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AE505

Using Multi-Sensor Soil Moisture Probes to Decide When and How Long to Run Drip Irrigation[1]

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Introduction

With Florida's freshwater withdrawals expected to increase by 30% from 2000 to 2030, conservation strategies must be adopted across all water use sectors, including agriculture, to meet future demand. Implementation and proper management of more efficient crop irrigation systems can create significant water savings. Drip irrigation for vegetable production in Florida has been shown to be more efficient than the seepage irrigation (20%–50% efficiency), because drip irrigation supplies water and nutrients directly to the root zone, allowing efficiencies of 80%–90% to be achieved with proper management. Without proper management, however, the use of a drip system in itself does not necessarily translate to increased water and nutrient use efficiency.

Soil Water and Irrigation Management

Efficient drip irrigation systems must be able to supply enough water to meet a crop's needs and apply it in the proper amounts at the proper times to minimize leaching losses. Water is held in the soil by suction pressure (*capillarity*) exerted from small pores in the soil. This suction force holds water in soil by working against the force of gravity. The soil moisture level representing the most water a soil can hold against gravity drainage is called *field capacity*.

From an agronomic standpoint, soils at field capacity are holding the greatest amount of water that can be accessed by plants. When the root zone soil moisture is already at field capacity, irrigating a crop is considered "excessive" because the soil cannot hold any more water. Excess irrigation water (along with any associated soluble nutrients) will end up leaching. To achieve optimum water use, drip systems should keep soil moisture in the crop's root zone at a level between field capacity and a specified depletion level (before the plant begins to feel stressed). Knowing when the soil moisture reaches field capacity can help stop irrigation so that water and dissolved nutrients do not leach below the root zone.

Several methods of irrigation scheduling are used by producers, including the feel method, calendar method, soil water balance method, and soil moisture measurement method. The latter two methods are superior and help avoid too much or too little irrigation, because they consider the water storage within the plant root zone. The soil moisture method commonly involves measuring soil moisture in the root zone and irrigating when the soil moisture falls below 33% or 50% depletion of available water capacity (water in soil that is available to the plant).

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Soil Moisture Measurements

A variety of automated soil moisture measurement units are available in the market with varying accuracy (for more information, refer to EDIS document AE266, *Field Devices for Monitoring Soil-Water Content* at http://edis.ifas.ufl.edu/ae266). These measurement units come in single- or multiple-sensor assemblies. A single sensor measures soil moisture within a particular zone (up to 4 inches). Soil moisture sensors have varying accuracy and commonly used sensors can have errors of up to 25% or perhaps greater. Large errors in soil moisture sensor accuracy present a problem for the sandy soils of Florida due to the soil's relatively small water storage capacity. Multiple-sensor assemblies are probes with sensors positioned vertically at regular intervals (commonly 4 inches) within a single access tube. The advantages of multiple-depth sensor probes over single-sensor units are the ability to (1) monitor soil water levels for the entire root zone, which can be up to 12 inches for vegetable crops; (2) monitor water uptake with plant growth; and (3) determine when to stop irrigation by monitoring water movement below the root zone.

Root growth for vegetable crops, from planting to maturity, can vary widely from 3 inches to more than 8 inches. To develop and manage an effective irrigation schedule using soil moisture measurements from a single-sensor unit, you would need to remove the sensor from its shallower depth (where it should be installed during the initial growth period) and re-install the sensor at a lower depth as the root grows. If several single-sensor probe units are purchased and installed at multiple depths, monitoring ability is limited due to the inability to install all sensors at the same location. Installing probes at multiple locations makes it difficult to accurately track vertical water movement because soil properties, root growth, and water uptake can vary by location. However, packing multiple single-sensor probes close to a single location can (1) cause installation errors (due to soil disturbance caused by uneven packing of soil around the probes); and (2) limit root growth and water movement in the monitoring area (due to the physical presence of the probes themselves), such that the location no longer accurately represents the natural field condition. The culmination of cost, time, and sensor errors often discourages growers from using single-sensor units.

Multiple-sensor units (e.g., EasyAg from Sentek Technologies) come with sensors placed at multiple depths (e.g., 4, 8, 12, 16, and 20 inches) within an access tube. The access tubes for these probes come in varying diameter (e.g., 1.2 to 2.2 inches). For plasticulture vegetable beds (≈ 30 inch widths), narrower access tubes (1.2 inches) are better suited because they take up less area and create less soil disturbance.

Using soil moisture probes with sensors at multiple depths throughout the growing season can be a valuable tool in drip irrigation management. Probes with sensors at various depths are able to provide information on soil moisture within and below the root zone as a crop grows. Interpreting real-time soil moisture data at various depths can help determine how long and when to irrigate, how the crop's water demands change during a day, and how deep the crop is able to access water.

Determining Where to Install Soil Moisture Probes

The location of soil moisture probes in the field is important. Proper placement allows irrigation management by probes to provide the most water savings without putting at risk the crops grown within the management zone (irrigation zone). Soil, topography, underlying restrictive layers, and water table levels, along with other site characteristics, can vary from location to location at a given farm. Different characteristics require different management schemes, so multiple probes may be needed for ideal monitoring and management, based on variability of the site. For details on how to determine the number of probes needed to manage a specific area, refer to EDIS document HS1222, *Minimum Number of Soil-Moisture Sensors for Monitoring and Irrigation Purposes* at http://edis.ifas.ufl.edu/hs1222.

Budget constraints may prevent deploying the exact number of probes suggested for monitoring and managing irrigation of a specific area. When this is the case, one option is to place soil moisture probes in areas with the greatest differences in site characteristics. Alternatively, growers can purchase one or two multi-sensor probes and rotate them within different irrigation zones to determine a "typical" irrigation run time, and then use that determination along with knowledge of their farm for irrigation management. Most growers know the drier areas within their farm and can place probes at these locations to ensure that sufficient water is available to plants. Even one probe, installed and utilized correctly, is better than managing irrigation without any measurements. For example, a low-risk probe location option for growers would be placing a probe at the farthest plant from the irrigation source. Because there is often a lag (e.g., 5 min) in irrigation delivery between the plants nearest and farthest from the irrigation source within a zone, management from a probe placed at the farthest plant assures that all plants within the zone will meet or exceed desired water delivery. This irrigation management option provides yield protection from plant water stress due to under-irrigation, while still improving irrigation efficiency.

Interpreting Soil Moisture Data from a Probe with Multiple Depth Sensors at a Tomato Farm in South Florida

To show how to use soil moisture data from various depths to improve irrigation management, here we present example datasets from an EasyAG soil moisture probe (Sentek Technologies) with multiple depth sensors (4, 8, and 12 inches; Figure 1) installed at a tomato farm in south Florida.

The farm uses raised beds covered by plastic mulch, with a single drip tape placed underneath the mulch to supply drip irrigation/fertigation. The drip tape has an emitter spacing of 12 inches and a flow rate of 0.33 GPH/emitter. The farm maintains a shallow water table throughout the growing season, especially during the period from bedding to plant establishment, after which it is allowed to gradually recede. Examples shown here focus on how to (1) differentiate between proper and excess irrigation, (2) determine run times that minimize leaching, and (3) select the best times to irrigate throughout the day.

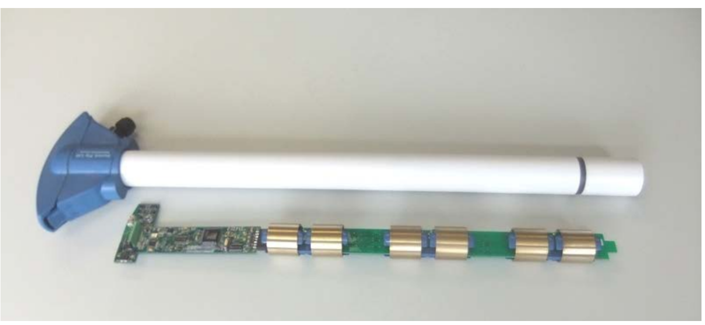

Figure 1. EasyAg multi-sensor probe with sensors (bottom) at 4, 8, and 12 inches. The PVC pipe (top) is the access tube (1.2 inch diameter) that houses the probe. The probe can be connected to a wireless datalogger and transmit the data to the farm office for its use or be made available on the Internet for it to be accessed by anyone.
Credits: http://www.sentek.com.au

Background

The majority of Florida's vegetable production occurs on raised beds covered by plastic mulch and in a shallow water table environment. Most vegetable growers in south Florida believe root zones are contained within the top 8–12 inches (20–30 cm) of soil due to the presence of the shallow water table. At the farm where the soil moisture data was collected, beds were 30 inches wide by 8 inches high. Data from a soil moisture probe with sensor depths of 4, 8, and 12 inches were collected, with each depth representing soil moisture within the root zone, at the bed bottom, and at the bottom of the root zone, respectively. Interpreting levels in soil moisture and changes due to an irrigation event reveals where the irrigation water is and how deep it has moved. An increase in soil moisture after an irrigation event at the 4-inch depth indicates that irrigation water is in the root zone. If a spike in soil moisture is seen at the 8-inch depth, water has reached the bottom of the bed. Roots of most mature vegetable crops will reach 8 inches in depth. A change in soil moisture due to an irrigation event at the 12-inch depth means water has reached below the bottom of the root zone and will leach below. It takes time for water to travel downward, and a delay in the response to an irrigation event will be seen at each sensor depth.

Recognizing Over-Irrigation

Leaching due to excessive irrigation decreases water use efficiency and nutrient use efficiency, especially when fertilizers are being delivered by fertigation. Over-irrigation can be recognized by using a soil moisture probe with sensors at various depths and then analyzing the change in soil moisture due to irrigation events detected by the sensor at the bottom of the root zone. An example of over-irrigation can be seen in Figure 2, which presents soil moisture and irrigation data within a day during the middle of the tomato growing season.

Over-irrigation can be recognized by analyzing the sensor located at the bottom of the root zone, 12-inch depth. A response in soil moisture at the 12-inch depth means all irrigation water applied was not taken up by the plant or stored in the root zone above; instead, some irrigation water moved below the root zone to be leached away. A look at the soil moisture graph (Figure 2) shows that the irrigation events of 75-, 60-, and 60-minute durations occurring around 13:35 (1:45 p.m.), 17:00 (5:00 p.m.), and 19:30 (7:30 p.m.), respectively, all caused a spike at both the 8- and 12-inch sensor depths. These spikes show that irrespective of crop growth stage, leaching was occurring due to excessive irrigation. Data also show that sufficient time was not given for soil moisture to return to initial levels between irrigation events. Irrigation water was being applied on top of water from the preceding event, further exacerbating the leaching. The management scheme with run times of 60 and 75 minutes (with two hours between events) represented excess irrigation, because each event had leaching below the root zone. Water use efficiency would improve by irrigating more frequently, with shorter run times that are spread throughout the day and with increased time

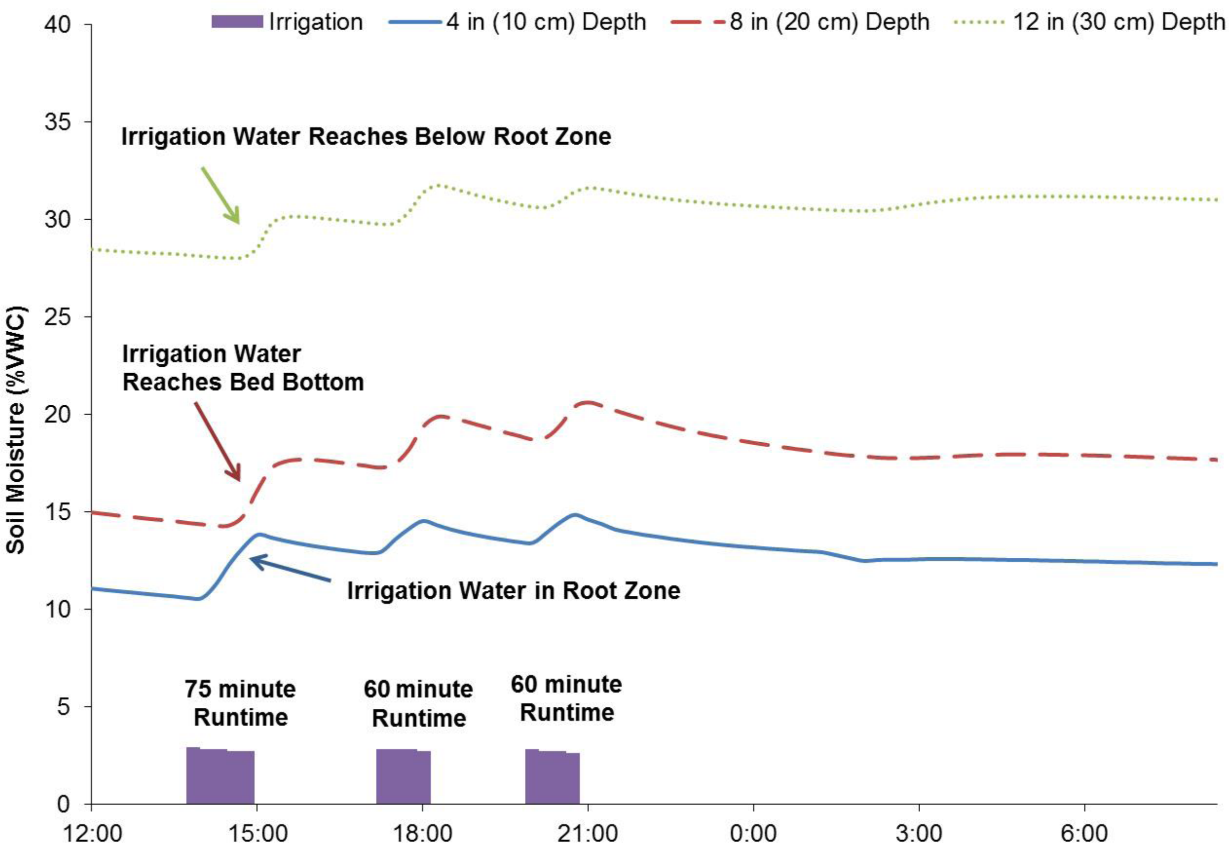

Figure 2. Soil moisture for different irrigation events within a day. Depending on the bottom of the root zone, if a spike is seen at the sensor located below the root zone, it means the water has reached below the root zone and irrigation should stop.

between consecutive events. Typically, irrigation cycles longer than 45 minutes should not be used for most crops (see EDIS document AE500, *How to Determine Run Time and Irrigation Cycles for Drip Irrigation: Tomato and Pepper Examples* at http://edis.ifas.ufl.edu/ae500).

How to Identify the Run Time That Does Not Result in Leaching

Along with recognizing excess irrigation, soil moisture probes with sensors at various depths can also be used to determine the optimum run time that minimizes leaching. Being able to manage irrigation/fertigation schemes and prevent leaching will help decrease water and nutrient losses. Figure 3 shows soil moisture on another day when irrigation was run for only 45 minutes, which is closer to the general irrigation duration for vegetable crops. Looking at Figure 3 it can be seen that irrigation caused a response in soil moisture at the 4-inch depth but had a small response at the 8-inch depth and a negligible response at the 12-inch depth. Water did not pass below the root zone, which is evident because no change in soil moisture occurred at the 12-inch depth. Minimal soil moisture response at the 8-inch depth also reveals that little irrigation water reached the bottom of the bed. Water was instead retained within the bed to be taken up by the plant, as shown by the increase in soil moisture at 4-inch depth. Figure 3 represents a good example of when to stop irrigation to avoid leaching.

Upflux from the shallow water table maintained at the farm is part of the reason why soil moisture from the 12-inch depth is high. Typically, most of south Florida has a shallow water table environment that often reaches the surface during the wet season (June–October). Here the 45-minute run time represents an optimum irrigation strategy, as water was not lost below the root zone. By identifying irrigation events that do not cause leaching, management decisions can be tailored to deliver needed water and nutrients to the crop with improved efficiency.

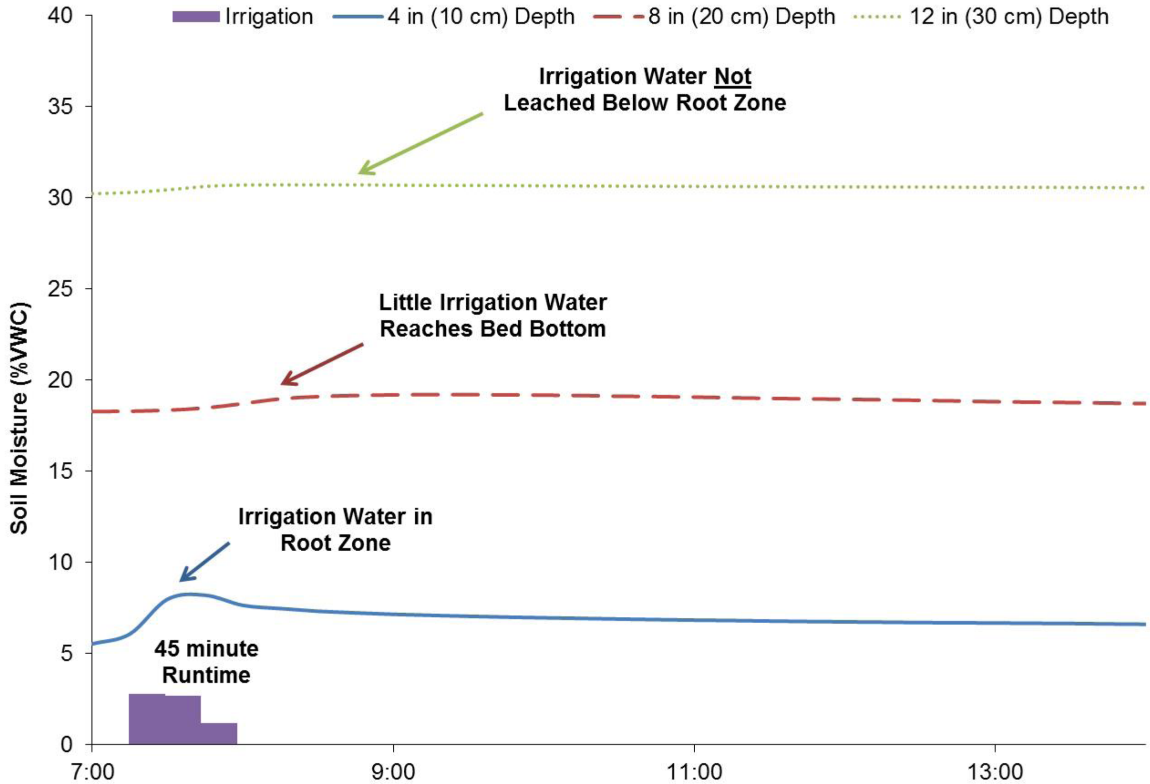

Figure 3. Soil moisture at 4-, 8-, and 12-inch depths after 45 minutes of irrigation at a tomato farm. The 45-minute cycle represents an ideal irrigation event because necessary water was delivered to the root zone but did not leach below.

How Run Time and Time of Day Impact Irrigation Management

A variety of factors that change throughout a growing season have an impact on irrigation management, including root zone size, water demand, and climate conditions. However, a crop's water demands also change throughout a given day. Because most multi-sensor probes can collect data at high frequency (up to 1 minute resolution) and transmit this data wirelessly to the farm office, close monitoring of water movement is feasible for the purpose of identifying proper management schemes during the season as well as during the day. Identifying the proper run time and time of day to deliver the necessary water/nutrients allows for better irrigation management. Figure 4 provides an example of how to use data from a multi-sensor probe to identify proper run times and determine the active uptake period within a day.

The first irrigation event in Figure 4 had a runtime of 150 minutes (2.5 hours). For most farms and crop conditions, this represents excessive irrigation (see EDIS document AE500, *How to Determine Run Time and Irrigation Cycles for Drip Irrigation: Tomato and Pepper Examples* at http://edis.ifas.ufl.edu/ae500). The 2.5-hour irrigation caused a significant amount of water to be leached below the root zone and a large increase in soil moisture can be seen at all the depths, including the 12-inch depth. Even after such a long irrigation run time, the soil moisture returned to its initial level by 12:00 (12:00 p.m.) when the 45-minute run time event started. Figure 4 shows that, under typical conditions, irrigating for a long time in the early morning does not have any real benefit in terms of providing insurance against lack of moisture by midday, when the evaporative demands are highest. Spikes in soil moisture at the 4-inch and 8-inch depths indicate that water from the 45-minute run time wetted the entire depth of the bed. However, the 45-minute event did not cause any leaching, as no response in soil moisture can be seen at the 12-inch depth. Therefore, a good strategy at this farm is to use 45-minute irrigation applications at the time of the plants' greatest water uptake demand during this growth stage, because negligible irrigation water was lost through leaching. The last irrigation event of the day started at 15:30 (3:30 p.m.) and lasted 90 minutes (1.5 hours). This event was twice as long the previous and resulted in leaching, shown by a spike in soil moisture at the 12-inch depth.

Interpreting a soil moisture probe with multiple depth sensors can provide valuable information about the appropriate run times and time of day to initiate irrigation events. As Figure 4 indicates, the longer run times initiated toward the beginning and end of the day caused leaching, whereas

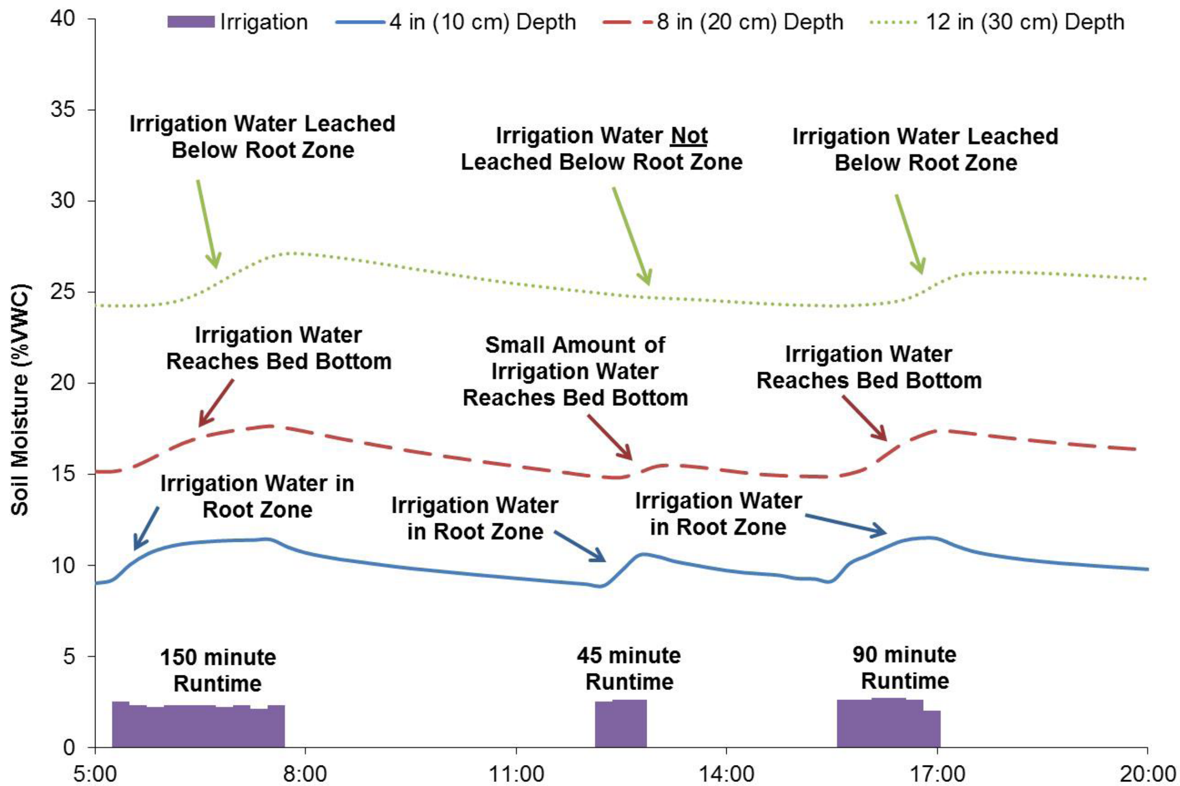

Figure 4. Soil moisture at 4, 8, and 12 inches below the plastic-mulched bed surface at a tomato farm almost three months after transplant. The figure shows the effects of run time and time of the day on leaching.

the shorter irrigation event in the middle of the day did not. The example data from the farm clearly show that irrigation events with shorter run times (around 45 minutes at this farm) would help keep most water and fertilizer within the root zone. It is recognized here that in certain situations (e.g., salt problems), a longer run time (e.g., 1 hour or more) may be needed. Often, farms are limited to a set number of cycles per day because of pump/well constraints. Under these conditions, if growers must use a longer run time, it should be done toward the middle of the day when the crop's water demands are greatest, instead of early morning or evening.

Summary

A soil moisture probe with sensors at multiple depths is a useful tool in managing drip irrigation/fertigation, because it is able to capture the evolution in the demand of water uptake and the zone from which water uptake can occur throughout a growing season. Because a soil moisture probe is continuously collecting data, it is also able to provide information about the differences in plant uptake rate within a day. By interpreting responses in soil moisture from a sensor at or near the bottom of the root zone, excess irrigation can be identified. Having a sensor placed at the bottom of the bed provides information on when irrigation water has moved through the entire bed depth. Improved irrigation run times and scheduling can be achieved by using soil moisture data from multiple depths for a given day and throughout a season. Using multi-depth soil moisture probe data throughout a growing season can improve drip irrigation/fertigation management by applying and keeping water and nutrients in the root zone for the plants to use, thereby decreasing losses and improving efficiency. Minimizing leaching of water as well as fertilizer reduces the cost of production (i.e., fuel, labor, and fertilizer, especially liquid fertilizer) for the grower, improves water use, and decreases the amount of nutrients that reach downstream waters.