serv., Gainesville, Fla.
- Fernald, E.A. and E.D. Purdum. 1998. Water resources atlas of Florida. Florida State University, Tallahassee.

- Florida Agricultural Statistics Service. 2006. Vegetable acreage, production, and value report. Florida Agr. Stat. Serv., Orlando.
- Florida Department of Agriculture and Consumer Services. 2005. Water quality/quantity best management practices for Florida vegetable and agronomic crops, 2005 edition. Florida Dept. of Agr. and Consumer Serv., Tallahassee.
- Florida Department of Agriculture and Consumer Services. 2006. Overview of Florida agriculture. 18 Dec. 2006. <<http://www.florida-agriculture.com/agfacts.htm>>.
- Hochmuth, G., D. Maynard, C. Vavrina, E. Hanlon, and E. Simonne. 2004. Plant tissue analysis and interpretation for vegetable crops in Florida. 19 Dec. 2006. <<http://edis.ifas.ufl.edu/EP081>>.
- Jaber, F.H., S. Shukla, T.A. Obreza, P. Stofella, and E.A. Hanlon. 2005. Effects of inorganic and organic fertilizers on groundwater nitrogen transport in sandy and calcareous soils. *Compost Sci. Util.* 13:194–200.
- Jaber, F.H., S. Shukla, and S. Srivastava. 2006. Recharge, upflux, and water table response for shallow water table conditions. *Hydrologic Processes* 20:1895–1907.
- Maynard, D.N., G.J. Hochmuth, C.S. Vavrina, W.M. Stall, T.A. Kucharek, S.E. Webb, T.G. Taylor, and S.A. Smith. 2001. Cucurbit production in Florida, p. 153–180. In: D.N. Maynard and S. Olson (eds.). *Vegetable production guide for Florida*. Vance Publ., Lincolnshire, Ill.
- Shukla, S., G.S. Hendricks, T.A. Obreza, and E. McAvoy. 2004. Evaluation of water and nutrient BMPs for vegetable production with seepage irrigation in southwest Florida. Report No. WRP-SP-03. Florida Dept. of Agr. and Consumer Serv., Tallahassee and Southwest Florida Water Mgt. District, Brooksville.
- Simonne, E.H. and G.J. Hochmuth. 2005. Soil and fertilizer management for vegetable production in Florida, p. 3–15. In: S.M. Olson and E. Simonne (eds.). *Vegetable production handbook for Florida 2005–2006*. Vance Publ., Lincolnshire, Ill.
- Smith, S. and T. Taylor. 2005. Watermelon: Estimated production costs in a double-crop system for the southwest Florida area. 22 Jan. 2007. <<http://www.agbuscenter.ifas.ufl.edu/cost/COP04-05/SWWatermelonDC.doc>>.
- Spectrum Technologies, Inc. 2006a. Cardy potassium K⁺ meter, user's manual. 18 Dec. 2006. <<http://www.specmeters.com/pdf/2400%20CARDY%20K%20Meter.pdf>>.
- Spectrum Technologies, Inc. 2006b. Cardy nitrate NO₃⁻ meter, user's manual. 18 Dec. 2006. <<http://www.specmeters.com/pdf/2300%20CARDY%20NO3%20Meter.pdf>>.
- U.S. Department of Agriculture. 1993. *Irrigation water requirements, National engineering handbook*. U.S. Dept. Agr., Natural Resources Conservation Serv., Washington, D.C.
- U.S. Department of Agriculture. 2006a. *Vegetables, 2005 summary*. 19 Dec. 2006. <<http://usda.mannlib.cornell.edu/reports/nassr/fruit/pvg-bban/vgan0106.pdf>>.
- U.S. Department of Agriculture. 2006b. *Average U.S. farm prices of selected fertilizers*. 18 Dec. 2006. <<http://www.ers.usda.gov/Data/FertilizerUse/Tables/Table7.xls>>.