THE EFFECTS OF IRRIGATION METHOD ON PLANT GROWTH, WATER AND NUTRIENT EFFICIENCY, AND RUN-OFF

BY

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The purpose of this study was to determine the effect of water and fertilizer efficient irrigation systems and methods on the growth of greenhouse floriculture crops. The information gained from this research will enable growers to efficiently produce high quality plants while minimizing the amount of nutrients released to the environment.

This research was the fourth year of an on-going project funded by the Oklahoma Agricultural Experiment Stations to promote the use of water and fertilizer conserving greenhouse practices. I want to thank my principle advisor Dr. John Dole for having faith in me as a research assistant and giving me the guidance, assurance, and encouragement I needed.

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CHAPTER I

INTRODUCTION

Improving the quality of water released from large containerized production nurseries and greenhouse operations is an increasing concern to both growers and consumers. Container crop production is limited by the amount of nutrients and water available to the plant because of the small volume of growing medium held within the containers. This limitation leads to more frequent irrigation and fertilization compared to plants grown in the field without container restriction. The result of intense irrigation and fertilization is possible contamination of ground and surface water sources. Many large nurseries and greenhouses are located near surface and underground water sources. Horticultural operations often use water from, and release run-off containing nutrient and pesticide pollutants back into these sources. Reducing potential contamination of these waters is a regional as well as state concern since river and underground aquifers often cross state lines. Thus, residents of several states may use potentially contaminated water for drinking and irrigation.

Over 99% of the earth's nitrogen is in the form of N_2 and is unavailable to plants. Nitrogen is made available to plants by the process of fixation where microorganisms and certain atmospheric phenomena, such as lightning, convert nitrogen to NH_3, the first plant available form. From this point soil nitrogen is subject to volatilization or mineralization to form NH_4, which is then either taken up by the plant, immobilized, or converted to

NO_3 by the process of nitrification. At the end of the nitrogen cycle, denitrification occurs, converting NO_3 back to atmospheric nitrogen. Fixation and denitrification occur at approximately equal rates, while soil nitrogen processes may be affected by conditions in the soil such as pH, temperature, and moisture. Soilless medium allows greater leaching of NH_4 than field soils where natural exchange sites and clay minerals bind ammonium ions. Nitrate is also more susceptible to leaching due to the small volume of medium in the container where the nutrient solution is often partially or completely replaced at each irrigation.

The importance of research leading to environmentally sound crop management is illustrated by nitrate loading to underlying greenhouse soils. Common practice is to apply soluble forms of fertilizer with irrigation water. Plants are irrigated with water amounts exceeding what the media can retain, allowing for beneficial leaching of excess nutrients and preventing damaging soluble salt buildup. The water and chemicals leached from the growing media then drain to the greenhouse floor which is generally porous. The water may then leach through to underlying soils. Soils underlying greenhouses are often excessively compacted. The glazed greenhouse structures exclude rainfall, allowing loading of nitrates to groundwater sources (Molitor, 1990). In addition to nitrates, phosphorus, minor elements, and pesticides may also be a potential cause of contamination. If containerized plants could be grown with less leaching, water and nutrient efficiency would increase while reducing the amount of contaminates released to the environment through run-off. In addition, the cost of fertilizer and water may be reduced.

New water and nutrient control regulations and standards will likely be implemented during the next few years by federal, state, and local agencies (Conover and Poole, 1992). Compliance is of highest concern to most growers, yet producing a high quality, salable plant is crucial to a greenhouse business. Plant quality and protecting the environment must be carefully balanced through the use of water conserving irrigation methods and environmentally sound cultural practices.

IRRIGATION SYSTEMS

Several studies have indicated that high quality plants can be grown using subirrigation systems (Conover and Poole, 1992; Dole et al., 1994; Yelanich and Biernbaum, 1994). Yelanich and Biernbaum (1990) found that subirrigated plants were of acceptable quality and noted that the excessive run-off produced in greenhouse production could be controlled by decreasing the amount of water and fertilizer applied at each irrigation or by changing to a subirrigated system with recirculated water and fertilizer solutions. When compared to overhead irrigation, ebb-and-flow produced higher quality plants (Conover and Poole, 1992, Dole et al., 1994). Ebb-and-flow irrigation, at a fertilizer rate of 175 mg/liter of nitrogen, produced poinsettias with the greatest total dry weight per liter of water applied, when compared to capillary mats, hand-watering, and microtube (Dole et al., 1994).

On the other hand, capillary mat subirrigation used the highest amount of water and released the greatest amount of run-off when compared to ebb-and-flow, hand-watering, and microtube irrigation (Dole et al., 1994). Alleman and Weiler (1994) noted contrasting results, where water efficiency was significantly increased by using recirculated irrigation water with capillary mats.

Microtube irrigation systems, also referred to as trickle or drip irrigation, are used in outdoor containerized or field crop production. Rathier and Frink (1989) found that in containerized juniper and spruce production, trickle irrigation used less water and released run-off with a lower N concentration than overhead sprinkler irrigation, while N loading to the soil and N loss due to leaching were decreased. For greenhouse production, microtube irrigation caused more water to be retained in the media and produced plants with the greatest dry weight compared to capillary mats, ebb-and-flow, and hand-watering (Dole et al., 1994).

Types of overhead irrigation include sprinklers, mist systems, and manual or hand-watering. Yelanich and Biernbaum (1990) found that a 10-15% LF is recommended for overhead watering, but noted that some growers leach more than 40-50%. Dole et al. (1994) found that hand-watering produced higher quality plants only at a higher fertilizer rate than other irrigation systems. For example, hand-watering produced plants with greater dry weight at 250 mg/liter N than at 175 mg/liter N, with a greater volume of run-off than microtube irrigation (Dole et al., 1994).

IRRIGATION FREQUENCY

Along with the method of application, the amount of water applied and the frequency at which plants are irrigated can greatly effect plant growth and run-off. Conover and Poole (1992) noted that irrigation amounts above 100 ml/pot applied twice daily increased NO_3 and P in the leachate with no significant increase in foliage plant quality or fresh weight. Also, leaching was eliminated with no difference in quality for short term crops by applying less water at shorter intervals (Poole and Conover, 1992). Fare et al. (1994) found that applying water in two or three cycles rather than an equal amount in one continuous application decreased total effluent, container leachate, and nitrogen loss while increasing plant growth.

Stewart et al (1981) found that privet watered daily had thicker stems, greater height, and wider diameters with significantly more dry weight than plants irrigated every other day (bidaily); this difference was attributed to a greater available moisture supply. The plant N concentration and N in the media was significantly greater when irrigated daily than bidaily, however, although only twice as much water was applied in daily irrigation, the volume of run-off was almost four times more than bidaily (Stewart et al., 1981). The objective of this study was to determine the effect of irrigation system and frequency on plant growth and water and nutrient efficiency.

FERTILIZER TYPE AND NITROGEN PARTITIONING

Two basic fertilizer types are used in greenhouse crop production: constant liquid fertilizer (CLF) and control release fertilizer (CRF). These two types of fertilizer can affect plant growth and leachate nutrient content differently. Production of plants with CLF relies on porous media and excessive amounts of water to provide leaching and can produce unacceptable levels of nitrates in leachate (Conover and Poole, 1992). CRF is known to decrease N run-off and increase N retention by the crop (Cox, 1985). Conover and Poole (1992) found no significant difference in plant height, quality, or EC for plants grown with either CRF or CLF in an ebb-and-flow system; however, foliage plants grown with CRF used more water than those grown with CLF. By reducing leaching, CLF and CRF can be used at lower rates since fewer nutrients would be lost through leaching. For example, N loss ranged from 12-23% for CRF, and N loss for CLF was 12-48% (Hershey and Paul, 1982). Rathier and Frink (1989) found that CRF applied in split applications prevented high initial N release and high N concentrations in leachate. In a nitrogen balance experiment, Stewart et al. (1981) noted that N taken up by roots, and N adsorbed or absorbed by pots was insignificant. However, N concentration in leachate was significantly lower for CRF than for CLF containing either ammonium sulfate of calcium nitrate. The purpose of this study was to determine the effect of fertilizer source interacted with irrigation system on plant growth, nitrogen partitioning, and run-off.

ROOT, pH, AND SOLUBLE SALT DISTRIBUTION IN MEDIA

Plant growth is significantly affected by water application method, regardless of fertilizer source or rate (Argo and Biernbaum, 1994; Conover and Poole, 1992; Dole et al., 1994; Molitor, 1990). Irrigation method has a direct influence on many other factors and characteristics which influence growth, such as pH, soluble salt content, root growth, and nutrient distribution, as well as their distribution within the growing medium (Argo and Biernbaum, 1994; Ku and Hershey, 1991; Molitor, 1990).

Medium soluble salt concentration and pH distribution has been most commonly studied to compare top irrigation and subirrigation systems. Ku and Hershey (1991) found that when using overhead irrigation, a low leaching fraction increased soluble salt concentration in the middle and lower third of the medium due to displacement of old fertilizer solution in the soil by newly applied fertilizer solution. Therefore, soluble salt concentration was lowered in the upper portion of the media, while for subirrigation, the reverse occurred in the upper layers.

Molitor (1990) found that subirrigation decreased pH in the lower layer of the pot, while trickle irrigation resulted in a similar pH throughout the root zone. Molitor suggested that the low pH of the bottom region of media from plants grown with subirrigation could be due to an increased amount of nitrifying bacteria in the lower layer, which is promoted by high ammonium fertilizer. In contrast, trickle irrigation distributed ammonia more uniformly throughout the root zone (Molitor, 1990). The purpose of this study was to determine the effect of irrigation system on the distribution of pH, soluble salts, roots, and nitrogen in the media.

OBJECTIVES

The research presented has three objectives:

1) to determine the effect of irrigation system and frequency on plant growth and water and nutrient efficiency;

2) to determine the effect of fertilizer source interacted with irrigation system on plant growth, nitrogen partitioning, and run-off;

3) to determine the effect of irrigation system on the distribution of pH, soluble salts, roots, and nitrogen in the media.

The information gained from this research will enable growers to efficiently produce high quality plants while minimizing the amount of nitrogen and phosphorus released to the environment through run-off.

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CHAPTER II

EFFECTS OF IRRIGATION SYSTEM AND FREQUENCY ON POINSETTIA GROWTH, WATER USE, AND RUN-OFF

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Additional index words. *Euphorbia pulcherrima* 'Gutbier V-14 Glory', microtube, ebb-and-flow, capillary mat, pulse irrigation, subirrigation, nitrate, ammonium, phosphorus.

Abbreviations. HD, hand-irrigation; MT, microtube; EF, ebb-and-flow; CM, capillary mat; EC, electrical conductivity; LF, leaching fraction.

Abstract. *Euphorbia pulcherrima* 'Gutbier V-14 Glory' were grown with 220 $mg \cdot liter^{-1}$ N (20N-4.4P-16.6K) using hand irrigation (HD), microtube (MT), ebb-and-flow (EF), and capillary mat (CM) irrigation systems and were irrigated either daily (pulse - P) or as needed (regular - R). For all irrigation systems, pulse irrigation produced plants with the greatest total dry weight. HD produced lower total plant dry weight than all other irrigation systems and frequencies. Root dry weight was greatest with pulse subirrigation (EF and CM). Run-off from MT-P and EF-P treatments had the lowest concentration of NO_3, NH_4, and PO_4. MT-P, EF-P, and EF-R were the most water efficient treatments.

CM-P, CM-R, and HD were the least water efficient treatments. The experiment was repeated twice with similar results.

INTRODUCTION

Greenhouse container crop production is limited by the amount of nutrients and water available to the plant because of the small volume of growing medium held within the containers. This limitation leads to more frequent irrigation and fertilization compared to plants grown in the field without container restriction. The result of intense irrigation and fertilization is possible contamination of ground and surface water sources. Irrigation practices that conserve water and fertilizer also reduce the potential of contaminating water sources. The need for more conservative cultural practices presents growers with the concern of sacrificing plant quality, and subsequently, profit. Several studies have indicated that high quality plants can be grown using subirrigation systems (Conover and Poole, 1992; Dole et al., 1994; Yelanich and Biernbaum, 1990). Yelanich and Biernbaum (1990) found that subirrigated plants were of acceptable quality and noted that the excessive run-off produced in greenhouse production could be controlled by decreasing the amount of water and fertilizer applied at each irrigation or by changing to a subirrigated system with recirculated water and fertilizer solutions. When compared to overhead, or top irrigation, ebb-and-flow produced higher quality plants (Conover and Poole, 1992, Dole et al., 1994). Ebb-and-flow irrigation, at a fertilizer rate of 175 $mg \cdot liter^{-1}$ of nitrogen, produced poinsettias with the greatest total dry weight per liter of water applied, when compared to capillary mats, hand-watering, and microtube (Dole et al., 1994).

On the other hand, capillary mat subirrigation used the highest amount of water and released the greatest amount of run-off when compared to ebb-and-flow, hand-watering, and microtube irrigation (Dole et al., 1994). Alleman and Weiler (1994) noted contrasting results, where water efficiency was significantly increased by using recirculated irrigation water with capillary mats.

Microtube irrigation systems, also referred to as trickle or drip irrigation, are often used in outdoor containerized or field crop production. Rathier and Frink (1989) found that in containerized juniper and spruce production, trickle irrigation used less water and released run-off with a lower N concentration than overhead sprinkler irrigation, while N loading to the soil and N loss due to leaching were decreased. For greenhouse production, microtube irrigation caused more water to be retained in the medium and produced plants with the greatest dry weight compared to capillary mats, ebb-and-flow, and hand-watering (Dole et al., 1994).

Types of overhead irrigation include sprinklers, mist systems, and manual or hand-watering. Yelanich and Biernbaum (1990) found that a 10-15% LF is recommended for overhead watering, but noted that some growers leach more than 40-50%. Dole et al. (1994) found that hand-watering produced higher quality plants only at a higher fertilizer rate than other systems. For example, hand-watering produced plants with greater dry weight at 250 $mg \cdot liter^{-1}$ N than at 175 $mg \cdot liter^{-1}$ N, with a greater volume of run-off than microtube irrigation.

Along with the method of application, the amount of water applied and the frequency at which plants are irrigated can greatly effect plant growth and run-off (Conover and Poole, 1992; Stewart et al., 1981). Conover and Poole (1992) noted that irrigation amounts above 100 ml/pot per 15-cm pot applied twice daily increased NO_3 and P in the leachate with no significant difference in foliage plant quality or fresh weight. Also, leaching was eliminated with no difference in quality for short term crops by applying less water at shorter intervals (Poole and Conover, 1992). Fare et al. (1994) found that applying water in two or three cycles rather than an equal amount in one continuous application decreased total effluent, container leachate, and nitrogen loss while increasing plant growth.

Stewart et al. (1981) found that privet watered daily had thicker stems, greater height, and wider diameters with significantly more dry weight than plants irrigated every other day (bidaily); this difference was attributed to a greater available moisture supply. Stewart et al. (1981) also found that the plant N concentration and N in the medium were significantly greater when plants were irrigated daily than bidaily, and that the volume of run-off from daily irrigation was almost four times more than bidaily while only twice as much water was applied. The objective of our study was to determine the effect of irrigation method and frequency on poinsettia growth and water and nutrient use and run-off.

MATERIALS AND METHODS

1993. *Euphorbia pulcherrima* 'Gutbier V-14 Glory' poinsettia cuttings were propagated from greenhouse stock plants on 10 August 1993 and rooted in oasis root cubes (Smither-Oasis, Kent, Ohio). Before insertion, cutting bases were treated with 0.1% IBA (indole-3-butyric acid, Hormex Powder #1, Brooker Chemical, North Hollywood, Calif.) and rooted under intermittent mist. Rooted cuttings were planted on 5 September 1993 in 15-cm (1270-ml) azalea pots filled with 1.5 liters of a commercial peat-based medium (Fafard Growing Mix no. 2; Conrad Fafard, Springfield, Mass.). The medium had 94.1% porosity, 77.4% total water-holding capacity, 40.9% available water, and 36.5% unavailable water, based on oven dried medium. Each plant was pinched to six nodes above the medium on 24 September 1993. Plants were grown in a corrugated polycarbonate covered greenhouse with an average air temperature of 23.4/21.3C day/night, and maximum PPF of 1296 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Standard disease and insect control procedures were followed (Ecke et al., 1990). All plants received monthly drenches of magnesium sulfate at $600 mg \cdot liter^{-1}$, and the amount of water applied was recorded. Plants were spaced 38 by 38 cm on containerized benches and fertilized with 220 $mg \cdot liter^{-1}$ N as 20N-4.4P-16.6K water soluble fertilizer intended for soilless medium (Peters 20-10-20 PLS, Sierra Chemical Co., Milpitas, Calif.).

Plants were irrigated with one of four irrigation systems 1) hand-watering (HD) (16-mm internal diameter hose and breaker nozzle), 2) microtube (MT) [2.5-mm main line, 1.9-mm internal diameter leader tubes and lead weight emitters (Chapin Watermatics, Watertown, N.Y.)], 3) capillary mat (CM) [1.5 by 1.8-m black plastic (6-mm) bottom layer, mat, and black perforated plastic covering (Vattex Capillary Watering System; OS Plastics, Norcross, Ga.)], or 4) ebb-and-flow (EF) [1.5 by 1.8-m bench top, 190-liter tank, pump, and drain tube (Midwest Gromaster, St. Charles, Ill.)] and two irrigation frequencies, pulse and regular. A pulse treatment was not included for HD due to the commercial impracticality of pulse irrigation by hand. One replication of sixteen plants were placed on each bench.

For regular irrigation treatments, all plants in each replication were irrigated when one previously selected test plant per replication was at or below the target weight as determined by daily weighing. To determine the target irrigation weight, six additional cuttings were planted as described above, watered, and allowed to dry to the point that wilting was first observed. At this time, the weight of the entire plant, pot, and medium was recorded. The plants were then watered to saturation and weighed again to determine container capacity. Target irrigation weights were calculated as follows: [(Container capacity weight - wilting point weight) (0.40)] + wilting point weight = the total plant weight at 40% container capacity. The target test plant weight was obtained by averaging the six plant weights. Pulse irrigation treatments were irrigated daily.

The HD and MT regular irrigation treatments had a 0.3-0.5 LF. The CM regular irrigation treatment was irrigated by applying the designated amount of water to the mat, allowing the mat and plants to take up water for 15 min, and draining the excess water from the mat by draping one edge of the mat over the edge of the bench for 15 min. The water was collected in a trough hung from the edge of the bench and slanted slightly downward toward a bucket. In the recirculating EF system, water was contained in a covered tank, pumped to the containerized bench top, held for the designated time to allow uptake by plants, and drained back into the tank after each irrigation. The only run-off produced from the EF system was during periodic leachings with unamended water when the bench was unplugged, and the excess water drained from the bench top rather than returned to the tank. The tanks were filled to capacity with fertilized water periodically and at the end of the growing season to determine the amount of water used. The run-off from regular HD and MT treatments was collected from a drain under each bench, and measured. All pulse treatments had a 0.0 leaching fraction, and no run-off was collected except during leachings, where a 0.3-0.5 LF was used. The amount of water applied at each irrigation was determined with a flow meter (Electronic Digital Meter, Great Plains Industries, Witchita, Kan.) installed in the water line.

Regular irrigation treatments were irrigated with the following rates: HD - two sec per pot, at a flow rate of 17.0 liters/min (Electronic Digital Meter; Great Plains Industries, Wichita, Kan.), MT - 45 sec per bench, at a flow rate of 17.0 liters/min, CM - 60 sec per bench, applied to the mat with a 17.0 liters/min flow rate, EF - 12 min per bench. The HD, CM, and EF treatments were leached from top to bottom every fifth irrigation with unamended water for two sec per pot at a flow rate of 17.0 liter/min. The CM mats were leached an additional 15 sec at a flow rate of 17.0 liter/min to reduce soluble salt concentration in the mats. The MT treatments were leached for 45 sec with unamended water at a flow rate of 17.0 liter/min.

Pulse irrigation treatments were irrigated with the following rates: MT - 15 sec per bench; EF - 8 min per bench; and CM - 7.6 liters per bench, applied to the mat.

Pulse irrigation treatments were leached every two weeks as specified above for regular irrigation.

The following data were recorded daily: weight of test plant, amount of water applied, irrigation number, and amount of run-off. For all regular treatments, run-off water samples were collected every eighth irrigation out of each ten irrigation cycle. For pulse treatments, run-off water samples were collected from every leaching. Water samples were stored at 4.4C until analyzed for pH (Fisher Accummet pH Meter; Fisher Scientific, Pittsburgh), EC (Solu-Bridge; Beckman Instruments Inc., Cedar Grove, N.J.), NH_4 (Harwood and Kuhn, 1970), NO_3 (cadmium reduction method, Page et al. 1982), and PO_4 (hydroquinone method, Olsen and Sommers, 1982).

Plants were harvested when at least 50% of each replication reached anthesis (9-13 December, 1993) and the following data were collected: date of anthesis, height, diameter (average of measurements taken at widest point and perpendicular to the first), and quality rating (1 to 5 scale, 1 = poorest and 5 = best salable quality). The poinsettias were severed into bracts and transitional bracts, flowers, leaves, and stems, dried at 65 C for five days and weighed. Leaf tissue was combined into one sample per replication, ground to pass through a 917-µm screen (20 mesh), and stored in air tight jars until analysis. Foliar samples were then analyzed for ammonia-based N by the macro-Kjeldahl method (Horowitz, 1980), PO_4 colorimetrically (Olsen and Sommers, 1982), Mg, Zn, K, Ca, Mn, and Fe (ash method, Isaac and Johnson, 1975) by atomic absorption spectroscopy (model 2380; Perkin-Elmer, Norwalk, Conn.). Medium samples were collected as a vertical core of medium from the top to the bottom of each root ball, and combined by replication. Medium samples were air dried and prepared for analysis using a 1:2 (v/v) medium to deionized water ratio. The samples were allowed to equilibrate for thirty min, and pH (Fisher Accumet pH meter, Fisher Scientific) and EC (Solu-Bridge, Beckman Instruments Inc.) was recorded. Medium samples were also analyzed for ammonia-based N (Horowitz, 1980).

The experimental design consisted of a completely randomized four by two factorial with four irrigation systems, two irrigation frequencies, benches as replications and plants as subsamples. Data were analyzed by the general linear model procedure with means separation by orthogonal contrasts and paired *t*-tests comparing all irrigation treatments to the HD treatment (SAS Institute, Cary, N.C.).

1994. Similar materials and methods and the same treatments as in 1993 were used except that plants were propagated on 7 August 1994. The rooted cuttings were planted on 31 August, 1994 and grown with an average air temperature of 23.9/21.2 C day/night. Plants were pinched to six nodes above the medium line on 19 September 1994. Plants were drenched monthly with magnesium sulfate at 600mg·liter^{-1}, and mg·liter^{-1} soluble trace-element mixture (STEM, Sierra Chemical Co., Milpitas, Calif.) was applied on 17 October 1994; and the amount of water applied was recorded. Poinsettias were harvested 2-7 December 1994.

RESULTS

PLANT GROWTH

Height. In both years, plants grown with the MT, CM, and EF irrigation systems were taller when grown with pulse irrigation than those grown with regular irrigation; however, differences for year 2 were not statistically significant (Table 2.1). For both years, plants grown with HD irrigation were shorter than those grown with other treatments, except in year 2 where plants grown with CM treatments were not significantly taller than those grown with HD irrigation.

Diameter. For year 1, the MT, CM, and EF irrigation systems produced plants with larger diameters when grown with pulse irrigation than those grown with regular irrigation (Table 2.1). In year 2, no significant differences were noted between pulse and regular treatments. In both years, plants grown with HD irrigation had significantly smaller diameters than those grown with any other irrigation system regardless of frequency.

Plant quality. In year one, quality ratings were significantly lower for plants grown with pulse irrigation than regular irrigation (Table 2.1). Regular MT, CM, and EF irrigation did not significantly influence plant quality compared with HD irrigation. In year 2, plant quality was not influenced by irrigation system nor frequency.

Dry weights. In year 1, plants grown with MT, CM, and EF irrigation systems had higher flower, bract, leaf and total dry weights when grown with pulse irrigation than those grown with regular irrigation (Table 2.1). EF pulse irrigation produced plants with significantly higher flower, bract, leaf, stem, and root dry weights than those grown with

HD irrigation. MT pulse and CM pulse irrigation produced plants with higher flower, bract, leaf, and root dry weights than plants from HD irrigation. Pulse subirrigation (CM and EF) produced plants with higher root dry weights than those grown with top irrigation (HD and MT). All irrigation treatments produced plants with higher root dry weight than those grown with HD irrigation, except that root weights for CM regular irrigation were not significantly different than those from HD irrigation. Only EF pulse produced plants with a significantly higher stem weight than those grown with HD irrigation. In year 2, plants irrigated with MT and EF systems had higher flower, bract, and root dry weights when grown with pulse irrigation than those grown with regular irrigation. In addition, total dry weight tended to be equal or higher for pulse irrigated plants than for regular irrigated plants, although no significant differences were found. Total dry weights were significantly lower for plants produced by HD irrigation than all other irrigation systems and frequencies. Plants irrigated with the CM system had higher bract and root dry weights when grown with pulse irrigation than those grown with regular irrigation. Leaf and stem dry weights from plants grown with CM pulse and regular were not significantly different than those of plants grown with HD irrigation. Flower, bract, leaf, stem, and root dry weights were highest for plants produced with MT pulse irrigation, followed by EF pulse. Flower and bract dry weights were lower when grown with HD irrigation than any other irrigation system and frequency. Root dry weight of plants from CM regular were not significantly different than those of plants irrigated by HD.

MEDIUM ANALYSIS

Medium pH. In year 1, while medium pH of plants grown with CM pulse irrigation was significantly lower than that of plants grown with HD irrigation, all other treatments had a medium pH similar to HD irrigation (Table 2.2). For subirrigated plants, medium pH was lower when grown with the CM system than EF irrigation system. For year 2, while EF pulse irrigation resulted in a lower medium pH than HD irrigation, all other treatments had a medium pH similar to HD irrigation.

Medium EC. In year 1, plants grown with pulse irrigation tended to have higher medium EC than those grown with regular irrigation; however, the difference was not significant (Table 2.2). Medium EC in plants grown with CM pulse irrigation was higher than that of plants grown with HD irrigation. For subirrigated plants, medium EC was higher when grown with the CM system than the EF irrigation system. For year 2, plants grown with pulse irrigation tended to have higher medium EC than those grown with regular irrigation with the exception of MT pulse irrigation which produced plants with significantly lower medium EC than plants grown with hand irrigation.

WATER EFFICIENCY

Amount of water applied. For both years, the amount of water applied increased with pulse irrigation (Table 2.2). The CM pulse and regular irrigation treatments required the largest amount of water and significantly more than HD irrigation. Subirrigation systems required more water than top irrigated systems. In year 1, significantly less water was applied to the MT regular irrigation treatment than HD irrigation. The CM pulse treatment required significantly more water than HD irrigation, followed by CM regular and EF pulse, respectively. The amount of water applied to MT pulse and EF regular irrigation treatments was not significantly different from HD irrigation. In year 2, HD, MT regular and EF regular irrigations required similar amounts of water. The CM pulse treatment required significantly more water than HD irrigation, followed by CM regular, MT pulse, and EF pulse, respectively.

Amount of run-off. For both years, the amount of run-off significantly decreased with pulse irrigation, except in the EF system where pulse irrigation produced more run-off than regular irrigation (Table 2.2). The CM regular irrigation treatment lost significantly more water as run-off than HD irrigation. In year 1, all irrigation treatments except CM regular produced less run-off than HD irrigation. The EF regular irrigation treatment produced the least amount of run-off, followed by MT pulse, MT regular, EF pulse, and CM pulse, respectively. In year 2, the amount of run-off produced by MT regular and CM pulse was not significantly different from that of HD irrigation. The EF regular irrigation treatment produced less run-off than HD irrigation, followed by MT pulse and EF pulse, respectively.

RUN-OFF ANALYSIS

Run-off pH. For both years, EF regular irrigation produced run-off with the lowest pH (Table 2.2). In year 1, MT regular and pulse also produced run-off with significantly lower pH than HD irrigation. In year 2, only the EF regular irrigation treatment significantly influenced run-off pH.

Run-off EC. In year 1, the run-off water's EC was highest in MT pulse, followed by CM regular, and CM pulse, respectively (Table 2.2). The EF pulse and regular irrigation treatments produced run-off with lower EC than HD irrigation, however the differences were not significant. In year 2, the run-off from EF pulse and regular had significantly lower EC than HD irrigation. The CM regular treatment produced run-off with higher EC than HD irrigation. All other irrigation treatments did not significantly influence run-off EC.

Run-off nutrient concentration. In year 1, run-off NO_3, NH_4, and PO_4 concentrations tended to be lower with pulse irrigation; however, differences were not significant (Table 2.2). The run-off from EF pulse and MT pulse had lower NH_4 concentrations than HD irrigation. The MT and EF pulse irrigation treatments produced run-off with lower PO_4 concentration than that of HD irrigation. In year 2, run-off NO_3, NH_4, and PO_4 concentrations from the MT and EF systems tended to be lower with pulse irrigation; however, the differences were not significant. In contrast, the CM system produced run-off with higher NO_3, NH_4, and PO_4 concentrations with pulse irrigation than regular irrigation treatments. The run-off from EF pulse had a lower NO_3 concentration than HD irrigation. The CM pulse irrigation treatment produced run-off with significantly higher NO_3, NH_4, and PO_4 concentrations than HD irrigation. The run-off from MT pulse and EF pulse had lower NH_4 and PO_4 concentrations than that of HD irrigation. The EF regular treatment also produced run-off with a lower NH_4 concentration than HD irrigation.

<u>*TISSUE ANALYSIS*</u>

Plant tissue nutrient content. For both years, plants irrigated with MT, CM, and EF systems had higher concentrations of foliage N and P when grown with pulse irrigation than those grown with regular HD irrigation (Table 2.3). Foliage K concentration was significantly lower in plants grown with MT pulse irrigation, and foliage Mn concentrations were significantly higher in plants with CM pulse irrigation than those grown with hand irrigation. Foliage Zn concentrations were not significantly influenced by irrigation system nor frequency. In year one, the combination of subirrigation and pulsing increased N and P concentrations more than top irrigation and pulsing. Foliage Ca concentrations increased with pulse irrigation and were significantly higher in plants grown with both EF pulse and regular irrigation than plants grown with hand irrigation. The MT regular irrigation treatment produced plants with lower Mg concentrations, and EF regular irrigation had significantly higher Fe concentration than plants grown with all other treatments. In year 2, pulse irrigation produced plants with significantly lower foliage K content than hand irrigation. Foliage N concentration was significantly lower in plants from EF regular irrigation than plants from hand irrigation treatments. Foliage P and Ca concentrations were lowest when grown with HD irrigation. Foliage Mg concentrations were significantly higher in plants grown with EF pulse, MT regular, and EF regular, respectively than in plants from HD irrigation. Subirrigation increased foliage Mn concentration in plants grown with pulse irrigation compared to those with regular irrigation, while pulse and regular top irrigated plants had a similar Mn concentration. Foliage Fe concentrations were not significantly influenced by irrigation system nor frequency.

DISCUSSION

IRRIGATION FREQUENCY

Pulse irrigation produced large, vigorous plants and reduced the amount of run-off; thus, the amount of nutrients released as run-off was decreased over the season of the crop (Tables 2.1 and 2.2). Stewart et al. (1981) also found that privet watered daily had thicker stems, greater height, wider diameters, and significantly more dry weight than plants irrigated every other day (bidaily), which was attributed to a more constant water supply. Gilman et al. (1994) noted an increase in plant canopy with 1.3 cm of water applied every day over plants irrigated with 2.5 cm every two to three days; however, caliper was not different. In another study comparing the effects of constant and variable moisture levels on bedding plant growth and quality, de Graaf-van der Zande (1990) found that elevated moisture levels increased height, leaf area, dry and fresh weights, buds, flowers, and shoots of petunia. In contrast, Fare et al. (1994) studied the effect of cyclic irrigation on nursery grown holly plants using equal amounts of water applied either as one continuous irrigation, or divided into two to three cycles of lesser amounts. The results were inconsistent, the irrigation cycles increased shoot growth index in one experiment and had no significant effect in a repetitive experiment (Fare et al., 1994). Similarly, Poole and Conover (1992) found that increased irrigation rates of 2, 3, or 4 times per week resulted in no significant increase in plant growth.

In our experiment, the amount of water applied to pulse plants was just enough to saturate the medium; therefore, no water leached from the container at each fertigation. The amount of run-off recorded was obtained only from leaching with clear, unamended water every fourteenth irrigation (every two weeks) to prevent the build up of excessive salts in the medium. This discussion will include several studies which have similarly investigated the effect of 0.0 leaching fraction (LF) (Yelanich and Biernbaum, 1990, 1993, and 1994; Ku and Hershey, 1991; Conover and Poole, 1992).

Although plants produced on pulse irrigation in year one were larger in height, diameter, and weight, quality ratings were significantly lower than plants produced by regular irrigation (Table 2.1). The low quality ratings for pulse irrigated plants reflected excessively lush and weak growth due to constant moisture and nutrient levels in the root zone. A lower fertilizer concentration may be necessary to prevent luxury nutrient uptake. de Graaf-van der Zande (1990) also noted decreased plant quality and shape with elevated moisture levels and no decrease in fertilizer. Several studies have indicated the need for reduced fertilizer concentration when using more frequent irrigation or decreased LF (Fare et al., 1994; George, 1989; McAvoy, 1994; Yelanich and Biernbaum, 1993). Reduced fertilizer rates or the use of pulse irrigation on short term crops could have increased the desirable effects of this irrigation method.

Pulse irrigation required more water than regular irrigation (Table 2.2), which was probably due to increased evaporation from the medium surface. Laurie and Ries (1950) described peat growing medium as fibers acting as a wick to move water to the surface where evaporation is more rapid. This situation may have been accentuated by the high moisture level during pulse irrigation. Heiskanen (1995) found that proportionally more water evaporated from containers holding medium with a higher moisture level than those with a variable moisture level, or dryer medium. Higher evaporation rates and more frequent water application (daily) accounted for the higher water usage. Although the amount of water applied to pulse treatments was greater than regular treatments, the amount of run-off was greatly reduced by pulse irrigation in the HD, MT, and CM irrigation systems, due to the minimal amount of leachate from each irrigation. However in the EF irrigation system, the pulse treatment produced more run-off than the regular treatment. This difference can also be attributed to a higher constant moisture level. Both frequency treatments received equal amounts of water during leaching, and because the EF system recirculated the irrigation solution, this was the only run-off recorded for EF irrigation. The higher medium moisture level in pulse irrigated plants caused relatively more water to be flushed from the container at each leaching, therefore the amount of run-off was elevated over that of the regular irrigation treatment.

The average NO_3-N, NH_4-N, and PO_4 concentrations released in run-off throughout the experiment were lower with pulse irrigation than regular irrigation (Table 2.2). Yelanich and Biernbaum (1990 and 1994) also found that a decreased LF reduced the amount of nutrients lost as run-off. Fare et al. (1994) noted that when irrigated in one continuous water cycle, 68% of applied N was leached as NO_3; however, if irrigated with the same amount of water in three cycles, the amount of NO_3 leached was reduced to 11%. The impact of reducing the amount of NO_3 leaching from greenhouse crops was made evident in a nitrate loading study by McAvoy (1994). After only two weeks of irrigation with water soluble fertilizer, NO_3 concentration in the top 15 cm of soil beneath the greenhouse was 3.4 times higher with a high LF than with a low LF. In the current experiment, our results supported the conclusion that regular irrigation did not increase plant growth and significantly increased nutrient concentrations in the run-off.

Medium EC was higher in pulse irrigated plants (Table 2.2); similarly, Yelanich and Biernbaum (1990 and 1994) and Ku and Hershey (1991) found an increase in medium EC with decreasing leaching fraction. However, Yelanich and Biernbaum (1990 and 1994) noted that plant growth was reduced with increasing medium EC (Yelanich and Biernbaum, 1990).

Pulse irrigation produced plants with higher foliage concentrations of N and P (Table 2.3). Yelanich and Biernbaum (1993) found that leaf P and Mg concentrations were also increased with a lower LF. These results may have been due to a higher constant moisture level and higher medium EC, therefore making nutrients more available for plant uptake.

<u>*IRRIGATION SYSTEM*</u>

Hand-irrigation. In both years, HD irrigation produced shorter plants with a smaller diameter than any other treatment or frequency, and generally lower dry weights than other regular irrigation systems (Table 2.1). Dole et al. (1994) also found that hand irrigation produced smaller plants and attributed the result to touching the plants with the sprayer during irrigation. Brief shaking or touching can reduce stem elongation and growth (Hammer et al., 1974; Turgeon and Webb, 1971). In year two, HD irrigation required the least amount of water; however, due to the large amount of run-off, the system remained inefficient, having lost 32.9% of applied water as run-off. Most water was lost between the pots causing direct run-off. Also, because of the strong spray of water applied, the medium may have become compacted and retained less water (Dole et. al. (1994).

Microtube irrigation. As with Dole et al. (1994), plants produced by MT irrigation had the second greatest total dry weight in year one, and the greatest in year two (Table 2.1). The MT irrigation system used the least amount of water in year one and slightly greater than HD in year two, and as with Rathier and Frink (1989), MT irrigation run-off had the lowest nutrient concentrations both years (Table 2.2). The slow rate of water application with MT irrigation may have caused less mass flow of water and less nutrient ions to be flushed from the pot. The percentage of applied water lost as run-off was similar to that of the EF system (Table 2.2). Therefore, the total amount of nutrients released from MT irrigation was lower than HD and CM irrigation. The low amount of run-off may be due to high water retention. Dole et al. (1994) found the water retention rate of MT irrigated plants was greater than those irrigated with HD or CM systems.

Capillary mat irrigation. The CM irrigation system produced plants with greater total dry weight than HD irrigation but similar in some plant growth factors such as height, and leaf, stem, and root dry weights (Table 2.1). The N concentration of the plant tissue was slightly greater in year one, and significantly greater in year two than those produced by other irrigation systems (Table 2.3). Medium EC from the CM system was significantly greater than HD, and may have suppressed potential growth due to an elevated plant N concentration, so that plant growth was not greater than other plants with lower N concentrations (Yelanich and Biernbaum, 1990).

In addition, the CM system used the greatest amount of water and produced the greatest amount of run-off, while nutrient concentrations in the run-off were greater than any other irrigation treatment (Table 2.2). Thus, the amount of nutrients lost as run-off was much greater than all other treatments which agrees with Dole et al. (1994). In our study, the large amount of water required by the CM system was attributed to evaporation from the mats, accentuated by high light intensity and high temperatures. Biernbaum et al. (1991) found that 30-60% of total water lost from a containerized plant was caused by evaporation from the medium surface. The addition of the mat extended the area of evaporation causing an even greater percentage of water to be lost. In contrast, Alleman et al. (1994) found that water efficiency was significantly improved by use of capillary mat systems in New York state, where fall/winter light intensity and temperatures would be lower than Oklahoma. A large amount of nutrients may have been held within the absorbent mat; however, further research is needed to determine if the amount is significant.

Ebb-and-flow irrigation. Plants irrigated by EF had the greatest total dry weight in year one, and the second greatest in year two, interchanging with the MT system (Table 2.1). Although the EF system required the second greatest amount of water, the average amount of run-off was only 6.6% for year 1, and 8.7% for year two, and was obtained only from leaching. The NO_3-N, NH_4-N, and PO_4-P run-off concentrations reported were the result of samples taken from the sump tanks holding the fertilizer solution and run-off from periodic leaching. If samples had been taken from only the effluent that is lost to the environment, the run-off concentrations would have been much lower. The EF irrigation system was water efficient, and because of the lack of run-off with this subirrigation system, the potential for groundwater contamination was greatly reduced. In support, George (1989) found that subirrigation could produce plants with similar quality of top irrigation, while using only half as much fertilizer. Similarly, many studies have concluded that subirrigated plants could benefit from reduced fertilizer rates (Barrett, 1991; Molitor, 1990; Nelson, 1991).

In summary, pulse irrigation increased water use efficiency, reduced the amount of nutrients lost as run-off, and produced large, vigorous plants. The MT and EF irrigation systems were both water and fertilizer efficient. The CM irrigation system was the least water efficient, used the greatest amount of water, produced the greatest amount of run-off, and released the greatest amount of NO_3-N, NH_4-N, and PO_4-P to the environment. The commonly-used HD irrigation produced the smallest plants, with reduced height, diameter, and dry weight. By reducing applied fertilizer rates, and using the EF or MT irrigation system with pulse irrigation frequency, growers could greatly decrease potential contamination to ground and surface water sources, while producing high quality, profitable plants. Also, operating costs would be lowered by increasing water and fertilizer efficiency.

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Table 2.1. Influence of irrigation system and frequency on growth of *Euphorbia pulcherrima* 'Gutbier V-14 Glory'[Z] grown with 220 $mg \cdot liter^{-1}$ N. Year one-1993 and year two-1994. Means are an average of data from three replications (benches) of 16 plants.

Irrigation system	Irrigation frequency	Height (cm)	Diameter (cm)	Quality rating[Y]	Dry Weights (g)					
					Flowers	Bracts	Leaves	Stems	Roots	Total
Year one - 1993										
Hand	Regular	23.1	45.8	3.7	0.9	9.1	6.0	5.7	3.0	24.8
Microtube	Pulse	28.3^{***}	60.1^{***}	2.6^{*}	1.3^{**}	14.0^{***}	8.0^{**}	7.4^{NS}	4.1^{*}	35.2^{**}
Microtube	Regular	25.6^{*}	51.4^{*}	3.8^{NS}	1.0^{NS}	10.9^{NS}	7.2^{NS}	7.3^{NS}	4.2^{*}	30.5^{NS}
Capillary mat	Pulse	29.4^{***}	55.1^{***}	2.7^{*}	1.3^{**}	11.8^{**}	8.8^{***}	6.9^{NS}	5.1^{***}	33.5^{**}
Capillary mat	Regular	26.3^{*}	53.0^{**}	3.0^{NS}	0.8^{NS}	9.9^{NS}	6.8^{NS}	6.1^{NS}	3.8^{NS}	26.7^{NS}
Ebb-and-flow	Pulse	31.5^{***}	60.6^{***}	2.2^{**}	1.6^{***}	15.9^{***}	10.9^{***}	8.7^{*}	5.5^{***}	44.0^{***}
Ebb-and flow	Regular	24.2^{NS}	52.2^{*}	3.6^{NS}	1.0^{NS}	10.6^{NS}	7.5^{*}	6.3^{NS}	4.3^{*}	30.4^{NS}
<u>Contrasts</u>										
Pulse v. regular		***	***	***	***	***	***	NS	*	***
Subirrigation v. top irrigation		NS	NS	NS	NS	NS	*	NS	NS	NS
Ebb-and-flow v. capillary mat		NS	NS	NS	**	**	*	NS	NS	***

<u>Interactions</u>										
Frequency and subirrigation v. top irrigation		NS	NS	NS	NS	NS	*	NS	*	NS
Frequency and ebb-and-flow v. capillary mat		*	NS	NS	NS	*	NS	NS	NS	NS
				Year two - 1994						
Hand	Regular	21.9	40.5	3.0	0.4	3.5	3.5	1.8	1.7	10.6
Microtube	Pulse	27.6***	54.5***	3.0^{NS}	0.9***	8.2***	6.3***	4.1***	2.8***	21.3***
Microtube	Regular	25.1***	52.7***	3.0^{NS}	0.6***	6.4***	5.4***	3.1***	2.1**	17.5***
Capillary mat	Pulse	22.9^{NS}	45.2***	3.2^{NS}	0.5**	4.8***	3.7^{NS}	2.0^{NS}	2.2***	13.2*
Capillary mat	Regular	22.6^{NS}	47.5***	3.4^{NS}	0.5**	4.6**	3.8^{NS}	2.1^{NS}	1.9^{NS}	13.2*
Ebb-and-flow	Pulse	26.2***	53.5***	3.3^{NS}	0.8***	7.2***	6.2***	3.6***	2.8***	20.8***
Ebb-and-flow	Regular	24.9***	52.7***	3.1^{NS}	0.7***	6.4***	5.4***	3.2***	2.3***	18.7***
<u>Contrasts</u>										
Pulse v. regular		NS	NS	NS	*	*	NS	NS	*	NS
Subirrigation v. top irrigation		NS	NS	NS	NS	NS	NS	NS	NS	NS

Ebb-and-flow v. capillary mat	NS	NS	NS	NS	NS	NS	NS	NS	NS
<u>Interactions</u>									
Frequency and subirrigation v. top irrigation	NS	NS	NS	NS	NS	NS	*	NS	NS
Frequency and ebb-and-flow v. capillary mat	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Planting date; Year one, 5 September 1993; Year two, 31 August 1994 and each replication harvested when 50% of the plants reached anthesis.
[Y] 1-5 rating with 5 the best.
*, **, ***, NS Significant at $P \leq 0.05$, 0.01, 0.001 or nonsignificant, respectively, as compared to hand irrigation.

Table 2.2. Influence of irrigation system and frequency on medium pH and EC, water use, and run-off nutrient content of Euphorbia pulcherrima 'Gutbier V-14 Glory'^{z} grown with 220 mg·liter $^{-1}$ N. Year one-1993 and year two-1994. Means are an average of data from three replications (benches) of 16 plants.

Irrigation method (mg·liter^{-1})	Irrigation frequency	Medium		Applied water	Run-off					
		pH	EC (mS)	(liter)	Water (liter)	pH	EC (mS)	NO_3-N (mg·liter^{-1})	NH_4-N (mg·liter^{-1})	PO_4-P
Year one - 1993										
Hand	Regular	5.7	1.9	294.4	93.4	6.5	1.8	94.3	100.0	26.7
Microtube	Pulse	5.7^{NS}	2.2^{NS}	266.4^{NS}	15.7***	6.0***	2.9**	81.3^{NS}	53.1**	17.4^{NS}
Microtube	Regular	6.0^{NS}	1.8^{NS}	195.5***	27.0***	6.1**	2.2^{NS}	98.1^{NS}	78.1^{NS}	30.6^{NS}
Capillary mat	Pulse	5.2*	3.8**	811.0***	77.1**	6.4^{NS}	2.6*	104.9^{NS}	87.5^{NS}	33.4^{NS}
Capillary mat	Regular	5.3^{NS}	2.7^{NS}	508.5***	109.8**	6.6^{NS}	2.8**	147.2**	118.8^{NS}	50.4*
Ebb-and-flow	Pulse	5.5^{NS}	3.0^{NS}	396.9***	30.4***	6.5^{NS}	1.5^{NS}	72.1^{NS}	46.9**	13.6^{NS}
Ebb-and-flow	Regular	5.3^{NS}	2.2^{NS}	302.8^{NS}	15.6***	5.8***	1.7^{NS}	124.6^{NS}	100.0^{NS}	36.5^{NS}
<u>Contrasts</u>										
Pulse v. regular		NS	NS	**	**	NS	NS	NS	NS	NS
Subirrigation v. top irrigation		NS	NS	**	NS	NS	NS	NS	NS	NS

Ebb-and-flow v. capillary mat		*	*	**	NS	NS	NS	NS	NS	NS
<u>Interactions</u>										
Frequency and subirrigation v. top irrigation		*	NS	***	***	NS	NS	NS	NS	NS
Frequency and ebb-and-flow v. capillary mat		NS	NS	NS	NS	NS	NS	NS	NS	NS
				Year two - 1994						
Hand	Regular	5.8	3.2	181.9	59.8	6.2	2.7	167.4	252.1	65.9
Microtube	Pulse	5.7^{NS}	1.9^{**}	259.8^{***}	22.4^{***}	6.3^{NS}	2.3^{NS}	106.4^{NS}	143.1^{**}	25.1^{**}
Microtube	Regular	5.6^{NS}	2.8^{NS}	193.7^{NS}	64.5^{NS}	6.0^{NS}	3.0^{NS}	154.7^{NS}	210.9^{NS}	79.1^{NS}
Capillary mat	Pulse	5.6^{NS}	4.2^{NS}	827.9^{***}	52.3^{NS}	6.2^{NS}	4.8^{***}	315.6^{***}	344.7^{*}	90.4^{*}
Capillary mat	Regular	5.6^{NS}	2.7^{NS}	485.4^{***}	136.0^{***}	6.3^{NS}	3.2^{NS}	169.9^{NS}	207.4^{NS}	48.5^{NS}
Ebb-and-flow	Pulse	5.5^{*}	4.2^{NS}	230.6^{**}	22.6^{***}	6.3^{NS}	2.1^{*}	91.5^{*}	124.1^{**}	28.7^{**}
Ebb-and-flow	Regular	5.6^{NS}	3.4^{NS}	201.7^{NS}	15.0^{***}	5.5^{**}	1.9^{**}	114.9^{NS}	160.7^{*}	50.4^{NS}
<u>Contrasts</u>										
Pulse v. regular		NS	NS	***	***	NS	NS	NS	NS	NS

Subirrigation v. top irrigation	NS	NS	***	NS	NS	**	*	NS	NS
Ebb-and-flow v. capillary mat	NS	NS	***	**	NS	NS	NS	NS	NS
Interactions									
Frequency and subirrigation v. top irrigation	NS	NS	***	**	NS	***	**	NS	*
Frequency and ebb-and-flow v. capillary mat	NS	NS	***	**	NS	NS	NS	NS	NS

[z] Planting date; Year one, 5 September 1993; Year two, 31 August 1994 and harvested when 50% of the plants reached anthesis.
*, **, ***, NS Significant at $P \leq 0.05$, 0.01, 0.001 or nonsignificant, respectively, as compared to hand irrigation.

Table 2.3. Influence of irrigation system and frequency on *Euphorbia pulcherrima* 'Gutbier V-14 Glory'[z] leaf tissue nutrient content grown with 220 mg·liter $^{-1}$ N. Year one-1993 and year two-1994. Means are an average of data from three replications (benches) of 16 plants.

Irrigation System	Irrigation Frequency	%					$\mu g \cdot g^{-1}$		
		N	PO_4-P	K	Ca	Mg	Zn	Fe	Mn
Year one - 1993									
Hand	Regular	4.5	0.80	2.1	1.3	0.9	32.7	76.3	59.3
Microtube	Pulse	4.7^{NS}	0.85^{NS}	1.7^{*}	1.4^{NS}	0.9^{NS}	21.7^{NS}	148.3^{NS}	71.3^{NS}
Microtube	Regular	4.3^{NS}	0.71^{NS}	2.0^{NS}	1.2^{NS}	0.8^{*}	30.3^{NS}	167.0^{NS}	53.3^{NS}
Capillary mat	Pulse	5.1^{**}	1.23^{***}	2.1^{NS}	1.4^{NS}	1.0^{NS}	24.3^{NS}	120.3^{NS}	95.7^{**}
Capillary mat	Regular	4.8^{NS}	0.98^{NS}	2.2^{NS}	1.3^{NS}	0.9^{NS}	36.0^{NS}	113.0^{NS}	68.7^{NS}
Ebb-and-flow	Pulse	5.0^{*}	1.17^{**}	2.0^{NS}	1.5^{**}	1.0^{NS}	20.7^{NS}	114.0^{NS}	71.0^{NS}
Ebb-and-flow	Regular	4.8^{NS}	1.00^{NS}	2.0^{NS}	1.4^{*}	1.0^{NS}	21.7^{NS}	249.5^{*}	51.3^{NS}
Contrasts									
Pulse v. regular		*	NS	NS	*	NS	NS	NS	NS
Subirrigation v. top irrigation		NS	NS	NS	NS	NS	NS	NS	NS

Ebb-and-flow v. capillary mat		NS	*	NS	NS	NS	NS	NS	NS
Interactions									
Frequency and subirrigation v. top irrigation		NS	NS	NS	NS	NS	NS	NS	NS
Frequency and Ebb-and-flow v. capillary mat		NS	NS	NS	NS	NS	NS	NS	NS
Year two - 1994									
Hand	Regular	5.0	0.73	2.9	1.0	0.7	42.0	134.0	65.0
Microtube	Pulse	5.3*	1.08**	2.0***	1.2**	0.8NS	37.3NS	201.3NS	61.7NS
Microtube	Regular	5.2NS	0.99**	2.5NS	1.2**	0.8*	35.0NS	134.3NS	70.0NS
Capillary mat	Pulse	6.0***	1.09***	2.5*	1.4***	0.8NS	41.0NS	194.7NS	87.0*
Capillary mat	Regular	5.2NS	0.85NS	2.5*	1.3***	0.8NS	41.7NS	111.7NS	52.7NS
Ebb-and-flow	Pulse	5.3*	1.07**	2.4**	1.3***	0.9**	36.3NS	157.3NS	73.3NS
Ebb-and-flow	Regular	4.7*	0.96*	2.6NS	1.2**	0.8*	47.0NS	99.0NS	50.3NS
Contrasts									
Pulse v. regular		NS	NS	*	NS	NS	NS	NS	NS
Subirrigation v. top irrigation		NS	NS	NS	NS	NS	NS	NS	*

Ebb-and-flow v. capillary mat	NS	NS	NS	*	NS	NS	NS	NS
<u>Interactions</u>								
Frequency and subirrigation v. top irrigation	NS	NS	NS	NS	NS	NS	NS	NS
Frequency and ebb-and-flow v. capillary mat	NS	NS	NS	NS	NS	NS	NS	NS

[z] Planting date; Year one, 5 September 1993; Year two, 31 August 1994 and each replication harvested when 50% of the plants reached anthesis.

*, **, ***, NS Significant at $P \leq 0.05$, 0.01, 0.001 or nonsignificant, respectively, as compared to hand irrigation.

CHAPTER III

EFFECTS OF FERTILIZER SOURCE AND IRRIGATION SYSTEM ON PLANT GROWTH, AND NITROGEN PARTITIONING

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Abbreviations. CLF, constant liquid fertilizer; CRF controlled release fertilizer; HD, hand-irrigation; MT, microtube; EF, ebb-and-flow; CM, capillary mat; EC, electrical conductivity.

Abstract. *Pelargonium hortorum* 'Pinto Red' were grown with 260 mg·liter^{-1} N applied as 1) 100% CLF composed of 410 mg·liter^{-1} NH_4NO_3, 484 mg·liter^{-1} $(NH_4)_2PO_5$, and 520 mg·liter^{-1} K_2SO_4, plus 0.04 g triple superphosphate, 2) 50% CRF + 50% CLF composed of 205 mg·liter^{-1} NH_4NO_3, 242 mg·liter^{-1} $(NH_4)_2PO_5$, and 260

mg·liter^{-1} K_2SO_4, plus 0.02 g triple superphosphate, and 5.33 g CRF (Osmocote 14-14-14) per pot, 3) 100% CRF consisting of 10.65 g CRF (Osmocote 14-14-14) per pot and irrigated with unamended water using hand-irrigation (HD), microtube (MT), ebb-and-flow (EF), and capillary mat (CM) irrigation systems. Fertilizer rates were calculated to produce equal amounts of retained N among the three fertilizer treatments based on irrigation number. MT irrigation produced the greatest growth, HD irrigation produced the least, and CM and EF were intermediate. The EF system was the most water efficient, followed by MT. The treatments receiving 50% CLF/50% CRF or 100% CRF produced greater total dry weights, and significantly lower concentrations of NO_3, NH_4, and PO_4 in the run-off than the 100% CLF treatment. The 100% CRF treatment significantly increased the amount of nutrients retained (not lost as run-off) with up to 98.3% N and 99.8% P being retained. The percent of N lost as run-off was also reduced with the use of CRF.

INTRODUCTION

Greenhouse container crop production is limited by the amount of nutrients and water available to the plant from a small volume of growing medium held within the containers. This limitation leads to more frequent irrigation and fertilization compared to plants grown in the field without container restriction. The result of more intense irrigation and fertilization is possible contamination of ground and surface water sources. Irrigation practices that conserve water and fertilizer also reduce the potential of contaminating water sources. The need for more conservative cultural practices presents growers with the concern of sacrificing plant quality, and subsequently, profit. Several studies have indicated that high quality plants can be grown using subirrigation systems. Yelanich and Biernbaum (1990) found that subirrigated plants were of acceptable quality and noted that the excess amount of run-off produced in greenhouse production can be controlled by decreasing the amount of water and fertilizer applied at each irrigation or by changing to a subirrigated system with recirculated water and fertilizer solutions. When compared to overhead, or top irrigation, ebb-and-flow produced higher quality plants (Conover and Poole, 1992, Dole et al., 1994). Ebb-and-flow irrigation, at a fertilizer rate of 175 $mg \cdot liter^{-1}$ of nitrogen, produced poinsettias with the greatest total dry weight per liter of water applied, when compared to capillary mats, hand-watering, and microtube (Dole et al., 1994).

On the other hand, capillary mat subirrigation used the highest amount of water and released the greatest amount of run-off when compared to ebb-and-flow, hand-watering, and microtube irrigation (Dole et al., 1994). Alleman and Weiler (1994) noted contrasting results, where water efficiency was significantly increased by use of recirculated irrigation water and capillary mats.

Microtube irrigation systems, also referred to as trickle or drip irrigation, are used in outdoor containerized or field crop production. Rathier and Frink (1989) found that in containerized juniper and spruce production, trickle irrigation used less water and released run-off with a lower N concentration than overhead sprinkler irrigation, while N loading to the soil and N loss due to leaching were decreased. For greenhouse production, microtube irrigation caused more water to be retained in the medium and produced plants with the greatest dry weight compared to capillary mats, ebb-and-flow, and hand-watering (Dole et al., 1994).

Types of overhead irrigation include sprinklers, mist systems, and manual or hand-watering. Yelanich and Biernbaum (1990) state that a 10-15% leaching fraction (LF) is recommended for overhead watering, but noted that some growers leach more than 40-50%. Dole et al. (1994) found that hand-watering produced higher quality plants only at a higher fertilizer rate than other systems. For example, hand-watering produced plants with greater dry weight at 250 $mg \cdot liter^{-1}$ N than at 175 $mg \cdot liter^{-1}$ N, with a greater volume of run-off than microtube irrigation (Dole et al., 1994).

The type and method of fertilizer application also influences the release of nutrients and their concentrations in run-off water. Two types of fertilizer are typically used in greenhouse crop production: constant liquid fertilizer (CLF) and controlled release fertilizer (CRF). These two types of fertilizer affect plant growth and leachate content differently. Production of plants with CLF relies on porous medium and excessive amounts of water to provide leaching and can produce unacceptable levels of nitrates in leachate (Conover and Poole, 1992). CRF is known to decrease N run-off and increase N retention by the crop (Cox, 1985). Conover and Poole (1992) found no significant difference in plant height, quality, or EC for plants grown with either CRF or CLF in an ebb-and-flow system; however, foliage plants grown with CRF used more water than those grown with CLF. Hershey and Paul (1982) found that N loss ranged from 12-23% for CRF, while N loss for CLF was 12-48%. Rathier and Frink (1989) found that CRF could be more efficient if applied in split applications, which prevented high initial N release and high N concentrations in leachate. In a nitrogen balance experiment, Stewart et al. (1981) found that N concentration in leachate was significantly lower for CRF than for CLF containing either ammonium sulfate or calcium nitrate. This study determined the effect of irrigation methods and fertilizer source on plant growth, and nitrogen and phosphorus partitioning of potted geraniums.

MATERIALS AND METHODS

Commercially grown *Pelargonium hortorum* 'Pinto Red' geranium seedling plugs were planted three per pot on 3 February 1994 using 1.5 liters of 3 peat moss :1 perlite :1 vermiculite medium (by volume) amended with 6.87 g dolomite per 15 cm (1270-ml) azalea pot. The medium had 80.0% porosity, 70.2% total water-holding capacity, 48.0% available water, and 22.2% unavailable water, based on oven dried medium. Plants were grown in a corrugated polycarbonate covered greenhouse with an average air temperature of 29.8/19.7C day/night, and maximum PPF of 1296 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Standard disease and insect controlled procedures were followed (White, 1993).

Plants were spaced 38 by 38 cm on containerized benches and irrigated with one of three irrigation treatments 1) 100% of the recommended rate of CLF composed of 410 $mg \cdot liter^{-1}$ NH_4NO_3, 484 $mg \cdot liter^{-1}$ $(NH_4)_2PO_5$, and 520 $mg \cdot liter^{-1}$ K_2SO_4, plus 0.04 g triple superphosphate, and 6.87 g dolomite per pot, 2) 50% of the recommended rate of CRF + 50% of the recommended rate of CLF composed of 205 $mg \cdot liter^{-1}$ NH_4NO_3, 242 $mg \cdot liter^{-1}$ $(NH_4)_2PO_5$, and 260 $mg \cdot liter^{-1}$ K_2SO_4, plus 0.02 g triple superphosphate, 6.87 g dolomite, and 5.33 g CRF (Osmocote 14-14-14) per pot, 3) 100% of the recommended rate of CRF consisting of 6.87 g dolomite, and 10.65 g CRF (Osmocote 14-14-14) per pot and irrigated with unamended water. Fertilizer amounts were calculated to provide a total of 260 mg·liter^{-1} N with equal amounts of NH_4-N, NO_3-N, and P per fertilizer treatment. Rates were based on 12 irrigations with fertilizer solution, three leachings with unamended water, and 330 ml of water retained per pot. Since actual water retention volumes vary depending on irrigation system, the water retention volume used was an average of values reported by Dole et al. (1994).

To determine the target irrigation weight, 18 additional plugs were planted in six pots as described above, watered, and allowed to dry to the point that wilting was first observed. At this time, the weight of the entire plant, pot, and medium was recorded. The plants were then watered to saturation and weighed again to determine container capacity. Target irrigation weights were calculated as follows: [(Container capacity - wilting point weight) (0.40)] + wilting point weight = the total plant weight at 40% container capacity. The target test plant weight was obtained by averaging the weights of the six geranium pots at 40% container capacity. One previously selected test plant from each replication was weighed daily. Each of the four treatments were irrigated when the test plant of each replication was at or below the set target irrigation weight.

The plants were irrigated by one of four irrigation systems 1) hand-watering (HD) (16-mm internal diameter hose and breaker nozzle, 2) microtube (MT) [2.5-mm main line, 1.9-mm internal diameter leader tubes and lead weight emitters (Chapin Watermatics, Watertown, N.Y.)], 3) ebb-and-flow (EF) [1.5 by 1.8-m bench top, 190-liter tank, pump, and drain tube (Midwest Gromaster, St. Charles, Ill.)], or 4) capillary mat (CM) [1.5 by

1.8-m black plastic (6-mm) bottom layer, mat, and black perforated plastic covering (Vattex Capillary Watering System; OS Plastics, Norcross, Ga.)]. Sixteen plants were placed on each bench.

In the recirculating EF system, water was contained in a covered tank, pumped to the containerized bench top, held for the designated time to allow uptake by plants, and drained back into the tank after each irrigation. This system only releases run-off from periodic leachings with unamended water; the bench is unplugged, allowing the excess water to flow from the bench top rather than into the tank. The tanks were filled to capacity with the appropriate fertilizer solution periodically and at the end of the growing season to determine the amount of water applied. The MT and HD irrigation treatments had a 0.3-0.5 leaching fraction. The CM treatment was irrigated by applying the designated amount of water to the mat, allowing the mat and plants to take up water for 15 min, then draining the excess water from the mat by draping one edge of the mat over the edge of the bench for 15 min. The run-off water was collected in a trough that hung from the edge of the bench and was slanted slightly downward toward a bucket. The run-off from other treatments and leaches was collected from a drain under each bench, and measured. The exact amount of water applied at each irrigation was determined with a flow meter (Electronic Digital Meter, Great Plains Industries) installed in the water line.

Irrigation amounts were as follows: HD - two sec per pot, at a flow rate of 17.0 liters/min (Electronic Digital Meter; Great Plains Industries, Wichita, KS.), MT - 60 sec per bench, at a flow rate of 17.0 liters/min, EF - 14 min per bench, CM - 75 sec per bench applied to the mat with 17.0 liters/min flow rate. The HD, EF, and CM treatments were leached from top to bottom every fifth irrigation with unamended water for two sec per pot with a 17.0 liters/min flow rate. The CM mats were leached an additional 15 sec and drained to reduce soluble salt concentration in the mats. The MT treatments were leached for 75 sec with unamended water at a flow rate of 17.0 liters/min.

The following data were recorded daily: weight of test plant, amount of water applied, irrigation number, and amount of run-off. For all treatments, applied fertilizer solution and run-off water samples were collected for each irrigation treatment or leaching. Samples were stored at 4.4C until analyzed for pH (Fisher Accummet pH Meter; Fisher Scientific, Pittsburgh), EC (Solu-bridge; Beckman Instruments Inc., Cedar Grove, N.J.), NH_4 (Harwood and Kuhn, 1970), NO_3 (cadmium reduction method, Page et al., 1982), and PO_4 (hydroquinone method, Olsen and Sommers, 1982).

Plants were harvested when each treatment received 15 irrigations (19 March-17 April 1994) and the following data were collected: date of anthesis, height, diameter (average of measurement taken at widest point and perpendicular to the first), and quality rating (1 to 5 scale, 1 = poorest and 5 = best salable quality).

The geranium shoots were removed, dried at 65C for five days, and weighed. Shoot tissue was combined into one sample per replication, ground to pass through a 917-μm screen (20 mesh), and stored in air tight containers until analyzed for ammonia-based N by the macro Kjeldahl method (Horowitz, 1980), PO_4 colorimetrically (Olsen and Sommers, 1982), and Mg, Zn, K, Ca, Mn, and Fe (ashing method, Isaac and Johnson, 1975) by atomic absorption spectroscopy (model 2380; Perkin-Elmer, Norwalk, Conn.). The roots of 10 plants per replication were washed, dried at 65C for five days, and weighed. Roots were combined into one sample per replication, ground and stored as described above, and analyzed for ammonia-based N content (Horowitz, 1980), PO_4 colorimetrically (Olsen and Sommers, 1982), and Mg, Zn, K, Ca, Mn, and Fe (Isaac and Johnson, 1975) by atomic absorption spectroscopy (model 2380; Perkin-Elmer, Norwalk, Conn.). The remaining six root balls were left intact, dried at 65C for five days, then weighed to determine the amount of medium remaining in pots. Medium samples were collected as a vertical core of medium from the top to the bottom of each root ball, and combined by replication. Medium samples were allowed to air dry and prepared for analysis using a 1:2 (v/v) medium to deionized water ratio. The samples were allowed to equilibrate for thirty minutes, and pH (Fisher Accumet pH meter, Fisher Scientific) and EC (Solu-bridge, Beckman Instruments Inc.) were recorded. Medium samples were also analyzed for ammonia based N (Horowitz, 1980) and PO_4 (Olsen and Sommers, 1982) using a saturated medium extract. Samples of each capillary mat were taken from three randomly selected areas on each mat. Three 13-cm^2 samples from each mat were placed in 500 ml of deionized water and allowed to equilibrate for 24 hours. The mat samples were removed, and the resulting solution was analyzed for pH (Fisher Accummet pH Meter, Fisher Scientific), EC (Solu-bridge, Beckman Instruments Inc.), NH_4 (Harwood and Kuhn, 1970), NO_3 (Page et al., 1982), and PO_4 (Olsen and Sommers, 1982).

To provide initial nutrient data for the nitrogen partitioning, medium and geranium plug samples were collected prior to the experiment. The medium samples were allowed to air dry and analyzed as described above to determine the initial pH (Fisher Accumet pH Meter, Fisher Scientific), EC (Solu-bridge, Beckman Instruments Inc.), ammonia-based

N (Horowitz, 1980), and PO_4 (Olsen and Sommers, 1982) content of the medium. Ten geranium plugs were collected, separated into shoots or roots and medium, dried, ground, and stored as described above. The geranium plug samples were analyzed for ammonia-based N, Mg, Zn, Ca, K, Mn, and PO_4 to determine the initial nutrient content of the geranium shoots and medium/roots.

The experimental design consisted of a completely randomized four by three factorial with four irrigation systems, three fertilizer treatments, benches as replications, and plants as subsamples. Data were analyzed by the general linear model procedure and trend analysis (SAS Institute, Cary, N.C.).

RESULTS

PLANT GROWTH

Height and diameter. Plants irrigated with HD irrigation were smallest, having significantly less height and diameter than plants grown with any other irrigation system (Table 3.1). The MT irrigation system produced plants with significantly greater height and diameter than plants grown with any other irrigation system. Fertilizer source did not influence height nor diameter.

Quality rating. Quality ratings were not significantly different for irrigation system or fertilizer source (Table 3.1).

Dry weights. Shoot dry weight was lowest when irrigated with CM and HD irrigation (Table 3.1). The EF irrigation system produced plants with significantly greater shoot dry weight than those grown with CM and HD. Root dry weight was lowest for plants produced with HD and EF irrigation. CM produced significantly higher root weight than HD, but weights were not different from those produced by EF. Total dry weights were lowest when irrigated with HD and CM irrigation, and significantly higher for plants grown with EF irrigation. Shoot, root, and total dry weight was greatest for plants irrigated with the MT irrigation system. Shoot and root dry weights were not influenced by fertilizer source. Total dry weights increased as use of CRF increased, however, total dry weight of 100% CLF does not appear to differ from the other two treatments due to rounding.

MEDIUM ANALYSIS

Medium pH. The medium pH was lowest in plants irrigated with the MT system and slightly higher when irrigated with the CM system (Table 3.1). Medium pH was highest and not significantly different in plants irrigated with the EF and HD systems. Plants fertilized with 100% CRF had significantly lower medium pH than those fertilized with 200% CLF or the combination of 50% CLF/50%CRF.

Medium EC. The medium EC was significantly lower for plants grown with HD irrigation than with all other irrigation systems, which were not different from each other (Table 3.1). Fertilizer source had no significant effect on medium EC.

WATER EFFICIENCY

Amount of water applied. The MT irrigation system required the least amount of water, HD and EF required intermediate amounts, while the CM system required the greatest amount of irrigation water (Table 3.2). Within the HD irrigation system, the 100% CRF treatment required more water than the 100% CLF and 50% CLF/50% CRF treatments. Within the MT irrigation system, the 100% CLF treatment required more water than the other two treatments. For the two subirrigation systems, the 50% CLF/50% CRF combination required the least amount of water. For plants irrigated with the CM system, the 100% CRF treatment required the greatest amount of water, while the 100% CLF treatment required the greatest amount of water when irrigated with the EF system.

Amount of run-off. The EF irrigation system produced the least amount of run-off, HD and MT irrigation produced a significantly greater but intermediate amount, and the CM irrigation system produced the greatest amount of run-off (Table 3.2).

RUN-OFF ANALYSIS

Run-off pH. Run-off from the CM irrigation system had the highest pH, followed by HD irrigation with the second highest pH (Table 3.2). Run-off from the MT and EF irrigation systems had significantly lower pH than that from the HD and CM systems. For the two top irrigation systems, the 100% CRF treatment produced run-off with significantly lower pH than 100% CLF or the combination of the two fertilizers. For the two subirrigation systems, the 50% CLF/50% CRF treatment produced run-off with an intermediate pH. For the CM system, run-off from the 100% CLF treatment had the highest pH and 100% CRF the lowest, while EF run-off was affected inversely with 100% CRF having the highest pH and 100% CLF the lowest.

Run-off EC. Run-off EC was the lowest for EF irrigation, while HD, CM, and MT irrigation produced run-off with significantly higher EC, respectively (Table 3.2). For all irrigation systems, the 100% CRF treatment produced run-off with the lowest EC, while the 50% CLF/50% CRF, and 100% CLF treatments had significantly greater run-off EC, respectively.

Run-off nutrient concentration. Run-off NO_3, NH_4, and PO_4 concentrations significantly decreased with the increased use of CRF. Run-off NO_3 concentration was greatest with the combination of CM irrigation and 100% CLF. Both subirrigation systems produced significantly lower NO_3, NH_4, and PO_4 concentrations when using 100% CRF than the top irrigation systems. The greatest decrease in run-off NO_3 concentration was with CM irrigation and 100% CRF. For the 50% CLF/50% CRF treatment, EF irrigation produced the lowest NO_3 concentration. For the 100% CRF treatment, MT irrigation produced the greatest run-off NH_4 concentration, followed by HD, CM, and EF respectively.

TISSUE ANALYSIS

Shoot nutrient analysis. Shoot P concentrations for the two top irrigation systems, HD and MT, were not significantly different from each other (Table 3.3). The two subirrigation systems, CM and EF, produced plants with significantly higher shoot P concentrations than the top irrigation systems and were not different from each other. Plants grown with 100% CRF had a lower shoot P concentration than those grown with 100% CLF or the 50% CLF/50% CRF combination, which were not significantly different. Shoot K and Mg concentration was lowest for plants irrigated with the MT system, and highest for HD irrigation. The CM and EF systems produced intermediate shoot K and Mg concentrations. Shoot Mn concentrations were lowest in plants grown with MT irrigation, while HD, CM, and EF produced plants with significantly higher concentrations. The 100% CRF and 50% CLF/50% CRF treatments produced plants with lower shoot Mn concentrations than the 100% CLF treatment. Shoot Ca and Fe concentrations were not influenced by irrigation system. Shoot K, Ca, Mg, and Fe levels were not significantly influenced by fertilizer source.

Root nutrient analysis. Root P concentrations were lowest in plants grown with HD irrigation and highest in those grown with MT irrigation, CM and EF produced plants with intermediate root P levels (Table 3.4). Root P levels were not influenced by fertilizer source. Root K, Ca, Mg, Zn, Fe, and Mn, concentrations were not influenced by irrigation system nor fertilizer source.

Shoot and root N concentration. For all irrigation systems except HD, shoot and root N concentration was significantly lower in plants grown with 100% CRF than those grown with 100% CLF or 50% CLF/50%CRF. (Table 3.5) For plants grown with HD, shoot N concentration was similar in plants grown with 100% CLF or 100% CRF, but was significantly higher in plants grown the 50% CLF/50% CRF combination. For plants irrigated with the MT system, those fertilized with 100% CLF had significantly higher shoot and root N concentrations than those fertilized with 50% CLF/50% CRF or 100% CLF, respectively. Each subirrigation system produced plants with shoot and root N concentrations that were not significantly different when fertilized with either 100% CLF or the combination of 50% CLF/50% CRF; however, N concentrations from CM plants were higher than those from EF. For plants irrigated with the HD system, those fertilized with 100% CLF had significantly higher root N concentration than those fertilized with

100% CRF or 50% CLF/50% CRF, and was also significantly higher than all other irrigation systems and fertilizer combinations (Table 3.5).

<u>*NITROGEN PARTITIONING*</u>

N applied and retained. The amount of N applied increased with increased use of CLF, and the percentage of N retained (not lost as run-off) was greater with increased use of CRF (Table 3.6). Nitrogen retention was greatest with use of 50% or 100% CRF and EF irrigation, and lowest for 100% CLF and CM irrigation. Actual N retained was similar for fertilizer type but was significantly higher for CM, than the other irrigation systems due to N retention by the mat. Total N retention was lowest for MT.

Run-off N. The amount of N lost as run-off was greatest for CM irrigation, followed by MT, HD, and EF respectively (Table 3.6). The amount of run-off N increased with greater amounts of CLF, and the percent of N lost as run-off increased significantly with increased use of CLF, however, the increase was greater for subirrigation systems than for top irrigation systems.

Plant N. The amount of N in the shoots and the percentage of retained N in the shoots was greatest for MT irrigation and tended to be greater in all irrigation systems when grown with the 50% CLF/50% CRF than other fertilizer treatments, with the exception of CM irrigation where the percentage of retained N in the shoot was greater when grown with 100% CLF (Table 3.6). The amount of N in the roots was not influenced by irrigation system; however, the percentage of retained N in the roots was greatest for MT irrigation and significantly lower for both subirrigation systems. Root N decreased with use of CRF. The percentage of retained N in the roots was decreased the 100% CRF treatment, but was not significantly different for HD and EF irrigation.

Medium N. For the two subirrigation systems, the amount of N in the medium was significantly lower with 100% CLF than the two CRF treatments (Table 3.6). For top irrigated plants, medium N was similar for all fertilizer treatments. The percentage of retained N in the medium was greatest for MT irrigation and lowest for HD.

Container N. The percentage of retained N adsorbed to the container was similar for the MT and CM irrigation systems, while with HD and EF irrigation the percentage increased as use of CRF increased (Table 3.6). However, the amount of N remaining on the container was not significant compared to the amount partitioned to other variables.

DISCUSSION

CLF VS. CRF

Increasing the percentage of N as CRF not only increased total dry weight, but also decreased run-off EC, NO_3-N and P_2O_5-P, and increased the percentage of N retained (Tables 3.1, 3.2, and 3.6). Conover and Poole (1992) noted that production of plants with CLF relied on porous medium and excessive amounts of water to provide leaching and could produce unacceptable levels of nitrates in leachate. In the current study, as CLF was applied there was direct run-off (leaching) of the fertilizer solution through the medium. However, the CRF nutrients were released by the moisture in the medium into the root zone nutrient solution after the irrigation water had leached through the container, lowering the amount of nutrients actually flushed from the container. In support, Stewart et al (1981) found that N concentration in leachate was significantly lower for CRF than for CLF.

While total dry weight was influenced by fertilizer type, height, diameter, and quality were not affected (Table 3.1). Conover and Poole (1992) also found no significant difference in plant height, quality, or EC for plants grown with either CRF or CLF in an ebb-and-flow system, and noted that foliage plants grown with CRF used more water than those grown with CLF.

Although the fertilizer treatments were designed to provide balanced amounts of nutrients, differences existed in the actual grams of N applied to each treatment (Table 3.6). This variation was attributed to differences in the calculated and actual nutrient release of the CRF and differences in the calculated N rate and the actual N rate applied by the fertilizer injector. Therefore, nutrient retention and partitioning of nutrients to appropriate sinks were also expressed in percentages.

Nitrogen retention by the crop (plant, medium, and pots) was significantly increased with the use of CRF (Table 3.6). The percentage of N retained by treatments fertilized with 100% CRF ranged from 80.2-98.3%. While the 100% CLF treatments retained only 54.3-72.5% of the applied N. Similarly, Hershey and Paul (1982) found that N loss ranged from 12-23% for CRF, while N loss for CLF was 12-48%. Cox (1985) reported that CRF was known to have decreased N run-off and increase N retention by the crop.

Interestingly, the percentage of N in the shoots and roots tended to be lower for plants irrigated with either 50% CLF/50% CRF or 100% CRF. However, percent of N retained by shoots and roots was greater with 50% CLF/50% CRF than any other fertilizer treatment, indicating the increase in dry weight balanced the decrease in N concentration. In addition, the amount of N adsorbed to the container was an insignificant amount compared to other sinks (Table 3.6), which is in agreement with Stewart et al. (1981).

IRRIGATION SYSTEM

Although all irrigation systems produced similar quality plants, there were significant differences in growth, water use, and run-off (Tables 3.1 and 3.2). The commonly used HD irrigation produced the smallest plants with the least height, diameter, and dry weight (Table 3.1). Dole et al. (1994) also found that hand irrigation produced smaller plants and attributed the result to touching the plants with the sprayer during irrigation.

The MT irrigation system produced plants with the greatest height, diameter, and dry weight, used the least amount of water and released little more run-off than HD irrigation (Tables 3.1 and 3.2). The amount of N in the shoots and the percentage of retained N in the shoots was also greatest for MT irrigation (Table 3.6). The low amount of run-off may have been due to water retention as Dole et al. (1994) found that medium water retention in MT irrigated plants was greater than those irrigated with HD or CM systems. A more constant moisture level in the root zone could account for the increased in N taken up by MT irrigated plants.

The CM irrigation system produced plants with the second greatest height and diameter; however, CM used the greatest amount of water and released the greatest amount of run-off with greater EC than all other irrigation systems (Tables 3.1 and 3.2).

Thus, the amount of nutrients lost as run-off was much greater than all other treatments as with Dole et al. (1994). In our study, the large amount of water required by the CM system was attributed to evaporation from the mats, accentuated by high light intensity and high temperatures. Biernbaum et al. (1991) found that 30-60% of total water lost from a containerized plant was caused by evaporation from the medium surface. The addition of the mat extended the area of evaporation causing an even greater percentage of water to be lost. In contrast, Alleman and Weiler (1994) found that water efficiency was significantly improved by use of capillary mat systems in New York state, where fall/winter light intensity and temperatures would be lower than in Oklahoma.

The EF irrigation system produced plants with greater total dry weight than HD and CM irrigation and lost only 4.7% of applied water as run-off (Tables 3.1 and 3.2). Overall, the NO_3-N, NH_4-N, and P_2O_5-P concentrations in the run-off and run-off EC were lower than those released from the other irrigation systems, because the only run-off released from the EF system was from leachings of clear, unamended water. At regular irrigations, the fertilizer solution drained into a holding tank and was recirculated for future irrigations. The EF irrigation system was water efficient, and because of the lack of run-off with this subirrigation system, the potential for groundwater contamination was greatly reduced. In support, George (1989) found that subirrigation produced plants with similar quality of top irrigation, while using only half as much fertilizer. Similarly, many studies concluded that subirrigated plants could benefit from reduced fertilizer rates (Barrett, 1991; Molitor, 1990; Nelson 1991).

In summary, the nutrient efficiency of greenhouse irrigation systems was increased if at least 50% of fertilizer was supplied by CRF. Fertilizing with 100% CLF caused higher concentrations of nutrients to be released to the environment with no significant increase in growth or quality. The efficiency of CRF was increased with the use of EF or MT irrigation systems, which produced large, high quality plants and released small volumes of run-off. By utilizing water efficient irrigation systems together with nutrient efficient fertilizer sources, the potential of contaminating ground and surface water sources would be greatly reduced.

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Table 3.1. Influence of irrigation system and fertilizer source on medium pH, EC, and growth of *Pelargonium hortorum* 'Pinto Red'.[Z] Means are an average of data from three replications (benches) of 16 plants.

Treatment	Height (cm)	Diameter (cm)	Quality rating[Y]	Dry weights (g) Shoots	Roots	Total	Medium pH	EC (mS)
Irrigation system								
Hand	16.5	29.2	4.2	10.1	1.7	11.8	5.5	2.6
Microtube	19.8	32.3	4.1	13.5	2.3	15.8	5.2	4.0
Capillary Mat	18.2	31.0	4.4	9.7	2.0	11.7	5.3	4.6
Ebb-and-flow	17.9	30.7	4.6	10.9	1.9	12.9	5.4	4.1
LSD	0.8	1.3	0.6	0.7	0.2	0.9	0.2	0.6
Fertilizer source								
100% CLF	17.9	30.8	4.2	10.3	1.9	12.0	5.5	3.7
50% CLF/50% CRF	18.5	31.3	4.5	11.2	2.1	13.2	5.4	3.9
100% CRF	17.9	31.2	4.2	11.6	2.0	13.5	5.2	3.9
LSD	1.0	1.8	0.6	1.3	0.4	1.6	0.1	0.8
Irrigation system	***	***	NS	***	***	***	**	***
Fertilizer treatment	NS	NS	NS	NS	NS	*	***	NS
Irrigation*treatment	NS	NS	NS	NS	NS	NS	NS	NS

[Z] Planting date, 3 February, 1994 and each replication harvested after receiving 12 irrigations.
[Y] 1-5 with 5 the best.
*, **, ***, NS Significance at $P \leq 0.05$, 0.01, 0.001, or nonsignificant, respectively.

Table 3.2. Influence of irrigation system and fertilizer source on the amount of water applied, pH, EC, and nutrient concentration of run-off water from *Pelargonium hortorum* 'Pinto Red'.[z] Means are an average of data from three replications (benches) of 16 plants.

Irrigation system	Fertilizer source	Applied water (liters)	Run-off water (liters)	Run-off pH	Run-off EC (ms)	Run-off NO_3 (mg·liter^{-1})	Run-off NH_4 (mg·liter^{-1})	Run-off PO_4 (mg·liter^{-1})
Hand	100% CLF	151.3	35.2	6.86	3.9	91.9	235.9	127.9
	50% CLF/50% CRF	151.4	36.6	6.90	3.0	63.4	150.3	73.4
	100% CRF	161.3	38.2	6.62	2.6	54.4	81.0	21.0
Microtube	100% CLF	143.8	41.9	5.64	3.8	81.6	234.0	142.0
	50% CLF/50% CRF	147.8	37.6	5.58	3.6	67.0	184.2	95.8
	100% CRF	145.8	34.7	5.21	3.4	57.0	155.8	33.9
Capillary Mat	100%CLF	305.3	76.9	6.72	4.8	126.3	290.9	174.6
	50% CLF/50% CRF	285.8	69.2	6.83	3.4	68.9	133.8	82.4
	100% CRF	320.2	86.0	7.22	1.9	12.6	36.0	3.0
Ebb-and-flow	100% CLF	169.2	8.4	5.70	2.3	92.7	211.8	124.6
	50% CLF/50% CRF	155.0	6.5	5.51	1.7	37.9	92.0	38.4
	100% CRF	162.6	8.0	5.27	1.5	28.5	27.3	8.7
Interactive LSD		3.8	2.5	0.05	0.1	4.3	7.2	3.7

Irrigation system	***	***	***	***	***	***	***
Fertilizer source	**	NS	**	***	***	***	***
Irrigation* fertilizer	**	*	***	***	***	***	***

[z] Planting date, 3 February 1994 and each replication harvested after receiving 12 irrigations.

*, **, ***, [NS]Significance at $P \leq 0.05$, 0.01, 0.001, or nonsignificant, respectively.

Table 3.3 Influence of irrigation system and fertilizer source on shoot tissue nutrient content of *Pelargonium hortorum* 'Pinto Red'.[z] Means are an average of data from three replications (benches) of 16 plants.

	%				$\mu g.g^{-1}$	
Treatment	P	K	Ca	Mg	Fe	Mn
Irrigation system						
Hand	0.43	3.3	1.0	0.5	291.4	314.2
Microtube	0.47	2.5	0.7	0.4	233.2	177.7
Capillary Mat	0.58	3.1	0.8	0.4	243.7	318.9
Ebb-and-flow	0.64	2.7	1.0	0.4	233.8	269.1
LSD	0.08	0.6	0.4	0.1	274.8	70.7
Fertilizer source						
100% CLF	0.58	3.4	0.9	0.4	212.9	303.8
50% CLF/50% CRF	0.60	2.8	0.8	0.4	186.5	231.5
100% CRF	0.42	2.6	1.0	0.4	352.3	274.6
LSD	0.06	0.8	0.3	0.1	246.8	65.4
Irrigation system	**	*	NS	*	NS	***
Fertilizer treatment	***	*	NS	NS	NS	*
Irrigation*treatment	NS	NS	NS	NS	NS	NS

[z] Planting date, 3 February 1994 and each replication harvested after receiving 12 irrigations.

*, **, ***, NS Significance at $P \leq 0.05$, 0.01, 0.001, or nonsignificant, respectively.

Table 3.4. Influence of irrigation system and fertilizer source on root tissue nutrient content of *Pelargonium hortorum* 'Pinto Red'.[z] Means are an average of data from three replications (benches) of 16 plants.

	%				$\mu g.g^{-1}$		
Treatment	P	K	Ca	Mg	Zn	Fe	Mn
Irrigation system							
Hand	0.23	0.3	0.9	0.2	55.6	482.4	107.7
Microtube	0.40	0.3	1.1	0.2	72.3	568.2	98.9
Capillary Mat	0.31	0.6	1.3	0.3	75.3	484.9	124.0
Ebb-and-flow	0.35	0.4	1.3	0.3	87.7	541.4	111.4
LSD	0.04	0.2	0.4	0.1	45.7	306.9	23.0
Fertilizer source							
100% CLF	0.34	0.4	1.1	0.3	71.8	537.5	99.8
50% CLF/50% CRF	0.32	0.4	1.3	0.3	79.9	524.8	110.1
100% CRF	0.31	0.5	1.0	0.3	66.5	495.5	121.7
LSD	0.04	0.4	0.5	0.6	35.5	308.2	25.4
Irrigation system	***	NS	NS	NS	NS	NS	NS
Fertilizer source	NS	NS	NS	NS	NS	NS	NS
Irrigation*source	NS	NS	NS	NS	NS	NS	NS

[z] Planting date, 3 February 1994 and each replication harvested after receiving 12 irrigations.

*, **, ***, NS Significance at $P \leq 0.05$, 0.01, 0.001, or nonsignificant, respectively.

Table 3.5 Interaction of irrigation system and fertilizer source on tissue N content, and shoot Zn content of *Pelargonium hortorum* 'Pinto Red'.[z] Means are an average of data from three replications (benches) of 16 plants.

Irrigation system	Fertilizer source	% N Shoots	% N Roots	% Zn shoots
Hand	100% CLF	3.6	2.7	107.3
	50% CLF/50% CRF	4.4	2.5	90.5
	100% CRF	3.7	2.6	59.0
Microtube	100% CLF	3.8	2.6	43.3
	50% CLF/50% CRF	3.6	2.3	46.0
	100% CRF	2.8	1.9	48.0
Capillary mat	100% CLF	4.3	2.5	68.3
	50% CLF/50% CRF	4.1	2.5	58.0
	100% CRF	3.0	1.7	61.0
Ebb-and-flow	100% CLF	3.7	2.5	119.0
	50% CLF/50% CRF	3.8	2.4	34.0
	100% CRF	2.8	1.8	56.3
Interactive LSD		0.2	0.1	14.7
Irrigation system		**	**	NS
Fertilizer source		***	***	NS
Irrigation*fertilizer		*	*	*

[z] Planting date, 3 February 1994 and each replication harvested after receiving 12 irrigations.
*, **, ***, NS Significance at $P \leq 0.05$, 0.01, 0.001, or nonsignificant, respectively.

Table 3.6 Influence of irrigation method and fertilizer source on partitioning of applied nitrogen in *Pelargonium hortorum* 'Pinto Red'[Z]. Means are an average of three replications (benches) of 16 plants.

Irrigation system	Fertilizer source	Applied (g)	Retained[Y] (g)	Retained[Y] %[X]	Run-off (g)	Run-off %[X]	Shoot (g)	Shoot %[W]	Root (g)	Root %[W]	Medium (g)	Medium %[W]	Container (g)	Container %[W]
HD	100% CLF	42.63	30.91	72.5	11.72	27.5	5.57	18.0	0.73	2.4	17.75	57.4	0.06	0.2
	50% CLF/50% CRF	39.36	31.45	79.9	7.91	20.1	7.49	23.8	0.73	2.3	17.99	57.2	0.09	0.3
	100% CRF	34.83	29.29	84.1	5.54	15.9	5.85	20.0	0.69	2.4	18.40	62.8	0.15	0.5
MT	100% CLF	39.33	28.15	71.6	11.18	28.4	7.34	26.1	0.85	3.1	19.23	68.3	0.06	0.2
	50% CLF/50% CRF	37.64	28.83	76.6	8.81	23.4	8.10	28.1	0.92	3.2	21.16	73.4	0.06	0.2
	100% CRF	35.23	28.26	80.2	6.97	19.8	6.39	22.6	0.73	2.6	21.05	74.5	0.06	0.2
CM	100% CLF	73.40	39.88	54.3	33.52	45.7	6.56	16.5	0.77	1.9	21.99	55.1	0.08	0.2
	50% CLF/50% CRF	53.86	39.48	73.3	14.38	26.7	5.98	15.2	0.85	2.1	24.99	63.3	0.06	0.2
	100% CRF	40.10	36.10	90.0	4.00	10.0	5.04	14.0	0.51	1.4	24.95	69.1	0.06	0.2
EF	100% CLF	55.91	40.31	72.1	15.60	27.9	5.96	14.8	0.72	1.8	21.00	52.1	0.09	0.2
	50% CLF/50% CRF	37.60	32.83	87.3	4.77	12.7	6.82	20.8	0.76	2.3	23.68	72.1	0.10	0.3
	100% CRF	35.14	34.56	98.3	0.58	1.7	5.36	15.5	0.56	1.6	24.05	69.6	0.11	0.3
Interactive LSD		1.47	1.33	1.4	0.74	3.0	0.50	1.5	0.07	0.2	1.12	4.5	0.02	0.1
Irrigation		***	***	***	***	***	*	***	NS	***	***	*	*	*

Fertilizer	***	NS	***	***	***	**	**	**	*	*	*	NS	NS
Irrigation*fertilizer	***	NS	***	***	***	NS	NS	NS	NS	NS	NS	NS	*

[Z]Planting date, 3 February 1994, and harvested when each replication received 12 irrigations.
[Y]Nitrogen retained by plant, medium, and pot.
[X]Percentage of applied nitrogen.
[W]Percentage of retained nitrogen.

CHAPTER IV

EFFECTS OF IRRIGATION SYSTEM ON THE DISTRIBUTION OF pH, SOLUBLE SALTS, ROOTS, AND NITROGEN IN THE MEDIUM

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Additional index words. *Pelargonium hortorum* 'Pinto Red', microtube, ebb-and-flow, capillary mat, EC, pH.

Abbreviations. HD, hand-irrigation; MT, microtube; EF ebb-and-flow; CM, capillary mat; EC, electrical conductivity.

Abstract. *Pelargonium hortorum* 'Pinto Red' were grown with 220 $mg \cdot liter^{-1}$ N (20N-4.4P-16.6K) using hand-irrigation (HD), microtube (MT), ebb-and-flow (EF), and capillary mat (CM) irrigation systems. At harvest, root balls were sliced into three equal regions: top, middle, and bottom. For all irrigation systems, root counts were lowest in the top region. EF root counts were greatest in the middle region. The two sub-irrigation

systems had higher average root counts than the two top irrigation systems (HD and MT). In general, less difference in soluble salt concentration and medium nitrogen existed between regions for top irrigated than for subirrigated root balls. Soluble salt concentration was lowest in the bottom and middle regions of EF and the bottom region of MT and CM. For subirrigation, the highest soluble salt concentration and medium nitrogen was in the top region. For all systems, pH was lowest in the bottom region.

INTRODUCTION

Plant growth is significantly affected by water application method, regardless of fertilizer source or rate (Argo and Biernbaum, 1994; Conover and Poole, 1992; Dole et al., 1994; Molitor, 1990). Irrigation method directly affects many factors that influence growth. These factors include pH, soluble salts, root growth, and nutrients, as well as the distribution of each within the growing medium (Argo and Biernbaum, 1994; Ku and Hershey, 1991; Molitor, 1990).

Medium soluble salt concentration and pH distribution has been most commonly studied to compare overhead irrigation and subirrigation methods. Ku and Hershey (1991) found that when using overhead irrigation, a low leaching fraction increased soluble salt concentration in the middle and lower third of the medium due to displacement of old fertilizer solution in the soil by newly applied fertilizer solution. Therefore, soluble salt concentration was decreased in the upper portion of the medium, while for subirrigation, salt concentration increased in the upper layers.

Molitor (1990) found that subirrigation decreased pH in the lower portion of the medium, while trickle irrigation resulted in a similar pH throughout the root zone. Molitor (1990) suggested that the low pH of the bottom region of medium from plants grown with subirrigation may have been due to an increased amount of nitrifying bacteria in the lower layer, which was promoted by high ammonium fertilizer. In contrast, trickle irrigation distributed ammonia more uniformly throughout the root zone (Molitor, 1990). The purpose of this study was to determine the effect of irrigation method on the distribution of roots, pH, soluble salts, and nitrogen in the medium.

MATERIALS AND METHODS

Commercially grown *Pelargonium hortorum* 'Pinto Red' geranium seedling plugs were planted three per pot on 31 May 1994 using 1.5 liters of 3 peat moss :1 perlite :1 vermiculite medium (by volume) amended with 6.87 g dolomite in 15 cm (1270 ml) azalea pots. The medium had 80.0% porosity, 70.2% total water-holding capacity, 48.0% available water, and 22.2% unavailable water, based on oven dried medium. Plants were grown in a corrugated polycarbonate-covered greenhouse with an average air temperature of 25.3/24.1C day/night, and maximum PPF of 1296 $\mu mol \cdot m^{-2} \cdot sec^{-1}$. Standard disease and insect control procedures were followed (White, 1993). Sixteen plants were spaced 38 by 38 cm on containerized benches and irrigated with 220 $mg \cdot liter^{-1}$ N of a commercial 20N-4.4P-16.6K water soluble fertilizer intended for soilless medium (Peters 20-10-20 PLS, Sierra Chemical Co., Milpitas, Calif.).

To determine the target irrigation weight, eighteen additional plugs were planted in six pots as described above, watered, and allowed to dry to the point that wilting was first observed. At that time, the weight of the entire plant, pot, and medium was recorded. The plants were then watered to saturation and weighed again to determine container capacity. Target irrigation weights were calculated as follows: [(Container capacity - wilting point weight) (0.40)] + wilting point weight = the total plant weight at 40% container capacity. The target test plant weight was obtained by averaging the weights of the six geranium pots at 40% container capacity. One test plant from each replication was selected and weighed daily. Each of the four treatments were irrigated when the test plant of each replication was at or below the set target irrigation weight.

The plants were irrigated by one of four irrigation systems 1) hand-watering (HD) (16-mm internal diameter hose and breaker nozzle), 2) microtube (MT) [2.5-mm main line, 1.9-mm internal diameter leader tubes and lead weight emitters (Chapin Watermatics, Watertown, N.Y.)], 3) ebb-and-flow (EF) [1.5 by 1.8-m bench top, 190-liter tank, pump, and drain tube (Midwest Gromaster, St. Charles, Ill.)], or 4) capillary mat (CM) [1.5 by 1.8-m black plastic (6-mm) bottom layer, mat, and black perforated plastic covering (Vattex Capillary Watering System; OS Plastics, Norcross, Ga.)]

In the recirculating EF system, water was contained in a covered tank, pumped to the containerized bench top, held for the designated time to allow uptake by plants, and drained back into the tank after each irrigation. The EF irrigation system only released run-off from periodic leachings with unamended water; then the bench was unplugged, allowing the excess water to flow from the bench top rather than returned to the tank.

Water samples for nutrient analysis were collected from the tank. The tanks were filled to capacity with fertilized water periodically and at the end of the growing season to determine the amount of water applied. The MT and HD irrigation treatments had a 0.3-0.5 leaching fraction. The CM irrigation treatment was irrigated by applying the designated amount of water to the mat, allowing the mat and plants to take up water for 15 min, then draining the excess water from the mat by draping one edge of the mat over the edge of the bench for 15 min. The run-off water was collected in a trough that hung from the edge of the bench and was slanted slightly downward toward a bucket. The run-off from HD, MT, and EF treatments and was collected from a drain under each bench, and measured. The amount of water applied at each irrigation was determined with a flow meter (Electronic Digital Meter, Great Plains Industries) installed in the water line.

Irrigation amounts were as follows: HD - two sec per pot, at a flow rate of 17.0 liters/min (Electronic Digital Meter; Great Plains Industries, Wichita, KS.), MT - 75 sec per bench, at a flow rate of 17.0 liters/min, EF - 14 min per bench, CM - one min per bench applied to the mat using a 16-mm internal diameter hose and breaker nozzle, with 17.0 liters/min flow rate. The HD, EF, and CM treatments were leached from top to bottom every fifth irrigation with unamended water for two sec per pot with a 17.0 liters/min flow rate. The CM mats were leached an additional 15 sec and drained to prevent high soluble salt concentrations. The MT treatments were leached for 75 sec with unamended water at a flow rate of 17.0 liters/min.

The following data were recorded daily: weight of test plant, amount of water applied, irrigation number, and amount of run-off. For all treatments, run-off water samples were collected every eighth irrigation out of each ten irrigation cycle. Samples were stored at 4.4C until analyzed for pH (Fisher Accummet pH Meter; Fisher Scientific, Pittsburgh), EC (Solu-bridge; Beckman Instruments Inc., Cedar Grove, N.J.), NH_4 (Harwood and Kuhn, 1970), NO_3 (cadmium reduction method, Page et al., 1982), and PO_4 (hydroquinone method, Olsen and Sommers, 1982).

Plants were harvested when 100% of the plants from each replication reached anthesis (6-19 July 1994) and the following data were collected: date of anthesis, height, diameter (average of measurements taken at widest point and perpendicular to the first), and quality rating (1 to 5 scale, 1 = poorest and 5 = best salable quality). The geranium shoots were removed, dried at 65C for five days, and weighed. Shoot tissue was combined into one sample per replication, ground to pass through a 917-um screen (20 mesh), and stored in air tight containers until analyzed for total N by the macro Kjeldahl method (Horowitz, 1980). The root balls of 10 plants per replication were measured into three equal regions: top, middle, and bottom. Root counts were taken on one randomly selected 6.5 cm^2 area of the outer medium surface per region. After counting, the roots were washed, dried at 65C, and weighed. The remaining six root balls from each replication were sliced into top, middle, and bottom regions. An homogenous sample of medium was taken from each region. Medium samples were allowed to air dry and prepared for analysis using a 1:2 (v/v) medium to deionized water ratio, allowed to equilibrate for 30 min, and pH (Fisher Accumet pH meter, Fisher Scientific), and EC (Solu-bridge, Beckman Instruments Inc.) recorded. Medium samples were also analyzed for ammonia-based N by the macro-Kjeldahl method (Horowitz, 1980).

The experimental design was completely randomized with four irrigation systems, benches as replications, and plants as subsamples. Data were analyzed by the general linear model procedure and mean separation was by Tukey's HSD (SAS Institute, Cary, N.C.).

RESULTS

PLANT GROWTH AND TISSUE ANALYSIS

Plant height, diameter, quality rating, and shoot and root dry weights were not influenced by irrigation system (Table 4.1). The HD irrigation system produced plants with a significantly lower N concentration than the other irrigation systems, while plants irrigated with the CM system had the highest N concentration (Table 4.1). The EF and MT systems were not significantly different from each other. Shoot P concentrations did not significantly differ by irrigation system.

WATER EFFICIENCY

Amount of water applied. The greatest amount of water was applied with the CM system, and the second greatest with the HD irrigation system (Table 4.2). The MT and EF irrigation systems required similar amounts of water.

Amount of run-off. The EF system produced the least, and the CM system produced the greatest amount of run-off (Table 4.2). The MT and HD systems produced an intermediate amount of run-off and were not significantly different from each other.

RUN-OFF ANALYSIS

Run-off pH and EC. Run-off pH and EC from the irrigation systems were not significantly different from each other (Table 4.2).

Run-off nutrient concentration. Run-off from the two top irrigated systems had lower NH_4 concentrations than that of the subirrigation systems (Table 4.2). Run-off from the EF system had the highest PO_4 concentration. The MT, HD, and CM irrigation systems produced run-off with lower PO_4 concentrations than EF, but were not significantly different from each other. Run-off NO_3 did not vary with the irrigation systems.

MEDIUM AND ROOT ANALYSIS

Medium pH. Medium pH was lowest in the bottom regions of pots irrigated with the HD, and MT systems, and the bottom and middle regions of pots on the CM system (Table 4.3). No significant difference occurred amount the regions of medium receiving EF irrigation.

Medium EC. For plants irrigated with the HD system, medium EC was similar among all three regions (Table 4.3). The top and middle regions of medium irrigated with the MT system had the same medium EC, while the EC of the bottom region was significantly lower. For EF irrigation system, the EC of both the middle and bottom regions of medium was significantly lower than that of the top region. In the CM irrigation system, medium from the top region had the highest EC, the middle region intermediate, and the bottom region had the lowest. Among the irrigation-region combinations, the lowest EC was found in the middle and bottom regions of medium from the EF system and the bottom region of medium from the MT and CM system. Overall, the highest medium EC was found in the top region of medium irrigated with the CM system.

Root count. For all irrigation systems, the root count in the top region was lower than the root counts in the middle and bottom regions (Table 4.3). The HD irrigation system had similar root counts in the middle and bottom regions which were both higher than in the top region. Root counts from the MT and CM irrigation systems were lowest in the top region, intermediate in the middle region, and highest in the bottom region. In the EF irrigation system, the root count was highest in the middle region, intermediate in the bottom region, and lowest in the top region. Subirrigation systems produced plants with higher root counts than top irrigated systems. Among all irrigation-region combinations, lowest root counts were found in the top regions of the MT and CM irrigation systems. The middle region of medium irrigated with the EF system and bottom region of the CM system had the highest overall root counts.

Medium N content. Irrigation system alone did not significantly influence the total amount of N from all three regions; however, N content was influenced by region and an interaction existed among irrigation system and region (Table 4.3). For the HD irrigation system, medium N content was lower in the middle region than in the top and bottom regions. The MT and EF irrigation systems had higher medium N content in the top region than in the middle and bottom regions, although the difference was smaller in the MT system. The highest N content among all irrigation-region combinations was in the top region of medium from the CM system and significantly lower N content was found in the middle and bottom regions.

DISCUSSION

MEDIUM REGIONS

As with previous reports (Argo and Biernbaum 1994, 1995; Molitor, 1990), electrical conductivity and medium N tended to be highest in the top region; however, less significant differences between the medium regions existed for top irrigated plants than for subirrigated plants (Table 4.3). The difference between irrigation methods may have been due to the mass flow of water in a downward direction, causing salts to be flushed through the medium with some leaching out of the container. Between irrigations, evaporation from the medium surface allowed salts to build up in the upper medium layers only to be flushed down again by the following irrigation. The up and down movement of fertilizer salts may cause salt concentrations to be less stratified. This concept is further supported by the medium EC patterns from the HD and MT systems (Table 4.3). Hand irrigation caused salts, medium nitrogen, and root count to be more evenly distributed than MT irrigation. Due to the nature of HD irrigation, the flow of water downward was more forceful than that of MT irrigation where water percolated slowly through the medium. In contrast, Ku and Hershey (1991) found that EC was greater in the lower medium layer due to piston displacement of soluble salts in the medium by the newly applied fertilizer solution.

When subirrigated, the highest soluble salt concentration and medium nitrogen was in the top region (Table 4.3) in agreement with Molitor (1990), Argo and Biernbaum

(1994, 1995), and Guttormsen (1969). For subirrigation the main movement of water and fertilizer salts was in an upward direction. Water was absorbed through the bottom of the container and drawn to the medium surface, where evaporation was most rapid, by the wicking action of the medium (Laurie and Ries, 1950). Although subirrigation treatments were leached from top to bottom with clear water periodically, the frequency and amount of water was not enough to cause soluble salts to stay in the bottom layers. Argo and Biernbaum (1995) described the medium surface in subirrigation as a point of salt removal similar to leaching through the bottom of the container in top irrigation systems, and indicated that salts were pulled away from the root zone preventing damage from high fertilizer rates. Likewise, in the current experiment, no differences in plant growth or quality existed among the irrigation methods, although the same fertilizer rates were used.

Medium pH was lowest in the bottom region of top irrigated medium, while the middle and top regions had significantly greater pH (Table 4.3). With subirrigation pH also tended to be lowest in the bottom region; however, the difference was not significant with EF irrigation. Molitor (1990) found that subirrigation decreased pH in the lower layer of the medium; however, the difference in pH was much greater with subirrigation than trickle irrigation. Molitor (1990) suggested that the low pH of the bottom medium region may have been due to an increased amount of nitrifying bacteria in the lower layer, which was promoted by high ammonium fertilizer. Trickle irrigation distributed ammonia more uniformly throughout the root zone; and pH was less stratified (Molitor, 1990).

In addition, Heiskanen (1995) found that the lower layer of peat medium has a higher moisture level than the middle and upper layers. The increased moisture in the lower region may have caused an increase in mineralization, and release of organic acids, therefore reducing pH as well as encouraging nitrifying bacteria. In contrast, Ku and Hershey (1991) concluded that pH was greater in the lower layer due to adsorption of ammonium to the medium.

The two subirrigation systems produced plants with higher average root counts than those grown with the two top irrigation systems (Table 4.3). However, root weights may not always correlate with root counts, as Dole et al. (1994) reported that overall root dry weights were not significantly different for EF and top irrigation, and root weights from the CM system were significantly lower than other irrigation treatments. Root counts in the bottom region of MT were significantly greater than the middle and upper regions. Root growth was visibly concentrated at the bottom of the container. Medium EC was also significantly lower in the bottom region, while the two upper regions were not different from each other. High soluble salt concentrations may have suppressed root growth. Root counts were significantly greater in the middle region of EF medium, while soluble salt concentration was lower in both the bottom and middle regions of medium than that of any other region and irrigation system. The decreased EC in the middle region may have allowed more root growth in the middle of the container, as compared to a higher EC in the middle region, and increased root growth in the area of more favorable growing conditions. Although there was no effect on plant growth in this experiment, Argo and Biernbaum (1995) found that plant growth decreased when root-zone nutrient concentrations were above the optimal SME (saturated medium extract) range. Yelanich and Biernbaum (1990) also noted decreased plant growth with increased medium EC.

Run-off from the two top irrigation systems had lower NH_4-N concentrations than that of the subirrigation systems. For all irrigation systems, run-off NO_3-N concentrations were not significantly different.

IRRIGATION SYSTEM

For all irrigation systems, no differences existed in plant grade, height, diameter, shoot and root dry weights, and shoot P content. The similar growth was attributed to a short crop duration due to high temperature and light conditions (25.3/24.1C, PPF 1296 $\mu mol \cdot m^{-2} \cdot sec^{-1}$) which allowed the plants to reach anthesis quickly (36-49 days). However, plants grown on HD irrigation had lower tissue N concentration than all other treatments, while plants irrigated by CM had greatest N concentrations. In contrast, Knight et al. (1993) found that geraniums grown with top irrigation had greater shoot N than those grown in an EF trough system.

The HD irrigation system required the second greatest amount of water and released an intermediate amount of run-off, making the system less water efficient than the MT and EF systems. The MT system required the least amount of water and produced an intermediate amount of run-off, but less than HD irrigation. The CM irrigation system required the greatest amount of water and produced the greatest amount of run-off; in addition, nutrient concentrations in the run-off were greater than that of MT and HD irrigation. Thus, the amount of nutrients lost as run-off was much greater than all other treatments which is in agreement with Dole et al. (1994). In the current study, the large amount of water required by the CM system was attributed to evaporation from the mats, accentuated by high light intensity and high temperatures (Dole et al., 1994). Biernbaum et al. (1991) found that 30-60% of total water lost from a containerized plant was caused by evaporation from the medium surface. The addition of the mat extended the area of evaporation causing an even greater percentage of water to be lost. In contrast, while Alleman and Weiler (1994) noted that water efficiency was significantly improved by use of capillary mat systems. This work was conducted in New York, where fall/winter light intensity and temperatures would be somewhat lower than in Oklahoma. A large amount of nutrients may have been held within the absorbent mat causing another outlet for nutrient loss; however, further research is needed to determine if the amount is significant. Overall, medium N concentration was greatest for CM irrigation, and may have been the result of a greater amount of water and fertilizer applied.

The EF system lost only 6.5% of applied water as run-off. The amount of run-off recorded was actually from leaching with clear, unamended water every fifth irrigation when the irrigation water was allowed to flow from the bench, rather than water that leached from the container at each irrigation. The run-off P_2O_5-P was greater than all other irrigation systems. Run-off concentrations reported were the result of a mixture of samples taken from the sump tanks holding the fertilizer solution and run-off from periodic leaching. These concentrations are misleading. If samples had been taken from only the effluent that was lost to the environment, the leachings, the concentrations would have been much lower. Run-off NH_4-N concentrations are also greater, though not significantly different than that of CM run-off.

In summary, the medium pH decreased in the bottom region of the rootball when irrigated with any irrigation system. Soluble salts and medium N were concentrated in the top region of rootballs grown with subirrigation systems, while top irrigation, especially the HD irrigation system caused a relatively even distribution of salts, medium N, and root growth. Irrigation system effected both the vigor and distribution of root growth, which may be correlated with soluble salt concentrations in the medium regions. To correlate the direct effect of these factors on plant growth, this experiment would need to be repeated using a crop with a longer growing season to allow growth differences to become evident. Over a longer season, root growth would increase and fill the rootball more completely, including the middle and top regions where pH and EC would have a more significant effect on plant growth.

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Table 4.1. Influence of irrigation system on plant growth and shoot nutrient content of *Pelargonium hortorum* 'Pinto Red' grown with 220 mg·liter^{-1} N.[Z] Means are and average of four replications (benches) of 16 plants, except for root dry weights which were based on 10 plants per replication.

Irrigation system	Quality rating[Y]	Height (cm)	Diameter (cm)	Shoot dry weight (g)	Root dry weight (g)	Shoot N (%)	Shoot P (%)
Hand	3.8	14.1	23.9	9.06	1.43	2.55	0.33
Microtube	3.9	14.2	23.5	7.55	1.53	2.92	0.29
Capillary mat	3.9	13.9	24.5	7.93	1.40	3.00	0.39
Ebb-and-flow	4.0	14.1	23.7	8.05	1.77	2.80	0.42
HSD	0.6	1.4	2.7	2.64	1.23	0.17	
Irrigation	NS	NS	NS	NS	NS	***	NS

[Z] Planting date, 27 May 1994 and harvested when 100% of the plants reached anthesis.
[Y] 1-5 rating with 5 the best.
*, **, ***, NS Significant at $P \leq 0.05$, 0.01, 0.001, or nonsignificant, respectively.

Table 4.2. Influence of irrigation system on water use and run-off nutrient content of *Pelargonium hortorum* 'Pinto Red' grown with 220 mg·liter^{-1} N.[z] Means are an average of data from four replications (benches) of 16 plants.

Irrigation System	Applied (liter)	Runoff (liter)	Runoff				
			pH	EC	NO_3-N (mg·liter^{-1})	NH_4-N (mg·liter^{-1})	P_2O_5-P (mg·liter^{-1})
Hand	148.3	52.0	6.9	2.3	182.8	81.7	7.2
Microtube	108.0	47.8	6.1	2.2	211.5	79.1	4.4
Capillary mat	278.3	88.3	6.5	2.4	264.4	120.0	11.9
Ebb-and-flow	116.2	7.5	6.0	1.8	146.0	163.3	41.9
HSD	13.2	8.5	1.2	0.9	120.7	52.5	9.2
Irrigation	***	***	NS	NS	NS	**	***

[z] Planting date, 27 May 1994 and harvested when 100% of the plants reached anthesis.
*, **, ***, NS Significant at $P \leq 0.05$, 0.01, 0.001, or nonsignificant, respectively.

Table 4.3. Influence of irrigation system on pH, EC, root count, and nitrogen content of medium regions of *Pelargonium hortorum* 'Pinto Red' grown with 220 mg·liter^{-1} N.[z] Means are an average of data from four replications (benches) of 6 plants for pH, EC, and N determination, and 10 plants for root counts.

Irrigation system	Region	pH	EC (mS)	Root count	N (%)
Hand	Top	5.42	1.33	5.6	0.89
	Middle	5.45	0.98	13.6	0.79
	Bottom	4.73	1.09	14.7	0.87
Microtube	Top	5.42	1.86	3.5	0.91
	Middle	5.46	1.86	12.4	0.70
	Bottom	4.76	0.58	17.3	0.73
Capillary Mat	Top	5.17	3.12	5.3	1.25
	Middle	4.73	1.02	16.6	0.77
	Bottom	4.46	0.66	20.8	0.73
Ebb-and-flow	Top	5.25	2.15	9.1	1.02
	Middle	5.40	0.54	20.9	0.68
	Bottom	5.19	0.38	15.5	0.64
Interactive LSD		0.33	0.44	4.06	0.06
Irrigation		***	*	*	NS
Region		**	***	***	***
Irrigation*Region		**	***	***	***

[z] Planting date, 27 May 1994 and harvested when 100% of the plants reached anthesis.
*, **, ***, NS, Significant at $P \leq 0.05$, 0.01, 0.001, or nonsignificant, respectively.

CHAPTER V

SUMMARY

Pulse irrigation increased water use efficiency, reduced the amount of nutrients lost as run-off, and produced large, vigorous plants. The MT and EF irrigation systems were both water and fertilizer efficient. The CM irrigation system was the least water efficient, used the greatest amount of water, produced the greatest amount of run-off, and released the greatest amount of NO_3-N, NH_4-N, and PO_4-P to the environment. The commonly used HD irrigation produced the smallest plants, with reduced height, diameter, and dry weight. By reducing applied fertilizer rates, and using the EF or MT irrigation system with pulse irrigation frequency, growers could greatly decrease potential contamination to ground and surface water sources, while producing high quality, profitable plants. Also, operating costs would be lowered by increasing water and fertilizer efficiency.

The nutrient efficiency of greenhouse irrigation systems could be increased if at least 50% of fertilizer is supplied by CRF. Fertilizing with 100% CLF caused higher concentrations of nutrients to be released to the environment with no increase in growth or quality. The efficiency of CRF was increased with the use of EF or MT irrigation systems, which produced large, high quality plants and released small volumes of run-off. By utilizing water efficient irrigation systems together with nutrient efficient fertilizer sources, the potential of contaminating ground and surface water sources would be greatly reduced.

In addition to determining the most water and nutrient efficient irrigation and fertilizer practices, we found that the medium pH was lowest in the bottom region of the rootball when irrigated with any irrigation system. Soluble salts and media N were concentrated in the top region of rootballs grown with subirrigation systems, while top irrigation, especially the HD irrigation system, caused a relatively even distribution of soluble salts, media N, and root growth. Irrigation system effected both the vigor and distribution of root growth, which may be correlated with soluble salt concentrations in the media regions.

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