Proc. Fla. State Hort. Soc. 122:209–211. 2009.

Influence of Irrigation Programs, Mulches, and Fumigants on Tomato Performance

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Additional index words. drip irrigation, subsurface irrigation, seepage irrigation, water volumes, irrigation frequencies

Field studies were conducted to determine the effect of water management regimes on tomato (*Solanum lycopersicum* L.) production, and assess the effect of highly-retentive mulches and methyl bromide alternatives on the water volumes necessary for tomato irrigation. Twelve treatments resulted from combinations of fumigant and mulches, and irrigation programs. The combinations of fumigants and mulches were: 1) methyl bromide + chloropicrin (67:33 v/v) at a rate of 175 lb/acre under metalized mulch; 2) 1,3-dichloropropene + chloropicrin (65:35 v/v) at 16 gal/acre under metalized mulch; and 3) 1,3-dichloropropene + chloropicrin (65:35 v/v) at 32 gal/acre under high-density polyethylene mulch. The irrigation programs were seepage (subsurface) irrigation alone at 20 and 40 acre-inches/acre per season, and the same seepage irrigation volumes combined with a drip irrigation volume of 14 acre-inches/acre per season. Increasing seepage volume from 20 to 40 acre-inches/acre in combination with drip irrigation did not increase average soil moisture, ranging between 9.0% and 10.3%. In contrast, irrigation volumes had an effect on soil moisture when only seepage irrigation was provided, with values increasing from 9.4% to 11.9% when water volumes increased from 20 to 40 acre-inches/acre, respectively. Only the irrigation programs had significant effects on total marketable fruit weight. Adding drip irrigation to seepage-treated plots had a positive effect on fruit weight, increasing yields from 15.9 ton/acre in plots with only seepage to 17.6 ton/acre. Increasing seepage irrigation from 20 to 40 acre-inches/acre in plots under drip irrigation improved yields from 15.4 to 19.8 ton/acre. However, increasing seepage volumes in plots without drip irrigation had no effects on tomato total marketable yields.

Tomato production in Florida occurs on 38,500 acres, mostly in planted areas distributed in the west central, southwest, south, and east coast of the state (U.S. Department of Agriculture, 2007). Deep sandy soils with rapid infiltration are predominant in the majority of these production areas. The crop is planted on polyethylene-mulched beds, which are fumigated to eliminate soilborne pests. However, most of the current recommendations for tomato production were generated when bed fumigation with methyl bromide (MBr) was a viable option. Also, relatively inexpensive low-density polyethylene mulch was used, and environmental regulations about water run-off and nutrient leaching were not considered in research projects.

The current situation has changed considerably. Today, MBr is being phased-out because it is an ozone-depleting agent. Also, other mulch types are commercially available and water conservation is a primary focus of research, creating the necessity for more current tomato research that could address these concerns. The Florida Department of Agriculture and Consumer Services (FDACS) has started a vigorous campaign to address these concerns through its Best Management Practices (BMP) program, which seeks to provide guidelines for water use and consumption of most vegetable and agronomic crops (FDACS, 2009). FDACS uses University of Florida's vegetable production recommendations as reference points for regulations. Within that context, the use of new developments in fumigation techniques and mulch materials that tend to reduce water use makes sense.

Direct field observations have shown that current MBr alternatives, such as 1,3-dichloropropene + chloropicrin (1,3-D + Pic; Telone C-35) have poor efficacy against soilborne pests when applied in saturated soils, as it was customary for MBr, likely because these molecules can bind more tightly to water molecules than MBr. Another reason that justifies exploring reduced water irrigation programs is the use of highly-retentive mulch films [virtually impermeable (VIF) and metalized films]. These mulches appear to retain more moisture into the planting beds than high density impermeable (HDPE) mulch, which adds another component to fumigant and water management in tomato and pepper production. No research has been conducted in Florida to examine the possibility of reducing water irrigation volumes for tomato by combining the lower water requirement of new fumigants and the higher water retention of new mulch films.

There are two irrigation methods used in most farms to produce tomatoes: seepage (subsurface) alone and the combination of subsurface and drip irrigation. Seepage irrigation is a common method in muck and sandy soils of southern Florida and consists of elevating the water table through the use of lateral field ditches to allow upward water movement through capillarity in soils with an underlying impermeable layer (Simonne and Morgant, 2005). In this method, the water table is maintained between 18 and 24 inches deep by continuously providing water to the lateral ditches, regardless of the soil water volume fluctuations throughout the day. The irrigation efficiency of this method was reported to be very low because it uses large water volumes and it does not provide complete wetted fronts in planting beds (Bouman et al., 1994; Smajstrla et al., 2002). Stanley and Clark (2003) indicated that capillary rise from a perched water table is not sufficient to maintain a soil moisture content above 10% in the upper 6 inches of planting beds when the water table level is below 24 inches. Some of the drawbacks of this method include reduced soil water-holding capacity, increased risks of flooding

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The authors thank the financial support of the Southwest Florida Water Management District.

*Corresponding author; email: bmsantos@ufl.edu; phone: (813) 634-0000 and off-site discharge, and likely rapid nutrient leaching. Recent consultations among growers indicated that between 30 and 40 acre-inches/acre of water are used for crop establishment and maintenance during the growing seasons in southwest and west central Florida. This irrigation method is used in approximately 44% of the planted acreage with vegetable and fruit crops in Florida (Smajstrla and Haman, 2005).

With drip irrigation, water is pressurized and delivered to the soil through tubes with uniformly-spaced emitters, which provide water near the crop root zone. This is a highly efficient irrigation system (between 90% to 95% efficiency) because it provides small amounts of water on a frequent basis (Smajstrla et al., 2002). The appropriate scheduling of drip irrigation is necessary to maximize crop yields and to reduce nutrient leaching (Bar-Yosef, 1977). Some advantages of drip irrigation over other irrigation systems include 1) significantly reducing water use, 2) reducing the incidence of diseases and weeds in dry row middles, 3) using smaller pumps to provide the necessary daily amounts of water, 4) combining with fertilizers and certain pesticides with the irrigation water (Locascio, 2005). Although establishing drip irrigation is more expensive, it uses one-third the water volume of seepage with higher wetting efficiency in tomato production (Pitts et al., 2002). Current reference evapotranspiration values for west-central Florida are between 15 and 16.4 acre-inches/acre per season during the fall (February to May) and the spring (August to November) tomato seasons (Simonne et al., 2007). However, a recent informal survey among growers indicated that there is a tendency to overirrigate the crop. Additionally, overirrigation is a common practice among growers to maintain a high water table in tomato fields even with drip irrigation (Simonne and Morgant, 2005). The objectives of this study were to 1) determine the effect of varying water management regimes on tomato production, and 2) assess the effect of highly retentive mulches and MBr alternatives on the water volumes necessary for tomato irrigation.

Materials and Methods

Two field trials were conducted in between Feb. and May 2007 and Aug. and Dec. 2008 at the Gulf Coast Research and Education Center of the University of Florida in Balm, FL. The soil at the experimental site was classified as a Myakka fine sand siliceous hyperthermic Oxyaquic Alorthod with 1.5% organic matter and pH 7.3. Planting beds were preformed with a standard bedder and were 32 inches wide at the base and 28 inches wide on top. Bed height was 8 inches. Twelve treatments resulted from three combinations of fumigant and mulches, and four irrigation programs. The combinations of fumigants and mulches were: 1) MBr + Pic (67:33 v/v) at a rate of 175 lb/acre under metalized mulch; 2) 1,3-D + Pic (65:35 v/v) at 16 gal/acre under metalized mulch; and 3) 1,3-D + Pic (65:35 v/v) at 32 gal/acre under HDPE mulch. The irrigation programs were seepage irrigation alone at 20 and 40 acre-inch/acre per season, and the same seepage irrigation volumes combined with a drip irrigation volume of 14 acre-inch/acre per season. Treatments were arranged in a split-plot design with six and four replications in 2007 and 2008, respectively, where the irrigation programs were the main plots and the fumigant plus mulch combinations were the subplots.

Beds were fumigated using a single-bed rig equipped with three chisels spaced 12 inches apart, which delivered fumigant 6 inches deep. Soil fumigation occurred 3 weeks before transplanting. Within 1 min after fumigation, a drip irrigation tubing (0.45 gal/min per 100 ft of bed; T-Tape Systems International, San Diego, CA) was placed in all plots, regardless of irrigation program, 1 inch deep down the center of the bed. Planting beds were covered with either 1-mil-thick silver on black mulch or 0.6-mil black HDPE mulch, depending on the treatments. 'Florida-47' tomato seedlings in the four true-leaf stage (8 inches tall) were planted 2 ft apart in a single rows and 2 inches offset of bed centers approximately 3 weeks after fumigation. During the 3 d prior to transplanting, the water table was maintained at 24 inches below the bed tops by providing constant seepage irrigation to maintain the experimental site at field capacity. Depth of the water table was monitored every 3 d by installing one observation well (36 inches long by 4 inches in diameter) for every three planting beds. Each well was installed at the end of the selected plots and buried up to bed tops. After transplanting, a water volume of 0.4 acre-inches/acre per day (10,862 gal/acre per day) applied through seepage was used for the first 10 d after transplanting to establish the young plants. This volume was constantly applied (24 h per day) through 1-ft-deep irrigation ditches oriented along the mulched beds. The experimental site was set up to have one irrigation ditch for each three planting beds. After this period of tomato establishment, seepage water volumes were controlled with standard water meters and timers (Nelson Co., Peoria, IL) installed on each seepage spigot. These meters and timers allowed keeping a constant flow of approximately 0.4 acre-inches/acre per day, which is the normal production practice for tomato produce under seepage irrigation. Plots with seepage irrigation were physically separated by a 30-ft-wide buffer from those with seepage plus drip irrigation. In the treatments with drip irrigation, water was provided three times per day with irrigation cycles between 15 and 45 min (after 10 min of line pressurization), depending on the crop growth stage. Time adjustments to water volumes were made at 3 and 6 weeks after transplanting to satisfy crop growing stage and evapotranspiration. Water volumes were monitored using the same water controllers previously described.

Experimental units were 50 ft long, equivalent to 25 tomato plants per plot, with a 5-ft-long nontreated buffer zone at the end of each plot. Plant nutrients were injected using recommended sufficiency levels during the last irrigation cycle (between 1 and 3 PM) three times per week with a hydraulic injector (Dosatron, Clearwater, FL). The crop was staked at 3 WAT and tied three times at 3, 5, and 7 weeks after transplanting. Current recommendations for insect and disease control were followed (Olson et al., 2006). Soil temperature was measured at 5 inches below the bed surface and 2 inches away from the main tomato stem and it was determined weekly by inserting an analog thermometer in two randomly-selected locations per plot between 2 and 4 PM. Soil moisture was collected using a time-domain reflectometry probe at 5 inches deep and on bed centers. These readings were collected ten times per month between 7 and 8 AM and before the first drip irrigation cycle. Petiole samples were extracted 9 weeks after transplanting from between 10 to 15 mature petioles per plot collected from recently-open mature leaves in each plot. The sap was extracted from 8 to 10 (0.5 inch long) petiole sections using a kitchen garlic presser and the samples were measured for NO_3^- concentrations with a NO_3^--ion analyzer (Cardy Meter, Horiba Group, Kyoto, Japan). Marketable tomato fruit were harvested twice (10 and 12 weeks after transplanting) in the mature green stage and were graded following current market standards as extra-large, large, and medium fruit (Sargent et al., 2005). Resulting data were analyzed to determine the significance ($P < 0.05$) of the individual factors and their interactions. Preplanned comparisons were separated using single degree-of-freedom contrasts.

Table 1. Main effects of irrigation programs on soil moisture, petiole NO_3 concentrations at 9 weeks after transplanting, and total marketable, medium, large, and extra-large fruit weight. Balm, FL, 2007 and 2008.

Irrigation program	Seepage volume	Drip volume	Soil moisture	Petiole NO_3 concn	Medium	Large	Extra-large	Total
	---(acre-inch/acre) --		(%)	(ppm)	---------------- (ton/acre) ---------------			
Seepage alone	20	0	9.4	357	2.69	5.15	8.54	16.4
Seepage alone	40	0	11.9	334	2.69	4.77	7.80	15.3
Seepage + drip	20	14	9.0	373	2.49	4.69	8.22	15.4
Seepage + drip	40	14	10.3	393	3.73	5.76	10.33	19.8
Single degree-of-freedom contrasts								
Seepage alone (20) vs. seepage (20) + drip			NS	NS	NS	NS	NS	NS
Seepage alone (20) vs. seepage alone (40)			*	NS	NS	NS	NS	NS
Seepage (20) + drip vs. seepage (40) + drip			NS	NS	*	NS	*	*
Seepage alone vs. seepage + drip			NS	NS	*	NS	*	*

NS, *Nonsignificant and significant at the 5% level, respectively.

Results and Discussion

During both planting seasons, the interaction of soil fumigant plus mulch by irrigation program was nonsignificant for all the variables; thus only the main effects were discussed. Soil temperatures were affected only by the fumigant plus mulch combinations. Average soil temperatures in plots covered with HDPE mulch were significantly higher (68.7 °F) than in those with metalized mulches (64.6 °F), regardless of the applied fumigant. However, average soil moisture was not affected by the fumigant plus mulch combinations, but rather by the irrigation programs (Table 1). There were no significant soil moisture differences between plots treated with seepage alone with a volume of 20 acre-inch/acre (9.4%) and those with the same seepage volume plus drip irrigation at 14 acre-inch/acre (9.0%). Similarly, increasing seepage volume from 20 to 40 acre-inch/acre in combination with drip irrigation did not increase average soil moisture, ranging between 9.0% and 10.3%. In contrast, irrigation volumes had an effect on soil moisture when only seepage irrigation was provided to the plots, with values increasing from 9.4% to 11.9% when water volumes increased from 20 to 40 acre-inch/acre. Adding drip irrigation to the seepage treatments failed to increase soil moisture, regardless of water volume. Concentrations of NO_3 in the tomato petioles at 9 weeks after transplanting were not influenced by the irrigation programs or the fumigant plus mulch combinations, ranging between 334 and 393 ppm (Table 1), which are within sufficiency for that growth stage (Olson et al., 2006).

Only the irrigation programs had significant effects on total marketable, medium, and extra-large fruit weight categories, but not on the large fruit (Table 1). For total marketable fruit weight, adding drip irrigation to seepage-treated plots had a positive effect on fruit weight, increasing yields from an average of 15.9 ton/acre in plots with only seepage in comparison with an average yield of 17.6 ton/acre. Increasing seepage irrigation from 20 to 40 acre-inch/acre in plots under drip irrigation caused yields to improve from 15.4 to 19.8 ton/acre. However, increasing seepage volumes in plots without drip irrigation had no effects on tomato total marketable yields. These trends repeated in the medium and extra-large fruit. These data indicated that in seepage-only fields, using 20 acre-inch/acre is sufficient to produce tomato. However, crop yields can be improved by adding drip irrigation to seepage-irrigated fields with 40 acre-inch/acre per season. The results of this study suggested that tomato growers producing under only seepage irrigation programs could significantly reduce water volumes used to produce the crop, which can considerably reduce water utilization in those growing areas. Although polyethylene mulches have an effect on soil temperature, their effect was not sufficient either to improve crop yields or soil moisture.

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