vivo: Theory and application. Ann. Rev. Plant Physiol. 15:451-470.
Campbell, R.J., K. Mobley, R. Marini, and D. Pfeiffer. 1990. Growing conditions alter the relationship between SPAD-501 values and apple leaf chlorophyll. HortScience 25:330-331.
Eagles, H.A., A.K. Hardacre, I.R. Brooking, A.J. Cameron, R.M. Smillie, and S.E. Hetherington. 1983. Evaluation of a high altitude tropical population of maize for agronomic performance and seedling growth at low temperature. New Zealand J. Agr. Res. 26:281-287.
Evans, J.T. 1985 Nitrogen and photosynthesis in the flag leaf of wheat. Plant Physiol. 72:297-302.
Gausman, H.W. 1985. Plant leaf optical properties in visible and near-infrared light. Texas Tech Press, Lubbock.
Hardacre, A.K. and H.F. Nicholson. 1984. A portable photometer for the measurement of chlorophyll in intact leaves. New Zeland J. Expt. Agr. 12:357-362.
Hains, J. 1985. Practical considerations for routine chlorophyll measurements: Precautions and comparison of extraction methods. J. Freshwater Ecol. 3:175-179.
Hiscox, J.D. and G.F. Israelstam. 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. Can. J. Bot. 57:1332-1334.
Maas, S. and J. Dunlap. 1989. Reflectance, transmittance, and absorbance of light by normal, etiolated, and albino corn leaves. Agron. J. 81:105-110.
Macnicol, P., M. Dudzinski, and B. Condon. 1976. Estimation of chlorophyll in tobacco leaves by direct photometry. Ann. Bot. 40:143-152.
Marquard, R.D. and J.L. Tipton. 1987. Relationship between extractable chlorophyll and an in situ method to estimate leaf greenness. HortScience 22:1327.
Minolta. 1989. SPAD-502 Owner's manual. Industrial meter division. Minolta Corp., Ramsey, N.J.
Palta, J. 1990. Leaf chlorophyll content, p. 207-213. In: N. Goel and J. Norman (eds.). Instrumentation for studying vegetation canopies for remote sensing in optical and thermal infrared regions. Remote Sensing Revs. vol. 5(l).
Porra. R.J. W.A. Thompson. and P.E. Kriedemann. 1989. Determination of accurate extinction coefficients and simultaneous equations for assaying chlorophylls a and b extracted with four different solvents: Verification of concentration of the chlorophyll standards by atomic absorption Spectroscopy. Biochem. Biophys. Acta 975:384-394.
Seemann, J.R., T.D. Sharkey, J. Wang, and C.B. Osmond. 1987. Environmental effects on photosynthesis, nitrogen-use efficiency, and metabolite pools in leaves of sun and shade plants. Plant Physiol. 84:796-802.
Singha, A. and E.C. Townsend. 1989. Relationship between chromaticity values and chlorophyll concentration in apple, grape, and peach leaves. HortScience 24:1034.
Snedecor, G. and W. Cochran. 1980. Statistical methods. Iowa State Univ. Press, Ames.
Terashima, I. and T. Saeki. 1983. Light environment within a leaf. Plant & Cell Physiol. 24:1493-1501.
Vogelmann, T.C. 1986. Light within the plant, p. 307-337. In: I. Kendrick and R.E. Kronenberg (eds.). Photomorphogenesis in plants. Martinus Nijhoff, Dordrecht, The Netherlands.
Vogelmann, T.C. 1989. Penetration of light into plants. Photochemistry & Photobiology 50:895-902.
Yadava, U.L. 1986. A rapid and nondestructive method to determine chlorophyll in intact leaves. HortScience 21:1449-1450.

A Pulsed Subirrigation System for Small Plots

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Abstract. **A schematic diagram and parts list is presented for a simple and inexpensive system for pulsed subirrigation (commerically referred to as ebb and flow or flood and drain). The system can be readily modified for flowing solution culture. It has proven useful in teaching and research applications. It can be assembled from readily available parts using hand tools.**

Intermittent or pulsed subirrigation systems (commercially referred to as ebb and flow, or flood and drain) have substantial advantages in greenhouse crop production, including the potential to significantly reduce runoff of water and fertilizers (Elliott, 1990). Research is needed to provide fertilizer recommendations and to investigate media-fertilizer interactions relevant to crop production using this method. As these systems are being widely adopted in the industry, students of greenhouse management and crop production need to learn the principles of pulsed subirrigation in greenhouse operations.

Commercially pulsed irrigation systems are available, but these systems may be difficult to use in research and teaching applications. Because of the size and expense of these systems, it is difficult to provide for true replication of treatments in which the basic unit of observation (research plot) involves factors that require separate irrigation capabilities, such as fertilizer composition, growing medium, or crop. For these reasons, I have developed a simple, modular system for small-plot pulsed subirrigation experimental units.

In this system (Fig. 1), the basic unit comprises a tray to which a single treatment is assigned. Irrigation solution is pumped into the tray by a centrifugal pump from a reservoir. The level of solution in the tray is regulated by an overflow outlet. When the pump shuts off, the solution returns to the reservoir via the inlet line. The tray can be supported by a frame that allows the inlet and return lines to be fitted, or can rest directly on the reservoir.

The tray (parts list item 1) is a commercial nursery flat, without drainage holes, made of structural foam plastic (Kadon Corp., Dayton, Ohio, mode1 2014-4-P). The structural foam is thick enough (6.5 mm) to drill and tap for a threaded fitting (parts list 14). The inlet fitting must be flush with the inner surface of the tray, so that the tray drains completely at the end of the irrigation cycle. An earlier model, similar to the microcosm proposed for toxicity testing by the Environmental Protection Agency (Federal Register, 1987), used a thinner tray with the inlet fitting welded or glued to the underside of the tray, but these tended to leak or break off. A hole saw is used to cut an opening for a bulkhead fitting (parts list 2) for the overflow return line. Either a single or dual thread bulkhead fitting can be used. The dual thread has the advantage of allowing the use of a threaded fitting (parts list 3) as a standpipe to adjust the solution height in the tray. Without a standpipe, the solution will rise to -1 cm. If this flexibility is not required, a single thread fitting is less cumbersome and less expensive.

The irrigation solution (water or nutrient solution) is contained in a reservoir (parts list 8). I have found that » 8 to 10 liters/tray is required to fill the tray to a depth of 1 cm while maintaining enough solution in the reservoir to keep the pump submerged. A cover to reduce evaporation and contamination is useful but not essential. Solution can be added to the reservoir manually or with an automatic fertilizer proportioner. The solution is pumped into the tray by a small submersible centrifugal pump (parts list 9; Little Giant Pump Co., Oklahoma City, Okla., model NK-1). The pump can be controlled by a spring-wound appliance timer (M.H. Rhodes, Inc., Avon, Conn., model 78305) or a conventional repeat cycle time clock. Solution inlet flow rate can be controlled with a quarter-turn valve (parts list 15; Gilmour Mfg., Somerset, Pa., model 07V). Depending on the physical relation of the tray and reservoir, it may be more convenient to locate the valve near the point at which the inlet supply line leaves the reservoir.

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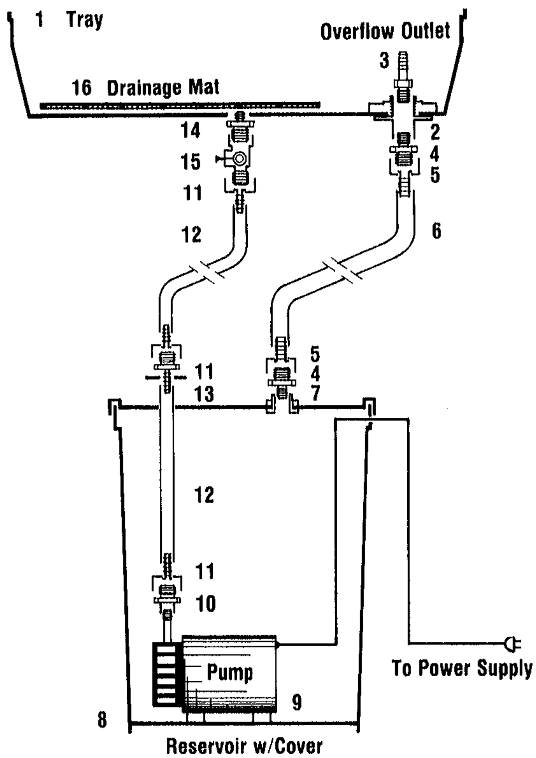

Fig. 1. Schematic diagram of pulsed subirrigation tray system. All fitting and tubing sizes are expressed as nominal dimensions. Abbreviations used: mpt, male pipe thread; fpt, female pipe thread; mht, male garden hose thread; fht, female garden hose thread; i.d., inside diameter. Parts list: 1, Structural foam tray, 36 × 50 × 10 cm; 2, Bulkhead fitting, 1/2" dual thread; 3, Adapter, 1/2" mpt × 1/2" barb; 4, Adapter, 1/2" mpt × mht; 5, Swivel, fht × 1/2" barb; 6, Garden hose, 1/2" i.d.; 7, Bulkhead fitting, 1/2" single thread; 8, Bucket (18-liter) with lid; 9, Submersible pump with 1/4" mpt outlet; 10, Adapter, 1/4" fpt × mht; 11, Swivel, fht × 1/4" barb; 12, Polyethylene tubing, black 1/4" i.d.; 13, Adapter, mht × 1/4" barb; 14, Adapter, mht × 3/8" mpt; 15, Ball valve, 1/4 turn; 16, Drainage mat.

The inlet line is black polyethylene tubing, while the return line is ordinary garden hose. All connections are made with garden hose thread fittings to simplify plumbing and allow rapid interchange. The garden hose fittings and pipe thread-garden hose adapters (parts list 3, 4, 5, 10, 11, 13, 14) are widely available from plastic suppliers. The fittings used to attach the return line to the tank cover (parts list **4,** 5, **7)** are not essential, but are useful to prevent accidental dislodging of the return line.

Several trays may be supplied from one reservoir using tee fittings in the inlet and return lines. This is useful for factorial experiments using split-plot designs in which fertilizer solution composition is the major plot. Each tray can be irrigated separately, allowing the use of individual trays as subplots.

The system has proven useful for research in greenhouse and growth chamber applications, including comparisons of water and fertilizer use in crop production with subirrigation and overhead irrigation systems (Elliott, 1990), water retention by potting media, and fertilizer-media interactions in bedding plant production. The system could also be used, with minor modifications, for continuous-flowing solution culture (Elliott and Nelson, 1983). The cost of an individual system, exclusive of labor and time, was about $80 in 1991. Economy of scale is possible since the timer can control more than one pump, and a single reservoir and pump can supply more than one tray. A single system can easily be set up in 2 h.

Literature Cited

Elliott, G.C. 1990. Reduce water and fertilizer with ebb and flow. Greenhouse Grower 8(6):70-75.

Elliot, G.C. and P.V. Nelson. 1983. Relationships among nitrogen accumulation, nitrogen assimilation and plant growth in chyrsanthemums. Physiol. Plant. 57:250-259.

Federal Register. 1987. Rhizobium-legume chronic toxicity test. Federal Register 52(187):36341-36343.