

Testing of Nutrient Sensors at Two BMP Demonstration Sites

Task 3:

Irrigation and nitrogen management strategies for water savings on seepage, subsurface drip irrigation, tile drainage and sprinkler irrigation on potatoes

Report on Deliverable 3c:

Provide a final report outlining findings of the trial. This report will include the following data: crop yield, irrigation water use for each irrigation system, water table management and climatic data.

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By

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Executive Summary

A field experiment was conducted in Hastings, FL to evaluate water use and nitrogen fertilizer requirements for potato production under four irrigation systems. Conventional seepage irrigation was compared to three alternative irrigation systems, tile drainage, subsurface drip irrigation for water table management and overhead sprinkler irrigation. The field experiments were installed at the University of Florida, Hastings Research and Extension Center in Hastings, FL. Twelve treatments combining nitrogen fertilizer rate and fertilizer application timings were tested within each irrigation system. The average potato yield was 310, 323, 351 and 309 cwt/ac for seepage, tile drainage, subsurface drip and overhead sprinkler irrigation, respectively. Irrigation water savings were 51%; 58% and 68% with tile, subsurface drip and overhead sprinkler irrigation, respectively, compared to seepage irrigation. The application of 50 and 100 lb/ac N fertilizer at potato planting resulted in significant higher tuber yield compared to 0 lb/ac of N in all irrigation systems. The highest potato yields were achieved with the total N-fertilizer treatment rates above 200 lb/ac. There were no significant differences in tuber yield for total N rates between 200 and 300 lb/ac. A second year of data collection is necessary to increase the reliability of the testing, development and validation of the BMPs for potato production in Florida under different irrigation systems.

Deliverable description:

Deliverable 3c. Provide a final report outlining findings of the trial. This report will include the following data: crop yield, irrigation water use for each irrigation system, water table management and climatic data. Any problems with the experiment will be identified. (Zotarelli)

Introduction

Alternative irrigation systems for water conservation were introduced in agricultural areas of northeast Florida in 2011. Since April 2013, fourteen vegetable growers have converted part of their agricultural land to more efficient irrigation systems through the Tri-County Agricultural Area (TCAA) Cost-Share Program (a partnership between Florida

Department of Agriculture and Consumer Services, Florida DEP, St. Johns River Water Management District and NRCS). The available options to replace conventional seepage include tile drainage, subsurface drip irrigation for water table control and overhead sprinkler irrigation.

The tile drainage system is comprised of buried perforated pipes that allow soil water to flow into the pipes, discharging the water by gravity, with the pipes draining directly into open ditches. The system can also be used for irrigation by controlling the water table level and by applying water into the pipes. The system components are laterals, collectors and outlets pipes installed above the impermeable soil layer. Tile drainage allows a more uniform soil moisture control in the root zone by uniformly raising the water table when irrigating and by draining excess of water from rainfall. As tile drainage is used for both irrigation and drainage, there is no need for irrigation furrows as in the conventional seepage resulting in 12% increase in the land available for cultivation. When tile drainage is used to irrigate and control the water table, the water savings can be up to 60% of the traditional seepage system, due to reduction of water evaporation from furrows and less irrigation water leaving the field. The tile system can also be used as an effective strategy to control the soil salinity. Tile drainage lasts more than 20 years when properly maintained. Since 2011, five growers have installed tile drainage in the TCAA, totaling 371 acres.

Subsurface drip irrigation for water table control (SDI) is used in northeast Florida for potato irrigation. The SDI is characterized by the application of water below the soil surface and above the soil impermeable layer by microirrigation (high flow drip tape). SDI improves the distribution of soil moisture across the field and reduces the time required to raise the water table compared to seepage irrigation. Furrows placed every 60 feet are needed for drainage during heavy rainfall. In the 1990's, IFAS-Research had proposed the use of SDI to establish and maintain shallow water tables (Smajstrla et al., 2000). The findings for a three year research trial comparing the traditional seepage irrigation management with SDI showed no differences in potato yield, however, there was a consistent 36% reduction in the volume of water applied using SDI compared to the traditional seepage. Currently, about 150 acres of potatoes (5 growers) have been converted their fields to SDI for water table management. One advantage

of subsurface drip is the lower cost of implementation compared to tile drainage. According to Rogers et al. (2014) the installation costs for SDI and tile drainage are estimated to be approximately \$705 and \$2,316 per acre, respectively.

The third available irrigation system is sprinkler irrigation. Sprinkler irrigation accounts for 11% of the irrigated land in Florida (Dukes et al., 2010). Nearly 1,200 acres in southwest Florida and 660 acres of commercial land in northeast Florida have been converted from seepage to overhead sprinkler irrigation for potatoes. However, almost no research has been done to evaluate the efficiency, strategies or potential problems with the conversion from seepage systems to overhead sprinkler irrigation on potatoes.

Due to the fertilizer application method, low nitrogen use efficiency of potato, and the inefficiency of seepage irrigation systems, increased N fertilizer rates may be necessary to compensate for N losses, especially after intense rainfall (Simonne et al., 2010). In recent years, many potato growers in northeast Florida have adapted to banding fertilizer instead of broadcast application. Despite the application method, seasonal N application is generally split into three applications. The first application occurs about 30 days before planting, coinciding with field fumigation. Approximately 20% of the total N is supplied with this pre-plant fertilizer application. This is followed by 50 to 60% of total N at plant emergence around 25 days after planting, and the final 20 to 30% of total N is applied at the onset of tuber initiation, about 40 days after planting. With N fertilizer costs increasing approximately 250% since 2000 (USDA, 2013), more efficient practices for fertilizer application including N rate and timing are crucial to keep Florida potato production competitive. Best management practices for potato production are needed to increase nitrogen use efficiency, maximize yield, and reduce N losses to the environment. These practices focus on placement, timing, and rate of N-fertilizer application.

The main objective of this project is to evaluate the irrigation water requirement, soil water dynamics, and nitrogen fertilizer practices in four irrigation systems (tile drainage, subsurface drip, overhead sprinkler, and traditional seepage) and their effects on potato plant development and yield cultivated in northeast Florida. With the rising interest in alternative irrigation systems to replace the conventional seepage, it is imperative that soil water dynamics and the response of the potato crop to different nitrogen fertilization strategies and irrigation

water delivery systems be understood. The information collected from this trial will be used in the development and validation of Best Management Practices for irrigation and N-fertilizer for potatoes.

Materials and Methods

Field trials were performed at the IFAS - Hastings Research and Extension Center. The soil at the research center is classified as sandy, siliceous, hyperthermic Arenic Ochraqualf belonging to the Ellzey series, typically found in the northeast Florida region with high potential for cultivated crops (Soil Survey, 1983). The soil texture is sandy and proportions of the particle fractions in the top soil are 94.0% sand, 2.5% silt, and 3.5% clay. The soil is very poorly drained due to an impermeable soil horizon at 3 ft.

Commercially potatoes are planted from beginning of January to the end of February. For this research, potato seeds (*Solanum tuberosum*, var. 'Atlantic') were planted on January 29th and 30th 2015. Seeds were planted with an in-row spacing of 8-in with a 40-in between row spacing.



Figure 1. View of potatoes irrigated with seepage, Spring 2015.

Potato rows were hilled to 16-in in height. Each bed consisted of 16 rows separated by drainage furrows. The drainage furrows were approximately 8-in deeper than the alley between

rows in the bed, as shown in Figure 1. The tile drainage system did not required drainage furrows. Crop management adopted in these trials was identical to the standard practices adopted by growers in the region.

Experimental design and N-fertilizer treatment layout

The goal of the experiment was to evaluate the ideal nitrogen fertilizer rate at different application timings in order to maximize potato yield with the least amount of nitrogen fertilizer. In a recent survey, potato growers in northeast Florida reported applying a total N rate ranging from 200 to 315 kg ha⁻¹ split into three applications throughout the season (Asci et al. 2012). The first application occurs 30 to 40 days before planting, supplying 0 to 60% of the total N fertilizer. Followed by a fertilizer application at plant emergence, which ranges from 0 to 70% of the total N. The final application of N occurs at tuber initiation (side-dress), with 0-50% of total N.

Three nitrogen fertilizer rates (0, 50 and 100 lb/ac) were applied at planting, while two nitrogen fertilizer rates (50 and 100 lb/ac) were applied at each plant emergence and at tuber initiation. Total nitrogen applied per treatment ranged from 100 to 300 lb/ac of N. The treatments were applied in a randomized complete block design with four replications in each irrigation system (seepage, tile drainage, overhead sprinkler irrigation and SDI). Table 1 shows the combinations of N-rates for each application timing and the total N- fertilizer applied. The nitrogen fertilizer applications for planting, emergence and tuber initiation occurred on January 27th 2015, February 21st 2015 and March 17th 2015, respectively. The nitrogen source was granular ammonium nitrate (34-0-0).

Table 1. N-fertilizer rate and application timing for seepage, tile drainage, SDI and overhead sprinkler irrigation.

Treatment	Nitrogen rates (lb/ac)			Total N
	Planting	Emergence	Tuber Initiation	
1	0	50	50	100
2	0	50	100	150
3	0	100	50	150
4	0	100	100	200
5	50	50	50	200

6	50	50	100	200
7	50	100	50	200
8	50	100	100	250
9	100	50	50	200
10	100	50	100	250
11	100	100	50	250
12	100	100	100	300

Comparison between irrigation systems

Figure 2 shows the location of each irrigation system on the research farm. Water table level and soil moisture sensors from PraxSoft Inc. were installed in the field after potato planting on February 10th 2015. The water table level sensors were installed at a 50-in depth into well screens installed down to 60-in in the soil profile. Soil moisture sensors were installed at 6-, 10-, 18- and 30-inches depth. Soil moisture and water table level data collected every 15 minutes. Water applied by irrigation was recorded by positive displacement flowmeters. Weekly meter measurements were manually recorded. Flowmeters were installed inline after the solenoid valve for each irrigation system. Reference evapotranspiration calculated based on information provided by a weather station on-site, which was connected to the Florida Automated Weather Network (FAWN). Crop evapotranspiration (ET_c) was calculated from the product of crop coefficient (K_c) (Table 2) and ET_o (Doorenbos and Pruitt, 1977).

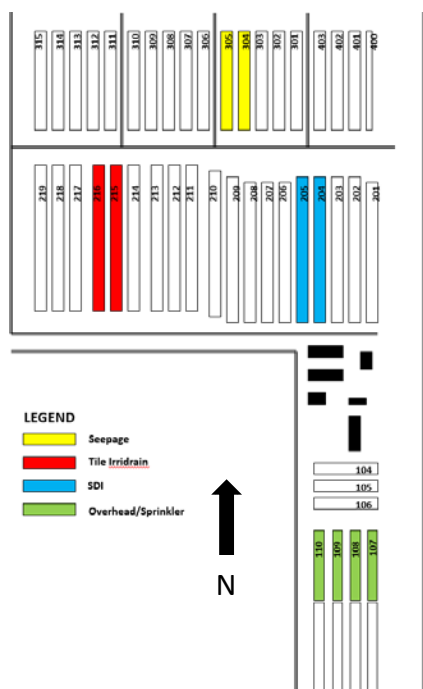


Figure 2. Location of seepage, tile drainage, subsurface drip irrigation and overhead sprinkler irrigation system at the Hastings Research and Extension Center.

Total potato yield from each nitrogen fertilizer treatment and irrigation system was evaluated after harvest, which occur between May 5th ~~and to~~ 8th 2015.

Table 2. Potato crop coefficient (Kc) at different growth stages adapted from Allen et al. (1998).

Crop Stage	Days after planting	Kc
Initial	0-25	0.6
Development	26-55	1.15
Mid-season and Maturation	55-110	0.75

Statistical Analysis

Statistical analyses were performed using PROC GLM procedure of SAS (SAS, 2011) to determine N rate and timing effects for potato yield in each irrigation system. When the F value was significant, a multiple means comparison was performed using Tukey-Kramer at a P value of 0.05.

Results

Water usage and irrigation management

The potato crop was not irrigated until plant emergence to avoid seed disease and decay. Thus, on March 10th 2015, the first irrigation application occurred for all four irrigation systems. Figure 3 shows the cumulative crop evapotranspiration, rainfall events and irrigation applications for the overhead sprinkler irrigation system during the entire season.

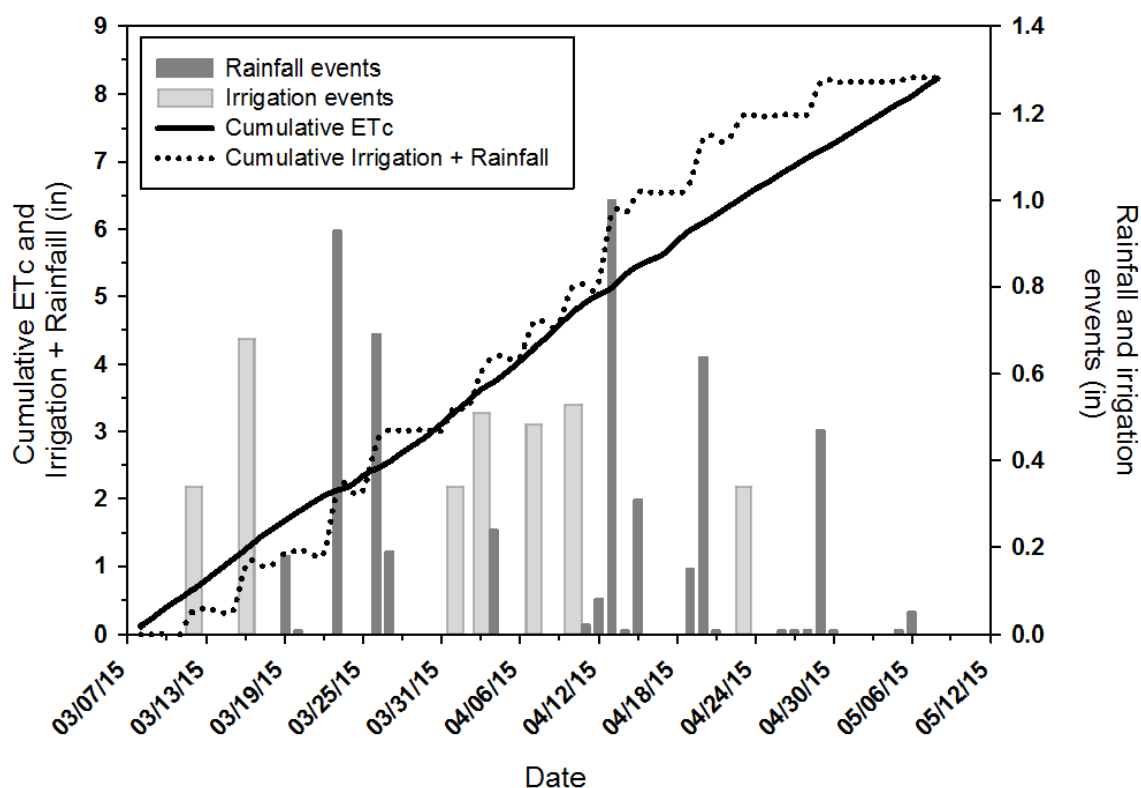


Figure 3. Daily rainfall, cumulative crop evapotranspiration (ETc), and cumulative irrigation water applied and rainfall, for potato cultivated under overhead sprinkler irrigation in Hastings during the Spring of 2015.

Volumetric soil moisture and water table level data obtained by the PraxSoft sensors and weather forecast from National Weather Service (weather.gov) were used to support irrigation decisions. The irrigation management goal was to maintain the volumetric soil moisture content within the top 10 inches around field capacity ($0.18 \text{ in}^3/\text{in}^3$) for all irrigation

systems. The irrigation start time and duration were recorded, as well as the volume of water applied for each irrigation system. Between March 10th and April 25th the irrigation volumes applied were 315,456; 153,440; 133,460 and 102,318 gal/ac for seepage irrigation, tile drainage, SDI and overhead sprinkler irrigation, respectively.

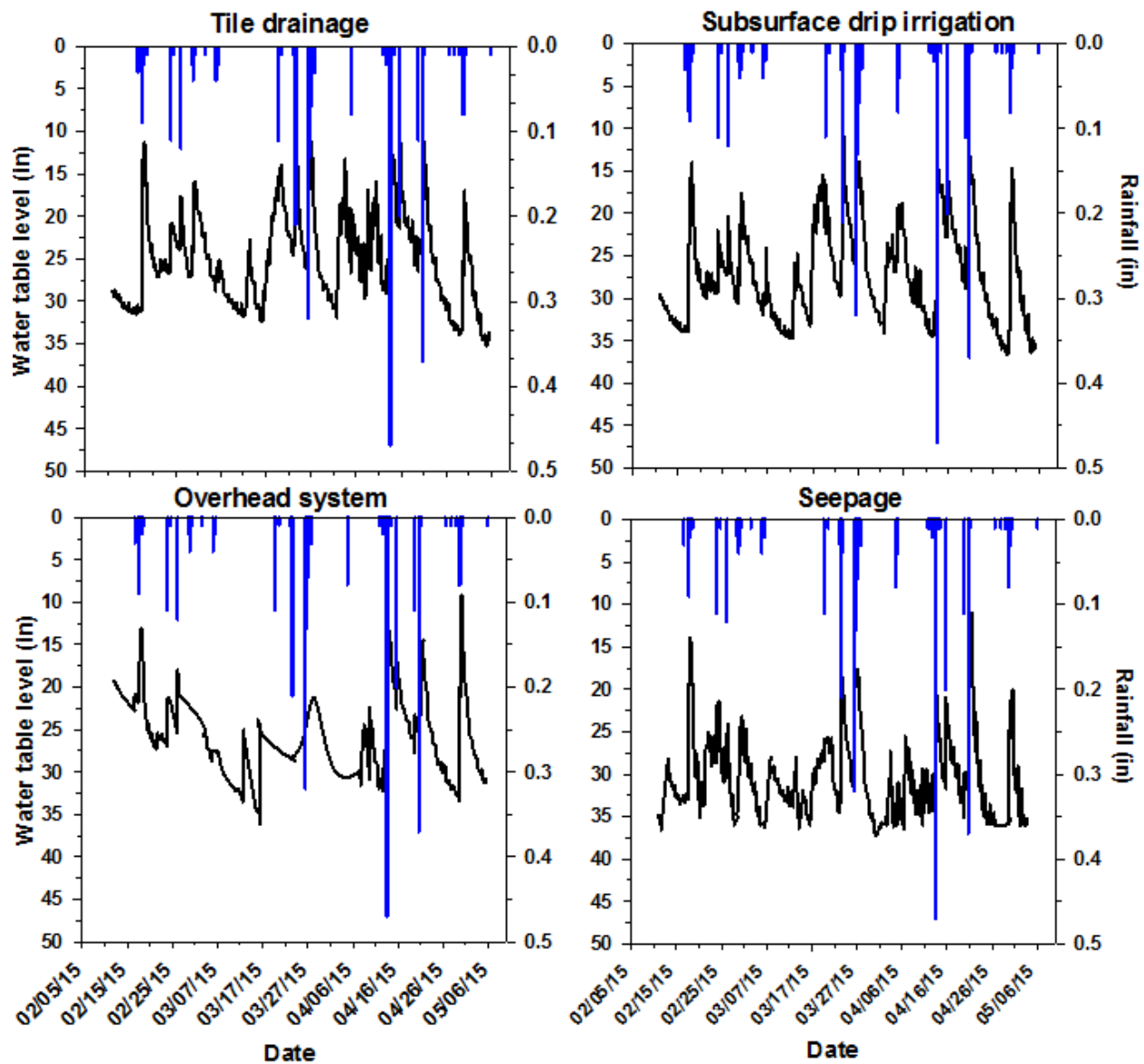


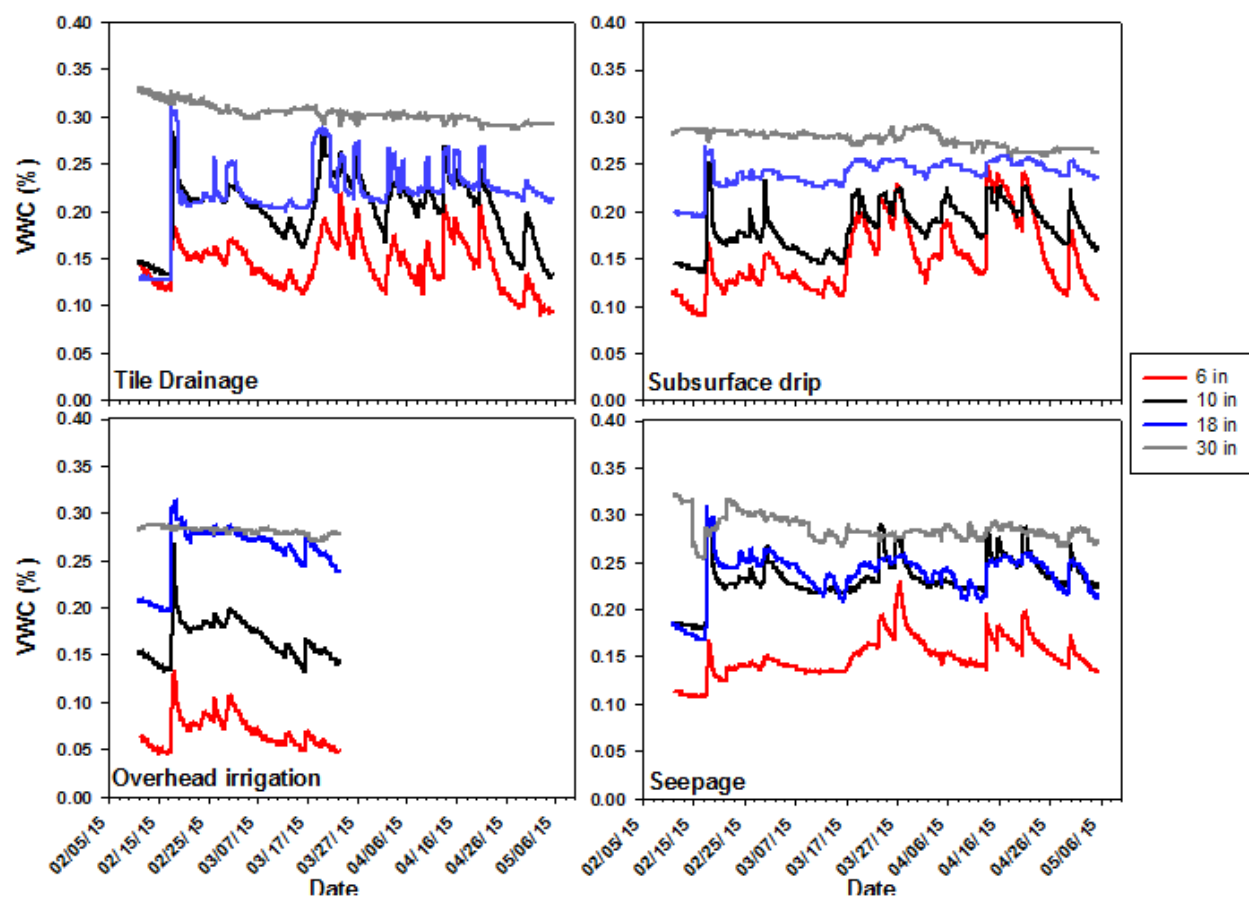
Figure 4. Water table level and rainfall events at each irrigation system from March 2nd to 24th 2015.

Rainfall had a direct impact on water table level throughout the season. The water table level responded similarly to rainfall events in all irrigation systems (Fig. 4). For seepage, SDI and tile drainage, the water table was manipulated accordingly to maintain the water level between depths of 27 and 30 inches below the soil surface. In few occasions, water table level increased up to 15 inches from the surface in response to precipitation events higher than 0.5 inches. At the overhead sprinkler irrigation area, the water retention structures were completely lowered and the water table was maintained at the lowest level.

As tile drainage and SDI relied on buried pipe and drip tape, respectively, to distribute the irrigation water across the fields. In both systems a more uniform distribution of soil moisture was expected in the root zone compared to the conventional seepage, which relied exclusively on irrigation furrows distributed every 60 feet.

After rainfall events the excess water was removed from the field to bring the water table level to an ideal point. Tile drainage allowed a fast removal of the water out of the field, consequently resulting in a more efficient control of the soil moisture in the root zone compared to subsurface drip and seepage system. This effect occurred around March 26th and 27th (Fig. 5), when after a spike in soil moisture due to consecutive rainfall events, the soil moisture in the root zone in the tile drainage returned to an ideal soil moisture level faster than seepage and SDI system. Soil moisture sensors installed at the overhead irrigation areas showed problems of communication after March 27th.

The average potato yield for each irrigation system was 310, 323, 351 and 309 cwt/ac (hundredweight per acre) for seepage, tile drainage, SDI and overhead sprinkler irrigation, respectively. The irrigation water use efficiency (IWUE) was 11.8, 25.3, 31.6 and 36.3 kg/m³ (kg of fresh tuber per m³ of irrigation water) for seepage, tile drainage, SDI and overhead sprinkler irrigation, respectively.



Figures 5. Volumetric soil moisture content at 6, 10, 18 and 30-inch depth installed at tile drainage, seepage, subsurface drip irrigation (SDI) and overhead sprinkler irrigation.

N-fertilizer rate and timing within each irrigation system

Potato tubers were mechanically harvested and yield was evaluated for each N-fertilizer rate and application timing for each irrigation system. Table 3 shows the analysis of variance for N-fertilizer rates applied at planting (0, 50 and 100 lb/ac of N), emergence (50 or 100 lb/ac of N) and side-dress (50 or 100 lb/ac of N) and their interactions.

There was a significant main effect of the at-planting N fertilizer rate on yield for all irrigation systems. The interaction between N rates at planting and emergence was significant for potatoes grown in tile drainage and seepage irrigation. In addition, there were interactions between emergence and side-dress N applications and planting and side-dress N applications only when potatoes were irrigated with tile drainage.

Table 3. Analysis of Variance (ANOVA) for application N-rate and timing treatment for each irrigation system.

Source	DF	Probability > F			
		Seepage	SDI	Tile	Overhead
Planting (Pl)	2	***	***	***	***
Emergence (Emg)	1	ns	ns	***	ns
Side-dress (Sd)	1	ns	ns	**	ns
Pl * Emg	2	**	ns	*	ns
Pl * Sd	2	ns	ns	*	ns
Emg * Sd	1	ns	ns	*	ns
Pl * Emg * Sd	2	ns	ns	ns	ns

ns – not significant; * significant at $P \leq 0.05$; ** significant at $P \leq 0.01$; *** significant at $P \leq 0.001$.

Results of N fertilizer rate and application timing on potato yield are presented by irrigation system type below:

Seepage

There was an interaction for N fertilizer rates applied at planting and at emergence for potato yield under seepage irrigation. The effect of N rates applied at planting was analyzed within each N fertilizer rate applied at emergence (50 or 100 lb/ac) (Table 4).

Potato yield increased linearly in response to increasing N fertilizer rates at planting when 50 lb/ac of N was applied at emergence. There was no relationship between N rates at planting and yield when 100 lb/ac of N was applied at emergence. The highest potato yield was achieved with the application of 100 lb/ac of N at planting when 50 lb/ac of N were applied at emergence.

When no N fertilizer was applied at planting, the application of 100 lb/ac of N at emergence resulted in 12% increase in yields compared to the application of 50 lb/ac of N at emergence. With the application of 50 or 100 lb/ac of N at planting, there was no difference in tuber yield between treatments with application of 50 or 100 lb/ac of N at emergence.

Application of 0 and 50 lb/ac of N at planting and emergence, respectively, resulted in the lowest potato yield under seepage irrigation, which indicated that these two application timings were important for potato production under seepage.

Table 4. Interaction between N fertilizer rates applied at planting and at emergence in seepage irrigation system in Hastings, FL, in 2015 growing season.

Planting N (lb./ac)	Yield (cwt/ac) Emergence N (lb/ac)	
	50	100
0	269 b	307 a
50	321 a	327 a
100	334 a	316 a
Regression	L*	ns

Regression analysis for effect of N planting rates; L, linear; Q, quadratic, significant at the 5% (*), non significant (ns).

Tile Drainage

Under tile drainage there was an interaction between N rates and timing of application for planting vs. emergence, planting vs. side-dress and emergence and side-dress applications on potato yield (Table 3). The effect of N rates applied at planting were analyzed within each N fertilizer rate (50 or 100 lb/ac) applied at emergence and at side-dress (Table 5).

Planting vs. Emergence N application and Planting vs. Side-dress N application

Tuber yield increased linearly in response to increasing N-fertilizer rates applied at planting within treatments that received 50 lb/ac of N at both emergence and side-dress. In both cases, the highest yields were achieved with N rate of 100 lb/ac at planting. On the other hand, when a higher N rate (100 lb/ac) was used at emergence or at side-dress, there were quadratic responses for increased N applications at planting (Table 5). The combination of 100 lb/ac applied at planting with 100 lb/ac applied at emergence or at side-dress resulted in a significant decrease in tuber yield when compared with lower N rate combinations.

Lower N fertilizer application (0 or 50 lb/ac of N) at the planting required higher N rate (100 lb/ac of N) applied at emergence or at side dress to maintain high potato yields. For N application rates of 50 lb/ac at planting, potato yield significantly increased from with N application of 100 lb/ac at emergence 305 to 366 cwt/ac or at side-dress. However, when 100 lb/ac of N was applied at planting, no increase in yield was reported with N rates above 50 lb/ac (Table 5).

Table 5. Interactive effect of N fertilizer rates applied at planting (0, 50 and 100 lb/ac) with N fertilizer rates applied at emergence (50 or 100 lb/ac) or at side-dress (50 or 100 lb/ac) on potato yields under tile drainage irrigation.

Planting N (lb/ac)	Yield (cwt/ac)			
	Emergence N (lb/ac)		Side-dress N (lb/ac)	
	50	100	50	100
0	278 b	316 a	294 a	301 a
50	305 b	366 a	308 b	363 a
100	342 a	346 a	340 a	348 a
Regression	L*	Q*	L*	Q**

†Values followed by the same lowercase letters within planting N treatments indicate that the mean of yield are not significantly different ($P < 0.05$) according to t-test between 50 and 100 lb/ac applied at Emergence N or Side-dress N timing (rows).

Regression analysis for effect of N planting rates; L, linear; Q, quadratic, significant at the 5% (*), 1% (**) level or non significant (ns).

Emergence vs. Side-dress application

There was an interaction between N fertilizer rates applied at emergence and at side-dress (Table 6) regardless of the N rate applied at planting. When 50 lb/ac of N was applied at emergence, yield increased from 286 to 342 cwt/ac with application of 100 lb/ac of N in side-dress. But with 100 lb/ac of N applied at emergence, there was no difference in yield between 50 and 100 lb/ac applied at side-dress.

The results of the interaction between emergence and side-dress application for potatoes indicate that the combination of 50 lb/ac of N at emergence and 50 lb/ac of N at side-dress

(total of 100 lb/ac of N) resulted in significant reduction of tuber yields compared to the other 3 combinations, with higher N rates.

Table 6. Yield for the interaction of planting with emergence and emergence with side dress application timing treatments for potatoes grown with tile drainage.

Emergence N (lb/ac)	Yields (cwt/ac)	
	Side dress N (lb/ac)	
	50	100
50	286 bB	342 aA
100	332 aA	343 aA

†Values followed by the same lowercase letters within each Side-dress N treatment indicate that the mean of yield are not significantly different ($P < 0.05$) according to t-test between 50 and 100 lb/ac applied at Emergence N (columns).

†Values followed by the same uppercase letters within each Emergence N treatment indicate that the mean of yield are not significantly different ($P < 0.05$) according to t-test between 50 and 100 lb/ac applied at Side-dress N (rows).

Subsurface Drip Irrigation

There was a significant effect of N fertilizer application rates at planting on potato yield under SDI, however, a linear or quadratic trend was not significant. The application of 50 or 100 lb/ac of N at planting, resulted in a 13% increase in yield compared to 0 lb/ac of N, which indicates the importance of a N fertilizer application at planting (Roberts et al., 1982).

Table 7. Main effect of N fertilizer rates applied at planting on potato yield irrigated with subsurface drip irrigation (SDI) and overhead irrigation.

Planting N (lb/ac)	Yields (cwt/ac)	
	SDI	Overhead
0	318 b	317 b
50	366 a	331 b
100	368 a	365 a
Regression	ns	ns

†Values followed by the same lowercase letters within irrigation systems indicate that the mean of yield are not significantly different ($P < 0.05$) according to Tukey for N fertilizer rates applied at planting (column).

Regression analysis for effect of N planting rates; L, linear; Q, quadratic, significant at the 5% (*), non significant (ns).

Overhead sprinkler Irrigation

Similarly to SDI, there was a significant effect of the N rate application treatments on potato tuber yield at planting for overhead sprinkler irrigation system (Table 7). Under the overhead sprinkler irrigation system the application rate of 100 lb/ac of N applied at planting resulted in significant yield increase compared to 0 or 50 lb/ac applied at the same timing.

Overall effect of total N-fertilizer rate on total tuber yield

Figure 6 shows potato yield response to total N-fertilizer rates under all four irrigation systems. There was a significant quadratic response of tuber yield to increased N fertilizer application in all irrigation systems ($P < 0.05$). According to the quadratic model, potato yields were maximized at 326 cwt/ac with 221 lb/ac of N for seepage, 353 cwt/ac with 278 lb/ac of N for tile drainage; 370 cwt/ac with 239 lb/ac of N for SDI and 361 cwt/ac with 280 lb/ac of N for overhead system. Although potato yields were maximized between 221 and 280 lb/ac of N, there were no significant differences in tuber yield for N fertilizer rates of 200; 250 and 300 lb/ac within each irrigation system (Fig. 6).

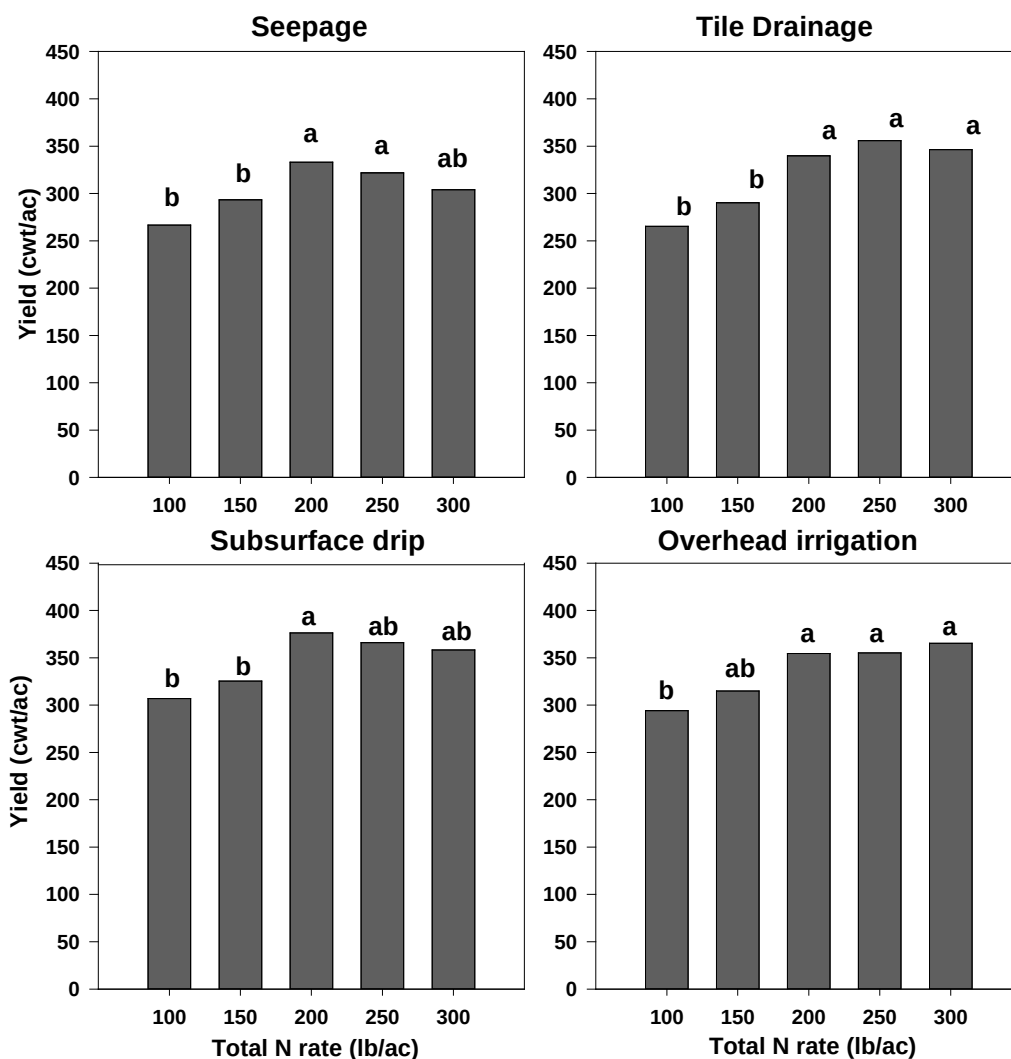


Figure 6. Potato yield response to total N fertilizer rates applied under seepage, tile drainage, subsurface drip irrigation (SDI) and overhead sprinkler irrigation during spring 2015, Hastings, FL.

Conclusion

This field study was conducted during Spring 2015 to evaluate irrigation water use, soil moisture and water table dynamics under tile drainage, overhead sprinkler, subsurface drip and seepage irrigation. In each irrigation system, potato yield response to N-fertilizer rate and timing of application was also tested. Seepage irrigation required more irrigation water to keep soil moisture at desirable levels, which resulted in the lowest irrigation water use efficiency (11.8 kg/m^3), while alternative irrigation systems produced similar or higher tuber yields with

low irrigation water requirements. The irrigation water use efficiency was 25.3; 31.6 and 36.3 kg/m³, for tile drainage, subsurface drip and overhead sprinkler irrigation, respectively. The application of N fertilizer of 50 and 100 lb/ac at potato planting resulted in significant higher tuber yield compared to the absence of N fertilizer at the planting. The highest potato yield was achieved with total N-fertilizer treatment rates above 200 lb/ac for all irrigation systems. There were no significant differences in tuber yield for N fertilizer rates between 200 and 300 lb/ac. A second year of data collection is necessary to increase the reliability of the testing, development and validation of the BMPs for potato production in Florida under different irrigation systems.

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