UF IFAS Extension UNIVERSITY of FLORIDA

UF/IFAS PEER REVIEWED AE615

doi.org/10.32473/EDIS-AE615-2026

Agricultural and Environmental Implications of Information-Driven Irrigation Scheduling: Insights from a Field-Scale Study with a Gravelly Loam Soil in South Florida[1]

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Introduction

Growing crops in Florida requires sufficient water to satisfy crop demands. Although south Florida has a relatively large annual rainfall of about 59 inches (in), agricultural systems cannot rely solely on natural rainfall due to its highly variable nature and frequent dry spells, especially during late winter/early spring. In addition, south Florida's soil is primarily oolitic limestone-based with low water-holding capacity; the surficial groundwater aquifer, such as the Biscayne Aquifer, is made up of highly permeable limestone and sandstone. The unique hydrological characteristics of the soil and aquifer cause water to drain quickly. Thus, effective irrigation management is critical. Conventional irrigation scheduling methods commonly used in south Florida are often based on a predetermined calendar (Zotarelli et al. 2010; Bayabil et al. 2020; Palacios et al. 2023) and tend to over-irrigate, resulting in the loss of fertilizers with draining water, which is also referred to as nutrient leaching, wasted irrigation water, and loss of applied fertilizer that is not taken up by plants. In addition to saving water and reducing nutrient loss, good irrigation practices can also help reduce greenhouse gas emissions. When soil stays too wet from overwatering, it can release gases such as nitrous oxide, which contribute to global warming. By keeping soil moisture at an appropriate level, smart irrigation methods can help protect both crops and the environment. This article presents findings from a study (Song et al. 2022) that investigated how irrigation scheduling methods using soil moisture sensors and estimates of water loss from soil and plants (i.e., evapotranspiration) can conserve water and reduce nutrient loss while maintaining or even improving crop productivity in south Florida. The insights gained are intended to help farmers, homeowners, and Extension agents better understand the benefits of information-driven irrigation scheduling and adopt an evidence-based practice for improved agricultural productivity and environmental sustainability.

Field Experiment

Two field experiments were conducted at the UF/IFAS Tropical Research and Education Center (UF/IFAS TREC) in Homestead, FL, to test four irrigation scheduling methods on snap beans and St. Augustine turfgrass (Figure 1). These crops were chosen for their economic and practical importance. Snap beans (*Phaseolus vulgaris* L.) are a major vegetable crop in Florida and across the United States, while St. Augustinegrass (*Stenotaphrum secundatum*) is the most widely used lawn grass in Florida, with turfgrass acreage expected to expand further as urbanization increases.

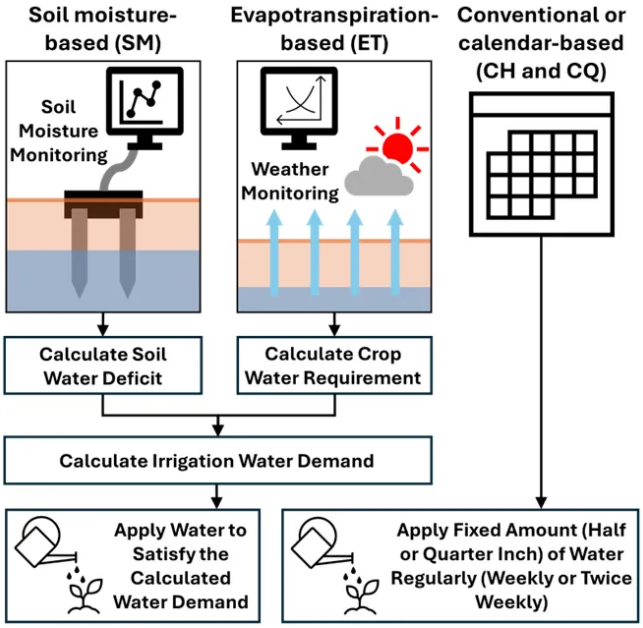


Figure 1. Overview of the field experiment conducted at UF/IFAS TREC in Homestead, FL.
Credit: Young Gu Her, UF/IFAS.

Snap beans were grown for two seasons (December 2019–February 2020 and February–April 2020), while St. Augustinegrass was monitored over a five-month period from January to June 2020.

Weather data (precipitation, temperature, humidity, solar radiation, and wind speed) were obtained from a Florida Automated Weather Network (FAWN) station located near the site. The soils are Krome very gravelly loam, which are shallow and moderately well-drained and overlay limestone bedrock, making irrigation essential for both agriculture and landscaping in south Florida.

The irrigation scheduling methods were:

1. **Soil moisture-based (SM)**: Irrigation was applied when soil moisture dropped below crop-specific thresholds, restoring soil water to field capacity. Thresholds were set at the wilting point plus 55% of available water for snap beans and 60% for turfgrass.
2. **Evapotranspiration-based (ET)**: Irrigation was scheduled using the FAO-56 dual crop coefficient method, which estimates crop water demand based on weather data and crop-specific factors.
3. **Conventional half inch (CH)**: A fixed half inch of water was applied per event once a week.
4. **Conventional quarter inch (CQ)**: A fixed quarter inch of water was applied per event once a week.

For the two conventional methods (CH and CQ), irrigation followed local grower and homeowner practices (weekly for snap beans, twice weekly for turfgrass). Irrigation events were skipped if measurable rainfall (> 0.01 in) occurred.

Box 1. Practice summary for SM and ET irrigation scheduling on gravelly loam soils.

When to Irrigate (Thresholds)

- In this study on Krome very gravelly loam, irrigation was triggered when the average soil moisture in the root zone dropped to about 15.0% for snap beans and 15.5% for turfgrass.
- These trigger points correspond to roughly wilting point + 55%–60% of AWC.
- As a practical rule, irrigate when about 55% to 60% of the available water has been depleted, then refill the root zone toward field capacity.

How Much Water Was Applied (Seasonal Irrigation Totals)

- Snap beans
  - SM: 6.3 in
  - ET: 6.2 in
  - CH: 7.5 in
  - CQ: 5.0 in
- Turfgrass
  - SM: 7.7 in
  - ET: 6.8 in
  - CH: 21.0 in
  - CQ: 11.5 in

Findings

See Table 1.

Water Quantity

The conventional irrigation scheduling methods over-irrigated or under-irrigated the snap beans (Table 1). For example, CH (applying the half inch of water per irrigation event) was found to have applied water significantly more than the other treatments. On the other hand, CQ (the quarter inch) gave the snap beans substantially less water than the other treatments. The amounts of irrigation water recommended by the SM and ET methods were very close to each other: 6.3 in and 6.2 in on average, respectively. On average, the SM and ET methods applied 83% of the amount of water that the CH method provided. Compared to CQ, however, the SM and ET methods provided 25% more water. In the case of turfgrass, the SM and ET methods applied significantly less water to the plots than the conventional methods. The SM and ET methods could save, on average, 33% to 63% (SM: 7.7 in) and 41% to 68% (ET: 6.8 in) of water, respectively, compared to CQ (11.5 in) and CH (21.0 in). The ET method was found to be slightly more efficient than the SM method.

Water Quality

Irrigation water can wash away nutrients and fertilizers from plant surfaces (e.g., foliar applications) and soil, reducing nutrient availability and negatively affecting the

environment. Nitrate (NO_3^-), ammonium (NH_4^+), and total phosphorus (TP) were selected as water quality indicators due to their relevance in nutrient pollution and fertilizer management. These nutrients are frequently associated with fertilizer losses from agricultural fields and urban landscapes, posing risks to groundwater and surface water quality. The four different irrigation scheduling methods did not show significant differences in the concentrations of these water quality parameters at either the snap bean or turfgrass plots (Table 1). The monitoring data showed that soil water did not increase to the field capacity during the evaluation period. This was likely due to the small amount of rain received (less than 0.40 in over the two weeks following irrigation) and high evapotranspiration rates (approximately 0.16 in/day to 0.20 in/day on average). This imbalance between low rainfall input and high atmospheric demand prevented sufficient soil moisture recovery. The relatively dry soil conditions during the snap bean growing period prevented water from percolating, since gravitational water only drains from the root zone when soil moisture content exceeds field capacity.

In the case of turfgrass, however, the amount of soil water percolated from the plots treated with SM and ET was significantly lower than that of CH. SM and ET reduced the amount of water moving downward through soil, also referred to as percolation, by 48% and 40%, respectively. In the SM and ET treatments, irrigation water was applied only when the soil water content dropped below the predefined threshold values (15.0% for snap bean and 15.5% for turfgrass), corresponding to the sum of the wilting point and 55% or 60% of available water content, respectively. In contrast, the conventional methods irrigated on fixed schedules regardless of soil water conditions. In addition, the SM and ET methods applied sufficient water to reach field capacity. Such alternative scheduling mechanisms can keep soil water content lower than the field capacity, helping to minimize the loss of excess gravitational water and associated nutrient leaching.

In the cases of the CH and CQ methods, turfgrass received twice as much irrigation as snap beans, two applications per week compared to one, which helps explain the greater percolation observed in the turfgrass plots (e.g., 1.70 in) relative to the snap bean plots (e.g., 0.87 in). In addition, the turfgrass plots were irrigated for much longer periods (161 days vs. 51–58 days), requiring more water.

The amount of nutrients leached from the snap bean and turfgrass plots was not significantly different by the various irrigation scheduling treatments. For instance, although the amount of water percolated from the turfgrass plots treated with CH and ET (or SM) differed significantly, with CH plots showing greater percolation, this did not lead to meaningful difference in nutrient leaching via gravitational soil water. Average concentrations of leached nutrients remained relatively consistent across treatments, with nitrate ranging from 1.2 ppm to 1.6 ppm, ammonium from 0.4 ppm to 0.6 ppm, and total phosphorus from 0.2 ppm to 0.3 ppm. The drainage of gravitational soil water had little effect on the nutrient leaching, as variations of the nutrient concentrations were substantially greater than differences in the amount of water draining below the root zone. This result suggests that nutrient loss from the soil was affected more by the amount of fertilizer present than by the amount of water drained through the soil.

Greenhouse Gas Emission

Soil water content controlled by irrigation influences soil microbial activity and nutrient chemical processes, affecting greenhouse gas emissions. Of the 64 measurements of carbon dioxide (CO_2) emission (i.e., the rate of CO_2 emissions from the soil) taken at the snap bean and turfgrass plots, only 17 were above the detection limit, and all of these occurred in the turfgrass plots. CO_2 emissions were higher in June than in February, when most of the detectable emissions were recorded. Although emissions increased in June, there was no difference in CO_2 emission among the different irrigation treatments (Table 1).

For example, the average amount of CO_2 released from the soil, CO_2 flux as an indicator of biological activity, was very similar across treatments. In turfgrass plots, CO_2 release ranged from 0.62 units to 0.67 units, while in snap bean plots, it ranged from 0.44 units to 0.52 units. These small differences were within the expected range of variation, meaning irrigation had no significant impacts on CO_2 emission in the study with the gravelly loam soil.

As for nitrous oxide (N_2O) and methane (CH_4), both gases were consistently too low to be detected in any of the treatments throughout the study. This is likely because the soil was gravelly and drained well, keeping oxygen levels high. Such conditions prevent the low-oxygen environments that typically encourage microbes to produce these greenhouse gases.

Productivity and Biomass

The four different irrigation scheduling methods did not significantly affect the snap bean productivity or turfgrass biomass (Table 1). For example, snap bean pod yields ranged narrowly from 3.70 US ton/acre to 3.80 US ton/acre. Turfgrass aboveground biomass, which reflects the total weight of plant material above the soil, varied slightly from 0.71 US ton/acre to 0.76 US ton/acre across treatments, with no statistically significant differences detected. There was no statistically significant correlation between the amount of water applied and the biomasses. This result suggests that the information-driven

scheduling methods (i.e., SM and ET) can save water while maintaining crop growth or biomass.

In the case of snap beans, there was no significant difference in water use efficiencies, which are defined as yield per unit of irrigation water applied, between the calendar-based (or conventional: CH and CQ) and information-based (SM and ET) treatments. This could be attributed to the fact that only a small amount of rainfall contributed to the snap bean growth in the experiment period, making irrigation the primary water source across all treatments. As a result, variations in irrigation amounts had minimal impact on crop production per unit of water, or overall water use efficiency. On the other hand, the conventional treatment (CH and CQ) exhibited significantly lower turfgrass water use efficiencies compared to the information-driven treatments (SM and ET). The ET treatment provided the highest water use efficiencies, followed by SM, CQ, and CH. The use of efficient management practices can conserve natural resources and improve agricultural sustainability.

How to Use Advanced Irrigation Scheduling Methods

To help growers and homeowners adopt these irrigation scheduling methods, UF/IFAS has published step-by-step guidance through several EDIS articles. Table 2 summarizes key resources related to using soil moisture sensors and evapotranspiration data for scheduling irrigation. These articles are freely available and provide practical information tailored to different user needs.

The integration of soil moisture sensors (SM) and evapotranspiration (ET)-based irrigation scheduling offers significant advancements in agricultural water management, turfgrass management, and residential lawn care. These sensors provide real-time data on the soil's available water, allowing for precise scheduling and optimal plant growth. These technologies are particularly beneficial in well-drained soils, such as the gravelly loam Krome series, where water moves rapidly and retaining adequate moisture in the root zone is challenging. In addition, the technologies can lead to significant improvements in water conservation and crop yields across various agricultural contexts, including vegetable and citrus production (Muñoz-Carpena et al. 2003; Kadyampakeni and Guzmán 2021).

Summary

Using soil moisture sensors and weather-based tools to schedule irrigation helped save up to 30% of water compared to a fixed watering schedule, without reducing snap bean harvest or turfgrass growth. The four irrigation scheduling methods tested did not show major differences in how much fertilizer was lost through water draining out of the soil. Still, the use of soil and weather information tended to reduce extra water drainage, which can carry nutrients away from the root zone. Adjusting irrigation based on current field conditions can make water use more efficient and reduce the risk of fertilizer loss, especially during rainy or dry periods. The results show that these types of smart irrigation can help growers and homeowners manage water better without hurting plant growth, while also protecting the environment. The findings also suggest growers and homeowners consider adopting smart irrigation methods that respond to on-site conditions using sensors or weather data.

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Table 1. Summary of the findings from a study (Song et al. 2022) that investigated how irrigation scheduling methods influenced irrigation amount, measured soil water content, and turfgrass or crop responses.

Method	Soil Water Content	Nutrient Leaching	GHG Emission	Productivity
Soil Moisture Sensing (SM)	Moderately irrigated	Statistically indifferent to irrigation levels	Statistically indifferent to irrigation levels	Statistically indifferent to irrigation levels
Evapotranspiration (ET)	Moderately irrigated			
Conventional — Half Inch per Irrigation (CH)	Over-irrigated			
Conventional — Quarter Inch per Irrigation (CQ)	Under-irrigated			

Table 2. Summary of advanced irrigation scheduling methods discussed in the EDIS articles. SM: Soil moisture sensor. ET: Evapotranspiration estimate. "Crop/Plant" means the types of crops and plants used as an example in the article. "Year" represents the year of the article's most recent review.

Method	Title	Crop/Plant	Year	Link
SM	"Minimum Number of Soil Moisture Sensors for Monitoring and Irrigation Purposes"	Perennial pasture	2024	https://ask.ifas.ufl.edu/publication/HS1222
	"Smart Irrigation Controllers: How Do Soil Moisture Sensor (SMS) Systems Work?"	General	2025	https://ask.ifas.ufl.edu/publication/AE437
	"Common Questions When Using Soil Moisture Sensors for Citrus and Other Fruit Trees"	Citrus trees	2024	https://ask.ifas.ufl.edu/publication/AE551
	"Alternatives of Low Cost Soil Moisture Monitoring Devices for Vegetable Production in South Miami-Dade County"	Vegetables	2024	https://ask.ifas.ufl.edu/publication/AE230
	"Interpretation of Soil Moisture Content to Determine Soil Field Capacity and Avoid Over-Irrigating Sandy Soils Using Soil Moisture Sensors"	General	2025	https://ask.ifas.ufl.edu/publication/AE460
	"Interpretación del Contenido de la Humedad del Suelo para Determinar Capacidad de Campo y Evitar Riego Excesivo en Suelos Arenosos Utilizando Sensores de Humedad"	General	2025	https://ask.ifas.ufl.edu/publication/AE496
	"Field Devices for Monitoring Soil Water Content"	General	2024	https://ask.ifas.ufl.edu/publication/AE266
	"Automatic Irrigation Based on Soil Moisture for Vegetable Crops"	Vegetables	2024	https://ask.ifas.ufl.edu/publication/AE354
Both	"2025–2026 Florida Citrus Production Guide: Irrigation Management of Citrus Trees"	Citrus trees	2025	https://ask.ifas.ufl.edu/publication/CG093
	"Irrigation Scheduling for Young Pongamia (*Millettia pinnata* (L.) Panigrahi) Trees"	Pongamia	2023	https://ask.ifas.ufl.edu/publication/AE590

Method	Title	Crop/Plant	Year	Link
ET	"Evapotranspiration-Based Irrigation for Agriculture: Sources of Evapotranspiration Data for Irrigation Scheduling in Florida"	General	2023	https://ask.ifas.ufl.edu/publication/AE455
	"Evapotranspiration-Based Irrigation for Agriculture: Implementing Evapotranspiration-Based Irrigation Scheduling for Agriculture"	General	2025	https://ask.ifas.ufl.edu/publication/AE458
	"Net Irrigation Requirements for Florida Turfgrass Lawns: Part 2 — Reference Evapotranspiration Calculation"	Turfgrass	2024	https://ask.ifas.ufl.edu/publication/AE481
	"Net Irrigation Requirements for Florida Turfgrass Lawns: Part 3 — Theoretical Irrigation Requirements"	Turfgrass	2024	https://ask.ifas.ufl.edu/publication/AE482
	"Smart Irrigation Controllers: Operation of Evapotranspiration-Based Controllers"	General	2025	https://ask.ifas.ufl.edu/publication/AE446
	"Smart Irrigation Controllers: Programming Guidelines for Evapotranspiration-Based Irrigation Controllers, or ET Controllers"	General	2025	https://ask.ifas.ufl.edu/publication/AE445
	"Smart Irrigation Controllers: What Makes an Irrigation Controller Smart?"	General	2025	https://ask.ifas.ufl.edu/publication/AE442
	"Step by Step Calculation of the Penman-Monteith Evapotranspiration (FAO-56 Method)"	General	2024	https://ask.ifas.ufl.edu/publication/AE459
	"Programación de riego basado en el método de evapotranspiración para papaya (*Carica papaya*) en Florida"	Papaya	2024	https://ask.ifas.ufl.edu/publication/AE547
	"Irrigation Scheduling Tips for Tropical Fruit Groves in South Florida"	Tropical fruits	2025	https://ask.ifas.ufl.edu/publication/TR001
	"ET-Based Irrigation Scheduling for Papaya (*Carica papaya*) in Florida"	Papaya	2023	https://ask.ifas.ufl.edu/publication/AE540

[1] This document is AE615, a publication of the Department of Agricultural and Biological Engineering, UF/IFAS Extension. Original publication date March 2026. Visit the Ask IFAS website at https://ask.ifas.ufl.edu for the currently supported version of this publication. © 2026 UF/IFAS. This publication is licensed under CC BY-NC-ND 4.0.

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