Agenda

Vegetable and Citrus BMP Water and Nutrient Management Field Day

March 6, 2014

9:00 Introduction and Status of Southwest Florida Research and Education Center Funding Request – Dr. Phil Stansley

9:15 Demonstration of Web and Smartphone Based Evapotranspiration (ET) Tools Available for Water Management Using Weather Station Data – Dr. Kelly Morgan (Auditorium)

9:45 Depart from field demonstrations

10:00 Effect of Run Time and Drip Tape Type on Wetting and Leaching for Plastic Mulch Beds – Dr. Sanjay Shukla (Field 1)

10:25 Soil Moisture Devices for Vegetable Irrigation Management – Dr. Sanjay Shukla (Field 1)

10:50 Demonstration of Tensiometers and Water Table Observation Wells = Dr. Monica Ozores-Hampton and Gene McAvoy (Field 2)

11:30 Results of Fall Drip Fertigation Experiment – Dr. Kelly Morgan and Muriel Bermudez Herrera (Field 2)

12:00 Lunch – Sponsored by Ag-Tronix (Auditorium)

12:30 Display and discussion of weather stations and automated irrigation controls – Ag-Tronix
The Florida Automated Weather Network (FAWN): Ten Years of Providing Weather Information to Florida Growers

William Lusher, John Jackson, and Kelly Morgan

History
For almost 50 years the National Weather Service (NWS) collected data in rural locations and issued agricultural forecasts and advisories to alert Florida growers to potential freeze conditions. On April 1, 1996 the NWS discontinued this service in an effort to reduce expenses. On the night of January 18-19, 1997, temperatures were expected to drop into the mid to upper 30s. However, this forecast was based on data collected at city and airport sites, which are typically warmer than rural areas. That night, temperatures in rural locations ended up much lower than forecasted and significant damage (an estimated $300 million) resulted primarily to winter vegetables (Lucier and Love, 1997).

Due to the lack of rural weather information, growers were not aware of the potential for damaging temperatures. In response to this event, an Agricultural Weather Task Force was formed to find a solution to this problem – the lack of agricultural weather information. The task force was composed of members of the Florida Farm Bureau, the Florida Fruit and Vegetable Association, Florida Citrus Mutual, the Florida Nurseryman Association, Growers, and Landscape Association, the Florida Department of Agriculture and Consumer Services, Senator Bob Graham’s office, and the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS). The recommendation of the task force was the installation of a network of automated weather stations located in rural locations that would provide representative data and weather-related information to growers in Florida.

Figure 1. Locations of original 16 FAWN sites.

The Florida Automated Weather Network (FAWN) was initiated in 1997 with a legislative appropriation to UF/IFAS. Eleven sites were established and integrated into an existing county Cooperative Extension Service network of 5 sites in Lake and Orange counties in 1998. Figure 1


2. William Lusher, director, FAWN Project, IFAS Office of Information Technology; John Jackson, Extension agent and FAWN coordinator, Lake County Extension; Kelly Morgan, assistant professor, Department of Soil and Water Science, Southwest Florida Research and Education Center (REC)–Immokalee; Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611.

The Institute of Food and Agricultural Sciences (IFAS) is an Equal Opportunity Institution authorized to provide research, educational information and other services only to individuals and institutions that function with non-discrimination with respect to race, creed, color, religion, age, disability, sex, sexual orientation, marital status, national origin, political opinions or affiliations. U.S. Department of Agriculture, Cooperative Extension Service, University of Florida, IFAS, Florida A&M University Cooperative Extension Program, and Boards of County Commissioners Cooperating. Thomas A. Obreza, Interim Dean.
shows the locations of the 16 original sites. Over the next three years 5 sites were added bringing the total to 21. In 2002 12 more sites were added, primarily in north and west Florida, bringing the total number of locations to 33. In 2004 sites were added in Arcadia and Frostproof, and in 2007, a station was installed near Clewiston. Over time several stations were relocated, and others removed, for a total of 35 sites. FAWN’s database, originally designed by UF faculty and graduate students has been upgraded and is now housed in the University of Florida Computer Center with 24 hour support.

Present
Figure 2 shows the current locations of FAWN’s 35 sites, located from Homestead to Jay, near Pensacola. Future plans are to add sites to areas that lack coverage, for a maximum of 40 sites. Most sites are located at UF/IFAS research centers, USDA facilities, Florida Division of Forestry sites, state/county parks, and county Extension offices. FAWN continues as a program of UF/IFAS, residing in the Information Technology unit, and working closely with the UF/IFAS Deans for Extension and Research. FAWN maintains an Advisory Committee comprised of individuals from industry organizations, water management districts, and other state and federal agencies, which provides oversight for the program. UF/IFAS, South Florida Water Management District, Southwest Florida Water Management District, St. John’s River Water Management District, and the Florida Department of Agriculture and Consumer Services provide most of the annual operating budget for FAWN. Other “Sponsors”—private companies, associations, and individuals—contribute annually to help offset some of FAWN’s operating expenses. A business plan is also in place that outlines long term goals related to the development of new production weather-related tools (e.g., cold weather protection and irrigation scheduling), location of additional sites, data delivery, tool enhancement, and educational efforts.

Data Collection and Delivery
Each FAWN tower is equipped with sensors that measure a number of parameters, including temperature (-10cm, 60cm, 2m, and 10m), barometric pressure, solar radiation, wind speed and direction, and rainfall amount. Several parameters are calculated as well, including dew point temperature, and evapotranspiration. Figure 3 shows the configuration of a typical FAWN tower. Detailed information on the sensors used and tower configuration can be obtained from the FAWN website at http://fawn.ifas.ufl.edu/tour/tech_info.php.
remaining sites utilize the cellular network. Once all data are collected, they are compared to a known standard range of acceptable values, and then processed into the master database and the online database (for access via the FAWN website). Once processed into the online database, data are displayed, used to create summaries, and incorporated into the FAWN management tools.

Data Access
The overarching goal of FAWN is to “provide timely and accurate weather data to a wide variety of users,” and to be considered the most reliable and useful source of real time weather data in Florida. Additionally, by providing effective management tools to assist decision makers, FAWN can also have a substantial financial impact on numerous segments of Florida and be a valuable asset to resource managers and those involved with protecting life and property. Visitors to the FAWN website in 1998 had a limited number of options (Figure 4 shows what a visitor to the site would have seen). Users could view current data from all or selected sites in table format; data from a selected site on a line graph; and daily, weekly, and monthly summaries from a selected site. Additionally, there was some information about data collection, a map of locations, and links to external resources.

During the 10 years since its inception, the FAWN system has undergone a number of improvements and enhancements. Expansion of the network, development of new management tools, and data quality have been at the forefront of these improvements. The FAWN website has also seen a number of revisions. Figure 5 shows several pages from the FAWN Web site launched in 2009. With this revision came an improved user-interface, enhanced data access, and more efficient management tools. The Homepage shows a map of the state of Florida with 2 meter air temperature displayed at each FAWN location. Specific ranges of values are assigned a color/shade to indicate warmer or cooler conditions. Among other features, there are links to all pages within the site, as well as a News Box, where current information about FAWN can be posted and easily accessed. The FAWN Management Tools page has 10 weather-related management tools (several are shown in Figure 5) to aid users with cold protection, irrigation scheduling, and disease control. Planned enhancements to these tools include integrating real-time data from nearby FAWN sites into the tool for improved decision-making. For example, the Urban Irrigation Scheduler suggests an irrigation schedule based on geographical region—using climatological rainfall—and sprinkler-type. Real-time rainfall and evapotranspiration data from the FAWN site nearest the user’s location will enhance this tool for a more informed decision regarding irrigation. The Report Generator allows the user to retrieve archived data from any (or all) of the FAWN sites. Users can view results in a table on the screen, or download the results in .CSV format for display in a spreadsheet application. The FAWN website also includes a monthly FAWN FOCUS, an article that contains information on various topics related to weather, climate, agriculture, and using the Web site.

In addition to data access via the Internet, users can listen to current observations at any FAWN site via the FAWN Interactive Voice Response System. This system allows users to call a toll-free phone number, enter a 3-digit station ID number, and listen to the latest values of all observed parameters. This can be particularly useful when current data are still needed, but access to the FAWN website is not practical.

Management tools
From the inception of FAWN it was evident that the project had to have more than weather data. The original concept was to assist growers with managing their crops during cold weather. FAWN has made a concerted effort to develop Management Tools to aid users with decision making. The first tools were naturally in the area of cold protection. A detailed explanation of these tools can be found elsewhere in this publication. FAWN will continue to seek new ways to assist users with the decision making process.

Management tools are a key component to the success of FAWN.
Part of FAWN’s mission is informing the public about its services and products. This is accomplished in several ways. FAWN attends trade shows and conferences to conduct presentations and exhibits about various components of the program: use of the tools, and data access, for example. FAWN also makes presentations to user groups around the state, such as farm growers and homeowners. FAWN is currently involved in a student 4-H outreach effort in which students will learn in a hands-on environment about weather and climate, conducting routine weather observations using different platforms (e.g., manual and automated), and use of weather and climate data.
Impact

Accountability is extremely important to FAWN. Financial support for the program comes from a number of public agencies and private sources, and each need to know their support is making a positive impact through FAWN.

According to the members of the Agricultural Weather Task Force, FAWN has had a multi-million dollar impact on agriculture through more informed production, harvesting, and marketing decisions. While there has been no major attempt to document the overall impact, feedback from non-agricultural users indicates substantial use and value. For example, The NWS uses FAWN data when evaluating fire risks and developing high-resolution surface maps; the Florida Division of Emergency Management uses the data when tracking the southward progression of cold air, to monitor wind speeds during hurricanes, and in making decisions regarding potential risks from weather events; the Florida Division of Forestry relies on the information in issuing burning authorizations, fighting forest fires and in monitoring smoke plumes; University of Florida researchers use the data for many projects; and various media outlets have incorporated the data into numerous articles and presentations (WESH in Orlando, FL uses FAWN data for early morning reports, for example).

Statistics have been collected regarding the use of the FAWN website. Table 1 below best shows the level of use for the past ten (10) years. There has been a steady increase in visitors and peak use continues to occur during freeze events as shown below.

It has been determined that users of FAWN data and tools for cold protection can potentially save substantial amounts of water and numerous dollars. Using information from the Florida Agricultural Statistics Service, Florida Citrus Mutual, the Florida Strawberry Association, the Florida Growers Association, the Florida Nurserymen, Growers and Landscape Association, and the Florida Fruit and Vegetable Association, estimates of potential savings have been calculated (Table 2). FAWN Cold Protection tools provide growers with a guide for when to start and stop irrigation used for cold protection. Use of FAWN Cold Protection tools can save an estimated 2 hours of irrigation per cold event, which can bring about substantial savings over a winter season. For example, during a relatively warm winter, 1 to 3 nights may require cold protection for a total savings of 2 to 6 “irrigation-hours.” A cold winter, however, may produce 4 to 10 nights requiring cold protection for a savings of 8 to 20 hours. Therefore, the average number of gallons of water and dollars saved during relatively warm and cold winters can be estimated (Table 2). Depending on the number of nights that need protection, 7 - 25 billion gallons of water and $3 - 13 million can potentially be saved by using FAWN Cold Protection tools.

Recognition of FAWN’s impact

FAWN was presented the Davis Productivity Award in 1998 as the top state project regarding teamwork, productivity, and performance. And in 2004 the FAWN team received the USDA Award for Superior Service, one of three awarded from the thousands of projects across the country. FAWN has been extremely successful due to the hard work of many; it has truly been a team effort. Growers, irrigators, pest managers, cold protectors, fire fighters, researchers, weather nuts, and many others all enjoy the benefits of FAWN due to the vision and hard work of the founders, staff, administrators, advisory committee, financial partners and idea contributors. It has been a most productive first ten years for FAWN and has laid the groundwork for continued improvement in the delivery of quality weather data and management tools well into the future.
Figure 5. The current FAWN Website (2009). The Homepage, Management Tools page, and Report Generator page are shown.

Figure 6. The FAWN station, report type, range of dates and measurements can be selected to generate a custom weather data report in either HTML or .csv formats.

Conclusion

FAWN is one product of the freezes that occurred during the 1980's. Timing is everything and FAWN certainly is a good example. There was a need for automated weather information in order to more efficiently deal with cold weather. Technology had advanced to provide accurate equipment at a reasonable cost. The National Weather Service eliminated agricultural products. A collection of competent and motivated individuals saw the need and responded. Thus FAWN evolved into a state-wide network of automated weather sites that have provided weather data for many users for the benefit of the citizens of Florida. Creative individuals will continue to develop new and beneficial products using the FAWN weather data. Some of these products will be a Management Tool while others will be housed with the developer. No matter the location, FAWN will continue to be a major contributor of accurate and timely weather information for a wide variety of users. Due to the hard work of many, FAWN was established and continues to operate in a cost effective mode. Using University of Florida faculty and staff allowed for the establishment of FAWN with minimum cost. Excellent support from public and private sector funding provides data and tools at no cost to the user. FAWN has been and will continue to be successful because it provides useful information which justifies broad-based financial support.

Acknowledgements

A special note needs to be added to the FAWN story. Without the leadership and encouragement of Dr. Jim App, former Assistant Dean for Extension, FAWN would never have progressed past the Agricultural Weather Task Force. Dr. App convinced Mr. Jackson to develop the proposal, secured a one-year transfer for Mr. Ayers to spend full time designing and installing towers, interacted with UF/IFAS administration to accept the challenge of sponsoring the project, convinced research station directors to cooperate by providing labor and site locations, secured support from research by convincing the Assistant Dean for Research to serve on the management team, obtained the services of UF/IFAS External and Media Relations to publicize the effort, and much more. Professor Howard Beck, UF/IFAS Information Technology unit and his graduate students designed and operated the original data base and website. Visionary leadership provided by Dr. Fedro Zazueta, former UF/IFAS Director of Information Technology provided existing faculty and staff for operation of FAWN.

Without financial support from public and private sources FAWN could not exist. The list of sponsors can be found on the website. FAWN and the citizens of Florida owe a tremendous debt of gratitude and appreciation to the following agencies and their staff that have worked hard to keep FAWN financially alive and well for ten years.

Southwest Florida Water Management District
South Florida Water Management District
Florida Department of Agriculture – Office of Agricultural Water Policy
St. Johns River Water Management District
Table 1. History of average number of pages viewed per month and peak level of use.

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Number of Pages Viewed Monthly</th>
<th>Number of Pages Viewed for Highest Month</th>
<th>Month with Maximum Pages Viewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>170,000</td>
<td>260,000</td>
<td>Jan</td>
</tr>
<tr>
<td>2007</td>
<td>212,000</td>
<td>431,000</td>
<td>Feb</td>
</tr>
<tr>
<td>2008</td>
<td>266,000</td>
<td>462,000</td>
<td>Jan</td>
</tr>
</tbody>
</table>

Table 2. Water savings estimates and associated savings using FAWN Cold Protection Toolkit.

<table>
<thead>
<tr>
<th>Hours Saved</th>
<th>Winter Type</th>
<th>Average # of Nights Protected</th>
<th>Total Volume Saved (gallons)</th>
<th>Total Cost Saved (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Warm</td>
<td>2</td>
<td>7,215,216,000</td>
<td>3,780,168</td>
</tr>
<tr>
<td>2</td>
<td>Cold</td>
<td>7</td>
<td>25,242,600,000</td>
<td>13,230,588</td>
</tr>
</tbody>
</table>
Evapotranspiration-Based Irrigation for Agriculture: Sources of Evapotranspiration Data for Irrigation Scheduling in Florida

Isaya Kisekka, Kati W. Migliaccio, Michael D. Dukes, Bruce Schaffer, Jonathan H. Crane, and Kelly Morgan

This article is part of a series on ET-based irrigation scheduling for agriculture. The rest of the series can be found at http://edis.ifas.ufl.edu/topic_series_ET-based_irrigation_scheduling_for_agriculture.

Introduction
The first step to using evapotranspiration (ET) for irrigation scheduling is to estimate reference ET (ETᵣ). This article lists some of the public sources of ETᵣ in Florida.

Evapotranspiration: Basic Concepts
ET is the process through which water is lost to the atmosphere from the soil by evaporation and from plants by transpiration. ET of a specific crop (also referred to as "crop ET" or "actual ET") is affected by several factors including weather, the crop under consideration, its management, and environmental variables (Table 1). The more information available about factors affecting ET, the more accurate the ET prediction will be. Generally, ET is not directly measured but estimated using mathematical equations that have been developed over time and selected site-specific factors listed in Table 1. More information on basic ET concepts can be found in Evapotranspiration: Potential or Reference at http://edis.ifas.ufl.edu/ac256.

Crop ET (ETᵣ) is calculated as ETᵣ multiplied by the crop coefficient (Kᵣ). ETᵣ refers to ET from a well-watered hypothetical grass surface of known characteristics (height and surface resistance). It expresses the evaporative demand of the atmosphere at a given location independent of crop type, stage of development, and management practices. The different mathematical equations used for ETᵣ estimation are based on different concepts, and the variables (inputs) to include depend on the equation selected. ETᵣ may be determined using a complex equation (e.g., Penman-Monteith) or simpler equations (e.g., Hargreaves). It is important to know which radiation or temperature-based method to use in the calculation of ETᵣ because some equations are more accurate than others depending on the location where they are applied (Table 2). Basic information on how to estimate ETᵣ can be found in Smart Irrigation Controllers:


2. Isaya Kisekka, graduate student, Department of Agricultural and Biological Engineering, Tropical Research and Education Center, Homestead, FL; Kati W. Migliaccio, associate professor, Department of Agricultural and Biological Engineering, Tropical Research and Education Center, Homestead, FL; Michael D. Dukes, interim chair, Department of Environmental Horticulture, and professor, Department of Agricultural and Biological Engineering; Bruce Schaffer, professor, Department of Horticultural Sciences, Tropical Research and Education Center, Homestead, FL; Jonathan H. Crane, professor, Department of Horticultural Sciences, Tropical Research and Education Center, Homestead, FL; Kelly Morgan, associate professor, Department of Soil and Water Science, Southwest Florida Research and Education Center, Immokalee, FL; Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611.

The Institute of Food and Agricultural Sciences (IFAS) is an Equal Opportunity Institution authorized to provide research, educational information and other services only to individuals and institutions that function with non-discrimination with respect to race, creed, color, religion, age, disability, sex, sexual orientation, marital status, national origin, political opinions or affiliations. U.S. Department of Agriculture, Cooperative Extension Service, University of Florida, IFAS, Florida A&M University Cooperative Extension Program, and Boards of County Commissioners Cooperating. Nick T. Place, Dean
Operation of Evapotranspiration-Based Controllers at http://edis.ifas.ufl.edu/ae446.

The $K_c$ component of Equation 1 integrates the crop characteristics (e.g., crop height, fraction of net radiation absorbed at the land surface, canopy resistance, and evaporation from bare soil surface) into the $ET_c$ estimation equation, to account for the difference in transpiration between the actual crop and the reference grass. Typical $K_c$ values for some Florida crops can be found in *Evapotranspiration-Based Irrigation for Agriculture: Crop Coefficients of Some Commercial Crops in Florida* at http://edis.ifas.ufl.edu/ae456. General information on estimating crop water requirements for irrigation from $ET_c$ can be found in *Evapotranspiration-Based Irrigation Scheduling for Agriculture* at http://edis.ifas.ufl.edu/ae457.

**Sources of ET Data for Implementing ET-Based Irrigation Scheduling in Florida**

Two types of $ET_o$ data can be used in ET-based irrigation scheduling: 1) historical $ET_o$ and 2) real-time $ET_o$. Historical $ET_o$ should represent long-term daily, monthly, or seasonal $ET_o$ averages, for a long record of data that includes yearly and 10-year variations. Real-time $ET_o$ used to schedule irrigation is updated daily, which provides an advantage over the historical $ET_o$-based approach because it accounts for daily variations in weather conditions. Florida growers can easily obtain real-time $ET_o$ and monthly average $ET_o$ data from the Florida Automated Weather Network (FAWN) website at http://fawn.ifas.ufl.edu/ where $ET_o$ is estimated using the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) (1984) modified Penman equation. Daily, average daily, and historic monthly $ET_o$ can be obtained from the FAWN database for numerous locations throughout Florida using the following steps:

- Go to http://fawn.ifas.ufl.edu/.
- Click Tools on the top menu.
- Click Evapotranspiration (ET) on the drop-down menu (under Irrigation).
- A table with daily $ET_o$ for the past 7 calendar days and the 7-day average $ET_o$ for each of the FAWN weather station sites will appear. A graph with the past 14 days $ET_o$ for selected FAWN sites is also available.

Historical data can also be obtained from FAWN by clicking on the Data Access menu tab and selecting Report Generator.

Actual ET data in Florida can be obtained from the United States Geological Survey (USGS). Data can be accessed as follows:

- Go to http://fl.water.usgs.gov/et/
- Click Links to NWIS Web Data to view a map of monitoring stations and site names.
- Click on the station closest to you.
- In the dialogue box that appears, click NWIS Web Data.
- Daily ET data are then presented using graphs or tables.

Of the two public sources of ET data, data from USGS has the greatest quality control in estimating actual ET over the different land covers where USGS has ET monitoring stations, but the data available is limited to only a 10-year period (1995–2005) at some sites. FAWN has a wider coverage of weather stations and a more continuous period of record.

**Conclusion**

Obtaining $ET_o$ or actual ET values from the above public weather data sources will improve estimation of crop water requirements, which are key to implementing ET-based irrigation schedules. For ET estimation using radiation- or temperature-based methods, always select the method most suitable for your area.

**References**


Table 1. Factors that influence ET.

<table>
<thead>
<tr>
<th>Factors that influence ET</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weather parameters</strong></td>
<td></td>
</tr>
<tr>
<td>solar radiation</td>
<td>relative humidity</td>
</tr>
<tr>
<td>air temperature</td>
<td>wind speed</td>
</tr>
<tr>
<td><strong>Crop factors</strong></td>
<td></td>
</tr>
<tr>
<td>crop type</td>
<td>variety</td>
</tr>
<tr>
<td>soil water management</td>
<td>pest control</td>
</tr>
<tr>
<td>soil salinity</td>
<td>impenetrable soil layers</td>
</tr>
<tr>
<td><strong>Management</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>stage of development</td>
</tr>
<tr>
<td></td>
<td>poor soil management</td>
</tr>
<tr>
<td><strong>Environmental</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>plant density</td>
</tr>
</tbody>
</table>

Table 2. Examples of simpler radiation-based equations that can be used to estimate ET$_{o}$ for different locations in Florida.

<table>
<thead>
<tr>
<th>Geographical location</th>
<th>Radiation-based methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast Florida</td>
<td>Turc (1961)</td>
</tr>
<tr>
<td></td>
<td>Priestley-Taylor</td>
</tr>
<tr>
<td></td>
<td>SFWMD-SWP</td>
</tr>
<tr>
<td>Northeast and North-Central Florida</td>
<td>Turc (1961)</td>
</tr>
<tr>
<td></td>
<td>Hargreaves SFWMD</td>
</tr>
</tbody>
</table>

*Note:* These simpler radiation-based ET$_{o}$ estimation equations should only be used when complete weather data sets are not available to evaluate the American Society of Civil Engineers-Environmental and Water Resources Institute (ASCE-EWRI) standardized ET$_{o}$ estimation equation.

1Methods selected are based on comparison of ET$_{o}$ estimation equations in Southeast Florida (Miami-Dade and Broward Counties) by Kisekka et al. (2009) (unpublished).

2Methods selected are based on comparison of ET$_{o}$ estimation equations in Northeast and North-Central Florida (Jacksonville, Gainesville, and Daytona Beach) by Jacobs and Satti (2001).

3South Florida Water Management District (SFWMD)-Simple Method


5Modified Blaney-Criddle with SFWMD crop coefficients.
A Web-Based Irrigation Scheduling Model to Improve Water Use Efficiency and Reduce Nutrient Leaching for Florida Citrus

Kelly T. Morgan, Edward A. Hanlon, and Thomas A. Obreza

Introduction
The competition for water supply is increasing throughout Florida. Increasing demands from residential and commercial users are often met at the expense of agricultural and environmental water supplies. One way that citrus producers can address this trend is by improving their water use efficiency. Irrigation managers can reduce grove water consumption while avoiding tree damage or fruit yield/quality loss due to insufficient irrigation. The key to improving water management is to include soil characteristics and weather factors in irrigation scheduling decisions. An easy to use web-based water-balance irrigation scheduling tool has been developed. This tool will assist growers in determining irrigation schedules that can improve water use efficiency and reduce nutrient leaching. The tool can be found at: http://fawn.ifas.ufl.edu/tools/irrigation/citrus/scheduler/.

Grove managers may have several objectives for irrigating. Increased profit through the effective use of irrigation to produce high quality citrus is the overall goal. Irrigation scheduling in combination with fertilizer best management practices (BMPs) will provide maximum nutrient uptake efficiency, which is defined as the amount of fertilizer taken up by the tree divided by the amount applied. This objective attempts to hold nutrients, especially the mobile nutrients such as nitrate-nitrogen, in the root zone via measured irrigation events. Irrigation timing and duration are based upon crop need and soil-moisture content. In addition to addressing plant water needs, moisture changes in the soil volume containing the root zone are included, as well as irrigation delays for rainfall events.

Factors Affecting Irrigation Scheduling
Citrus soils vary from the deep, well-drained soils of the Florida central ridge to the poorly-drained, coastal flatwoods soils. The surface layers of both types of soil are similar (greater than 95% sand and less than 2% organic matter). However, the soil layers below 24 inches vary greatly. Ridge soils can have very little change in soil characteristics to several feet deep and are considered excessively well drained, and other ridge soils may have broken or complete clay layers a few feet below the surface that make them less well drained. Flatwoods soils typically have a clay and/or organic layer at less than 3 to 5 feet that makes them poorly drained. Management techniques for irrigating commercial citrus groves must take differences in soils and related water regimes into consideration. The water holding capacity and physical characteristics of these soils vary greatly, affecting irrigation needs.
soil types greatly influence root distribution, the presence of
a water table, and the need for drainage. Irrigation practices
must address these characteristics to effectively irrigate the
trees without leaching nutrients below the root zone and
into surface or ground water.

Ridge soils allow citrus roots to penetrate deep into the
soil. This root distribution pattern anchors the tree and
provides a large volume of soil, typically 36 inches or
deeper, from which the tree may extract both nutrients and
water. Flatwoods soils are almost always poorly drained,
and they flood relatively easily. Drainage and the presence
of an impermeable soil layer have considerable influence
on citrus root distribution in these soils. The shallow root
system is restricted to the upper 12 to 18 inches of soil.

Irrigation duration and flow rate determine the volume of
water that is added to the grove. Irrigation water applied in
excess of the soil water holding capacity either continues
through the soil profile below the root zone and/or reaches
the water table. In both cases, water applied above the
amount required to refill the soil in the root zone is wasted
and may potentially contribute to water contamination.
This simplified model of water movement has been called
“piston flow” because water entering the soil from irrigation
or rainfall forces existing water in the soil to move deeper
into the soil profile. This process also describes the flow
of mobile nutrients in the sandy soils of central and south
Florida, making them vulnerable to nutrient leaching.
Irrigation must be scheduled to avoid or minimize loss of
nutrients, especially nitrogen, from the citrus root zone.

A good way to know if irrigation water is being used
correctly (avoiding too wet or too dry conditions) is to
estimate the depth of wetting and the total depth of soil that
will be filled to field capacity. A simple irrigation schedule
can be estimated using available information and making
some assumptions. The addition of one inch of water
will wet a Candler soil to field capacity to a depth of
approximately 50 inches, given an original soil-water content
of 1/3 depletion (the recommended soil moisture content
for irrigation in the spring). Using the same assumptions, a
flatwoods soil (e.g., Wabasso) would be wet to field capacity
to a depth of about 25 inches by the same one inch of water
at the same 1/3 depletion. Of course, a wetter soil at the
beginning of the irrigation cycle would result in soil being
brought to field capacity to a greater depth. Based upon tree
rooting depths, the implication is that a water application
in excess of one inch may extend field capacity conditions
below the rooting depth of the citrus trees grown in both
Candler and Wabasso soils.

Water budgeting and use of soil moisture sensors are two
methods of irrigation scheduling that will improve the
likelihood of obtaining the irrigation goals stated above.
The reminder of this article will address the use of a water
budget for irrigation scheduling.

**Water Budget Approach**

When water is lost from the soil by evaporation and the
citrus tree loses water through transpiration, water must be
supplied to replace evapotranspiration (ET). A reference
evapotranspiration (ET0) can be used as a basis for estimat-
ing citrus grove ET (ETc) or irrigation demand. Reference
ET is calculated on a daily basis using weather data (e.g.,
maximum temperature, minimum temperature, relative
humidity, solar radiation, and wind), which are available
from the nearest FAWN site at [http://fawn.ifas.ufl.edu](http://fawn.ifas.ufl.edu).

Two factors (Kc and Ks) must be used to convert the ET0
(calculated based on a grass crop) to one that reflects citrus
growing in specific soils and conditions observed in the
grove of interest. The equation: ETc = ET0*Kc*Ks uses these
components to estimate the ETc. The crop coefficient (Kc)
determines the relative amount of water used by a crop
based on growth patterns and changes throughout the year.
It is low during the cooler months when water use is low
and higher in the warm summer months when water use by
the citrus trees is high. The soil-water extraction factor (Ks)
is an estimate of the trees’ ability to remove water through-
out a range of water contents. As soils dry out, the Ks is
reduced. Tree roots must expend more and more energy to
take up water from the soil, thus the trees remove less water,
and the Ks gets smaller. When soil water is depleted by as
little as 50%, tree water uptake can be reduced by as much
as 40%. Reduced water uptake by the tree can result in
reduced tree growth and yield. Thus, growers are advised to
keep their soil above the recommended maximum allow-
able soil water depletion for the given time of the year so
that Ks remains as high as possible. The UF/IFAS rec-
ommendation is to allow 25 to 33% soil-water depletion during
February through May, and 50 to 66% depletion during
June through January. These allowable depletions provide
more available soil water in the spring for bloom, fruit set,
and vegetative growth. The increased allowable soil water
depletion in the summer and fall allows for more effective
use of rainfall during the rainy season and sufficient water
for fruit expansion.

**The Citrus Irrigation Scheduler**

To aid citrus growers in water management decision
making, the Florida Automated Weather Network (FAWN)
has developed a useful irrigation scheduling method: http://fawn.ifas.ufl.edu/tools/irrigation/citrus/scheduler/.

The computer-based support system was developed to improve water use efficiency for site-specific soil characteristics and local weather data. Grove in-row and between-row tree distances are used to estimate the canopy volume, which in turn is used to calculate root distribution. Irrigation system characteristics provided by the user are spray diameter, shape of wetting pattern, and flow rate. These factors are used to determine irrigation delivery rate and application time. Soil characteristics for a given site can be specified from a list of soil types. The current ET is automatically provided from a selected FAWN site near the grove and appropriate Kc and allowable moisture depletion are used based on the current date. A schedule of days between irrigation and hours of irrigation duration are provided. Suggested irrigation application delays for rainfalls of up to one inch are also provided.

Field Testing
A field test of the Citrus Irrigation Scheduler was conducted in six groves for a period of three years. Weather stations were placed in the groves, irrigation schedules were provided to the grower cooperators, and soil moisture measurements were taken every half-hour. Evapotranspiration at these sites were compared with ET estimated at the closest FAWN site (Fig. 1). Soil moisture sensor data were also compared with values estimated from the model (Fig. 2). It was concluded that the web-based Citrus Irrigation Scheduler tool using the model described would provide the accuracy needed for grower irrigation decisions. Furthermore, it was concluded that FAWN stations provided reliable ET data for these grower irrigation schedules, thus growers would not be required to have and maintain their own weather stations.

Conclusions
We have discussed the importance of soil characteristics and rooting depth on irrigation scheduling. Understanding the root zone depth is key to determining the depth to which soil moisture must be managed by irrigation. Growers can then use generic tables, soil water balance, or soil water sensors to determine when the next irrigation should occur. However, the grower needs to further understand that these irrigation schedules vary by time of year due to irrigation demand (ET) and allowable depletions. The use of a computer tool like the Citrus Irrigation Scheduler available at the FAWN Web site can simplify the calculations required for proper irrigation scheduling. With proper irrigation scheduling, sufficient water is provided for tree growth, fruit development, and yield. It can also protect the environment through reduced leaching of fertilizer nutrients, and improve the grower’s bottom line by reducing costs of both water and fertilizer.
Citrus Cold Weather Protection and Irrigation Scheduling Tools Using Florida Automated Weather Network (FAWN) Data

John L. Jackson, Kelly Morgan and William R. Lusher

Introduction
With a crop value of $597 million in 2006/07, citrus is the most important horticultural crop grown in Florida. The 2.4 million tons of annual citrus production in Florida accounts for approximately 75 and 20% of United States and world citrus production, respectively. Agricultural water use has become a greater concern for citrus production in Florida due to increasing competition between agricultural, commercial, and residential use of limited water supplies. Tools have been developed for the FAWN that will assist citrus growers in improving frost protection and irrigation scheduling while saving water. These tools are the Cold Protection Toolkit and the Citrus Microsprinkler Irrigation Scheduler. Use of these tools, potential benefits to citrus growers and water savings are described below.

History of the Cold Protection and Irrigation Tools
Winters in Florida are generally very pleasant with afternoon temperatures near 70°F and minimum temperatures ranging from 40°F to 60°F. These temperatures allow winter production of vegetables, citrus, strawberries, ornamental plants, ferns, and many other crops that cannot be grown in other states during this time of the year. However, Florida is not free from frosts and freezes, and many growers must have a cold protection plan in place to deal with the sporadic arrival of cold air. Generally speaking central and south Florida growers are more concerned with freeze/frost events than those in the northern or western parts of the state.

Several methods of cold protection are used in Florida. In a few isolated situations, heaters are used to protect high-cash crops. A few citrus growers still use wind machines during calm nights to mix warm air aloft with cold air that has settled near the ground. However, these two methods of frost protection require high volumes of fuel and are becoming less used in Florida. More and more growers are using “heat blankets” to capture heat stored in the ground during the day and radiated back to the sky at night. This method of cold protection works well with low growing crops, but must be removed in a relatively short period of time to avoid damaging the plants.

By far the most widely used method of cold protection in Florida is the application of water. Some crops such as ferns and strawberries require relatively large amounts of water per acre to protect the entire crop, while citrus trees require much smaller amounts to protect primarily the tree trunk and scaffold limbs.


2. John L. Jackson, Extension agent and FAWN coordinator, Lake County Extension Office; Kelly Morgan, assistant professor, Department of Soil and Water Science, Southwest Florida Research and Education Center (REC) – Immokalee; William R. Lusher, FAWN director; Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611.

The Institute of Food and Agricultural Sciences (IFAS) is an Equal Opportunity Institution authorized to provide research, educational information and other services only to individuals and institutions that function with non-discrimination with respect to race, creed, color, religion, age, disability, sex, sexual orientation, marital status, national origin, political opinions or affiliations. U.S. Department of Agriculture, Cooperative Extension Service, University of Florida, IFAS, Florida A&M University Cooperative Extension Program, and Boards of County Commissioners Cooperating. Thomas A. Obreza, Interim Dean.
When using water for cold protection, growers must determine the critical minimum temperatures for their crop(s). Then they must operate their irrigation systems to keep their crops from being damaged, while at the same time minimizing water use. Growers have followed a fairly general procedure when dealing with cold events in Florida. FAWN examined the various steps in the process and then developed methods to collect and display information useful to growers, utilizing current data from its sites, and forecast products from the National Weather Service (NWS), such as its 7-day Point Forecast.

Management tools evolve over time as refinements are made and additional data are collected. The FAWN cold protection tools are a classic example of this process. The first tools provided guidance for operation of irrigation systems used for cold protection—simply turning them on and off. The Brunt Equation has provided guidance over the past 10-20 years related to estimating the minimum overnight temperature and was a minor aid used only to add a little confidence to the forecasted minimum temperature. More recently, however, the Wet-Bulb Based Irrigation Shutoff Temperature tool was developed to tell users when it is safe to turn off irrigation systems based on their critical temperature to avoid tree damage due to evaporative cooling. This tool is now considered critical for anyone using water for cold protection.

Irrigation scheduling is simply applying water to crops at the "right" time and in the "right" amount. Soils hold different amounts of water depending on their pore size distribution and their structure. The greatest amount of water available is often called "field capacity" (FC), while the lowest is called the "permanent wilting point" (PWP). The total amount of water available for plant uptake is the "available water" (AW), which is the difference between FC and PWP and is often expressed a percent by volume (volume of water/volume of sample). The "plant available water" (PAW) is determined by the root zone depth where water extraction occurs. Depletion of the water content below a "maximum allowable depletion" (MAD) is essentially the operating range of soil water content for irrigation management. For citrus, MAD is generally 25 to 33% of PAW in the spring and 50 to 66% of PAW the rest of the year. Theoretically, irrigation scheduling consists of irrigating at MAD until the depleted water has been replaced to but not more than the FC level, otherwise drainage and or deep percolation will occur.

Scheduling methods often consist of grower judgment or a calendar-based schedule of irrigation events based on previous seasons. The simplest form of scheduling is the "feel" method. Other methods are use of published tables by month or use of soil moisture sensors. Soil moisture sensors have improved greatly over the past several years, but are still expensive and require maintenance and site-specific calibration to be effective. Evapotranspiration (ET) is the amount of water transpired by a crop or evaporated from the soil on a daily basis. Crop ET can be determined using weather data and is accurate for a relatively large area. The amount of ET for citrus has been determined and can be used to schedule irrigation using weather information from FAWN.

**FAWN Cold Protection Tool Kit**

These are several examples that demonstrate how cold protection tools have evolved over the years. Additional cold protection tools have been developed and added to FAWN, for a total of six currently available. These are described in greater detail below. All FAWN management tools contain "background" information that describes the tool and provides the names and contact information for the developers/authors of those tools.

**Determining Critical Temperature**

The first step in the cold protection process is to determine the critical temperature for a given crop. Many growers already know this value and can simply enter it into the tool. However, the online guide, *Determining Critical Freezing Temperatures for Plants in Florida*, provides assistance with determining the critical temperature for various crops and can be found at http://fawn.ifas.ufl.edu/tools/coldp/crit_temp_select_guide.php. Once entered, the critical temperature is saved for use with other steps in the toolkit.

Citrus is somewhat unique with regard to critical temperature as the plant acquires hardiness from exposure to cool temperature and loses hardiness if exposed to warm temperatures. Leaf freezing temperatures for several varieties of citrus have been documented over the years by several scientists. Currently, citrus leaf freezing temperatures are being studied by scientists at several locations in Florida with funding from the Southwest Florida Water Management District, and can be found at http://fawn.ifas.ufl.edu/tools/coldp/crit_temp_select_guide_citrus.php.

**Fruit Frost Station Forecast**

Once a critical temperature is determined, users generally wish to know when this critical temperature may occur. Forecasts are not part of the Cold Protection Tool Kit. However, FAWN provides quarterly agricultural climate outlooks from the Southeast Climate Consortium (www.
agclimate.org), and short-range forecasts from the National Weather Service (NWS) 7-day Point Forecasts so that growers can plan for future events.

For more than 60 years the NWS collected data during the winter from as many as 350 locations in the peninsular Florida and used these data to issue a 24-hour Fruit Frost Forecast. Each location contained a minimum recording thermometer and a thermograph housed in a standard "government" weather shelter. During the early years of this program thermograph charts were collected weekly and were processed to provide a summary of each winter's temperatures. Many of these shelters became notorious for low temperatures due to their cold locations. Some of the original sites are now housing developments, shopping complexes, and industrial warehouses. However, FAWN obtained the locations of 178 of these shelters and used the section, range and township to determine the latitude and longitude coordinates for the station's location. The FAWN Fruit Frost Station Forecast tool uses these coordinates to retrieve a NWS 7-day Point Forecast for the three (3) mile square area centered on the latitude/longitude coordinates. Locations of interest are selected from a table of approximately 180 of the prior "government shelter" locations. Upon selecting a station, a NWS 7-day Point Forecast for that location is shown, providing an overview of whether cold protection may be needed during the following week. This tool can be found at http://fawn.ifas.ufl.edu/tools/coldp/ffs_forecast_links.php. Future implementations of this tool will display the locations on a map and, upon selecting a site, a 7-day graph so users can determine the NWS forecast for known cold areas.

**Forecast Tracker**

Once a forecast for the week ahead has been obtained, the FAWN Forecast Tracker offers a unique "look" at individual cold events. Users can select a FAWN site and view a 48-hour graph (Figure 1) that displays the NWS forecasted temperature (24 hours prior to, and ahead of, the current time), and the FAWN observed temperature (24 hours prior to the current time). This tool, called the forecast tracker, allows users to examine how well the forecast has performed over the past 24 hours. A critical temperature can also be displayed on the graph to assist the user in determining the likelihood of the forecasted temperature for the FAWN site reaching their critical temperature, and the length of time the temperature is expected to remain at (or below) that level.

Visual display of the forecast Tracker available on the FAWN website. This tool provides a forecast from the

![Figure 1. Forecast Tracker](image)

National Weather Service for a selected area of Florida with past 24 hour data from the nearest Florida Automated Weather Network station.

This tool is extremely useful for short term forecast evaluations, but is not intended to discount a forecast. Local conditions such as land surface, terrain, and landscape may cause the forecasted temperature to vary from the actual temperature, and these variations, though usually small, can be significant when considering crop livelihood. The Forecast Tracker can be found at http://fawn.ifas.ufl.edu/tools/coldp/forecast_tracker.php.

**Minimum Overnight Temperature**

The Minimum Overnight Temperature tool can be used to further evaluate the likelihood of the forecasted temperature occurring. This tool utilizes the Brunt equation, which requires an air temperature and dew point temperature at sunset. The sunset air and dew point temperature can be either manually submitted (ideally for the user's location), or obtained from the nearest FAWN site. Air temperature can vary considerably over a short distance, while the moisture content of the air generally does not. Therefore, a local air temperature and FAWN dew point temperature are generally suitable for use in this tool. This tool can be found at http://fawn.ifas.ufl.edu/tools/minimum_temperature/

**Evaporative Cooling Potential**

There is always a risk when using irrigation systems (e.g., micro-sprinkler or conventional sprinkler) for cold and/or frost protection. Dry and windy conditions can result in a wet bulb temperature 5°F to 6°F degrees lower than the air temperature. When air blows over a wetted plant surface in dry conditions, evaporation occurs, and this can cool the plant surface to temperatures lower than the air temperature. This **evaporative cooling** may result in plant
damage when the wet bulb temperature is below the critical temperature for that plant. Therefore, on nights when the air temperature is close to the critical temperature, introduction of water could produce more damage than if no action was taken at all.

The risk of damage due to evaporative cooling can be determined by considering two factors: the difference between the air and wet bulb temperatures, and the wind speed. FAWN utilizes the Jackson/Cross/Fayrma Evaporative Cooling Table, which shows 4 categories of risk and criteria for each category. In its current format, user-supplied forecasted values of air temperature, wet bulb temperature, and wind speed are used in conjunction with the table to make a determination of whether evaporative cooling is possible. Future implementations of this tool will automatically obtain these values and provide a level of risk for each FAWN site.

This tool in conjunction with leaf freezing temperature data mentioned previously can have a significant impact on the use of water for cold protection of citrus. There are many nights that are unsuitable for the use of water for cold protection. Using this tool can aid growers in saving both dollars and water, and at the same time eliminate evaporative cooling damage to the plant. The Evaporative Cooling tool can be found at http://fawn.ifas.ufl.edu/tools/coldp/evaporative_cooling.php.

**Wet-Bulb Based Irrigation Cutoff Temperature**

The last tool in the Cold Protection Tool Kit is Wet-Bulb Based Irrigation Cutoff Temperature tool. This tool simplifies the basic cold protection recommendation to discontinue irrigation when the wet bulb temperature reaches the critical temperature of the crop being protected (Harrison, et al., 1974). However, it is difficult to know when the wet bulb temperature is going to equal the critical temperature. As mentioned previously, the moisture content of an air mass does not vary much over a short distance. Therefore, the wet bulb temperature at the closest FAWN site is a good indicator of moisture content for nearby locations. This tool retrieves a current air and wet bulb temperature (both calculated every 15 minutes) from each FAWN site, calculates the difference between these, and then calculates a “new” wet bulb temperature at the user-supplied critical temperature. This “new” wet bulb temperature is the temperature at which the system can be safely shutdown. Water and dollar savings from this simple tool can be tremendous.

**FAWN Citrus Microsprinkler Irrigation Scheduler**

Citrus is typically produced on sandy soils with poor water holding capacity of 0.04 to 0.09 cm³ cm⁻¹ in Florida. Adequate supply of both irrigation water and fertilizer on an annual basis are therefore required for optimal citrus production. The key to plant water status is soil water availability, thus soil water content must be maintained within a relatively narrow range such that water availability to the crop does not limit growth or adversely impact yield or quality. The Citrus Microsprinkler Irrigation Scheduler estimates the soil water balance in multiple soil layers under a mature citrus tree using tree spacing and irrigation system information provided by the user (Figure 2). A 2-week irrigation schedule is provided for the user based on evapotranspiration (ET) rates obtained from FAWN sites (Figure 3).

In a three-year field evaluation of weather and soil moisture data, it was concluded that this Web-based tool provides the accuracy needed for grower irrigation decisions. Furthermore, it was concluded that FAWN stations and not grove sites weather stations can provide reliable data for these grower irrigation schedules and not require growers to maintain their own weather station. Irrigation scheduling tools for other crops are being evaluated.

**Value of the Cold Protection Tool Kit and Citrus Microsprinkler Irrigation Scheduler**

Accountability is extremely important to FAWN. Financial support for the program comes from a number of public agencies and private sources, and each need to know their support is making a positive impact through FAWN.

According to the members of the Agricultural Weather Task Force, FAWN has had a multi-million dollar impact on agriculture through more informed production, harvesting, and marketing decisions. While there has been no major attempt to document the overall impact, feedback from

---

**Figure 2.** Input data required to determine irrigations schedule for citrus using the FAWN Citrus Microsprinkler Scheduler.
non-agricultural users indicates substantial use and value. For example, the NWS uses FAWN data when evaluating fire risks and developing high-resolution surface maps; the Florida Division of Emergency Management uses the data when tracking the southward progression of cold air, to monitor wind speeds during hurricanes, and in making decisions regarding potential risks from winter events; the Florida Division of Forestry relies on the information in issuing burning permits and in monitoring smoke plumes; the University of Florida DISC (Decision Information System for Citrus) project uses FAWN data for crop models; and various media outlets have incorporated the data into numerous articles and presentations (WESH in Orlando, FL uses FAWN data for early morning reports, for example).

It has been shown that users of FAWN data and tools for cold protection can potentially save substantial amounts of water and numerous dollars. Using information from the Florida Agricultural Statistics Service, Florida Citrus Mutual, the Florida Strawberry Association, the Florida Fern Growers Association, the Florida Nurserymen Growers and Landscape Association, and the Florida Fruit and Vegetable Association, estimates of potential savings have been calculated and are presented below.

The table below shows the average amount of water applied per acre per hour, the number of acres protected, and the total number of gallons of water used per hour for several Florida industries.

It costs $14.17 to apply 1 acre with 1 inch of water. Using this information and the hourly water usage from above, the cost per hour and total cost per industry can be estimated, and are presented below.

Therefore, 1,803,840,000 gallons of water are required for one hour of irrigation for cold protection at a cost of $945,042.

FAWN Cold Protection tools provide growers with a guide for when to start and stop irrigation used for cold protection. Use of FAWN Cold Protection tools can save an estimated 2 hours of irrigation per cold event, which can bring about substantial savings over a winter season. For example, during a relatively warm winter, 1 to 3 nights may require cold protection for a total savings of 2 to 6 “irrigation-hours.” A cold winter, however, may produce 4 to 10 nights requiring cold protection for a savings of 8 to 20 hours. Therefore, the average number of gallons of water and dollars saved during relatively warm and cold winters can be estimated, and are shown below.

Therefore, depending on the number of nights that need protection, 7 - 25 billion gallons of water and $3 - 13 million can potentially be saved by using FAWN Cold Protection tools.

From data provided by participants testing the Citrus Microsprinkler Irrigation Scheduler, growers saved approximately 20% of the water used prior to initiation of the project. Using an estimated cost of $166 per acre per year for irrigation, a 20% savings would be approximately $33 per acre per year. This savings would be low for the small 100 to 500 acre grower ($3,300 to $16,500); however, the annual savings would be large for the 1000 to 5000 grower organizations ($33,000 to $165,000). Large corporate citrus operations of several tens of 1000 acres are becoming commonplace. Irrigation savings for these large growers would be greater than $330,000 per year assuming 20% savings.

**Conclusion**

For ten (10) years FAWN has been meeting its mission of “providing a wide variety of users with timely and accurate weather information.” FAWN has taken its weather information and developed cold protection and citrus irrigation scheduling tools that have saved billions of gallons of water and reduced cold protection costs by millions of dollars. FAWN has demonstrated that an Internet-delivered weather network in Florida provides essential information in a timely and efficient manner. FAWN has been a major asset to the citizens of Florida.
Table 1.

<table>
<thead>
<tr>
<th>Industry</th>
<th>Average Water Applied per acre (gallons)</th>
<th>Area Protected (acres)</th>
<th>Total Water Use (gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citrus</td>
<td>2,100</td>
<td>500,000</td>
<td>1,050,000,000</td>
</tr>
<tr>
<td>Strawberry</td>
<td>16,200</td>
<td>6,200</td>
<td>100,440,000</td>
</tr>
<tr>
<td>Fern</td>
<td>13,500</td>
<td>7,400</td>
<td>99,900,000</td>
</tr>
<tr>
<td>Vegetables</td>
<td>10,800</td>
<td>40,000</td>
<td>432,000,000</td>
</tr>
<tr>
<td>Ornamentals</td>
<td>8,100</td>
<td>15,000</td>
<td>121,500,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>68,600</strong></td>
<td><strong>109,600</strong></td>
<td><strong>1,803,840,000</strong></td>
</tr>
</tbody>
</table>

Table 2.

<table>
<thead>
<tr>
<th>Industry</th>
<th>Cost per hour per acre (USD)</th>
<th>Total Cost per hour(USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citrus</td>
<td>1.10</td>
<td>550,000</td>
</tr>
<tr>
<td>Strawberry</td>
<td>8.48</td>
<td>52,576</td>
</tr>
<tr>
<td>Fern</td>
<td>7.09</td>
<td>52,466</td>
</tr>
<tr>
<td>Vegetables</td>
<td>5.66</td>
<td>226,400</td>
</tr>
<tr>
<td>Ornamentals</td>
<td>4.24</td>
<td>63,600</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>24.59</strong></td>
<td><strong>945,042</strong></td>
</tr>
</tbody>
</table>

Table 3.

<table>
<thead>
<tr>
<th>Hours Saved</th>
<th>Winter Type</th>
<th>Average # of Nights Protected</th>
<th>Total Volume Saved (gallons)</th>
<th>Total Cost Saved (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Warm</td>
<td>2</td>
<td>7,215,216,000</td>
<td>3,780,168</td>
</tr>
<tr>
<td>2</td>
<td>Cold</td>
<td>7</td>
<td>25,242,600,000</td>
<td>13,230,588</td>
</tr>
</tbody>
</table>
Smart Phone Apps for irrigation Scheduling

Programs for scheduling irrigation using FAWN weather data have been developed and can be found in the tools tab at the FAWN website (http://fawn.ifas.ufl.edu). These tools are being made into smart phone apps and are available for citrus and strawberry as apps for iphone and android. Other apps including vegetable drip irrigation will be available soon. IFAS/FAWN and FDACS joint program of weather station data collection.

We will demonstrate the FAWN tools and smart phone tools. Instructions on install the smart phone apps using the instructions below.

Smart Irrigation Smart Phone Apps for irrigation Scheduling

On your iphone link to the App Store, on your android link to the Play Store

At both App Store and Play Store, search for apps using the word smarirrigation

You will see the three apps now available Citrus, Strawberry, and Turf. Install those that pertain to your program

We will demonstrate the use and features of the citrus app that will be close to the vegetable app to be available soon.

Florida Farm Weather program –

On your iphone link to the App Store, on your android link to the Play Store

At both App Store and Play Store, search for apps using the word Florida Farm

You will see the Florida Farm Weather App.
Tensiometers for Soil Moisture Measurement and Irrigation Scheduling

Allen G. Smajstrla and Dalton S. Harrison

Tensiometers are instruments that are used to measure the energy status (or potential) of soil water. That measurement is a very useful one because it is directly related to the ability of plants to extract water from soil. Irrigators often use tensiometers for irrigation scheduling because they provide direct measurements of soil moisture status and they are easily managed. In addition, tensiometers can be automated to control irrigation water applications when the soil water potential decreases to a predetermined critical value.

Tensiometer Components

A tensiometer consists of a porous cup, connected through a rigid body tube to a vacuum gauge, with all components filled with water. The porous cup is normally constructed of ceramic because of its structural strength as well as permeability to water flow. The body tube is normally transparent so that water within the tensiometer can easily be seen. A Bourdon tube vacuum gauge is commonly used for water potential measurements. The vacuum gauge can be equipped with a magnetic switch for automatic irrigation control. A mercury manometer can also be used for greater accuracy, or a pressure transducer can be used to automatically and continuously record tensiometer readings. Figure 1 illustrates the components of one model of a commercially available tensiometer using a vacuum gauge.

Figure 1.

Tensiometer cost depends on its length, or the depth at which it will be installed. In general, prices of standard, manually-read instruments range from about $60 each for the 6-inch size to about $75 for the 4-ft size. Automatic switching tensiometers cost about $30 more. Vacuum gauge tensiometers are manufactured by several companies and are available at most irrigation supply businesses.

2. Allen G. Smajstrla and Dalton S. Harrison, Professor and Professor emeritus, respectively, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 32611.
Principle of Operation

Tensiometers are placed in the field with the ceramic cup firmly in contact with the soil in the plant root zone. The ceramic cup is porous so that water can move through it to equilibrate with the soil water. A partial vacuum is created as water moves from the sealed tensiometer tube. The vacuum causes a reading on the vacuum gauge which is a direct indication of the attractive forces between the water and soil particles. This reading is a measure of the energy that would need to be exerted by the plant to extract water from the soil.

Because the porous ceramic cup is permeable to both water and dissolved salts, tensiometers do not record the water potential due to dissolved salts (osmotic potential). The actual total potential that plants would need to overcome to extract water from soils includes the osmotic potential. If soils are saline, or if poor quality irrigation water is being used, the osmotic potential will be a large portion of the total potential. In those cases, osmotic potential should also be measured using soil salinity sensors.

As the soil dries, water potential decreases (tension increases) and the tensiometer vacuum gauge reading increases. Conversely, an increase in soil water content (from irrigation or rainfall) decreases tension and lowers the vacuum gauge reading. In this way, a tensiometer continuously records fluctuations in soil water potential under field conditions.

Rapid and accurate tensiometer response will occur only if air does not enter the water column. Air expands and contracts with changes in pressure and temperature, thus causing inaccurate tensiometer readings. Even if instruments do not have leaks, dissolved air enters with water flow through the ceramic cup during normal operation of the instrument. When a significant amount of air enters the instrument, it must be expelled and the tensiometer refilled with water before it will operate reliably again.

Units of Measurement

The tensiometer measures water potential or tension. Water potential is commonly measured in units of bars (and centibars in the English system of measurement) or kilopascals (in metric units). One bar is approximately equal to one atmosphere (14.7 lb/in²) of pressure. One centibar is equal to one kilopascal.

Figure 2.

Because water is held by capillary forces within unsaturated soil pore spaces, its water potential is negative, indicating that the water is under tension and that work must be done to extract water from the soil. A water potential reading of 0 indicates that the soil is saturated, and plant roots may suffer from lack of oxygen. As the soil dries, water becomes less available and the water potential becomes more negative. The negative sign is usually omitted for convenience when soil water potentials are measured with tensiometers. The negative sign will be omitted in this publication, and readings will be reported as soil water tensions.

Figure 2 The gage illustrates the dial face of a typical tensiometer vacuum gauge. Divisions are in units of centibars (cb), with a range of 0-100 cb. Recently, one company began to manufacture a "Florida" tensiometer with a range of 0-40 cb. The expanded scale in this range is ideal for irrigation scheduling in typical Florida sandy soils.
Range of Operation

Because of the vaporization of water at low pressure, the range of operation of a tensiometer is limited to 0 to about 85 cb. Above 85 cb the column of water in the plastic glass tube will form water vapor bubbles (cavitate), and the instrument will cease to function. This range represents only a fraction of the water tension range that is normally considered to be available for plant growth. Many plants can survive to a water tension of 15 bars. However, plant growth and productivity cease well before this point. In sandy soils, tensiometers measure the entire range of soil water tension of interest for irrigation. Thus, the tensiometer is an excellent instrument for irrigation management in Florida.

Research has shown that to optimize production, irrigation should be scheduled when soil water tension reaches 10-20 cb in sandy soils. The exact values to be used depend on soil hydraulic properties, crop susceptibility, and production objectives. These water tensions are well within the tensiometer range of application.

Site Selection

Tensiometers measure soil water tension in only a small volume of soil immediately surrounding the ceramic cup. Therefore, the ceramic cup must be placed in the active root zone of the crop for which irrigations are being scheduled. Depending upon crop type, two or more tensiometers may be required at a measurement site. Figs. 3 and 4 illustrate proper depths of installation for row crops and tree crops, respectively.

Because of differences in soil and plant characteristics, several measurement sites may be required to adequately assess the water status of large areas. For more valuable or more sensitive crops, more tensiometers should be used. For uniform soil types fewer tensiometers may be adequate.

The sites selected for installation should be representative of the surrounding field conditions. Isolated low, wet areas or high, dry areas should be avoided. Tensiometers should be placed within the plant canopy in positions where they will receive typical amounts of rainfall and irrigation. Placement

of tensiometers with depth is critical. For shallow-rooted (less than 1 ft) crops such as some vegetables, only one tensiometer may be required with depth. It should be centered in the crop root zone, but at least 4-6 inches below the surface. The ceramic cup should not be exposed to the atmosphere.

For crops with deeper root zones such as most field crops, two tensiometers should be used at each measurement site. The shallower one should be placed in the zone of maximum root concentration. This is normally at 6 inches or about one-third of the active rooting depth. In tree crops, depths of 6 to 24 inches are often used. Other depth combinations may be used where appropriate.
When multiple instruments are used, most irrigations will be scheduled to replenish the upper part of the root zone monitored with the shallow instrument. The deeper instrument will indicate when less frequent larger irrigations are needed to replenish the entire root zone.

**Installation**

The tensiometer can be a useful instrument for irrigation scheduling only if it is properly installed. In general, proper installation requires that the instruments be in good hydraulic contact with the surrounding soil so that water can move into and away from them as efficiently as possible. In addition, tensiometers must be properly located in the crop root zone as discussed in the previous section on site selection.

![Figure 5.](image)

Before field installation, each tensiometer should be tested to verify that it is operating properly. Fill each tensiometer with clean water (deionized water is preferred to help prevent organic growths) and allow it to stand in a vertical position for at least 30 minutes so that the ceramic tip will saturate. A plastic squeeze bottle and small diameter plastic tube can be used to fill the tube from the bottom to help eliminate air bubbles (Figure 5). When its tip is thoroughly wetted, it can be refilled and capped. The tensiometer will not be serviceable immediately because of air bubbles in the vacuum gauge. A small hand vacuum pump (Figure 6), obtainable from tensiometer manufacturers, can be used to remove air bubbles and test for air leaks. This service will be necessary before installation as well as periodically in the field.

**Figure 6.**

Tensiometers are installed in previously cored holes in the field. Manufacturers sell coring tools of the proper dimensions for tensiometer installation. In sandy soils, the access holes can be cored by hand, while on heavier soils it may be necessary to use a hammer to aid the installation (Figure 7). The tensiometer is pushed into the access hole to the proper depth. In this position, the vacuum gauge will be located 2-3 inches above the soil surface. The soil around the tensio-meter should be tamped at the surface to seal the instrument from air contact with the ceramic cup and to prevent surface water from running down around the tube (Figure 8). If commercially available coring tools are not available, a length of standard water pipe or other tubing of the proper diameter can be used with acceptable results. It is critical, regardless of the installation method used that the ceramic cup be in intimate contact with soil in order for the tensiometer to function properly.

![Figure 7.](image)
If a rock or other obstacle is encountered, the tensiometer should be moved to another location to avoid possible damage when it is placed in the cored hole. The tensiometer should not be driven into place with a hammer or other object. Although adequate for normal use, the mechanical strength of the ceramic cup is not adequate to allow it to be hammered into place.

In very loose cultivated soils, such as frequently encountered in commercial row crop production, it is possible to push shallow tensiometers into place without coring a hole. This method of installation is acceptable when applicable. Again, the surface soil must be firmly packed around the instrument after installation.

After installation, several hours may be required before the tensiometer reads the correct soil water potential value. This is because of the disturbance to the soil caused by the installation procedure, and because of the need for water to move through the ceramic cup before equilibrium is reached. The correct reading will be reached more quickly in moist soils than in dry soils. After this initial equilibrium period, the tensiometer will accurately indicate the soil water tension, and it will closely follow changes in tension as they occur in the soil.

Tensiometers are delicate instruments and should be protected from harm both before and after installation. They should be handled carefully and protected from impact by equipment or animals in the field. Also freezing conditions will damage tensiometers. They should not be left filled with water during freezing conditions.

**Field Service**

To operate properly, tensiometers must be serviced in the field periodically. This is because with normal use, air is extracted from water under tension.

The air becomes trapped within the tensiometer and reduces response time progressively until the instrument fails to operate.

If the soil in which the tensiometer has been installed is moist, soil tensions will be low and very little air will accumulate. If, however, the tensiometer is installed in drier soils, with water potentials in the range of 40 to 60 cb, air will accumulate more quickly.

The body tube should be inspected for accumulated air each time the tensiometer is read. If over 1/4 inch of air has accumulated beneath the service cap, the cap should be removed and the tube refilled with water as shown in Figure 9.

In wet soils, the tensiometer will probably need to be serviced approximately every 2 weeks. In dry soils, servicing may need to be more frequent, perhaps as often as every time the tensiometer data is collected.
Irrigation Scheduling

Tensiometer measurements are useful in deciding when to irrigate because they give a continuous indication of soil water status, but they do not indicate how much water should be applied. The decision to irrigate is made when the average tensiometer reading exceeds a given critical value. To optimize production the critical value is normally in the range of 10 to 20 cb for typical Florida sandy soils. The critical values are different for specific soil types, crops, and stage of crop growth. At critical stages of crop growth, lower values are used, resulting in irrigations being scheduled more frequently. The critical values are also functions of economic considerations, with higher values set if the irrigated commodity price drops or if the cost of irrigation increases.

A tensiometer indicates only when irrigation should be scheduled, and not how much water should be applied. To determine the amount of water to be applied, a moisture characteristic curve specific for the irrigated soil must be used. Figure 10 is a moisture characteristic curve for Lake Fine Sand, a typical deep sandy soil of central Florida. The depth of irrigation water to be applied should be adequate to restore only the root zone to field capacity. Excessive water will be lost to deep percolation below the crop root zone, carrying nutrients with it.

Figure 11

The data illustrates tensiometer field data and irrigations scheduled by the tensiometer method. In this illustration, timing and amount of irrigation were controlled with tensiometers at two depths. When the major root zone (12 inch) depth became as dry as desired, small irrigations were scheduled to rewet the 12-inch zone, but not the 24-inch depth which was still sufficiently wet. When, eventually, the 24-inch zone also reached the desired degree of dryness, a larger irrigation was scheduled to rewet the entire soil profile.

Automated Tensiometers

A major advantage of tensiometers is that they can be instrumented to provide automatic control of irrigation systems. A modification is required to allow a tensiometer to be used as an irrigation controller. The vacuum gauge is equipped with a magnet and a magnetic pick-up switch so that, when a desired (and preset) water tension occurs, the switch closes, starting the irrigation pump. The pump operates for a preset period of time, lowering the tensiometer reading, after which the tensiometer is again monitored until the critical water tension again occurs. A schematic of such an automatically controlled irrigation system is shown in Figure 12.

Summary

The schedules in Table 5 are for a typical season's duration and may need to be adjusted depending on specific cultural practices and growing season conditions. Some factors that might lead to
Tensiometers for Soil Moisture Measurement and Irrigation Scheduling

Figure 12.

expanding or compressing the injection schedule are described in this section.

Crop development rate can be increased by transplanting in contrast to direct seeding. For example, watermelons can produce earlier fruit by about 7 to 10 days from transplants compared to seeds. Transplanted crops will require slightly greater amounts of nutrients early in the season than seeded crops. Injection rates can be increased by 0.5 lb per acre per day for the first 4 to 6 weeks compared to a seeded crop. Since transplanted crops mature faster than seeded crops, the rates of injection can be reduced or discontinued earlier than for seeded crops. Although the scheduling may change slightly for seeded and transplanted crops, the total amount of nutrients injected by the end of the crops should be similar.

The crops and schedules detailed in this publication are for vegetables produced on polyethylene mulch. Mulch has a growth enhancing effect on crop development. Some growers desire to use drip irrigation without mulch. In these situations, the growth season might be increased by 7 to 10 days where the mulch is absent. Therefore, injection schedules can be expanded by reducing the amount injected in the early weeks.

For a given crop, growth in the fall is usually faster than spring growth. The difference can be one week for a crop such as squash or two weeks for tomato or pepper. Therefore, fall injection schedules would need to be compressed compared to spring schedules. Amounts of nutrients injected can be increased during the first few weeks by 0.5 lb per acre per day. Total seasonal fertilizer amounts for spring and fall crops should be similar.

The schedules in this publication are for situations where all N and K will be injected. It is usually best to place some nutrients in the bed before mulch application. The general rule-of-thumb is 20% of N and K as a starter. For most crops, this results in about 25 to 30 lb N per acre in the bed. Under these situations, the first injection can be delayed by one or two weeks.

The length of harvest period can have an effect on extending the injection schedule. In some of the southern winter-growing regions, the production season for pepper might encompass 4 to 6 months. In these situations, the injection schedule will be considerably longer than for a typical 3- to 4-week harvest season. Where the crop will be continued through the winter with approximately biweekly harvests, growers can inject 1 to 1.5 lb of N per acre per day as a maintenance program for these extra months. The exact amount of N and K should be determined by plant tissue analysis.

Finally, the cultivar (variety) can affect the crop development rate. In a given season, early cultivars might mature as much as 2 weeks ahead of later-maturing cultivars. The schedules in this publication are for the standard cultivars presently recommended. In general, most cultivars currently being grown will do well under these injection schedules. For situations where a particular cultivar may mature significantly earlier or later than currently grown cultivars, an adjustment in the schedule might be needed.

References

Depending on the soil type and production experiences of the grower, some considerations will need to be taken into account when establishing a crop where drip irrigation will be used. In situations where drip irrigation will be used on a Spodosol, it might be advantageous to maintain adequate soil moisture with subirrigation for 1 week after seeding or transplanting the crop. Subirrigation may be needed to maintain soil moisture during soil bed preparation, fumigation, and mulching. It is probably
a good idea, then, to maintain soil moisture during planting and for up to 1 week after planting. This might be needed most often with direct-seeded crops to ensure uniform germination. After crops have become established, the water table can be lowered with irrigation and fertilization being taken over by the drip-irrigation system.

In some cropping situations where water tables cannot be maintained, especially the rockland soil in Dade County, overhead-sprinkler irrigation might be needed for crop establishment. Following crop establishment, irrigation and fertilization can then be taken over by the drip-irrigation system.

Growers will need to pay particular attention to the wetting pattern of the drip irrigation. It is important to utilize as much of the wetted bed area as possible for a particular crop. Reducing the bed width helps maintain the effective root zone in a moist condition under the plastic mulch. In situations where crop establishment must be done without subirrigation for soil moisture maintenance, placement of seeds and plants in the moist soil near the drip tube becomes important to ensure uniform germination. For single-row crops such as melons, one option would be to place the drip tube in the middle of the bed and then place the plants in a pattern that alternates on both sides of the drip tube. This is an acceptable planting pattern compared to placing the drip tube off-center in the bed and then planting a single row of plants in the center of the bed. The alternating planting pattern utilizing both sides of the drip tube allows the drip tube to be placed in the middle of the bed and increases the potential for wetting the entire width of the bed. If the drip tube were placed off-center, it might be impossible to wet all the way to the shoulder of the bed farthest from the drip tube. In any event, seeds or transplants must be placed within the wetted zone of soil in the bed.
QUICK FACTS:

- Tensiometers continuously monitor soil water status, which is useful for practical irrigation scheduling, and are extensively used on high-value cash crops where low water tension is desirable.
- Tensiometers are ideal for sandy loam or light-textured soils.
- Measurement range is limited to less than one bar tension. Clay soils will still have plant available water past this limit, although the most readily available water is gone.
- Tensiometers may be used in clay soils for crops that need low soil water tension for maximum yield or high crop quality.

Tensiometers are soil water measuring devices that are sensitive to soil water change and useful for irrigation scheduling. Irrigation scheduling is a process to determine when to irrigate and how much water to apply. Applying too little or too much water in an untimely manner can result in yield reductions. Over irrigation wastes water, costs money to pump, and may leach nutrients beyond the root zone. Irrigation scheduling is important and can be achieved by monitoring soil water status with tensiometers.

Plant roots undergo tension as they pull the water out of a soil matrix. Tensiometers are devices that measure the soil water tension by acting like a mechanical root. This mechanical root is equipped with a gauge that continuously registers how hard the root must work to extract water from soil. Tensiometers are particularly accurate at low tensions, which is the wettest part of the soil water range. They are popular with growers of high-value crops, such as vegetables and fruits on sandy soils.

A tensiometer is a sealed, water-filled tube equipped with a vacuum gauge on the upper end and a porous ceramic tip on the lower end. The basic components are a reservoir and cap, body tube, vacuum dial gauge, and a ceramic tip (Figure 1).

Reservoir and cap. The reservoir acts as a water supply for the body tube. The cap on the reservoir must provide a airtight seal for the tensiometer or the device will not work. Some models do not have an enlarged reservoir; the body tube works as a reservoir, and the cap directly seals the system.

Body tube. The body tube provides support and a liquid connection between the porous tip and the vacuum gauge. Tensiometers come in various lengths. Standard lengths are 6, 12, 18, 24, 36, 48, and 60 inches.

Ceramic tips. The ceramic tip is porous, but the openings are so small that when saturated with water, air cannot pass through within the range of soil water tensions to be measured. Water moving out through the porous tip causes the vacuum gauge reading to change indicating the suction, or tension, at which the water is being pulled by the surrounding soil.

Vacuum gauges. The vacuum gauge (Figure 2) is calibrated in centibar or hundredths of one “bar.” A bar is the unit of pressure, either positive
<table>
<thead>
<tr>
<th>Reading (centibars)</th>
<th>Status</th>
<th>Explanation/Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Saturated</td>
<td>Soil is saturated regardless of soil type. If readings persist, there is possible danger of waterlogged soils, a high water table, poor drainage and soil aeration; or the continuity of the water column in the tube may have broken.</td>
</tr>
<tr>
<td>5–10</td>
<td>Surplus water</td>
<td>Indicates a surplus of water for plant growth. Drainage continues and persistent reading indicates poor drainage.</td>
</tr>
<tr>
<td>10–20</td>
<td>Field Capacity</td>
<td>Field capacity for all types of soils. Additional water will drain as deep percolation carrying nutrients without opportunity for plant use. Sandy soils, however, have very little storage capacity, and suction values increase rapidly as water is removed by plants past 15 to 20. For sensitive crops, like potato, rapid irrigation may be required before damaging stress can develop.</td>
</tr>
<tr>
<td>20–40</td>
<td>Irrigation range</td>
<td>Available water and aeration good for plant growth in fine- and medium-textured soils. Irrigation is not required for these soils at this range. Coarse-textured soils may require irrigation in the 20 to 30 range and finer sandy soils at 30 to 40 centibar ranges.</td>
</tr>
<tr>
<td>40–60</td>
<td></td>
<td>Usual range for starting irrigation. At 40 to 50 centibar, irrigation may need to be started for loamy soils. On clay soils (silty clay loams, silty clays, etc.) irrigation usually starts from 30 to 60. Heavy clay soils still have some available water. Irrigation, however, ensures maintaining readily available soil water. The stage of growth and type of crop will influence the decision.</td>
</tr>
<tr>
<td>70</td>
<td>Dry</td>
<td>Stress range. However, crop is not necessarily damaged. Some soil water is available in clay soils but may be low for maximum production.</td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>Top range of tensiometer accuracy; higher readings are possible, but tension within the water column inside tensiometer will break between 80 to 85 centibar. This has relationship to elevation of the area compared to mean sea level. At higher elevations, the water inside the tube may break at a lower reading according to atmospheric pressure.</td>
</tr>
</tbody>
</table>

or negative, that has been adopted for the expression of soil suction. The bar is an international unit of pressure in the metric system and is equivalent to 14.5 psi (pounds per square inch) or 0.987 atmospheres. One centibar is also equal to 1 kPa (kilopascal). A reading of zero corresponds to a completely saturated condition, regardless of the type soil. A reading of 80 indicates a very dry condition for sandy soils or sensitive crops. This also is the functional upper limit for tensiometer readings. A tension higher than 80 will cause the water column inside the tube to break rendering it nonfunctional.

A depth label is usually placed on the vacuum gauge or on the side of the tube to indicate the depth at which the ceramic tip will be set when installed. This is important for identification purposes.

The soil suction reading on the vacuum gauge dial is an indication of soil water availability for plant use and does not require calibration for salinity or temperature. The readings have different meaning in terms of use for irrigation scheduling depending on soil type. Table 1 and Figure 3 suggest interpretation of tensiometer readings in relation to soil texture.

Each situation is different, so irrigators should monitor_crop_conditions, such as wheel track compaction or plow pans, that can affect root development and water movement in the soil.

**Tensiometers with Electronic Reader**

Electronic technology has been added to the tensiometers to be remotely read and used to automatically start irrigation. The manufacturers have developed equipment that will read the tensiometer and turn on an irrigation controller or solenoid valve to initiate irrigation.

There are two systems currently available. One of the systems is comprised of an electronic switch that can be mounted on the vacuum gauge dial of the tensiometer and set to start irrigation at a certain reading. As the soil water tension rises, the gauge needle, which has a magnetic property, moves to a set reading and coincides with the eye of the switch. At this point the electric circuit closes and establishes a current flow to the controller or the solenoid valve, which turns the system on for irrigation. With the progress of irrigation, the soil water gets recharged. The tensiometer is very sensitive to soil water change, and the increase in soil water reduces the tension. The gauge needle falls back, electric current flow is discontinued, and the system automatically shuts down. These switches are normally operated by alternating current (AC) flow. The need for a direct (DC) current system should be specified at the time of ordering. Follow the manufacturer’s instructions for installation.

The other automatic system operates by using a pressure transducer. In this system, the vacuum gauge is replaced by a pressure transducer, which senses any change in pressure and modifies the electric current flow to reflect that change. The reading is continuous. By directly attaching it to the tensiometer body in place of the vacuum gauge, it is connected to the tensiometer system. The transducer is read by an ammeter or voltmeter, which may be interfaced with a data logger or computer. The reading is translated into soil water tension. This information can be used to make decisions for controlling the irrigation system. The computer may be programmed to start an irrigation system at a certain value. The power requirement for the transducer input may vary, but many have requirements of less than 10 volts.

The automated versions of tensiometers enable remote system operation. The irrigation systems now can be controlled based on the soil water content.

**Working Principle**

Soil water exists primarily as thin films around and between soil particles and is bound to soil particles by strong molecular forces. As the soil dries, the water films become thinner and more tightly bound to soil.
matrixes. This increase in tension within the films now in contact with the tensiometer causes water to be drawn from the ceramic tip. The withdrawal of water from the ceramic tip creates a partial vacuum in the tensiometer. Water continues to be drawn until the vacuum created inside the tensiometer equals the tension of the water films outside. At this point equilibrium is reached and water ceases to flow. The vacuum gauge reading indicates the amount of suction or tension.

As water is added to the soil from rainfall or irrigation, the soil suction is reduced. The higher vacuum in the tensiometer causes soil water to be drawn into the tensiometer, and the vacuum will be reduced until a balance in tension is reached. The tensiometer continuously responds and maintains a balance with the soil water suction or tension and the vacuum gauge indicates the amount of tension, hence the name tensiometer.

**TENSIOmeter preparation**

As with any measurement device, proper care and maintenance are required. Check the tensiometer before installation in the field. If the tensiometer was used previously, begin by washing and rinsing it inside and out. Residues on the porous ceramic tip that were not removed by washing may be removed by sanding lightly. Fill the reservoir and body tube with distilled water, taking care that the ceramic tip is wetted from one direction to avoid air entrapment in the finer pores. Allow the tensiometer to stand upright, soon the tip will wetup and free water will appear like a sweat. Refill as necessary to dispel all the air from the tensiometer. After letting it stand in a bucket of water overnight, seal the tensiometer and set it upright in the air. The air will start drying the tip. The gauge should read 70 when air dried. Periodic checking of the gauge reading will indicate if it is functioning properly. Repeat the wetting and drying cycle with the tensiometers that do not respond correctly the first time.

Distilled water treated with three to five drops of chlorine bleach per gallon may be used to inhibit algae growth. Manufacturers also provide solutions for water treatment that may be used according to direction. Distilled water available in a grocery store has been found adequate. If excessive air bubbles are noticed, boiling may be helpful, but the remaining waters need to be stored in an airtight container. Some manufacturers provide a

**Figure 3. Interpretation of tensiometer readings.**

**Figure 4. Zone of soil water control with a two-tensiometer station.**
hand-operated vacuum pump to help remove air from the tensiometer. Operating the pump when the tensiometer is filled with water and the tip is submerged in water helps remove gases from the pores of the ceramic tip and solution. After each pumping, refill the tensiometer completely with water and repeat until no more bubbles are observed. The tensiometer is then sealed by screwing the reservoir cap down securely.

If tensiometers are not to be installed immediately, cover the tips with a plastic bag to prevent evaporation or let them stand in a bucket of water until installed.

**TENSIOMETER INSTALLATION**

**Depth selection.** The number of tensiometer installation sites required will depend on the crops grown and field conditions. Fewer stations of tensiometers are needed when a single crop is grown in large blocks of uniform soil. If the soils are varied or different crops are to be grown, more stations are necessary. Stations need to be selected to represent an area, and care should be taken not to cause excessive compaction or destruction of plants around during installation, which may alter the condition.

Except for very shallow-rooted crops, tensiometers are normally installed in groups of two or more to characterize the soil in the top half to three quarters of the root zone. If the potential root zone is less than 12 inches, a single tensiometer may be installed in the center of the zone at 6 inches deep. With deeper-rooted crops, one tensiometer should be placed at the upper one quarter of the rooting depth and another at the lower quarter point or three quarters of the depth (see Figure 4).

In deeply rooted crops or situations where there is a distinct break in soil textures, three or more tensiometers may be needed. An example might be 18 inches of sand overlying a silty soil growing corn where 3 to 4 feet of the root zone is to be managed. One tensiometer might be placed at 6 inches, a second at 18 inches and a third at 2 to 3 feet. The differences in tension readings would make it possible to better assess the soil water conditions. Almost 70 percent of crop water is supplied by the top half and only 10 percent from lower one fourth of the rooting depth. Irrigators, therefore, often manage only the top half or three fourths of the root zone. Tensiometers should be long enough to reach the desired depth and diaphragm vacuum gauges not touching the ground. They should never be set in a hole.

**Site selection.** Location of the tensiometers in the field generally depends on the type of irrigation system used. For large fields, generally, there will be at least four stations or locations in each field.

If the tensiometers are installed in a flood-irrigated field, stations will be located at the top and bottom of the first and last sets (Figure 5). Each station should be far enough in from the top or bottom of the field so it is not affected by initial wetting effects or by ponding of water.

Under a sprinkler system, use two stations on each side of the pivot when it is in its normal stop position (Figure 6). Set one station on each side near the middle of the pivot, and one station on each side near the outer tower of the pivot, usually about the middle of the outer span. The stations on each side should be far enough away from the pivot so the sprinklers will not wet them when the system is stopped or until after the system is moving. This system of positioning stations on flood or sprinklers will give start and stop indicators for the irrigation sequence.

Tensiometers may be installed using a soil auger or a probe. Manufacturers also provide simple coring tubes. Placement should be in a crop row to avoid traffic. Where furrow irrigation is used, the tensiometers may be angled slightly to place the tip under the furrow. The electronic tensiometers may require a cover to safeguard the electric connections from sprinkler or rain water. If a valve cover box is used, the tensiometer tips need to be slanted out to be in the crop area. The hole should be small enough to create resistance to insertion of the tensiometer and shaped to form close soil contact at the tip. This may be accomplished by returning a little loosened portion of the soil from the depth of placement back into the hole and adding a little water. When the tensiometer is pushed for placement, the soft soil will move around the tip to conform to the rounded shape and make a good contact. Tensiometers must be handled with care— the tips may break if handled roughly.

Ceramic tips of the tensiometers must be kept wet until installed. Steady and firm pressure may be applied while inserting the tensiometer until it reaches the desired depth. The depth label on the tensiometer will identify the root zone being monitored as either deep or shallow. Tensiometer locations need to be marked both in the row and at the edge of the field. A brightly painted wooden stake or a metal rod with a colored flag attached are good markers. Locating tensiometers in tall crops can be a problem. A written log of the station locations also is recommended.

**SERVICE**

Tensiometers are weatherproof, except for freezing, and generally require very little service. When first installed, there may be tiny air bubbles...
clinging to the sides of the body tube. However, after one cycle of soil water use, which creates a high vacuum, the bubbles will rise to the top and can be eliminated by refilling. The amount of bubbles will depend on the gas originally present in the vacuum gauge and the amount dissolved in the water.

Servicing is best done soon after irrigation. Tensions are low at night that may have been drawn into the cup at high tensions can be eliminated by refilling. Tensiometers return to equilibrium at low tensions. They also respond quickly to a very minute withdrawal of water from the system. If much air is drawn into a tensiometer at low tensions, the porous cup may be defective, and the tensiometer may need to be replaced. Some air entry is unavoidable. When using a number of tensiometers, watch for tensiometers that accumulate abnormal amounts of air. The colored fluid concentrate supplied by the manufacturer for control of algae helps to spot collected air bubbles in the tensiometer.

Some tensiometers may require gauge adjustments. The pointers may be adjusted to read zero at the atmospheric pressure of the location of use by opening a screw provided to let air enter into the fill gauge. This may be needed to take care of the difference in pressure due to elevation change. In others, this is accomplished by adjusting to zero with the tensiometer cup standing in a bucket of water. The depth of water outside of the tensiometer in the bucket must not stand too high to avoid outside pressure.

Tensiometers should be removed from the field before freezing. The water can freeze and break the ceramic tip or the body or damage the vacuum gauge. Tensiometers need to be emptied before long-term storage. This prevents salt deposition in the porous material with evaporation or rusting of the gauge.

TROUBLE SHOOTING

A tensiometer that is out of water or leaking will remain at zero on the gauge, or the reading will fluctuate in the low suction range. Two or more successive zero readings may be a sign of a malfunction and should be investigated. If the gauge remains at zero, refill with water and use a hand pump to remove air. The tensiometer may have been empty because of dry soil. If the tip was dry, fine air bubbles will rise rapidly for several minutes and then cease. If larger bubbles rise and continue, a leak is indicated, and the source should be determined.

If the bubbles rise from the bottom, remove the tensiometer and replace the tip. If the bubbles enter from the side, the body tube may be cracked and should be fixed. If bubbles rise from the gauge, the leak may be in the gauge or the thread connection. A leaky gauge needs to be replaced, but a threaded connection can be resealed. If no large bubbles rise, yet the reading remains at zero, the reservoir cup may be cracked or the seal may be defective. Inspect for an "O" ring. There needs to be one for a proper seal. In most cases, the trouble is easily corrected.

A damaged vacuum gauge may stick in one position or may not register smoothly with changes in soil water. Check a suspect gauge against one known to be in good working order, or replace the suspect gauge with a new one. Readings higher than expected, especially after irrigation, are generally not tensiometer failure. The irrigation water may not have penetrated to the depth of the tensiometer tip.

DRAWBACKS

The major criticism of the tensiometer is that it functions reliably only in the wet range of soil water at readings of about 80 centibars or less. At higher readings, the porous tip may leak air, and the gases will be drawn out of the water. At low pressure, the water will vaporize causing discontinuation of the tension column or vacuum. The gauge reading will fall to zero. This is not as serious as it may seem because most of the available water in coarse-textured soils and about 50 percent or more in fine-textured soils have already been used at this range.

Another criticism is the price, which ranges from $45 to $60. When used in large quantities, the cost may seem prohibitive. Irrigation scheduling, however, has shown to easily pay for itself through increased yields or reduced pumping. Proper handling may extend the useful life, and the cost may be spread over many seasons making it cost-effective.

Finally, the ceramic tip may gradually fill with precipitates because of soil water movement through the pores. This slows water transfer through the tip and increases the time required for the tensiometer to respond to a change in soil-water conditions. Some slowing does no harm, but if the response time becomes too slow, a new tip should be installed. The response time may be improved by rubbing the exterior of the tip with fine sandpaper or soaking the tip in a mild acid solution. The amount of plugging depends on the soil water chemistry and the manner of use.

Where tensiometers can be left in the ground, the tip porosity remains satisfactory for several years in most soils. But each time the tensiometer is removed from the soil, tip life is reduced. This is particularly true if the soil is calcareous or saline. In extreme cases, where the tensiometer is installed and removed several times per season, the tip may need to be replaced after one year of use. To minimize this damage, a tip that is removed from the soil should be protected from drying until the tensiometer has been emptied, cleaned, and dried.

Before winter storage, the tensiometer needs to be cleaned and flushed with distilled water. Flushing is done by filling the tube and letting the water drain out of the tip by gravity. If stored where frost protection is not available, make certain all the water from the system had been drained.

The gauges will hold some water that is not readily visible. The vacuum pump may be used to remove the water by holding the tube horizontal with the gauge in upright position. At the time of reuse, the preparation process should be repeated.

GENERAL GUIDELINES

- Place two or more tensiometers of different lengths near one another (a station), usually in the crop rows. Two stations may be enough in a small field with uniform soil and slope, but four stations is the usual minimum recommendation. The location of stations will depend upon the type of irrigation system. With furrow irrigation, this may be at the upper and lower quarter...
points of the first and last set in the field. For a center pivot, it may be in the outer and middle spans, with pairs of stations at the start point and at the end point of the pivot.

- Tensiometer stations should be located in representative areas of the field. Do not position tensiometers in low spots or on knobs, and place them where the plant population is representative of the field.

- Tensiometer installation depth is determined by the active root zone of the crop. For example, for a corn crop on a deep soil, three tensiometers, installed at depths of 12, 24, and 36 inches, are recommended at each station.

- Wait 24 hours after installing the tensiometer to obtain reliable readings. If the soil was dry at installation, irrigation or rainfall may be needed before obtaining satisfactory readings.

- Tensiometers should be left in the field for the duration of the growing season. The roots of the crop must grow around the porous tip for reliable readings. Moving the tensiometer during the growing season is not recommended.

OTHER AVAILABLE IRRIGATION PUBLICATIONS

Considerations for Sprinkler Packages on Center Pivots L908
Efficiencies and Water Losses of Irrigation Systems MF2243
Evaluating Pumping Plant Efficiency L885
Guidelines for Use of Propeller-Type Irrigation Water Methods L896
Irrigation Water Measurement L877
Large Acreage Center Pivot Systems L902
LEPA Irrigation Management for Center pivots L907
Managing Furrow Irrigation Systems L913
Managing LEPA Bubblers and Flat Sprays on Corn L879

Predicting the Final Irrigation for Corn, Grain Sorghum, and Soybeans MF2174
Scheduling Irrigations by Electrical Resistance Blocks L901
Soil Water Measurement: An Aid to Irrigation Water Management L795
Soil, Water and Plant Relationships L904
Sprinkler Package Effects on Runoff L903
Subsurface Drip Irrigation for Field Corn: An Economic Analysis L909
Surge Irrigation L912
Tensiometer Use in Scheduling Irrigation L796

Using Evapotranspiration Reports for Center Pivot Irrigation Scheduling L915
Using Evapotranspiration Reports to Schedule Irrigation on Furrow Irrigated Ground L914
Water Measurement as a Management Tool L878

To order any of these publications, contact Production Services/Distribution at:

e-mail: orderrp@lists.oznet.ksu.edu
FAX: (785) 532-7938

Mail: Production Services/Distribution
Kansas State University
26 Umberger Hall
Manhattan, KS 66506-3404

Telephone: (785) 532-5830
Step 1 - Preparation — Take the plastic wrappers off the tips and fill IRROMETERS with clean water. Do not handle the ceramic tip. Leave the instrument cap OFF and place the tip of the IRROMETER in clean water overnight (use clean non-rusting glass jar, plastic bucket or basin). Water in the instrument will drain through the tip and this operation may be repeated as often as time permits. After soaking and you are ready to install, protect the tip from air drying with wet paper towels or the plastic tip bag while transporting to the installation site.

Step 2 - Installation — Drive a hole in the ground with an IRROMETER Installing Tool or with a standard piece of 1/2 in. pipe. Standard 1/2 in. pipe will make a hole for an exact fit. Install in the root zone of the crop. Insert IRROMETERs in the hole, leaving at least 1 in. of space between the bottom of the gauge and ground surface. Be sure instrument is “seated” firmly in the bottom of the hole.

Step 3 - Servicing — Fill all IRROMETERs with a diluted solution of IRROMETER fluid (1 scant capful of concentrate to 1 gallon of water). Fill the IRROMETERs to the circle on the reservoir. Tap top of the IRROMETER with the palm of your hand to relieve any air lock. Take the vacuum pump and extract air from the instruments by pulling a vacuum of 80–85 cb (kPa) as registered on the gauge. Leave pump on the instrument for 10–15 seconds to allow air to rise and then release vacuum gently. Refill if necessary and replace cap until stopper comes in contact with bottom of the reservoir, then continue tightening for 1/4 turn only. Repeat pumping as above each time, after reading, for three or four times to improve sensitivity.
Step 4 - Protection — Instruments should be installed so they will not be damaged by equipment during routine crop maintenance operations. Stations should be covered and clearly marked for protection. In areas with temperatures falling below 32°F (0°C) the gauges must be protected against freezing. This can easily be done by covering the gauges with an insulating material and placing a box over the top to trap ground heat. In permanent tree crops or vineyards IRROMETERs can be covered with dirt or the gauge removed from the IRROMETER to eliminate the necessity of reinstalling the instrument.

Step 5 - Storage — In seasonal cropping, where the ground will lie fallow over the winter, remove IRROMETERs before the first frost, clean exterior thoroughly with water. DO NOT let the ceramic tip dry while dirty. Soak the tip in a clean plastic bucket of water overnight with clean water draining through the tip, gravity flow. Air dry instruments and store. Gauges may have water in them and must be stored where temperatures are above freezing.

Please refer to your IRROMETER Reference Book furnished with the Service Unit for complete information.

IRROMETER®
THE IRROMETER COMPANY, INC.
P.O. Box 2424, Riverside, CA 92516
(951) 689-1701 PHONE
(951) 689-3706 FAX
www.IRROMETER.com
sales@IRROMETER.com
<table>
<thead>
<tr>
<th>CROP</th>
<th>SHALLOW INSTRUMENT (INCHES)</th>
<th>DEEP INSTRUMENT (INCHES)</th>
<th>FOR EXTRA DEPTH, SET AT (INCHES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MELONS</td>
<td>18</td>
<td>36</td>
<td>60-70</td>
</tr>
<tr>
<td>MILO</td>
<td>24</td>
<td>48</td>
<td>72</td>
</tr>
<tr>
<td>MINT</td>
<td>20</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>MONTEREY PINES, FIRS</td>
<td>12</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>MUMS</td>
<td>4-6</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>MUSTARD</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>NECTARINES</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>OATS</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>OKRA</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>OLIVES</td>
<td>24</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>ONIONS</td>
<td>24</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>PAPAYA</td>
<td>12</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>PARSNIPS</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>PEACHES</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>PEANUTS</td>
<td>12</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>PECANSEAN</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>PECANS</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>PEPPERS</td>
<td>15</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>PERMANENT PASTURES</td>
<td>8-15</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>PERSIMMONS</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>PINEAPPLE</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>PISTACHIO NUTS</td>
<td>12</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>POMEGRANATES</td>
<td>8-10</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>POTATOES (Irish)</td>
<td>24</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>POTATOES (sweet)</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>PLUMS</td>
<td>24</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>PRUNES</td>
<td>24</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>PUMPKIN</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>RADISHES</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>RASPBERRIES</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>SORGHUM</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>SOY BEANS</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>SPINACH</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>SQUASH (Summer)</td>
<td>15</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>STRAWBERRIES</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>SUDAN GRASS</td>
<td>18-24</td>
<td>36-48</td>
<td></td>
</tr>
<tr>
<td>SUGAR CANE</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>SUNFLOWERS</td>
<td>24</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>TEA</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>TOBACCO</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>TOMATOES</td>
<td>24</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>TURNIPS</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>WALNUTS</td>
<td>24</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>WATERMELON</td>
<td>24</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>WHEAT, HAY</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
</tbody>
</table>
Moisture Indicator Reference Book
## Contents

- Checking in Shipments .......................................................... 2
- Preparing IRROMETERS for Installation ................................. 2
- Selecting Locations for Installation ....................................... 4
  - Installation ........................................................................ 6
  - IRROMETER Charts ............................................................ 7
  - Taking Readings .................................................................. 8
  - Field Servicing ................................................................. 8
  - Hand Vacuum Pump ............................................................ 9
  - Protection of IRROMETERS ................................................ 10
- Starting Irrigations ................................................................. 10
- Accuracy of IRROMETERS ..................................................... 11
- Interpreting IRROMETER Readings ....................................... 11
- Irrigating with IRROMETERS ................................................. 12
- Discontinuing Irrigations ....................................................... 12
- Waterlogged Soils ............................................................... 12
- Increasing Profits ............................................................... 12
- Saving Water/Energy ............................................................ 13
- Common Questions ............................................................. 14
- Storage of IRROMETERS ....................................................... 15
- Care of Ceramic Tips ........................................................... 16
  - Vacuum Gauges ............................................................... 16
- Factory Service ..................................................................... 17
- Warranty ............................................................................. 18
- Registration ........................................................................ INSIDE AND OUTSIDE BACK COVER
You have made an investment with your IRROMETER®, which will repay its cost many times over. This reference book will give you information that will insure the maximum benefit from your investment.

**Hermetically Sealed Vacuum Gauge**

- Cap Assembly
- Reservoir
- #0 Neoprene Stopper (PART OF CAP ASSEMBLY)
- Hermetically Sealed Vacuum Gauge
- Air Free Gauge Chamber
- Body Tube
- Ceramic Tip

**IRROMETERS** are manufactured of the highest quality materials and workmanship. Whether you are using IRROMETERS in research, in the turf and landscape or on the farm, adherence to the suggestions given on the following pages will assure you years of trouble-free, accurate and reliable service from these instruments.

If you have questions that are not answered in this booklet, our staff is ready to assist you. Please call us at any time.

**IRROMETER Co, Inc.**
P.O. Box 2424
Riverside, CA 92516-2424

**PHONE** –
951-689-1701

**FAX** –
951-689-3706

**E-MAIL** –
technical@IRROMETER.com

**VISIT OUR WEBSITE** –
www.IRROMETER.com
Checking In Shipments

Shipments should be unpacked carefully and checked immediately upon arrival. Do not remove the plastic tip covering until preparing for installation.

Instruments are shipped dry and must be prepared for installation according to the instructions given below.

Preparing IRROMETERS for Installation

When instruments are received, it is necessary to prepare them for installation as outlined in steps 1 through 6 below.

1. Take the plastic wrappers off the tips and fill IRROMETERS with clean water. Do not handle the ceramic tip. Leave the instrument cap off and place the tip of the IRROMETER in clean water overnight (use clean non-rusting glass jar, plastic bucket or basin). Water in the instrument will drain through the tip and this operation may be repeated as often as time permits. After soaking and you are ready to install, protect the tip from air drying with wet paper towels, the plastic tip bag or insert into a bucket of wet sand while transporting to the installation site.

2. Prepare IRROMETER Field Solution as directed on the bottle label — (a scant capful of concentrated IRROMETER Fluid to one gallon of clean, de-aired water, such as distilled, rainwater, boiled water that has cooled or tap water that has been allowed to sit).

3. Remove the filler cap and fill the instrument, including reservoir, with IRROMETER Field Solution or distilled water. If the tube does not completely fill, it may be due to an “air lock” which has formed at the tube filler hole at the bottom of the reservoir. Tap the top of the reservoir with the palm of your hand to break this “air lock” and facilitate complete filling of the tube. See picture. Using a plastic squeeze bottle makes filling easier as you can aim the flow of water into the body tube of the instrument. See picture.

4. Apply a strong vacuum to the IRROMETER with the hand vacuum pump. With the filler cap removed and the tip submerged in water or the bucket of wet sand, place the suction cup over the reservoir and pump vigorously until a reading of 80-85 shows on the gauge, usually 5 or 6 quick pulls. (See page 9 — Hand Vacuum Pump) At higher elevations, maximum vacuum will be lower (i.e. 70-75 at 4000’ above sea level). Release the vacuum slowly, using the finger release valve on the suction cup, to avoid gauge damage. Repeat the above procedure to remove all air from the gauge, usually 2-3 times is sufficient. Replace filler cap by tightening until the neoprene stopper makes
contact with reservoir bottom, then turn the cap 1/4 turn. Do NOT over tighten, this can damage the IRROMETER gauge or stopper.

5 Remove the plastic tip cover on the instrument, or remove from the bucket of sand, and install the IRROMETER in the prepared hole. See section "INSTALLATION" page 6.

6 Pump the IRROMETER as illustrated each day for 3 to 6 days or until no further air bubbles appear. Tapping the side of the instrument with cap assembly will facilitate air release. Refill the reservoir as necessary and replace filter cap. A well de-aired instrument increases sensitivity and reduces water use in maintaining reading.

NOTE: Small champagne type bubbles of air which appear during de-airing are not of concern.

If de-airing is more conveniently accomplished before installation, place the instruments in a large plastic container half filled with water and lower the above steps. Be sure to protect the tip from air drying when transporting IRROMETERS to installation site. See Note 2.

CAUTION for LT & MLT — with models "LT" and "MLT" carefully pull a vacuum to a reading of 30 to 35 on the gauge and be careful to bleed vacuum slowly. These gauges are very sensitive and can be damaged by a rapid release of vacuum or over-pumping. The MLT uses a syringe style vacuum pump, refer to supplemental instructions. See picture.

MODEL "MLT" FILL & AIR REMOVAL INSTRUCTIONS — 1.
Remove cap, tip protector and plastic bag covering tip. 2. Place tip in clean water and soak overnight – you do NOT need to fill the instrument. Step 5 below will complete the filling process. 3. Make IRROMETER field solution by adding one drop of IRROMETER fluid to a cup of clean water. 4. Fill syringe half full with IRROMETER field solution. 5. To fill, place syringe tip loosely in O-ring seal (located in cap opening), depress syringe plunger to squirt water into the body tube of the MLT. Do not seat the syringe to the O-ring in this step as it could force the gauge needle against the stop. (RSU units do NOT have a gauge needle). 6. To remove air, place syringe tip in O-ring seal (located in cap opening), press firmly to make a seal. With instrument at 45 angle (gauge or RSU down or on the underside), PULL GENTLY on syringe to create a partial vacuum on the gauge or RSU (on gauge model, do NOT exceed full scale of gauge or 40 kPa/CB) and release slowly. Pumping this way several times will get most of the air out of the gauge or RSU. 7. Remove syringe by slowly twisting while pulling out to avoid a rapid release of vacuum, fill instrument cap opening with water. 8. Replace cap – tighten until gauge needle moves toward
stop. 9. Tip (body) of instrument can be removed by pulling out from the top housing. Be sure to remove the cap before attempting to pull the tip (body) out to avoid damaging the gauge. Replacement tips (bodies) are available.

CAUTION for RSU — use the Test Pump service unit pump (with the gauge attached), as this model IRROMETER does not have a gauge. With the model "RSU" carefully pull a vacuum to a reading of 80 to 85 for standard (white tip) IRROMETERS, 30 to 35 for LT (blue tip) IRROMETERS and 10 to 12 for MLT (miniature blue tip) IRROMETERS. Be very careful to bleed vacuum slowly. The transducer diaphragm is very sensitive and can be damaged by a rapid release of vacuum or over-pumping.

Selecting Locations for Installation

Careful selection of key locations for installation is of utmost importance with IRROMETERS, as with all other methods of soil moisture measurement. Except where there is very level, uniform soil and subsoil and very uniform distribution of water — as with sprinklers — do not install the instruments in a "checkerboard" pattern. Almost invariably such factors as productivity in good and poor sections, topography, infiltration rate and water holding capacity of varying types of soil and subsoil will govern the location of "stations".

With furrow or basin irrigation, instruments are usually placed near the lower end of the run. In very long furrows, a second station of instruments is sometimes installed at the upper end or at some intermediate point in the run.

If, after an irrigation cycle or two, the appearance of the crop indicates that more critical areas exist, either move some of the instruments to these areas or install additional instruments.

The IRROMETERS should always be installed in the root zone of a vigorous plant or tree. Also, where the plants are large enough to shade part of the ground, it is customary to install all instruments in locations on the sunny side of the plant where ground surface evaporation losses are greatest.

When crops have a root system exceeding about 18", instruments should be installed at two depths — one at about 25% of root zone depth and one at about 75% depth.

In making an initial installation, concentrate more instruments than you think will ultimately be required in a relatively small area. Later, instruments can be moved to other areas if they are not needed. Otherwise, leave instruments in permanent locations for the entire growing season, so there will be continuity in the seasonal chart curves. Most of the value of the charts is lost when instruments are moved. In starting out it is better to do a thorough job in a small area than to scatter a few instruments over the entire acreage.

NOTE: Due to many infiel variations of soil types, it is best to use two "locations" in a single irrigation block. Then "average" the readings for a better overall picture.
Placement of IRROMETERS in Furrow Irrigation

Place IRROMETERS approximately 2/3 of the way down the run with tips angled slightly towards the furrow. In tree crops the IRROMETERS are generally placed on the side of the tree which gets the afternoon sun. In row crops they would normally be placed in the row. Since lateral movement of water varies widely with different soils, the closer the tip is located to the side of the furrow, the more representative the results will be.

Placement of IRROMETERS in Flood or Border Irrigation

In flood or border method of irrigation, IRROMETERS are normally placed approximately 2/3 of the way down the run as this generally is the point most critical for adequate penetration. The general rule of locating at the drip line of the tree in tree crops or in the row for row crops, is best. It is also best to order IRROMETERS at least 6" longer than desired for placement so that the gauges can be set higher, above the water level when irrigating. In some cases it has proved beneficial to place IRROMETERS on the border itself, at an angle, so that the tips are located in the root zone of field crops.

Placement of IRROMETERS in Sprinkler Irrigation

In sprinkler irrigation IRROMETERS are normally located on the side of the tree where the afternoon sun shines. Again, placement should be at the drip line of the tree. Special care should be exercised in tree crops to insure that limbs or heavy foliage do not obstruct the sprinkler pattern to the IRROMETER location or that they are not located beyond the normal pattern of the sprinkler. In row crops IRROMETERS are located in the row.

Placement of IRROMETERS in Drip Irrigation

In drip irrigation, IRROMETERS are normally located on the sunny side of the tree and essentially at the drip line of the tree. IRROMETERS are generally placed 12'-18' away from the emitter (24'-36' from the micro sprinkler or spray) to insure that they are in the wetted area. In newly planted trees, the shallow IRROMETERS should be placed in root ball of the tree regardless of emitter location. In row crops the IRROMETERS should be placed in the row. Additional IRROMETERS may be used to measure water movement away from the emitter but controlling IRROMETERS should be placed in representative locations 12" to 18" from the water source and in the root mass area.
Installation

A good contact between the buried portion of the IRROMETER and the soil is essential in order to obtain accurate readings.

If air is permitted to follow down the plastic tube, due to an oversize hole and reach the ceramic tip, false readings on the "high" side will occur. If free water falls/follows down the tube, false readings on the "low" side will occur. The specific suggestions below are offered to prevent either of these conditions.

In very loose soil, the shorter instruments can sometimes be installed by simply pushing them into the ground, without subjecting them to undue strain. This results in good contact with the soil and minimum disturbance to the soil structure and root system.

In most cases, however, it is necessary to prepare a hole before making installation. While IRROMETERS may be installed at any time, it is usually easier to prepare the hole when the soil is fairly moist.

The diameter of the IRROMETER tube is 78" (22 mm). A pointed 78" (22 mm) steel rod or a standard piece of 12" galvanized pipe usually makes the most convenient installation tool and makes a hole the exact size of the IRROMETER. This assures good soil contact with minimum disturbance to roots or soil structure. Drive it into the ground to the exact depth at which the ceramic tip is to be installed. Avoid drilling the hole too deep as this permits air and water to collect in the hole below the tip and affects the accuracy of the readings.

A variety of installation tools are available which make installation easier in hard or rocky soil and with deep depths. For very coarse or gravelly soils, an oversized hole (1" - 1.25" [25 mm - 32 mm]) may be needed to prevent abrasion damage to the sensor membrane. In this case, auger a hole to the desired depth and make a thick slurry with the soil and some water. Fill the hole with this slurry and then install the sensor. This will "grout in" the sensor to ensure a snug fit.

After the instruments are installed to the proper depth, the surface of the soil should be banked up around the plastic tube and packed to a depth of 3 or 4 inches, to ensure good contact between the soil and the instrument, and provide drainage for surface water away from the IRROMETER.

NOTE: In very light (coarse) soils, the access hole depth can be made 2" less than full depth. Pour some water in the access hole, set the instrument in hole and bear down on top of cap (NOT GAUGE) to push tip the last 2" into the soil. This helps establish a snug fit between tip and soil.

Handle the instruments carefully when installing or removing from the ground. Do not put a strain on the gauge connection by pushing or pulling on the gauge. Push straight down on the filler cap when installing. When removing from the ground, rotate the instrument first to break it loose from the soil. NOTE: Always rotate IRROMETERS with threaded tips clockwise to avoid loosening the tips. Then grasp the
main tube and pull straight up. Always avoid a lever or a "crow bar" action. It puts a strain on the ceramic tip connection.

Specify instruments of suitable lengths. There should be a minimum clearance of about 1 inch between the bottom of the gauge and the soil. This allows the gauge diaphragm to expand and contract freely with temperature fluctuations. Also, not more than about six inches of the main tube should project above ground to avoid damage.

In some cases, it is desirable to install the IRROMETERS at an angle. This allows the tip to be placed at specific depths without having too much of the IRROMETER body exposed above ground. In orchards, this helps to keep the exposed portion of the instrument under the canopy which offers better protection. Instrument bodies can even be bent to certain angles to make such installation easier. Consult factory for details. Always set the instrument so the gauge is in a downward position.

After installation, fill the reservoir with IRROMETER Fluid, and release any air that may have accumulated below the reservoir. (See section on "SERVICING.")

Installation of instruments invariably disturbs the normal soil structure and root system to some extent, yet in most soils IRROMETERS give an accurate indication of soil moisture content a few hours after installation. In rocky soils or when an oversize hole is drilled, it may take an irrigation to settle the soil normally around the ceramic tip and insure precise readings. De-airing the instruments thoroughly during the first 3-6 days after installation insures maximum sensitivity and accuracy.

**IRROMETER Charts**

Just as a thermostat in your home guides you in maintaining the desired temperature, the IRROMETER guides you in maintaining desired soil moisture content. And just as you need to know when and how much fuel is needed to keep a safe reserve on hand to meet varying climatic conditions, it is necessary to know when and how much to irrigate to maintain soil moisture content within the desired range. This requires planning irrigations in advance based on seasonal use in the past.

The IRROMETER charts provide the simplest method of keeping records for this purpose. Special pocket size chart forms are included with each IRROMETER Service Unit. Readings are plotted directly in the field. The resulting curves give a picture of the rapidly fluctuating soil moisture conditions throughout the root zone, in each section, that can be visualized in no other way. "Rate of change" may be the best indicator of WHEN to irrigate. That is, if the reading increases 10-15 centibars (kPa) in just a few days, the soil is drying rapidly. Thus the charts provide a complete original record with an absolute minimum of clerical work. Projecting the seasonal curves for each section makes it easy for the grower, or executive in charge of larger operations, to plan irrigations in advance.
Reference to past charts makes it possible to maintain the most desirable soil moisture content in each section, year after year. The charts are a very important factor in IRROMETER irrigation control, and it is strongly recommended that they be kept up to date.

The charts are also useful to keep rainfall information, fertilizer applications and unusual weather conditions posted with moisture readings for future reference.

Use of dataloggers makes such record keeping easy and automatic. IRROMETERS are available with electronic outputs for use with datalogging equipment.

**Taking Readings**

The frequency of charting readings depends upon how fast the soil dries out. In sandy soils or in hot weather, readings should be charted two or three times a week. In moderate climates, charting readings once a week is usually adequate. Even less frequent readings may be required in wet weather. After a few irrigation cycles, the charts will indicate how often readings are required in each section. It is best to chart the readings just before and just after an irrigation so that the maximum and minimum readings are recorded.

In areas where there are extreme daily fluctuations in temperature, readings should be taken the first thing in the morning. Especially during peak water use, readings can climb during the day and then drop back at night. Thus, early morning readings are usually most accurate. Tap the gauge lightly before taking a reading. The slight movement of the pointer will indicate whether the soil is drying out or soaking up moisture.

Usually the instruments are "serviced" on the same round that readings are taken. Readings should always be taken before servicing.

**Field Servicing**

It is normal for the fluid level just below the reservoir to fall as the soil dries out. A vacuum is created in this space. Following an irrigation, this vacuum draws moisture back out of the soil causing the fluid level to rise almost to its original level by the time the gauge reading indicates field capacity. However, with each cycle a little air is drawn in from the soil and collects below the reservoir. This air slows up response of the instrument to variations in soil moisture. It also tends to result in slightly lower than accurate readings.

The purpose of "servicing" tensiometers is to remove the entrapped air in order to maintain optimum accuracy. Servicing is simple with IRROMETERS. Loosening the cap allows air to escape by bubbling up out of the reservoir, whose water then drains back down to refill the instrument body. Fluid in the reservoir should be replaced as necessary.

Unscrew the cap slowly with a slight downward pressure, whenever there is a high vacuum reading on the gauge, so that the pointer does not slap back against the stop, causing shock to the gauge. The large cap and resilient stopper make control of this operation easy. To re-seal, it is not necessary to exert excessive pressure to get a positive seal with this closure. The resiliency of the stopper can be prolonged by tightening the cap only about 1/4 turn after the stopper makes contact with the bottom of the reservoir. If the stopper hardens, replace with a new stopper.

When relatively moist soil conditions are maintained, very little air is drawn into the instrument and the supply of fluid in the reservoir usually lasts for several months. Where very high gauge readings occur,
and especially if they continue over considerable periods, much more frequent servicing is required. The maximum reading that can be reached is about 85. As this point is approached, a greater amount of air is drawn into the instrument. In this range, the instruments should be "serviced" and the reservoir should be filled, if necessary, about once a week. If servicing is not performed, eventually all the water will be drawn out of the instrument and the vacuum will be lost, giving a "FALSE" zero reading.

For most field applications, less frequent refilling of the reservoir is required and satisfactory results are obtained by "servicing" only when air is visible in the portion of the instrument above ground, after gauge readings have dropped following an irrigation.

In research work, maximum accuracy and sensitivity are obtained if instruments are serviced every few days. This practice is also recommended for field use under saline conditions, as it ensures that almost all movement of fluid is outward. It thus reduces the amount of soluble salts drawn into the instrument from the soil, following an irrigation.

Provided IRROMETERS are kept in an upright position, the fluid seal on the gauge prevents air from entering the gauge, even though servicing is neglected for considerable periods. However, some air may accumulate in the pores of the ceramic tips or on the walls of the plastic, so the hand vacuum pump should be used in the field about every 20 to 60 days — particularly on instruments installed at an angle — to ensure that the instruments are maintained entirely air free. Tapping the reservoir lightly while the instrument is under vacuum from the pump helps to release any air present.

Make sure that there is considerable soil moisture, at ceramic tip depth, when using the hand vacuum pump and apply the vacuum for only a few seconds. (Excessive vacuum applied when the soil is dry, draws air into the instrument.)

Systematic servicing is essential to accuracy and quick response to irrigations. If this is done just after changing readings, the extra time required is almost negligible.

**Hand Vacuum Pump**

This pump has a universal suction cup that fits all standard size models of the IRROMETER. Remove the IRROMETER filler cap and apply the hand vacuum pump. Four or five quick strokes of the piston will produce an 80 to 85 gauge reading, the maximum vacuum. The pump will then adhere to the instrument "hands-off." This is a great convenience, as it leaves one hand free to release air bubbles by tapping the main tube lightly. Refer to "NOTES" on page 3 regarding LT, MLT and RSU IRROMETERS.

Always release the vacuum slowly so as to prevent shock to the gauge movement. The suction cup of the pump has a built-in finger release valve to facilitate slow release of the vacuum. Push the tip of the release valve gently in any direction to bleed off the vacuum slowly.

Periodic cleaning of the pump parts can be accomplished by disassembling the pump and flushing all parts with clean water. After drying, all parts, particularly the ball valve, should be lubricated with a silicone lubricant spray.

**NOTE:** See "TEST PUMP" option on page 18.
Protection of IRROMETERS

Growers find that they protect their investment by protecting the instruments. The purposes of protection are:

1. To prevent accidental damage to the instruments resulting from field operation.
2. To facilitate taking readings by keeping the gauge crystal clean.
3. To inhibit the growth of algae by keeping out of sunlight.
4. To provide a measure of frost protection. In areas where temperatures drop only a few degrees below freezing for short periods, protection makes it possible to keep the instruments in the ground all through the winter. In this case, mineral wool, straw or other insulation should be packed around the instrument.
5. To minimize temperature fluctuations which have a slight effect on gauge readings.

With tree crops or in other permanent installations where furrow or flood irrigation is used, sections of steel, concrete or PVC pipe, or wood boxes are recommended. The cover may either be a waterproof fertilizer sack or a wood lid.

When used in pastures, IRROMETERS should be protected with a heavy concrete or steel pipe and the instruments installed at an angle so that the tips extend beyond the protective covering.

Wherever IRROMETERS are installed, it is advisable to mark them plainly with a flag or stake to minimize the danger of accidental damage and to locate them easily when taking readings.

Starting Irrigations

It is impossible to give specific instructions as to when to start irrigations for all crops, all soils, all climatic conditions and all methods of irrigation. You will learn the best time to start irrigations for your particular crop and local conditions by following your charts after a few irrigation cycles. If you have not used IRROMETER control the following suggestions are offered as a starting point.

For most crops, a rule-of-thumb recommendation is to start irrigations at a gauge reading of about 50 (except with drip or low volume irrigation – see below).

In order to do this properly, you will need to allow a reserve of soil moisture as a safety factor, as few growers can wait until the last minute to irrigate. The following are typical of adjustments in irrigation treatments.

In hot, dry climates, irrigations start at the following readings for most crops:
- 10-55 in sandy soils
- 35-50 in medium soils
- 50-60 in fine textured soils

In cool humid climates – coastal areas, for example – it is often safe to delay irrigations until readings are 10 to 15 points higher in each case.

The concept of drip irrigation is to apply low volumes of water very frequently to maintain readily available water to the plant. To accomplish this, the IRROMETER located 12”-18” from the water source should be maintained at or near field capacity (3-20 reading on the gauge). This will assure outward and downward water movement in the soil as in a blotting action.

IT IS IMPORTANT when the emitter wets the entire root zone of a newly planted tree or plant that soil not be saturated (0-5 reading) for extended periods.
It is possible to grow some crops in some fine soils at even higher readings and get good yields. However, we know of no cases where yields or quality have been increased by starting irrigations at higher readings during the vegetative period of growth. On the other hand, there is considerable evidence that this practice results in a substantial loss of yield and delayed maturity with most crops.

In any case, the above adjustments should not be confused with the "Soil Calibrations" required with other methods of measuring available soil moisture. The purpose of these adjustments is to maintain available moisture in accordance with the requirements of the particular crop and allow a safety factor in the event of delayed irrigations. This is necessary with every method of irrigation control. The use of "Soil Calibration" charts involves an additional operation and complication.

NOTE: The trend or "rate of change" can be as important as the IRROMETER reading in making irrigation decisions, as discussed under "IRROMETER Charts."

Accuracy of IRROMETERS

Exhaustive tests by leading soil scientists have demonstrated that IRROMETER type instruments provide the most accurate and most sensitive method of measuring soil moisture in the range in which most crops are grown. In fact, they are widely used as reference instruments to check the accuracy of soil moisture determinations made by other methods. The slightest variations in available soil moisture resulting from soil type or compaction, root density or other factors – variations too small to be measured easily by other methods – are automatically evaluated and registered on the IRROMETER gauge. This feature is very valuable in many research applications where precise measurement of soil moisture is required.

However, the same accuracy of control may not be practical nor necessary under field conditions. For example, if the objective is to start irrigations at a reading of 50, variations of 10 to 15 points in either direction are to be expected on instruments in various areas due to the extreme sensitivity of the IRROMETER. Soil moisture will still be maintained well within the range for optimum crop growth.

Even greater variations may occur for short periods without loss of yield or quality.

Interpreting IRROMETER Readings

The IRROMETER measures energy directly – the energy, that is, the roots must exert to extract moisture from the soil – whereas other methods of making soil moisture determinations measure the total amount of soil moisture and then in effect, convert it into root energy for each type of soil by means of soil calibration charts.

Obviously, then, the IRROMETER requires an entirely different unit of soil moisture measurement.

The IRROMETER gauge is graduated 0-100, the graduations representing hundredths of an atmosphere. The unit of measurement is centibars or kilopascals, with a gauge reading of 50 representing 10 atmosphere or about 7 pounds of negative pressure (vacuum). This reading is a direct measurement of how hard the root system has to work to extract water. If this seems complicated, think of your IRROMETER readings as you would a thermostat and schedule irrigations to maintain soil moisture within the desired "comfort" range.

NOTE: Low Tension (LT & MLT) IRROMETERS have a gauge which is graduated from 0-40 centibars (kilopascals). This provides for better resolution in the very wet end of the soil water spectrum.

Average Percentage of Moisture Extraction from Normal Root Zones

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Quarter</td>
<td>40%</td>
</tr>
<tr>
<td>2nd Quarter</td>
<td>30%</td>
</tr>
<tr>
<td>3rd Quarter</td>
<td>20%</td>
</tr>
<tr>
<td>4th Quarter</td>
<td>10%</td>
</tr>
</tbody>
</table>

11
Irrigating with IRROMETERS

Your charts enable you to determine how soon and how much to irrigate after a rain. Most growers find surprising differences in penetration in different areas, due to variations in soil type and topography. Even in the same areas, infiltration rates often vary considerably depending upon how recently the soil has been cultivated and how wet the soil happens to be at the time rainfall occurs. 

Wilt starts at the roots. By the time the leaves indicate stress, plant growth has either stopped or slowed. Unless the stress is severe, growth will resume following an irrigation, but some loss of production and delayed maturity will result. For this reason, most research workers recommend that irrigations start well before there is any evidence of stress.

Be sure to maintain plenty of soil moisture in the vital feeder root zone. Note that about 70% of the plants' moisture requirements are taken from the upper half of the root zone. Adequate soil moisture in the lower root zone helps to tide over temporary periods of stress but is not sufficient to promote maximum growth. IRROMETERS installed at two or more depths register soil moisture condition at different root horizons and thus give a more accurate picture of the moisture profile than composite soil samples taken with a soil tube or auger.

With crops grown for the seeds or fruit, the same recommendation applies during the period of vegetative growth. For instance, research has demonstrated that yields with corn are reduced materially by even short periods of stress from seeding up through the dough stage. With some of these crops, research work indicates that irrigations should be reduced during the ripening period of growth. The amount that irrigation is reduced varies with the crop and climatic conditions.

With seasonal crops, you can expect to effect marked improvement the first year with IRROMETER control. With tree and perennial crops, that are in poor condition, it may take longer. In any case, you will find that IRROMETER control eliminates the most important variable affecting production — irrigation. This enables you to concentrate on improving other cultural practices that may be necessary to improve production.

Finally — if you have been irrigating by rule of thumb methods, based on the calendar, acre inches of water per crop or per year or any of the older concepts, be prepared to make very radical changes. They are usually indicated. The degree of change is often an index of the degree of improvement. You can rely upon the accuracy of your IRROMETERS in making these changes.

Discontinuing Irrigations

As soon as irrigation water penetrates to the ceramic tips, gauge readings will go down. Discontinue irrigations when the readings on the shorter instruments drop to the 0-15 range and readings on the 36" to 48" instruments drop to the 10-15 range. It is not necessary to continue irrigating until the readings reach 0. In poorly drained soils, discontinuing irrigations at reading of about 30 is advisable to avoid any possibility of water logged soils.

The gauge readings should begin to rise after gravity water has had time to seep down and the roots begin to take up moisture from the soil. Continuous readings in the 0-20 range indicate poor drainage and saturated soil. Irrigations should be discontinued or reduced until this condition is corrected.

Waterlogged Soils

Where there is poor drainage, three IRROMETERS per "station" are used in critical areas. The third IRROMETER is of extra length and usually extends below the normal root zone. It provides a continuous check on the water table and helps to prevent over irrigation and waterlogged soils.

Increasing Profits

Investigate the possibility of using IRROMETER control to increase plant population per acre with your particular crops. Various agricultural experiment stations have demonstrated that this is possible with
a number of crops provided there is increased fertilization and proper irrigation. With corn, for example, increased fertilization alone produced no benefits, but with increased — and controlled — irrigation, yields were more than doubled.

Controlled irrigation is just as beneficial in increasing quality and insuring early maturities as in increasing yields. IRRROMETERS are used extensively by the United States Department of Agriculture, state experiment stations, and large commercial growers with fruits and vegetables, sugar cane, tobacco and other crops. In one project with sweet corn, yield was improved and the crop was ready for market two weeks earlier by increasing fertilization and maintaining readily available soil moisture during the critical early period of growth.

We are continually collecting data on progress in these fields which is available upon request.

**Saving Water/Energy**

It is never recommended that a direct attempt be made to save water by reducing soil moisture below optimum conditions for plant growth. The proper use of IRRROMETERS allows you to eliminate the guesswork involved in irrigation scheduling and usually results in reducing irrigation cost.

Wetting soil might be compared to wetting a sponge. The sponge will hold only so much water and will absorb that water in a few seconds. Holding it under the faucet for an hour will neither cause it to absorb more water nor hold that water longer. Soils take longer to absorb water but the same principle applies. Any excess water applied is wasted by deep percolation or run-off. By far the greatest waste is usually due to percolation because this loss is not visible.

Probably the greatest saving in water affected by IRRROMETER control results from saving unnecessary and excessively heavy irrigations. Most growers find that they had previously been holding certain sections "under the faucet" far longer than necessary at times, while other sections may have been short of water. Correcting these conditions — using water where, when and in the amount needed — often results in surprisingly large net savings of water at the end of the year. However, it is not unusual to find that more water is required, in some sections, during some periods.

In soils where there is a very slow rate of infiltration, seepage to the level of the ceramic tip on the "deep" instrument may take two or three days. The drop in gauge readings will be delayed accordingly. Under these conditions, a substantial saving in water can be effected by applying half the water used previously and waiting to see whether this brings gauge readings on the "deep" instruments down to field capacity, instead of continuing to irrigate right up to the time that penetration is registered on the gauge. Experience over two or three irrigation cycles will indicate the minimum amount of water required to insure penetration to the lower root zone. Also in these soils, there is usually a material saving in water, if irrigations start while there is still considerable moisture in the soil. Water penetrates moist soil much more rapidly than dry soil, so less water is required to infiltrate to the lower root zone.

It is usually found that gauge readings on the "shallow" instrument rise much faster than on the "deep" instrument, due to higher plant use of water in the feeder root zone and to surface evaporation. If readings on the deep instrument indicate that there is adequate soil moisture at this level, water is saved by applying only enough water to bring down the readings on the "shallow" instruments.

Under some conditions, water is saved by irrigating alternate furrows, during at least part of the irrigation season.

In hillside plantings, IRRROMETERS placed at upper and lower locations frequently indicate
unsuspected run off or subsoil drainage. Radical reduction or even discontinuance of irrigations in the lower sections during some periods often results in material saving in water and at the same time maintains better soil moisture content for crop growth.

In soils containing rock or gravel, frequent soil sampling is often either impractical or the cost is prohibitive, yet these are the soils where irrigation control is needed most. They dry out quickly in hot weather and to ensure adequate moisture, much water is often wasted to deep percolation by "guesswork" irrigation. Charting IRRROMETER readings frequently – even daily – often results in material water savings and in better soil moisture conditions for plant growth.

In many cases, the value of IRRROMETER control goes far beyond cash savings on the monthly water bill. It makes a limited supply of water go farther and thus saves the investment required for developing new sources of supply.

**Common Questions**

The following are answers to questions that sometimes arise when IRRROMETERS are used for the first time.

**INSTRUMENTS ALWAYS READ ZERO**

Soil is saturated from irrigation, rainfall or poor drainage.

Instrument has no water or lost suction due to low water level in the IRRROMETER. Refill IRRROMETER.

Check gauge calibration and fill the IRRROMETER (gauge should read 80-85 with vacuum applied by hand vacuum pump, less with LT, MLT).

**INSTRUMENTS DO NOT SEEM TO RECORD TRUE SOIL MOISTURE CONTENT**

This is by far the most common question. Almost invariably it is due to the fact that actual soil moisture content is very different from what you thought existed. Taking soil samples within about 6” of an IRRROMETER station and at the exact depth of the ceramic tips with a soil tube auger or shovel will usually demonstrate the instrument readings are accurate. Refer to the sections on "GAUGES" and "CERAMIC TIPS" on page 17.

**INSTRUMENTS REQUIRE FREQUENT REFILLING**

This usually indicates under-irrigation – readings in the upper range for periods of several days. Other occasional causes may be:

- Improper installation – soil not properly packed around the instrument.
- A leaky seal at the closure. Replace rubber stopper if it has hardened.
- A leaky gauge connection.

**INSTRUMENTS RESPOND SLOWLY TO IRRIGATIONS**

This is usually due to a slow infiltration rate of the particular type of soil.

Make sure that the instrument is full of fluid and free of air. See section on "FIELD SERVICING" on pages 9-9.

Ceramic tips partially sealed with salts. See section on "CERAMIC TIPS" on page 16.

Gauge movement "sticky" due to minor damage. Tap the gauge lightly before taking readings.

IF IRRROMETERS are several years old or tip has been frequently oiled by removing from the soil, factory reconditioning the IRRROMETER is desirable. For a nominal cost, the IRRROMETER tip, stopper and cap is replaced. The IRRROMETER is returned to you as new.

**WIDE VARIATIONS IN RATE OF CHANGE OF INSTRUMENT READINGS**

This is to be expected. Almost all new users discover amazing variations in soil moisture content in different sections due to topography and different soil types. That is the reason that an adequate number of instruments is necessary for reliable irrigation control. Attempting to control irrigations on the basis of inadequate information can be misleading rather than helpful.
Storage of IRRROMETERS – When not in use

When IRRROMETERS are in continuous use, as with tree crops in moderate climates, they operate for years with no attention except for routine servicing. The few operating problems that have been experienced, have almost all occurred with instruments that have been used intermittently and have been improperly stored. Therefore, the following recommendations are very important.

1. Remove instruments from the ground immediately at the end of the growing season. This will prevent deposits of salts on the ceramic tip and frozen gauges.

2. Never let a ceramic tip partially air dry. Preparing a plastic container with 4" of fully saturated sand in the bottom provides for a convenient way of keeping tips wet while transporting them. Simply stick the instrument tip into the saturated sand with cap removed. Tips which are allowed to air dry usually will plug up badly and will require factory replacement.

3. See “DRY” Storage Instructions (next page). Transport instruments to shop area and begin by shaking out all fluid in the tube. Then begin cleaning and flushing operation under “Dry” storage.

Temporary Storage

When instruments are to be stored for only a few weeks, “Wet” storage is recommended.

Fill and cap the instruments. Clean the exterior of the ceramic tips with a moist towel and immerse in IRRROMETER Field Solution in a glass or plastic container.

Do NOT store in rusty or oily container. Maintain the level in the container high enough to keep the tips completely submerged at all times. If evaporation takes place add distilled water. This maintains a uniform concentration of solution as the active ingredients in IRRROMETER Fluid are not volatile.

This method of storage keeps the instruments in operating condition and ready for immediate installation.

“DRY” Storage (Important)

When instruments are to be out of use for several months, “Dry” storage as described below is preferable.

1. Clean the surface of the ceramic tip carefully with a handful of wet soil or a stiff brush. Wash all plastic surfaces with soap solution, rinse thoroughly and drain. After cleaning, it is advisable to flush the tip by filling the IRRROMETER with clean water, with cap removed, and allow water to gravity-flow through the tip.

2. Replace caps loosely. Hang and store in a clean dust-free location which is heated adequately to avoid freezing temperatures.

3. If a frost-free location is not available, wash and drain the instruments as above, then evacuate water from the gauges using the hand vacuum pump or other source of vacuum. Hold the instrument in a horizontal position with the gauge upright. Each gauge holds about a teaspoonful of water.
4. Prepare the instruments for re-installation the same as new instruments. If a week or so is allowed for the ceramic tips to become thoroughly saturated, subsequent operations will be facilitated.

**Care of Ceramic Tips**

If the above directions are followed, years of trouble-free operation can be expected from the ceramic tips. If salt deposits do clog the pores of the tip, the speed of response to irrigations will be slowed. This is when factory reconditioning is recommended. To check response, prepare the instrument for installation, wipe the ceramic tip dry with an absorbent paper towel. Visually check the response to drying to 50 cb, by keeping a dry portion of the towel on the ceramic tip, then immerse in water and return gauge to zero. This should be accomplished in minutes.

An additional test is to fill instrument with clean water to the very top of the reservoir and let drain for 24 hours with the cap removed. If a minimum of 1" of water drains through the tip in this period, the tip is responsive. If this drainage does not occur, the tips should be replaced at our factory.

**Vacuum Gauges**

The IRROMETER vacuum gauge will give years of trouble-free service with reasonable care. It is sealed against dirt and moisture. The IRROMETER filler cap and hand vacuum pump are specially designed to prevent harmful compression and strain on the gauge movement. But it should be remembered that the gauge has a delicate movement, similar to a watch, and care should be exercised in handling to avoid shock or jarring.

Protect your gauges against freezing even more carefully than the radiator of your car. When short periods of cold weather start, the fluid in the instruments may already be at a relatively low temperature whereas the water in the radiator is likely to be hot.

If you suspect a gauge has been damaged, check as follows:

Remove the filler cap. The reading should drop to zero. With the instrument filled, apply the hand vacuum pump. It should be possible to obtain a gauge reading of 60-85 with the hand vacuum pump (less with LT and MLT). If the gauge passes both of these tests it is working. At higher elevations the maximum reading will be lower (i.e. 3,500 ft. elevation, 75 cb).

If the needle does not drop back within the box at zero or if it falls several points short of reaching 80-85, it indicates that the gauge has been jarred slightly out of calibration. A plus or minus correction may be made on the gauge crystal with wax pencil and appropriate adjustment made in recording future readings, if only a minor correction. This saves the cost of repair.
If the gauge needle sticks in one location, or is too far out of calibration it indicates the gauge has either been frozen or damaged. The gauge should be returned to the factory for repair or replacement, as necessary.

The presence of heavy condensation inside the gauge (under the plastic face cover) indicates the gauge seal has been broken. Reconditioning is advisable.

NOTE: The "Test Pump" option affords the user the convenience of having a gauge mounted on the pump for comparing instrument gauges to the pump gauge. Assuming that the pump gauge is in good calibration, differences greater than 4-5 cb (kPa) between pump and instrument gauges should prompt factory service of gauges. The "Test Pump Adaptor" can be purchased to convert a standard pump to a test pump.

Factory Service

Our policy is to produce an instrument that will give years of trouble-free operation, rather than rely upon sales of parts and repairs as a source of income. Repairs are made at a very modest cost, much less than the cost of a new instrument.

In case of accidental damage to an instrument, pack it carefully for shipment to the factory for repairs. This eliminates the possibility of damage to the gauge in transit.

If only the gauge is needed, we supply a special pipe thread dope on the replacement. Be careful not to cross thread the gauge and use a 9/16" open end wrench to both remove and replace gauge. Thread the replaced gauge to the next to last thread. DO NOT FORCE.

Your supplier can easily arrange for factory reconditioning of your instruments. Always allow 6-8 weeks lead time for this service, which is best accomplished over the winter when instruments are not being intensively used.

NOTE: Test Pump gauges will be recalibrated at a discount from regular cost of gauge recalibration.
— WARRANTY —

The IROMETER COMPANY warrants its products against defective workmanship or materials under normal use for one year from date of purchase.

Defective parts will be replaced at no charge for either labor or parts if returned to the manufacturer during the warranty period. The seller's or manufacturer's only obligation shall be to replace the defective part and neither seller nor manufacturer shall be liable for any injury, loss or damage, direct or consequential, arising out of the use of or inability to use the product.

This warranty does not protect against abuse, shipping damage, neglect, tampering or vandalism, freezing or other damage whether intentionally or inadvertently caused by the user.

When returning instruments to the factory for reconditioning or repair, ship them prepaid via United Parcel Service (UPS) to our street address:

8835 Philbin Avenue, Riverside, California 92503

If you do not have access to UPS, use the Postal Service (USPS), and address them to:

P. O. Box 2424, Riverside, CA 92516

(not the street address).
**THIS IS YOUR IRROMETER REGISTRATION CARD**

Clip out this warranty registration, fill it out completely and mail today. You must return this registration card to obtain factory service under the IRROMETER warranty.

Consult Reference Book for complete IRROMETER instructions.

---

**IRROMETER WARRANTY REGISTRATION**

<table>
<thead>
<tr>
<th>Date of Purchase: Month</th>
<th>Day</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Purchaser's Name: ____________________________________________

Address ______________________________________________________

City __________________________ State ______ Zip ____________

Dealer's Name: ____________________________________________

Address ______________________________________________________

City __________________________ State ______ Zip ____________

Number of IRROMETERS purchased by lengths:

<table>
<thead>
<tr>
<th>6&quot;</th>
<th>12&quot;</th>
<th>18&quot;</th>
<th>24&quot;</th>
<th>36&quot;</th>
<th>48&quot;</th>
<th>60&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Crops IRROMETERS are to be used in:

________________________________________________________

________________________________________________________
Tensiometer Service, Testing and Calibration

A.G. Smajstrla and D.J. Pitts; reviewed by D.Z. Haman

Tensiometers are useful instruments for measuring soil water status in the field. Tensiometers measure soil water potential or tension, which is a measure of the amount of energy required for a plant to overcome capillary and gravitational forces to extract water from a soil. Thus, tensiometers can be used to schedule irrigations when the soil water tension is low -- that is, before plant water stress occurs. Tensiometers do not measure the osmotic component of soil water potential, which is due to soil salinity. However, this would not be expected to be a limitation to the use of tensiometers in Florida except in saline soils or where saline irrigation water is used.

A tensiometer is a water-filled tube with a vacuum gauge and filling port at the upper end and a ceramic cup at the lower end (Figure 1). When it is placed in the soil, the water in the instrument comes to equilibrium with the water in the soil by flowing through the ceramic cup. At equilibrium, the water tension in the instrument is equal to the water tension in the soil. Then the vacuum gauge measures the soil water tension.

Figure 1.

A tensiometer is used by placing it in the field so that the ceramic cup is located within the root zone of the plants to be irrigated. Then the instrument measures the soil water tension that the plants are experiencing.

The tensiometer is a fairly simple instrument that will work well if it is properly installed and in good condition. The instrument is in good repair if: 1) the vacuum gauge is accurate, 2) the ceramic cup allows free water movement between the soil and the instrument, and 3) there are no air leaks.

New instruments are normally in good repair. However, with time and usage, mechanical vacuum gauges may begin to fail, the ceramic cups may begin to plug, or air leaks may develop. Therefore,
Tensiometers should be periodically tested to insure that they are working properly, and that soil tensions are accurately read. As a minimum, tensiometers should be tested before each crop season for short-season crops. They should be tested at least every three or four months for longer-season or perennial crops. They should also be tested whenever their readings appear to be unusual, such as if the gauge remains on zero even though the soil dries as a crop uses water.

This publication presents procedures for servicing, testing, and calibration of tensiometers so that the user can determine that the instrument is working properly and reading accurately for irrigation scheduling purposes.

**SERVICING A Tensiometer**

Servicing a tensiometer means preparing it for field operation or testing. This requires cleaning it if necessary, then filling it with fluid and expelling any entrapped air.

First wash the instrument to remove dirt, algae, bacterial slime and other foreign debris from both the inside and outside of the ceramic cup and tensiometer tube. This can be done with plain water and a brush. Use a small diameter bottle brush to clean inside the tube and cup. Use a household detergent if necessary to clean the instrument thoroughly.

If the instrument, especially the ceramic cup, is slimy this is probably the result of bacterial growth in the soil and water. Wash the ceramic cup and tube in a chlorine solution, using about 1/4 cup of household bleach (5.25% sodium hypochlorite solution) in a gallon of water. You may want to allow the ceramic cup to soak in this solution overnight to be sure that all the bacteria are killed. Then rinse the instrument with water.

Fill the instrument with clean water or water with a mild biocide to help prevent organic growths in the tensiometer fluid. Most tensiometer manufacturers sell a fluid additive that is both a biocide and coloring agent that allows the tensiometer fluid to be easily seen. Deionized water may be used in order to keep the instruments clean longer in the field. However, with time they will again become contaminated by contact with the soil solution and bacteria in the soil. It is not mandatory that fluid additives be used, however additives will reduce the maintenance needed to keep the instruments clean and working properly.

Allow the ceramic cups to soak in water or tensiometer fluid for several hours or overnight to be sure that the ceramic is thoroughly saturated. Then fill the instrument with tensiometer fluid. A plastic squeeze bottle is useful for filling the instruments.

Remove excess air from the instrument using a hand held vacuum test pump available from the tensiometer manufacturer (Figure 2). The vacuum test pump has a neoprene suction cup or stopper that allows it to replace the tensiometer cap. Then as the pump is operated, air is extracted from the ceramic cup, tube, and vacuum gauge and pulled to the top of the tube. Pump the tensiometer several times, refilling the tube with fluid each time if necessary until no further air is removed. Then remove the vacuum pump and refill the tube to the top with tensiometer fluid. The instrument is now ready to be tested for leaks or capped for use.

![Vacuum Test Pump](image)

Figure 2.

**TESTING A Tensiometer**

To determine whether a tensiometer is working properly, three tests need to be conducted: 1) test for air leaks, 2) test that the mechanical vacuum gauge works, and 3) test that water can flow through the ceramic cup.

Begin by testing for large air leaks using the hand-held vacuum test pump. After the tensiometer has been cleaned and serviced as previously described, fill it completely full of fluid, then use the vacuum pump to make this test. Operate the vacuum pump to create a vacuum in the instrument and look
for the continued flow of air into the instrument. A steady stream of air bubbles will indicate a large air leak.

When large air leaks occur, they are often around fittings or gaskets such as where the pressure gauge is threaded into the plexiglass tube or where an o-ring seal is used to attach the tip to the tube on some tensiometer models. If so, these can often be repaired by using thread sealant or replacing o-rings. Large air leaks sometimes occur where the ceramic cup is cemented onto the plexiglass tube. If that is the case, it can often be repaired with a waterproof epoxy, however, all components need to be thoroughly dry before applying epoxy. Several days may be required to thoroughly dry the ceramic cup and the epoxy.

If no large air leaks occur, the mechanical vacuum gauge can be tested by comparing its reading with the test gauge on the vacuum test pump. Always buy a test pump with a test gauge installed. Then when the vacuum pump is used, the tensiometer gauge should read the same values as the test gauge. This is a quick and easy test that the tensiometer vacuum gauge is working and that its readings are approximately correct. Unfortunately, if the instrument gauge does not work, or if it is not accurate, most types must be replaced. Some can be calibrated, however, most that are commonly used must be discarded and replaced with a new gauge.

The final instrument test is a test for leaks and proper operation of the ceramic cup with the tensiometer sealed and ready for field installation. After the extraction of air and test of the vacuum gauge as described above, refill the tensiometer to the top and seal it with the tensiometer cap. Then place or hang the instrument in the atmosphere where water can evaporate from the ceramic cup to simulate soil drying. Because the instrument is sealed, as evaporation occurs the vacuum gauge reading should slowly increase (depending on the rate of drying) throughout the tensiometer range. This process may take an hour or more during which time the tensiometer fluid can be observed for streams of small air bubbles which indicate small leaks in the instrument. Such leaks must be found and repaired because if they are not, the instrument will require frequent refilling in the field and the gauge reading will lag the true soil reading.

While the above slow-leak test is being conducted, a test of the ceramic cup flow properties is being conducted at the same time. If the ceramic cup pores are plugged, water will not flow through the ceramic and the instrument will not respond or will respond only very slowly to drying by the atmosphere. This will indicate a need for the ceramic to be cleaned more thoroughly before the instrument will work in the field. Because of the small pore sizes in the ceramic, they can readily be plugged by oil, grease, or other contaminants. Never use oil or grease on or around these instruments where the ceramics might become contaminated.

**Tensiometer Calibration**

Because tensiometers commonly use mechanical vacuum gauges, these instruments can become inaccurate or fail with time. Calibration is periodically required when tensiometers are used to control irrigation scheduling, especially for crops that are very sensitive to water stress. Two calibrations can be performed: 1) the vacuum test gauge quick calibration, and 2) the vacuum chamber detailed calibration.

**Vacuum Test Gauge Quick Calibration**

The vacuum test gauge calibration was previously described in the tensiometer testing section of this publication. This is a quick test made by comparing the tensiometer gauge with the vacuum test gauge. The accuracy of this calibration depends on maintaining and using an accurate test gauge. If the tensiometer vacuum test pump used is equipped with a check valve to sustain the vacuum in the tensiometer tube, and a small bleed valve to slowly release the vacuum as desired, then the test instrument can easily be used to compare the gauges at several vacuum levels. First, operate the test pump to create a high level of vacuum in the tensiometer and read both gauges when they have equilibrated. Then operate the bleed valve to gradually reduce the vacuum level, stopping at each new level to read and record both vacuum gauges.

This procedure allows a quick test of a tensiometer gauge to be made throughout its range of operation. It offers the advantage that an instrument's calibration can quickly be checked in the field, using
only a small, easily-portable vacuum pump and test gauge.

**Vacuum Chamber Detailed Calibration**

Figure 3 shows a vacuum chamber that can be constructed to allow detailed tensiometer calibrations and extended leak tests to be performed. The calibration chamber is constructed from pressure-rated PVC pipe and PVC end caps. Holes are drilled along the length of the pipe for tensiometer ports, and other small ports are drilled for the installation of a vacuum regulator, vacuum gauge, and drain valve. Number 11 neoprene rubber stoppers with 3/4 or 7/8-inch diameter holes in them are used to seal tensiometers into the chamber, and solid stoppers are used to plug tensiometer access ports when they are not in use. A wooden stand is used as a base for the chamber.

![Tensiometer Calibration Chamber](image)

**Figure 3.**

A vacuum pump is used to create the vacuum required in the chamber, and a vacuum regulator is used to precisely set the vacuum level during calibration. Water is placed in the chamber to a level approximately midway up the ceramic cup.

Tensiometers are calibrated by servicing them and installing them in the chamber as shown in Figure 3. A vacuum level is created by operating the vacuum pump and setting the vacuum regulator, then the tensiometer gauges are allowed to come to equilibrium with the vacuum level set, and both the chamber vacuum gauge and the tensiometer gauges are read. This process is repeated at several vacuum levels to verify that each instrument is accurate or to create a calibration curve for each instrument tested.

The advantage of this method is that the entire instrument is inserted into the chamber during the test procedure. Thus, leak tests, ceramic cup flow properties, and tensiometer vacuum gauges are all tested at the same time. The vacuum level can be maintained for a long time (such as overnight) to test for slow leaks.

Both manually-read tensiometers and automatic switching tensiometers or pressure transducers can be calibrated using the chamber described here. Since all of these instruments measure soil water tension, all of the calibrations performed are independent of soil type, thus no further field calibration is required. When manual or pressure-transducer tensiometers are used, calibration curves can be determined by measuring the chamber vacuum level and the gauge or transducer outputs at the same time. A mercury manometer or high precision test gauge can be used to accurately monitor the chamber vacuum level if that degree of accuracy is required.

Automatic switching tensiometers use a magnetic pickup switch to indicate when a preset vacuum level has been reached. At that point, an irrigation can be automatically scheduled. To calibrate these switching tensiometers, the desired vacuum level is set in the chamber and the tensiometer vacuum gauges are allowed to equilibrate with it. Then the magnetic pickup switch is slowly rotated until switch closure occurs. This setting is marked on the vacuum gauge. This procedure insures that the switch setting will occur at the same vacuum level in the field. Again, no field calibration of these instruments is required. All calibration can be done in the convenience and comfort of the shop or laboratory.

**SUMMARY**

Tensiometers are useful instruments for irrigation scheduling under field conditions, however, they require servicing, testing and calibration to ensure that they are working properly. A tensiometer is a fairly simple instrument that will work well if it is properly installed and in good repair. The instrument is in good repair if: 1) the vacuum gauge is accurate, 2) the ceramic cup allows free water movement between the soil and the instrument, and 3) there are no air leaks. This publication presents both field and
laboratory procedures for servicing, testing, and calibration of tensiometers so that the user can determine that the instrument is working properly and reading accurately for irrigation scheduling purposes.

Because tensiometers commonly use mechanical vacuum gauges, these instruments can become inaccurate or fail with time. Calibration is periodically required if these instruments will be used to control irrigation scheduling, especially for crops that are very sensitive to water stress. Two calibrations can be performed: 1) the vacuum test gauge calibration, and 2) the vacuum chamber calibration. The vacuum test gauge procedure allows a quick test of a tensiometer gauge to be made throughout its range of operation. It offers the advantage that an instrument's calibration can quickly be checked in the field, using only a small, easily-portable vacuum pump and test gauge.

With the vacuum chamber method, the entire instrument is inserted into the chamber during the test procedure. Thus, leak tests, ceramic cup flow properties, and tensiometer vacuum gauges are all tested at the same time. The vacuum level can be maintained for a long time (such as overnight) to test for slow leaks.

All of the calibrations performed are independent of soil type, thus no field calibration is required. All calibrations can be done in the convenience and comfort of the shop or laboratory.

REFERENCES


Simple Water Level Indicator for Seepage Irrigation

A.G. Smajstrla

The use, construction, calibration, installation and maintenance of a simple, low-cost field water level indicator for seepage irrigation management is presented in this publication. When seepage irrigation (subirrigation) is used, field water tables must be accurately controlled near the soil surface so that water can flow into the plant root zone by capillarity.

Because water movement in the soil pores occurs by capillary forces, it is important that the water table be accurately maintained just below the plant root zone to avoid plant water stress. For most Florida crops, the water table should be maintained within 18 to 24 inches below the soil surface. See the appropriate crop production guide for water table recommendations for a specific crop.

A water table that is too low will stress plants by not providing sufficient water for the crop needs. A water table that is too high will stress plants by limiting root growth and providing a root zone that is too wet. Also, runoff from rainfall will increase when the water table is too high, reducing rainfall effectiveness and possibly increasing the loss of nutrients or other chemicals from the field.

USE

The simple water level indicator described in this publication (Figure 1) is used to directly read the depth from the ground surface down to the field water table level. The water level indicator serves as a shallow water table well and monitoring instrument which is installed in the field and can be left in the field throughout the irrigation season. The plastic float and 1/2-inch PVC pipe continuously moves up or down with the water table. Thus, if the water level indicator is properly calibrated and installed, the user can read the field water table level directly from the scale on the length of 1/2-inch PVC pipe that extends above the 4-inch diameter pipe cap.

Because it permits a direct reading of the field water table level to be made, this instrument allows growers or other irrigators to quickly and easily check field water table levels. This allows growers to save time and labor costs, while improving the management of their irrigation systems. Readings can be taken by walking up to the instrument, rather than stopping to insert a probe into the shallow wells. If these instruments are located near the edge of a field, they can be read by simply driving by the field site.
Simple Water Level Indicator for Seepage Irrigation

![Diagram of water level indicator](image)

**Figure 1.** Sketch of water level indicator and components (not to scale).

Surveying tape or other flags can be tied on the 1/2-inch PVC pipe to improve its visibility, or the pipe can be painted so that the desired water table level can easily be seen.

Because this instrument is constructed of PVC pipe with few moving parts, it can be installed in the field for extended periods of time with little maintenance. The well is designed to provide a low profile for easy clearance by farm equipment. If necessary, the 1/2-inch PVC indicator scale and the 4-inch PVC pipe cap can easily be removed to provide additional equipment clearance. If the indicator scale is removed, a spare PVC pipe cap can be used to cover the well during field operations to prevent debris from falling into the well.

**CONSTRUCTION**

The water level indicator described in this publication can be constructed of readily available parts, obtainable from most hardware or building supply stores. A materials list is given below. The materials cost is estimated to be $15 to $20 for each water level indicator.

**Materials list for seepage irrigation water level indicator:**

- 4 ft length of 4-inch diameter thin-wall PVC pipe
- 4 ft length of 1/2-inch diameter PVC pipe
- 4-inch diameter PVC pipe cap
- 1/2-inch diameter PVC pipe cap
- plastic toilet-bowl float
- 1-inch length cotter pin

The water level indicator can be constructed using the following steps:

1. Cut a 4-ft length of 4-inch diameter PVC pipe. This will serve as a shallow well to monitor the field water table level. Longer or shorter pipe lengths can be used if desired, however, 4 ft is often best for typical Florida water table levels. Thin wall pipe is adequate since it will not be required to withstand high pressures. Drill several 1/4-inch diameter holes through the pipe wall to allow water from the surrounding field to flow into the well.

2. Sand or mill the inside of the 4-inch pipe cap so that it easily slips over the end of the 4-inch diameter well pipe. This will permit the cap to easily be removed and replaced in the field if desired. This may be necessary so that the well can be inspected or so that the indicator scale can be removed to provide clearance for field equipment.

3. Drill a 1-inch diameter hole through the top of the 4-inch diameter pipe cap. This size will allow the 1/2-inch diameter PVC pipe to be inserted through the pipe cap and to freely move without binding.

4. Cut a 4-ft length of 1/2-inch diameter PVC pipe. This pipe will serve as a scale or ruler to directly indicate the field water table level. A calibration procedure for constructing the scale is given later in this report.

5. Attach the plastic float to the PVC pipe with a cotter key. Slip the PVC pipe over the plastic nipple on the float and drill a small hole through the PVC pipe and float nipple. Then insert a cotter key through the hole.

6. Slip the 1/2-inch PVC pipe through the hole in the 4-inch PVC pipe cap so that the float is downward as shown in Figure 1. Then tap the
Simple Water Level Indicator for Seepage Irrigation

1/2-inch PVC pipe cap firmly onto the 1/2-inch PVC pipe. If necessary, a small set screw can be used to keep the 1/2-inch cap from slipping off. Drill a small hole through the walls of the pipe and pipe cap, and thread the screw into the hole. The water level indicator is now ready to be calibrated to read field water levels directly.

**CALIBRATION**

After the field water level indicator has been constructed, it must be calibrated so that field water table levels can be read by direct inspection of a scale drawn on the 1/2-inch PVC pipe. An easy and accurate way to calibrate this instrument is:

1. Assemble the water level indicator as shown in Figure 1.

2. Make a permanent mark on the outside of the 4-inch PVC well pipe to indicate the depth that the well should be inserted into the ground (ground level mark) when the well is installed. A permanent marking pen or paint can be used, or the mark can be permanently scratched into the PVC pipe. When installed, the well will be placed so that this mark is at the ground surface. This ground level mark should be near the upper end of the 4-inch PVC well pipe, just below the PVC pipe cap. The actual location can be varied, depending on how far the well can be allowed to stick up above the ground. Normally, the mark is made about 4-inches below the top of the well pipe, so that the instrument will present a low profile, and equipment clearance will not be a problem.

3. Fill a bucket or tub with several inches of water, and stand the water level indicator assembly upright in the bucket or tub. Use enough water so that the float assembly (float and 1/2-inch PVC pipe) float freely.

4. Using a carpenter's tape or yard stick, measure the distance from the permanent ground level mark made on the 4-inch PVC well pipe in Step #2 down to the water level in the bucket or tub. At the same time, make a permanent mark on the 1/2-inch PVC pipe where it protrudes through the hole in the 4-inch PVC pipe cap. For convenience, add or remove small amounts of water from the bucket or tub until the measured distance is a "round" number, such as a whole number of inches or centimeters, rather than a fraction of inches or centimeters.

5. Using a permanent marking pen, write the measured water table depth (from Step #4) directly onto the 1/2-inch PVC pipe where it was marked in Step #4. This is a direct reading of the water level in the well, and it will be used as a reference for the scale to be marked on the 1/2-inch PVC pipe.

6. Using a permanent marking pen and a ruler or yard stick, make additional scale marks along the length of the 1/2-inch PVC pipe, beginning at the calibration point marked in Step #5. Marks should probably be made and labeled at each inch or centimeter. Notice that the numbers must get larger near the top of the 1/2-inch PVC pipe, and smaller near the plastic float, since the scale will read distance from the ground surface down to the water table.

**INSTALLATION**

The water level indicator can easily be installed in the field using only a manual post-hole digger. If the instrument is constructed following the specifications given in this publication, the total length of the well pipe will be 4 ft. The hole to be dug will be about 3-ft, 8-inches deep, since approximately the upper 4 inches covered by the pipe cap will extend above the ground. Note that these dimensions can be changed, depending on site-specific conditions such as normal depth to the water table and clearance of field equipment.

In row crop production systems, the instrument can be located on the plant beds so that it will be out of the way of most field equipment operations. The well only protrudes a short distance above the ground surface so that clearance by field equipment should not be a problem.

If the dimensions suggested in this publication are used, dig a hole approximately 3-ft, 8-inches deep and place the 4-inch diameter well pipe vertically in the hole. Adjust the depth of the hole until the upper indicator mark on the 4-inch diameter well pipe is flush with the ground surface. Then backfill around the well pipe with the soil removed from the well. Normally, only a few minutes should be required to install each water level indicator.
Simple Water Level Indicator for Seepage Irrigation

The indicator will begin to operate as soon as the water level in the well reaches the level in the surrounding soil. Normally, this will only take a few minutes. To speed response time, more 1/4-inch holes should be drilled in the wall of the 4-inch diameter well pipe when the instrument is constructed.

Since the exterior of the instrument is relatively smooth PVC pipe, it can easily be removed from the field at the end of the season or before major tillage operations. First, remove the 4-inch PVC pipe cap and water level indicator, then grasp the edge of the 4-inch PVC well pipe and pull it upward. It is sometimes helpful to use vice grip pliers to grasp the edge of the PVC pipe in order to provide a better grip on the pipe.

MAINTENANCE

The water level indicator described in this publication has very low maintenance requirements. The only moving part is the float-actuated indicator scale. It will move smoothly upward and downward if the guide hole in the 4-inch PVC pipe cap is large enough so that the parts do not bind up from blowing sand or debris in the field. This potential problem can be avoided by drilling an oversized 1-inch diameter hole in the pipe cap as recommended.

With time, the scale and reference markings may fade and require marking again. If permanent marking pens are used, this maintenance need will probably not occur more often than each season.

With time, soil may begin to fill the well so that the float hits the bottom of the well. If this occurs, the well can be cleaned with a soil auger which can be inserted into the well. The well could also be moved a short distance and reconstructed. Normally, wells would not be expected to fill up in less than one crop season unless the saturated soil is extremely unstable.

SUMMARY

The use, construction, calibration, installation and maintenance of a simple, low-cost water level indicator for seepage irrigation management was presented in this publication. This instrument can be used to continuously indicate field water table levels to improve the management of seepage irrigation systems. It can be constructed of readily available parts, obtainable from most hardware or building supply stores. A materials list and instructions for construction were presented. The materials cost is estimated to be $15 to $20 per instrument. Calibration can be accurately done with no specialized equipment. Because this instrument is constructed of PVC pipe with few moving parts, it can be installed in the field for extended periods of time with little maintenance. Installation and removal time and labor requirements are expected to be small, and the low profile of the instrument should not be an obstacle to most field equipment operations.
Fertilization for Vegetables: A Practical Guide for Small Fields

Jim DeValerio, David Nistler, Robert Hochmuth, and Eric Simonne

Introduction

More and more farmers are growing fruits and vegetables on small acreage for specialty local markets. The production areas are often comprised of several small blocks that range from 1/10–1 acre in size and frequently utilize drip irrigation systems to deliver water and soluble fertilizers (http://edis.ifas.ufl.edu/hs388). When fertilizer is mixed and added to irrigation water, the term often used is fertilization (Figure 1). Farmers commonly grow several crops at different stages of development simultaneously in order to have a variety of produce to sell to customers at weekly intervals (Figure 2). This situation forces farmers to schedule plantings accordingly and be prepared to make several fertilizer calculations because of their diverse crop demands. Additionally, farmers can enhance their production and irrigation efficiency by grouping crops with similar nutrient requirements. Water and nutrient requirements vary according to the crop and stage of development. This guide is intended to help growers correctly interpret fertilizer recommendations and calculate accurate fertilizer amounts to be used in fertilization events based on crop nutrient requirements.

Figure 1. Fertilization unit for small acreage
Credit: UF/IFAS
[Click thumbnail to enlarge.]

Figure 2. Diversity of vegetable crops in small blocks
Credit: UF/IFAS
[Click thumbnail to enlarge.]
Step 1. Test the soil

Have the soil tested 1–2 months prior to planting so that timing requirements might be addressed well in advance of planting. A soil test will also assess levels of available phosphorus, potassium, magnesium, sulfur, calcium, and micronutrients (minor elements) in the soil. Typical recommendations are expressed in elemental or oxide forms needed per planted acre (http://edis.ifas.ufl.edu/ss170).

Example: 50 lbs N/acre, 30 lbs P₂O₅/acre, or 50 K₂O/acre

Step 2. Calculate planted acre, taking into account field surface and bed spacing

The University of Florida Vegetable Production Handbook includes information about the crop nutrient requirements for specific crops and growth stages. Use the guide for specific weekly crop nutrient requirements because each crop varies. In addition, crop nutrient requirements are based on standard bed or row spacing (e.g., 8 ft for watermelon; 5 ft for tomato, pepper, cucumber, squash, and cantaloupe; and 4 ft for strawberry) (http://edis.ifas.ufl.edu/ss516).

Field surface area in acres = [Distance between the center of one bed to the center of the next bed in ft × length of beds in feet × the number of beds] divided by 43,560

Example: A strawberry field that has eight, 250 ft long beds on 4 ft centers

The resulting acreage would be:

\[(4 \times 250 \times 8)/43,560 = 0.184\text{ acres}\]

Step 3. Select the correct fertilizer

Fertilizers can be formulated in three ways: granular, dry soluble, or liquid. Either dry soluble or liquid forms may be used with drip irrigation. Granular formulations are usually not used in drip irrigation systems because they are not soluble, but they are routinely used for applications to the soil before or after the beds have been formed and before or during the time when the drip tape and plastic mulch are installed. This application is referred to as the preplant application. Based on UF/IFAS recommendations, the entire crop demand for phosphorus and micronutrients should be applied in this step. Up to 50% of the total crop nutrient requirement for nitrogen (N) and potassium (K₂O) may be applied in the preplant application because both elements leach readily in the soil. The remaining N and K₂O should be injected in small increments during the growing season because the crop needs them in varying amounts for each particular plant growth stage. There are situations where no preplant application of N or K₂O is used, meaning all N and K₂O can be successfully applied via fertigation. This publication is based on programs in which all phosphorus and micronutrients, as well as a small portion of nitrogen and potassium, are applied preplant, and only nitrogen and potassium need to be supplied during the growing season. For the purposes of simplicity in this document, the general assumption is that N and K₂O will be recommended in equal amounts, as is common the case in Florida. If fertigation plans result in injections in which N and K₂O are not equal, then growers will need to use an analysis of a liquid fertilizer matching those amounts needed or use individual dry ingredients at rates that best match the recommended amounts.

Step 4. Calculate the correct amount of fertilizer needed

University of Florida researchers have determined fertilizer requirements for most vegetable crops (http://edis.ifas.ufl.edu/topic_vph). The crop nutrient requirements are usually determined on the basis of N, P₂O₅, or K₂O pounds per acre for the entire crop cycle (http://edis.ifas.ufl.edu/pdfs/files/cv/cv10100.pdf).

Example: Assume a strawberry crop soil test recommends 150 lbs N, P₂O₅, and K₂O per acre for the entire season (http://edis.ifas.ufl.edu/pdfs/files/cv/cv13400.pdf). In the case of strawberry, a typical strategy based on soil test results may be to supply 40 lbs N, 150 lbs P₂O₅, and 40 lbs K₂O per acre in the preplant fertilizer step. The remaining 110 lbs of N and K₂O will be injected weekly at 0.3–0.75 lbs/A/day, depending on the plant growth stage. The nutrients are spoon-fed to the crop in small increments because they may be leached from the soil during heavy rain events. If they were applied in their entirety early in the crop cycle, they would most likely be lost to heavy rains and need to be replaced at considerable and unnecessary expense.

Example: Using the strawberry example above, injection rates start at 0.3 lbs and increase to 0.75 lbs N and K₂O per acre per day. To determine the amount needed if you inject once a week, multiply those daily amounts by 7 to convert them to lbs per acre per week (Tables...
1-3) (0.75 lbs per day × 7 days = 5.25 lbs per week). Recommendations are for daily injections. However, growers may elect to inject daily, weekly, or twice weekly.

**Step 6. Determine how much fertilizer is needed per planted acre**

Unfortunately, all fertilizers are not created equal! This is because they are raw elements, and the presence and/or proportion of either N or K are fixed according to the type of fertilizer (Tables 1-3). This guide focuses on a few of the most common fertilizer formulations (Tables 4-7) used in drip irrigation systems on small acreages in Florida.

The liquid formulations often have equal amounts of N and K₂O because equal amounts are often recommended for sandy soils. This makes it simple to calculate how much to use as long as the same amount of N and K₂O are needed. Notice that the entire amount of potassium supplied comes from potassium nitrate because ammonium nitrate has no potassium in it. On the other hand, both ammonium nitrate and potassium nitrate supply nitrogen.

**Example:** Continuing with the strawberry example used above, suppose the crop is at a stage that requires 0.75 lbs N and 0.75 lbs K₂O per planted acre per day. Multiplying by 7 to convert daily amounts to the amounts per week results in 5.25 lbs N and K₂O per planted acre per week.

Calculate the amount of fertilizer needed per week for small acreage: 5.25 lbs N and K₂O per acre per week × 0.184 planted acres = 0.97 lbs (round to 1 lb) of N and K₂O each. Consulting Tables 1 and 2, 2 lbs of 13.5-0-46 provides 0.9 lbs K and 0.3 lbs N. The additional N can be supplied by adding about 2 lbs of ammonium nitrate.

**Step 6. Determine how much water is needed to solubilize the fertilizer**

Small acreage fertigation events often do not require very much water to solubilize the dry fertilizers, such as ammonium nitrate and potassium nitrate, as these materials are readily soluble. Growers need to make sure the fertilizer sources dissolve in water and should avoid field-grade materials intended to be side-dressed only. If a fertilizer material is a "greenhouse grade," it will readily dissolve in water. Using hot water to dissolve the fertilizer is helpful if hot water is conveniently available. The hotter the water, the less water is needed to make the fertilizer solution. As you will see in Step 7, it is preferable to use as little water volume as possible because excessive volumes of solution may take too long to inject. Some fertilizer materials are not compatible in concentrated solutions. For example, concentrated solutions of fertilizers containing calcium and phosphorus result in cross-precipitation, leaving an insoluble precipitate (clay-like material) in the bottom of the bucket. In general, be careful when mixing fertilizers that contain calcium, magnesium, or phosphorus, and always conduct a jar test of any mixtures first. Ammonium nitrate plus potassium nitrate, or calcium nitrate plus potassium nitrate are common mixtures that are compatible and often used.

**Step 7. Determine the time needed to inject fertilizer through an irrigation system**

Properly applying fertilizer during a scheduled irrigation event ensures that most of the fertilizer will be placed within the crop root zone. Before injecting fertilizer into any irrigation system, make sure all required backflow prevention requirements are in place and properly working (Figure 3). To see how to properly assemble a small fertigation unit, visit http://vfd.ifas.ufl.edu/gainesville/small_farm_drip_irrigation/index.shtml. When preparing to inject fertilizer, first allow time for the irrigation system to fully pressurize the drip tape. In most small irrigation zones, the full system pressure is about 8-12 psi and is reached in 15 minutes or less, but you should check each zone to determine the actual time. Once the system reaches full pressure, you should begin fertigation. For most sandy soils, the total run time of a single irrigation event should not be more than 1-1.5 hours in duration to avoid leaching. Calculations may be done by timing an actual injection, or by calculations based on the volume of solution to be injected and the system flow rate and pump. After fertigation, continue to run water to evenly distribute all of the fertilizer throughout the zone. The length of this run is generally a little longer than the time required initially to bring the system up to full pressure. After each fertigation application, flush the system and allow particles to be flushed from the drip tape that may clog emitters. Second, determine the time required to inject the quantity of fertilizer needed. In summary, the total time for an entire fertigation event includes the following:

- Time for water to travel from the injection point to the farthest emitter and bring the system up to full pressure
- Time to inject the fertilizer solution
- Time for the last bit of fertilizer solution to reach the farthest emitter
- Additional time to flush the system
Example: Assume it takes 10 minutes for water to travel from the injection point to the farthest emitters and reach full system pressure, 30 minutes to inject the solution, and 15 minutes to flush the remaining fertilizer through the system.

As a result, a total fertigation event should have the following timing:

10 minutes for water to travel from the injection point to the farthest emitter and reach full pressure +
30 minutes to inject the solution +
15 minutes for the last bit of fertilizer solution to reach the farthest emitter +
5 minutes to flush the system =

Total time of 60 minutes

Fertilizer must be completely flushed from the system after fertigation in order to keep drip lines clean and prevent emitters from clogging. If clogging is an issue, open the ends of the systems lateral (the lines to which the drip tape is attached) and flush water through the drip tape several times during the growing season. If a fertilizer injection system is very small and, therefore, takes more than 1–1.5 hours to run the single weekly fertigation event, then the grower must inject smaller amounts more than once a week to avoid leaching irrigation events. A simple way to check if leaching is occurring is to uncover a portion of the plastic without cutting the drip tape and use a shovel to dig out a cross section of the bed to view the irrigation pattern after an irrigation event (Figure 4). Irrigation run times should be adjusted for optimal delivery to the root zone. An educational video on the topic of using blue dye to better visualize the movement of water through the soil profile can be viewed at http://vfd.ifas.ufl.edu/gainesville/blue_dye/index.shtml.

Table 1. Amount (rounded to the nearest tenth of a lb) of N and K₂O supplied in various amounts of potassium nitrate (13.5-0-46)²

<table>
<thead>
<tr>
<th>Potassium nitrate (13.5-0-46) (lbs)</th>
<th>N (lbs)</th>
<th>K₂O (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.135</td>
<td>0.46</td>
</tr>
<tr>
<td>Amount (lbs)</td>
<td>N (lbs)</td>
<td>N (lbs)</td>
</tr>
<tr>
<td>-------------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
<td>0.9</td>
</tr>
<tr>
<td>5</td>
<td>0.7</td>
<td>2.3</td>
</tr>
<tr>
<td>10</td>
<td>1.3</td>
<td>4.6</td>
</tr>
<tr>
<td>15</td>
<td>2.0</td>
<td>6.9</td>
</tr>
<tr>
<td>20</td>
<td>2.6</td>
<td>9.2</td>
</tr>
<tr>
<td>25</td>
<td>3.3</td>
<td>11.5</td>
</tr>
<tr>
<td>30</td>
<td>3.9</td>
<td>13.8</td>
</tr>
<tr>
<td>35</td>
<td>4.6</td>
<td>16.1</td>
</tr>
<tr>
<td>40</td>
<td>5.2</td>
<td>18.4</td>
</tr>
<tr>
<td>45</td>
<td>5.8</td>
<td>20.7</td>
</tr>
<tr>
<td>50</td>
<td>6.5</td>
<td>23.0</td>
</tr>
</tbody>
</table>

For amounts not included in column 1, take the amount of the first row (0.135 for N and 0.46 for K₂O) and multiply it by the number of pounds of potassium nitrate needed.

Table 2. Amount (rounded to the nearest tenth of a lb) of N supplied from various amounts of ammonium nitrate.

<table>
<thead>
<tr>
<th>Ammonium nitrate (34% N) (lbs)</th>
<th>N (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.34</td>
</tr>
<tr>
<td>2</td>
<td>0.7</td>
</tr>
<tr>
<td>5</td>
<td>1.7</td>
</tr>
<tr>
<td>10</td>
<td>3.3</td>
</tr>
<tr>
<td>15</td>
<td>5.0</td>
</tr>
<tr>
<td>20</td>
<td>6.7</td>
</tr>
<tr>
<td>25</td>
<td>8.3</td>
</tr>
<tr>
<td>30</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>35</td>
<td>11.7</td>
</tr>
<tr>
<td>40</td>
<td>13.3</td>
</tr>
<tr>
<td>45</td>
<td>15.0</td>
</tr>
</tbody>
</table>

2 For amounts not included in column 1, take the amount of the first row (0.34) and multiply it by the number of pounds of ammonium nitrate needed.

Table 3. Amount (rounded to the nearest tenth of a lb) of N supplied from various amounts of calcium nitrate2

<table>
<thead>
<tr>
<th>Calcium nitrate (15.5-0-0) (lbs)</th>
<th>N (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.155</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
</tr>
<tr>
<td>10</td>
<td>1.6</td>
</tr>
<tr>
<td>15</td>
<td>2.3</td>
</tr>
<tr>
<td>20</td>
<td>3.1</td>
</tr>
<tr>
<td>25</td>
<td>3.9</td>
</tr>
<tr>
<td>30</td>
<td>4.7</td>
</tr>
<tr>
<td>35</td>
<td>5.4</td>
</tr>
<tr>
<td>40</td>
<td>6.2</td>
</tr>
<tr>
<td>45</td>
<td>7.0</td>
</tr>
</tbody>
</table>

2 For amounts not included in column 1, take the amount of the first row (0.155) and multiply it by the number of pounds of calcium nitrate needed.

Table 4. Examples of various fertilizer options and amounts needed for weekly fertilization events

<table>
<thead>
<tr>
<th>Recommended fertilizer rate (lbs/A/day)</th>
<th>Amounts of four fertilization options injected once a week per acre (lbs/A/week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid premix</td>
<td>Liquid premix</td>
</tr>
<tr>
<td>Option 1</td>
<td>Option 2</td>
</tr>
<tr>
<td>Dry grower mix</td>
<td>Dry grower mix</td>
</tr>
<tr>
<td>Option 3</td>
<td>Option 4</td>
</tr>
<tr>
<td>N</td>
<td>K₂O</td>
</tr>
<tr>
<td>----</td>
<td>-----</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>3.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

1 acre = 43,560 sq ft

Assuming that 1 gallon weighs 10 lbs, 1 gallon of liquid 7-0-7 contains 0.7 lbs of N and 0.7 lbs of K₂O

Table 5. Example calculations of amounts of three fertilizer options to be injected once per week, Field #1²

<table>
<thead>
<tr>
<th>Recommended daily fertilizer rate (lbs/A/day)</th>
<th>Amounts of three fertilization options injected once a week for Field #1 (amount/week/22 acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Liquid premix Option 1</td>
</tr>
<tr>
<td>Liquid solution (7-0-7)</td>
<td>Liquid solution (8-0-8)</td>
</tr>
<tr>
<td>N</td>
<td>K₂O</td>
</tr>
</tbody>
</table>

²Field setup and calculations:
16 beds 150 ft long spaced on 4 ft centers. 16 x 150 ft rows = 2400 linear bed ft (lbf)
One acre with beds spaced on 4-ft center = 10,890 lbf
2400/10,890 = .22 acre

Table 6. Example calculations of amounts of three fertilizer options to be injected once per week, Field #2

http://edis.ifas.ufl.edu/hs1206
<table>
<thead>
<tr>
<th>Recommended daily fertilizer rate (lbs/A/day)</th>
<th>Amounts of three fertilization options injected once a week for Field #2 (amounts/week/.55 acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Liquid premix Option 1</td>
</tr>
<tr>
<td>N</td>
<td>K₂O</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>3.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

2Field setup and calculations:

20 beds 200 ft long spaced on 6 ft centers. 20 x 200 ft = 4000 LBF
43,560/6 = 7260 LBF/A
4000/7260 = .55 acres

Table 7. Example calculations of amounts of three fertilizer options, including calcium nitrate plus potassium nitrate, to be injected once per week, Field #2.

<table>
<thead>
<tr>
<th>Recommended daily fertilizer rate (lbs/A/day)</th>
<th>Amounts of three fertilization options injected once a week for Field #2 (amounts/week/.55 acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Liquid premix Option 1</td>
</tr>
<tr>
<td>N</td>
<td>K₂O</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
</tr>
</tbody>
</table>

Field setup and calculations:

- 20 beds 200 ft long spaced on 6 ft centers. 20 x 200 ft = 4000 LBF
- 43,560/6 = 7260 LBF/A
- 4000/7260 = .55 acres

Footnotes

1. This document is HS1206, one of a series of the Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date October 2012. Visit the EDIS website at http://edis.ifas.ufl.edu.

2. Jim DeValerio, Extension agent II, Bradford County; David Nisler, Extension agent II, Clay County; Robert Hochmuth, Multicounty Extension agent IV, Suwannee Valley Agricultural Extension Center; and Eric Simone, professor, District Extension Director, Gainesville, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611

The Institute of Food and Agricultural Sciences (IFAS) is an Equal Opportunity Institution authorized to provide research, educational information and other services only to individuals and institutions that function with non-discrimination with respect to race, creed, color, religion, age, disability, sex, sexual orientation, marital status, national origin, political opinions or affiliations. For more information on obtaining other UF/IFAS Extension publications, contact your county's UF/IFAS Extension office.

U.S. Department of Agriculture, UF/IFAS Extension Service, University of Florida, IFAS, Florida A & M University Cooperative Extension Program, and Boards of County Commissioners Cooperating. Nick T. Place, dean for UF/IFAS Extension.

Copyright 2013 | Site Feedback | About This Site
Injection of Chemicals Into Irrigation Systems: Rates, Volumes, and Injection Periods

G.A. Clark, D.Z. Haman and F.S. Zazueta

Irrigation systems can be used to transport soluble chemicals to the crop. Depending on the type of irrigation system, chemicals may be applied to the root zone, the aerial part of the plant, or both. The process of chemical transport using the irrigation system is referred to as chemigation. Specific terms may be used to refer to specialized applications of chemigation, such as nematigation and fertigation.

Irrigation systems designed or adapted for chemigation require specialized equipment for the injection of the chemical solution into the irrigation system at a controlled rate. Several injection methods are possible and are discussed in detail in other publications (Nakayama and Bucks, 1986; Smajstrla et al., 1987; and Yeager and Henley, 1987). The cost, accuracy, reliability, and longevity of the equipment varies greatly among manufacturers.

It is important to select adequate equipment, maintain it regularly, and properly operate it to insure a successful chemigation system. New irrigation system designs must consider which chemicals are to be injected while selecting the system components to insure compatibility. Uniformity of chemical application cannot exceed that of the irrigation system. Therefore, it is very important to have a well designed and well maintained irrigation system to provide the greatest potential for a high level of application uniformity. When existing irrigation systems are to be adapted for chemigation, they should be thoroughly examined for uniformity of application as well as compatibility of the chemicals to be injected with existing components.

Water quality is another factor to consider in the design or adaptation of an irrigation system for chemigation. Some water supplies require chemical amendment to prevent bacterial growths or chemical precipitants from clogging the system. This publication will concentrate on the management aspects of chemigation and how chemigation influences other aspects of irrigation management.

Chemical Mixtures and Injections

Chemicals may be applied as a precisely managed level of concentration or as a bulk mass of chemical with possibly varying concentration levels. Concentration management requires a precise injection system and is more involved than bulk injection. The injection system must be specifically calibrated for the irrigation system it is to be operated on and under the operating conditions that will exist when chemicals are to be injected. Variations in operating pressure, system flow rate, and at times even temperature can influence the calibration of the system. Bulk injection simply involves the injection of a desired volume or amount of chemical into the system. The injection rate does not need to be precisely controlled. However, it should not be damaging to any part of the system or crop, should not exceed manufacturers’ recommended application rates, and

---


2. G.A. Clark, Assistant Professor, Extension Irrigation Specialist, Gulf Coast Research and Education Center, Bradenton, FL; D.Z. Haman, Associate Professor and F.S. Zazueta Assistant Professor, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 32611.

The Institute of Food and Agricultural Sciences (IFAS) is an Equal Opportunity Institution authorized to provide research, educational information and other services only to individuals and institutions that function with non-discrimination with respect to race, creed, color, religion, age, disability, sex, sexual orientation, marital status, national origin, political opinions or affiliations. U.S. Department of Agriculture Cooperative Extension Service, University of Florida, IFAS, Florida A&M University Cooperative Extension Program, and Boards of County Commissioners Cooperating. Millie Ferrer-Charney, Interim Dean.
should apply the chemical in a time period which does not result in over-irrigation or leaching of previously applied chemicals.

**Concentration Mixtures of a Stock Solution**

Some chemical applications require that a certain concentration level be maintained for proper use of that chemical in that situation. Concentrations are generally expressed in parts per million (ppm), which is not a convenient term for mixing purposes. Chemicals may be supplied in dry form or liquid form; however, the end result is a liquid mixture of a desired concentration. The following equation can be used to determine the mass of chemical required to achieve a particular ppm level. (Equation 1)

\[
\text{lb of raw chemical per 100 gal} = \frac{\text{desired ppm}}{1205}
\]

This provides the mass of actual chemical that must be dissolved per 100 gallons of water. For example, a 200 ppm concentration level of nitrogen as a fertilizer solution will require as shown in Equation 2:

\[
\frac{200 \text{ ppm}}{1205} = 0.17 \text{ lb of } N \text{ per 100 gal. of water}
\]

This is pounds of actual nitrogen required and not pounds of fertilizer mix as either a dry or liquid source.

Many chemicals are supplied as either a percentage by weight of a dry or liquid mixture. Therefore the mass of chemical mixture required will depend on the concentration of raw chemical in the mixture. Equation 3 can be used to determine the mass of chemical mixture required to provide the necessary level of raw chemical.

\[
M(\text{mixture}) = \frac{(M_x)(100)}{\%X}
\]

where

- \(M(\text{mixture})\) = the required mass of chemical mixture (lb.),
- \(M_x\) = the desired mass of chemical X (lb.), and
- \(\%X\) = the percentage of chemical X in the mixture.

If in the above example a 16-4-8 (N-P\textsubscript{2}O\textsubscript{5}-K\textsubscript{2}O) dry fertilizer mix was used, then the required mass of fertilizer mix for 100 gallons of solution is shown in equation 4:

\[
\frac{(0.17 \text{ pounds})(100)}{16\%} = 1.1 \text{ pounds}
\]

Therefore 1.1 pounds of 16-4-8 fertilizer source mix are required to supply 0.17 pounds of nitrogen.

Table 1 combines both Equations (1) and (3) to provide the mass of chemical mixture (for example, fertilizer mix) to add to 100 gallons of water to obtain a certain ppm level for the desired chemical. An example using Table 1 is included in the Appendix.

It is important to remember that the A-B-C analysis of a fertilizer label refers to the nitrogen (N), phosphorus oxide (P\textsubscript{2}O\textsubscript{5}), and potash (K\textsubscript{2}O). Therefore only 44% of the B factor (P\textsubscript{2}O\textsubscript{5}) refers to actual phosphorus (P), and only 83% of the C factor (K\textsubscript{2}O) refers to actual potassium (K). Equation (3) can be slightly rearranged to solve for \(M\), based on \(M(\text{mixture})\), and used to determine the mass of actual P or K contained in a fertilizer mix. For example, in 50 pounds of 16-4-8 fertilizer the mass of P\textsubscript{2}O\textsubscript{5} is shown in Equation 5:

\[
\frac{(50 \text{ pounds})(4\%)}{100} = 2.0 \text{ pounds of } P\textsubscript{2}O\textsubscript{5}
\]

Similarly, the mass of actual P is shown in Equation 6:

\[
\frac{(2.0)(4\%)}{100} = 0.88 \text{ pounds of } P.
\]

Therefore 50 pounds of a 16-4-8 fertilizer mixture contains only 0.88 pounds of actual P. The same procedure can be used to determine that the amount of actual K is 3.32 lbs.

When chemicals are supplied in liquid form, it is more convenient to measure volumes rather than masses or weights. This requires the specific density or specific weight (S\text{sp}) of the liquid mixture such as pounds of chemical per gallon of liquid. This property should be provided by the manufacturer or chemical supplier and can be used to simply convert from required lbs. to required gallons. For example a liquid fertilizer provided as a 4-0-8 solution has 4% nitrogen by weight. However, the amount of nitrogen is not known unless the specific weight of the chemical (fertilizer) solution is known, such as 9.6 lb. per gallon. As was previously mentioned, this value varies among chemical mixtures and should be on the chemical label, but may be obtained from the chemical supplier.

**Concentration Injection Rates**

The previous section described the procedure for mixing particular concentrations of a stock solution. However, many systems will have flowing water with a requirement to maintain a desired concentration of a chemical in that system. This requires injecting a supply mixture at the proper rate to maintain the desired concentration level. The
following equation or Tables 2 and 3 can be used to determine the injection rate necessary to maintain the desired concentration of a chemical X. (Equation 7)

\[ Q_i = \frac{(ppm_x)(Q_w)(8.3)}{[(%X)(S_x)(10000)] - [(ppm_x)(S_x)]} \]

where

- \( Q_i \) = Injection rate in gallons per minute (gpm),
- \( Q_w \) = Water supply flow rate (gpm),
- 8.3 = Specific weight of water (lb./gal.),
- ppm \( x \) = Desired ppm level of chemical X,
- %X = Percentage of chemical X in the stock solution, and
- \( S_x \) = Specific weight of the stock solution mix (lb./gal.).

For example, chlorine is to be injected to provide 10 ppm of free chlorine into a micro-irrigation system which has a system flow rate of 550 gpm. (Equation 8) The chlorine stock solution contains 5% free chlorine (sodium hypochlorite source, NaOCl) and has a specific weight of 9.1 lbs. per gallon. Therefore,

\[ Q_w = 550 \text{ gpm}, \ ppm_x = 10; \ %X = 5; \ S_x = 9.1; \text{ and } Q_i = \frac{(10)(550)(8.3)}{(5)(9.1)(10000)} - [(10)(9.1)] = 0.100 \text{ gpm} \]

Therefore, the injector should be set to provide 0.10 gallons per minute of stock solution into the irrigation system in order to maintain an injected free chlorine level of 10 ppm. The actual ppm of free chlorine throughout the system will depend on how much free chlorine is used by organic in the water supply and in the irrigation system.

If the specific weight of the chemical is close to that of water, Equation (7) can be simplified. The simplified approximation to Equation (7) is shown in Equation 9:

\[ Q_i = \frac{(ppm_x)(Q_w)}{(9.1)(10000)} \]

where

- \( Q_i \) = Injection rate in gallons per minute (gpm),
- \( Q_w \) = Water supply flow rate (gpm),
- ppm \( x \) = Desired ppm level of chemical X, and
- %X = Percentage of chemical X in the stock solution.

In repeating the above chlorine example we get as shown in Equation 10:

\[ Q_w = 550 \text{ gpm}, \ ppm_x = 10; \text{ and } %X = 5; \text{ and } Q_i = \frac{(10)(550)}{(5)(10000)} = 0.10 \text{ gpm} \]

This result is consistent with the previous example. In most cases, Equation (9) may be used. However, if greater accuracy is needed, then use Equation (7). Some injectors are operated to inject on a gallons-per-hour (gph) basis. Therefore, the injector rate determined above must be converted using Equation 11:

\[ Q_i (\text{gph}) = (60)(Q_i [\text{gpm}]) \]

For example, a flow rate of 0.10 gpm is equal to a flow rate of 6.0 gph.

**Injection Volumes and Periods**

Chemical mixtures may be injected directly from the stock supply tank or from an injector feeder tank. Injector feeder tanks are useful for injecting a specific volume of liquid, regardless of the injection rate. When the tank is empty the desired volume of chemical mixture has been injected. This procedure eliminates excess applications of chemicals which may occur due to pump or controller failure.

The size of the required feeder tank will depend on the volume of chemical mixture to be injected, which in turn will depend on either the total amount or volume of chemical to be applied or on the length of the injection period. Volumetric applications can be based on area applications or the sum of individual applications. For example, a pesticide may require that \( X \) pounds of a chemical be applied per acre; a vegetable grower may want to apply a certain mass of fertilizer per acre or per 1000 bedded feet of plant row; or a citrus or nursery operator may want to supply a certain amount of fertilizer per irrigated plant. In addition to the desired level of fertilization, these situations require knowledge of the irrigated acreage per set, total feet of bedded production area irrigated per set, or the number of plants or trees irrigated in each set.

**Summary**

Information pertaining to the injection of chemicals into irrigation systems was discussed in terms of concentration injections, bulk injections, quantity of chemicals to be injected, injection system calibration and injection periods. The information was provided to assist irrigation system
designers and operators with the chemigation aspects of irrigation system design, scheduling and management.

Table Examples
1. How much 10-10-10 soluble fertilizer mix is required to mix with water to make a 100 ppm solution of actual nitrogen? From Table 1 a value of 0.83 lb of soluble fertilizer is required per 100 gallons of water (solution) to provide a 100 ppm solution of nitrogen.

2. Chlorine is to be injected into an irrigation system which has a water delivery (supply) rate of 400 gpm. The chlorine stock solution contains 8% of "free" chlorine. What stock solution injection rate is necessary to provide 20 ppm of "free" chlorine to the irrigation supply water? Table 2 (or Table 3) indicates that to provide a 20 ppm concentration level with an 8% stock solution, approximately 0.025 gpm (1.50 gph) of stock solution injection is necessary per 100 gpm of water delivery rate. Therefore, a 400 gpm water delivery rate requires a stock solution injection rate of:

\[ \frac{0.025 \text{ gpm}}{100 \text{ gpm}} \cdot 400 \text{ gpm} = 0.10 \text{ gpm} \]

or

\[ (1.50 \text{ gph}) \cdot \frac{100 \text{ gpm}}{400 \text{ gpm}} = 6.0 \text{ gph} \]

Therefore, injecting an 8% stock solution of chlorine at 0.10 gpm (6.0 gph) into an irrigation system with a system flow rate of 400 gpm will provide approximately 20 ppm of "free" chlorine into the system.

1. A vegetable field is to be fertigated (have fertilizer injected) on a weekly basis with three pounds of nitrogen (N) per 1000 feet of plant bed per week. The field is 25 acres in area with 6000 bedded feet per acre. What size of feeder tank is necessary to hold the required volume of fertilizer mixture if the mixture is a 4-0-8 solution with a specific weight of 10 lb/gal?

The required amount of fertilizer is:

\[ 3 \text{ lb/1000 ft} \cdot \frac{6000 \text{ ft}}{1 \text{ acre}} = 18 \text{ lb/acre} \]

\[ 18 \text{ lb/acre} \cdot 25 \text{ acres} = 450 \text{ lb of N per week} \]

Table 4 is used to determine the amount of chemical (nitrogen) per gallon of solution. A 4-0-8 solution of fertilizer (S, = 10) has 4% nitrogen.

From Table 4 read the actual amount of N as 0.40 lb per gallon of solution.

Next use Table 5 to determine the required volume of mixture. For a 0.40 lb/gal chemical (nitrogen) density and 450 lb requirement, read 1125 gallons of fertilizer mixture required. Therefore, the supply tank must have a minimum capacity of 1125 gallons to hold the weekly supply of fertilizer.

References


Table 1. The mass (lb) of chemical mixture (i.e., fertilizer mix) to add to 100 gallons of water for different ppm level solutions.

<table>
<thead>
<tr>
<th>PPM Level</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20 (lb per 100 gallons)</th>
<th>25 (lb per 100 gallons)</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.17</td>
<td>0.08</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>20</td>
<td>0.33</td>
<td>0.17</td>
<td>0.11</td>
<td>0.08</td>
<td>0.07</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>30</td>
<td>0.50</td>
<td>0.25</td>
<td>0.17</td>
<td>0.12</td>
<td>0.10</td>
<td>0.08</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>40</td>
<td>0.66</td>
<td>0.33</td>
<td>0.22</td>
<td>0.17</td>
<td>0.13</td>
<td>0.11</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td>50</td>
<td>0.83</td>
<td>0.41</td>
<td>0.28</td>
<td>0.21</td>
<td>0.17</td>
<td>0.14</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>60</td>
<td>1.00</td>
<td>0.50</td>
<td>0.33</td>
<td>0.25</td>
<td>0.20</td>
<td>0.17</td>
<td>0.12</td>
<td>0.10</td>
</tr>
<tr>
<td>70</td>
<td>1.16</td>
<td>0.58</td>
<td>0.39</td>
<td>0.29</td>
<td>0.23</td>
<td>0.19</td>
<td>0.15</td>
<td>0.12</td>
</tr>
<tr>
<td>80</td>
<td>1.33</td>
<td>0.66</td>
<td>0.44</td>
<td>0.33</td>
<td>0.27</td>
<td>0.22</td>
<td>0.17</td>
<td>0.13</td>
</tr>
<tr>
<td>90</td>
<td>1.49</td>
<td>0.75</td>
<td>0.50</td>
<td>0.37</td>
<td>0.30</td>
<td>0.25</td>
<td>0.19</td>
<td>0.15</td>
</tr>
<tr>
<td>100</td>
<td>1.66</td>
<td>0.83</td>
<td>0.55</td>
<td>0.41</td>
<td>0.33</td>
<td>0.28</td>
<td>0.21</td>
<td>0.17</td>
</tr>
<tr>
<td>200</td>
<td>3.32</td>
<td>1.66</td>
<td>1.11</td>
<td>0.83</td>
<td>0.66</td>
<td>0.55</td>
<td>0.41</td>
<td>0.33</td>
</tr>
<tr>
<td>400</td>
<td>6.32</td>
<td>3.32</td>
<td>2.21</td>
<td>1.66</td>
<td>1.33</td>
<td>1.11</td>
<td>0.83</td>
<td>0.66</td>
</tr>
<tr>
<td>600</td>
<td>9.96</td>
<td>4.98</td>
<td>3.32</td>
<td>2.49</td>
<td>1.99</td>
<td>1.66</td>
<td>1.24</td>
<td>1.00</td>
</tr>
<tr>
<td>800</td>
<td>13.28</td>
<td>6.64</td>
<td>4.43</td>
<td>3.32</td>
<td>2.66</td>
<td>2.21</td>
<td>1.66</td>
<td>1.33</td>
</tr>
<tr>
<td>1000</td>
<td>16.60</td>
<td>8.30</td>
<td>5.53</td>
<td>4.15</td>
<td>3.32</td>
<td>2.77</td>
<td>2.07</td>
<td>1.66</td>
</tr>
</tbody>
</table>

Table 2. Chemical injection rate expressed in gpm of injection rate per 100 gpm of irrigation system flow rate for different desired concentration levels (ppm) and different stock solution concentration levels.

<table>
<thead>
<tr>
<th>Desired PPM Level</th>
<th>4</th>
<th>8</th>
<th>12</th>
<th>16</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.025</td>
<td>0.013</td>
<td>0.008</td>
<td>0.006</td>
<td>0.005</td>
<td>0.003</td>
<td>0.003</td>
<td>0.002</td>
</tr>
<tr>
<td>20</td>
<td>0.050</td>
<td>0.025</td>
<td>0.017</td>
<td>0.013</td>
<td>0.010</td>
<td>0.007</td>
<td>0.005</td>
<td>0.004</td>
</tr>
<tr>
<td>30</td>
<td>0.075</td>
<td>0.038</td>
<td>0.025</td>
<td>0.019</td>
<td>0.015</td>
<td>0.010</td>
<td>0.008</td>
<td>0.006</td>
</tr>
<tr>
<td>40</td>
<td>0.100</td>
<td>0.050</td>
<td>0.033</td>
<td>0.025</td>
<td>0.020</td>
<td>0.013</td>
<td>0.010</td>
<td>0.008</td>
</tr>
<tr>
<td>50</td>
<td>0.125</td>
<td>0.063</td>
<td>0.042</td>
<td>0.031</td>
<td>0.025</td>
<td>0.017</td>
<td>0.013</td>
<td>0.010</td>
</tr>
<tr>
<td>60</td>
<td>0.150</td>
<td>0.075</td>
<td>0.050</td>
<td>0.038</td>
<td>0.030</td>
<td>0.020</td>
<td>0.015</td>
<td>0.012</td>
</tr>
<tr>
<td>70</td>
<td>0.175</td>
<td>0.088</td>
<td>0.058</td>
<td>0.044</td>
<td>0.035</td>
<td>0.023</td>
<td>0.018</td>
<td>0.014</td>
</tr>
<tr>
<td>80</td>
<td>0.200</td>
<td>0.100</td>
<td>0.067</td>
<td>0.056</td>
<td>0.040</td>
<td>0.027</td>
<td>0.020</td>
<td>0.016</td>
</tr>
<tr>
<td>90</td>
<td>0.225</td>
<td>0.113</td>
<td>0.075</td>
<td>0.056</td>
<td>0.045</td>
<td>0.030</td>
<td>0.023</td>
<td>0.018</td>
</tr>
<tr>
<td>100</td>
<td>0.250</td>
<td>0.125</td>
<td>0.083</td>
<td>0.066</td>
<td>0.050</td>
<td>0.033</td>
<td>0.025</td>
<td>0.020</td>
</tr>
<tr>
<td>200</td>
<td>0.500</td>
<td>0.250</td>
<td>0.167</td>
<td>0.125</td>
<td>0.100</td>
<td>0.067</td>
<td>0.050</td>
<td>0.040</td>
</tr>
<tr>
<td>400</td>
<td>1.000</td>
<td>0.500</td>
<td>0.333</td>
<td>0.250</td>
<td>0.200</td>
<td>0.133</td>
<td>0.100</td>
<td>0.080</td>
</tr>
<tr>
<td>600</td>
<td>1.500</td>
<td>0.750</td>
<td>0.500</td>
<td>0.375</td>
<td>0.300</td>
<td>0.200</td>
<td>0.150</td>
<td>0.120</td>
</tr>
<tr>
<td>800</td>
<td>2.000</td>
<td>1.000</td>
<td>0.667</td>
<td>0.500</td>
<td>0.400</td>
<td>0.267</td>
<td>0.200</td>
<td>0.160</td>
</tr>
<tr>
<td>1000</td>
<td>2.500</td>
<td>1.250</td>
<td>0.833</td>
<td>0.625</td>
<td>0.500</td>
<td>0.333</td>
<td>0.250</td>
<td>0.200</td>
</tr>
</tbody>
</table>

1. (Caution: these values assume a stock solution specific weight equal to water. If necessary, these numbers may be adjusted by multiplying by the ratio of the specific weight of the chemical solution to the specific weight of water.)
Table 3. Chemical injection rate expressed in gph of injection rate per 100 gpm of irrigation system flow rate for different desired concentration levels (ppm) and different stock solution concentration levels.

<table>
<thead>
<tr>
<th>Desired PPM Level</th>
<th>4</th>
<th>8</th>
<th>Percent Analysis of the Chemical in the Stock Solution (gph of injection per 100 gpm of irrigation rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.5</td>
<td>0.75</td>
<td>0.50</td>
</tr>
<tr>
<td>20</td>
<td>3.0</td>
<td>1.50</td>
<td>1.00</td>
</tr>
<tr>
<td>30</td>
<td>4.5</td>
<td>2.25</td>
<td>1.50</td>
</tr>
<tr>
<td>40</td>
<td>6.0</td>
<td>3.00</td>
<td>2.00</td>
</tr>
<tr>
<td>50</td>
<td>7.5</td>
<td>3.75</td>
<td>2.50</td>
</tr>
<tr>
<td>60</td>
<td>9.0</td>
<td>4.50</td>
<td>3.00</td>
</tr>
<tr>
<td>70</td>
<td>10.5</td>
<td>5.25</td>
<td>3.50</td>
</tr>
<tr>
<td>80</td>
<td>12.0</td>
<td>6.00</td>
<td>4.00</td>
</tr>
<tr>
<td>90</td>
<td>13.5</td>
<td>6.75</td>
<td>4.50</td>
</tr>
<tr>
<td>100</td>
<td>15.0</td>
<td>7.50</td>
<td>5.00</td>
</tr>
<tr>
<td>200</td>
<td>30.0</td>
<td>15.0</td>
<td>10.00</td>
</tr>
<tr>
<td>400</td>
<td>60.0</td>
<td>30.0</td>
<td>20.00</td>
</tr>
<tr>
<td>600</td>
<td>90.0</td>
<td>45.0</td>
<td>30.00</td>
</tr>
<tr>
<td>800</td>
<td>120.0</td>
<td>60.0</td>
<td>40.00</td>
</tr>
<tr>
<td>1000</td>
<td>150.0</td>
<td>75.0</td>
<td>50.00</td>
</tr>
</tbody>
</table>

1. (Caution: these values assume a stock solution specific weight equal to water. If necessary, these numbers may be adjusted by multiplying by the ratio of the specific weight of the chemical solution to the specific weight of water.)

Table 4. The mass (lb) of active chemical contained per gallon of stock solution (Sm) for different combinations of specific weight and chemical concentration.

<table>
<thead>
<tr>
<th>Specific Weight (lb/gal)</th>
<th>4</th>
<th>8</th>
<th>Percent Concentration of the Active Chemical</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.0</td>
<td>0.32</td>
<td>0.64</td>
<td>0.96</td>
</tr>
<tr>
<td>8.5</td>
<td>0.34</td>
<td>0.68</td>
<td>1.02</td>
</tr>
<tr>
<td>9.0</td>
<td>0.36</td>
<td>0.72</td>
<td>1.08</td>
</tr>
<tr>
<td>9.5</td>
<td>0.38</td>
<td>0.76</td>
<td>1.14</td>
</tr>
<tr>
<td>10.0</td>
<td>0.40</td>
<td>0.80</td>
<td>1.20</td>
</tr>
<tr>
<td>10.5</td>
<td>0.42</td>
<td>0.84</td>
<td>1.26</td>
</tr>
<tr>
<td>11.0</td>
<td>0.44</td>
<td>0.88</td>
<td>1.32</td>
</tr>
<tr>
<td>11.5</td>
<td>0.46</td>
<td>0.92</td>
<td>1.38</td>
</tr>
</tbody>
</table>
Table 5: Required volume (gal) of chemical mixture to provide a desired level of an active chemical for different concentrations (lb/gal) of the chemical in the stock solution from Table 4.

<table>
<thead>
<tr>
<th>Mass of Chemical Desired (lb)</th>
<th>0.2</th>
<th>0.4</th>
<th>( S_m ) (gallons of stock solution)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.6</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>20</td>
<td>33</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>40</td>
<td>67</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>60</td>
<td>100</td>
<td>75</td>
<td>60</td>
</tr>
<tr>
<td>80</td>
<td>133</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>100</td>
<td>167</td>
<td>125</td>
<td>100</td>
</tr>
<tr>
<td>150</td>
<td>250</td>
<td>188</td>
<td>150</td>
</tr>
<tr>
<td>200</td>
<td>333</td>
<td>250</td>
<td>200</td>
</tr>
<tr>
<td>250</td>
<td>417</td>
<td>313</td>
<td>250</td>
</tr>
<tr>
<td>300</td>
<td>500</td>
<td>375</td>
<td>300</td>
</tr>
<tr>
<td>350</td>
<td>583</td>
<td>438</td>
<td>350</td>
</tr>
<tr>
<td>400</td>
<td>667</td>
<td>500</td>
<td>400</td>
</tr>
<tr>
<td>450</td>
<td>750</td>
<td>563</td>
<td>450</td>
</tr>
<tr>
<td>500</td>
<td>833</td>
<td>625</td>
<td>500</td>
</tr>
</tbody>
</table>
Fertigation Nutrient Sources and Application Considerations for Citrus

Brian Boman and Tom Obreza

Introduction

Fertigation is the application of liquid fertilizer through an irrigation system. Microirrigation and fertigation offer the potential for precise control of nutrients and water, which are the main grower-controlled inputs to plant growth. A major benefit of fertigation is that it provides greater flexibility and control of applied nutrients than conventional broadcast applications. Fertilizers are applied when needed and in small doses, so water-soluble nutrients are less subject to leaching by excess rainfall or over-irrigation.

Care must be exercised to avoid emitter plugging problems resulting from reactions of the fertilizer with the irrigation water. The fertilizer source must be water-soluble. Chemical reactions between fertilizer materials can result in the formation of precipitates, which can plug the irrigation system. The uniformity of the fertigation application depends on the uniformity of the water application. Therefore, high water application uniformity is very important for fertigation.

Nitrogen

Nitrogen (N) is the plant nutrient most often injected as fertilizer into microirrigation systems. One of the major benefits of small, frequent nitrogen applications is a potential reduction in leaching of nitrate into the groundwater. Only small amounts of N are applied at any one time, therefore excess nitrate is not present to be leached in the event of heavy rainfall. Nitrogen can be applied using a number of different compounds, but urea and ammonium nitrate are the most desirable sources because they have a low plugging risk. Anhydrous or aqua ammonia are not recommended for use in micro irrigation systems because they will increase the pH of the irrigation water. Consequently, calcium, magnesium, and phosphorus may precipitate in the line and increase the plugging potential. Ammonium sulfate and calcium nitrate can be dissolved in water, but they may also cause plugging problems. If calcium or magnesium levels are high in the irrigation water, ammonium phosphate may cause precipitates to form, which can plug emitters. Nitrogen can contribute to microbial growth if it is applied continuously and remains in the irrigation line after the system has been shut off.

Nitrogen movement in the soil depends on the type of nitrogen fertilizer. The ammonium cation is less mobile in the soil than nitrate. The depth of movement depends on the cation exchange capacity (CEC) of the soil, and the rate of fertilizer application. Application of ammonium fertilizer to the soil surface may result in loss to the atmosphere by ammonium volatilization, especially if soil pH is greater than 7. Most ammonium will be transformed biologically to nitrate within 2 to 3 weeks at soil temperatures in the 75° to 90°F range. Nitrate will move with the irrigation water to the wetted front. Thus, with subsequent irrigations,
Nitrates may be leached beyond the root zone or may be pushed to the periphery of the wetted soil volume and only part of the root zone will have access to it. Urea is very soluble in irrigation water, and it is not adsorbed by soil. Thus, it will move deeper below the soil surface than ammonium, but will not leach as easily as nitrate. A balance between ammonium and nitrate in the nitrogen fertilizer is usually recommended.

Some water sources (such as recycled wastewater) may contain a significant amount of nitrate. This nitrogen should be taken into account when determining tree fertilizer requirements. The nitrogen added to the crop due to nitrate in the irrigation source water can be determined by:

\[
N = C_n \times I_n \times D_i \quad \text{--- Eq. 1}
\]

Where:

- \(N\) = nitrogen (lbs/ac),
- \(C_n\) = a constant for unit conversion (0.226),
- \(I_n\) = NO\(_3\)-N concentration in the irrigation water (mg/L),
- \(D_i\) = depth of irrigation water applied (inches).

**Example**

Determine the nitrogen supplied by the irrigation water if 14 inches of water are applied annually and the NO\(_3\)-N concentration is 10 mg/L.

\[
N = 0.226 \times 10 \times 14 = 32 \text{ lbs N/acre}
\]

**Nitrogen Cycle**

Compounds containing nitrogen are of great importance in the life processes of all plants and animals. The chemistry of nitrogen is complex because of the numerous oxidation states that it can assume, and by the fact that changes in the oxidation state can be brought about by living organisms.

Because of environmental concerns, nitrate (NO\(_3\)) is of particular interest. It is very mobile and easily transported by water. In surface water systems, NO\(_3\) is a nutrient source and can contribute to the over-production of algae or other aquatic life, resulting in eutrophication of surface water bodies. Nitrate in ground water is of even greater concern since groundwater is the principal domestic water source in many areas. The EPA has established a drinking water maximum concentration level (MCL) of 10 mg/L as NO\(_3\)-N or 45 mg/L NO\(_3\). Nitrogen is a very complex nutrient, and it exists in the environment in many forms. It is continually transformed because of biological and chemical influences. Nitrogen can be divided into two categories:

1. **Organic N** contains carbon in the compound and exists in plant residues, animal waste, sewage sludge, septic effluent, and food processing waste.

2. **Inorganic N** contains no carbon in the compound and exists as ammonium (NH\(_4\)), nitrite (NO\(_2\)), nitrate (NO\(_3\)), and nitrogen gas (N\(_2\)).

Understanding the behavior of N in the soil is essential for good fertilizer management. Many N sources are available for use in supplying N to crops. In addition to inorganic (commercial) fertilizer N, organic N from animal manures and waste products are also a significant source of N. Nitrogen fixation by legume crops can also supply significant amounts of N.

Sources of NO\(_3\)\(_2\) are both man-made and natural. The principal man-made sources of nitrate are commercial fertilizer and septic and sewage systems. The ultimate source of N used by plants is N\(_2\) gas, which constitutes 78% of the earth's atmosphere. Nitrogen gas is converted to plant-available N by one of the following methods:

- Fixation by microorganisms that live symbiotically on the roots of legumes (also certain non-legumes).
- Fixation by free-living or non-symbiotic soil microorganisms.
- Fixation as oxides of N by atmospheric electrical discharges.
- Fixation by the manufacture of synthetic N fertilizer (Haber-Bosch process).

The virtually unlimited supply of nitrogen in the atmosphere is in dynamic equilibrium with the various fixed forms in the soil-plant-water system. The N cycle can be divided into N inputs and outputs (Fig. 1). Understanding this process can influence how nitrogen is managed to minimize its negative effects on the environment, while maximizing the beneficial value of N for plant growth.

Animals and higher plants are incapable of utilizing nitrogen directly from the atmosphere. The nitrogen cycle with inputs, outputs and cycling is complex. N in plant and animal residues and N derived from the atmosphere...
through electric, combustion, and industrial processes is added to the soil. N in these residues is mobilized as ammonium (NH₄⁺) by soil organisms as an end product of decomposition. Plant roots absorb a portion of the NH₄⁺, but much of the NH₄⁺ is converted to nitrate (NO₃⁻) by nitrifying bacteria in a process called nitrification. The NO₃⁻ is taken up by plant roots and is used to produce the protein in crops that are eaten by humans and fed to livestock. NO₃⁻ is lost to groundwater or surface water as a result of downward movement of percolated water through the soil. NO₃⁻ is also converted by denitrifying bacteria into N₂ and nitrogen oxides that escape into the atmosphere. The major processes of the nitrogen cycle (Fig. 1) are N-mineralization, nitrification, NO₃ mobility, de-nitrification, and volitilization.

N-mineralization

The conversion of organic N to NH₄⁺ is called mineralization. Mineralization occurs through the activity of heterotrophic microorganisms, which are organisms that require organic carbon compounds (organic matter) for their energy source. The NH₄⁺ produced by mineralization is subject to several fates:

- Converted to NO₃⁻ and then to NO₂⁻ by the process of nitrification.
- Absorbed directly by higher plants.
- Utilized by heterotrophic organisms to further decompose organic residues.
- Fixed in a biologically unavailable form in the lattices of certain clay minerals.
- Released to the atmosphere as N₂.

The quantity of N mineralized during the growing season can be estimated. Soil organic matter contains about 5% N by weight; during a single growing season, 1 to 4% of the organic N is mineralized to inorganic N.

Example

If a soil contained 3% organic matter (OM) in the top 6 inches and 2% mineralization occurred, calculate the N made available (lbs/acre). (Assume an acre of soil 6 inches deep weighs 2 million lbs).

2,000,000 lb x 3% OM x 2% mineralization x 5% N = 60 lbs/acre of N mineralized

N-immobilization

The conversion of inorganic N (NH₄⁺ and NO₃⁻) to organic N is termed immobilization, and is basically the reverse of N mineralization. If decomposing OM contains low N relative to C, the microorganisms will immobilize NH₄⁺ or NO₃⁻ in the soil. Since soil organisms need N in a C:N ratio of about 8:1 or less, they will utilize inorganic N. They are very effective at competing with plants for available N. Thus, N fertilizer is often applied to compensate for N immobilization. After the decomposition of the low residuals, the N in the microorganisms is mineralized back to NH₄⁺.

Nitrification

The biological conversion of NH₄⁺ to NO₃⁻ is called nitrification. This is a two-step process in which NH₄⁺ first changes to NO₂⁻, then to NO₃⁻. This process is performed by autotrophic bacteria that obtain their energy from the oxidation of N, and their C from CO₂. Nitrate leaching from field soil must be carefully controlled because of the serious impact that it can have on the environment. Since NO₃⁻ is very mobile and subject to leaching in the soil, understanding the factors that affect nitrification will provide insight into best management practices to minimize nitrate losses by leaching. Factors that affect nitrification in the soil are the following:
• Supply of NH₄⁺: If conditions do not favor mineralization of NH₄⁺ from organic matter, nitrification does not occur. (If organic residue with a high C:N ratio is plowed into the soil before planting, microorganisms will tie up available N while trying to decompose the residue).

• Population of nitrifying organisms: Soils differ in their ability to nitrify NH₄⁺, even under similar conditions of temperature, moisture, and level of added NH₄⁺. One factor that may be responsible for this is the variation in the number of nitrifying organisms present.

• Soil pH: Nitrification takes place over a wide range of pH (4.5 to 10) conditions, but the optimum is thought to be about 8.5. The nitrifying bacteria also need an adequate supply of Ca. Thus, liming of low pH soil helps nitrification influence by both driving the soil pH closer to optimum, and also providing more available Ca for the activity of the nitrifying organisms.

• Soil aeration: Aerobic nitrobacteria will not produce NO₃⁻ in the absence of O₂.

• Soil moisture: Nitrobacteria activity is sensitive to soil moisture. Nitrification is greatest under moist (but not saturated) soil conditions.

• Temperature: Nitrification increases between 40° F and 95° F activity decreases at temperatures over 95° F.

NO₃⁻ mobility

The nitrate anion is very soluble in water, so leaching is a major cause of N loss from soils in humid climates or under irrigated conditions. Under irrigated conditions, the factors that most affect nitrate leaching from irrigation are as follows:

• Timing of irrigation
• Duration of irrigation
• Uniformity of irrigation
• The amount of NO₃⁻ available for leaching.

Denitrification

Crop removal and leaching constitute the major N losses from the soil; however, under certain conditions inorganic N ions can be converted to gases and lost to the atmosphere. When soil becomes waterlogged, O₂ is excluded and anaerobic decomposition takes place. Some anaerobic organisms have the ability to obtain their O₂ from sulfate and nitrate, with the accompanying release of N₂ and N₂O. This is a common occurrence under Florida Flatwoods growing conditions.

Volatilization

Volatilization is the loss of N from the soil to the atmosphere. Ammonia volatilization can be significant, especially from calcareous (pH>7) soils under warm conditions.

Ammonium Process

The major source of nitrogen in synthetic fertilizers is ammonia, and it is produced by the Claude-Haber process. Purified nitrogen gas (N₂) reacts with hydrogen gas (H₂) at high temperature and pressure to form ammonia:

\[ N₂ + 3H₂ \xrightarrow{\text{heat/pressure}} 2NH₃ \]

Ammonia is the starting point from which nearly all other nitrogen fertilizers are made (Table 1). It contains 82% nitrogen and is the cheapest source of nitrogen compared to other nitrogen materials. It is used extensively in many areas of the U.S., either as anhydrous ammonia or aqua ammonia, accounting for nearly half of the total nitrogen fertilizer consumed. Ammonia is used in the U.S. primarily as a direct-application material. A direct-application material is a fertilizer material that is purchased as the pure material, rather than as a blend with other fertilizer materials in mixed fertilizers.

Losses of nitrogen from direct application of anhydrous ammonia to soils can be severe, particularly when applied to sandy soils. Application of anhydrous ammonia is not recommended for Florida citrus soils.

Urea and ammonium nitrate are mixed together with water and are often sold as a solution fertilizer containing up to 32% nitrogen. This material is quite stable and can be applied with relatively inexpensive, non-pressurized equipment. Nitrogen solutions are quite popular for direct applications to soil and are a major source of nitrogen for liquid fertilizer.

Nitrate-nitrogen (NO₃⁻-N) is very mobile in soil and will move freely in irrigation and rain water. Since water percolates through sandy soils quite rapidly, application of large quantities of nitrate-nitrogen may increase nitrogen losses because of potential leaching.
Ammonium-nitrogen (NH₄⁺-N) is adsorbed on cation exchange sites within the soil and is retained to some extent against leaching. However, it is rapidly converted to nitrate-nitrogen by soil microorganisms and, in this form, may be leached readily. Nitrate-nitrogen is also lost rapidly from flooded soils because, as soon as the oxygen in the soil is depleted, certain micro-organisms can immediately begin to utilize the oxygen present in nitrate-nitrogen. This process, called denitrification, converts nitrate-nitrogen back into nitrogen gas (N₂) which escapes to the atmosphere and is unavailable to plants. Recovery of fertilizer nitrogen by crops rarely exceeds 50% and often is less than 25%.

Other chemical processes can occur to cause nitrogen losses from soil. For example, ammonium sources of nitrogen should never be surface applied to soils recently limed or containing free calcium carbonate. In the alkaline pH environment surrounding the lime, ammonium will revert to ammonia gas and escape into the atmosphere:

\[
\text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3 + \text{H}_2\text{O}
\]

The application of urea directly to the soil surface should also be avoided. Urea is quickly broken down into ammonia and carbon dioxide by the enzyme urease, which is normally abundant in cultivated soils:

\[(\text{NH}_2\text{CO}) \rightarrow \text{urease} \rightarrow \text{NH}_3 + \text{CO}_2 + \text{H}_2\text{O}\]

It is always a good idea to mix urea thoroughly with the soil to minimize gaseous losses of nitrogen. All nitrogen fertilizers containing ammonium nitrogen leave an acid residue in soil as a result of the nitrification process:

\[2\text{NH}_4^+ + 4\text{O}_2 \rightarrow 2\text{NO}_3^- + 4\text{H}^+ + 2\text{H}_2\text{O}\]

The use of high rates of nitrogen on sandy soils low in calcium needs careful attention. These soils are poorly buffered against changes in pH caused by the acidity released during nitrification (Table 2). Florida has many soils in agricultural production that are sandy, low in organic matter (the principal component that aids in buffering) and containing less than 200 pounds of calcium per acre. These soils tend to be only mildly acid initially, but should be monitored carefully when large amounts of ammonium-nitrogen fertilizer are being applied.

Ammonium sulfate is by far the most acid-forming source of nitrogen. This is because all the nitrogen is present as ammonium-nitrogen. Ammonium nitrate requires much less lime per pound of nitrogen since only half of the nitrogen is present as ammonium. If ammonium sulfate is used instead of ammonium nitrate, more than twice as much lime is needed to neutralize the acidity produced. The initial reactions involving urea and anhydrous ammonia in soil are quite basic, which tends to neutralize, to some extent, the acidity produced during subsequent nitrification.

**Fertilizer Solubility**

Several dry fertilizer products (Table 3) used for making fertilizer solutions are marketed with or without a protective conditioner. Whenever possible, the “solution grade” form of these products should be purchased to avoid having to deal with the conditioners and the potential plugging problems they can cause. Most dry-solid fertilizers are manufactured by coating them (commonly clay, diatomaceous earth, or hydrated silica) to keep the moisture from being absorbed by the fertilizer pellets. To avoid having these materials create plugging problems, it is best to prepare a small amount of the mix to observe what happens to the coating. If the coating settles to the bottom of the container, the clear transparent liquid can be taken from the top portion without disturbing the bottom sediment. If a scum forms on the surface, conditioners may need to be added to facilitate the removal of the conditioner by skimming.

When urea, ammonium nitrate, calcium nitrate, and potassium nitrate are dissolved, heat is absorbed from the water and a very cold solution results. Consequently, it may not be possible to dissolve as much fertilizer as needed to achieve the desired concentration. It is often necessary to let the mixture stand for several hours and warm to a temperature that will allow all the mixture to dissolve.

Before injecting fertilizer solutions, a “jar test” should be conducted to determine clogging potential of the solution. Some of the fertilizer solution should be mixed with irrigation water in a jar to determine if any precipitate or milkiness occurs within one to two hours. If cloudiness does occur, there is a chance that injection of the chemical will cause line or emitter plugging. If different fertilizer solutions are to be injected simultaneously into the irrigation system, they all should be mixed in the jar. The jar test should be conducted at about the same dilution rate that is used in the irrigation system.

**Nitrogen**

Urea, ammonium nitrate, calcium nitrate, potassium nitrate, and ammonium sulfate are very soluble in water. These nitrogen fertilizer materials are readily available on
the market, and are used extensively in the preparation of single nutrient or multi-nutrient fertilizer solutions.

**Phosphorus**

Commercial fertilizers contain the guaranteed percentage of $P_2O_5$ on the label as water soluble and citrate soluble phosphate. Phosphorus is not very mobile in many soils and is much less likely to be lost when applied conventionally than nitrogen. Plants generally need phosphorus early in their life cycle, so it is important that this element, if deficient in the soil, be applied at or before planting. If the plant shows phosphorus deficiency symptoms during the growing season, injection of phosphorus into the irrigation water allows for later stage correction.

Phosphorus fertilizer injection may cause emitter plugging. Solid precipitation in the line occurs most often due to interaction between the fertilizer and the irrigation water. Most dry phosphorus fertilizers (including ammonium phosphate and superphosphates) cannot be injected into irrigation water because they have low solubility. Monoammonium phosphate (MAP), diammonium phosphate (DAP), monobasic potassium phosphate, phosphoric acid, urea phosphate, liquid ammonium polyphosphate, and long chain linear polyphosphates are water soluble. However, they can still have precipitation problems when injected into water with high calcium concentration. Problems occur when the polyphosphate injection rates are too low to offset the buffering effects of the calcium and magnesium concentrations in the irrigation water.

The application of ammonium polyphosphate fertilizers to water that is high in calcium will always result in the formation of precipitants, which can plug the emitters. These precipitants are very stable and not easily dissolved. Phosphorus and calcium, when in solution together, may form di- and tri-calcium phosphates, which are relatively insoluble compounds. Similarly, phosphorus and magnesium can form magnesium phosphates, which are also insoluble and plug emitters. Of considerable concern in south Florida is the formation of iron phosphates, which are very stable. Given the high levels of calcium, iron, and bicarbonate in Florida irrigation water, phosphorus should not be injected unless significant precautions are taken.

Phosphoric acid is sometimes injected into micro irrigation systems. It not only provides phosphorus, but also lowers the pH of the water, which can prevent the precipitation problems previously mentioned. This practice will be effective as long as the pH of the fertilizer-irrigation water mixture remains low. As the pH rises due to dilution, phosphates precipitate. One approach that is sometimes successful is to supplement the phosphoric acid injections with sulfuric or urea sulfuric acid to assure that the irrigation water pH will remain low (pH < 4.0). Continuous use of phosphoric acid at levels in excess of 25 mg/L, however, can produce zinc deficiencies in some crops. Phosphoric acid injection should be used only when the combined Ca and Mg concentration of the water is below 50 ppm and the bicarbonate level is less than 150 ppm.

**Potassium**

Potassium fertilizers are all water soluble, and injection of K through micro irrigation systems has been very successful. The problem most often associated with potassium injection is solid precipitants that form in the mixing tank when potassium is mixed with other fertilizers. The potassium sources most often used in micro irrigation systems are potassium chloride (KCl) and potassium nitrate (KNO$_3$). Potassium phosphates should not be injected into micro irrigation systems. Potassium sulfate is not very soluble and may not dissolve in the irrigation water. Potassium thiosulfate (KTS) is compatible with urea and ammonium polyphosphate solutions; however, it should not be mixed with acids or acidified fertilizers. When KTS is blended with urea ammonium nitrate solutions, a jar test is recommended before mixing large quantities. Under certain mixing proportions, particularly when an insufficient amount of water is used in the mix, potassium in KTS can combine with nitrates in the mix to form potassium nitrate crystals. If this happens, adding more water and/or heating the solution should bring the crystals back into solution.

**Calcium**

Fertilizers containing calcium should be flushed from all tanks, pumps, filters, and tubing prior to injecting any phosphorus, urea-ammonium nitrate, or urea sulfuric fertilizer. The irrigation lines must be flushed to remove all incompatible fertilizer products before a calcium containing fertilizer solution is injected. Calcium should not be injected with any sulfate form of fertilizer. It combines to create insoluble gypsum.

**Micronutrients**

Several metal micronutrient forms are relatively insoluble and therefore, not used for fertigation purposes. These include the carbonate, oxide, or hydroxide forms of zinc, manganese, copper, and iron. These relatively inexpensive materials can be broadcast and incorporated into the soil. However, they constitute a long term source of
micronutrients and will supply only a low level of nutrients for many years.

The sulfate form of copper, iron, manganese, and zinc is the most common and usually the least expensive source of micronutrients. These metal sulfates are water soluble and are easily injected. However, using these materials for fertigation is not very successful in alleviating a micronutrient deficiency, since the metal ion has a strong electrical charge (2+) and becomes attracted to the cation exchange sites of clay and organic matter particles, where it tends to sit near the soil surface. Consequently, the micronutrient usually does not reach the major plant root zone. If the soil pH is high, manganese, iron, and copper are changed into unavailable forms, and little or no benefit will be obtained from their use. If the metal sulfate solutions are acidified, however, the availability of the micronutrient can be prolonged in the soil.

Common Fertigation Materials

Ammonium Nitrate Solution (20-0-0)

$\text{NH}_4\text{NO}_3 \cdot \text{H}_2\text{O}$ is ammonium nitrate fertilizer dissolved in water with a density of 10.5 pounds per gallon. It is the most widely used nitrogen source used for Florida citrus.

Urea-ammonium Nitrate Solution (32-0-0)

$(\text{NH}_2)_2\text{CO} \cdot \text{NH}_4\text{NO}_3$: Urea-ammonium nitrate solution is manufactured by combining urea (46% N) and ammonium nitrate (35% N) on an equal nitrogen content basis. The combination of urea and ammonium nitrate contains the highest concentration of nitrogen of all the nitrogen solution products. When urea-ammonium nitrate solutions are combined with calcium nitrate, a thick, milky-white insoluble precipitate forms, presenting a serious potential plugging problem.

Calcium Nitrate (15.5-0-0-19 Ca)

$5\text{Ca(NO}_3)_2 \cdot \text{NH}_4\text{NO}_3 \cdot 10\text{H}_2\text{O}$: This fertilizer is high in nitrate-nitrogen (14.5%) with 1% ammonium-nitrogen, and supplies calcium. The product can be combined with ammonium nitrate, magnesium nitrate, potassium nitrate, and muriate of potash. It should not be combined with any products containing phosphates, sulfates or thiosulfates.

Ammonium Thiosulfate (12-0-0-26)

$(\text{NH}_4)_2\text{S}_2\text{O}_3$ is used as both a fertilizer and as an acidulating agent. When applied to the soil, Thiobacillus bacteria oxidize the free sulfur to sulfuric acid. The acid then dissolves lime in the soil and forms gypsum. The gypsum helps to maintain a good, well granulated, aerated, and porous soil structure. Ammonium thiosulfate is ideal for treatment of calcareous (high lime) soils. It is compatible with neutral or alkaline phosphate liquid fertilizers and nitrogen fertilizers. Ammonium thiosulfate can be applied in liquid mixes or by itself.

Ammonium thiosulfate should not be mixed with acidic compounds because it will decompose into elemental sulfur and ammonium sulfate at pH < 6. Application to neutral and acidic soils (without free lime) may result in a pronounced drop in soil pH over several weeks. The extent of the pH drop in these types of soils depends upon the total amount of this fertilizer applied, the cation exchange capacity of the soil, and the buffering capacity of the soil. The higher the clay content and the higher the lime content of the soil (i.e., the larger the buffering capacity), the slower the pH will drop with the same fertilizer application.

Phosphoric Acid (0-54-0)

$\text{H}_3\text{PO}_4$ has a density of approximately 14.1 pounds per gallon. The acid is a syrupy liquid that requires storage in stainless steel (No. 316) tanks. Phosphoric acid can be used in many formulations of nitrogen, phosphorus, and potassium mixes. Phosphoric acid should never be mixed with any calcium fertilizer. It will form insoluble calcium phosphate, which can plug irrigation lines.

Potassium Chloride (0-0-62)

Potassium chloride (KCl) is generally the least expensive source of potassium and is the most popular K fertilizer applied through fertigation. It may not be desirable for use on citrus if irrigation water contains high salinity levels.

Potassium Nitrate (13-0-46)

Potassium nitrate is expensive, but the consumer benefits from both the nitrogen and the potassium in the product. It is an excellent choice of potassium fertilizer for areas where irrigation water salinity problems are present. It is less soluble than potassium chloride, but more soluble than potassium sulfate.

Potassium Sulfate (0-0-52)

$\text{K}_2\text{SO}_4$ can be an alternative to KCl in high salinity areas and provides a source of sulfur. It is fairly popular for fertigation. It is less soluble than potassium chloride and potassium nitrate.
Potassium Thiosulfate (0.0-25-17 and 0.0-22-23)

K$_2$S$_2$O$_3$ (KTS) is marketed in two grades and is a neutral to basic, chloride-free, clear liquid solution. This product can be blended with other fertilizers, but KTS blends should not be acidified below pH 6.0. The proper mixing sequence for KTS is water, pesticide, KTS, and/or other fertilizer. Always perform a jar test before injecting blends. Potassium thiosulfate provides not only potassium, but the thiosulfate is oxidized by *Thiobacillus* bacteria to produce sulfurous acid. This acid reacts with calcium carbonate in the soil, which releases additional calcium for the plant. Thus, potassium thiosulfate use on calcareous soils not only supplies potassium and sulfur, but aids in increasing the availability of calcium to plants.

**Sulfuric Acid**

H$_2$SO$_4$ is not a fertilizer, and thus has a grade of 0-0-0. It has a density of approximately 15.3 pounds per gallon when concentrated. Sulfuric acid is a clear liquid when pure; however, much of the agricultural material may have a brown to black color. It has no odor and pours as an oily liquid. It is injected into high bicarbonate water to control the pH by reducing it to about pH 6.5 to 7.0. It is sometimes injected directly into calcareous soils (high lime) where the reaction produces gypsum. Sulfuric acid should not be injected with calcium fertilizers since calcium sulfate (gypsum) will form and create a creamy suspension very much like cottage cheese, which can easily plug the lines. OSHA requirements for safe handling preclude fertilizer dealers from storing sulfuric acid on the premises; therefore, it is difficult to find a source of sulfuric acid.

Sulfuric acid is extremely corrosive and must be handled with proper equipment and clothing. Never combine urea and sulfuric acid in the field.

**Urea Solid (46-0-0) and Urea Solution (23-0-0)**

Urea is sold as 46-0-0 dry fertilizer or as a liquid 23-0-0 urea solution. Commercial urea contains about 2.25% biuret, a byproduct that forms only during the manufacturing process. It can inhibit plant growth or damage plants. Urea with less than 0.25% biuret content should be used for foliar applications. Urea should never be mixed with sulfuric acid.

**Urea Sulfuric Acid**

Urea sulfuric acid (CO(NH$_2$)$_2$·H$_2$SO$_4$) is an acidic fertilizer that combines urea and sulfuric acid. By combining the two materials into one product, many disadvantages of using these materials individually are eliminated. The sulfuric acid decreases the potential ammonia volatilization losses from the soil surface and ammonia damage in the root zone that can occur with the use of urea alone. Urea sulfuric acid is safer to use than sulfuric acid alone. Urea sulfuric acid is well suited for fertigation and can be used for other purposes such as to acidify the irrigation water (reducing plugging potential from carbonates and bicarbonates); maintenance injections to keep lines and emitters clear of calcium carbonate deposits; to clean irrigation lines once they have been plugged; and to acidify the soil.

**Corrosion**

Fertilizers and other injected chemicals can be corrosive to irrigation equipment. Table 4 lists the relative corrosion of six metals immersed in eight different fertilizer solutions for four days. Higher ratings mean greater damage to the material. Note that severe damage resulted to galvanized iron from ammonium nitrate and phosphoric acid solutions. A general materials acid compatibility chart for materials commonly used in irrigation systems is presented in Table 5.

**Injection Time**

To determine the time required to fertigate and flush the system, the time for water to travel from the injection point to the farthest emitter must be known. The travel time for a chemical that is water soluble can be estimated by the average velocity of the irrigation water. The travel time from the injection point to the last emitter can be calculated by summing the travel times for each pipe segment. For a pipe segment, travel time can be determined as follows:

$$T = \frac{D}{V} \quad \text{Eq. 3}$$

Where:

- **T** = time of travel (minutes)
- **D** = distance or length of pipe (ft)
- **V** = velocity (ft/min)

**Example:** Determine the travel time from the injection point to the manifold based on average velocity, given a 6-inch (0.5 ft) ID 1,000 ft pipe with a flow rate (Q) of 500 gpm.

$$X/C\text{ area } = 3.14 \times \frac{d^2}{4} = 3.14 \times 0.5 \ ft^2/4 = 0.2 \ ft^2$$

$$\frac{500 \ gpm}{7.48 \ gal/ft^3} = 66.8 \ ft^3/min$$
\[ V = \frac{Q}{A} = \frac{66.8 \text{ ft}^3/\text{min}}{0.2 \text{ ft}^2} = 334 \text{ ft/min} \]

\[ T = \frac{D}{V} = \frac{1000 \text{ ft}}{344 \text{ ft/min}} = 2.9 \text{ min.} \]

The travel time for a lateral of uniform diameter with evenly spaced emitters that have equal discharge rates can be estimated as follows:

\[ T = t \left(0.577 + \ln(N)\right) \quad \text{Eq. 4} \]

Where:

- \( T \) = travel time for entire lateral (minutes)
- \( t \) = travel time between the last two emitters (minutes)
- \( N \) = total number of emitters on the lateral
- \( \ln \) = natural logarithm

The value of \( t \) is determined by:

\[ t = \frac{A \times S}{q} \quad \text{Eq. 5} \]

Where:

- \( A \) = cross-sectional area of the pipe (\( \text{ft}^2 \))
- \( S \) = emitter spacing (\( \text{ft} \))
- \( q \) = emitter discharge (\( \text{ft}^3/\text{min} \))

**Example:**

Determine the travel time based on average velocity for:

- Emitter flow = 0.21 gph, lateral diameter = 0.632 inches, emitter spacing = 1 foot, and lateral length = 250 ft.

\[ A = 0.00218 \text{ ft}^2 \]

\[ S = 1 \text{ ft} \]

\[ q = 0.000468 \text{ ft}^3/\text{min} \]

\[ t = \frac{AS}{q} = \frac{0.00218 \text{ ft}^2 \times 1 \text{ ft}}{0.000468 \text{ ft}^3/\text{min}} = 4.66 \text{ minutes} \]

\[ T = 4.66 \left[0.577 + \ln(250)\right] = 28 \text{ minutes} \]

The above procedure can be applied to the submain if it has equally-spaced lateral outlets. However, the manifold is often tapered (non-uniform diameter) and in that case a step-by-step analysis must be performed. Total travel time is the sum of the all the segment travel times for the entire pipe system from the injection point to the last emitter, which would typically include the mainline, submain, manifold, and lateral line.

Travel time calculations are based on average velocity of water in the pipeline. Actually, velocity is higher at the center of the pipe than near the pipe wall. So to insure complete flushing, the flush time should be twice the calculated travel time.

For an existing irrigation system, chemical travel time can be easily measured in the field by injecting a dye, acid, or fertilizer salt. If a fertilizer is used, a simple electrical conductivity (EC) meter can detect when the fertilizer has arrived at the farthest outlet of the irrigation system. Sampling should be continuous until the chemical arrives, which will be indicated by an increase in the EC of the water. Similarly, a pH meter (or pH strips) may be used if the injected material is an acid.

**Calibration of Fertilizer Injectors**

Only water-soluble fertilizers or fertilizer suspensions that are compatible with the irrigation and crop production systems should be injected. Because they are potentially corrosive, fertilizers should be flushed from the irrigation system after each application. Fertilizer solutions should always be injected before (upstream of) the filters in microirrigation systems. The compatibility of fertilizer solutions with the irrigation water and with any other chemicals being injected should be tested to avoid the formation of chemical precipitates in the irrigation system.

Care must be taken to ensure that injected materials do not react with dissolved solids in the irrigation water in such a way as to form precipitates or deposits in the irrigation system. The chemicals must be soluble and remain in solution throughout the operating conditions of the irrigation system. The fertilizers selected to be injected into the irrigation water need to be entirely soluble in water, and should not react with salts or chemicals in the water. Most nitrogen sources cause few clogging problems. The exceptions are anhydrous ammonia, aqua ammonia, and ammonium phosphate, which increase the pH of the water and cause precipitates with calcium and magnesium to form. Application of most forms of phosphorous through the system can result in extensive clogging. However, phosphoric acid can be safely injected in most waters since it acidifies the solution to a point where precipitation is prevented. All of the common potassium fertilizers are readily soluble and present no clogging problems.
Fertilizers can be highly corrosive, and are a potential health hazard to skin and eyes. Therefore, all system components including pumps, injection devices, lines, filters, and tanks should be inspected prior to use. There should be a routine monitoring program of the fertigation process with particular emphasis on the start-up and shut-down periods. Injection rates and times should be calibrated and re-checked frequently to ensure proper operation of the system. Leaks, runoff, excess applications, and application to areas with open water should be prevented. All system components should be flushed with clean water following each use.

When injecting fertilizers, the salinity of the irrigation water with the fertilizer in it should be checked. Heavy dosages of fertilizers can cause leaf burn, even if relatively low salinity water is used. It is generally preferable to inject small dosages of fertilizer frequently rather than make fewer applications at a high rate.

It is essential that proper and legal backflow prevention devices be used in the irrigation system to prevent fertilizers from being back-siphoned into the water supply. The injection device itself should have a screen and check valve. It is recommended that injection take place upstream of filters, so that any contaminants or precipitates can be filtered out.

Fertigation rates and times should be calibrated for each area that is fertigated. Flushing time needs to be at least as long as the travel time in the system from the injection point to the farthest emitter. In many microirrigation systems, this time is often 20-30 minutes. Fertilizer injections need to be at least this amount of time, and flush times need to exceed this travel time so that nutrients will not remain in the lateral tubing and promote algal growth.

Table 1. Synthetic nitrogen fertilizer materials that are derived from ammonia.

| Reaction | Material | Commercial Grade
|-----------|----------|---------------------|
| \(\text{NH}_3 + 2\text{O}_2 \rightarrow \text{HNO}_3 + \text{H}_2\text{O}\) | nitric acid | N-P-O-K
| \(\text{NH}_3 + \text{HNO}_3 \rightarrow \text{NH}_4\text{NO}_3\) | ammonium nitrate | 33.5-0-0
| \(2\text{NH}_3 + \text{H}_2\text{SO}_4 \rightarrow (\text{NH}_4)\text{SO}_4\) | ammonium sulfate | 20.5-0-0
| \(\text{NH}_4\text{H}_2\text{PO}_4 \rightarrow \text{NH}_4\text{H}_2\text{PO}_4\) | monoammonium phosphate | 11-48-0
| \(\text{NH}_4\text{H}_2\text{PO}_4 \rightarrow (\text{NH}_4)\text{HPO}_4\) | diammonium phosphate | 18-46-0
| \(2\text{NH}_3 + \text{CO}_2 \rightarrow (\text{NH}_4)\text{CO} + \text{H}_2\text{O}\) | urea | 45-0-0

Table 2. Pounds of lime required to neutralize the acidity produced by one pound of nitrogen when applied as a particular fertilizer.

<table>
<thead>
<tr>
<th>Material</th>
<th>N (%)</th>
<th>Lb of lime per lb N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium sulfate</td>
<td>20.5</td>
<td>5.35</td>
</tr>
<tr>
<td>Urea</td>
<td>45</td>
<td>1.8</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>33.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Anhydrous ammonia</td>
<td>82</td>
<td>1.8</td>
</tr>
<tr>
<td>Nitrogen solutions</td>
<td>21-32</td>
<td>1.08</td>
</tr>
</tbody>
</table>
Table 3. Solubility rates for various fertilizer materials used to prepare fertigation solutions.

<table>
<thead>
<tr>
<th>Material</th>
<th>Grade</th>
<th>Form</th>
<th>Temp (°F)</th>
<th>Solubility (gm/100mL)</th>
<th>Solubility (Lbs./gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen Fertilizers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium Nitrate</td>
<td>34-0-0</td>
<td>NH₄NO₃</td>
<td>32</td>
<td>18.3</td>
<td>9.87</td>
</tr>
<tr>
<td>Ammonium Polysulfide</td>
<td>20-0-0</td>
<td>NH₄S₄</td>
<td></td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Ammonium Sulfate</td>
<td>21-0-0</td>
<td>(NH₄)₂SO₄</td>
<td>32</td>
<td>70.6</td>
<td>5.89</td>
</tr>
<tr>
<td>Ammonium Thiosulfate</td>
<td>12-0-0</td>
<td>(NH₄)₂S₃O₄</td>
<td></td>
<td>v. high</td>
<td>v. high</td>
</tr>
<tr>
<td>Calcium Nitrate</td>
<td>15.5-0-0</td>
<td>Ca(NO₃)₂</td>
<td>62</td>
<td>121.2</td>
<td>10.11</td>
</tr>
<tr>
<td>Urea</td>
<td>46-0-0</td>
<td>CO(NH₂)₂</td>
<td></td>
<td>100</td>
<td>8.34</td>
</tr>
<tr>
<td>Urea Sulfuric Acid</td>
<td>28-0-0</td>
<td>CO(NH₂)₂ ⋅ 9H₂SO₄</td>
<td></td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Urea Ammonium Nitrate</td>
<td>32-0-0</td>
<td>CO(NH₂)₂ ⋅ NH₄NO₃</td>
<td></td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Phosphate Fertilizers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium Phosphate</td>
<td>8-24-00</td>
<td>NH₄H₂PO₄</td>
<td></td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td>Ammonium Polyphosphate</td>
<td>10-34-0</td>
<td>(NH₄)₃PO₄ &amp; others</td>
<td></td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Ammonium Polyphosphate</td>
<td>16-37-0</td>
<td>(NH₄)₃PO₄ &amp; others</td>
<td></td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Phosphoric Acid, green</td>
<td>0-52-0</td>
<td>H₃PO₄</td>
<td></td>
<td>45.7</td>
<td>high</td>
</tr>
<tr>
<td>Phosphoric Acid, white</td>
<td>0-54-0</td>
<td>H₃PO₄</td>
<td></td>
<td>45.7</td>
<td>high</td>
</tr>
<tr>
<td>Potash Fertilizers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium Chloride</td>
<td>0-0-60</td>
<td>KCl</td>
<td>68</td>
<td>34.7</td>
<td>2.89</td>
</tr>
<tr>
<td>Potassium Nitrate</td>
<td>13-0-44</td>
<td>KNO₃</td>
<td>32</td>
<td>13.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Potassium Sulfate</td>
<td>0-0-50</td>
<td>K₂SO₄</td>
<td>77</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Potassium Thiosulfate</td>
<td>0-0-25-175</td>
<td>K₂S₂O₇</td>
<td></td>
<td>150</td>
<td>12.5</td>
</tr>
<tr>
<td>Monopotassium Sulfate</td>
<td>0-52-34</td>
<td>K₂PO₄</td>
<td></td>
<td>33</td>
<td>2.75</td>
</tr>
<tr>
<td>Micronutrients</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Borax</td>
<td>11% B</td>
<td>NB₂O₄</td>
<td>32</td>
<td>2.1</td>
<td>0.17</td>
</tr>
<tr>
<td>Boric Acid</td>
<td>17.5% B</td>
<td>H₃BO₃</td>
<td>86</td>
<td>6.35</td>
<td>0.53</td>
</tr>
<tr>
<td>Solubor</td>
<td>20% B</td>
<td>Na₃BO₃</td>
<td>86</td>
<td>22</td>
<td>1.84</td>
</tr>
<tr>
<td>Copper Sulfate (acidified)</td>
<td>25% Cu</td>
<td>CuSO₄</td>
<td>32</td>
<td>31.6</td>
<td>2.63</td>
</tr>
<tr>
<td>Cupric Chloride (acidified)</td>
<td></td>
<td>CuCl₂</td>
<td>32</td>
<td>71</td>
<td>5.93</td>
</tr>
<tr>
<td>Gypsum</td>
<td>23% Ca</td>
<td>CaSO₄</td>
<td></td>
<td>0.241</td>
<td>6.65</td>
</tr>
<tr>
<td>Iron Sulfate (acidified)</td>
<td>20% Fe</td>
<td>FeSO₄</td>
<td></td>
<td>15.65</td>
<td>1.31</td>
</tr>
<tr>
<td>Magnesium Sulfate</td>
<td>9.67% Mg</td>
<td>MgSO₄ ⋅ 7H₂O</td>
<td>68</td>
<td>71</td>
<td>5.93</td>
</tr>
<tr>
<td>Manganese Sulfate (acidified)</td>
<td>27% Mn</td>
<td>MnSO₄ ⋅ 4H₂O</td>
<td>32</td>
<td>105.3</td>
<td>8.79</td>
</tr>
<tr>
<td>Ammonium Molybdate</td>
<td>54% Mo</td>
<td>(NH₄)₆Mo₃O₁₀ ⋅ 4H₂O</td>
<td>44.3</td>
<td>43</td>
<td>3.59</td>
</tr>
<tr>
<td>Sodium Molybdate</td>
<td>39% Mo</td>
<td>Na₂MoO₄</td>
<td></td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Zinc Sulfate</td>
<td>36% Zn</td>
<td>ZnSO₄ ⋅ 7H₂O</td>
<td>68</td>
<td>96.5</td>
<td>8.05</td>
</tr>
<tr>
<td>Copper Chelate</td>
<td>5 - 14% Cu</td>
<td>DTPA &amp; EDTA</td>
<td></td>
<td>v. Sol.</td>
<td>v. Sol.</td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>95%</td>
<td>H₂SO₄</td>
<td></td>
<td>V. high</td>
<td>v. high</td>
</tr>
</tbody>
</table>
Table 4. Relative corrosion of various metals (adapted from Martin, 1953). Solutions made by dissolving 100 lbs. of material in 100 gallons of water - metals immersed for 4 days. Ratings: 0=none, 1=slight, 2=moderate, 3=considerable, 4=severe.

<table>
<thead>
<tr>
<th>Kind of Metal</th>
<th>Calcium Nitrate</th>
<th>Sodium Nitrate</th>
<th>Ammonium Nitrate - 20</th>
<th>Ammonium Sulfate</th>
<th>Urea</th>
<th>Phosphoric Acid</th>
<th>Diammonium Phosphate</th>
<th>17-0-17 mix (NH₄)₂SO₄ + DAP + K₂SO₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galvanized Iron Sheet</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Phospho-Bronze</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Yellow Brass</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Solution pH</td>
<td>5.6</td>
<td>8.6</td>
<td>5.9</td>
<td>5.0</td>
<td>7.6</td>
<td>0.4</td>
<td>8.0</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Observations:
Ammonium nitrate, phosphoric acid, and ammonium sulfate very corrosive. Brass and bronze are corroded by phosphate, especially if ammonium is present. Copper is very corrosive to aluminum even in small doses. 316 grade stainless is corrosion resistant, other grades of stainless may be corrode.

---

Table 5. General acid compatibility of component materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Occasional</th>
<th>Continual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buna-N</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Ceramic/Graphite</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>EPDM</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Hypalon</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Leather</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Neoprene</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Teflon</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Viton</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>PVC</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Brass</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>303 stainless</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>316 stainless</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Galvanized</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
How to Reduce Clogging Problems in Fertigation

Guodong Liu and Gene McAvoy

Introduction

Fertigation is the process of applying fertilizers through an irrigation system, such as a drip, sprinkler, or pivot system, by injecting selected fertilizers into the water. Because of its effectiveness and efficiency, fertigation is widely used in vegetable and fruit production. However, clogging of lines and emitters may become a problem (Figures 1 and 2) if not managed appropriately. The purpose of this publication is to provide practical suggestions for fruit and vegetable growers to better manage fertigation and reduce clogging problems.

![Image of scale-like deposits in a drop irrigation system for organic bell pepper production](http://edis.ifas.ufl.edu/hs1202)

Figure 1. Scale-like deposits in a drop irrigation system for organic bell pepper production

Credit: Guodong Liu

[Click thumbnail to enlarge.]

![Image of scale-like deposits in a microirrigation system for peach production](http://edis.ifas.ufl.edu/hs1202)

Figure 2. Scale-like deposits in a microirrigation system for peach production

Credit: Guodong Liu

[Click thumbnail to enlarge.]

Why does clogging occur?

Since fertigation is a combination of irrigation and fertilization, clogging problems can be traced back to either the water supply or injected fertilizers.

Water
The primary reason for clogging associated with water is poor water quality. Water quality includes the physical, chemical, and biological qualities of irrigation water. Please refer to Causes and Prevention of Emitter Plugging in Microirrigation Systems (http://edis.ifas.ufl.edu/AE032) for additional information.

**Physical:** The irrigation water could have too many suspended solids, such as debris and tiny clay particles, which can plug irrigation lines and emitters. When suspended solids exceed 50 parts per million (ppm) in the irrigation water, clogging problems are likely. The clogging problem will be severe if suspended solids are in excess of 100 ppm (Table 1). Please refer to Irrigation and Household Water Test and Interpretation (http://edis.ifas.ufl.edu/SS440) for more information.

**Chemical:** Chemical problems include high pH and high concentrations of cations and/or anions in the irrigation water. In the presence of high pH (pH greater than 5.3 [Obreza, Hanlon, and Zekri 2011]) and oxygen within the water, the ferrous iron species is vulnerable to oxidation and creates a ferric iron precipitate. This oxidation not only reduces the bioavailability of iron applied through fertigation but also creates clogging problems. Generally speaking, when the water’s pH is greater than 5.3, the ferrous iron species can be oxidized. Studies indicate that approximately 50% of the ferrous iron species can be oxidized to ferric iron at pH 6.3 in 20 minutes (Morgan and Lahov 2007). The higher the pH, the more serious the clogging problem if the irrigation water has a total iron concentration greater than 0.2 ppm (Table 1). Irrigation with “hard” water, which is high in minerals such as calcium and magnesium, can also cause clogging problems because the calcium and magnesium ions are susceptible to precipitation with carbonates and phosphates. Please refer to Water Quality Note: Alkalinity and Hardness (http://edis.ifas.ufl.edu/SS540) for more information.

**Biological:** Bacterial growth can cause clogging problems when the bacterial population is greater than 2600 colony-forming units (CFU) per gallon. When the number exceeds 13200 CFU per gallon, bacteria in the water may cause severe clogging problems (Table 1). Water sources rich in nutrients have greater potential to support the growth of bacteria and clog irrigation systems. The bacteria oxidize iron and manganese and initiate the slime-like growth of biofilms, which can clog the system. Iron and manganese oxides can also form without bacteria, but when bacteria are present, bacterial formation of the oxides dominates (Burt, O'Connor, and Ruehr 1995). Finally, the presence of algae in surface water supplies can also clog fertigation systems, as can root intrusion into buried drip emitters.

**Fertilizer**

The effect of different fertilizers on clogging is statistically significant (Bozkurt and Ozekici 2006). Some fertilizers can also cause clogging problems if they are incompatible with fertigation. Chemical reactions may occur after the fertilizers are injected into the irrigation system. Additional problems can occur with regard to the temperature of the mixing water, the coagulation and secondary chemical reactions in the mixing tank, or failure to keep suspensions for a number of reasons, as shown below.

**Fertilizer incompatibility:** For example, calcium nitrate and diammonium phosphate are commonly used for commercial crop production, but these two fertilizers are NOT compatible. If these fertilizers are mixed together, calcium from calcium nitrate and phosphate from diammonium phosphate can form calcium phosphate, which is insoluble and precipitates out, clogging lines and emitters during fertigation.

**Chemical reactions:** There may be additional chemical reactions after the selected fertilizers are injected into irrigation water. These reactions include hydrolysis, dissociation, oxidation, and precipitation. The first two types of reactions can accelerate the second two types of reactions. These chemical reactions can all cause clogging.

**Hydrolysis:** When urea is injected into the irrigation water, the following hydrolytic reaction occurs. This reaction produces ammonia and carbon dioxide, as the following urease-activated enzymatic equation shows:

\[(\text{NH}_2\text{CO}) \text{ + H}_2\text{O} \xrightarrow{\text{enzyme}} 2\text{NH}_3\text{+ CO}_2\]

**Dissociation:** After the above hydrolysis of urea, the two products, ammonia and carbon dioxide, dissociate in water immediately, as shown below:

\[\text{CO}_2\text{ + H}_2\text{O} \xrightarrow{\text{dissociation}} \text{HCO}_3^- + \text{H}^+\]

Carbon dioxide is a very weak acidic gas. After carbon dioxide is dissociated, the acidity of the irrigation water can be lowered a little bit to pH 6.4. However, as compared with the acidity of carbon dioxide, the alkalinity of ammonia is approximately a hundredfold stronger. Accordingly, the dissociation of ammonia generates hydroxide and raises the pH to 9.3. Particularly, ammonia in urea is stoichiometrically twice the concentration of that of carbon dioxide. Thus, as a net result of urea dissolved in water, the resulting pH can be greater than 9.0.

\[\text{NH}_3\text{ + H}_2\text{O} \xrightarrow{\text{dissociation}} \text{NH}_4^+ + \text{OH}^-\]
Urea has the potential to generate a considerable amount of hydroxide ions, hence increasing water pH. This hydroxide formation can accelerate oxidation of micronutrients, such as iron and manganese. Iron and manganese oxides may form accordingly. Ferric and manganese oxides/hydroxides are insoluble in water. In addition, the bicarbonate ions from the hydrolysis may react to form calcium carbonate and magnesium carbonate because there is a dynamic equilibrium between bicarbonate and carbonate. The concentration of carbonate increases with bicarbonate concentration for the same reason. These carbonates can contribute to slime-like deposits inside irrigation lines and emitters.

Potassium thiosulfate (K₂S₂O₃) and potassium polysulfide (KS₂) are liquid fertilizers frequently used in fertigation. Potassium thiosulfate is 0-0-25-17S and potassium polysulfide 0-0-22-23S. These numbers represent percentages of nitrogen, phosphorus pentoxide, potassium oxide, and sulfur. For example, 0-0-25-17S means that fertilizer has 0% N and P but 25% potassium oxide and 17% sulfur. These solutions have high pH because of the dissociation of thiosulfate and polysulfide and may cause clogging problems, as described above, if proper steps are not taken. Therefore, the above two liquid fertilizers should not mix with iron and manganese fertilizers nor with calcium and magnesium fertilizers.

Oxidation: Only the form of ferrous iron, Fe(II), is bioavailable to fruit and vegetable plants. Because of the great reduction-oxidation potential difference between ferrous iron and oxygen, particularly at high pH, ferrous iron is very susceptible to being oxidized to ferric iron (Scott and Renaud 2007), which usually forms insoluble compounds with hydroxide or phosphate. The ferric iron species contributes to slime-like growth inside the fertigation system.

Precipitation: Ferric iron can precipitate with different anions, such as hydroxide, phosphate, and sulfide, when it is formed. At neutral pH, ferric iron can be precipitated at less than 0.1 ppm. As described, urea can drive water pH up to 9 after hydrolysis. At this high pH, both calcium and magnesium are readily precipitated with carbonate or hydroxide. All of these precipitations cause slime-like deposits and intensify clogging problems.

How can clogging be reduced?

Filter irrigation water

Good-quality water is crucial to reducing clogging problems in fertigation systems. If the irrigation water has visible debris and/or algae, irrigation water filters should be used to improve the quality of irrigation water and remove debris, clay particles, and algae before they enter the fertigation part of the system. Please refer to Design Tips for Drip Irrigation of Vegetables (http://edis.ifas.ufl.edu/ae093) for more information.

Acidify irrigation water

When water pH is high, a suitable acid is needed to acidify the water source (Kidder and Hanlon 2012). Safety is always the top priority when acidifying irrigation water. When acidifying a water source, acid must always be added to water, but water must NEVER be put into acid. Refer to Neutralizing Excess Bicarbonates from Irrigation Water (http://edis.ifas.ufl.edu/ss165) for more information. There are different acids, such as hydrochloric, sulfuric, citric, and phosphoric. Acidic fertilizers can also acidify irrigation water. For example, urea-sulfuric (N-pHURIC® products) nitrogen fertilizers can provide acid, fertilizer, and lower water pH. Urea-sulfuric fertilizers are NOT compatible with many compounds. Growers should NEVER combine urea-sulfuric fertilizers with other fertilizers or compounds when acidifying irrigation water.

When citric acid or phosphoric acid is chosen, more acid is needed than either hydrochloric acid or sulfuric acid because both citric acid and phosphoric acid can build pH buffer systems in the irrigation water. Economically, urea-sulfuric fertilizers, hydrochloric acid, or sulfuric acid may be more effective (Kidder and Hanlon 2012). Special care should be taken when phosphoric acid is injected into the irrigation water because it may be precipitated out with calcium in the water. When calcium concentration is over 50 ppm, phosphoric acid should NOT be injected (Burt, O’Connor, and Ruehr 1995). Calcium- or iron-fouled emitters can be cleaned by soaking emitters in a 0.5%-1.0% citric acid solution for 24-48 hours (Runyan et al. 2007).

Acidic solutions can damage irrigation system hardware. Corrosion-resistant fittings and components should be used if acids are to be injected. Acidifying irrigation water to pH 3.0 should NOT be longer than 30 minutes (Burt, O’Connor, and Ruehr 1995). Cleaning the fouled lines and emitters does NOT need to dissolve the buildup scales or slime inside the lines or emitters, but it does need to break them up and flush them out. Following irrigation water acidification, the irrigation system should be flushed for half an hour to ensure that the injected acid is completely cleaned out of the system (Obreza, Hanlon, and Zekri 2011).
Chlorinate irrigation water

To effectively prevent bacterial growth in irrigation water, chlorine may be injected continuously at low levels. Either liquid or gas chlorine can be used. Sodium hypochlorite (NaOCl) solution (household bleach) is also readily available. At a concentration of 5 ppm or lower, active chlorine, and not chloride, can effectively kill bacteria in irrigation water. After chlorine application, the free chlorine concentration should be measured at the hose ends toward the completion of an irrigation set. For irrigation water with high bacteria populations, a continuous application may be needed, and 0.5–1.0 ppm free available chlorine should persist at the ends of lines. For irrigation water with relatively low bacterial populations, intermittent application of chlorine may be used. For occasional application, a concentration of approximately 5 ppm should be measured at the ends of lines. Regarding the bacterial density in the irrigation water, surface water has the potential to have greater bacterial population than deep well water.

Ensure that injected nutrients are compatible

Fertilizer compatibility problems may occur when mixing two liquid fertilizers or liquid fertilizers with solid fertilizers. Before preparing fertilizer solutions from different sources, growers must consider the following points to ensure compatibility (Burt, O’Connor, and Ruehr 1995):

- The operator’s safety when making the fertilizer solutions
- The likelihood of the fertilizers clogging the fertigation system
- The effects of the solutions on each other when mixed
- The reactions of the fertilizers injected into the irrigation system

If there is uncertainty about the safety of a fertilizer solution or the compatibility of its ingredients, growers should consult their county Extension agent or fertilizer specialist before proceeding. If both cations and anions can combine to form an insoluble compound, then the sources are NOT compatible. If the newly formed compound is slightly soluble, the grower needs to be very careful because fertilizers with low solubility properties can cause clogging problems (Table 2). For fertilizer compatibility, see Fertigation Nutrient Sources and Application Considerations for Citrus (http://edis.ifas.ufl.edu/ch185).

To test the compatibility of a fertilizer solution with different ingredients, the best way is to prepare a small quantity of the solution before mixing various fertilizer solutions and performing fertigation. This test is called a “jar test” (Boman and Obreza 2012; Obreza, Hanlon, and Zekri 2011). To perform a jar test, put some of the fertilizer solution into a jar of irrigation water and then carefully watch for any cloudiness for approximately 2 hours. If milkiness occurs, then the injection of the fertilizer solution will cause clogging problems. If two different fertilizer solutions are to be injected into the irrigation system, mix them in a jar. When performing a jar test, use the approximate dilution rate that would be used for the actual fertigation application. For example, if a fertilizer solution is to be injected at the rate of 15 gallons per hour into an irrigation system that delivers 600 gallons per minute to the crop, the dilution rate would be 1 to 2400. For more information, please refer to How to Calculate Fertigation Injection Rates for Commercial Blueberry Production (http://edis.ifas.ufl.edu/hg1197). To run the jar test for fertigation, 1 teaspoon (5 milliliters) of fertilizer solution put into 3 gallons (about 12000 milliliters) of water should be the same as the field injection rate.

If roots are causing buried emitters to clog, then the emitters need to be properly cleaned or replaced.

Practical take-home message

- Clogging of irrigation lines and emitters is a common problem in fertigation. The problem can be reduced by improving the quality of irrigation water and injecting fertilizers judiciously.
- Use of irrigation water filters can significantly improve the quality of irrigation water and reduce clogging problems when water sources contain particulate matter, including debris or algae.
- Acidifying water sources can alleviate oxidization of iron and manganese and reduce chemical precipitation between cation and anion nutrients.
- When acidification of a water source is required, acid must always be added to water, but water must NEVER be put into acid.
- Chlorination of the water source is necessary for irrigation water containing high bacterial populations to prevent the formation of bacterial slimes.
- Performing a “jar test” for fertilizer compatibility is strongly encouraged before mixing fertilizers for the first time in the mixing tank for fertigation.

References
HS1202/HS1202: How to Reduce Clogging Problems in Fertigation


Tables

<table>
<thead>
<tr>
<th>Problem</th>
<th>Hazard level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Physical</td>
<td></td>
</tr>
<tr>
<td>Suspended solids (ppm)</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>Chemical</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>&lt; 7.0</td>
</tr>
<tr>
<td>Salt (ppm)</td>
<td>&lt; 500</td>
</tr>
<tr>
<td>Biocarbonate (ppm)</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Manganese (ppm)</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Total iron (ppm)</td>
<td>&lt; 0.2</td>
</tr>
<tr>
<td>Hydrogen sulfide (ppm)</td>
<td>&lt; 0.2</td>
</tr>
</tbody>
</table>

http://edis.ifas.ufl.edu/hs1202

3/5/2014
### Biological

| Bacterial population per gallon | < 2642 | 2642–13210 | > 13210 |

*Note: When testing for iron and manganese, the water sample needs to be acidified to a pH of 3.5 immediately after sampling.*

(Source: Bucks and Nakayama 1980; Burt, O'Connor, and Ruehr 1995)

### Table 2: Solubility chart of both main anion and cation nutrients in water of pH 6–7 at ambient temperatures

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Carbonate (CO$_3^{2-}$)</th>
<th>Chloride (Cl$^-$)</th>
<th>Hydroxide (OH$^-$)</th>
<th>Nitrate (NO$_3^-$)</th>
<th>Oxide (O$_2^{2-}$)</th>
<th>Phosphate (PO$_4^{3-}$)</th>
<th>Sulfate (SO$_4^{2-}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium (NH$_4^+$)</td>
<td>I</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>-</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Calcium (Ca$^{2+}$)</td>
<td>I</td>
<td>S</td>
<td>sS</td>
<td>S</td>
<td>sS</td>
<td>I</td>
<td>sS</td>
</tr>
<tr>
<td>Copper (Cu$^{2+}$)</td>
<td>I</td>
<td>S</td>
<td>I</td>
<td>S</td>
<td>I</td>
<td>I</td>
<td>S</td>
</tr>
<tr>
<td>Iron(II) (Fe$^{2+}$)</td>
<td>I</td>
<td>S</td>
<td>I</td>
<td>S</td>
<td>I</td>
<td>I</td>
<td>sS</td>
</tr>
<tr>
<td>Iron (III) (Fe$^{3+}$)</td>
<td>-</td>
<td>S</td>
<td>I</td>
<td>S</td>
<td>I</td>
<td>I</td>
<td>sS</td>
</tr>
<tr>
<td>Magnesium (Mg$^{2+}$)</td>
<td>I</td>
<td>S</td>
<td>I</td>
<td>S</td>
<td>I</td>
<td>I</td>
<td>S</td>
</tr>
<tr>
<td>Manganese (Mn$^{2+}$)</td>
<td>I</td>
<td>S</td>
<td>I</td>
<td>S</td>
<td>I</td>
<td>I</td>
<td>S</td>
</tr>
<tr>
<td>Potassium (K$^+$)</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Zinc (Zn$^{2+}$)</td>
<td>I</td>
<td>S</td>
<td>I</td>
<td>S</td>
<td>I</td>
<td>I</td>
<td>S</td>
</tr>
</tbody>
</table>

*Note: When one ion is mixed with other ions, they can become precipitates or remain aqueous. The "S" (soluble) marking indicates that mixing results in an aqueous product, while the "sS" (slightly soluble) marking or the "I" (insoluble) marking means that there is a precipitate that will form. This formation of precipitates clogs lines and/or emitters of the fertigation system. The formation should and can be reduced, and the line or emitter clogging problem will be minimized significantly if the information in this table is followed.*

### Footnotes

1. This document is HS1202, one of a series of the Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date June 2012. Visit the EDIS website at [http://edis.ifas.ufl.edu](http://edis.ifas.ufl.edu).

2. Guodong Liu, assistant professor, Horticultural Sciences Department, and Gene McAvoy, regional vegetable extension agent IV, Hendry County Extension, University of Florida Institute of Food and Agricultural Sciences, Gainesville, FL 32611.

The Institute of Food and Agricultural Sciences (IFAS) is an Equal Opportunity Institution authorized to provide research, educational information and other services only to individuals and institutions that function with non-discrimination with respect to race, creed, color, religion, age, disability, sex, sexual orientation, marital status, national origin, political opinions or affiliations. For more information on obtaining other UF/IFAS Extension publications, contact your county's UF/IFAS Extension office.

[http://edis.ifas.ufl.edu/hS1202](http://edis.ifas.ufl.edu/hS1202)  3/5/2014
Chemical Injection Methods for Irrigation

Dorota Z. Haman and Fedro S. Zazueta

METHODS OF CHEMICAL INJECTIONS
Chemical application through irrigation systems is called chemigation. Chemigation has been practiced for many years especially for fertilizer application (fertigation). In recent years, other chemicals are also being applied through irrigation systems with increasing frequency. The primary reason for chemigation is economy. It is normally less expensive to apply chemicals with irrigation water than by other methods. The other major advantage is the ability of applying chemical only when needed and in required amounts. This “prescription” application not only follows plant needs much closer than traditional methods, but also minimizes the possibility of environmental pollution. Through chemigation, chemicals can be applied only in amounts needed and thus large quantities are not subject to leaching losses if heavy rainfalls follow applications. Additional advantages of chemigation include less operator hazard and possibly reduced amounts of chemicals.

There are several methods of chemical injection into an irrigation system. These methods can be classified into four major groups: centrifugal pumps, positive displacement pumps, pressure differential methods, and methods based on the venturi principle. These four groups can be further subdivided into specific methods (see Figure 1). In addition, some injectors use a combination of these methods. This publication will discuss each group of chemical injectors, their applications, and advantages and disadvantages.

A summary of advantages and disadvantages of injectors discussed in this publication is presented in Table 1.

Figure 1. Classification of chemical injection methods for irrigation systems.

CENTRIFUGAL PUMPS
Small radial flow centrifugal pumps (booster pumps) can be used to inject chemicals into irrigation systems. The principle of operation of a centrifugal pump is described in detail in IFAS Extension Circular 832. Basically, fluid enters the centrifugal pump near the axis of the high-speed impeller, and by centrifugal force is thrown radially outward into the pump casing. The velocity head imparted to the fluid by the impeller is converted into pressure head by means of volute or by a set of stationary diffusion vanes surrounding the impeller (Figure 2).


2. D.Z. Haman, Associate Professor; A.G. Smajstrla and F.S. Zazueta, Professors, Agricultural Engineering Department, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville FL 32611.

The Institute of Food and Agricultural Sciences (IFAS) is an Equal Opportunity Institution authorized to provide research, educational information and other services only to individuals and institutions that function with non-discrimination with respect to race, creed, color, religion, age, disability, sex, sexual orientation, marital status, national origin, political opinions or affiliations. U.S. Department of Agriculture, Cooperative Extension Service, University of Florida, IFAS, Florida A&M University Cooperative Extension Program, and Boards of County Commissioners Cooperating. Milie Ferrez-Chaney, Interim Dean.
For a centrifugal pump to operate as an injector, it is necessary that the pressure produced by the pump be higher than the pressure in the irrigation line. However, the flow rate of the chemical from the pump depends on the pressure in the irrigation line. The higher the pressure in the irrigation line, the smaller the flow rate from the injection pump. Because of that, centrifugal pumps require calibration while operating. It is also not recommended that this type of pumps will be used for the injection of toxic chemicals where the injection rate must be controlled very precisely.

**POSITIVE DISPLACEMENT PUMPS**

Positive displacement pumps are frequently used for injection of chemicals into a pressurized irrigation system. Positive displacement pumps are classified as reciprocating, rotary and miscellaneous types (Figure 1) depending on the mechanism used to transfer energy to the fluid. Reciprocating pumps include piston, diaphragm and combination piston/diaphragm pumps all commonly used for chemical injection into irrigation systems. Most rotary and miscellaneous pumps are not used for chemical injections and are not discussed in this publication. The exceptions are gear and lobe rotary pumps which are occasionally used, and peristaltic pumps which can be used when only small injection rates are required. Therefore, gear, lobe and peristaltic pumps will be discussed briefly in this publication. An interested reader is referred to IFAS Extension Circular 826 for a detailed description, typical applications and discussion of advantages and disadvantages of the various positive displacement pumps used in agriculture.

By definition, a positive displacement pump moves a certain, constant volume of fluid from the intake side of the pump to the discharge side of the pump. Theoretically, the volume displaced by the pump should be independent of the pressure encountered at the discharge point. However, this is not necessarily true for all pumps classified as positive displacement pumps. If the internal parts of the pump can deform due to the increased pressure (as in a mechanically driven diaphragm pump) the displacement volume of the pump will change and the injection rate will not be constant. Excessive pressure at the discharge may also result in some back flow through the clearances of the pump parts (for example, between the gears and the housing in the gear pump). Piston, fluid filled diaphragm, and piston/diaphragm pumps come closest to being ideal positive displacement pumps and to providing a constant flow rate independent of the discharge pressure. However, even with these pumps, excessive discharge pressures should be avoided (for example, due to a closed valve in a discharge line) because excessively high pressures may result in pump or line damage.

**Reciprocating Pumps**

Reciprocating pumps are pumps in which a piston or a diaphragm displaces a given amount of chemical with each stroke. The change in internal volume of the pump creates high pressure, which forces chemical into the discharge pipe. These pumps are classified as piston pumps, diaphragm pumps or a combination of piston and diaphragm.

In most of diaphragm, piston, and diaphragm/piston combination pumps the rotary motion of a drive wheel is transformed into reciprocating motion of a cylinder or a diaphragm.

The operation of a piston pump is similar to the operation of the cylinder of an automobile engine. On an intake stroke (Figure 3a), the chemical enters the cylinder through the suction check valve. On a compression stroke (Figure 3b) the chemical is forced into the discharge line through the discharge check valve.

The operation of a diaphragm pump is similar to that of a piston pump. The pulsating motion is transmitted to the diaphragm through a fluid or a mechanical drive, and then through the diaphragm to the chemical being injected (Figure 4a and Figure 4b).
Combination pumps usually contain a piston that forces oil or other fluid against a diaphragm which displaces the concentrated chemical. The advantage of these pumps is that they combine the high precision of a piston pump with the resistance to chemicals characteristic of diaphragm pumps.

Reciprocating pumps are often electrically driven. The chemical injection rate from an electrically driven pump is approximately constant regardless of the water flow rate. Thus, the injection rate must be adjusted between zones if the flow rate is not constant to all zones.

To assure constant concentration of chemical in the irrigation line an electrically driven injector can be equipped with a water flow sensor to detect changes in flow rate and automatically adjust the speed of the injector or injection time. The other possibility is to measure the conductivity of the irrigation water (if fertilizers are being injected) and use this information for automatic adjustment. Sensors that measure the conductivity must be recalibrated for different chemicals.

Some piston and diaphragm pumps are driven by a water motor. As water flows through the injector, it causes a cam to turn and push a piston back and forth. In a diaphragm pump, the piston or cam motion is transmitted to the diaphragm. Consequently, since the revolution of the cam
depends on the flow rate of water in the irrigation system. Oscillation of the piston and/or diaphragm also varies with water flow rate. In this case the chemical flow is proportional to the flow rate in the irrigation system.

Another way of driving the injector using irrigation water is presented in Figure 5. In this case a mechanism contains two pistons of different size and a series of valves. The larger piston is driven by the pressure in the irrigation system. A smaller piston injects a chemical into the irrigation line.

Piston and diaphragm pumps inject chemicals in concentrated pulses separated in time. Some pumps are equipped with double acting pistons or diaphragms to minimize variations in the concentration of chemicals in the irrigation system. In these cases the volume on both sides of the piston or the diaphragm is used for pumping chemical (Figure 6). However, if the pipe line length between the injection port and the first point of application is short, a blending tank should follow the injection to ensure adequate mixing of water and fertilizer.

**ROTARY PUMPS**

Rotary pumps transfer chemical from suction to discharge through the action of rotating gears, lobes or other similar mechanisms. Both, gear or lobe types of rotary pumps are sometimes used for chemical injection into irrigation systems. The operation of a gear or lobe pump is based on the partial vacuum which is created by the unmeshing of the rotating gears (Figure 7) or lobes (Figure 8). This vacuum causes the chemical to flow into the pump. Then, it is carried between the gears or lobes and the casing to the discharge side of the pump. Gear and lobe pumps produce approximately constant flow for a given rotor speed, and the injection rate does not change with flow rate in the irrigation system. Flow sensors, described above for reciprocating pumps, can be used to assure a constant injection rate.
**Peristaltic Pumps**

Peristaltic pumps are used mostly in chemical laboratories, but they can be used for injection of chemicals into small irrigation systems. Their capacity is limited and most of them produce a pressure of only 30 to 40 psi. A typical peristaltic pump is presented in Figure 9. A flexible tube is pressed by a set of rollers and an even flow is produced by this squeezing action. The pump is suitable for pumping corrosive chemicals since the pumped liquid is completely isolated from all moving parts of the pump.

**PRESSURE DIFFERENTIAL METHODS**

The idea of injection using pressure differential is quite simple. Basically, if the pressure at the point of injection is lower than at the point of intake of the chemical, the chemical will flow into the line. There are several injection techniques which use the above principle. They can be separated into two distinctive groups. Injection on the suction side of the irrigation pump and injection on the discharge side of the irrigation pump.

**Suction Pipe Injection**

The suction pipe injection technique can be used in irrigation systems using centrifugal pumps which are pumping water from the surface source such as a pond, lake, canal or river. In Florida, this method is not permitted for irrigation systems using groundwater supply, and it is approved for injection of fertilizer only (see IFAS Extension Bulletin 217).

The method described above requires only a minimum investment. The equipment necessary for this type of injection is a pipe or a hose, a few fittings and an open container to hold the fertilizer solution (Figure 10). The rate of chemical flow depends of the suction produced by the irrigation pump, the length and size of the suction line, and the level of chemical in the supply tank. This rate can not be easily adjusted.

---

**Figure 8. Lobe pump.**

**Figure 9. Peristaltic pump.**

**Figure 10. Suction line injection.**
Discharge Line Injection

The differential pressure injection technique can also be used on the discharge side of the pump. This is usually done by redirecting part of the main flow through the chemical tank and providing a pressure drop in the irrigation line between the point where the water is taken and the point where the chemical enters the irrigation line. The pressure drop is accomplished by using some kind of restriction in the line such as a valve, orifice, pressure regulator or other device which would create a pressure drop. The use of valves allows for adjustment of the pressure drop which also allows for some adjustment of the injection rate.

PRESSURIZED MIXING TANKS

A mixing tank injector operates at the discharge line on a pressure differential concept. The water is diverted from the main flow, mixed with fertilizer and injected or drawn back into the main stream of the system (Figure 11). A measured amount of fertilizer required for one injection is placed in the cylinder. The flow back into the main line is often controlled by a metering device installed on the inlet side of the reactor. The concentration of the injection changes as the chemical becomes diluted as the water enters the tank during injection. To operate, again, as described previously, there must be a pressure differential in the irrigation line between the inlet and the outlet of the injector.

Figure 12. Proportional mixer.

In irrigation systems where flow fluctuations can be expected, proportioning control valves must be used. If the injector is a true proportioning mixer the proportioning valve must respond to the changes of flow not pressure changes in the irrigation system.

VENTURI INJECTOR

Chemicals can be injected into a pressurized pipe using the venturi principle. A venturi injector is a tapered constriction which operates on the principle that a pressure drop accompanies the change in velocity of the water as it passes through the constriction. The pressure drop through a venturi must be sufficient to create a negative pressure (vacuum) as measured relative to atmospheric pressure. Under these conditions the fluid from the tank will flow into the injector (Figure 13). Most venturi injectors require at least a 20% differential pressure to initiate a vacuum. A full vacuum of 28 in of mercury is attained with a differential pressure of 5% or more.

Figure 13. Venturi injector in the main line.
A small venturi can be used to inject small chemical flow rates into a relatively large main line by shunting a portion of the flow through the injector. To assure that the water will flow through the shunt, a pressure drop must occur in the main line. For this reason the injector is used around a point of restriction such as valve, orifice, pressure regulator or other device which creates a differential pressure (Figure 14). A centrifugal pump, used to provide additional pressure in the shunt (Figure 15), can also be used.

A venturi injector does not require external power to operate. It does not have any moving parts, which increases its life and decreases probability of failure. The injector is usually constructed of plastic and it is resistant to most chemicals. It requires minimal operator attention and maintenance. Since the device is very simple, its cost is low as compared to other equipment of similar function and capability. It is easy to adopt to most of new or existing systems providing that there is sufficient pressure in the system to create the required pressure differential.

Venturi injectors come in various sizes and can be operated under different pressure conditions. Suction capacity (injection rate), head loss required, and working pressure range will depend on the model. It is important to realize that the suction capacity depends on the liquid level in the supply tank. As the liquid level drops, the suction head increases resulting in the decreased injection rate. To avoid this problem some manufacturers provide an additional small tank on the side of the supply tank, where the float valve maintains the fluid level relatively constant. The fluid is injected from this additional tank.

**COMBINATION METHODS**

There are some injectors on the market which employ combination of the different principles of injection at the same time. The most common combination is a pressure differential combined with a venturi meter or some measuring device which operates on the venturi principle.

Direct use of pressure differential in combination with a venturi can be found in some systems where the pressure drop required for a venturi may be difficult to provide due to design restrictions of the existing irrigation system. The combination of a venturi device with a pressurized chemical tank may be used in this case (Figure 16). The chemicals are placed in the tank. Since the water flowing through the tank is under pressure, a sealed airtight pressure supply tank which is constructed to withstand the maximum operating pressure is required. In this case the injection rate will change gradually due to the change of chemical concentration in the tank as the water enters the tank during injection.

Various metering valves which are used with mixing and proportioning tanks operate on pressure or flow changes in the irrigation system. There are many designs of these valves. Frequently it is some application of the venturi meter or the orifice with changing diameter. The manufacture should be contacted for descriptions and operation instructions for various metering and proportioning valves.
According to Environmental Protection Agency (EPA) only piston and diaphragm injection pumps can be used for pesticides and other toxic chemicals. Other methods described in this publication can be used for injection of fertilizers or cleaning agents, such as chlorine or acids.

SUMMARY
Different types of injectors are discussed in this publication. These injectors are classified into five basic groups depending on their principles of operation. Basic principles of operation, advantages and disadvantages are presented.

REFERENCES


### Table 3. Fertilization recommendations for tomato grown in Florida on sandy soils testing very low in Mehlich-1 potassium (K₂O)

<table>
<thead>
<tr>
<th>Production system</th>
<th>Nutrient</th>
<th>Recommended-Base fertilization&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Recommended-Supplemental fertilization&lt;sup&gt;4&lt;/sup&gt;</th>
<th>Leaching rain&lt;sup&gt;4&lt;/sup&gt;</th>
<th>Measured &quot;low&quot; plant nutrient content&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Extended harvest season&lt;sup&gt;4&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drip irrigation,</td>
<td>N</td>
<td>200</td>
<td>0-70</td>
<td>n/a</td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>raised beds, and</td>
<td>K₂O</td>
<td>220</td>
<td>0-70</td>
<td>n/a</td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>polyethylene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>mulch (on deep</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>sands or on soils</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>with shallow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>impermeable layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>Seepage irrigation,</td>
<td>N</td>
<td>200</td>
<td>0-70</td>
<td>n/a</td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>raised beds, and</td>
<td>K₂O</td>
<td>220</td>
<td>0-70</td>
<td>n/a</td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>polyethylene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>mulch (on soils</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>with shallow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
<tr>
<td>impermeable layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5 to 2 lbs/A/day for 7 days&lt;sup&gt;4&lt;/sup&gt;</td>
<td>1.5 to 2 lbs/A/day</td>
</tr>
</tbody>
</table>

<sup>2</sup> A-7,260 linear bed feet per acre (5-8 bed spacing); for soils testing “very low” in Mehlich 1 potassium (K₂O). Seeds and transplants may benefit from applications of a starter solution at a rate no greater than 10 to 15 lb/acre for N and P₂O₅, and applied through the plant hole or near the seeds.

<sup>3</sup> Applied using the modified broadcast method (fertilizer is broadcast where the beds will be formed only, and not over the entire field). Preplant fertilizer cannot be applied to doublecrop crops because of the plastic mulch; hence, in these cases, all the fertilizer must be injected.

<sup>4</sup> This fertilization schedule is applicable when no N and K₂O are applied preplant. Reduce schedule proportionally to the amount of N and K₂O applied preplant. Fertilizer injection may be done daily or weekly. Inject fertilizer at the end of the irrigation event and allow enough time for proper flushing afterwards.

<sup>5</sup> For standard 13 week-long, transplanted tomato crop.

<sup>6</sup> Some of the fertilizer may be applied with a fertilizer wheel through the plastic mulch during the tomato crop when only part of the recommended base rate is applied preplant. Rate may be reduced when a controlled-release fertilizer source is used.

<sup>7</sup> Plant nutritional status may be determined with tissue analysis or fresh petiole-sap testing, or any other calibrated method. The "low" diagnosis needs to be based on UF/IFAS interpretive thresholds.

<sup>1</sup> Plant nutritional status must be diagnosed every week to repeat supplemental fertilizer application.

<sup>8</sup> Supplemental fertilizer applications are allowed when irrigation is scheduled following a recommended method (see Chapter 3 on irrigation scheduling in Florida). Supplemental fertilizations are to be applied in addition to base fertilization when appropriate. Supplemental fertilization is not to be applied "in advance" with the preplant fertilizer.

<sup>9</sup> A leaching rain is defined as a rainfall amount of 3 inches in 3 days or 4 inches in 7 days.

<sup>10</sup> Supplemental amount for each leaching rain

<sup>P</sup> Plant nutritional status must be diagnosed after each harvest before repeating supplemental fertilizer application.

### Table 4. Plant tissue analysis for tomato at first flower stage. Dry wt. basis.

<table>
<thead>
<tr>
<th>Status</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>B</th>
<th>Cu</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parts per million</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deficient</td>
<td>&lt;2.6</td>
<td>0.2</td>
<td>2.5</td>
<td>0.8</td>
<td>0.3</td>
<td>0.3</td>
<td>40</td>
<td>30</td>
<td>25</td>
<td>15</td>
<td>5</td>
<td>0.2</td>
</tr>
<tr>
<td>Adequate range</td>
<td>2.6-4.0</td>
<td>0.2-0.4</td>
<td>2.5-4.0</td>
<td>0.8-2.0</td>
<td>0.3-0.5</td>
<td>0.3-0.8</td>
<td>40-100</td>
<td>30-100</td>
<td>25-45</td>
<td>15-30</td>
<td>5-10</td>
<td>0.2-0.8</td>
</tr>
<tr>
<td>High</td>
<td>&gt;4.0</td>
<td>0.4</td>
<td>4.0</td>
<td>2.0</td>
<td>0.5</td>
<td>0.8</td>
<td>100</td>
<td>100</td>
<td>40</td>
<td>40</td>
<td>15</td>
<td>0.6</td>
</tr>
<tr>
<td>Toxic</td>
<td>&gt;1500</td>
<td>&gt;300</td>
<td>&gt;250</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fertigation of Tomatoes – Results of Fall 2013 Trial

Miurel Bermudez Herrera and Kelly Morgan

SWFREC Soil and Water Science Department

The study was located at University of Florida, Southwest Florida Research and Education Center (SWFREC), in Immokalee, Florida. The soil series was Immokalee fine sand. The classification of this soil is sandy, siliceous, hyperthermic, Arenic Haplaquods (USDA, 1990).

The study was conducted on tomato planted on beds. There were three beds per plot with the following dimensions: length 90 feet, height 8 inches and distance between beds centers of 7 feet. The area of each plot was 240 ft². The beds were irrigated with a surface drip irrigation system (12 inches apart), the space between plants was 24 inches, and plastic mulch was used to cover the beds. The treatments involved were as follow: T1) no fertigation, T2) 50% UF/IFAS recommendation rates for tomato (Olson et al., 2012a,b), T3) 100% of the UF/IFAS recommendations, T4) 150% of the UF/IFAS recommendations) and T5) 200% of the UF/IFAS recommendations. All the treatments had 4 replicates located randomly and they were fertigated twice a week using 20-2-20.

The tomatoes were planted on September 16, 2013 (fall season). Bottom fertilizer was applying before the beds were made, 50 pounds of N per acre (16-4-8). After transplanting, 1.5 pounds of 20-2-20 in 100 gallons of water were applied in the planting hole in all the replicates. The variety of tomato used was 6153 (Syngenta). Weekly scouting was made for white fly, leaf miner, and worm counting for the purpose to keep the pest controlled. The following pesticides were used to control the pest Malathon, Hero, Kocide and Manzate.
### Table 1. Mean percent of nutrient in tomato leaves, 12 weeks after transplanting.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Percent of nutrient on tomato leaves</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1.41 C</td>
<td>0.64 A</td>
<td>1.59 B</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>2.35 B</td>
<td>0.69 A</td>
<td>1.87 B</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>2.74 B</td>
<td>0.65 A</td>
<td>3.03 A</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>3.51 A</td>
<td>0.61 A</td>
<td>3.17 A</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>3.63 A</td>
<td>0.62 A</td>
<td>3.28 A</td>
</tr>
</tbody>
</table>

*Means with the same letter are not significantly different.

### Table 2. Mean percent of nutrient in tomato stems, 12 weeks after transplanting.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Percent of nutrient on tomato stems</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>0.67 C</td>
<td>0.82 A</td>
<td>2.64 A</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>0.74 C</td>
<td>0.64 BA</td>
<td>2.04 A</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>1.38 B</td>
<td>0.57 BA</td>
<td>2.69 A</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>1.53 B</td>
<td>0.42 B</td>
<td>3.18 A</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>2.18 A</td>
<td>0.53 B</td>
<td>3.33 A</td>
</tr>
</tbody>
</table>

*Means with the same letter are not significantly different.

### Table 3. Mean percent of nutrient in tomato fruit, 12 weeks after transplanting.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Percent of nutrient on tomato fruit</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>2.53 D</td>
<td>0.99 C</td>
<td>6.38 A</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>3.73 C</td>
<td>0.97 C</td>
<td>6.29 A</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>4.39 BC</td>
<td>1.12 B</td>
<td>6.60 A</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>4.62 BA</td>
<td>1.09 B</td>
<td>5.99 A</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>5.24 A</td>
<td>1.45 A</td>
<td>6.80 A</td>
</tr>
</tbody>
</table>

*Means with the same letter are not significantly different.
Table 4. Number of boxes per treatment per acre.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of boxes per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>508</td>
</tr>
<tr>
<td>2</td>
<td>1236</td>
</tr>
<tr>
<td>3</td>
<td>2042</td>
</tr>
<tr>
<td>4</td>
<td>2539</td>
</tr>
<tr>
<td>5</td>
<td>2489</td>
</tr>
</tbody>
</table>

Figure 1. Grams of nutrient in tomato stems, 12 weeks after transplanting.
Figure 2. Grams of nutrient in tomato leaves, 12 weeks after transplanting.

Figure 3. Grams of nutrient in tomato fruit, 12 weeks after transplanting.
Figure 4. Yield pounds per acre per treatment.