IRRIGATION MANAGEMENT OF FRESH MARKET TOMATO ON SANDY LOAM SOILS IN THE MID-ATLANTIC

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SUMMARY

Fresh market tomatoes are an intensively grown vegetable crop on the Eastern Shore of Virginia. With so many acres (ac) dedicated to tomato production in close proximity to the Chesapeake Bay and tributaries, nutrient leaching and runoff are of high concern. Irrigation management can reduce nutrient leaching and increase fertilizer use efficiency. Tomato nitrogen sufficiency status measurements were performed to determine fertilizer needs and included petiole sap nitrate tests and infrared camera tests at fruit set. Results indicated that 1.0 evapotranspiration (ET) irrigation calculations were comparable to tensiometer triggered irrigation treatments and were superior to under or over-irrigated treatments with respect to crop nitrogen status. The infrared camera tests need more refinement in vegetable crops before they will prove beneficial to farmers for predicting nitrogen status midseason.

INTRODUCTION

Tomatoes (*Solanum lycopersicum*) are an intensively grown vegetable crop on the Eastern Shore of Virginia. In 2008, 4,700 ac of commercial fresh market tomatoes were harvested in Virginia, with an estimated value of 51 million dollars (USDA-National Agricultural Statistics Service, 2009). The United States harvested a total of 105,250 ac of fresh market tomatoes with Virginia ranked third after California and Florida (37,000 ac and 31,500 ac, respectively) (USDA-National Agricultural Statistics Service, 2009). In regards to value of production, Virginia ranked fourth behind Florida, California, and Ohio (622, 387, and 61 million dollars, respectively) (USDA-National Agricultural Statistics Service, 2009). With so many acres dedicated to tomatoes grown in close proximity to the Chesapeake Bay and tributaries, irrigation efficiency, nutrient efficiency, nutrient leaching and runoff are of high concern.

According to the Chesapeake Bay Program (2009), the Chesapeake Bay watershed is the largest estuary in the United States, covering over 64,000 square miles, with the shoreline stretching over 11,000 miles long. The watershed encompasses parts of Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia, and the District of Columbia. Over 100,000 tributaries flow through the watershed and eventually into the Chesapeake Bay that supports more than 3,600 species of plants, fish and animals (Chesapeake Bay Program, 2009).

Nutrient pollution from rural and urban areas has caused water quality problems in the environmentally sensitive Chesapeake Bay (Chesapeake Bay Program, 2009). Nutrient loading has caused excessive algae growth, or eutrophication, in the Chesapeake Bay and caused many water quality problems. Nitrogen is one of the main nutrients of concern since nitrogen is often

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the limiting nutrient in saltwater ecosystems. Many efforts and programs have been put in place to protect the watershed from nutrient loading stressors. However, further efforts are needed to reduce nutrient loading to improve water quality in the Chesapeake Bay.

The soils on the Eastern Shore of Virginia are predominantly sandy loams (~65% sand) that are predisposed to leaching nutrients with excessive irrigation or rainfall. Possible nutrient inflows from over-fertilization and over-irrigation have caused the Chesapeake Bay Foundation to place Virginia's Chesapeake Bay coastal waters in the 75 to 100 percentile range for agricultural nutrient loading (Wolf, 2008). Outcry from the general public resulted in a petition for non-point source pollution regulation of large agricultural operations on the Eastern Shore of Virginia. Large tomato operators utilizing plastic mulch and drip irrigation production systems were the main target of a December 2008 petition submitted to the State Water Control Board of the Virginia Department of Environmental Quality with the degradation of water quality from nutrient and sediment inflows being the major complaint (Terry, 2008).

Water availability often correlates with N availability since soluble nitrogen fertilizer moves readily throughout the soil profile with the irrigation wetting front; therefore, over irrigation can move fertilizer below the effective root zone. Infrared camera and petiole nitrate sap concentrations at fruit set can be used to test for nitrogen availability. By testing the plant during the growing season, problems related to nitrogen can be diagnosed and resolved. Hochmuth, (1994a, 1994b), states that field tomatoes with two-inch diameter fruit should have a fresh petiole sap concentration of 400 to 600 ppm nitrate-N. Petiole sap tests are a quick and fairly inexpensive way to monitor nitrate concentrations in plants to help achieve optimal fertilization (Hochmuth, 1994b). Similarly, normalized difference vegetation index (NDVI) readings can give an instant indication of nitrogen status in many crops, although no algorithms are established for tomato production in Virginia (Raun et. al., 2002; Phillips et. al., 2004). The NDVI readings can depict in-season N status of plants and correlate well with plant biomass, plant petiole nitrate concentration, and yield (Osborne, 2007).

Government agencies are pushing for regulations to reduce nutrient loading into the Chesapeake Bay and tributaries by reducing nutrient and sediment loading in runoff. However, there is little current scientific data showing the amount of nitrogen and irrigation that should be applied to plastic mulch tomatoes in the Mid-Atlantic. This study will investigate irrigation volumes to find greatest water use efficiency to decrease economic losses by reducing fertilizer and irrigation waste. This project will prove a starting point for implementation of best management practices (BMPs) for local farmers and will provide guidance to decrease agricultural nonpoint source pollution, reduce fertilizer and water waste, and protect the tributaries and the Chesapeake Bay.

MATERIAL AND METHODS

This study was established in Spring 2003 on a Bojac sandy loam (coarse-loamy, mixed, semiactive, thermic Typic Hapludults) at the Virginia Tech Eastern Shore Agricultural Research and Extension Center in Painter, Virginia (37.59°N 75.77°W). Bojac sandy loam has 61.4% sand, 27.8% silt, and 10.8% clay in the Ap horizon (Sukkariyah, et. al 2007). The soil was conventionally tilled, and 8 inch raised beds were constructed on 6 foot centers and covered with plastic mulch. Nitrogen was incorporated into the beds at a rate of 86 lb N/ac. Tomato seedlings were transplanted on May 20, 2009 into 40 foot plots.

The amount of irrigation necessary for optimal tomato fruit production was based on estimations from a combination of assumptions and equations based on previous research. Calculated ET was the water amount expected to be removed via evaporation and transpiration and is the calculated “optimal” irrigation value used for water replacement. The optimal calculated ET value was considered 1.0. Irrigation treatments are comprised of “optimal” ET at 1.0 and multiplied by 0.5, 1.0, 1.5, and 2.0 coefficients to develop a crop irrigation response curve.

Calculating ET

Tomato’s evapotranspiration coefficient (ET_c) was calculated by multiplying crop coefficient (K_c) by a reference ET (ET_o) using $ET_c = K_c * ET_o$. The ET_o was determined using the Hargreaves equation = $ET_o = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a$; where T is temperature (ºC) and R_a is extraterrestrial solar radiation (mm/day) found in Table 2.6 in Allen and coworkers (1998). Temperature values were taken from the 1971-2000 monthly climate summaries for Painter, Virginia from the Southeast Regional Climate Center (2007). Extraterrestrial solar radiation can be found in Table 2.6 of Allen and coworkers (1998) and is based on the site’s latitude. Table 1 shows monthly calculations for ET_o.

To calculate ET_c for different stages over the growing season, K_c was interpolated from Figure 7 in Doorenbos and Pruitt (1977). Figure 1 shows the crop coefficient curve of tomatoes with an estimated value of 0.6 for K_c in the initial crop growth stage ($K_{c\ ini}$). From Figure 1, the K_c value during the crop development stage was estimated to be 0.8. Allen and coworkers (1998) report K_c for the mid-season stage ($K_{c\ mid}$) and K_c for the late-season stage ($K_{c\ end}$) are 1.15 and 0.70-0.90, respectively. Any K_c reductions due to the use of plastic mulch were taken into consideration when calculating ET_c. Tables 2, 3, and 4 show calculated (ET_c) values during initial, crop development, and mid-season stages using the reduced K_c values for plastic mulch systems. Evapotranspiration is reported in millimeters per day.

Calculating Irrigation

The proper amount of daily irrigation for a crop is the amount of daily ET taking place minus any daily precipitation. To simplify the irrigation regime, long-term average precipitation data was used from the Southeast Regional Climate Center (2009) instead of monitoring daily precipitation and changing irrigation amounts daily. A 1971-2000 Monthly Climate Summary for Painter, VA provided average monthly total precipitation and was thusly subtracted from ET_c to determine irrigation for different tomato growth stages. The resulting value was our 1.0 ET treatment in the study.

Irrigation Treatments

Four irrigation treatments were initiated based on ET calculations. Irrigation treatments were set using automatic timers (Hunter Smart Valve Controller, San Marcos, CA, 92069) to irrigate twice a day, 7 days a week, to deliver 0.5, 1.0, 1.5 and 2.0 calculated ET values. A fifth treatment was triggered automatically with a wired tensiometer (Model RA, Irrometer, Riverside, CA). Irrigation for the tensiometer treatment will initiate after the 12 inch depth tensiometer reading raises above 40 kilopascal (kPa) and will run until the 12 inch depth reading falls below the 40 kPa value (Kuhar et. al., 2009). Irrigation was provided through trickle irrigation tubing with a flow rate of 0.45 gallons per 100 feet per minute at 10 psi. All other production practices, with the exception of N management, will be conducted according to Kuhar and coworkers (2009).

Fertilizer Treatments

A total of 172 lb nitrogen/ac was applied using a 50-50% split between at-planting and fertigation (Kuhar et al., 2009). At-planting treatments were applied using ammonium nitrate (34%N, 34-0-0) and incorporated using a rotary tiller prior to laying plastic mulch. Liquid urea-ammonium nitrate (32%N; 32-0-0) was used to apply fertigation treatments. Nitrogen rates increased as the growing season progressed to match plant N uptake. Fertigation took place on Monday and Thursday during the afternoon irrigation cycle. Fertigation N was applied at 0.5, 0.7, 1.0, 1.5, 2.2, and 2.5 lb N/day for time periods 0-14, 15-28, 29-42, 43-56, 57-77, and 78-98 days after planting, respectively. All treatments will receive the same amount of N during planting and bi-weekly fertigation.

Fruit Set Nitrate Status Tests

Petiole sap nitrate tests and infrared camera tests were performed when fruit was two inches in diameter (July 13-14, 2009). Petioles were collected from 6 plants per plot from the upper most fully expanded leaf. The sap of all six petioles was combined and nitrate concentrations were found using a Cardy meter (Spectrum Technologies, Plainfield, Illinois 60585). An infrared camera (Greenseeker, NTech Industries, Ukiah, CA 95482) was used to determine NDVI readings.

Statistics

The overall experimental design was a randomized complete block design that has treatments replicated four times, giving a total plot combination of 20 plots. Statistical analysis was conducted in SAS using PROC GLM and PROC REG. Fisher's Least Significant Difference values were established at alpha = 0.10. A Regression correlation was used to relate petiole nitrate concentrations to NDVI readings.

RESULTS AND DISCUSSION

Petiole nitrate-N concentrations at fruit set were significant when comparing different irrigation treatments (Table 5). For petiole nitrate concentrations, 1.0 ET, 1.5 ET, and tensiometer treatments had statistically similar petiole nitrate-N concentrations (792, 648, and 696 ppm nitrate-N, respectively; Table 5). Of these treatments, 1.0 ET treatments had higher petiole nitrate concentrations than 0.5 ET treatments (792 vs. 501 ppm, respectively; Table 5). Although all petiole readings were above the lower threshold suggested by Hochmuth (1994a, 1994b) of 400 ppm nitrate-N, higher concentrations indicate more plentiful supply of nitrogen to tomatoes at fruit set. We speculate that the 0.5 ET treatment did not solubilize nitrogen fertilizer in the soil or did not have adequate water assimilation for nutrient uptake. Inversely, the 2.0 ET treatment had lower concentrations than the 1.0 ET treatment since excessive irrigation likely leached nitrogen below the effective tomato root zone (521 vs. 792 ppm, respectively). Increased water use efficiency should minimize nitrate-N leaching; therefore, nutrients should be more plant available (Zotarelli et. al, 2009). Zotarelli and coworkers (2009) found that excessive leaching in sandy soils reduced crop N uptake as demonstrated by petiole nitrate concentrations in this tomato study.

The NDVI readings at fruit set were not significantly different and averaged 0.899. More research needs to be conducted to established NDVI readings for tomatoes during the growing season.

When plotting petiole nitrate-N concentrations versus NDVI values, a significant inverted quadratic correlation was established ($NDVI = 1.04 – 0.0005N + 4\times10^{-7}N^2$; $R^2 = 0.247$; Fig. 2). We do not fully understand the reasoning behind the aforementioned correlation; however, we suspect that plants with higher fruit loads had lighter NDVI readings. The lowest NDVI readings were between 400 and 800 ppm nitrate-N; which is similar to the optimal range at fruit set established by Hochmuth (1994a, 1994b). Therefore, we speculate that lower petiole nitrate concentrations had lower fruit loads and higher petiole nitrate concentrations experiences excessive vegetative growth.

CONCLUSION

Irrigation amounts impact petiole nitrate-N concentrations. Excessive irrigation leaches nutrients and causes lower petiole nitrate-N concentrations while too little irrigation also reduces nitrogen uptake. By calculating and irrigating at1.0 ET or using a tensiometer, optimal amounts of irrigation and nutrients are provided to the plant. More work with NDVI measurements and resulting correlations needs to be conducted in the Mid-Atlantic with vegetable crops.

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TABLES AND FIGURES

Table 1. Calculated reference evapotranspiration (ETo) values used in the Hargreaves equation for the fresh market plastic mulch tomato irrigation efficiency study for Painter, Virginia

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Average Max (°C)	8.3	9.9	14.1	19.0	23.8	27.9	30.4	29.4	26.5	21.1	14.6	10.9
Average Min (°C)	-1.1	-0.2	3.3	7.7	12.8	17.6	20.4	19.5	16.1	10.2	4.6	1.4
Avg (°C)	3.6	4.9	8.7	13.3	18.3	22.8	25.4	24.5	21.3	15.6	9.6	6.1
R_a†	16.2	21.5	28.1	35.2	39.9	41.8	40.8	37.0	30.7	23.6	17.5	14.8
ET_o (mm/day)	2.45	3.57	5.63	8.49	11.00	12.54	12.82	11.34	8.90	5.97	3.49	2.51

†Extraterrestrial solar radiation (Ra) based on 38°N latitude, Painter, VA = 37.5°.

Table 2. Calculated specific crop evapotranspiration (Et_c) for initial growth stage using a reduced K_c value for plastic mulch tomato production systems on sandy loam soils.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
ET_o (mm/day)	2.45	3.57	5.63	8.49	11.00	12.54	12.82	11.34	8.90	5.97	3.49	2.51
$K_{c\ ini}$	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
0.65 $K_{c\ ini}$	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
$ET_{c\ ini}$ (mm/day) using 0.65 K_c	0.95	1.39	2.19	3.31	4.29	4.89	5.00	4.42	3.47	2.33	1.36	0.98

Table 3. Calculated specific crop evapotranspiration (Et_c) for crop development (CD) growth stage using reduced K_c value for plastic mulch tomato production systems on sandy loam soils.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
ET_o (mm/day)	2.45	3.57	5.63	8.49	11.00	12.54	12.82	11.34	8.90	5.97	3.49	2.51
$K_{c\ CD}$	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
0.65 $K_{c\ CD}$	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
$Et_{c\ CD}$ (mm/day) using 0.65 K_c	1.27	1.86	2.93	4.41	5.72	6.52	6.66	5.90	4.63	3.11	1.81	1.31

Table 4. Calculated specific crop evapotranspiration (Et_c) for mid-season (mid) growth stage using reduced K_c values for plastic mulch tomato production systems on sandy loam soils.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
ET_o (mm/day)	2.45	3.57	5.63	8.49	11.00	12.54	12.82	11.34	8.90	5.97	3.49	2.51
$K_{c\ CD}$	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
0.69 $K_{c\ CD}$	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
$Et_{c\ CD}$ (mm/day) using 0.69 K_c	1.77	2.59	4.08	6.15	7.97	9.09	9.29	8.22	6.45	4.33	2.53	1.82

Table 5. Mean petiole sap nitrate-N concentrations and normalized difference vegetative index (NDVI) measurements for irrigation treatments based on evapotranspiration (ET) on a sandy loam soil.

Treatment	Nitrate-N	NDVI
	----------ppm----------	
0.5 ET	501 c†	0.926 a
1.0 ET	792 a	0.911 a
1.5 ET	648 abc	0.859 a
2.0 ET	521 bc	0.893 a
Tensiometer	696 ab	0.908 a
$LSD_{0.10}$	191	NS‡

†Means followed by the same letter are not statistically different at $p = 0.10$.
‡Not significantly different ($p = 0.221$).

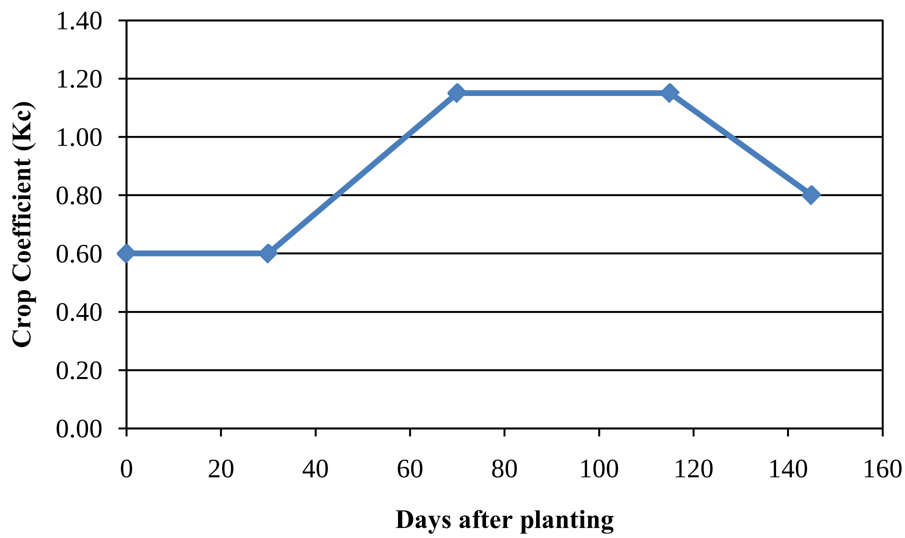

Figure 1. Crop coefficient (K_c) curve for tomatoes over the growing season.

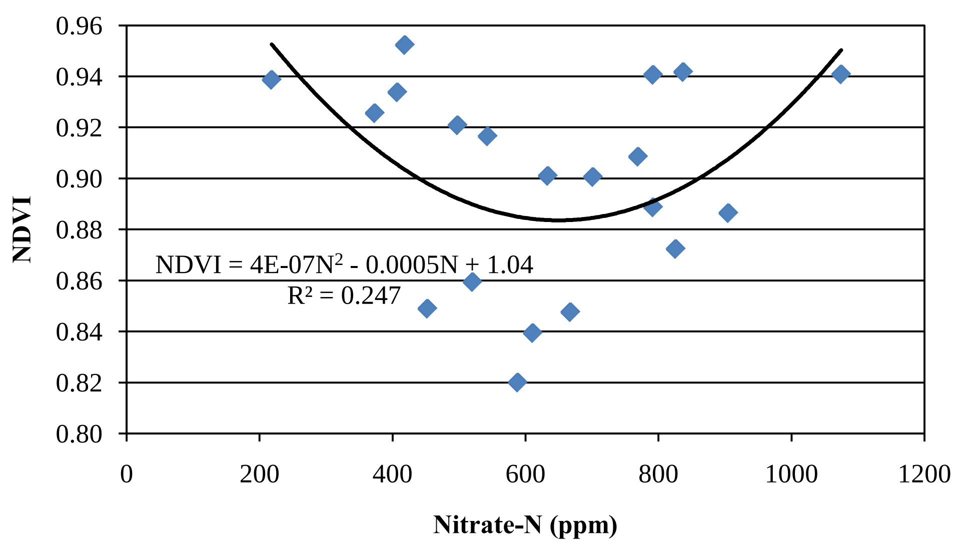

Figure 2. Petiole nitrate-N concentrations versus normalized difference vegetative index (NDVI) readings in response to irrigation regimes.