Monitoring Water Use, Nutrient Management, Drainage and Leachate in Pot-in-Pot Nursery Container Production

Heping Zhu[1], Charles R. Krause[2], Randall H. Zondag[3]

[1, 2] USDA-ARS, Application Technology Research Unit, Wooster, Ohio, USA
[3] The Ohio State University Extension, Lake County, Ohio, USA
[1] zhu.16@osu.edu, [2] krause.2@osu.edu, [3]zondag.1@osu.edu

ABSTRACT

An experimental system to examine water and nutrition application in pot-in-pot nursery container production was established in a commercial nursery field. The system mainly consisted of three plots containing 50 trees planted in 50 pot-in-pot containers and irrigated with micro spray stakes, drainage water measurement devices, container-substrate moisture probes, thermocouples, a weather station and data loggers. Content level of nitrate nitrogen, phosphate and potassium in drainage water was determined by a liquid Ion chromatography analyzer and a Simultaneous ICP analyzer. The system provided a method to monitor not only the use of water and nutrients, drainage water quality, tree growth and substrate temperature and moisture content, but also monitor level and timing of nitrogen, phosphate and potassium loss through drainage to optimize fertility management practices, and protect water resources by aiding decisions whether drainage water should be recycled or released from the nursery.

Keywords: *Container Tree Production, Substrate, Micro Irrigation, Moisture, Ornamentals.*

INTRODUCTION

Water will be one of the most challenged resources in the world within the next 20 years (Postel, 2000). Efficient use and availability of quality water sources has been a major concern in the nursery industry for many years (Irmak, et al., 2003; Yeager, 1992). Without scientific guidelines for proper application of water and nutrients, future choices of nursery crop production sites and species will be limited (Beeson et al., 2004). Due to the current lack of scientific methodologies to guide irrigation practices, nursery growers often may apply water to crops by simply turning on valves without knowing how much water is lost through runoff or drainage. Overhead sprinkler systems are widely used to irrigate container-grown nursery crops, but water applied by this method is usually either excessive or insufficient, resulting in uneven application. During a growing season over 80% of the water from sprinkler systems may be lost through runoff, drainage and evaporation (Weatherspoon and Harrell, 1980).

Pot-in-pot system has been expanding rapidly during the past decade to produce high quality nursery crops at reduced labor cost. The system can moderate root temperature and improve root quality, prevent container-grown plants blowing over, and reduce harvesting costs (Ruter, 1997). However, with this technique, it is essential to apply sufficient water and nutrients to sustain rapid tree growth (Beeson and Keller, 2003; Ruter, 1998). Irrigation and fertilization practices have raised concerns over water use efficiency because of water loss from containers and the extent of nutrient and chemical leaching with drainage water entering soil and ground water (Fare et al., 1994; Yeager et al., 1993). With pot-in-pot systems due to containers are placed under soil surface, there is no proper methodology to easily observe water and nutrient loss because drainage water loss through in-ground containers cannot be directly observed during irrigation (Zhu et al., 2005).

Research has been limited with pot-in-pot production with respects to water drainage and chemical leaching under the wide variety of tree canopy structure, growing condition, and marketing requirement. Knowledge is lacking on interactions between water and nutrients for specific species and growing conditions. Techniques are needed to monitor nursery production practices to ensure proper use of water resources to determine irrigation application efficiency and assist with nutrient management. To fully explore potential impacts of pot-in-pot production systems on nursery production, knowledge of water quality and quantity is needed to produce healthy trees, improve application efficiency and prevent potential soil and groundwater contamination.

The objective of this research was to determine total amounts of nutrition, irrigation, rainfall and drainage water loss from pot-in-pot nursery crop production, nutrition leachate level, tree growth, container substrate moisture content and temperature, precipitation, and other weather conditions with a pot-in-pot production monitoring system.

MATERIALS AND METHODS

An experimental system (Figure 1) was established in a commercial nursery field to examine water quality, irrigation efficiency and drainage from pot-in-pot nursery container production. The system consisted of a plot containing 50 trees in a pot-in-pot system and irrigated with micro spray stakes, 10 drainage water measurement devices, 10 container substrate moisture probes, 10 thermocouples, a weather station, and two data loggers. After the system was established, data were collected on the amount of irrigation, drainage water loss, substrate moisture content and temperature, weather conditions, and tree caliper growth. The levels of nitrate nitrogen (NO_3-N), phosphate (P), and potassium (K) in water drainage were analyzed weekly from water samples. A detailed description of system development is given by Zhu et al. (2004, 2005).

Red Sunset maple (*Acer rubrum ‘Franksred’*) trees were selected for the test because of their popularity in nursery marketing. Caliper of each tree at 18 cm above the ground was measured during the growing season. The average tree caliper of bare root trees was 1.4 cm when they were transplanted to the pot-in-pot system.

The container substrate on a volumetric basis was composed of 55% aged pine bark, 3% sharp silica sand, 5% expanded shale Haydite soil conditioner (Hydraulic Press Brick Company, Indianapolis, IN), 20% steamed composted nursery trimmings and potting mix waste, 12% fibrous light Sphagnum peat, and 5% composted municipal sewage sludge.

A 5 to 6-month controlled release granular fertilizer 20-5-8 (N-P-K) (The Scotts Company, Marysville, OH) was applied on the top of substrate at a rate of 119 grams per tree when the bare root trees were transplanted in the containers. Then, water soluble urea with 28% nitrogen was injected into irrigation water at a constant rate of 200 ppm at every 19-day watering cycle although the application rate of this liquid feed program was supposed to vary with the condition of plant growth during the growing season.

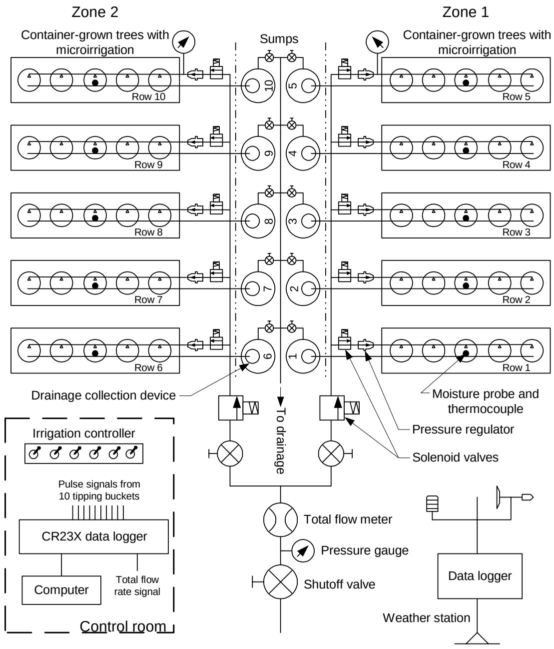

Figure 1. Schematic diagram of the experimental system for monitoring drainage water quantity and quality, and temperature and water content of container substrate in pot-in-pot nursery production

Each tree was irrigated with a spray stake (Part Number 01SSAYL-36, Netafim USA, Fresno, CA) inserted vertically near the container side wall to ensure all applied water was evenly distributed within the container. Nominal flow rate of the spray stake was 11.6 L/hr at 70 kPa. Each row had an irrigation supply line with a 70 kPa pressure regulator to minimize variations in application rate.

During 2003 growing season irrigation was applied twice a day until November 16 starting on August 6, 2003 with irrigation applied (or 14 weeks) under the conditions that there was insufficient rainfall to wet the container medium during the same day. Spray stakes with two different sizes (11.6 and 27.1 L/hr, respectively) at 70 kPa were used to verify the accuracy of the rain gage units for measuring amount of drainage from container-grown trees. Irrigation rate was controlled for five separate weeks during the growing season (Zhu. et al., 2004). Except for the five separate weeks, irrigation application rate during the rest of the 2003 growing season was managed following the production practice with 27.1 L/h for 6 minutes per day in a 18.2 ha commercial pot-in-pot production area adjacent to the experimental system. During 2004 growing season, the irrigation was applied twice a day at 11.6 L/hr rate for 8 minutes per day because high irrigation water loss through drainage was found from 2003 irrigation practice.

An electronic "tipping bucket" rain gauge unit was installed 43 cm below the soil surface in a 61 cm diameter and 122 cm deep sump to measure water drainage from five tree containers in each row (Zhu et al., 2004).

A cumulative drainage water sample from each row was collected every week for NO_3-N, P, K, and pH analysis. Samples were stored in a refrigerator before the analysis. A Model DX120 liquid Ion chromatography analyzer (Dionex Corporation, Strongsville, OH) was used to determine the NO_3-N level in each sample. A Model PS2000 Simultaneous ICP analyzer (Leeman Labs, Inc., Lowell, MA) was used to determine the P and K levels. The pH of drainage water samples was measured with a Model MA235 pH/Ion analyzer (Mettler-Toledo GmbH, Schwerzenbach, Switzerland) under laboratory conditions.

Container substrate moisture near upper root zones with majority of roots was measured with ten ML2X Theta probes (Delta-T Devices Ltd, Cambridge, England). The substrate temperature was measured by a thermocouple (Thermo Electric Co., Saddle Brook, NJ) with galvanic effect prevention at 5 cm below the surface in the middle container in each row. The thermocouple was installed beside the moisture probe.

A moveable weather station equipped with a CM-6 system (Campbell Scientific, Inc., Logan, Utah) was installed near the experimental plot to measure precipitation, air temperature, relative humidity, solar radiation, atmospheric pressure, and wind speed and azimuth. A CR23X data logger was used to process and acquire data from the rain gauge units, substrate moisture probes, thermocouples and the input flow meter at the interval of once a minute during the growing season.

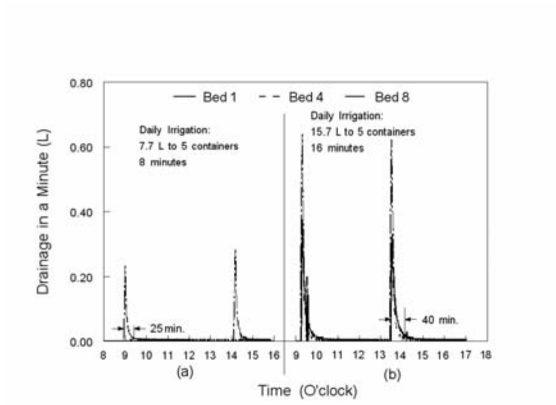

Figure 2. Real-time measurement of drainage water by tipping-bucket rain gauges for five container-grown trees in each bed with two different irrigation application rates and two times a day: (a) 7.7 L daily irrigation, and (b) 15.5 L daily irrigation

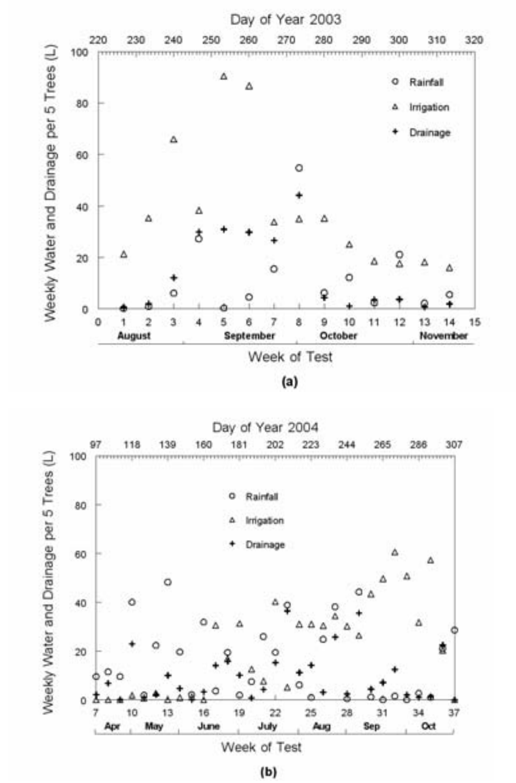

Figure 3. Weekly total rainfall and irrigation applied to, and drainage from, 50 pot-in-pot production containers during 2003 (a) and 2004 (b) growing seasons

RESULTS AND DISCUSSION

Amount of drainage. With the system, real-time data were acquired on drainage flow due to irrigation and rainfall. The average drainage start time from the 10 rows was 22.3 minutes after irrigation started with11.6 L/hr flow rate applied for three minutes, and was 7.6 minutes with 27.1 L/hr flow rate applied for three minutes. The initial peak drainage flow lasted less than 25 min for the 7.7 L irrigation and 40 min for the 15.5 L irrigation (Figure 2).

Data in Figure 3 (a) and (b) show the comparison of weekly total amounts of irrigation, rainfall and drainage water collected from 10 rows of the 50 pot-in-pot system during 2003 and 2004 growing seasons. During the 14-week period of 2003 growing season, total volume of drainage water from 5 containers in a row was 190 L while total irrigation water and rainfall to the 5 trees in a row was 694 L. About 27% of irrigation water and rainfall was lost through drainage during 2003 growing season while most portion of drainage water was from excessive irrigation. During 2004 growing season, about 26% of irrigation water and rainfall was lost through drainage while most portion of water drainage was from rainfall.

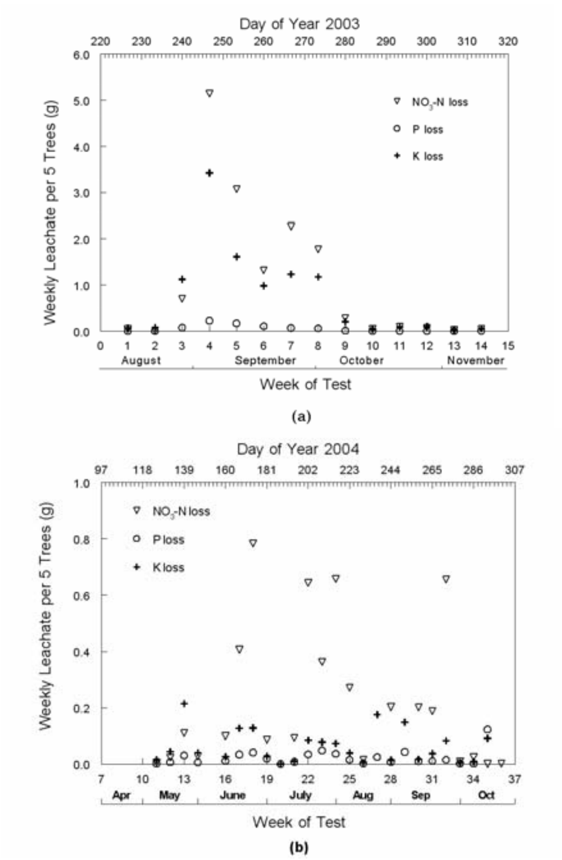

Figure 4. Average weekly amount of NO_3-N, P, and K in drainage water from 10 rows of total 50 pot-in-pot containers during 2003 (a) and 2004 (b) growing seasons

NO_3-N, P and K leachate. Figure 4 illustrates the average weekly amount of NO_3-N, P, and K leachate in drainage water from 10 rows during 2003 (a) and 2004 (b) growing seasons. The system detected that the total amount of NO_3-N, P and K lost through drainage from 50 containers during 14 weeks of 2003 growing season was 142.8, 7.2 and 97.8 grams, respectively. Most loss of nutrition occurred between week 4 and week 8 because of large amount of drainage. After week 9, the amount of NO_3-N, P, and K leachate decreased considerably because it was close to the end of the growing season and the residual level of NO_3-N, P, and K in the container substrate might be very low. The total amount of N, P and K leachate in the second growing season was considerably lower than the first growing season.

Substrate moisture content. Figure 5 shows the response of substrate moisture content in rows 1, 3, 7, and 10 to 27.1 L/hr of irrigation applied for 3 minutes and twice a day. The moisture content of the substrate near upper root zones reached the saturated point at about 55% in a very short time and then decreased to about 40% within 2 hours after irrigation stopped. The moisture content varied with the amount of rainfall, duration and row location. Longer intensive rainfall caused the substrate to remain longer in saturated condition. Moisture contents for other rows responded similarly to those shown in Figure 5.

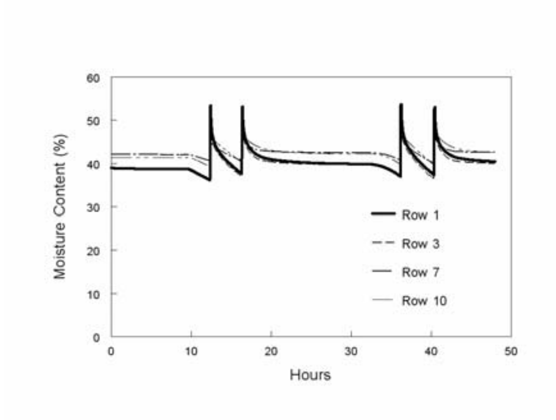

Figure 5. Example of substrate moisture content near upper root zones for four rows when 27.1 L/hr of irrigation was applied for 3 minutes, twice a day on September 9 and 10, 2003

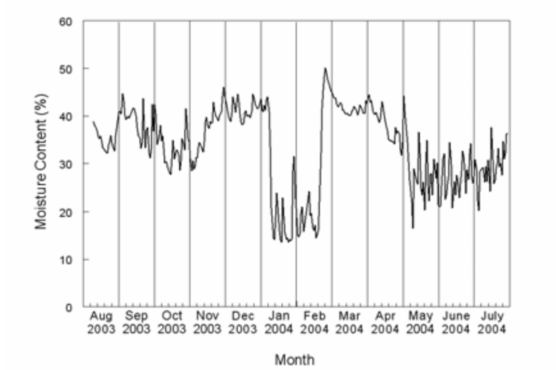

Figure 6. Mean container substrate moisture content measured with 10 probes between August 6, 2003 and July 31, 2004

Daily mean substrate moisture content near upper root zones fluctuated widely during four seasons, with the largest variation in January and February (Figure 6). The substrate moisture content from the end of November through December was higher than that in September and October. In late

November through December and early January, due to rainfall and snowfall, the top substrate was covered with ice which could hold moisture near probe-sensing area in the root zone. The moisture content in January and February generally declined below 20% because the probe-sensing area was frozen. However, in later February, due to the high ambient temperature, ice at the top of the substrate melted, and the moisture content increased above 40%. Moisture content of the container substrate varied with rows although the amount of irrigation water and rainfall to all rows were the same. Such differences might be caused by the variations in substrate uniformity, tree sizes in different containers, and other unknown factors.

Substrate temperature. The system acquired real-time data on substrate temperature for pot-in-pot production during the four seasons throughout a year. Figure 7 shows the average daily substrate temperature of 10 rows and maximum and minimum daily ambient air temperatures between August 2003 and July 2004. In September, the substrate temperature in 10 rows ranged from 11.7 to 25.4°C while the ambient air temperature ranged from 5.1 to 28.9 °C. Comparatively, in February the substrate temperature in 10 rows ranged from -4.4 to 0.4°C while the ambient air temperature ranged from -19.7 to 15.7 °C. The substrate temperature in the pot-in-pot system had much lower variation than the

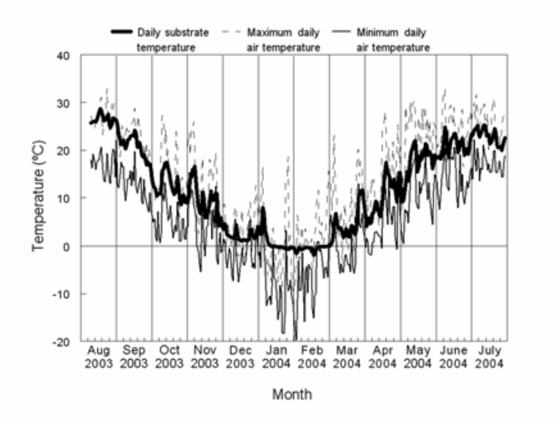

Figure 7. Average daily substrate temperatures in 10 rows and daily minimum and maximum ambient air temperatures between August 2003 and July 2004

ambient temperature within a day, and was independent of moisture levels before the substrate was frozen. In contrast to the substrate moisture content, the substrate temperature did not have much variation between different rows.

Drainage water pH. The mean pH of drainage water samples stayed within the range from 4.4 and 8.6 for all 10-row samples during both 2003 and 2004 growing seasons (Figure 8). The average irrigation water pH was 7.5. High water pH could result in negative impact on tree uptake, substrate quality and drainage water quality.

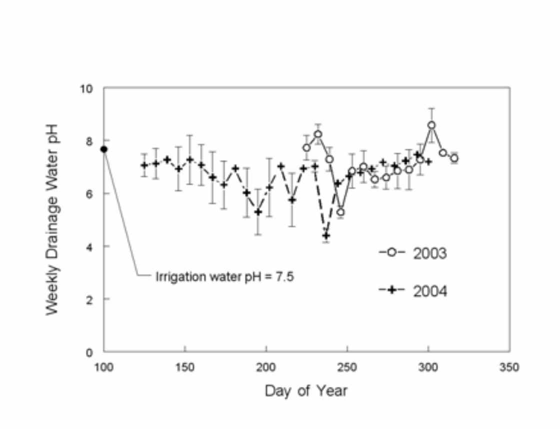

Figure 8. Average weekly drainage water pH from 10 rows of total 50 pot-in-pot containers during 2003 and 2004 growing seasons

Tree growth. The system can be used to evaluate response of tree growth to changes in weather conditions and inputs of water and nutrition to pot-in-pot production systems. Figure 9 shows the caliper of trees at 18 cm above the ground between July 2003 and October 2004. Growth rate of trees was very low during winter and spring. Despite growth rate among the 50 trees was not consistent, the average tree caliper growth was 178% increase at the end of the first growing season, and was 310% increase at the end of second growing seasons.

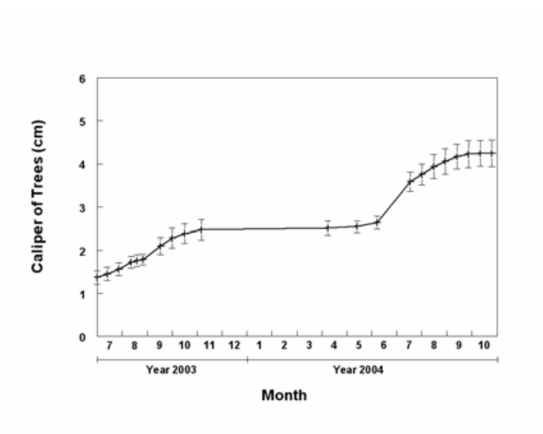

Figure 9. Average trunk caliper of 50 trees at 18 cm above the substrate during 2003 and 2004 growing seasons

The system operated satisfactorily during two growing seasons after it was established to monitor amounts of irrigation, rainfall, drainage water loss, and substrate nutrient loss, and the substrate temperature and moisture content during four seasons.

SUMMARY

Results from this study indicated that the amount of drainage water loss and nutrition leachate varied with the amount of water received by pot-in-pot containers. The system could be used to evaluate water and nutrition utilization efficiency, and tree growth response to changing weather conditions. Detection of NO_3-N, P, and K leachate and drainage water pH might be useful to optimize nutrient application time and rate to produce healthy trees with less negative environmental impact. The system continuously monitored the substrate temperature and moisture content during four seasons of a year, and provided a technical tool to evaluate the potentials of winter injury or summer heat damage to roots for pot-in-pot nursery production. It also provided a method to monitor not only water and nutrient loss but also monitor conditions that could cause changes in water and nutrient application in tree production.

Future research with the system will emphasize investigations of: (1) irrigation schedule, irrigation frequency, and the amount of water required for a tree to grow properly under varied rainfall and climate conditions; (2) water loss due to drainage, methods to minimize water loss, and water resource managements; (3) level and timing of NO_3-N, P, and K loss through drainage to develop optimal fertility management practices, and protect water resources by aiding decisions whether drainage water should be recycled or released from the nursery; (4) amount of pesticide leachate through water drainage following chemigation, injection or spray application in pot-in-pot system production; (5) influence of temperature on substrate moisture content, prevention of possible winter injury of plants and irrigation start time for plants in spring; (6) feasibility of developing an expert control system using substrate moisture content for the best irrigation strategy to achieve efficient plant growth and health with environmentally sound practices.

REFERENCES

Beeson, R.C., Jr., M.A. Arnold, T.E. Bilderback, B. Bolusky, S. Chandler, H.M. Gramling, J.D. Lea-Cox, J.R. Harris, P.J. Klinger, H.M. Mathers, J.M. Ruters, and T.H. Yeager. 2004. Strategic vision of container nursery irrigation in the next ten years. Journal of Environmental Horticulture 22(2): 113-115.

Beeson, R.C., Jr. and K. Keller. 2003. Effect of cyclic irrigation on growth of magnolias produced using five in-ground systems. Journal of Environmental Horticulture. 21(3): 148-152.

Fare, D.C., C.H. Gilliam, G.J. Keever, and J.W. Olive. 1994. Cyclic irrigation reduces container leachate nitrate-nitrogen concentration. HortScience 29: 1514-1517.

Irmak, S., D.Z. Haman, A. Irmak, J.W. Jones, K.L. Campbell, T.H. Yeager. 2003. New irrigation-plant production system for water conservation in ornamental nurseries: quantification and evaluation of irrigation, runoff, plant biomass, and irrigation efficiencies. Transactions of the ASAE. Vol. 19(6): 651-665.

Postel, S. 2000. Redesigning irrigation agriculture. National Irrigation Symposium, Proceedings of the 4th Decennial Symposium. American Society Agricultural Engineers, St. Joseph, MI 49085. pp. 1-12.

Ruter, J.M., 1997. The practicality of pot-in-pot. American Nurseryman. Vol. 185 (1): 32-37.

Ruter, J.M. 1998. Pot-in-pot production and cyclic irrigation influence growth and irrigation efficiency of 'Okame' cherries. Journal of Environmental Horticulture. 16: 159-162.

Weatherspoon, D.M. and C.C. Harrell. 1980. Evaluation of drip irrigation for container production of woody landscape plants. HortSci. 15: 488-489.

Yeager, T.H. 1992. Introduction to workshop: impact of runoff water quality on future nursery crop production. HortTechnology 2(1): 80.

Yeager, T.H., R.D. Wright, D. Fare, C. Gilliam, J. Johnson, T. Bilderback, and R. H. Zondag. 1993. Six state survey of container nursery nitrate nitrogen runoff. J. Environ. Hort. 11(4): 206-208.

Zhu, H., C. R. Krause, R.C. Derksen, R.D. Brazee, R. Zondag and N. R. Fausey. 2004. Real-time measurement of drainage from pot-in-pot container nurseries. Transactions of the ASAE. Vol. 47(6): 1973-1979.

Zhu, H., C. R. Krause, R.H. Zondag, R.D. Brazee, R.C. Derksen, M.E. Reding and N. R. Fausey. 2005. A new system to monitor water and nutrient use efficiency in pot-in-pot nursery production systems. *Journal of Environmental Horticulture* 23 (1): 47-53.