

***Developing Production Practices for Efficient Fertilizer & Irrigation Use in Vegetable Crops
(fourth quarterly and final project progress report 2-27-2007 through 14-6-2007)***

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Summary:

This report provides an update on research activities from a comprehensive research program that aims to evaluate the interactive effects of irrigation and N-fertilizer management practices on yield, fertilizer/water use efficiency, and potential N leaching. During the spring of 2007 we completed the labeled isotopes (^{15}N) fertilizer uptake trial for sweet corn which was conducted during the spring and summer of 2006. Results showed that initial fertilizer uptake efficiency is low and that use of either ammonium-based and/or slow release fertilizers may be preferable during initial growth. We also implemented two additional field trials for sweet pepper and tomato during the spring of 2007 to confirm previous research findings. Results from these studies confirm our previous findings that use of sensor based systems results in substantial (40-100%) reduction in irrigation requirements, while potential nitrate leaching underneath production beds during the production season is reduced by 75-80% as well. Based on these results we conclude that use of these production techniques will result in much more efficient water and fertilizer use. We would therefore like to propose to test these technologies on a larger field scale in collaboration with commercial growers during a next project phase.

Introduction

Urban and agricultural water use restriction has recently been approved for South Florida region due to the lack of rainfall during the last few months. As a result, South Florida residents must cut water use by up to 30%, while farmers in that area must cut water use by 45%. Agricultural water use is still the largest single category of water use in Florida, and farmers are being forced to become more efficient with their use of irrigation water.

Improved irrigation scheduling is one potential method to increase irrigation water use efficiency. It has been shown that irrigation water use efficiency for vegetable crop production can be improved through better irrigation management. The use of frequent but low water application volumes has proven superior to the more traditional scheduling of few applications of a large irrigation volumes (Locascio, 2005). However, such approach is labor intensive and/or technically difficult to employ. The use of automated irrigation systems, which make use of soil moisture sensing devices may greatly facilitate the successful employment of low volume-high frequency irrigation systems for commercial vegetable crops (Muñoz-Carpena et al., 2005).

Soil moisture sensors configured to provide feedback within an irrigation control system have been shown to reduce water use for tomato production in South Florida by as much as 70% (Muñoz-Carpena et al., 2005) and on green bell pepper as much as 50% (Dukes et al., 2003) with minimal or no impact on vegetable yields.

The technology being tested in this project includes commercially available controllers that have been marketed for irrigation control but have not been tested under Florida conditions for vegetable crops. However, these controllers have been shown to save significant amounts of irrigation water on turfgrass with respect to time irrigation schedules (Cardenas-Lailhacar et al., 2005). This program thus aims to develop more efficient irrigation practices and to evaluate the interactive effects of irrigation management on crop nitrogen requirements of pepper and tomato. The program also evaluated and improved methods for monitoring crop N status and N leaching for commercial Florida vegetable production systems.

Two field experiments were implemented during the spring of 2007 to confirm previous research findings and to determine the effects of water and nitrogen application rates on nitrogen leaching, crop nitrogen uptake, tomato growth and yield. This project has allowed for critical technological innovations and generated a comprehensive knowledge base that could be used for development of improved production guidelines, Best Management Practices (BMPs), calibration and verification of computer models, and innovative in-season irrigation and nutrient management tools for Florida vegetable crops.

Project Objectives:

The overall objectives of this program are to: 1) Develop irrigation systems/practices that will reduce nitrogen leaching; 2) Determine the interactive effects of irrigation practices and fertilizer rates on yield, fertilizer use efficiency, and N-leaching; 3) Quantify when and how much water and nutrients are taken up vegetable crops; 4) Determine rooting and irrigation patterns and combine this information to develop improved irrigation guidelines; 5) Provide information on improved integration of cover crops in vegetable cropping systems to improve soil nutrient retention; 6) Develop a scientific basis for developing management tools for improved irrigation and in-season crop nutrient status assessment and outline their appropriate use; 7) Integrate research results into BMPs and future computer-based in-season management tools for vegetable crops.

Research findings and project deliverables

I) Bell Pepper irrigation management x N rate study

Experimental conditions and treatments

The planning phase of this project started in January 2007 with the design of the field trial. The experiment was conducted at the University of Florida Plant Science Research and Education Center (PSREU) near Citra, Florida in Marion County and the experimental irrigation treatments were established according to Table 1. The experimental design consisted of a complete factorial including five irrigation treatments ranging from sensor based control systems to time-based and three N-rates. Treatments were replicated four times in a complete randomized block design.

Table 1. Experimental treatment codes and description for pepper.

Treatment	Threshold (VWC ^[z])	Description
I1	8%	Acclima RS500, 5 daily watering windows
I2	10%	Acclima RS500, 5 daily watering windows
I3	13%	Acclima RS500, 5 daily watering windows
I4	10%	Acclima RS500, 5 daily watering windows “Twin drip lines”
I5	N/A	Fixed time irrigation, one event each day (2 hours)

^[z]Volumetric water content

Irrigation treatments

The experimental design consisted of a complete factorial including five irrigation treatments ranging from sensor based control systems to time-based and three N-rates. Treatments were replicated four times in a complete randomized block design.

Irrigation was applied via drip tape (Turbulent Twin Wall, 0.20 m (8 inch) emitter spacing, 0.25 mm (1 inch) thickness, 3.8 L hr⁻¹ (1gph) at 69 kPa (10 psi), Chapin Watermatics, NY). Water applied by irrigation and/or fertigation was recorded by positive displacement flowmeters (V100 16 mm (5/8 inch) diameter bore with pulse output, AMCO Water Metering Systems, Inc., Ocala, FL). Weekly manual meter measurements were manually recorded and data from transducers that signaled a switch closure every 18.9 L (5 gal) were collected continuously by data loggers (HOBO event logger, Onset Computer Corp., Inc., Bourne, MA) connected to each flow meter. Pressure was regulated by inline pressure regulators to maintain an average pressure in the field of 69 kPa (10 psi) during irrigation events.

The irrigation treatments were regulated by the commercial RS500 soil moisture sensor (SMS) controller manufactured by Acclima, Inc. (Meridian, ID) for I1-I3 and an Acclima CS3500 for I4. The RS500 unit controls irrigation application by bypassing timed events if soil moisture was at or above a preset threshold of 8-12% volumetric water content (VWC) depending on irrigation treatment (Table 1). The CS3500 controls irrigation by maintaining soil moisture content within a user specified range of low to high and a time clock is not necessary.

For all soil moisture sensor controllers, a sensor was installed at a 30 degree angle between two plants and the sensor measured the soil moisture in the upper 0 to 0.2 m of the bed. Timed irrigation windows were specified as five possible events per day, starting at 8:00 am, 10:00 am, 12:00 pm, 2:00 pm, and 4:00 pm for 24 minutes each (2 hr/day total). As a reference treatment, a time-based irrigation treatment was set for one fixed 2 hr irrigation event per day.

Nitrogen treatments

Weekly N-fertilizer applications rates were designated as $N_{0.8}$, $N_{1.0}$, and $N_{1.5}$ of IFAS N recommendation rate, which corresponded to 166; 208 and 312 kg ha⁻¹ of NO₃-N, respectively (Fig. 1). All nutrients (except for P and micro nutrients) were applied via injection in the irrigation system (fertigation). Fertilizer sources used were calcium nitrate (N), potassium chloride (K) and magnesium sulfate (Mg and S). Additional fertilizer was applied before transplanting: 40 kg N ha⁻¹; 134 kg P₂O₅ ha⁻¹ and 100 kg K₂O ha⁻¹ pre-plant fertilizer was incorporated into the beds. On tomatoes, it was applied 134 kg P₂O₅ ha⁻¹ and 100 kg K₂O ha⁻¹ pre-plant fertilizer incorporated into the beds.

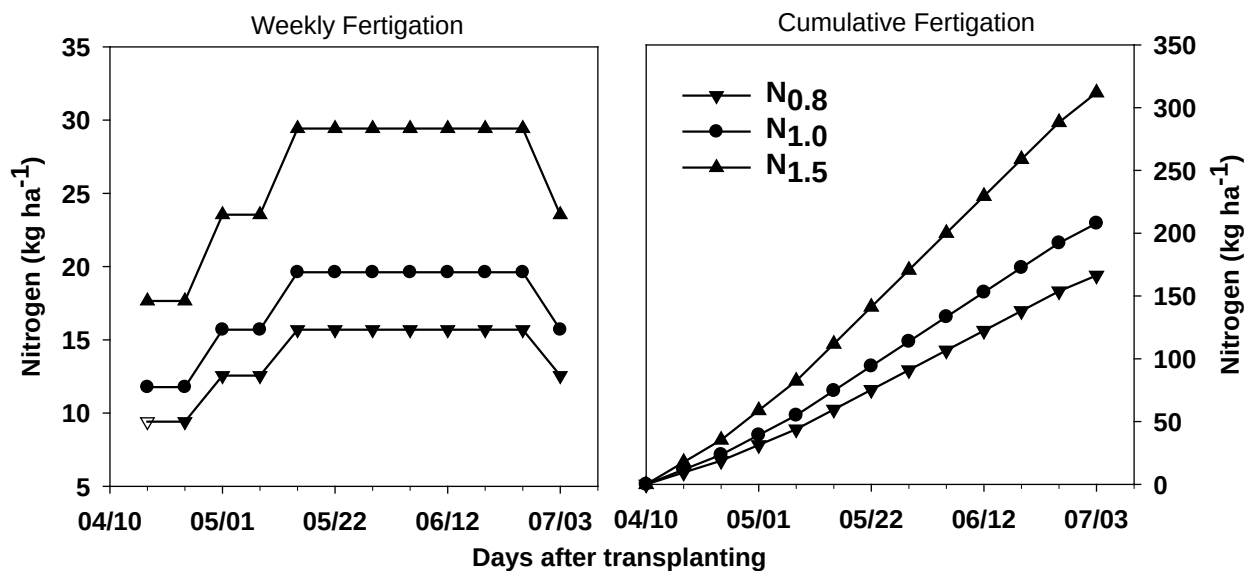


Figure 1. Weekly and cumulative N application (fertigation) for pepper and tomato plots, spring 2007.

After the initial establishment period and irrigation implementation, sensor treatments were initiated (13 DAT). During the establishment period, about 5-6 mm day⁻¹ was applied to all treatments, which makes

the N-fertilizer vulnerable to leaching. In order to increase the N-fertilizer availability to the pepper and tomato plants, the same N-rate has been applied rate was applied twice a week, on Tuesdays and Fridays. After the irrigation treatments started, the entire fertilizer rate has been applied at once, on Tuesdays.

Plant growth, yield and water use efficiency

For harvest measurements, an area of 10.5 m (34.4 ft) in central region within each plot will be sampled. Number and weight of fruits per grading class were recorded for individual plots. Pepper fruits were graded into culls, U.S. Number 2 (medium), U.S. Number 1 (large), and Fancy (extra-large) according to USDA (1997) standards. Marketable weight was calculated as total harvested weight minus culls. Irrigation water use efficiency (WUE) expressed in kg of fruits m^{-3} of irrigation was calculated by the quotient of marketable yields (kg ha^{-1}) and the total seasonal irrigation applied ($\text{m}^3 \text{ha}^{-1}$). Total biomass will be sampled between 60-70 days after transplanting for each crop, these results will be used to calculate the fertilizer use efficiency.

Monitoring soil water and N leaching

The volumetric water content in the top 15 cm of each plot was monitored by coupling time domain reflectometry (TDR) probes (CS-615, Campbell Scientific, Inc. Logan, Utah) with a datalogger (CR-10X, Campbell Scientific, Inc., Logan, Utah). Average volumetric water content was calculated for each treatment from measurements taken across all replicates.

Soil samples (0-30, 30-60, and 60-90 cm) soil depths were collected at 42 and 63 days after transplanting. A detailed soil sampling will be performed previous a fertigation event, 1, 3 and 7 days after fertigation event. After soil extraction samples were analyzed for $\text{NO}_3\text{-N}$.

Drainage lysimeters were installed 0.75 m below the surface of the bed prior to the bed formation (Fig. 2). Leachate extraction via a vacuum pumping system occurred weekly, one day before each fertigation event. Total leachate volume was determined gravimetrically, and subsamples collected from each bottle were analyzed for $\text{NO}_3\text{-N}$ so that total N loading rates could be calculated. Soil solution and soil core extracts were stored at -18°C until nitrate and nitrite analysis. Samples were analyzed using an air-segmented automated spectrophotometer

(Flow Solution IV, OI Analytical, College Station, TX) coupled with a Cd reduction approach (modified US EPA Method 353.2).

Statistical analyses

Statistical analyses were performed using PROC GLM of SAS (SAS Inst. Inc., 1996) to determine treatment effects. When the F value was significant, a multiple means comparison was performed using Duncan Multiple Range Test at a *P* value of 0.05.

Field implementation and initial research findings

Preparation of the field site began during the middle of January 1007 (Fig. 3) with tilling the field several times and leveling and smoothing the surface (Fig. 4). The beds were formed on March 22 and pre-plant fertilizer was incorporated into the beds. Fumigation, drip tape, and plastic mulch were applied in a single pass on just after bed formation (Fig. 4AB). The fumigant used was 80% methyl bromide and 20% chloropicrin by weight as planned. Approximately forty-five day old pepper plants (*Capsicum annuum*, ‘Brigadier’) were transplanted by hand on April 10. Bell peppers were planted 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. Four replicates were established in a randomized complete block design. Fixed irrigation of one hour each day was applied to the transplants until April 23, 13 days after transplanting (DAT) and Fig 5 shows the experimental irrigation control center. Irrigation treatments were implemented by activating the soil moisture controllers (Fig. 6), installing soil moisture probes (Fig. 7), and setting the irrigation time clock according to Table 1.

Weather data and soil moisture monitoring

A weather station within 500 m of the experimental site was used to provide temperature, relative humidity, solar radiation, and wind speed data which will be 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).

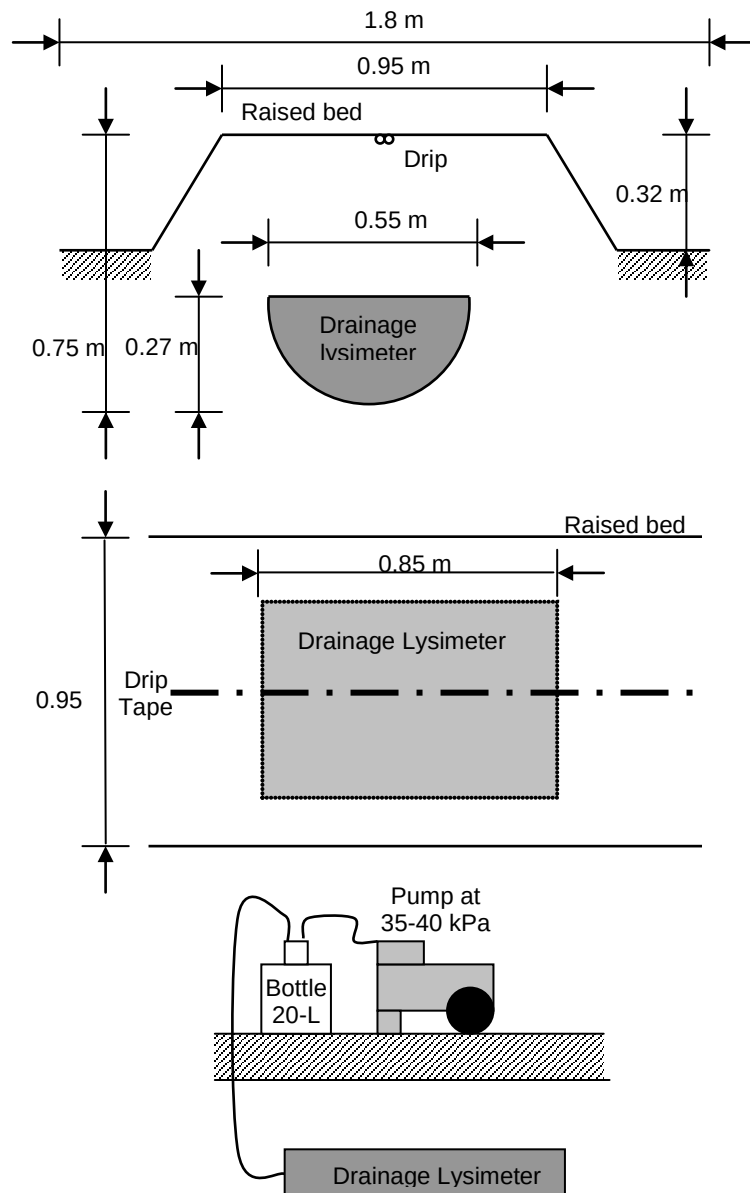


Figure 2. Overview of drainage lysimeter details.



Figure 3. Bell pepper 2007 experimental area after tillage (3/22/07).



Figure 4. A) Soil bed preparation (rototill) and B) soil fumigation and plastic mulching.



Figure 5. A) Experimental irrigation monitoring manifold showing flow meters, solenoid valves, and pressure regulation B) Acclima RS500 soil moisture controller.



Figure 6. TDR probes and Acclima soil moisture sensor installation (4/20/07).

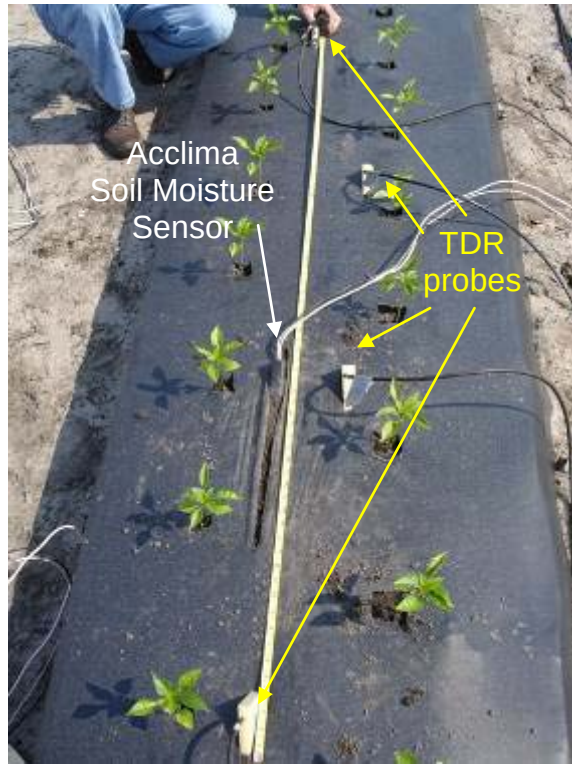


Figure 7. Campbell Scientific CS616 TDR probe distribution related to the Acclima RS500 soil moisture probe at raised bed with green bell pepper (4/20/07).



Figure 8. Overview of tomato and pepper experiment, detail of QIC SMS and TDR probe location, drainage lysimeters. (5/1/07).

Time domain reflectometry (TDR) probes were also installed to provide an independent measurement of soil moisture content in the root zone. They were installed approximately 7-8 cm from the drip line in between two plants and they were inserted at an angle to measure moisture content in the top 15 cm of the bed. In addition, TDR probes were also installed vertically to monitor the soil moisture content at 15 to 45 cm depth layer. Probe readings were measured at 5 minutes intervals and average

output for 15 minutes intervals were recorded via data loggers. The area close to the Acclima sensor was also monitored by a set of four probes which was installed around the Acclima sensor (Fig. 7).

Field observations

Special attention was given to the installation and monitoring of soil moisture sensors in the field in order to avoid similar problems that occurred during the spring season 2006 when malfunctioning of the irrigation controller systems resulted in over irrigation in the pepper plots. The cumulative irrigation for peppers is shown in Fig. 9. During the spring season all the initial technical problems with sensor settings and placements that occurred during the previous spring were addressed. The soil moisture sensors did a good job maintaining soil moisture at target values and bypassing irrigation events and reducing water application for lower threshold settings (e.g. I1 and I2). After the initial crop establishment period, the cumulative irrigation depths that were applied were: 90; 114; 179; 229 and 221 mm for I1, I2, I3, I4 and I5, respectively. The leaching patterns followed the same trend as that for irrigation. The volume of irrigation collected in the drainage lysimeters until early June was: 19; 23 and 29 mm, for I2, I3 and I5, respectively (Fig. 10)

Current Status

Monitoring of the project is ongoing and leachate samples are currently being analyzed. At the time at which the report was completed the final harvest was not yet completed (First harvest will occur on June 18th) so this report outlines preliminary leaching results only. Overall system performance of the irrigation system is superior to that in previous years although overall pepper yields may be lower compared to the fall season which is consistent with findings for previous years.

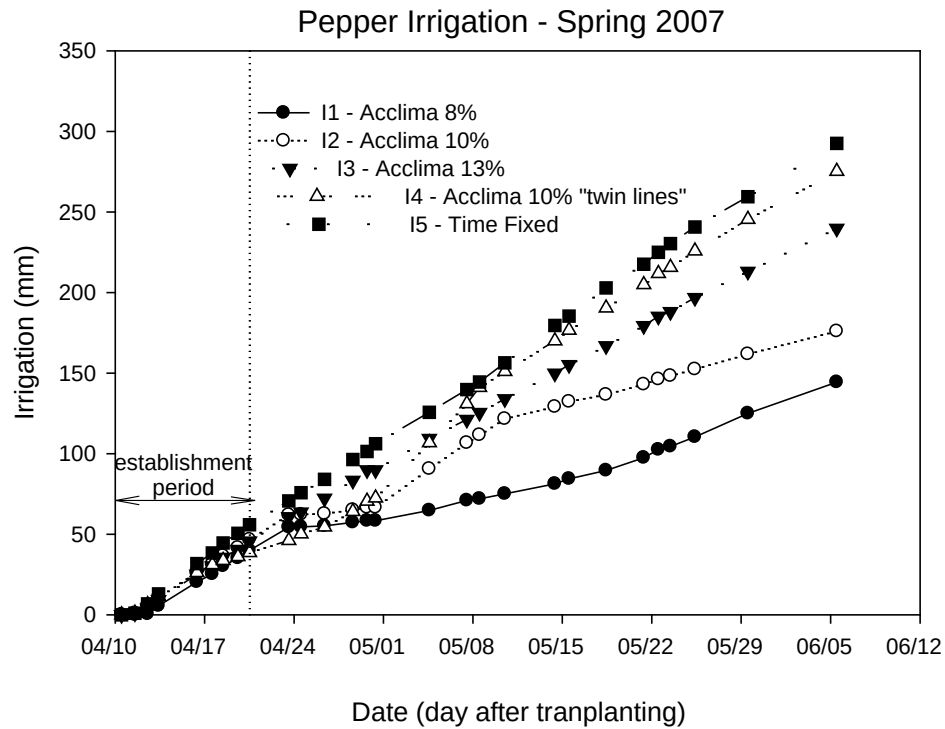


Figure 9. Cumulative irrigation on pepper plots, spring 2007.

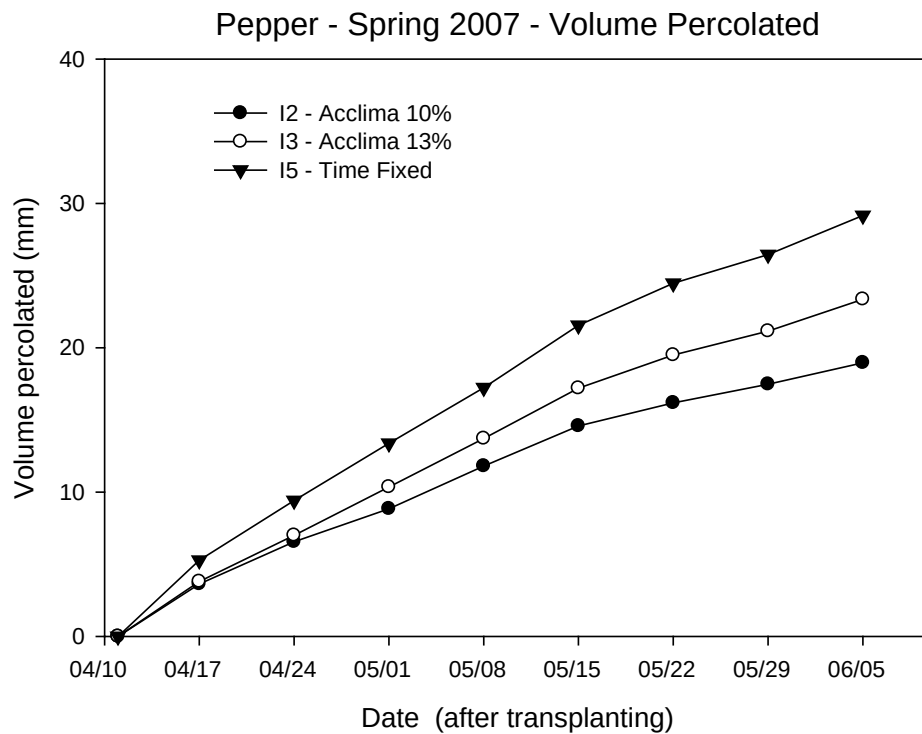


Figure 10. Cumulative volume percolated and captured on drainage lysimeters on pepper plots, spring 2007.

II) Tomato irrigation management x N rate study (spring 2006)

Experimental conditions and treatments

The planning phase of this project started in January 2007 with the design of the field trial. The experiment was conducted at the University of Florida Plant Science Research and Education Center (PSREU) near Citra, Florida in Marion County and the experimental irrigation treatments were established according to Table 2. The experimental design consisted of a complete factorial including five irrigation treatments ranging from sensor based control systems to time-based and three N-rates. Treatments were replicated four times in a complete randomized block design.

Table 2. Experimental treatment codes and description for tomato.

Treatment	Threshold (VWC ^[2])	Description
I1	10%	QIC-based control system for a maximum 5 irrigation windows per day, irrigation drip positioned 0.15cm below soil surface, and fertigation drip on the soil surface.
I2	10%	QIC-based control system for a maximum of 5 irrigation windows per day, Irrigation and fertigation drip positioned on the soil surface
I3	10%	Acclima soil moisture sensor for a maximum of 5 irrigation windows per day, Irrigation and fertigation drip placed on the soil surface
I4	N/A	Fixed time irrigation schedule, irrigation applied at three fixed windows per day
I5	N/A	Once daily fixed duration applied irrigation treatment and surface irrigation

^[2]Volumetric water content

For the tomato trial we also included an other soil moisture sensor based system referred to as the **Quantified Irrigation Controller (QIC)** system (Muñoz-Carpena et al., 2006) since it is relatively inexpensive and the QIC system was shown to be effective in other research settings. This system includes a 0.20 m long ECH₂O probe (Decagon Devices, Inc. Pullman, WA) to measure soil moisture in tomato plots. Probes were inserted vertically in order to integrate the soil water content in the upper 0.15 m of the soil profile. The QIC irrigation controllers allowed pre-programmed timed irrigation events if measured soil water content was below a volumetric water content (VWC) value of 0.10 m³ m⁻³ during one of five daily irrigation windows, each window lasting 24 min. Based on these readings up to a maximum of five irrigation events could occur per day totaling 2 hr, an amount of time equivalent to the timer application treatments. An overview of all included irrigation treatments for pepper is presented in Table 1.

In the tomato plots, a set of twelve Hydra Probe II (Stevens Water Monitoring Systems, Inc., Portland, Oregon) were also installed for the I1, I2, I3 and I5 irrigation treatments at a soil depth of 12.5; 37.5 and 67.5 cm. The Hydra Probe II is an in-situ soil sensing system that measures 21 different soil parameters simultaneously, including soil moisture and soil water salinity (Stevens Water Monitoring Systems, Inc., Portland, Oregon).

The use of a portable soil moisture monitoring probe (Sentek - Diviner 2000) allowed assessment of soil moisture content throughout the entire soil profile (5-105 cm). Access tubes were installed in different irrigation treatments, these measurements helped to understand the soil water movement in the soil profile during the irrigation events.

Nitrogen application rates and crop methods were the same as those reported for pepper and are shown in Fig. 2. General crop production practices and field sampling techniques including soil, water and plant sampling were the same as for peppers and will there not be discussed again. An overview of irrigation treatments for tomato is outlined in Table 2.

Field implementation and initial research findings

Approximately forty-five day old tomato plants (*Lycopersicon esculentum* Mill. var. “Florida 47”) were transplanted by hand on April 10, 2007. Tomatoes were planted in single rows with 0.3 m between plants within the row. Individual plots were 15.2 m long (50 feet) with a 9.1 m (30 feet) harvest length and the remainder of the plot was allocated for both soil and destructive plant sampling. Four replicates were established using a randomized complete block design. Fixed irrigation of one hour each day was applied to the transplants until April 23, 13 days after transplanting (DAT). At that time, the irrigation treatments were implemented by activating the soil moisture controllers (Fig. 6), installing soil moisture probes (Fig. 7), and setting the irrigation time clock according to target values outlined in Table 2.

Figure 11 shows the cumulative irrigation depth applied to specific irrigation treatments for tomato. After the establishment period the cumulative irrigation was 191; 121; 177; 216 and 204 mm for I1, I2, I3, I4 and I5, respectively. The leaching patterns for tomato followed the

same trend as that for irrigation. The volume of irrigation collected in the drainage lysimeters until early June was: 12; 26 and 32 mm, for I1, I2 and I5, respectively (Fig. 12).

Actual soil water transfer dynamics for an irrigation event for the fixed irrigation time control which mimics typical farmer practices is shown in Fig. 13. This figure shows that very high soil water values ($>>$ field capacity) occur to a soil depth of 50 cm within 1-2 hours after the completion of a 2-hour irrigation daily cycle. Since N moves with the wetting front, these results are consistent with those for dye test demonstrations where solute displacement reached a displacement depth of 40-50 cm within the first day. During subsequent irrigation events, the additional water being added acts like a piston and pushes the fertilizer down to below 3 feet within 7 days after initial fertilizer application. Using soil moisture sensors will allow growers to apply smaller volumes of water more frequently thereby avoiding wasting irrigation water and prevent excessive nitrate leaching losses. In this fashion similar or higher yields may be realized with less water and fertilizer.

Current Status

Monitoring of the project is ongoing and leachate samples are currently being analyzed. At the time at which the report was completed the final harvest was not yet completed (First harvest will occur on June 18th) so this report outlines preliminary leaching results only. Overall system performance of the irrigation system was superior to that in the first year while overall crop growth is similar to the second year and superior to that observed during the first year.

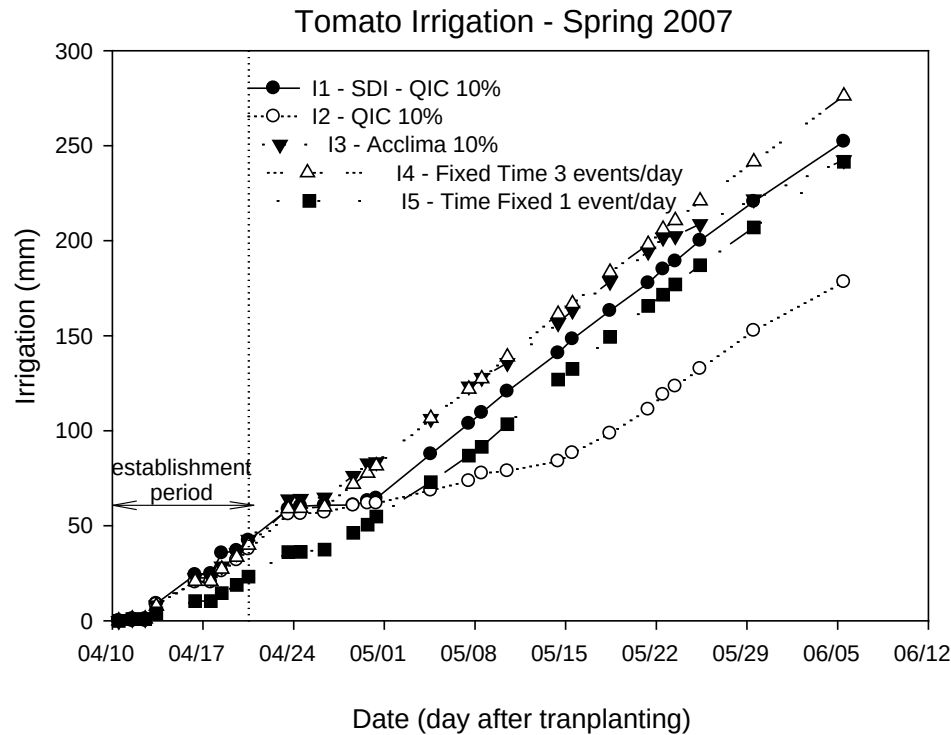


Figure 11. Cumulative amount of irrigation applied to tomato plots, spring 2007.

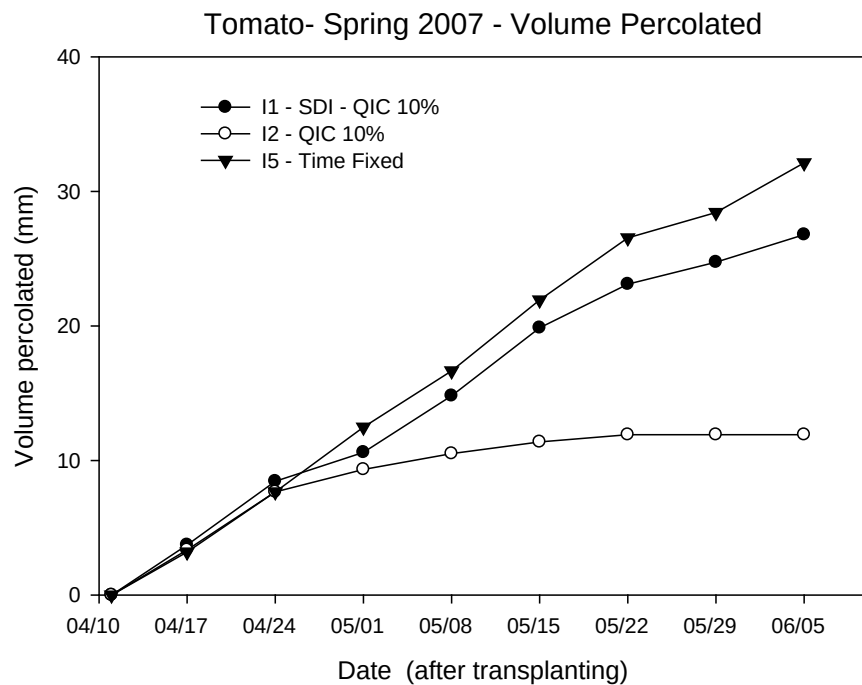


Figure 12. Cumulative leaching volume captured in drainage lysimeters underneath tomato plots.

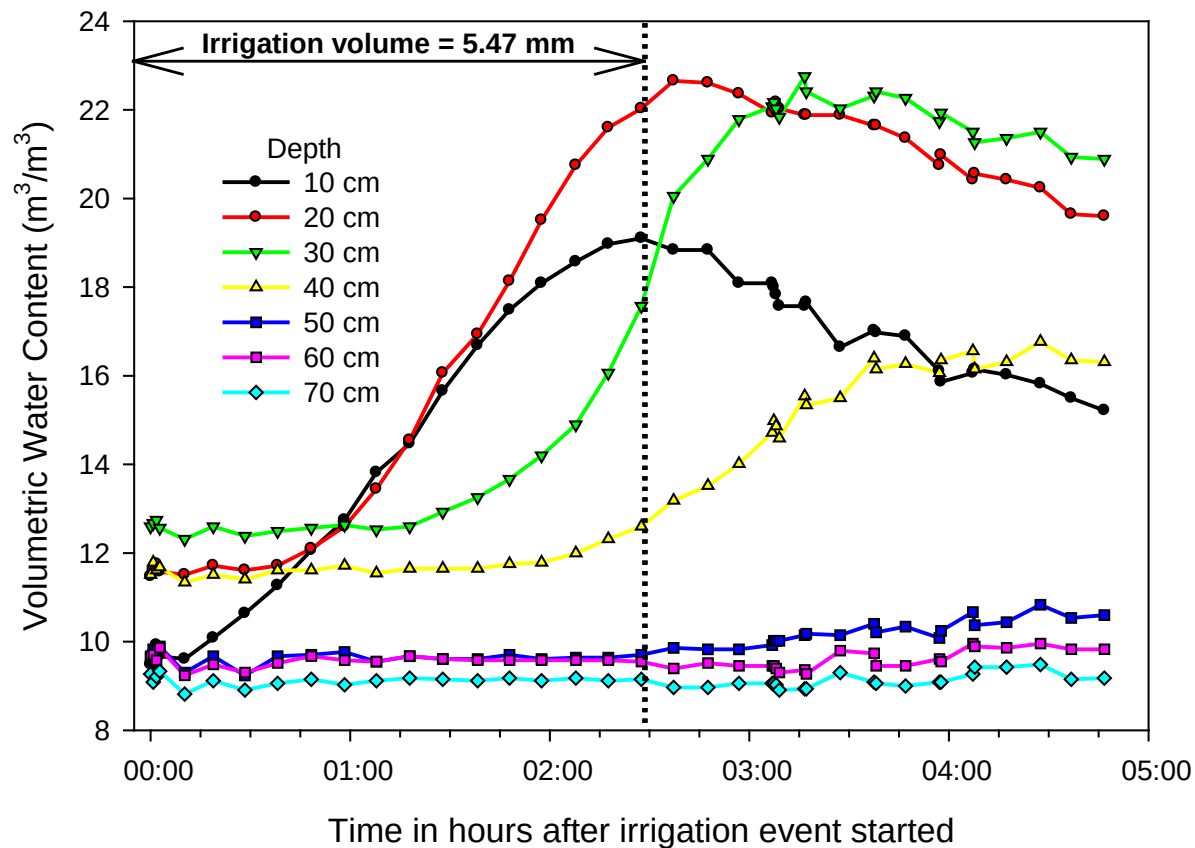


Figure 13. Changes in soil moisture as related to irrigation event in control treatment (I5).

III) Improved integration of cover crops in vegetable production systems

Experimental conditions and treatments

On March 23rd of 2006 all field plots were mowed and sweet corn was planted on April 7th of 2006. Sweet corn was fertilized at 0, 0.33 or 0.67 times IFAS N recommendations for cover crop based treatments and fertilizer was applied in 3 applications (0, 3 and 5 weeks after planting). Alternatively, conventionally managed plots were fertilized at 0, 0.33, 0.67, 1.0, or 1.33 times IFAS N recommendation for (this range of N rates allowed us to develop a representative N-fertilizer response curve and to verify IFAS N recommendations for sweet corn).

During the spring of 2006 we applied ^{15}N (a stable isotopic marker) at 3 different times (preplanting, 2 or 4 weeks after planting). In this manner we could determine what fraction of the applied fertilizer was taken up for these 3 application times. In addition to this we used two different labels. The first one had the label was inserted in the nitrate part ($^{15}\text{NO}_3\text{-N}$) of the fertilizer molecule while for the second material the ammonium part ($^{15}\text{NH}_4\text{-N}$) of the fertilizer molecules was labeled. By using this approach we could calculate the uptake efficiency of a nitrate vs a ammonium based N-fertilizer source for each application time (preplant, early and late). This technique is very powerful since it allows us to gain a better understanding of how nitrogen behaves in the soil.

Effects of N-fertilizer treatment on plant growth, and yield and N accumulation were determined by sampling plants at 3-week intervals and results were reported in a previous report. Soil nitrate levels were determined by soil coring at 0.3m increments upto the 0.9 m soil depth prior and after each fertilizer application. This field study was complemented with a column study during the spring of 2006 to assess how residence time (retention of fertilizer in the rootzone as related to N displacement associated with leaching rainfall or excessive irrigation), affects corn growth and fertilizer uptake efficiency. Effects of N-fertilizer rate on crop production as affected by cover crop treatments were presented in previous reports so this report will focus on the results of the labeled fertilizer recovery in the crop as related to fertilizer use efficiency instead.

Research Findings

By using the labeled fertilizer we were able to determine at what time and in what form fertilizer is used most efficiently in a sweet corn production systems. Moreover, we also looked at in what plant part the fertilizer is being accumulated. Table 3 shows how time of N-fertilizer application and N-form affects how much N is taken up in the vegetative (stover) and marketable (ears) plant parts. An asterisk (*) next to an fertilizer application event indicates that labeled fertilizer was applied at that time where as regular fertilizer was applied at the same rate for all the other applications (so total N rate was identical for all treatments shown in this table). The last rows shows the effect of splitting the labeled fertilizer in three smaller (equal) doses across all application events. Results reported in this row should therefore be

similar then the average of the first three rows, which is the case and shows that our technique worked well.

Overall N accumulation from labeled fertilizer in both vegetative and reproductive plant parts was greater for the second and third application when the N was applied later (Table 3). Early applications mainly resulted in N accumulation in the leaves and stems since ears were not present at that time although some N translocation from leaves to stems may occur during final growth. If the N applied later on it tend to accumulate more in ears since ears tend to form later on and at that point vegetative growth starts to decline.

In terms of fertilizer uptake efficiency, applying fertilizer early on during the season when root systems were poorly developed and crop N-demand is low resulted in limited plant uptake and poor fertilizer uptake efficiencies (Table 4). For N-fertilizer applied in nitrate form, the initial fertilizer uptake efficiency was 7% and values increased to 19 and 39% for the 2nd and 3rd N application, respectively. For N-fertilizer applied in ammonium form, the initial fertilizer uptake efficiency was twice as high (18%) and values increased to 26 and 38% for the 2nd and 3rd N application. Overall uptake efficiency was 27% for ammonium based material compared to 21% for nitrate based material. Poor efficiency for preplant applied nitrate fertilizer is related to this form being leached more rapidly while initial crop utilization is poor due to the lack of a well developed root system. Fertilizer banding and use of slow release materials may address some of these problems. At a later stage N can be applied in either form.

Table 3 Nitrogen accumulation from labeled (¹⁵N) fertilizer by sweet corn plants fertilized with ammonium nitrate fertilizer for which the ¹⁵N-label was inserted in either the **ammonium molecule** (¹⁵NH₄NO₃) or **nitrate molecule** (NH₄¹⁵NO₃) and the labeled fertilizer material applied at pre-plant, 14 or 28 days after planting or at four times (DAP).

Application Timing			¹⁵ N enrichment (atm % ¹⁵ N excess)			
Pre-plant	14 DAP	28 DAP	¹⁵ NH ₄ NO ₃		NH ₄ ¹⁵ NO ₃	
	N-rate		Stover	Ear	Stover	Ear
67*	67	67	0.27 ± 0.05	0.21 ± 0.04	0.12 ± 0.06	0.10 ± 0.05
67	67*	67	0.45 ± 0.09	0.30 ± 0.06	0.36 ± 0.10	0.28 ± 0.06
67	67	67*	0.34 ± 0.04	0.59 ± 0.05	0.39 ± 0.04	0.59 ± 0.07
67*	67*	67*	0.42 ± 0.06	0.40 ± 0.04	0.29 ± 0.02	0.31 ± 0.02

Table 4. Percentage of N uptake from labeled (^{15}N) fertilizer by sweet corn plants fertilized with ammonium nitrate fertilizer for which the ^{15}N -label was inserted in either the **ammonium molecule** ($^{15}\text{NH}_4\text{NO}_3$) or **nitrate molecule** ($\text{NH}_4^{15}\text{NO}_3$) and the labeled fertilizer material applied at pre-plant, 14 or 28 days after planting or at four times (DAP).

Application Timing			Fertilizer uptake efficiency (%)		Mean	
Pre-plant	14 DAP	28 DAP	$^{15}\text{NH}_4\text{NO}_3$	$\text{NH}_4^{15}\text{NO}_3$		
N-rate						
67*	67	67	17.8	6.9	12.4	c
67	67*	67	26.4	18.5	22.4	b
67	67	67*	37.6	38.9	38.2	a
Mean			27.3	21.4	B	
67*	67*	67*	26.4	23.1		
				F value	(P)	
N source				8.49	*	
Timing				18.38	***	
N source x Timing					ns	

Conclusions

Preliminary results for pepper and tomato seem to confirm the previous findings from previous years that use of sensor based irrigation control techniques can greatly reduce water requirements and/or N leaching.