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AE506

Interpreting Dye Test Results for Improved Drip Irrigation Management for the Mulched Vegetable-Production Systems in South Florida[1]

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Introduction

Florida's water withdrawals are expected to increase by 30% from 2000 to 2030. Conservation strategies need to be adopted to meet any potential shortfalls. One sector where efficiency improvements can mean significant water savings is agriculture. Traditionally, vegetable production systems in south Florida and the tri-county area of northeast Florida have employed seepage irrigation. This production system requires raising and maintaining the water table within 16–24 inches (40–60 cm) of the soil surface to supply water to the crop by upward movement. Seepage irrigation systems have typical water use efficiencies (WUE) between 20%–50%. Drip irrigation, however, can have up to 90% efficiency when used effectively. Adopting drip irrigation, which involves applying small amounts of water and fertilizer (fertigation) directly to the crop's root zone, leads to better water and nutrient use.

To reduce water and nutrient leaching, it is important to determine and implement management strategies to properly employ drip irrigation. Drip irrigation systems can supply water and nutrients based on crop needs and apply them in ways that minimize leaching beyond the root zone. These techniques can improve water and nutrient use, reduce production costs, and decrease environmental loss of nutrients. The shallow water table conditions in south Florida, combined with conductive soils with little water holding capacity, make it a challenge to supply needed water and nutrients and keep them in the root zone. Knowledge of how water moves and spreads in and below the raised plastic-mulched beds (typically 7–8 inches high) found in these productions systems is essential for improving irrigation management.

Dye tests can provide important information for implementing a proper drip irrigation management program. These tests are performed by injecting a soluble dye into the drip irrigation system. The movement of the dye into the soil with irrigation water allows for visual assessment of water movement in and below the bed for various run times, tape flow rates, and initial soil moisture conditions. Analyzing vertical and lateral dye movement under a variety of conditions allows decisions to be made about what flow rates, run times, soil moisture conditions, and emitter spacing most effectively deliver needed water and nutrients to the root zone with minimum leaching.

Due to factors such as soil type, depth to restrictive layers, bed geometry, and soil organic matter content, results of a dye test from one farm may not be transferable to another farm. On-farm dye tests provide simple, low-cost methods

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to understand how water and dissolved nutrients (e.g., nitrogen) will move within beds at a given farm. If it is not feasible for the grower to conduct an on-farm dye test, results from a dye test with similar site characteristics—including region, soil type, bed geometry, and drip tape—can be used. The intent of this publication is to explain procedures of a dye test and describe the movement pattern for Immokalee fine sand, a typical soil found in central and south Florida. We also show the effect of antecedent soil moisture on water movement in the bed. Soil moisture at the start of an irrigation cycle is important, because it helps determine the amount of water that a volume of soil can store against gravity drainage and therefore impacts the depth and width of the wetting front of water entering the soil. Water that is held in soil against gravity is accessible to plants for uptake. The soil moisture level representing the most amount of water held in the soil against gravity is called *field capacity* (FC). A soil at or above field capacity cannot hold any more water against gravity and any subsequent irrigation/rain water will percolate deeper into the profile. *Permanent wilting point* (PWP) is the lowest soil moisture level at which a plant can extract water held in the soil. The range of soil moisture between field capacity and permanent wilting point is *plant available water* (PAW). Optimum irrigation management should keep soil moisture levels between FC and a specified depletion level of PAW. Such management prevents leaching while also assuring that plants receive sufficient water.

Dye Test Results

Results of a dye test conducted at the research farm of the UF/IFAS Southwest Florida Research and Education Center in Immokalee, Florida, are presented here. Site characteristics were representative of those typically found in the raised-bed, plastic-mulch production systems of southern Florida.

Immokalee fine sand has a high hydraulic conductivity (a measure of how fast water moves in the soil) and low water holding capacity. Three different flow rate drip tapes representing a typical range of tapes utilized by growers in the area were tested: 0.24, 0.34, and 0.45 gallons per minute (GPM) per 100 feet. These drip tapes can be classified as *Low Flow*, *Medium Flow,* and *High Flow*, respectively (Table 1). Each tape was tested at run times of 0.5, 1, 1.5, and 2 hours. A total of twelve plastic-mulch beds were prepared for the dye test with each assigned a unique run time and drip tape flow rate. Soil moisture in each bed was measured (% volumetric water content) at the start of the dye test to examine the effect of initial soil moisture on water movement and storage. All tapes had an emitter spacing of 12 inches. Three-row blocks of beds were grouped by run time. Each run time block had a low-, medium-, and high-flow tape (see Figure 1). For further details on setting up, executing, and measuring results from an on-farm dye test, refer to EDIS document HS222, *How to Conduct an On-Farm Dye Test and Use the Results to Improve Drip-Irrigation Management in Vegetable Production* at http://edis.ifas.ufl.edu/hs222.

Table 1. Drip tapes evaluated in the dye test

Category	Flow Rate (GPM/100 ft)
Low Flow	0.24
Medium Flow	0.34
High Flow	0.45

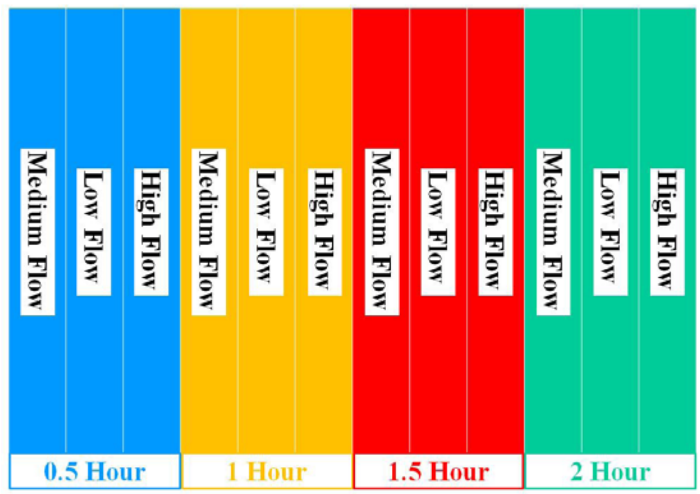

Figure 1. Dye test field layout with beds blocked by run time

After the dye test, three different measurements were taken: (1) depth of the wetting front, (2) wetting width along the bed, and (3) wetting width across the bed transects (Figures 2–4). These measurements tell how deep the water moved and how wide the water spread across and along the bed. The results of the dye test are shown in Table 2. Visual representations of wetting depth and wetting diameter are presented in Figure 5 and Figure 6, respectively. Wetting diameter is the average of wetting widths across and along the bed. Figure 7 provides an example of the relationship between wetting front and soil moisture levels at the start of the irrigation cycle.

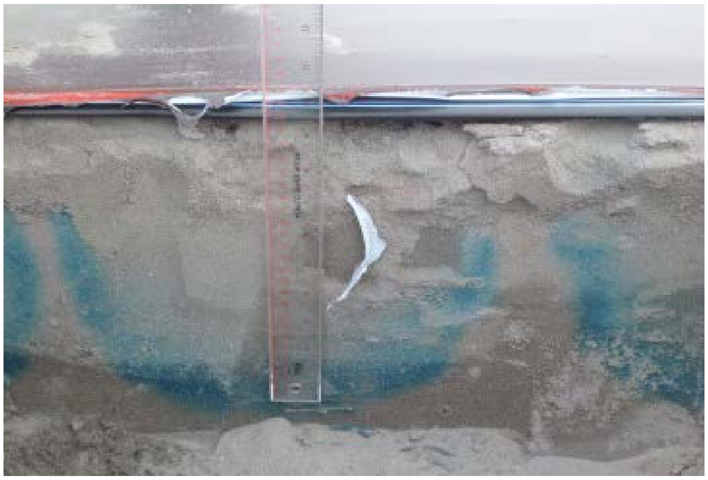

Figure 2. Wetting depth
Credits: Holt and Shukla

Figure 4. Wetting width along the bed
Credits: Holt and Shukla

Figure 3. Wetting width across the bed

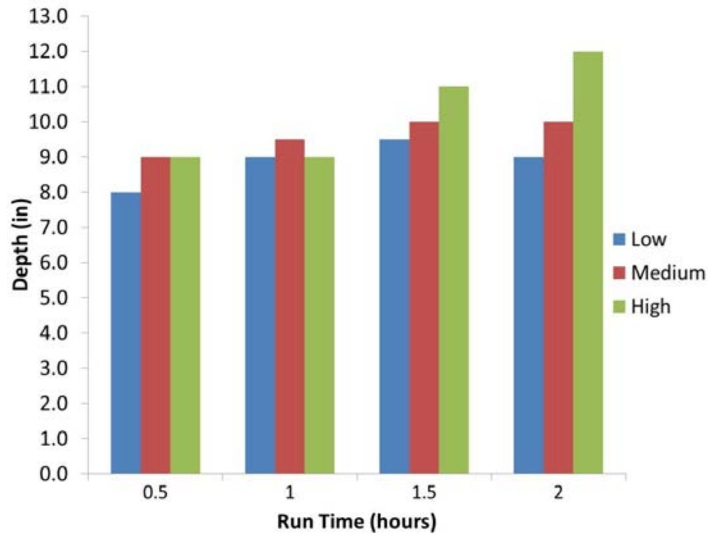

Figure 5. Wetting depths for different drip tapes and run times

Table 2. Dye test results for Immokalee Fine Sand at UF/IFAS Southwest Florida Research and Education Center, Immokalee, Florida

Run Time (hr)	Flow Rate (GPM/100 ft)	Initial Bed Soil Moisture (%)	Depletion (% PAW)	Wetting Depth (in)	Wetting Width Across Bed (in)	Wetting Width Along Bed (in)
0.5	Low (0.24)	5.3	41%	8.0*	8.0	7.0
	Medium (0.34)	4.6	49%	9.0	8.0	7.5
	High (0.45)	4.9	46%	9.0	8.5	9.0
1	Low (0.24)	5.9	34%	9.0	9.5	8.5
	Medium (0.34)	7.3	19%	9.5	11.0	9.0
	High (0.45)	6.9	23%	9.5	12.0	9.5
1.5	Low (0.24)	3.6	60%	9.5	10.5	8.5
	Medium (0.34)	3.7	59%	10.0	11.0	10.0
	High (0.45)	4.6	49%	11.0	12.0	10.0
2	Low (0.24)	3.8	58%	9.0	11.0	9.0
	Medium (0.34)	4.4	51%	10.0	12.0	9.5
	High (0.45)	3.9	57%	12.0	13.0	10.0

Note: The typical raised-bed, plastic-mulch depth in southern Florida is 8 inches. Wetting depths below 8 inches were considered to be out of the root zone depth. For farms where root zone extends beyond 8 inches, the interpretation of *out of root zone* can be changed accordingly.

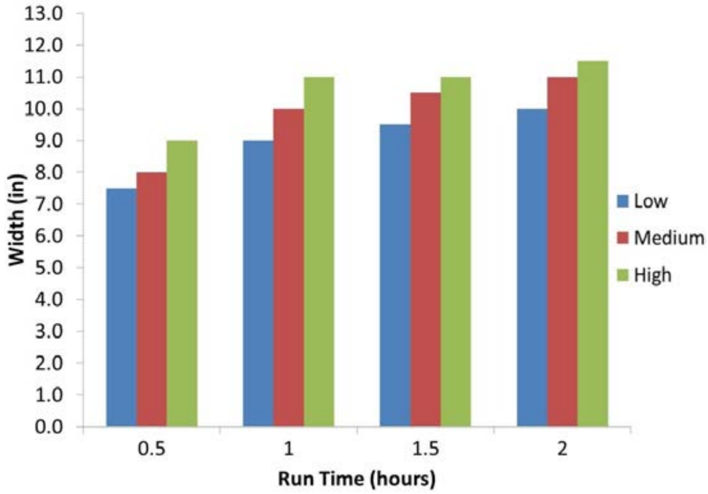

Figure 6. Average wetting diameter for the three tapes and four run times (30 min, 60 min, 90 min, and 120 min)

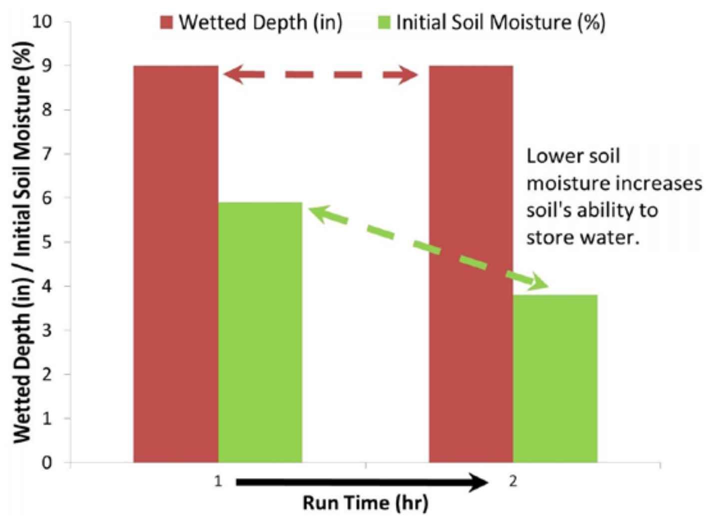

Figure 7. Wetting depth and soil moisture for low-flow tape (0.24 GPM/100 ft)

Interpreting Dye Test Results

The measured wetting depth, the wetting width along and across the bed (averaged as wetting diameter), and the impact of initial soil moisture conditions on water movement can be used to evaluate wetting characteristics. These are essential for an improved irrigation management scheme. These wetting characteristics include the run time until water reaches below the root zone, bed width wetted coverage, and the emitter spacing required for complete coverage (for details, see http://edis.ifas.ufl.edu/hs222). The run time until water reaches below the root zone can be determined based on measured wetting depths from the dye test. This time is an indication of how long irrigation can be run before water and mobile nutrients are lost below the root zone and leach into groundwater. Measured wetted width across the bed helps evaluate drip-injected fumigant coverage, how close the drip-to-plant spacing should be for coverage of the root zone, and whether more than one tape is needed for double-row crops or fumigation. Emitter spacing required for full emitter-to-emitter coverage can be determined from measurements of wetting width along the bed.

Knowing the soil-moisture level in the beds at the start of dye test provides information on what soil moisture levels are ideal at the beginning of an irrigation event for keeping water and nutrients in the root zone, which is especially important in the production systems of southern Florida and the tri-county area of northeast Florida. Raised beds in these areas often receive water from below by capillarity, commonly called *upflux*, due to a naturally occurring or artificially maintained shallow water table. Shallow water table conditions also result from the application of large volumes of water used in wetting soil for making the raised beds in south Florida, a typical practice adopted by both drip- and seepage-irrigated farms.

Wetting Depth

Results of the dye test indicate that the wetting depth reached 8 inches with a 30-minute run time for all drip tapes (see Figure 5). Plasticulture crops in south Florida generally have most of their roots in the top 8 inches below the bed surface (within the bed). This suggests that a 30-minute run time would be adequate for the majority of drip tapes selected for full root zone depth coverage. Run times of longer duration have the potential to transport water and nutrients below the root zone. However, the low-flow and medium-flow tapes had less downward water movement for longer run times than the high-flow tape.

Wetting Width across the Bed

The 30-inch bed widths used in the dye test are representative of the average bed width found in most crop production systems in southern Florida. Results show that the wetted width across the bed transect never covered more than 50% of the width, irrespective of run time and tape flow rate. Wetted width did increase with flow rate and run times. However, the maximum wetted width only reached 13 inches for the high-flow drip tape with a 2-hour run time. The corresponding wetted depth for this event was 12 inches, meaning significant leaching below the root zone would occur in order to achieve the 13-inch wetted width. The low-flow drip tape with a 2-hour run time wetted 11 inches of the bed width and the water only moved to a depth of 9 inches, making the low-flow tape a better option when trying to balance between bed width coverage and leaching below the root zone.

Results indicate that two options should be considered if fumigating by drip. The first would be to use two drip tapes to get fuller bed coverage. The second would be to change to a narrower bed. An experiment is underway (Shukla and Holt, 2014) to test whether narrower beds can maintain the same yield while improving water and nutrient uses and cost of production.

Wetting Width along the Bed

An emitter spacing that provides full wetting from emitter to emitter allows for complete water coverage along the bed. This allows drip irrigation/fertigation to supply water and nutrients to roots in the bed regardless of where the plant sits relative to the nearest emitter. The standard emitter-to-emitter spacing used in south Florida is around 12 inches. Results indicate that 12-inch emitter spacing is too far apart for the Immokalee fine sand soil in the study. None of the treatment combinations had more than 10-inch wetted widths along the bed, regardless of tape flow rate or run time. Thus, there were dry areas between emitters. A drip tape with an emitter spacing of 8 inches could achieve near full coverage for any tape flow rate and run time without creating significant overlap. If using run times longer than 30 minutes, an 8-inch emitter spacing would provide full wetted coverage along the length of the bed.

Wetting Front Depends on Soil Moisture at the Start of Irrigation

Like most sands in the region, field capacity for the test site's soil (Immokalee fine sand) was around 9%. Assuming a wilting point for the soil of 2%, the soil had an available water capacity of about 7%. The average soil moisture in the beds at the start of dye test was 5%, representing an approximate 50% depletion in available water. Many crops become water-stressed before permanent wilting point, so you should only allow a certain amount of depletion below field capacity before irrigation is required. The 50% depletion level has been suggested as the trigger level for those initializing irrigation based on soil moisture (see EDIS document AE 500, *How to Determine Run Time and Irrigation Cycles for Drip Irrigation: Tomato and Pepper Examples*).

Typical vegetable production farms in south Florida maintain moisture levels higher than 5%, with many near or above field capacity. High soil moisture in these systems is partly achieved by upward water movement from a naturally occurring or maintained shallow water table. Because the dye test was conducted with initial bed soil moisture levels almost 50% depleted below field capacity and a water table depth of more than three feet, the dye test represents a "best-case scenario" in terms of wetted coverage, because irrigation was applied at ideal moisture levels for retention and storage in the soil without reaching depletion levels that can stress the plant.

An example of the impact that soil moisture at the start of an irrigation event has on water movement can be seen in Figure 7, which compares wetting depth results between 1- and 2-hour run times for the low-flow drip tape. Initial soil moisture levels in the beds at the start of the dye test were 5.9% and 3.8% for the 1-hour and 2-hour run times, respectively. Wetting depth for both run times was 9 inches. The 2-hour run time did not increase wetting depth, even though it applied twice the water volume and lasted twice as long. This was possible because the soil-moisture level in the bed with the 1-hour run time was nearly 50% greater than the bed with the 2-hour run time (5.9% vs. 3.8%). Since both beds had initial soil-moisture levels below field capacity, the bed with the 2-hour run time had soil with the capacity to store nearly twice the volume of water as the bed with the 1-hour run time.

Summary

1. More irrigation events with shorter run times throughout the day will improve water and nutrient retention in the root zone compared to fewer, longer irrigation events.

2. Irrigation events with run times of 30 minutes provide adequate wetted coverage while keeping water in the top 8 inches of soil (see example for tomato and pepper in EDIS document AE 500, *How to Determine Run Time and Irrigation Cycles for Drip Irrigation: Tomato and Pepper Examples*). Retaining irrigation water in the bed prevents leaching of nutrients and helps keep roots from moving deeper into the soil profile, protecting the plant from flooding damage. Crops grown during the fall season (August–October) are especially susceptible to large tropical rainfall events that can flood row middles and damage the crop when roots run to deeper depths. The wet season in south Florida typically occurs between June and October.

3. An emitter spacing of 12 inches was too large to get complete wetted coverage between emitters, regardless of run time. Farms in south Florida grown on similar soils to Immokalee fine sand can employ a drip tape with an emitter spacing of 8–10 inches.

4. A single drip tape cannot wet more than around half the width of a 30-inch bed, regardless of drip tape flow rate or run time. If fumigating by drip, a narrower bed or two drip tapes can be used.

5. Irrigating when soil moisture is below field capacity but above maximum available depletion improves irrigation efficiency by increasing the soil's capacity to store irrigation water.