Irrigation Systems Alter Distribution of Roots, Soluble Salts, Nitrogen, and pH in the Root Medium

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SUMMARY. *Pelargonium hortorum* Bailey 'Pinto Red' plants were grown with 220 mg·L⁻¹ N (20N-4.4P-16.6K) using hand (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. A negative correlation existed between root medium electrical conductivity (EC) and N concentration to root number such that the best root growth was obtained with low medium EC and N concentrations. EF root numbers were greatest in the middle region. The two subirrigation systems (EF and CM) had higher average root numbers than the two surface-irrigation systems (HD and MT). For all irrigation systems, root numbers were lowest in the top region. In general, less difference in medium soluble salt and N concentrations existed between

regions for surface-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 medium soluble salt and N concentration was in the top region. For all systems, pH was lowest in the bottom region. Plant growth for all irrigation systems was similar. EF and MT systems required the least water and EF resulted in the least runoff volume.

Plant growth is 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, including soluble salts, nutrients, and pH, 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 in comparison of 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 medium 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).

Limited research has been conducted concerning root number, soluble salt and N concentration, and pH among irrigation systems. The purpose of this experiment was to study

the effect of four irrigation methods on the distribution of roots, soluble salts, N, and pH in the root medium.

Materials and methods

Commercially grown *Pelargonium hortorum* 'Pinto Red' geranium seedling plugs were planted three per 15-cm (1270-mL) azalea pot on 31 May 1994 using 1.5 L of 3 peatmoss : 1 perlite : 1 vermiculite medium (by volume) amended with 6.87 g dolomite per pot. The medium had 80% porosity, 70% total water-holding capacity, 48% available water, and 22% unavailable water, based on oven-dried medium. Plants were grown in a corrugated polycarbonate-covered greenhouse with an average air temperature of 25.3/24.1 °C day/night and maximum photosynthetic photon flux (PPF) of 1310 μmol·m⁻²·s⁻¹. Standard disease and insect control procedures were followed (White, 1993). Sixteen pots were spaced 38 × 38 cm on water-tight benches and irrigated with 220 mg·L⁻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 mass, 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 mass of the entire plant, pot, and medium was recorded. The pots were then watered to saturation and weighed again to determine container capacity. Target irrigation masses were calculated as follows: [(container capacity - wilting point mass) (0.40)] + wilting point mass = the total pot mass at 40% container capacity. The target test pot mass was obtained by averaging the masses of the six pots at 40% container capacity. One test pot from each replication (bench) was selected and weighed daily. Replications were irrigated when the test pot was at or below the set target irrigation mass.

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 emitters (Chapin Watermatics, Watertown, N.Y.)], 3) ebb-and-flow (EF) [1.5 × 1.8-m bench top, 190-L tank, pump, and drain tube (Midwest

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Gromaster, St. Charles, Ill.], or 4) capillary mat (CM) [1.5 × 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 water-tight bench top, held for 12 min to allow uptake by plants, and drained back into the tank after each irrigation. The EF irrigation system only released runoff from periodic leachings with unamended water; during which time the bench was unplugged, allowing the excess water to flow from the bench top rather than being returned to the tank. Irrigation solution 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; the additional solution was measured and totaled to determine the amount of water applied during the experiment. The MT and HD irrigation treatments had a 0.3 to 0.5 leaching fraction; MT treatments were irrigated for 45 s per bench and HD treatments were irrigated for 2 s per pot at a flow rate of 0.28 L·s⁻¹ (Electronic Digital Meter; Great Plains Industries, Wichita, Kan.) The CM irrigation treatment was irrigated by applying water for 60 s per bench at 0.28 L·s⁻¹, 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 runoff water was collected in a trough that hung from the edge of the bench and was slanted slightly downward toward a bucket. The runoff from HD, MT, and EF treatments was collected from a drain under each bench and volume was measured.

The amount of water applied at each irrigation was determined with a flowmeter (Electronic Digital Meter) installed in the water line. All pots were leached from the top every fifth irrigation with unamended water. The capillary mats were also leached an additional 15 s every fifth irrigation and drained to prevent high soluble salt concentrations.

The following data were recorded daily: mass of test pot, volume of water applied, and volume of runoff. For all treatments, runoff water samples were collected every eighth irrigation out of 10 irrigations. Samples were stored at

4.4 °C until analyzed for electrical conductivity (EC) (Solu-bridge; Beckman Instruments Inc., Cedar Grove, N.J.), pH (Fisher Accumet pH Meter; Fisher Scientific, Pittsburgh), NO₃⁻-N (cadmium reduction method, Page et al., 1982), NH₄⁺-N (Harwood and Kuhn, 1970), and PO₄⁻-P (hydroquinone method, Olsen and Sommers, 1982).

Each replication (bench) of 16 pots (3 plants/pot) per irrigation system was harvested when 100% of the plants reached anthesis (6–19 July 1994) and the following data were collected (n = 64): 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 65 °C for 5 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 total N by the macro Kjeldahl method (Horowitz, 1980). The root balls of 10 pots per replication were measured into three equal regions: top, middle, and bottom. The roots were counted on one randomly selected 6.5-cm² area of the outer medium surface per region (n = 40). After

counting, the roots were washed, dried at 65 °C, and weighed. The remaining six root balls from each treatment in each replication were sliced into top, middle, and bottom regions. A homogeneous medium sample was taken from each region. Medium samples were air dried and prepared for analysis using 1 medium : 2 deionized water (v/v) and allowed to equilibrate for 30 min, and EC and pH were recorded. Medium samples were also analyzed for N by the macro-Kjeldahl method (Horowitz, 1980).

A completely randomized experimental design was used with four irrigation systems replicated on four benches containing sixteen pots (sub-samples) per irrigation system. Data were analyzed by the general linear model procedure and means separation was by Tukey's HSD (SAS Institute, Cary, N.C.). Correlation coefficients were determined for EC, medium N, and pH with root number (SAS Institute).

Results and discussion

ROOT MEDIUM REGIONS. Root number was negatively correlated with medium EC ($r = -0.72$, $p = 0.0001$) and N ($r = -0.51$, $p = 0.0002$) (Table 1). Regions with low EC had high root numbers and, conversely, high soluble salt concentrations suppressed root

Table 1. Influence of irrigation system on root number, EC, N content, and pH of root medium regions of *Pelargonium hortorum* 'Pinto Red' grown with 220 mg·L⁻¹ N.² Means are an average of data from 40 pots for root number and 24 pots for EC, N, and pH determination.

Irrigation system	Region	Roots (no.)	EC (dS·m ⁻¹)	N (%)	pH
Hand	Top	5.4	1.33	0.89	5.42
	Middle	13.6	0.98	0.79	5.45
	Bottom	14.7	1.09	0.87	4.73
Microtube	Top	3.5	1.86	0.91	5.42
	Middle	12.4	0.70	0.70	5.46
	Bottom	17.3	0.58	0.73	4.76
Capillary mat	Top	5.3	3.12	1.25	5.17
	Middle	16.6	1.02	0.77	4.73
	Bottom	20.8	0.66	0.73	4.46
Ebb-and-flow	Top	9.1	2.15	1.02	5.25
	Middle	20.9	0.54	0.68	5.40
	Bottom	15.5	0.38	0.64	5.19
Interactive LSD		4.1	0.44	0.06	0.33
Irrigation		*	*	NS	***
Region		***	***	***	**
Irrigation × region		***	***	***	**
Correlation coefficient (r) with root number		---	-0.72***	-0.51***	-0.24 ^{NS}

²Planted 31 May 1994 and harvested when 100% of the plants reached anthesis.

*, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 2. Influence of irrigation system on plant growth and shoot nutrient content of *Pelargonium hortorum* 'Pinto Red' grown with 220 mg·L⁻¹ N.² Means are an average of data from 64 pots, except for root dry masses which were based on 40 pots.

Irrigation system	Quality rating ¹	Anthesis ² (days)	Ht (cm)	Diam (cm)	Shoot dry mass (g)	Root dry mass (g)	Shoot N (%)	Shoot P (%)
Hand	3.8	38.8	14.1	23.9	9.06	1.43	2.55	0.33
Microtube	3.9	38.5	14.2	23.5	7.55	1.53	2.92	0.29
Capillary mat	3.9	38.0	13.9	24.5	7.93	1.40	3.00	0.39
Ebb-and-flow	4.0	39.3	14.1	23.7	8.05	1.77	2.80	0.42
HSD	0.6	3.7	1.4	2.7	2.64	1.23	0.17	0.14
Irrigation	NS	NS	NS	NS	NS	NS	***	NS

¹Planted 31 May 1994 and harvested when 100% of the plants reached anthesis.

²1 to 5 rating with 5 the best.

NS,***Nonsignificant or significant at $P \leq 0.001$, respectively.

growth. Root numbers from the MT and CM irrigation systems were lowest in the top region, intermediate in the middle region, and highest in the bottom region, while EC decreased from the top region to the bottom region. A low EC in the bottom region may have allowed more root growth due to favorable growing conditions. Although the irrigation systems did not effect shoot growth in this experiment, numerous authors have noted that plant growth decreased when medium EC is above optimal levels (Argo and Biernbaum, 1995; Devitt and Morris, 1987; Judd and Cox, 1992; Yelanich and Biernbaum, 1990). For geraniums, Lieth and Burger (1993) recommended leaching when medium EC was above 1.5 dS·m⁻¹; the top regions of MT, CM, and EF systems had ECs above 1.5 dS·m⁻¹. In the EF irrigation system, the root number was highest in the middle region, intermediate in the bottom region, and lowest in the top region; the soluble salt concentration was lower in the bottom and middle regions than the top. The HD irrigation system had similar root numbers in the middle and bottom regions, which were both higher than in the top region. Subirrigation systems EF and CM produced plants with higher root numbers than surface-irrigated systems IID and MT. For all irrigations systems, the top regions had lower root numbers and higher ECs than the middle and bottom regions. Not surprisingly, medium N concentration was positively correlated with medium EC ($r=0.76$, $p=0.0001$) and produced a similar relationship to root number as medium EC.

As with previous reports (Argo and Biernbaum, 1994, 1995; Molitor,

1990), root medium EC and N concentration tended to be highest in the top region; however, EC was less stratified between the medium regions for surface-irrigated plants than for subirrigated plants (Table 1). 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, which is supported by the medium EC patterns from the HD and MT systems. Hand irrigation caused soluble salts, medium N, and root number 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 medium soluble salt and N concentrations were in the top region (Table 1), 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 surface-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.

Root medium pH was lowest in the bottom region of surface-irrigated medium, while the middle and top regions had significantly greater pH (Table 1). With subirrigation, pH also tended to be lowest in the bottom region; however, the difference was not significant with EF irrigation. While Molitor (1990) also found that subirrigation decreased pH in the lower layer of the root medium, the difference in pH was much greater with subirrigation than trickle irrigation. Molitor (1990) suggested that the low pH of the bottom root 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 had a higher moisture level than the middle and upper layers. The

Table 3. Influence of irrigation system on water use and runoff nutrient content of *Pelargonium hortorum* 'Pinto Red' grown with 220 mg·L⁻¹ N.^a Means are an average of data from four replications (benches) of 16 pots each.

Irrigation system	Applied (L)	Runoff (L)	EC (dS·m ⁻¹)	pH	Runoff		
					NO ₃ -N (mg·L ⁻¹)	NH ₄ -N (mg·L ⁻¹)	PO ₄ -P (mg·L ⁻¹)
Hand	148	52	2.25	6.90	183	82	7
Microtube	108	48	2.22	6.13	212	79	4
Capillary mat	278	88	2.44	6.50	264	120	12
Ebb-and-flow	116	8	---	---	---	---	---
HSD	13	9	0.90	1.24	121	53	9
Irrigation	***	***	NS	NS	NS	**	***

^aPlanted 31 May 1994 and harvested when 100% of the plants reached anthesis.

NS, **, *** Nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively.

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 in a hand-irrigation system.

IRRIGATION SYSTEMS. For all irrigation systems, no differences existed in plant quality, anthesis, height, diameter, shoot and root dry masses, and shoot P content (Table 2). The similar growth between irrigation systems was attributed to a short crop duration due to high temperature and light conditions (25.3/24.1 °C, PPF 1310 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$), which allowed the plants to reach anthesis quickly (36 to 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 surface 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 volume of runoff, making the system less water efficient than the MT and EF systems (Table 3). The MT system required the least amount of water and produced an intermediate volume of runoff, but less than HD irrigation. The CM irrigation system required the greatest amount of water and produced the greatest volume of runoff; in addition, nutrient concentrations in the runoff were greater than that of MT and HD irrigation. Thus, the amount of nutrients lost as runoff from CM irrigation was much greater than all other treatments, which is in agree-

ment 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% to 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) noted that water efficiency was significantly improved by use of capillary mat systems. Their work was conducted in New York, where fall-winter light intensity and temperatures would be somewhat lower than in Oklahoma. Overall, medium N concentration was greatest for CM irrigation, which probably resulted from greater amounts of water and fertilizer being applied (Table 1).

The EF system lost only 6.5% of applied water as runoff (Table 3). The amount of runoff recorded was actually from leaching with 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. Therefore, nutrient content of the runoff is not reported. Holcomb et al. (1992) and Dole et al. (1994) also noted that recirculatory ebb-and-flow irrigation produced the least runoff.

Conclusions

Irrigation system affected the distribution of root growth, which was negatively correlated with soluble salt and N concentrations in the root-medium regions (Table 1). Soluble salts and medium N were concentrated in

the top region of root balls produced with subirrigation systems, while surface irrigation, especially the HD irrigation system, caused a relatively even distribution of root growth, salts, and root medium N. The root-medium pH was lower in the bottom region of the root ball compared to the middle and top regions when irrigated with any irrigation system. While all irrigation systems produced similar shoot growth, EF resulted in the least runoff (Tables 2 and 3).

Literature cited

- Alleman, D.M. and T.C. Weiler. 1994. Comparison of greenhouse benching/irrigation systems for water use, fertilizer use, and crop quality with poinsettias and geraniums. *HortScience* 29:452. (Abstr.)
- Argo, W.R. and J.A. Biernbaum. 1994. Irrigation requirements, root-medium pH, and nutrient concentrations of Easter lilies grown in five peat-based media with and without an evaporation barrier. *J. Amer. Soc. Hort. Sci.* 119:1151-1156.
- Argo, W.R. and J.A. Biernbaum. 1995. The effect of irrigation method, water soluble fertilization, preplant nutrient charge, and surface evaporation on early vegetative and root growth of poinsettia. *J. Amer. Soc. Hort. Sci.* 120:163-169.
- Biernbaum, J.A., W. Argo, and M. Yelanich. 1991. Effect of a pot cover on irrigation and fertilizer requirements and media nutrient stratification. *HortScience* 26:764. (Abstr.)
- Conover, C.A. and R.T. Poole. 1992. Effect of fertilizer and irrigation on leachate levels of NH₄, NO₃, and P in container production of *Nephrolepis exalta* 'Fluffy Ruffle'. *J. Environ. Hort.* 10:238-241.
- Devitt, D.A. and R.L. Morris. 1987. Morphological response of flowering annuals to salinity. *J. Amer. Soc. Hort. Sci.* 112:951-955.

Dole J.M., J.C. Cole, and S.L. von Broembsen. 1994. Growth of poinsettias, nutrient leaching, and water-use efficiency respond to irrigation methods. *HortScience* 29:858-864.

Guttormsen, G. 1969. Accumulation of salts in the sub-irrigation of pot plants. *Plant Soil* 21:425-438.

Harwood, J. E. and A.L. Kuhn. 1970. A colorimetric method for ammonium in natural waters. *Water Res.* 4:805-811.

Heiskanen, J. 1995. Water status of sphagnum peat and a peat-perlite mixture in containers subjected to irrigation regimes. *HortScience* 30:281-284.

Holcomb, E.J., S. Gamez, D. Beattie, and G.C. Elliott. 1992. Efficiency of fertigation programs for baltic ivy and asiatic lily. *HortTechnology* 2:43-46.

Horowitz, W. 1980. Official methods of analysis of the Association of Analytical Chemists. 13th ed. Assn. of Official Anal. Chem., Washington D.C.

Judd, L.K. and D.A. Cox. 1992. Growth of New Guinea impatiens inhibited by high growth-medium electrical conductivity. *HortScience* 27:1193-1194.

Knight, P.R., D.J. Eakes, and C.H. Giliam. 1993. Method of irrigation and fertilizer application influence growth and nitrogen recovery for 'Scarlet Elite' geranium. *HortScience* 28:477. (Abstr.)

Ku, C.S.M. and D.R. Hershey. 1991. Leachate electrical conductivity and growth

of potted poinsettia with leaching fractions of 0 to 0.4. *J. Amer. Soc. Hort. Sci.* 116:802-806.

Laurie, A. and V.H. Ries. 1950. *Floriculture—Fundamentals and practices*. 2nd ed. McGraw-Hill, N.Y.

Lieth, J.H. and D.W. Burger. 1993. Irrigation, p. 31-38. In: J.W. White (ed.). *Geraniums. IV*. Ball Publishing, Geneva, Ill.

Molitor, H.D. 1990. The European perspective with emphasis on subirrigation and recirculation of water and nutrients. *Acta Hort.* 272:165-173.

Olsen, S.R. and L.E. Sommers. 1982. Phosphorus, p. 404-430. In: A.L. Page, R.H. Miller, and P.R. Keeney (eds.). *Methods of soil analysis. Part 2. Chemical and microbial properties*. Amer. Soc. Agron., Soil Sci. Amer., Madison, Wis.

Page A.L., R.H. Miller, and P.R. Keeney. 1982. Total nitrogen, p. 1162-1170. In: A.L. Page, R.H. Miller, and P.R. Keeney (eds.). *Methods of soil analysis. Part 2. Chemical and microbial properties*. Amer. Soc. Agron., Soil Sci. Amer., Madison, Wis.

White, J.W. 1993. *Geraniums. IV*. Ball Publishing, Geneva, Ill.

Yelanich, M.V. and J.A. Biernbaum. 1990. Effect of fertilizer concentration and method of application on media nutrient concentration, nitrogen runoff and growth of *Euphorbia pulcherrima* 'V-14 Glory'. *Acta Hort.* 272:185-189.