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CUSTOM-MADE DRIP-IRRIGATION SYSTEMS FOR INTEGRATED WATER AND NUTRIENT MANAGEMENT RESEARCH AND DEMONSTRATIONS

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Abstract. **Randomized factorial combinations of fertilizer and irrigation treatments (rate and/or source) are essential to test best management practices (BMP) for vegetables grown with plasticulture. This requires fertilization and irrigation to be applied independently from one another. In the past few years, five types of drip-irrigation systems have been used in different experiments. Their selection and design are presented here, as well as their respective advantages and disadvantages. In Type I systems, single drip tapes of different flow rates are used to create simultaneously water and fertilizer rates, thereby confounding the effects of irrigation and fertilization. When irrigation or fertilization treatments involve sources, treatments need to be delivered independently to each plot. In this case, a Type II system includes several injectors connected to separate main lines. When treatments are rates only, a set of valves and water meters at each plot are used to apply treatments based on operating time (Type III). This type is simple, but requires an operator to close the valves at predetermined times. Type IV and V systems involve the use of multiple main lines and different apparent flow rates for each treatment. Different apparent flow rates may be created with drip tapes of different nominal flow rates or with multiple drip tapes bundled together. A single injector (Type V) may be used for small numbers of treatments (<10), but larger tests require the use of multiple injectors (Type IV). In all cases, changes in pressure and flow rate need to be monitored throughout operation. Because of their relatively low labor requirement for operation, Type I (with confounding of water and fertilizer effects) and to a lesser extend Type V (without confounding) are best suited for on-farm demonstrations.**

Approximately 60,000 acres of high-value vegetable crops are produced with plasticulture in Florida, including tomato (*Lycopersicon esculentum* Mill.), bell pepper *(Capsicum annuum* L. var. *annuum* Grossum Group), eggplant (*Solanum melongena* L.), strawberry (*Fragaria* × *Ananassa* Duchesne.) and watermelon (*Citrullus lanatus* (Thunb.) Mastum and Nakai) (Witzig and Pugh, 2001). Plasticulture is the production system where raised beds are covered with polyethylene mulch and water is supplied by drip irrigation. Drip irrigation systems used in commercial fields are designed for high delivery efficiency, high application uniformity, and also delivery of fertilizers and pesticides. Water and nutrient management

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are among today's top concerns of Florida's vegetable growers. First, producing economical yields of vegetables grown with plasticulture requires a high level of fertilizer and irrigation management. This translates into delivering adequate amounts of water, fertilizer, and/or pesticides at the exact time the crop needs it. In addition, reducing the environmental impact of agriculture while achieving economical yields has become a statewide priority with the implementation of the Federal Water Pollution Control Act of 1948 (33 USC 1251-1376; Chapter 758; PL 845; 62 Stat. 1155; amended in 1972 and 1977, thereafter known as the Clean Water Act) and the adoption of the Surface Water Improvement and Management (SWIM) act by the Florida Legislature in 1987 (Chapter 373.453-373.459, Florida Statutes). In this context, the development and testing of total maximum daily loads (TMDL) and best management practices (BMP), real-time irrigation scheduling research, as well as fertilizer source and rate research, especially nitrogen, require an integrated approach to irrigation and fertilization.

Management projects involving irrigation and/or fertilization require randomization, replication, and hence separate delivery of water and fertilizer to each plot. In most cases, this cannot be accomplished without modification of the existing drip irrigation systems. Drip systems typically used in production or research fields must therefore be customized to accommodate the needs of each specific project or demonstration. Several factors need to be considered in a step-by-step decision making process when designing a custom-made drip system. First, whether the effects of water and fertilizer have to be measured separately, or if an experimental design with confounding effects is acceptable, needs to be assessed. Then, the nature of the treatments (rate or source) needs to be identified. Finally, the availability of labor for system installation and operation must be determined. In addition, the cost of modifications due to additional parts and labor needs to be calculated. The objectives of this paper are to present several custom-made drip irrigation designs and to discuss their suitability for use in on-farm BMP demonstrations based on the nature of the treatments, costs, and labor requirements. As each situation is unique, so will be the irrigation system designs. However, for the sake of simplicity, custom designs will be discussed in five types based on the three steps described above (Fig. 1).

Step 1. Is a drip-irrigation system that confounds the effect of water and fertilizer suitable?

Yes -> Drip-system Type I

No -> Step 2

Step 2. What is the nature of the treatments?

Rates and sources mixed (water or fertilizer) -> Drip-system Type II

Rates only -> Step 3

Step 3. How much labor is available for system operation?

Labor is readily available -> Drip-system Type III

Some labor is available -> Drip-system Type IV

Labor is limited -> Drip-system Type V

Fig. 1. Decision tree for selection of drip system type for water and nutrient research and demonstration.

Materials and Methods

Because bed formation, soil fumigation, drip-tape placement, and mulching are usually done in a single operation, it is easier to customize the drip system after all these operations have been performed. Whatever the selected type of customization, the sound principles of system design (Haman and Smajstrla, 1997), maintenance (Clark and Smajstrla, 1998; Pitts et al., 1993), and operation (Simonne et al., 2001a) have to be followed. In particular, water pressure has to be maintained within the pressure range recommended by the drip tape manufacturer in order to achieve the expected nominal flow rate and uniformity. In addition, a water meter will allow monitoring of actual amounts of water applied.

Drip-system Type I. When the effect of water and fertilizer rates may be confounded, water/nutrient rate treatments may be created by replacing the existing drip tape by sections of drip tapes with a different flow rate (Fig. 2a; Table 1). This modification was used in a commercial tomato field in 2001 in Hendry County, Fla. where the grower's drip tape (24 gph/100 ft flow rate) was replaced in 300-ft-long beds by drip tapes with flow rates of 28, 40, and 60 gph/100 ft. In this test, the control was the grower's practice (100% water/fertilizer), and the treatments were 117%, 167% and 250% of the control.

Drip-system Type II. When the effects of water and fertilizer must be assessed separately (without confounding), source (of fertilizer or water) may be the source of variation, with or without rates (Locascio and Alligood, 1992; Locascio et al., 1997). These designs require the independent delivery of each treatment with a different main line (Type II, Table 1). This design requires a relatively large number of main lines (as many as there are different sources), while that of drip tapes may be limited to one in each plot (Fig. 2b). This type also requires one separate fertilizer injector for each fertilizer source tested, thereby increasing cost and labor requirements for operation.

Drip-system Type III. When research or demonstration objectives do not allow for confounding, when treatments are rates only, and when labor is available for daily operations, it is possible to insert shut-off valves at each plot (Fig. 2c). Treatments are created by the timing of each valve closing. At the beginning of an irrigation or fertigation session, all valves are opened, and the entire system is operated As time progresses, valves are closed each at their proper time. While this system requires only one main line and a single drip tape per plot, it requires the presence of an operator during the entire irrigation or fertigation session. Moreover, the risk for random errors (due to incorrect valve closing times) in treatment application exists. In addition, pressure may fluctuate as fewer and fewer plots are irrigated or fertigated as time passes. Even if a pressure regulator will alleviate this, inserting water meters at each plot is necessary to know precisely how much water each plot has received. This drip system type was used to test a modified crop factor for bell pepper under different N rates (Simonne, 2000).

Drip-system Type IV. When no confounding is acceptable, and when water and/or fertilizer treatments are rates of the same material, and when labor availability is limited, it is possible to create treatments with a single irrigation main line, and different apparent flow rates in each plot (Fig. 2d). The single main line is divided into two submains, one for fertilizer injection (and water), the other for water only. Both submains are used on days when no fertigation is scheduled. Different

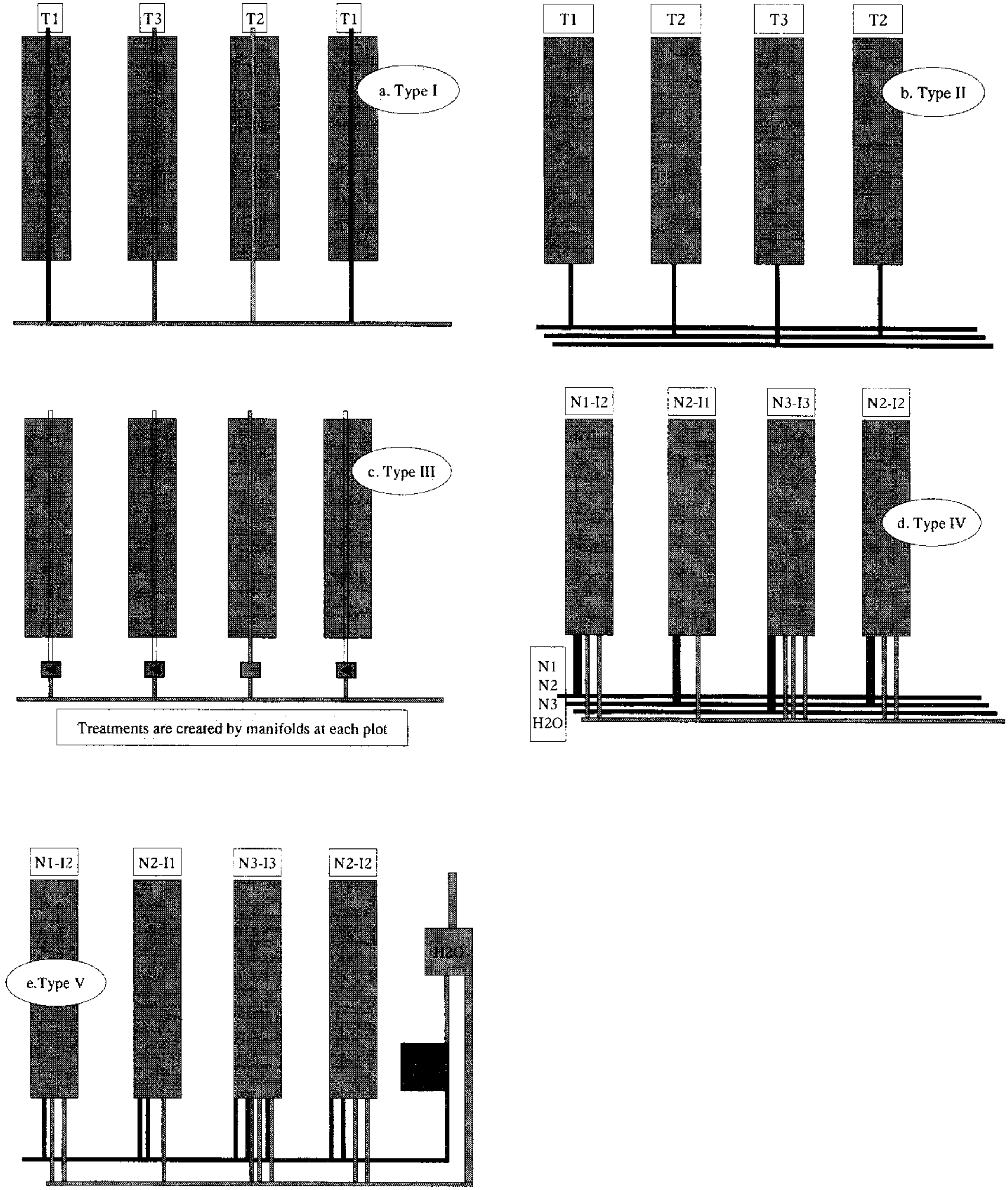

Fig 2. Schematic representation of drip irrigation systems Type I (a), II (b), III (c), IV (d) and V (e). See text and Table 1 for complete description of each type. Grey rectangles represent the mulched beds. T1, T2, T3, T4 and N_iI_j represent hypothetical treatments.

apparent flow rates may be created with drip tapes of different nominal flow rates, different numbers of similar drip tapes, or combinations. The actual number of drip tapes used will depend on the relative value of the treatments, and the nominal flow rates available. In all cases, it is preferable not to exceed five drip tapes in each plot. Bundles of six or more drip tapes

Table 1. Different types of drip systems for use in water and nutrient management research and their respective advantages and limitations.

Type	Description	No. of main lines	No. of fertilizer injectors	No. of drip tapes in each plot	Relative design complexity	Advantages	Limits
I	In an existing system, fertilizer/irrigation treatments are created by using drip tapes with different nominal flow rates.	1	1	1	Medium	• Treatments are applied "by design." • Unlimited number of treatments may be used. • Installation only requires switching drip tapes. • Practical for on-farm demonstrations. • No increased risk of leaks • Suitable for testing water and/or fertilizer rates.	• Confounding exists in effects of water and fertilizer. • Not suitable for testing water or fertilizer sources. • Requires the physical placement of drip tapes in each plot. Risk of plastic mulch zipping at that time.
II	Each factorial combination of irrigation and fertilizer rate is controlled by a separate injector. Treatments are created by the independent injection of water/fertilizer in each injector.	1 for each irrigation or fertilizer source tested	1 for each irrigation or fertilizer source tested	1	Very high	• Allows for factorial combinations of irrigation and fertilization treatments without confounding. • Allows for simultaneous testing of fertilizer rates or source, and of water quality and quantity. • Allows for a relatively large number of treatments (limited by the number of injectors available). • No changes required to the drip tape. No risk of zipping.	• Most costly system of all •Labor intensive at installation. • Multiple possibility of leaks due to increased number of connections. • The use of several injectors increases the time/supervision required for fertilizer injections; therefore unsuitable for on-farm demonstrations.
III	In an existing system, each plot is equipped with a shut-off valve. Treatments are created by the timing of valve closing.	1	1	1	Low	• Simple to install. • Extra cost of installation limited to that of shut off valves. • Allows for a large number of irrigation and/or fertilization rates without confounding.	• Very labor intensive when not automated as operator manually shuts off valves. • Risk of random error in shutting valves. • Pressure may increase as more valves are shut off. • Unpractical for on-farm demonstrations due to labor requirement. • Allows only one water or fertilizer source.
IV	Two independent drip systems are used independently: one for water, the other for fertilizer application. Treatments are created by the relative flow rates within fertilizer treatments, and cumulatively within the irrigation rates.	1 for water, 1 for each fertilizer treatment	1 for each fertilizer treatment	at least 2	High	• Allows for factorial combinations of irrigation and fertilization treatments • Treatments are applied "by design". The operator's role consist in checking total volume applied and injecting fertilizer. • Allows for a relatively large number of treatments.	• Requires the physical placement of drip tapes in each plot. Risk of plastic mulch zipping at that time. • Labor intensive at installation. • Multiple connections result in increased possibility of leaks. • The number of drip tapes in each plot should not exceed 5. • The use of several injectors increases the time/supervision required for fertilizer injections; therefore unsuitable for on-farm demonstrations.
V	Two independent drip systems are used together: one for water, the other for fertilizer application and water when fertilizer is not applied. Treatments are created by the relative flow rates within fertilizer treatments, and cumulatively within the irrigation rates.	2	1	at least 2	Medium to high	• Only one injector is used which shortens labor required for fertilization. • Allows for factorial combinations of irrigation and fertilization treatments. • Treatments are applied "by design." The operator's role is limited to checking total volume applied and injecting fertilizer. • Suitable for on-farm demonstrations due to the limited disruption to farmer's fertilization and irrigation practices.	• Number of treatments and relative ratios limited by the nominal flow rate of available drip tapes. • Requires the physical placement of drip tapes in each plot. Risk of plastic mulch zipping at that time. • Labor intensive at installation. • Multiple connections increase the possibility of leaks. • The number of drip tapes in each plot should not exceed 5.

Table 2. Combinations of drip tapes and apparent flow rates used to create simultaneous fertilization and irrigation treatments by using with multiple injectors in watermelon trials conducted in 2001 and 2002 at the North Florida Research and Education Center-Suwannee Valley[z] (Type IV, Table 1).

Treatments	Target ratios among treatments	Tapes used (no. and gphpe[y] nominal flow rate)	Apparent flow rate (gphpe)	Ratio achieved	Total no. of tapes used
			Irrigation		
I1	33%	1 @ 0.24	0.24	33%	1
I2	66%	2 @ 0.24	0.48	66%	2
I3	100%	3 @ 0.24	0.72	100%	3
I4	133%	4 @ 0.24	0.96	133%	4
			Nitrogen		
N1	75%	1 @ 0.24	0.24	100%	1
N2	100%	1 @ 0.24	0.24	100%	1
N3	125%	1 @ 0.24	0.24	100%	1

[z]The irrigation main line was separate from the fertilization main lines (one for each fertilizer rate) and hence could be operated separately. The water used to deliver the fertilizer was deducted from the amount of irrigation applied that day; see Simonne et al. (2001c) for complete methodology and results.
[y]gphpe = gallon per hour per emitter; all emitters spaced 12 inches apart.

are cumbersome, and may tear the mulch longitudinally (zipping), or even damage the transplants, when they are pulled under the plastic. In addition, increasing the number of drip tapes also increases the number of connections, thereby increasing the risk for leaks. Because of the limited number of flow rates available, the number of drip tapes needed in designs with large number of treatments may rapidly increase and become unmanageable. When larger number of treatments are needed, it may become necessary to use more than one injector for the fertilizer treatments (Type IV, Table 1). This allows one drip tape to be used for the fertilizer injection, by using a different fertilizer solution for each injector. The trade off is the increase in labor required to perform the injection. In a water and nutrient management test conducted

Table 3. Combinations of drip tapes and apparent flow rates used to create simultaneous fertilizer and irrigation treatments for use with a single injector in strawberry trials in 2000-2001 and 2001-2002 at the Gulf Coast Research and Education Center-Dover (Type V, Table 1).[z]

	Target ratios		Nitrogen treatments			Irrigation treatments				
Irrigation (I) and nitrogen (N) treatments	Irrigation	Nitrogen	Tapes used (no. and gphpe[y] nominal flow rate)[y]	Flow rate (gphpe)	Ratio achieved	Tapes used (no. and gphpe nominal flow rate)	Additional flow rate (gphpe)	Total flow rate (gphpe)	Ratio achieved	Total no. of tapes used
					2000-2001					
I1	100%									
N1		66%	2 tapes @ 0.38	0.78	66%	3 tapes @ 0.38	1.14	1.90	100%	5
N2		100%	3 tapes @ 0.38	1.14	100%	2 tapes @ 0.38	0.78	1.90	100%	5
N3		133%	4 tapes @ 0.38	1.52	133%	1 tapes @ 0.38	0.38	1.90	100%	5
I2	80%									
N1		66%	2 tapes @ 0.38	0.78	66%	2 tapes @ 0.38	0.78	1.52	80%	4
N2		100%	3 tapes @ 0.38	1.14	100%	1 tapes @ 0.38	0.38	1.52	80%	4
N3		133%	4 tapes @ 0.38	0.52	133%		0	1.52	80%	4
					2001-2002					
I1	60%									
N1		66%	1 tape @ 0.40	0.40	80%	2 tapes @ 0.25	0.50	0.90	60%	3
N2		100%	2 tapes @ 0.25	0.50	100%	1 tape @ 0.60	0.40	0.90	60%	3
N3		133%	1 tape @ 0.60	0.60	120%	2 tapes @ 0.15	0.30	0.90	60%	3
I2	80%									
N1		66%	1 tape @ 0.40	0.40	80%	2 tapes @ 0.40	0.80	1.20	80%	3
N2		100%	2 tapes @ 0.25	0.50	100%	2 tapes @ 0.15 + 1 tape @ 0.40	0.70	1.20	80%	5
N3		133%	1 tape @ 0.60	0.60	120%	1 tape @ 0.60	0.60	1.20	80%	2
I3	100%									
N1		66%	1 tape @ 0.40	0.40	80%	2 tapes @ 0.25 + 1 tape @ 0.40	1.10	1.50	100%	4
N2		100%	2 tapes @ 0.25	0.50	100%	1 tape @ 0.40 + 1 tape @ 0.60	1.00	1.50	100%	4
N3		133%	1 tape @ 0.60	0.60	120%	2 tapes @ 0.25 + 1 tape @ 0.40	0.90	1.50	100%	4

[z]The irrigation main line was separate from the fertilization main line. The fertilization main line was also used for irrigation; hence, the total apparent flow rate was the sum of the irrigation only and fertigation flow rate. Two water meters (one on the irrigation main line and one on the fertilization main mainline were used. See Simonne et al. (2001b) for complete methodology and results
[y]gphpe = gallon per hour per emitter; all emitters spaced 12 inches apart.

with watermelon involving 12 fertilizer-irrigation rate combinations (Simonne et al., 2001c), drip tape number per plot ranged between two and five (Table 2).

Drip-system Type V. When no confounding is acceptable, and when water and/or fertilizer treatments are rates of the same material, and when labor availability is limited, it is possible to create treatments with a single irrigation main line, and different apparent flow rates in each plot. When the number of treatments is relatively small (<10), it is possible to use a single injector to create water and fertilizer treatments (Fig. 2e). Thus, Type V is a simplified Type IV for fewer treatments. In addition, labor requirement for system operation is reduced since a single fertilizer solution is needed. Water and fertilizer treatments are both created by different apparent flow rates (Tables 1 and 3). This type was used for a research project on the effect of three N rates and two (in 2000) or three (in 2001) irrigation rates on strawberry yield (Simonne et al., 2001b).

Cost of drip system customization. Most small-scale drip systems (for less than 5-acre fields) require 0.5-inch pipes. For this diameter, common unit prices are $50 for water meters, $2 for shut off (ball) valves, a few dollars for each tee or elbow, and $60 for a Mazzi-type injector. In contrast, skilled labor cost is approximately $12 to $15 per hour. Therefore, labor cost is often the primary cost on these types of projects. Once experimental constraints have ben established (steps 1 and 2, Fig. 1), emphasis should be placed on labor needs for operation, even at the expense of design complexity.

Conclusions

All these custom-made drip-irrigation systems are designed for research and demonstration purposes. They are not intended to replace an existing grower design. However, they are valuable tools to compare irrigation and fertilization management levels within one field. On-farm demonstrations are an important aspect of BMP testing, especially in the context of the U.S. Environmental Protection Agency 319 (http://www.epa.gov/water/states/FL/) and Southern Region Sustainable Agriculture Research and Education (SARE; http://www.griffin.peachnet.edu/sare/) programs. Unless high levels of automation are achieved and skilled labor is available routinely, it is difficult to tie the demonstration treatments to the cooperator's existing irrigation system and fertigation program. Among the five drip system types discussed above, Type I (with confounding) and Type IV (without confounding) are the simplest designs to implement in growers' fields.

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