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 UF/IFAS 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/newsletter/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 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

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(F.S. 376.307); (2) a presumption of compliance with state water quality standards [F.S. 403.067 (7)(d)]; and, (3) an opportunity 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 UF/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 UF/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 UF/IFAS recommendation using a spreadsheet format (Figure 1). Correctly implementing soil test results is essential in increasing nutrient management to a level acceptable in the BMP era (Table 4).

	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 UF/IFAS recommendations provides a weekly schedule for fertigation with liquid 8-0-8 (right column).

Some growers do not believe that economical vegetable yields can be produced with UF/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. UF/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. UF/IFAS definition of a leaching rain is 3 in. of rain in 3 days or 4 in. of rain in 7 days.

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. Figure 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. 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, Figure 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.

Figure 3. Tools and techniques available to estimate evapotranspiration and irrigation needs: (3.1) weather data may be simply downloaded from a small automated weather station to calculate reference evapotranspiration (ETo) and (3.2) water loss in the reservoir of the atmometer mimics ETo.

Irrigation principle 2. Irrigation amount should not exceed soil water holding capacity. Otherwise, water is wasted and mobile nutrients are leached. How far water moves down the soil profile is a rather abstract concept because it is not visible. However, it is possible to visualize soil water movements by using colored dyes (Figure 4). Wetting patterns are affected by soil type, irrigation amount, and emitter spacing (Table 6). In the sandy soils of Hillsborough and Hendry counties, the wetting front reached maximum rooting depths at irrigation rates nearing 80 gallons/100ft.

Theoretical highest irrigation amounts can be simply calculated based on the soil physical properties. For a soil where the wetting width is 12 inches (6 inches each side of the drip tape), assuming a 0.75 in/foot soil water holding capacity and allowing a 50% soil water depletion, the theoretical largest water amounts that can be stored in the soil are 24 gal/100 ft within the top 12 inches, 36 gal/100 ft within the top 18 inches, and 48 gal/100 ft within the top 24 inches. These numbers can be used as guidelines. Actual amount that can be applied in one irrigation also depends on the rate of crop evapotranspiration, number of drip tapes, and soil type. The difference between observed (Table 6) and theoretical maximum water holding capacity may be due to bed compaction and wetting widths greater than

12 in. Irrigation greater than the maximum water holding capacity is likely to leach mobile nutrients below the root zone. This is why irrigation, fertilization, BMPs and TMDLs are tied together.

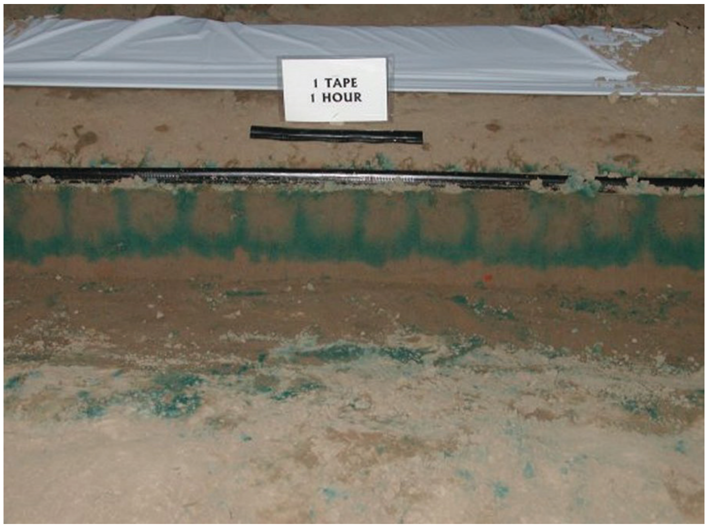

Figure 4. Soluble blue dye may be used to visualize wetting patterns and understand how irrigation volume affects water movement in the bed. For short irrigation times (1 hour) a more even water distribution pattern may be expected with a 4-in emitter spacing (4.1) than with an 12-in emitter spacing (4.2). Flow rates were 33 gal/100 ft/hr for the 4-in emitter spacing, and 30 gal/100ft/hr for the 12-in emitter spacing. The presence of an impermeable clay layer at the 10-in depth (in Gadsden county) resulted in lateral movement as shown in (4.3) where the blue dye is in the alley (between the 3rd and 4th bed from the right) after 6 hours of irrigation delivering 180 gal/100ft. The presence of water and soluble nutrients in the row middles will likely promote weed growth. Wetting patterns in the very compacted beds used for strawberry production in Hillsborough county are rectangular which corresponds to an increase in lateral water movement as shown in (4.4) after a 6-hr irrigation that delivered 144 gal/100 ft with a 12-in emitter spacing.

Irrigation principle 3. Rainfall contributes little to replenish soil moisture because of the plastic mulch. Several IFAS fertilizer recommendations for bare ground production allow for additional N and K fertilizer after leaching rains. Leaching rains are defined as three inches of rain in three days, or four inches in seven days**. However, it would take less rain to leach through the soil profile in the coarse soils found in South Florida**. Since the plastic mulch protects the bed from rainfall, there is no need to apply additional fertilizer after a leaching rain. However, when the field gets flooded, mobile nutrients may be leached out of the root zone or carried out of the field through surface run off. The need for additional fertilizer may be assessed after field drainage by monitoring sap tests levels of nitrate and potassium. Another consequence of using the plastic mulch is that an irrigation may be still needed after a small rain. Soil moisture measurements may be used to assess the need for additional irrigation.

Irrigation principle 4. Monitor soil moisture level daily to discover how much water stress the crop is exposed to. Soil moisture may be reported in terms of soil water tension (SWT) or volumetric water content (VWC). SWT represents the suction force that is necessary to free soil water from the soil attraction. The higher the value of SWT, the greater is the force needed. In some publications, SWT values are reported as negative values. The negative (-) sign is there to reflect the fact that the attraction is generated by the soil particles and therefore the plant has to spend energy to absorb water. SWT may be expressed in atmospheres (atm), bar (b), or kilo Pascals (kPa; the international unit). The conversion between units is 1 atm = 1.013 b = 101.3 cb = 100 kPa. The recommended range for vegetable production is to maintain SWT between 6 to 8 cb (field capacity) and 15 cb. Vegetables may tolerate SWT up to 25 cb without yield reduction on loamy soils. However, sandy soils with SWT above 15 cb may be difficult to re-wet. On the other hand, VWC represents the volume of water present in a volume of soil. VWC for sandy soils range between 14% and 18%, whereas it may reach 38% in clay soils. Instruments available for routine monitoring of soil moisture for vegetable crops are tensiometers, time domain reflectometry probes (TDR), and dielectric probes (Figure 5). Table 7 summarizes a comparison of these instruments in terms of cost, accuracy, response time, preparation, installation, management, and durability.

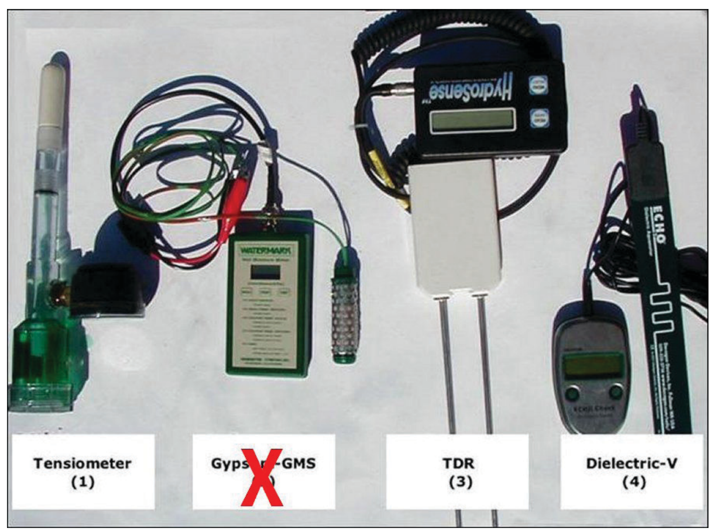

Figure 5. Soil moisture measuring tools currently available for vegetable crops.

Irrigation principle 5. Keep irrigation records daily. Vegetable growers are required to keep pesticide records. Fertilization records are usually kept in relation to soil testing and implementing the recommendations. However, vegetable growers seldom document their irrigation practices. For example, a daily log could contain soil moisture measurements (SWT or VWC) at selected depths, rainfall, an estimate of weather demand for water (evapotranspiration), and irrigation amount (gallons/field or duration of irrigation). Most growers who are already keeping irrigation records find them to be a useful management tool. It is likely that the documentation requested to support a BMP plan will include irrigation records, at the farm level and possibly at the field level.

Drip System Maintenance and Troubleshooting

Application uniformity of 85% to 95% is expected from a new, well-designed drip irrigation system (Figure 6). 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 (Figure 7). Without a maintenance plan, the risk of complete emitter clogging and crop loss becomes real.

Figure 6. Uniform growth and yield may be expected with drip irrigation (7.1) as shown here with strawberry. When the drip tape is not placed in the center, one row may be taller than the other (7.2) as shown here with bell pepper.

Every vegetable grower who uses drip irrigation should recognize that PREVENTION IS THE BEST MEDICINE in drip system maintenance. A maintenance plan should include (1) a filtration system, (2) chlorination and acidification, (3) flushing, and (4) regular observation of irrigation system components (Table 8 and Table 9).

Figure 7. Accumulation of precipitates around a drip-tape emitter (8.1) may result in an uneven water distribution pattern (8.2).

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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 UF/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 UF/IFAS recommendations, and correctly implementing them	Using a soil moisture measuring tool to start irrigation
4—Advanced	Soil testing, understanding UF/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 UF/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	UF/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
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
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
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	Hypochlorous 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
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
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)