

Corn Irrigation and Fertilizer Use BMPs versus Conventional Growing Practices, a Two-Year Overview

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Abstract. Can fertilizer be reduced and irrigation scheduling be optimized in corn production without reducing yield? The answer to this question has been studied during 2015 and 2016 on sandy soils in the Suwanee River, Florida region. Due to karst topography, rapid water flow and absence of a natural filtration system, an increased vulnerability to groundwater pollution characterizes this area. Thus, excess nitrogen (N) fertilizer applied with the intention of obtaining higher yields, is a potential threat to waterbodies. The main objective was to improve irrigation and fertilizer Best Management Practices (BMPs) compared to conventional practices. Five irrigation treatments determined irrigation by: (i) GROW, mimicking grower's practices, (ii) SWB, using a theoretical soil water balance, (iii) SMS, monitoring volumetric water content measured by soil moisture sensors and triggered using maximum allowable depletion (MAD) and field capacity (FC) as thresholds to refill the soil profile, (iv) Reduced: irrigation (60% of GROW) representing a low irrigation treatment and (v) NON: non-irrigated plots. Three fertility rates: F1=300, F2=220 and F3=140 lb N/ac were evaluated. The experimental design consisted of a randomized complete block arranged in a split plot with four replicates. During 2015, yield was not significantly different across irrigated treatments (GROW, SMS and Reduced: 193, 191 and 201 bu/ac); however, the non-irrigated treatment had significantly lower yield than all other treatments except SWB (SWB and NON: 178 and 143 bu/ac, respectively). Fertility rates 300 and 220 lb N/ac (196 and 180 bu/ac), or 220 and 140 lb N/ac were not significantly different (180 and 168 bu/ac); however, the 300 lb N/ac treatment was significantly higher than 140 lb N/ac (196 bu/ac vs. 168 bu/ac, respectively). In 2016, no significant differences in yield were found among irrigated treatments, except versus the NON treatment which had significantly lower yield (GROW, SWB, SMS and Reduced: 202, 184, 188, 191 bu/ac vs. NON: 127 bu/ac). Fertility treatments did not differ statistically (F1, F2 and F3: 183, 180 and 173 bu/ac). Irrigation and fertilizer were reduced without reducing yield by using BMPs compared to conventional practices during the first two years of research.

Keywords. Irrigation scheduling, soil moisture sensors (SMS), water conservation, BMPs, N leaching, corn.

Introduction

The Upper Floridan Aquifer (UFA) is the main aquifer in Florida and one of the most productive karst aquifers in the world. Thick carbonate deposits comprise the aquifer and underlay 116,000 square miles among Florida, Georgia and Alabama. The Suwannee River Basin (SRB) is located within the Coastal Plain and it comprises a highly variable hydrogeological system. The southern third of the basin is comprised by a thin layer of highly porous sands which overlies limestone karst and the UFA (Katz and Raabe 2005).

Most of the north-central Florida regions underneath the UFA are unconfined and characterized by a karst topography. By the dissolution of the carbonate rocks, karst features develop zones with enhanced porosity causing a highly heterogeneous aquifer system with rapid rates of groundwater movement and recharge (Katz et al. 2009; Tihansky and Knochenmus 2001). As well, direct pathways can be created between surface and groundwater, allowing rapid transport of nutrients or pollutants with little degradation or attenuation (Katz et al. 2009).

Nitrate (NO_3^-) is the most common and soluble form of nitrogen (N); thus, it can easily leach from the soil profile by irrigation or rainfall into the groundwater and streams (DeSimone 2009). Background NO_3^- concentrations are considered below laboratory detection limits (i.e. 0.05 mg/L NO_3^- , as N; i.e. natural concentrations without human activity intervention). N may originate from natural sources (e.g. precipitation, aquifer materials and organic debris leaching), as well as, from anthropogenic activities (e.g. fertilizer applications, wastewater, animal production) (DeSimone 2009). Nitrate from both sources is possibly the most widespread pollutant in groundwater that can persist for decades (Hallberg and Keeney 1993).

Several studies have shown the increase of nitrate-N in springs from background concentrations (≤ 0.1 mg/L $\text{NO}_3\text{-N}$) to above 5 mg/L $\text{NO}_3\text{-N}$ during the last 40 years (Katz et al. 1999; Katz 2004). Steady increments of nitrate-N have been found in several spring waters within the SRB in Florida (e.g. Convict spring with 8 mg/L $\text{NO}_3\text{-N}$) (Upchurch et al. 2007). During the period 1940-1998, continued studies in the SRB area reported evidence that the greatest nitrate-N pollution found in the lower basin comes from fertilizer sources (Katz et al. 2009).

The north-central regions are estimated as the most pollutant vulnerable regions due to the potential groundwater degradation (Arthur et al. 2007). Some of the consequences are excessive algal growth in aquatic systems, a reduction of the available dissolved oxygen, as well as, death to other organisms (FDACS 2015). Thus, the implementation of Agricultural Best Management Practices (BMPs) is imminent in areas susceptible to pollutants.

Total Maximum Daily Loads (TMDLs) and Best Management Practices (BMPs)

The maximum amount of a pollutant that can be discharged to a waterbody and meet state water quality standards is referred as a TMDL. Florida Department of Environmental Protection (FDEP) must identify impaired surface waters and establish TMDLs entering waterbodies (e.g. TMDLs established for total N) (FDACS 2015).

BMPs are defined as “practical, cost-effective actions that agricultural producers can take to conserve water and reduce pollutant loads (i.e. pesticides, fertilizers, animal waste and others) entering water resources. BMPs are designed to benefit water quality and quantity while maintaining or even enhancing agricultural production” (FDACS 2017).

Irrigation BMPs address the irrigation scheduling methods; whereas nutrient BMPs focus on the crop nutrient needs, sources and applications to reduce potential water and nutrient losses to the environment (FDACS 2017). Examples of nutrient BMPs consist of fertilizer timing (i.e. apply it in small amounts just before the uptake occurs), performing a soil test prior any fertilizer application, as well as, monitoring crop nutritional status. Thus, fertilizers are only applied when needed to avoid potential losses to the environment (FDACS 2015; Simmone 2006). Then, irrigation BMPs are for example implementing an irrigation schedule to determine how much and when to irrigate supplying the plant's requirements while reducing water and nutrient losses. If the amount of water applied exceeds the amount of water required by the crop, deep percolation and nutrient leaching from the rootzone to the environment occurs. Greater irrigation efficiency is achieved when based on weather and evapotranspiration (ET) parameters or soil moisture content (Irrigation Association 2011).

Typical corn production vs. new strategies of production

Corn is a high water and nutrient demanding crop. Traditionally, a calendar-based irrigation schedule is used by growers. This method uses growers' general knowledge of the crop and local weather conditions and applies water according to the crop stages (i.e. the amount of water applied increases as the plant grows). Commonly, nitrogen (N) fertilizers are applied exceeding the N uptake by the plants allowing the excess N to potentially leach increasing the N load to groundwater sources.

The use of soil moisture sensors (SMS) to continuously monitor the volumetric water content (VWC) in the soil, provides information about the status of the soil and the water available to the plants. Therefore, irrigation is applied only when it is needed avoiding overirrigation or deep percolation, while reducing potential N leaching.

Irrigation and N BMPs could be a management strategy to target load reductions for water quality improvements. The objective of this paper is to compare conventional irrigation practices and common applied fertility rates with new BMPs that might increase irrigation efficiency and reduce N leaching to the groundwater.

Materials and Methods

Experimental site and design

The experimental site is located at the Suwannee Valley Agricultural and Extension Center (SVAEC), near Live Oak, Florida. Predominant soils were identified as sandy Blanton-Foxworth-Alpin complex, Chipley-Foxworth-Albany, and Hurricane-Albany-Chipley soils (USDA 2013).

The experimental design was a randomized complete block arranged in a split plot. This design included four replicates (i.e. blocks) per treatment, five main plots (i.e. irrigation treatments) with three subplots (i.e. nitrogen rates) for a total of 60 plots. Each plot was 40 ft long x 20 ft wide separated by 20 ft alleys. An alley of 40 ft was included between the blocks and an alley of 20 ft separated the plots (Figure 1).

Corn (hybrid Pioneer 1498 YHR/Bt) was planted on 3 April 2015 and on 22 March 2016. A row spacing of 30 inches and a plant spacing of 6.5 inches were used for a total plant population of 32,500 plants/ac. Corn was harvested on 18 August 2015 and on 3 August 2016 on the 6th and 7th planting rows starting 20 ft inside each plot to avoid boarder effects, for a total of 100 ft² of each plot.

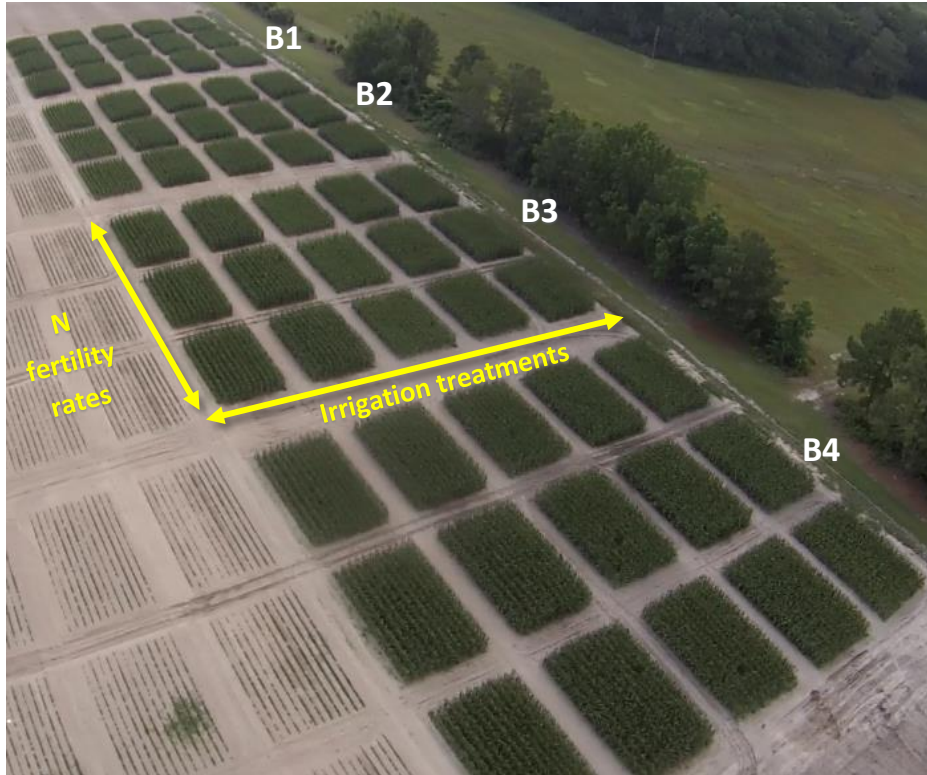


Figure 1. Aerial view of experimental site located at Suwannee Valley Agricultural and Extension Center, near Live Oak, Florida.

Crop evapotranspiration (ET_c) was calculated using phenologically based crop coefficients (K_c values: $K_{c\text{-ini}}=0.25$, $K_{c\text{-max}}=1.05$ and $K_{c\text{-end}}=0.55$) (K-State Research & Extension Mobile Irrigation Lab 2014) and reference evapotranspiration (ET_o) as:

$$ET_c = K_c ET_o$$

ET_o was calculated using weather data (daily minimum and maximum temperature, solar radiation, relative humidity and wind speed) from an onsite Florida Automated Weather Network (FAWN 2017)) with the FAO-56 Penman-Monteith equation (Allen et al. 1998).

Treatments

Irrigation

The irrigation system consisted of a two span Valley Linear End feed 8000 (Valmont Industries 2015), Valley, NE) with a Variable Rate (VRI) package. This machine is capable of irrigating a field area of 16.6 acres, using a flow of 300 GPM (18.03 GPM/acre) providing an application rate (AR) of 0.96 in/day at maximum capacity. Senninger (Senninger Irrigation, Inc., Clermont, FL) LDN-UP3 Flat Medium Groove $\frac{3}{4}$ M NPT nozzles were attached to drops at a 10 ft sprinkler spacing. To maintain a constant flowrate, Valley 10 psi pressure regulators (PSR-2 10 10(Psi) 3/4 F NPT) were installed on each drop.

The irrigation treatments consisted of:

1. I1 (GROW): irrigation mimicked grower's irrigation practices which consisted of zero irrigation for the first 30 days after planting (DAP) unless severe dry or windy conditions occurred. Beginning

on 31 DAP, a target amount of 1"/wk was established and could be made up of rain or irrigation but rain events had to be 0.25" or larger. For 40-59 DAP a 1.5"/wk target was established with irrigation events of 0.4". Irrigation was skipped if 0.5-0.75" rainfall occurred and two irrigations were skipped if >0.75" of rain occurred. For 60-105 DAP a 2-2.5"/wk irrigation target was used unless 0.5-1" of rain occurred the day prior to a scheduled irrigation. Two irrigations were skipped if >1" of rain occurred. Finally, around 105 DAP at full dent stage, weekly irrigation targets were reduced to 1.5"/wk until finally irrigation was terminated at physiological maturity. Irrigation was skipped if 0.5-0.75" rainfall occurred and two irrigations were skipped if >0.75" of rain occurred. This treatment used a fixed application rate of 0.4".

2. I2 (SWB): irrigation was determined using a theoretical soil water balance. Weather data (i.e. rainfall, ET, temperature) was obtained from the on-site FAWN weather station located in Live Oak, FL. Calculated crop evapotranspiration (ET_c) was used to estimate daily soil moisture and schedule irrigation when 50% of the available moisture was depleted during vegetative stages and when 30% moisture depletion during reproductive stages.
3. I3 (SMS): soil moisture content was monitored using the SENTEK probes (Sentek Pty Ltd 2003). Irrigation was determined using the maximum allowable depletion (MAD) and field capacity (FC) points to refill the soil profile with irrigation according to guidelines proposed by (Zotarelli et al. 2013). Volumetric water content (VWC) was monitored by plots; thus, when VWC at any replicate decreased below MAD, all replicates were irrigated to satisfy the needs of that plot.
4. I4 (Reduced): it applies only a 60% of I1 treatment but using the same frequency with fixed application rates of 0.4". It represents a lower irrigation treatment scenario.
5. I5 (NO): non-irrigated plots or control.

Fertilization

Three N fertility rates were evaluated: F1=300 lb/ac; a high scenario commonly applied in corn production, F2=220 lb/ac; representative of the UF-IFAS recommended rate (Mylavarapu et al. 2015), and F3=140 lb/ac; a low N scenario. The low and high treatments were 36.4% lower or higher than the recommendation.

During both years, a pre-plant soil sampling analysis was performed to determine initial soil conditions. At planting an initial liquid application of 30 lb/ac of 16-16-0 was applied on the soil surface across all treatments. The N fertility rates started 14 DAP with the first granular application (i.e. V3 corn growth stage) where 8, 22 and 30 lb N/ac of 33-0-0 (16.49% Ammoniacal N and 16.51% Nitrate-N), were applied on F3, F2 and F1, respectively.

The second granular application (33-0-0) took place on 1st May 2015 and 27 April 2016 (at V6 corn growth stage). A total of 10, 24 and 40 lb N/ac were applied on F3, F2 and F1, respectively. Afterwards, split liquid side-dress applications (28-0-0) took place at between V8 and VT- (tasseling) corn growth stages. At each liquid sidedress application the fertility rates F3, F2 and F1 had 23, 36 and 50 lb N/ac, applied respectively. In 2016, a supplemental granular application of 30 lb N/ac (21-0-0 at 145 lb/ac) was performed on 19 April to compensate the lost fertilizer due to leaching rain, following the BMP protocol recommendations (FDACS 2015).

Phosphorus and potassium applications were performed based on soil analysis results and equally applied across all fertility rates. Therefore, 75 lb P/ac of 0-46-0 (Triple Superphosphate) were applied during the first granular application in 2015; whereas no phosphorous was required in 2016. In terms of potassium,

98 lb K/ac and 77 lb K/ac of 0-0-60 were applied during the first and second granular applications in 2015, respectively; whereas 35 lb K/ac of 0-0-60 were applied on both granular applications in 2016.

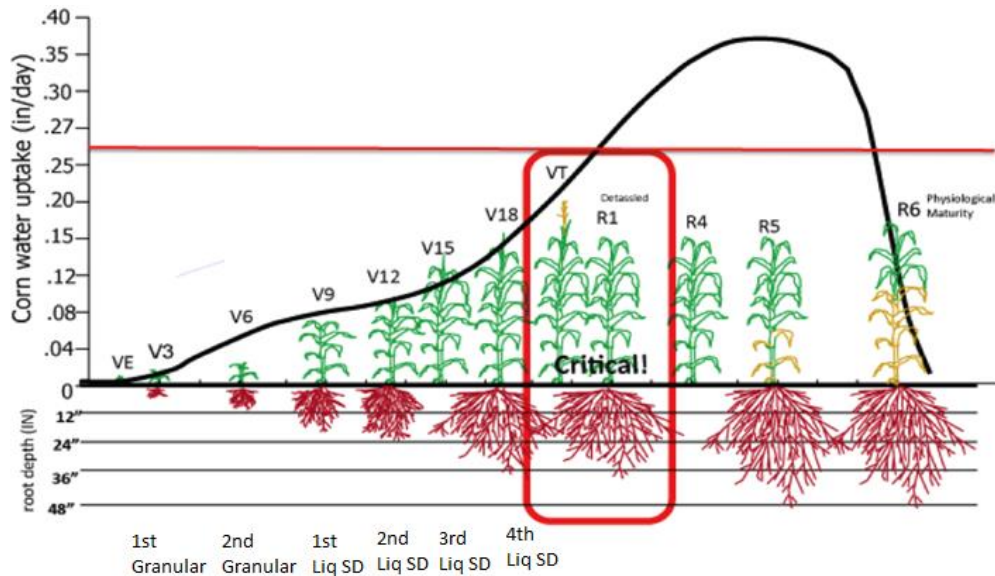


Figure 2. Fertilizer applications: initial pop-up (16-16-0), two granular applications and four liquid sidedress (Liq. SD) applications performed in corn experiment 2015 and 2016. An additional N application was performed in 2016 due to a leaching rain (see details in fertilization section) (Cropmetrics 2014).

Statistical analysis

The statistical program SAS (SAS Institute Inc. 2013, Cary, NC) was used to analyze final corn yield. Further, ANOVA and least squared means (LSD) differences with normal p-values and Tukey's adjusted p-values for multiple comparison were used in this experiment.

Results

Irrigation

In 2015, the corn growing season spanned from 3 April to 18 August. Cumulative rainfall was 21.9 inches and estimated crop evapotranspiration (ET_c) was 19.5 inches. During this period the GROW, SWB, SMS, Reduced and NON treatments applied 12.6, 7.3, 6.0, 8.3 and 0.6 inches of water, respectively. Irrigation treatments achieved 42%, 53%, 34% and 95% water savings in comparison to the GROW treatment, which represents conventional irrigation practices.

In comparison, 2016 was a drier year with the growing season from 22 March 22nd to 3 August. Cumulative rainfall was 14.6 inches and estimated ET_c was 16.6 inches. Larger amounts of irrigation were required due to the non-uniform rainfall distribution through the growing season. Irrigation treatments applied 20.0, 12.2, 11.5, 12.6 and 1.0 inches for GROW, SWB, SMS, Reduced and NON, respectively. Water savings achieved were 39%, 43%, 37%, 95% compared to GROW, correspondingly.

Yield

By irrigation treatment

In 2015, the GROW, SWB, SMS, Reduced and NON resulted in 193, 178, 191, 201 and 143 bu/ac. Yield obtained by irrigated treatments did not differ statistically versus the non-irrigated, except the SWB. During the first year of evaluation, this treatment initially had a 50% maximum allowable depletion (MAD) through the whole growing season and fixed application rates of 0.75". These conditions were limiting the available water during the reproductive stages, causing water stress to the plants which negatively impacted yield (Figure 3).

By contrast, in 2016 the MAD threshold for SWB treatment was 50% during vegetative stages and it was reduced to 30% in reproductive stages. These conditions allowed greater moisture in the soil during reproductive stages, which have a greater sensitivity to water stress. Average final yields resulted in 202, 184, 188, 191 and 127 bu/ac for GROW, SWB, SMS, Reduced and NON treatments, respectively. No significant differences were found between irrigated treatments, only versus the non-irrigated (NON) treatment, which resulted in a significantly lower yield (Figure 3).

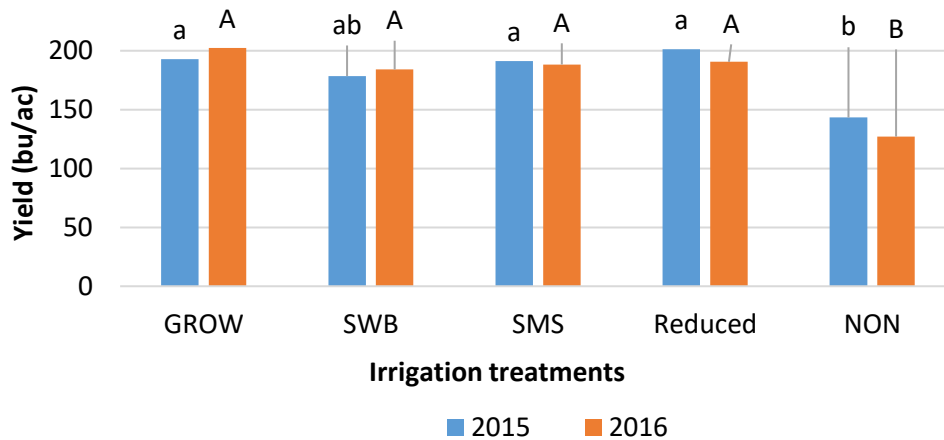


Figure 3. Average corn yields resulted from irrigation treatments in 2015 and 2016. Lowercase and uppercase letters indicate 95% CI for irrigation treatment means in 2015 and 2016, respectively.

By fertility treatment

Average final yields for the three fertility rates resulted in 196, 180 and 168 bu/ac for F1 (high), F2 (medium) and F3 (low), respectively during 2015. No statistical differences in yield were found between the high and the medium fertility rates. Neither the final yields obtained from the medium and the low fertility rates. Only the high N rate (F1=300 lb N/ac) resulted in a statistically higher yield (196 bu/ac) in comparison to the low N rate (F3=140 lb N/ac, 168 bu/ac) (Figure 4).

In 2016, F1, F2 and F3 final yields averaged: 183, 180 and 173 bu/ac, respectively. No statistical differences were found among the three fertility rates. Due to a leaching rain after the first granular application, an application of 30 lb N/ac extra were applied following the BMP recommendations.

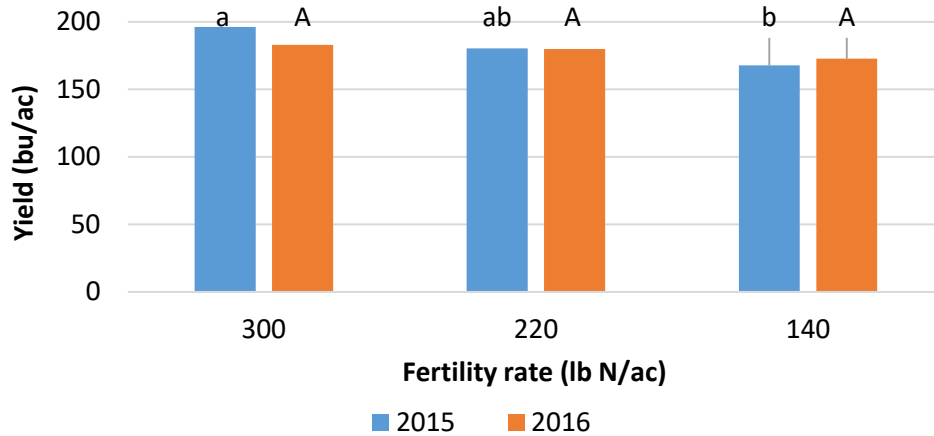


Figure 4. Average corn yields resulted from evaluated N fertility rates (F1, F2 and F3= 300, 220 and 140 lb N/ac, respectively) in 2015 and 2016. Lowercase and uppercase letters indicate 95% CI for irrigation treatment means in 2015 and 2016, respectively.

Summary and Conclusions

In 2015, the irrigation strategies evaluated (i.e. SWB, SMS and Reduced) resulted in total water savings of 42%, 53%, 34% compared to the GROW treatment, which mimics common irrigation practices in corn. Reducing the irrigation amounts did not have a negative impact on yield. No significant differences in yield were found between the irrigated treatments, only the SWB treatment resulted in statistically lower yields.

In 2016, the SWB, SMS and Reduced treatment achieved 39%, 43% and 37% water savings vs. GROW treatment. The difference between years was attributed to the variation in rainfall amounts and distribution patterns between 2015 and 2016. Greater amounts of irrigation were required in 2016; however, none of the irrigation alternatives resulted in negative impacts on yield. Average yields did not differ statistically compared to the conventional irrigation practices.

In 2015, following the UF/IFAS corn N fertilization recommendations (F2=220 lb N/ac) resulted in average yields with no statistical difference than average yield obtained with conventional N applications (F1=300 lb N/ac). Thus, same yield could be achieved with 220 lb N/ac while reducing the N applications by 26.6%. In 2016, no statistical differences were found between the three N fertility rates evaluated.

The implementation of BMPs focused on different irrigation strategies (i.e. SWB, SMS and Reduced) resulted in yields without statistical differences than the conventional irrigation practices and with substantial water savings in both years of evaluation. As well, no reductions in yield were found when following UF/IFAS recommendations (220 lb N/ac). These represent potential solutions to reduce N leaching and increase irrigation efficiency in corn production in Florida.

Acknowledgments

The ongoing research is supported by FDACS, FDEP and the SRWMD. Special thanks to M. Gutierrez, D. Hensley, M. Thomas, C. Harchick from ABE Department, as well as, Ben Broughton, Mike Boyette and staff from SVAEC and UF/IFAS staff for their assistance with field operations and project design.

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