Irrigation and Nitrogen Best Management Practices Under Drip Irrigated Vegetable Production

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Abstract. *Plastic mulch and drip irrigation are commonly used in high intensity vegetable production regions such as Florida. Drip irrigation can be much more efficient than sprinkler irrigation since only the root zone of the cropped area is irrigated. However, improper irrigation management can lead to wasted water and leaching of soluble chemicals such as nitrate. In this project, several irrigation treatments were established that allowed up to five watering events per day depending on a soil water threshold controller (SMS) for tomato and green bell pepper. As a comparison time based treatments (TIME) of once daily irrigation were established to mimic typical producer practices. In addition, zero tension drainage lysimeters were buried 0.6 m below the beds in several treatments to monitor leaching of water and nitrate nitrogen. SMS control of irrigation resulted in 29%-44% less irrigation water used on tomato and 37%-66% less water used on pepper when compared to TIME treatments. Tomato yield was significantly higher on SMS treatments compared to TIME treatments, but yield was similar across all pepper treatments. SMS treatments increased irrigation water use efficiency 2-3 times compared to TIME treatments on both tomato and pepper. Both the amount of water captured in drainage lysimeters and the mass on NO_3-N were significantly lower on soil water based irrigation control compared to once daily time based irrigation commonly used by producers.*

Keywords. *Nitrogen, leaching, vadose zone, fertigation, nitrate, drainage lysimeter, tomato, pepper, BMP, TMDL.*

Introduction

Vegetable crops are important in Florida where more fresh market tomatoes are sold than any other state and which ranks second in the sale of peppers. In 2003, there were 17,000 ha and 7,400 ha of tomato and pepper grown in Florida, respectively. These two crops have respective values of $500 million and $218 million (FLASS, 2005). Both of these crops are intensely managed due to their high value. Typically, they are transplanted onto raised beds that are covered with polyethylene plastic mulch and are drip irrigated. On well-drained soils, drip tape is used to supply both irrigation and fertigation to the crop. Many of the soils where these vegetables are grown are very sandy with water holding capacity of 6-8% by volume or less. Thus, these soils require frequent irrigation and fertigation to minimize crop stress and to attain maximum production. Irrigation and fertigation practices vary widely among growers but irrigation typically occurs 1-2 times each day in fixed timed events normally with longer events during peak growth stages. Fertigation on the other hand occurs 1-2 times each week. Although drip irrigation can be very efficient since water and nutrients are delivered to the crop root zone, mismanagement can lead to over-irrigation and excessive nutrient losses due to leaching. One example of water quality degradation due to nutrient enrichment is the Suwannee River basin where nitrate levels have been increased in recent years. The primary entry path has been shown to be springs which result in mixing of ground and surface water (Ham and Hatzell, 1996; Hornsby and Mattson, 1998). Studies conducted by the Suwannee River Water Management District have reported that groundwater nitrate nitrogen concentrations are elevated along the Suwannee River (Ceryak and Hornsby, 1998).

The objectives of this experiment were to evaluate irrigation water use between soil water controlled and traditional time based drip irrigation on tomato and green bell pepper production on sandy soils and to quantify the amount of nitrogen leached from the root zone of these production systems.

Materials and Methods

This experiment was conducted at the University of Florida Plant Science Research and Education Center (PSREU) near Citra, FL between March 8 and July 7, 2005. The soil at the research site has been classified as a Candler sand and Tavares sand (Buster, 1979). These soils contain 97% sand-sized particles and have a field capacity of 5.0% to 7.5% by volume in the upper 100 cm of the profile (Carlisle et al., 1978). After the raised beds (1.1 m top width and a bed spacing of 1.8 m) were formed, fumigant (80% methyl bromide, 20% chloropicrin by weight) was applied at a rate of 604 kg ha^{-1}, plastic mulch, and drip irrigation was installed in one pass across the field on March 23. Two lines of drip irrigation were installed on each bed stacked together, one for irrigation and one for fertigation.

Both tomato (*Lycopersicon esculentum*, 'FL47') and green bell pepper (*Capsicum annuum*, 'Brigadier') transplants were approximately 45 days old at transplanting on April 7. Tomato was transplanted in a single row approximately 0.1 m from the drip lines at 0.45 m spacing for a plant population of 11,960 plants ha^{-1}. Green bell pepper was transplanted in twin staggered rows approximately 0.1 m to either side of the drip lines at 0.3 m within row spacing for a plant population of 35,879 plants ha^{-1}. Individual plots were 15.2 m long with a 6.1 m harvest length and the remainder of the plot was used for both soil and destructive plant sampling. Four replicates were established in a randomized complete block design.

Water applied by irrigation or by fertigation was recorded by positive displacement flowmeters (V100 1.6 cm diameter bore with pulse output, AMCO Water Metering Systems, Inc., Ocala, FL) at least weekly. Pressure was regulated by inline pressure regulators to 83 kPa at the irrigation supply. Irrigation was applied via drip tape (Turbulent Twin Wall, 0.2m emitter spacing, 0.25 mm thickness, 3.72 L min^{-1} at 69 kPa, Chapin Watermatics, Inc., Watertown, NY).

A weather station was within 500 m of the experimental site and provided temperature, relative humidity, solar radiation, and wind speed data which were used to calculate reference evapotranspiration (ET_o) according to FAO-56 (Allen et al., 1998). Crop evapotranspiration (ET_c) was calculated based on the product of ET_o and crop coefficient (K_c) for a given growth stage (Simonne et al., 2004) reduced 30% for plastic mulched vegetable production (Amayreh and Al-Abed, 2005).

Irrigation

Irrigation treatments consisted of four types of soil water sensor control devices as outlined in Table 1. The Quantified Irrigation Controller (QIC), developed by the Agricultural and

Biological Engineering Department at the University of Florida (Muñoz-Carpena et al., 2006) was used on one tomato treatment while Acclima RS500 was used on both tomato and pepper (Acclima, Inc., Meridian, ID) and the Acclima CS3500 was used on pepper. The QIC device uses a 0.2 m long ECH_20 probe (Decagon Devices, Inc., Pullman, WA) inserted vertically to measure water content in the plant beds. Similar to the QIC probe installation, the probes of the Acclima devices were installed at an angle between two plants to measure soil water in the top 0.2 m of the vegetable beds. The RS500 and the QIC devices both function as bypass controllers to scheduled timed events using an electronic time clock as the primary scheduling device. This type of control system bypasses a scheduled timed event if the soil water level is above a preset threshold (Dukes and Muñoz-Carpena, 2006). Treatments using these devices were scheduled to apply irrigation in five daily events beginning at 0600, 0900, 1200, 1500, and 1800 hours in a total daily amount equaling the time based treatment of once daily irrigation. Time based irrigation was set at one hour each day (2.2 mm day^{-1}) initially and two hours each day from the peak to the end of the growth season for tomato (4.4 mm day^{-1}) and two hours each day for pepper. Alternatively, the CS3500 unit is an on-demand type of controller keeping soil moisture between 12% and 14%. Probes for all of the controllers were installed in one representative replication to control all plots of a given irrigation treatment.

Immediately after transplanting, soil water content was kept at field capacity with daily time based irrigation events to ensure even establishment of all plots. Irrigation treatments were imposed (i.e. soil water sensor control was activated) at 18 days after transplanting (DAT).

Fertilization

The nitrogen rate was set according to recommendations by the University of Florida Institute of Food and Agricultural Sciences (IFAS) for tomato and pepper with 192 kg N ha^{-1} and 208 kg N ha^{-1} applied to bell pepper and tomato, respectively (Olson et al., 2004a; 2004b). All nitrogen fertilizer was applied as weekly injections (Thursday) of a calcium nitrate source in the irrigation system beginning April 8 (1 DAT). ther fertilizer applied included potassiumsulfate and magnesiumsulfate are outlined in based on IFAS recommendations (Olson et al., 2004a; 2004b). Pesticides were applied to the field as needed to provide adequate control of weeds, diseases and insects following recommended pesticide application practices.

Drainage Lysimeters

Drainage lysimeters were constructed out of large drums that were cut in half lengthwise resulting in a drainage reservoir 0.85 m long and 0.27 m high with a volume of 104 L. The length of the lysimeter corresponded with 4-5 drip emitters (0.2 m spacing). A 0.8 m length of well screen (slot size = 0.3 mm) and a diameter of 32 mm was capped at both ends and placed in the bottom of each lysimeter. The end of the fitting outside of the well screen tube was fitted with a 6.4 mm inside diameter butyl rubber suction tube (FisherBrand, Fisher Scientific International, Inc., Pittsburgh, PA) that was routed to a location at the bottom of the raised bed to allow the extraction of the leachate collected at the bottom of the barrel using a partial vacuum (35 kPa). The lysimeters were buried to a bottom depth approximately 0.6 m below the surface of the bed to minimize root intrusion into the lysimeters and to ensure complete capture of vertical seepage within a short time after the leachate drained below the active root zone. A drainage lysimeter was installed in selected tomato and pepper plots as indicated in Table 1 (20 drainage lysimeters total) on March 8-10, 2005 before the raised beds were formed. Leachate extraction from lysimeters occurred weekly with individual vacuum bottles one day prior to the next fertigation application event. Total water in the bottles was determined by weight. Subsamples were analyzed for nitrate plus nitrite and are reported as NO_3-N in this paper (OI Analytical, 2001). The use of calcium nitrate as the sole N-fertilizer made analysis for NH_4-N redundant since sandy soils have inherent low residual NH_4-N levels.

Yield Determination

Harvest occurred on June 23 and June 30 (77 and 84 DAT), respectively for pepper; harvest occurred on June 30 and July 7 (84 and 93 DAT), respectively for tomato. Pepper fruits were graded according to USDA standards (USDA, 2005); tomato fruits were graded according to Florida Tomato Committee standards (Brown, 2000). Number of fruits from each plot and total weight were recorded. Irrigation water used efficiency was calculated as follows:

$$IWUE = \frac{MY}{I} \qquad [1]$$

where IWUE is irrigation water use efficiency (kg m^{-3}), MY is marketable yield (kg ha^{-1}), and I is total seasonal irrigation applied (m^3 ha^{-1}). Non-irrigated yield was assumed to be zero. The statistical analysis was conducted with the General Linear Models (GLM) procedure in SAS (SAS Institute, Inc., Cary, NC) and Duncan's Multiple Range Test was used for means separation.

Results and Discussion

Generally, the spring vegetable season in 2005 was cooler and wetter than normal. Total rainfall for the season was 449 mm (Fig. 1) while the historical average precipitation for April-June is 327 mm with 53% that amount in June (NOAA, 2005). Plastic mulched vegetable crops on a well-drained site such as this experiment receive negligible benefit from rainfall due to runoff induced by the plastic mulch and the lack of a shallow water table.

Irrigation trends across treatments for a specific crop were identical prior to 18 DAT (crop establishment) when the irrigation treatments were initiated on each crop. Cumulative irrigation slope of these treatments flattening out with respect to the time based treatment which remained constant throughout the pepper season but was increased in the tomato season on 49 DAT due to increased crop demands (Fig. 1). Time based application on tomato was 4.4 mm d^{-1} after 49 DAT and remained at that level throughout the pepper season. However, average daily irrigation application rate for the SMS treatments were 1.4±1.2 (± one standard deviation), 2.2±1.9, 1.1±1.1, 2.4±1.8, and 2.2±1.6 mm d^{-1} for tomato SMS 1-2 and pepper SMS 2-4 treatments, respectively. These results are consistent with reduced daily application rates from small frequent watering events reported by Muñoz-Carpena et al. (2005; 2006) on tomato and Dukes and Scholberg (2005) on sweet corn.

Total irrigation applied to SMS 1, SMS 2, and TIME on tomato was 154, 213, and 301 mm, respectively. Similarly on pepper total irrigation across SMS 2, SMS 3, SMS 4, and TIME was 111 mm, 202 mm, 187 mm, and 323 mm. The soil moisture based treatments thus resulted in lower water use compared to the time based treatment in all cases. Total seasonal irrigation applied to tomato was reduced 49% and 29% for SMS 1 and SMS 2 relative to the time based treatment (Table 2). Similarly, treatments SMS 2-4 received 66%, 37%, and 42% less irrigation water. These results are similar to Muñoz-Carpena et al. (2005) that reported 39-51% irrigation water savings on tomato using switching tensiometers and compared to irrigation scheduled according to historical ET. In a separate study, Muñoz-Carpena et al. (2006) reported 64% to 79% irrigation savings using switching tensiometers and QIC devices compared to traditional fixed time irrigation similar to local grower practices. Dukes et al. (2003) that reported 36% to 62% savings between soil water based controllers on green bell pepper relative to a fixed time schedule typically used by producers.

Total seasonal ET_c was calculated as 189 mm for tomato and 173 mm for pepper; with similar ET_c curves over the season. Time based treatments applied irrigation well in excess of crop needs while SMS treatments applied less irrigation than ET_c. The tomato SMS 1; SMS 2 and pepper SMS 3; SMS 4 treatments applied irrigation consistent ET_c over the season. Yield was reduced (see below) on pepper SMS 2 likely due to the low amount of irrigation applied to this treatment (111 mm) that was lower than ET_c of the pepper.

Leaching of water and NO_3-N followed the same trends as the irrigation treatments with higher irrigation rates resulting in more water movement to the lysimeters at the 0.6 m depth and more mass of NO_3-N lost from the root zone. On tomato, SMS 1 resulted in 6.8 mm of excess irrigation water leached out of the root zone which was 84% less than the 42.8 mm leached from the TIME treatment (Fig. 2). Even in treatment SMS 1 where a very low volume of water was leached, there was no reduction in crop yield. This observation suggests that the irrigation supplied to tomato SMS 1 was just enough to maintain crop needs throughout the season. On pepper, SMS 2 and 3 reduced leaching by 81% (12.2 mm vs. 62.8 mm) and 51% (30.6 mm vs. 62.8 mm) when compared to the TIME treatment, however on the pepper trial, a significant reduction in crop yield for SMS 2 compared to SMS 3 was observed.

The reduction in water moving through the root zone corresponded to a reduction in the amount of NO_3-N lost below the root zone. The SMS 1 tomato treatment had 7 kg NO_3-N ha^{-1} leached compared to 37 kg NO_3-N ha^{-1} for the TIME treatment (a 82% reduction; Fig. 3); whereas, on pepper SMS 2 and SMS 3 reduced leaching 84% (6 kg NO_3-N ha^{-1} vs. 36 kg NO_3-N ha^{-1}) and 20% (29 kg NO_3-N ha^{-1} vs. 36 kg NO_3-N ha^{-1}). One reason that water and NO_3-N leaching were reduced by using SMS control of irrigation is that the soil water content on the SMS treatments did not increase 5% or more due to irrigation; whereas, the TIME treatments had numerous occasions where this increase in soil water content occurred. Thus, the TIME treatments frequently increased the soil water content well-above field capacity and rapid drainage ensued.

For tomato, yield was significantly higher on the SMS treatments compared to the TIME treatment. In addition, quality was better on SMS 1 compared to the TIME treatment with more large and extra large fruits harvested. For pepper, yield differences were not as apparent as with tomato with the TIME treatment resulting in statistically similar yield as the SMS treatments; however, SMS 2 resulted in lower yield than SMS 3 and SMS 4. This lower yield was likely due to water stress since SMS 2 received 40% to 45% less water than SMS 3 and SMS 4 resulting in potential water stress as discussed previously.

Irrigation water use efficiency was significantly higher on all SMS treatments compared to TIME treatments (Table 2). IWUE ranged from 6.5 to 7.6 kg m^{-3} on tomato and pepper TIME treatments, respectively, while IWUE on SMS treatments ranged from a low of 12.9 kg m^{-3} on tomato and 14.4-14.7 kg m^{-3} on pepper to a high of 20.1 kg m^{-3} on tomato and 21.7 kg m^{-3} on pepper. The highest IWUE on tomato treatment SMS 1 resulted in statistically similar yield compared to SMS 2 and higher yield than TIME; whereas, the highest IWUE on pepper SMS 2 resulted in reduced yield relative to SMS 3 but similar to SMS 4 and TIME (Table 5). Although IWUE was 2-3 times higher on the SMS compared to TIME treatments, Muñoz-Carpena (2006) reported IWUE increases on tomato of 4-10 times with switching tensiometers and QIC soil water control compared to time based once daily irrigation.

Conclusions

For the first year of this experiment, soil water controlled irrigation on tomato and pepper resulted in 29% to 66% less irrigation water applied compared to a time based treatment similar to typical grower scheduled irrigation. In addition, yields on tomato were significantly higher on the two SMS treatments compared to the TIME treatment. Pepper yields on SMS treatments were similar to the TIME treatment. Accordingly, when the amount of irrigation water applied was reduced both leaching of water and NO_3-N decreased significantly. These initial results show that soil water based irrigation can be used as a water conservation tool and as a means to reduce NO_3-N leaching below the rootzone of commercial vegetable cropping systems.

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Table 1. Codes, description, and soil water thresholds of irrigation treatments along with an outline of treatments containing drainage lysimeters.

Treatment Code	Description	Threshold[α]	Irrigation Treatment[β]	Drainage Lysimeter
SMS-1	Quantified Irrigation Controller (QIC)	500 mV	T	T
SMS-2	Acclima RS500	10% VWC	T&P	P
SMS-3	Acclima RS500	13% VWC	P	P
SMS-4	Acclima CS3500	12-14% VWC	P	None
TIME	Fixed time based irrigation	Not Applicable	T&P	T&P

[α]500 mV threshold for the QIC is approximately 13% volumetric water content (VWC).

[βb]T denotes tomato and P denotes pepper.

Table 2. Seasonal irrigation, ET_c, number of irrigation events, irrigation water use efficiency, and percentage irrigation reduction compared to time based irrigation for bell pepper and tomato.

	Tomato					Pepper				
Treatment	Seasonal Irrigation Depth (mm)	ET_c (mm)	Total Seasonal Irrigation Events (#)	Irrigation Water Use Efficiency (kg m^{-3})	Irrigation Reduction[δ] (%)	Seasonal Irrigation Depth (mm)	ET_c (mm)	Total Seasonal Irrigation Events (#)	Irrigation Water Use Efficiency (kg m^{-3})	Irrigation Reduction (%)
SMS-1	154	189	134	20.1 a	49	--	173	--	--	--
SMS-2	213	189	144	12.9 b	29	111	173	223	21.7 a	66
SMS-3	--[ε]	189	--	--	--	202	173	140	14.4 b	37
SMS-4	--	189	--	--	--	187	173	65	14.7 b	42
TIME	301	189	70	6.5 c	0	323	173	65	7.6 c	0

[δ]Irrigation reduction compared to TIME treatment for a particular crop.

[ε]Treatment not established for a particular crop.

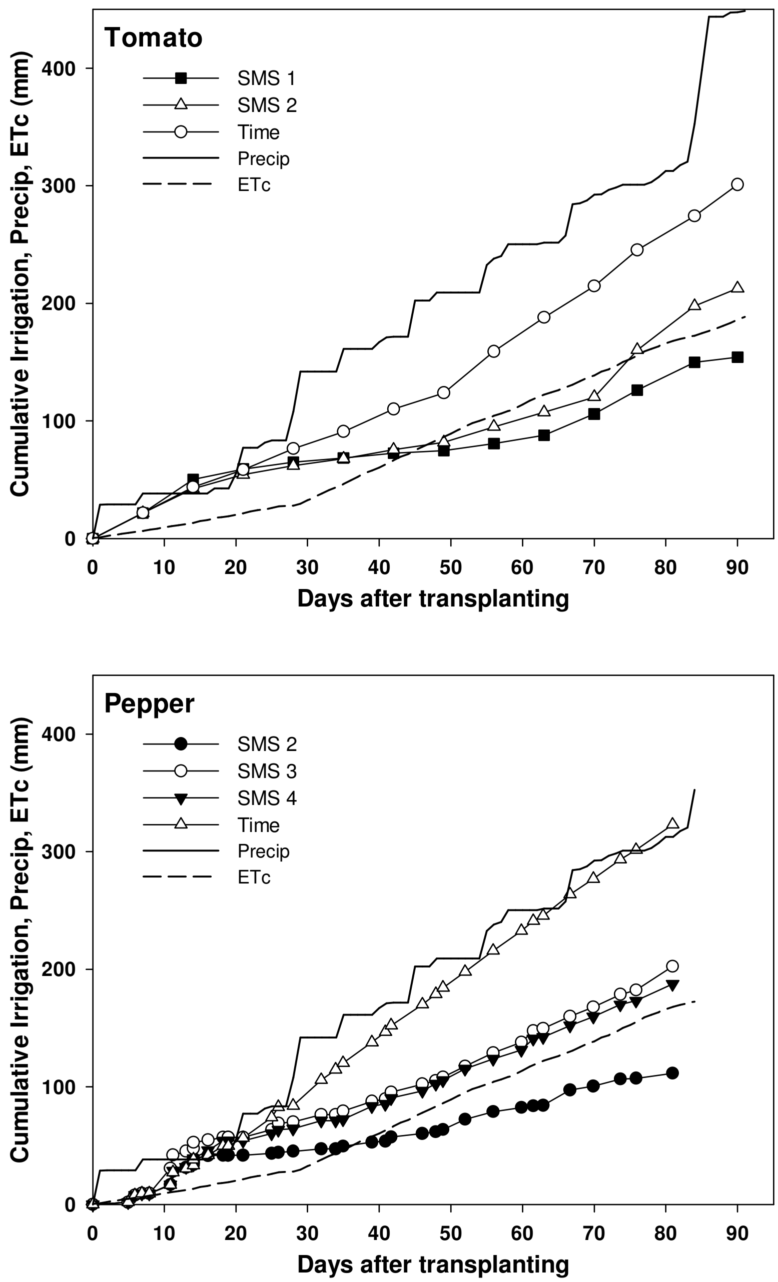


Figure 1. Cumulative irrigation, precipitation, and ET_c on tomato and pepper across each treatment where 0 DAT is April 7, 2005.

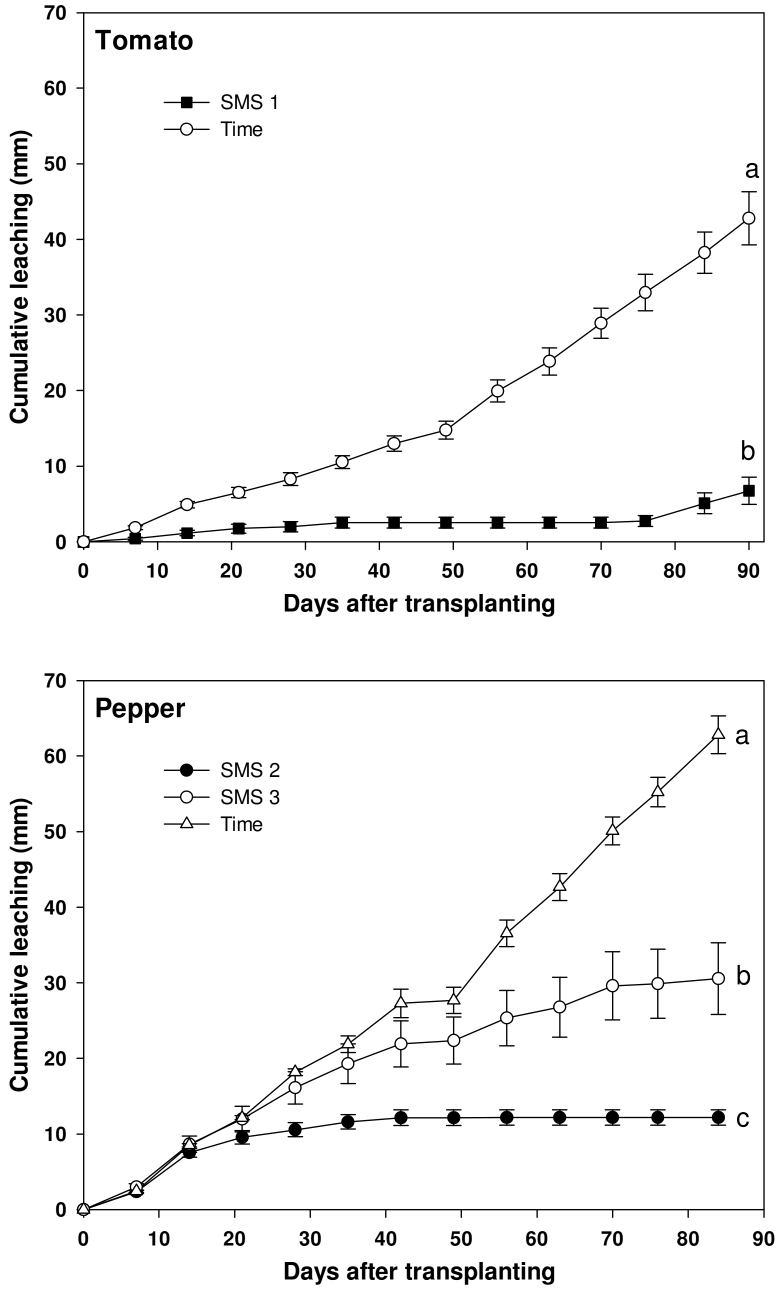
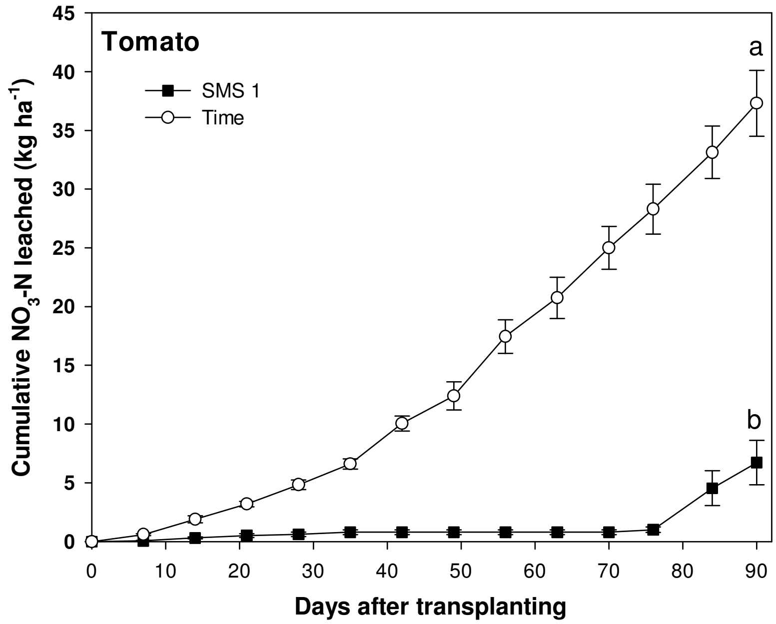


Fig. 2. Cumulative leaching into drainage lysimeters placed 0.6 m below the bed surface for tomato and pepper treatments with transplanting (DAT=0) occurring on April 7, 2005. Different letters indicate statistical differences ($p < 0.05$) and (error bars represent $\pm$ one standard error from the mean, n=4).



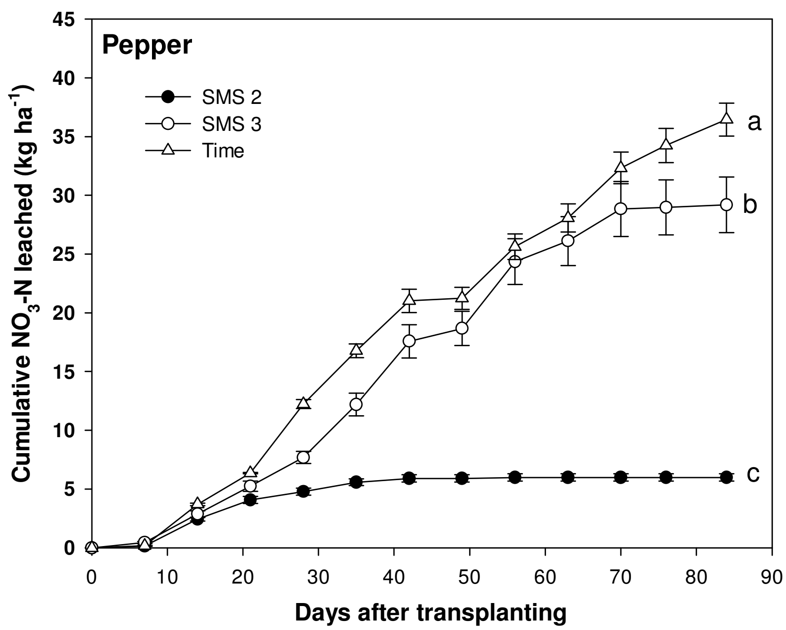


Fig. 3. Cumulative mass of NO_3-N leached into drainage lysimeters placed 0.6 m below bed surface for tomato and pepper treatments with transplanting (DAT=0) occurring on April 7, 2005. Different letters indicate statistical differences ($p < 0.05$) and (error bars represent $\pm$ one standard error from the mean, n=4).