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Drip Irrigation: The BMP Era - An Integrated Approach to Water and Fertilizer Management for Vegetables Grown with Plasticulture[1]

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In Florida, plasticulture is currently used on approximately 60,000 acres of vegetable (mainly tomato, bell pepper, eggplant, strawberry and watermelon). The Florida drip irrigation school is a one-day educational program offered by the Institute of Food and Agricultural Sciences at the University of Florida focusing on drip irrigation. Through talks, hands-on demonstrations and discussions, the goal of this program is to teach and help vegetable growers better manage fertilizer, water and fumigant applications through drip systems and to prepare them for the BMP era. This program involves county and state-wide Extension faculty and researchers, and members of the irrigation and fertilization industries.

Additional Florida Drip Irrigation Schools are being scheduled regularly thoughout Florida. These programs are offered at no charge, but require pre-registration. Contact your local Extension office to find out when the next drip irrigation school will be offered in your area or check announcements in the Vegetarian newsletter at http://www.hos.ufl.edu/vegetarian/vegetarian.htm

This article presents a summary of the information discussed on fertilizer management, irrigation scheduling, and drip system maintenance and troubleshooting. A list of additional references is also included.

Total Maximum Daily Loads (TMDL) and Best Management Practices (BMP): The Basics

As the development of TMDLs and BMPs for vegetables grown in Florida takes place, growers are eager to find out how this process will affect their operations. TMDLs and BMPs have their origin in Federal and State legislations (Table 1). A TMDL is the maximum amount of a pollutant a water body can receive and still meet its water quality standards. BMPs are specific cultural practices that aim at reducing the load of a specific compound, while maintaining economical yields (Table 2). Growers

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will benefit three ways from having a documented BMP plan. They will be offered (1) a waiver of liability from reimbursement of costs or damages associated with the evaluation, assessment, or remediation of nitrate contamination of ground water (F.S. 376.307); (2) a presumption of compliance with state water quality standards [F.S. 403.067 (7)(d)]; and, (3) an oportunity to receive cost-share reimbursement for implementation of selected BMPs [F.S. 570.085(1)].

The BMPs applicable to vegetable production will be included in the Agronomic and Vegetable Crop Water Quality and Water Quantity BMP Manual for Florida for row crops and vegetables, which is under development. BMPs are 1-to-3 page long chapters that include a working definition of the topic, list specific things to do (BMPs) as well as things to avoid (pitfalls), and present existing applicable technical criteria together with additional references. As the new legislative mandate for Florida agriculture, the BMPs largely embrace IFAS fertilization and irrigation recommendations.

Principles of Fertilization Management in the BMP Era

Fertilization principle 1. With plasticulture, think in terms of rows Y and not in terms of field surface for irrigation and fertilization. For bare ground production of vegetables, fertilizer and irrigation rates are typically expressed in lbs/acre and gallons/acre, respectively. However, when vegetables are grown with plasticulture, the number of linear feet of beds in an acre becomes more important than the actual surface of the field. Growers should think in terms of lbs/100 linear bed feet (lbf) for fertilization injections and gallons/100 lbf for irrigation, and take into account the bed spacing. Typical bed spacings are used in the IFAS fertilization recommendations for plasticulture (Table 3).

Fertilization principle 2. Plants need all the essential nutrients. Sixteen essential mineral elements are recognized as the essential elements. Carbon (C), hydrogen (H), and oxygen (O) are supplied by air and water. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) are the macronutrients. Boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) are the micronutrients. All these elements are essential because (1) vegetable crops cannot complete their life cycle without all of them, (2) typical deficiency symptoms appear when one is not available, and symptoms disappear upon the application of the deficient element, and (3) each element has a specific metabolic role. The overall success of a fertilizer program is determined by the essential element which is provided in smallest quantity (limiting factor). Adequate fertilization together with soil nutrient reserves should provide all these elements in adequate quantities, thereby ensuring that mineral nutrition is not limiting vegetable growth and yield.

Fertilization principle 3. Soil test and follow the recommendation. The only scientific method to apply fertilizer to vegetables is to use a calibrated soil test. A soil sample has to be recent, representative, and large enough to ensure valid results. The soil test recommendation has to be understood, and properly implemented. Typically, 20% to 50% of N and K_2O, and 100% of P_2O_5 and micronutrients are applied preplant. The remaining 50% to 80% of N and K_2O are injected through the drip system. A fertilizer program may be simply designed from IFAS recommendation using a spreadsheet format (Fig. 1). Correctly implementing soil test results is essential in increasing nutrient management to a level acceptable in the BMP era (Table 4).

Some growers do not believe that economical vegetable yields can be produced with IFAS fertilizer recommendations. Fertilizer recommendations are based on multiple trials and correspond to the fertilizer rates above which no yield response is likely to occur. IFAS fertilizer rate may not be optimal if excessive irrigation is applied. In this case, the solution is to adjust irrigation management, rather than increasing fertilizer rates. Fertilizer applications in excess of the recommended rate should not be made on a routine basis, but only when exceptional circumstances (leaching rain) occur or based on the results of petiole sap test and/or foliar nutrient analyses. IFAS definition of a leaching rain is 3 in. of rain in 3 days or 4 in. of rain in 7 days.

	Fertilizer rate (lbs/acre)			
	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	
Total IFAS recommendation [1] (based on soil test results)	150	0	150	
Preplant fertilizer (15% of total N) (example: 13-4-13 @173lbs/acre)	22	7	22	
Injected fertilizer (85% of total N) (example: liquid 8-0-8 @ 0.8 lb N/gal)	128	0	128	
Week [2]	Weekly recommended rate [1]			8-0-8 injected weekly (gal/acre)
	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	
1	7 [3]	0	7	0 [4]
2	7 [3]	0	7	0 [4]
3	10.5	0	10.5	13
4	10.5	0	10.5	13
5	17.5	0	17.5	22
6	17.5	0	17.5	22
7	17.5	0	17.5	22
8	17.5	0	17.5	22
9	10.5	0	10.5	13
10	10.5	0	10.5	13
11	10.5	0	10.5	13
12	7	0	7	9
13	7 (1)	0	7 (1)	0 [5]

[1] Recommendations from the Florida Vegetable Production Guide; assumes that beds are on 8-ft centers; weekly rates are calculated as 7 x daily rates
[2] Growing season is 13 weeks for a typical watermelon crop when transplants are used
[3] When no fertilizer is applied preplant
[4] Injections the first two weeks may be omitted with a preplant application
[5] Fertigation may be omitted the week before harvest; irrigation should continue that week

Figure 1. Sample spreadsheet for designing a fertigation program for a 1-acre watermelon field planted on 8-ft centers. Beginning with soil-test results (top section), this worksheet that uses IFAS recommendations provides a weekly schedule for fertigation with liquid 8-0-8 (right column).

Fertilization principle 4. Monitor crop nutritional status and discover how healthy the vegetable plants are. The nutritional status of vegetables may be monitored with sap test or foliar analysis early in the season (from transplanting to fruit set). A representative sample for petiole and leaf analysis should be made with at least 20 leaves selected randomly throughout the field from most recently, fully mature leaves. For sap analysis, blades should be carefully separated from the petiole and discarded. Fig. 2 shows how to collect sap and perform a reading. For leaf analysis, the sampled part should be the blade and its petiole attached.

Figure 2.a

Figure 2.b

Figure 2.c

Figure 2.d

Figure 2. Sap testing for vegetables involves separating the petiole from the leaf blade, (2.1) calibrating the nitrate (NO3-N) and potassium (K) ion specific electrodes (Cardi meter shown here) with standard solutions, (2.2) extracting the sap, (2.3) collecting the sap from the press, and (2.4) placing a droplet of sap on the electrode. A hydraulic press may be needed only when few petioles are available or when petioles contain little sap as may occur with strawberry. In most cases, a garlic press will be an adequate tool to extract the sap. Readings should be compared to published sufficiency ranges.

Principles of Irrigation Scheduling in the BMP Era

Irrigation scheduling is knowing when to start irrigation and how much to apply, in a way that satisfies crop water needs, conserves water, and does not leach mobile nutrients. Irrigation scheduling requires (1) a target water volume, (2) guidelines on how and when to split irrigation, (3) a method to account for rainfall, and (4) a practical method to monitor soil moisture.

Irrigation principle 1. Irrigation amount must reflect crop water use, no more, no less. Irrigation amounts may be estimated using historical weather data, climatic measurement in real-time, class A pan evaporation, atmometers, and empirical amounts (Table 5, Fig. 3). Empirical values have the advantage of being simple. However, they often result in excessive irrigation early in the season, and insufficient ones later in the season. This method alone (without monitoring of soil moisture) is unlikely to be part of the BMPs.

Drip System Maintenance and Troubleshooting

Application uniformity of 85% to 95% is expected from a new, well-designed drip irrigation system (Fig. 7). As the irrigation system is used for water and fertilizer applications throughout the growing season, the application uniformity may remain the same if the system is well managed, but will most likely decline with time. A comprehensive maintenance plan will reduce the adverse effects of the agents that reduce application uniformity: small solids in suspension, organic matter, micro-organisms, and chemical residues on application uniformity (Fig. 8). Without a maintenance plan, the risk of complete emitter clogging and crop loss becomes real.

References and Additional Readings

Related Web Sites

North Florida Research and Education Center - Suwannee Valley: http://nfrec-sv.ifas.ufl.edu/

Horticultural Sciences Department: http://www.hos.ufl.edu

Florida Department of Environmental Protection: http://www.dep.state.fl.us/water

Suwannee River Water Management District: http://www.srwmd.state.fl.us/

Small Scale Irrigation for Arid Zones (FAO): http://www.fao.org/docrep/W3094E/w3094e00.htm#TopOfPage

Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements - FAO Irrigation and Drainage Paper 56: http://www.fao.org/docrep/X0490E/X0490E00.htm

University of Florida Extension Soil Testing Laboratory: http://soilslab.ifas.ufl.edu/#ESTL

NRCS Nutrient Management homepage: http://www.nhq.nrcs.usda.gov/BCS/nutri/manage.html

General Irrigation

Soil Plant Water Relationships, D.Z. Haman and F.T. Izuno, Circ. 1085, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE021

Basic Irrigation Terminology, F.T. Izuno and D.Z. Haman, Fact Sheet AE-66, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE115

Principles and Practices of Irrigation Management for Vegetables, E.H. Simonne, M.D. Dukes, D.Z. Haman, pp.31-37, In: D.N. Maynard and S.M. Olson (eds.) Vegetable Production Guide for Florida, Univ. of Fla, Gainesville, FL.

Drip System Maintenance

Treating Irrigation Systems with Chlorine, G.A. Clark and A.G. Smajstrla, Circ. 1039, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE080

Injection of Chemicals Into Irrigation Systems: Rates, Volumes, and Injection Periods, G.A. Clark, D.Z. Haman and F.S. Zazueta, Bul. 250, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE116

Causes and Prevention of Emitter Plugging in Microirrigation Systems, D.J. Pitts, D.Z. Haman and A.G. Smajstrla, Bul. 258, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE032

Drip System Components

Micro-irrigation on Mulched Bed Systems: Components, System Capacities, and Management, G.A. Clark, C.D. Stanley, and A.G. Smajstrla, Bul. 245, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE042

Media Filters for Trickle Irrigation in Florida, D.Z. Haman, A.G. Smajstrla, and F.S. Zazueta, Fact Sheet AE-57, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/WI008

Screen Filters in Trickle Irrigation Systems, D.Z. Haman, A.G. Smajstrla and F.S. Zazueta, Fact Sheet AE-69, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/WI009

Principles of Micro Irrigation, D.Z. Haman and F.T. Izuno, Fact Sheet AE-24, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/WI007

Chemical Injection Methods for Irrigation, D.Z. Haman, A.G. Smajstrla and F.S. Zazueta, Circ. 864, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/WI004

Measuring Pump Capacity for Irrigation System Design, A.G. Smajstrla, D.Z. Haman and F.S. Zazueta, Circ. 1133, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE067

Florida Backflow Prevention Requirements for Agricultural Irrigation Systems, A.G. Smajstrla, D.S. Harrison, W.J. Becker, F.S. Zazueta, and D.Z. Haman, Bul. 217, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla.

Drip System Design

Water Hammer in Irrigation Systems, G.A. Clark, A.G. Smajstrla, and D.Z. Haman, Circ. 848, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE066

Design Tips for Drip Irrigation of Vegetables, D.Z. Haman and A.G. Smajstrla, Fact Sheet AE-260, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE093

Efficiencies of Florida Agricultural Irrigation Systems, A.G. Smajstrla, B.J. Boman, G.A. Clark, D.Z. Haman, D.S. Harrison, F.T. Izuno, D.J. Pitts and F.S. Zazueta, Bul. 247, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE110

Field Evaluation of Microirrigation Water Application Uniformity, A.G. Smajstrla, B.J. Boman, D.Z. Haman, D.J. Pitts, and F.S. Zazueta, Bul. 265, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE094

Flushing Procedures for Microirrigation Systems, A.G. Smajstrla and B.J. Boman, Bul. 333, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/WI013

Irrigation Scheduling

Microirrigation in Mulched Bed Production Systems: Irrigation Depths, G.A. Clark and D.Z. Haman, Fact Sheet AE-49, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE049

Using Reference Evapotranspiration Data, G.A. Clark, Fact Sheet 251, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE073

Scheduling Tips for Drip Irrigation of Vegetables, D.Z. Haman and A.G. Smajstrla, Fact Sheet AE-249, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE092

Alternatives of Low Cost Soil Moisture Monitoring Devices for Vegetable in South Miami-Dade County. R. Muñoz-Carpena, Y. Li and T. Fact Sheet AE-230, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE230

Using Tensiometers for Vegetable Irrigation Scheduling in Miami-Dade County, T. Olczyk, Y. Li, and R. Munoz-Carpena, FactSheet ABE 326, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/TR015

On-farm Irrigation Scheduling for Vegetables Using the Watermark Soil Moisture Sensor, E. Simonne, A. Andreasen, D. Dinkins, J. Fletcher, R. Hochmuth, J. Simmons, M. Sweat, and A. Tyree, Proceedings of the 2001 Florida Agricultural Conference & Trade Show, Lakeland FL, October 2-3, 2001, pp. 17-22.

Basic Irrigation Scheduling in Florida, A.G. Smajstrla, B.J. Boman, D.Z. Haman, F.T. Izuno, D.J. Pitts and F.S. Zazueta, Bul. 249, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE111

Irrigation Scheduling with Evaporation Pans, A. G. Smajstrla, F. S. Zazueta, G. A. Clark, and D. J. Pitts, Bul. 254, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE118

Trickle Irrigation Scheduling. I: Duration of Water Application, A.G. Smasjtrla, D.S. Harrison, and G.A. Clark, Bul. 204, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla.

Potential Impacts of Improper Irrigation System Design, A.G. Smajstrla, F.S. Zazueta, and D.Z. Haman, Fact Sheet AE-73, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE027

Tensiometers for Soil Moisture Measurement and Irrigation Scheduling, A.G. Smajstrla and D.S. Harrison, Circ-487, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE146

Tensiometer Service, Testing and Calibration, A.G. Smajstrla and D.J. Pitts, Bul. 319, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/AE086

Nutrient Management

Commercial Vegetable Fertilization Principles, G.J. Hochmuth and E.A. Hanlon, Circ. 225-E, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/CV009

IFAS Standardized Fertilization Recommendations for Vegetable Crops, G.J. Hochmuth and E.A. Hanlon, Circ. 1152, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/CV002

Plant Petiole Sap-testing for Vegetable Crops, G. Hochmuth, Circ. 1144, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/CV004

Fertilizer Application and Management for Micro (Drip)-irrigated Vegetables, G.J. Hochmuth and A.G. Smajstrla, Cir. 1181, Fla. Coop. Ext. Ser., IFAS, Univ. of Fla. http://edis.ifas.ufl.edu/CV141

Soil and Fertilizer Management for Vegetable Production in Florida, pp.3-14, Simonne, E.H. and G.J. Hochmuth, In: D.N. Maynard and S.M. Olson (eds.) Vegetable Production Guide for Florida, Univ. of Florida, Gainsville, FL.

Table 1. A brief legislative history of the Best Management Practices (BMP).

Year	Origin	Legislation	Public law #
1948	US Congress	Water Pollution Control Act (WPCA)	89-234
1965	US Congress	Amendment to the WPCA created fed. approved water quality standards for interstate waters. Name changed to Water Quality Act	89-234
1972	US Congress	Amendment 303(d) to WQA introduced Total Maximum Daily Loads (TMDL). Name changed to Federal Water Pollution Control Act (FWPCA)	92-500
1977	US Congress	FWPCA amended to introduce BMP development and renamed Clean Water Act	95-217
1987	US Congress	Amendments 304(1) and 319 introduced the development of numerical rather than qualitative water quality criteria. New name: Water Quality Act	100-4
1987	Florida Legislature	The Florida Surface Water Improvement and Management (SWIM) ACT created a program which focuses on preservation of the state's water bodies that were in good condition, and restoration of some of its most significant water bodies.	373.451 - 373.4595

Table 2. Driving forces behind the vegetable BMPs.

BMPs are meant to be	Comments
Educational	Through teaching and demonstration, the BMP process aims at raising the level of nutrient and irrigation management of growers.
Economically sound	BMP implementation is not aimed at reducing production or crop value.
Environmentally robust	BMPs are tools to achieve the TMDLs and therefore reduce nutrient discharge.
Based on science	Only science-based information will separate the facts from the perceptions.

Table 3. Typical bed spacing used in vegetables production and corresponding linear bed feet per acre. This spacing is used for fertilizer recommendations. When a different bed spacing is used, fertigation should be adjusted accordingly.

Bed Spacing	Vegetable Crop	Linear Bed Feet in One Acre
4	Strawberry, lettuce	10,890
5	Muskmelon	8,712
6	Bell pepper, tomato, eggplant, cucumber, summer squash, cabbage, broccoli, cauliflower	7,260
8	Watermelon	5,445
Linear bed feet per acre are calculated by dividing 43,560 sq-ft per acre by the bed spacing.		

Table 4. Levels of fertilizer and water management and corresponding fertilization and irrigation practices for vegetables.

Management Level	Nutrient Management	Irrigation Management
0 - None	Guessing	Guessing
1 - Very low	Soil testing and still guessing	Using the "feel and see" method
2 - Low	Soil testing and implementing 'a' recommendation (not sure about how to correctly implement IFAS recommendations)	Using systematic irrigation for the entire growing season based on irrigation time (for example, three hours per day) and not water volume applied
3 - Intermediate	Soil testing, understanding IFAS recommendations, and correctly implementing them	Using a soil moisture measuring tool to start irrigation
4 - Advanced	Soil testing, understanding IFAS recommendations, correctly implementing them, and monitoring crop nutritional status	Using a soil moisture measuring tool to schedule irrigation and apply amounts based on a budgeting procedure
5 - Recommended	Soil testing, understanding IFAS recommendations, correctly implementing them, monitoring crop nutritional status, and practice year-round nutrient management and/or following BMPs	Adjusting irrigation to plant water use, and using a dynamic water balance based on a budgeting procedure and plant stage of growth, together with a soil moisture measuring tool and/or following BMPs

Table 5. Comparison of methods available for determining crop water use and their adoption level by the vegetable industry in Florida. Although the most promising method uses real-time potential evapotranspiration data, empirical methods are most commonly used by the industry.

Method	Principle	Advantages	Limitation	Level of Adoption by Industry
Historical potential evapotranspiration	Weather data from the past 30+ years are averaged to estimate ETo	IFAS recommended method Crop water use (ETc) simply calculated as ETc=Kc x ETo, where Kc is the crop coefficient	Year to year variability may be +/- 20% of the historical average Most Kc values available are for bare-ground production	None
Real time potential evapotranspiration	ETo is computed daily using site-specific, current weather data	Data more available as the FAWN system expands Increasingly attractive as the cost of small, on-farm weather stations keeps decreasing Crop water use (ETc) simply calculated as ETc = Kc x ETo, where Kc is the crop coefficient. Variable Kc allows daily irrigation adjustment depending on crop age and weather demand. Likely to be part of BMPs	Most Kc values available are for bare-ground production	Currently limited, but with real potential
Class A pan evaporation (Ep)	ETo is related to water loss from a free water surface	Crop water use (ETc) simply calculated as ETc = CF x Ep, where CF is the crop factor. For practical purposes, CF and Kc can be inter-converted Principle can be used with pans other the expensive class A pan Variable Kc allows daily irrigation adjustment depending on crop age and weather demand Possible alternative BMP method	Most CF values available are for bare-ground production Old method that was not adopted widely	Virtually unused; should be replaced by the method above
Atmometers	Water loss from a ceramic plate with a canvas cover mimics ETo	Simple principle: water loss from a small surface closely estimates ETo Units are rather inexpensive	Calibration data usually not available	None

Table 5. Comparison of methods available for determining crop water use and their adoption level by the vegetable industry in Florida. Although the most promising method uses real-time potential evapotranspiration data, empirical methods are most commonly used by the industry.

Method	Principle	Advantages	Limitation	Level of Adoption by Industry
Empirical methods	Rely on experience and individual knowledge to estimate irrigation needs	Simple to implement Most farmers' favorite	Based on experience, rather than science Typically results in over-irrigation early in the season, and sometimes under-irrigation during peak demand periods Likely to be insufficient in the BMP era	Industry standard

Table 6. Effect of irrigation amount on water movement in three vegetable growing areas of Florida. Increasing irrigation volume increases vertical downward movement at a faster rate than the lateral movement. Emitter-to-emitter coverage (length) was reached after 3 hours with 12-in emitter spacings, while it was reached in only one hour with 4-in emitter spacing.

Irrigation volume (gph/100 ft)	Irrigation Time (hr)	Vertical depth (in)	Width (in)	Length (in)	Vertical depth (%)	Width (%)	Length (%)
Hillsborough County - 12-in emitter spacing drip tape (27 gal/100ft/hr)							
27	1	9	11	10	66	25	83
54	2	12	15	11.5	73	38	92
81	3	14	16	11	97	43	100
108	4	13	17	11	97	51	100
162	6	17	20	12	110	54	100
216	8	17	22	12	110	64	100
Hendry County - 18-in emitter spacing drip tape (24 gal/100ft/hr)							
12	0.5	7	6	6	50	17	33
24	1	9	7	7	61	19	39
36	1.5	10	9	8	68	23	43
48	2	10	9	8	68	24	46
72	3	12	10	11	80	26	59
96	4	17	9	14	115	25	80
144	6	15	10	10	102	28	80

Table 6. Effect of irrigation amount on water movement in three vegetable growing areas of Florida. Increasing irrigation volume increases vertical downward movement at a faster rate than the lateral movement. Emitter-to-emitter coverage (length) was reached after 3 hours with 12-in emitter spacings, while it was reached in only one hour with 4-in emitter spacing.

Irrigation volume (gph/100 ft)	Irrigation Time (hr)	Vertical depth (in)	Width (in)	Length (in)	Vertical depth (%)	Width (%)	Length (%)
192	8	13	10	9	100	28	80
Gadsden County - 4-in emitter spacing drip tape (33 gal/100ft/hr)							
33	1	6	8	4	60	22	100
66	2	8	12	4	80	33	100
132	4	7	20	4	70	56	100
198	6	8	23	4	80	64	100
Vertical depth (V) = vertical length from the top of the bed to the bottom of the blue ring; Vmax = 15 in, except in Gadsen co. where a clay layer was found at the 10-in depth). Width = Hortizontal length perpendicular to the bed axis at the widest point of the wetting bulb; Wmax = bed width = 36 in at all three locations. Length = Horizontal length parallel to the bed axis at the widest point of the wetting bulb; Lmax = emitter spacing.							

Table 7. Comparison of soil moisture measuring devices available to vegetable growers. While cost of the unit is always an issue, adoption of these techniques has been mainly determined by maintenance, reliability and dedication issues.

Point of comparison	Tensiometer	Granular Matrix Sensor (GMS)	Dielectric probe	Time Domain Reflectometry (TDR) probe
Principle of operation	Direct measurement of soil suction: changes in moisture in a porous cup in equilibrium with the soil can be expressed as changes in air pressure inside the cup	Indirect measurement of soil suction: in saturated saline condition, electrical conductivity is a function of soil moisture tension	Indirect measurement of water content: the soil dielectric constant depends on soil moisture and can be measured as an electrical signal (in volts)	Indirect measurement of water content: the soil dielectric constant depends on soil moisture and can be measured as an the speed of travel of wave signal (in seconds)
Unit reported to user	Soil water tension (cb or kPa)	Soil water tension (cb or kPa)	Volumetric water content (%)	Volumetric water content (%)
Cost for a complete operating unit	$70-110	$400-480 ($40 for 2 GMS blocks, $400 for reader)	$525 ($150 for sensor, $375 for reader)	$585 ($260 for sensor, $325 for reader)
Life span	Several years	Few years for sensors, many years for reader	Many years	Many years

Table 7. Comparison of soil moisture measuring devices available to vegetable growers. While cost of the unit is always an issue, adoption of these techniques has been mainly determined by maintenance, reliability and dedication issues.

Point of comparison	Tensiometer	Granular Matrix Sensor (GMS)	Dielectric probe	Time Domain Reflectometry (TDR) probe
Fragility and risk of damage	Very high	Low to very low	Low	Very low
Set-up	Involved	Minor	Minimal	Minimal
Maintenance	High, very important	None	None	None
Time needed for equilibrium with soil (first reading)	Few hours	Few hours	Instantaneous	Instantaneous
Change in moisture reading in response to change in soil moisture	Fast	Fast for fine textured or well compacted soils, but slow for coarse-textured soils	Immediate	Immediate
Need for calibration	No (only adjustment)	Yes	Yes	No (yes)

Table 8. Components of the maintenance-is-best-medicine program for drip irrigation.

Component	Description and Comments	Few Do's and No-no's!
Filtration	Use 200-mesh filter or equivalent when ground water is used Consider media filters when surface water is used. Angular sand particles should be used. Centrifugal sand separators may be used where inorganic particle levels greater than 50 ppm are present	Do not remove or by-pass filters when they are clogged. Clean filter regularly
Chlorination	Hypochlorus acid (HOCl) is the chemical that controls bacterial growth HOCl may react with iron and create a precipitate [Fe(OH)3] More Cl is in the active HOCl form at lower pH: 90% at pH = 6.5 50% at pH = 7.5 20% at pH = 8.0 Inject enough chlorine to detect 1 ppm Cl at the end of the line See references on detailed chlorination procedure	Do not place chlorination point after filter. Instead, place it before, so that precipitates may be filtered out Do not skip chlorination When well done, chlorination will not damage the crop Do handle chlorination products with care
Acidification	Sulfuric (H2SO4), hydrochloric (HCl) and phosphoric (H3PO4) acid are the acids most commonly used. Do run a trial-test in a 55-gal drum to determine the amount of acid needed	Do not ignore the risks of cross precipitation with calcium (Ca) when H2SO4 or H3PO4 are used Do handle acids with care

Table 8. Components of the maintenance-is-best-medicine program for drip irrigation.

Component	Description and Comments	Few Do's and No-no's!
Flushing	Water velocity and pressure may be increased to 1 foot/sec at the end of laterals and pressure may be increased from 8-10 psi to 12 to 15 psi for flushing Self-flushing valves allow for flushing at every irrigation, although usually these valves do not provide flushing long enough and not at the 1 ft/sec rate Consider flushing every 2 to 3 weeks	After system is installed, allow for thorough flushing as soil materials are likely to be introduced in the system; then tie the ends Do not use self-flushing valves in situations where the system pressure is too low; they may never close
Observation	Regularly look for leaks and system malfunctions Measure water volume delivered, water travel time, and pressure changes regularly Observe crop growth pattern	Do not assume that everything is working properly! Be on the lookout Keep record of benchmark operating values

Table 9. Observation component of the prevention-is-best-medicine maintenance program: possible drip irrigation system checks and frequency during the growing season.

What to check?	How often?	Compared to what?	What to look for?	Possible Causes
Pump flow rate and pressure, for each irrigation zone	Weekly	Design, benchmark flow rate and pressure, or water travel time (using dye)	High flow and/or low pressure Low flow and/or high pressure No flow, no pressure	Leaks in pipelines or laterals Flush valves remain open Open end of laterals Closed zone valves Pipeline obstruction Tape clogging Pump malfunction Well problems Broken well shaft Drop in water level
Pressure difference across filter	At each irrigation	Manufacturer specifications	Exceeds or is close to maximum allowable pressure difference	Filter becoming clogged Obstruction in filter Sudden change in water quality
Operating pressures at ends of laterals	Monthly, unless other checks indicate possible clogging	Benchmark pressures	High end pressure Low end pressure	Possible clogging High system pressure Obstruction in tape Broken lateral Leaks in laterals Low system pressure

Table 9. Observation component of the prevention-is-best-medicine maintenance program: possible drip irrigation system checks and frequency during the growing season.

What to check?	How often?	Compared to what?	What to look for?	Possible Causes
Water at lateral ends and flush valves	Bi-weekly	Water source	Particles in water Other debris	Broken pipeline Missing filter screen Hole in filter screen Tear in filter mesh Particles smaller then screen Filter problem Chemical/fertilizer precipitation Algae growth Bacterial growth
Overall pump station	Weekly	Manufacturer's specification and values at startup	Leaks, breaks, engine reservoir levels, tank levels	Mostly mechanical
Injection pump settings	Weekly	Calibrating setting at startup	Reduced injection rate	Injector clogged with debris (check filter) Precipitates in the fertilizer (check fertilizer compatibility) Precipitation between high-calcium water and phosphates or sulfates in fertilizer
Overall system	Weekly	System at startup	Discoloration at outlets or ends of laterals Leaks in tape Wilting crop	Indicates possible build up of minerals, fertilizer, algae, and/or bacterial slime Pest or mechanical damage Tape off fittings Tape blow out from high pressure Insufficient irrigation and/or high crop transpiration rate Tape clogged, obstructed or broken Root disease (bacterial and/or fungal soil born diseases, nematodes)