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A Continuously Diluting Injector for Applying Fertilizer to Experimental and Demonstration Plots

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Summary. Small-scale research plots and demonstrations of fertilizer application through a drip-irrigation system have inherent characteristics that make using commercial fertilizer injection systems difficult. Uniform fertilizer application, without excessive water, is essential for meaningful results in these small-scale, rate-specific studies. An inexpensive, easy to build, continuously diluting fertilizer injector is described. This injection system was reliable and provided uniform application under the confines of a low flow rate.

Drip-irrigation and fertilizer application through the irrigation system, known as fertigation, have revolutionized production systems for many horticultural commodities. Rapid adoption of these technologies by commercial producers has resulted in practices for which there is little supporting research. Researchers need reliable, accurate, small-scale injection systems to test fertigation rates, schedules, and materials for a variety of horticultural crops. In a recent project designed to evaluate six N rates applied daily via drip irrigation to small experimental tomato plots, the appropriate injection method was questioned (Lancaster et al, 1995). There are many types of fertilizer injectors for drip-irrigation systems designed to meet the needs of commercial producers; however, few injectors meet the requirements of researchers and extension personnel involved in small-plot research and demonstration, and they are expensive.

Selecting a fertilizer injection method for small-plot use should meet four criteria. First, the injection method must function at the low flow rates required for small experimental plots. The range of acceptable flow rates for drip irrigation is determined by intake and water-holding capacity and horizontal water conductivity of the soil. The application rate of a distribution system is defined by emitter discharge rate, line pressure, emitter spacing, and combined length of run of the drip-irrigation tubing. Inexpensive venturi-type injectors require minimum flow rates of >100 gal/h (380 $L \cdot h^{-1}$) and cannot function correctly when flow rates are restricted by short runs of drip-irrigation tubing.

Second, the system must provide uniform application across the length of individual experimental plots and between randomly located blocks. An injection method designed to overcome the low flow rate problem through rapid injection of the fertilizer material as a concentrated liquid mass of high conductivity or bolus at the proximal end of the distribution system has been shown to sacrifice application uniformity (Townsend, 1988). In addition, these methods often require long periods of flushing to disperse the bolus throughout the distribution system. This can result in leaching of freshly applied nutrients.

Third, the injector should be inexpensive enough that separate injectors could be used for each treatment and injection could occur over the same time frame via separate injectors. Moving a single injector from one set of treatment distribution lines to the next requires constant monitoring. Also, the time lapse between application of different treatments could influence results because application of treatments would occur under dissimilar circumstances of light intensity, temperature, soil moisture, etc. Commercially available injectors that provide accurate, uniform application under low flow rates and pressures are expensive. An example, the Dosatron (Dosatron International, Clearwater, Fla.) priced at about $250, uses hydraulic force to draw solution out of a nurse tank and proportion it into the distribution lines. These units operate at flow rates of 0.042 gal/min (0.16 $L \cdot min^{-1}$) and low pressures. The expense of several of these injectors could be cost-prohibitive for many research-project budgets and, particularly, for on-farm extension demonstrations.

Fourth, the injector must be dependable and easy to operate due to the rate-sensitive nature of fertigation research and demonstrations. Also, the amount of time that can be dedicated to managing the injection process may be limited. This is particularly true when daily applications are required or when research or extension personnel must depend on others to make applications.

Review of the literature concerning field research involving fertigation revealed that the injection method was rarely described or discussed. This leaves the reader to question whether fertilizer was applied uniformly or was ever moni-

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tored. Bar-Yosef (1977) referred to a continuously diluting method of fertilization with little explanation of the injection method. Hairston et al. (1981) suggested a method that used air pressure to eject fertilizer solution from a cylinder for delivery to small plots. With this method, pressure regulation and valves were used to control the injection rate. They also recommended a free-cycling manifold system to minimize pressure differentials influencing injection to small plots on nonlevel fields. They assumed that time lags between fertilizer treatments reaching distant points were of undue concern. It has been shown that uniformity of dispersion of fertilizer material can be greatly influenced by the injection method and degree of management given during the application process (Townsend, 1988).

The purpose of this project was to design an inexpensive fertilizer injection system for reliable, uniform fertilizer application to experimental plots using a drip-irrigation system limited to low flow rates.

Materials and methods

CONSTRUCTION. The continuously diluting injector (Fig. 1) designed for this project was easily constructed with readily available low cost materials. Total material costs for a single unit was about $75; this included secondary filtration and pressure reduction components. No special skills are required for construction. Injector components presented in Table 1 were either glued or threaded together using a heavy weight polyvinyl chloride (PVC) cement or Teflon pipe thread tape. The time to construct a single unit is ≈1 h. Orifices in the tank were drilled and tapped to accept the 0.5-inch (1.27-cm) thread of the nipple. The check valve prevented back flow and the pressure reducer lowered mainline pressure into the operational range of the drip-tape. A 100-µm screen filter provided secondary water filtration to remove suspended, postinjected particles while a media filter served as the primary filter. Media, screen, or sand separation type primary filters appropriate for the amount of particulate matter in the water supply are required before fertilizer injection.

This system, comprised of a bank of continuously diluting injectors, was designed and successfully used in a study to determine the effects of variable N rates on yield and tissue nutrient levels of staked tomatoes (Lancaster et al., 1995). The experimental design was a randomized complete block with six N treatments and four replications. Five continuously diluting injectors, whose daily solution load represented five total N rates, were coupled via flexible vinyl discharge hose and PVC reducing tees [PVC reducing tee specifications: 2 inch × 2 inch × 0.5 inch (5.08 cm × 5.08 cm × 1.27 cm; insert × insert × reducing insert] and are presented in Fig. 2. A null delivery unit, which did not introduce fertilizer, prevented back flow, reduced pressure, and provided secondary filtration and was configured from a check valve, pressure regulator, and screen filter. A general schematic of the six-treatment injector bank, including null treatment and accompanying distribution system, is illustrated in Fig. 3. Mainline components consisted of a pump, media filter, main valve, and a back-flow prevention device. The mainline itself was vinyl layflat. The first division of the main supply line accommodated five treatment dilutors and the null treatment. Polyethylene tubing (0.5 inch) served as treatment distribution lines from specific injectors to Typhoon 13 (Netafim Irrigation Inc., Valley Stream, N.Y.) drip-irrigation tape.

OPERATION. A 2-h fertigation cycle was applied by closing containment valves on opposite ends of the injection tank and fully opening the throttle valve (Fig. 1). The injection tank was filled

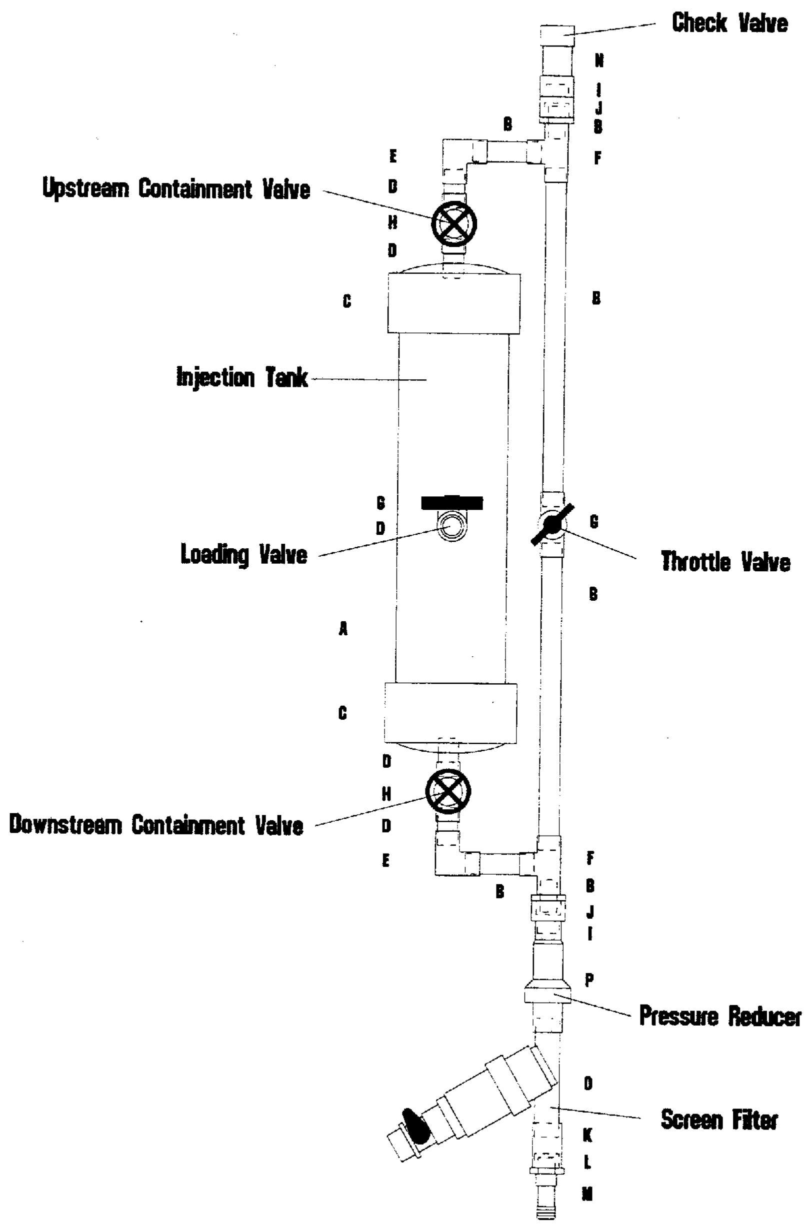


Fig. 1. Continuously diluting fertilizer injector for a small-plot drip-irrigation system. Alphabetic characters can be referenced to Table 1.

Table 1. Materials list for continuously diluting fertilizer injector.

Part[z]	Quantity	Size and fitting	Material
A	1	4 inch	PVC Sch 40, 18-inch pipe
B	1 each	1/2 inch	PVC Sch 40, 14-, 3-, and 1-inch pipe
C	2	4 inch	PVC Sch 40, Cap
D	5	1/2 inch; MIPT × MIPT	PVC Sch 80, 2-inch nipple
E	2	1/2 inch; Fslip × FIPT	PVC Sch 40, elbow
F	2	1/2 inch; Fslip × Fslip × Fslip	PVC Sch 40, tee
G	2	1/2 inch; Fslip × Fslip	PVC Sch 40, ball valve
H	2	1/2 inch; FIPT × FIPT	Stop and waste valve
I	2	3/4 inch; MIPT × Fslip	PVC Sch 40, adapter
J	2	3/4 × 1/2-inch; Mslip × Fslip	PVC Sch 40; Adapter
K	1	3/4 inch; FIPT × Fslip	PVC Sch 40, adapter
L	1	3/4 × 1/2 inch; Mslip × FIPT	PVC Sch 40, Adapter
M	1	1/2 inch; Insert × MIPT	PVC Sch 80, adapter
N	1	3/4 inch; FIPT × FIPT	Nylon check valve
O	1	3/4 inch; MIPT × MIPT	Screen filter[y]
P	1	3/4 inch; FIPT × FIPT; 10 psi at 0.5–5 gal/min	Pressure reducer[x]

[z]Refer to Fig. 1. MIPT = male iron pipe thread, FIPT = female iron pipe thread, Mslip = male slip, Fslip = female slip, Sch = schedule, PVC = polyvinyl chloride.
[y]Amaid Filtration and Irrigation systems, Chevel Korazin, Israel.
[x]Senninger Irrigation, Orlando, Fla.

with a predetermined amount of nutrient solution through the injection tank loading valve. The complete delivery system was allowed to reach operational pressure, which was defined as when the furthermost point from the pump was at full pressure. The upstream containment valve was completely opened, allowing the injection tank to fill, followed by partial opening of the downstream containment valve, and partial closing of the throttle valve. These settings were verified during preservice calibration, as described below. After 60 min, the throttle valve was closed and the downstream containment valve was completely opened, diverting all flow through the tank. This continued for an additional 60 min. Additional irrigation requirements beyond those required for fertilizer delivery may be based on demand determined by a tensiometer.

Calibration. The strategy of injector calibration is to inject the required amount of fertilizer over the longest possible period and to fix the flow rate through the diluter so that the flow just empties the vessel in the run time available. This produces greater field uniformity than methods that compress fertilizer injection into relatively short periods followed by relatively long periods of flushing (Townsend, 1988). To accomplish this, the volume of the injection tank must be well matched to the water volume that will pass through it in the run time. The continuously diluting injector described above, with a tank capacity of 1.06 gal (4.0 L), was well matched to the 30.38-gal/h ($115\text{-}L\cdot h^{-1}$) flow rate at 10 psi (69 kPa) of the four-block distribution system described in the construction section above. Adjusting the throttle valve and the downstream containment valve provided some level of control of the injection tank dilution rate by allowing some water to bypass the direct dilution process. Diluter calibration was a process of trial and error that must be completed before placing the distribution network in service.

Verifying uniformity of distribution. A treatment delivery system, as described above, was assembled on a level field to verify uniform application of nutrient solution across treatment plots and between replicates. Plot length was 40 feet (12.2 m) and distance between the four replications varied from 9.8 to 105 ft (3 to 32 m). Under every other drip tape-emitter, a 1-gal (3.8-L) plastic container was placed to capture

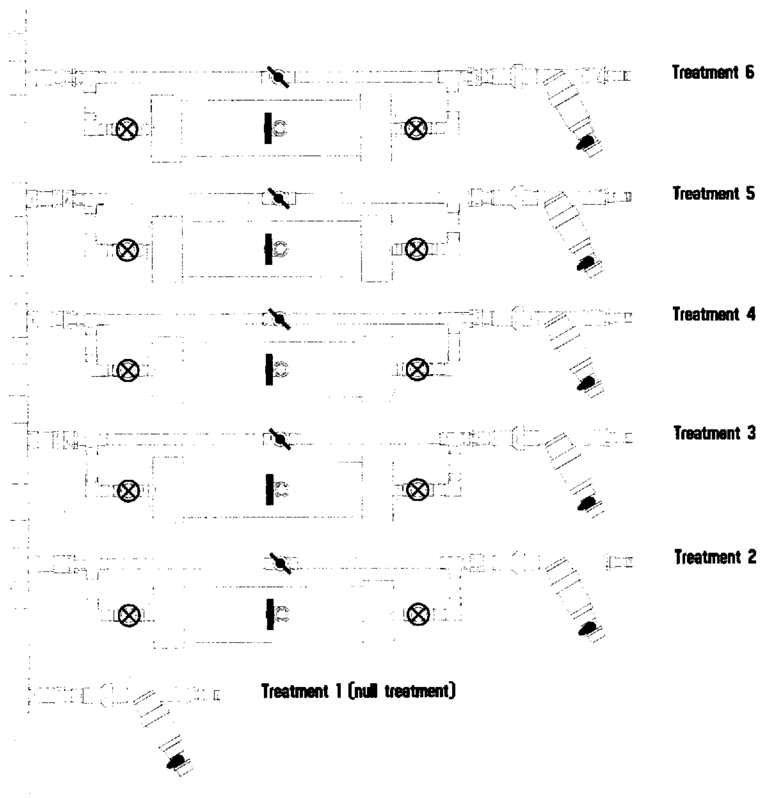
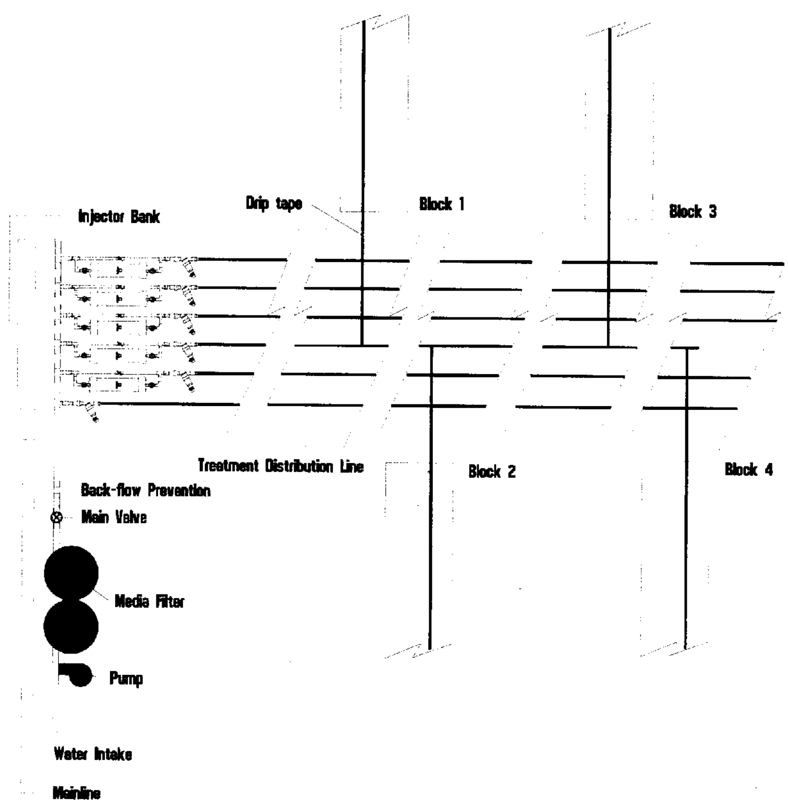


Fig. 2. A bank of five continuously diluting injectors representing five N-rate treatments and a null treatment configuration.

the fertigation solution. The injection tank of the continuously diluting injector was filled with a KNO_3 solution with an electrical conductance of 86.4×10^{-5} mhos/cm. The system was then charged and allowed to reach operating pressure before solution was released into the irrigation stream. Release was performed as described above. Upon completion of the cycle, the captured fertigated solutions were stirred vigorously and a representative sample was transferred to glass sample jars. Electrical conductance of each sample was measured using an electrical conductance meter. Electrical conductance of the 40 samples ranged from 3.74×10^{-5} to 0.75×10^{-5} mhos/cm with a mean conductance of 2.02×10^{-5} mhos/cm.

Data were evaluated statistically using PROC ANOVA of SAS (SAS Inst., Inc., Cary, N.C.). The null hypothesis of uniform solution distribution across the experimental plot failed to be rejected by the F test ($P = 0.5990$), i.e., the ANOVA failed to reject the null hypothesis. Therefore, it must be conceded that solutions were of equal concentrations. Uniform application across replications was also verified. A sample taken from the injection tank of the injector at completion of the run had a conductance of 1.36×10^{-5} mhos/cm. This value, which was similar to that collected from a single emitter, verified that the solution in the 1-gal injector tank had been adequately diluted. Furthermore, the volume of the injector tank and regulated out flow was well proportioned to the 60.8 gal (230 L) of water irrigated through the vessel in the 2-h run time.

Fig. 3. A fertilizer distribution network incorporating the continuously diluting injector and the null treatment in a randomized complete-block design. To simplify the illustration, only one of six treatments is shown with lateral lines connected to all four blocks.



Discussion

The challenge of using a continuously diluting injector in any research or demonstration project is sizing the dilutor to the water flow rates dictated by the crop, soil, and distribution system. Dilution rate through the injector must minimize the bolus effect described by Townsend (1988). At the same time, flow of water through the system during and following injection must be minimized to prevent leaching of nutrients out of the root zone of the crop during application while emptying the contents of the injection tank.

The time required to verify application uniformity relative to a specific delivery system is a limitation to the continuously diluting injector. This includes repetitive setup, capture, and solution analysis operations, as well as possible resizing of the injector tank.

The continuously diluting injector proved functional at low flow rates characteristic of small plots operating at a flow rate of 30 gal/h at 10 psi . Application of treatments is uniform across plots and replicates. The injector is inexpensive, constructed from readily available components valued at about $75.00 and assembly is straight forward requiring no special skills. Once in place, the continuously diluting injector is easy to operate and dependable. Operation procedures are easy to convey to first time operators. Daily management requirements, consisting of loading a bank of injectors with measured stock solutions, charging the system, releasing the nutrient loads, and shutting down, can be accomplished in <30 min. All system components have proven to be reliable. No maintenance was required in a 14-week operation period consisting of daily injections.

Fertigation schedules vary with crop. Most schedules attempt to supply nutrients as they are needed. When combined with weekly foliar nutrient sampling, fertigation techniques are particularly valuable. If shortages of preplant-applied elements occur, they can be added via the drip system or foliar application. The continuously diluting injector can be used by researchers or extension personnel involved in small-plot research and demonstration to deliver treatments targeted toward fertigation methodology.

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