A New System to Monitor Water and Nutrient Use in Pot-in-pot Nursery Production Systems[1]

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Abstract

Techniques are needed to monitor nursery production practices for proper use of water resources and nutrient management. An experimental system to examine water quality, irrigation efficiency and drainage from pot-in-pot nursery container production was established in a commercial nursery. The system mainly consisted of 50 pot-in-pot containers with 50 trees irrigated with micro spray stakes, drainage water measurement devices, container-substrate moisture probes, thermocouples, a weather station, and data loggers. Tests indicated the system was capable to measure irrigation and rainfall inputs, drainage water loss, container substrate moisture content and temperature, leachate of nitrogen, phosphate and potassium in drainage water, and tree growth in pot-in-pot nursery production. The system provided a method to not only monitor the loss of water and nutrients but also continuously monitor the substrate temperature and moisture content during four seasons of a year to evaluate potentials of winter injury or summer heat damage to roots for pot-in-pot nursery production.

Index words: container production, substrate, drainage, environment, micro irrigation, leachate, moisture, ornamentals, tree caliper, temperature, water pH, weather.

Significance to the Nursery Industry

The experimental monitoring system developed for this research provides engineering means to investigate water and fertilizer use in pot-in-pot nursery production, and helps growers apply water and nutrients only when needed by plants in pot-in-pot production systems. The outcome from studies with this system setup will impact the nursery industry as it seeks newer production methods to obtain: 1) improved water/nutrient usage management with most benefit to nursery crops for higher crop quality; 2) optimal production practices to reduce waste water and nutrient use to lower production cost, and 3) improved environmental stewardship by minimizing excess nutrients release into off-farm land.

Introduction

Water will be one of the most challenged resources in the world within the next 20 years (9). Efficient use and availability of quality water sources has been a major concern in the nursery industry for many years (8, 13). Without scientific guidelines for proper application of water and nutrients, future choices of nursery crop production sites and species will be limited (2). 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 (12).

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 (10). However, with this technique, it is essential to apply sufficient water and nutrients to sustain rapid tree growth (3, 11). 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 (5, 14). With pot-in-pot systems, due to containers being placed under the soil surface, there is no proper methodology to easily observe water and nutrient loss. Efforts to improve irrigation management in pot-in-pot production are limited because drainage water loss through in-ground containers cannot be directly observed during irrigation.

Drainage water losses from containers due to irrigation can be relatively low, but can also be considerably higher with extensive rainfall. Compared with field growing operations, pot-in-pot systems require complex production practices due to variations in container substrate, species and irrigation schedules. Small tipping-bucket units show promise as monitoring devices for this application (16). Large tipping buckets have been widely used to measure surface water runoff and subsurface drainage in farm fields for many years (1, 4, 6, 15).

For above ground container production, considerable research has been done on interactions among water quality,

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water use efficiency, nursery crop growth and production practices, when required amounts of fertilizer and pesticides were applied to crops. Research has been limited with pot-in-pot production with respect 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 develop a pot-in-pot production monitoring system to examine irrigation, rainfall, drainage water loss, substrate nutrient loss, time of drainage water loss after irrigation or rainfall, container substrate moisture content and temperature due to irrigation, rainfall or weather conditions, and tree growth.

Materials and Methods

An experimental system (Fig. 1) was established in a commercial nursery field to examine water quality, irrigation efficiency and drainage from pot-in-pot nursery container pro-

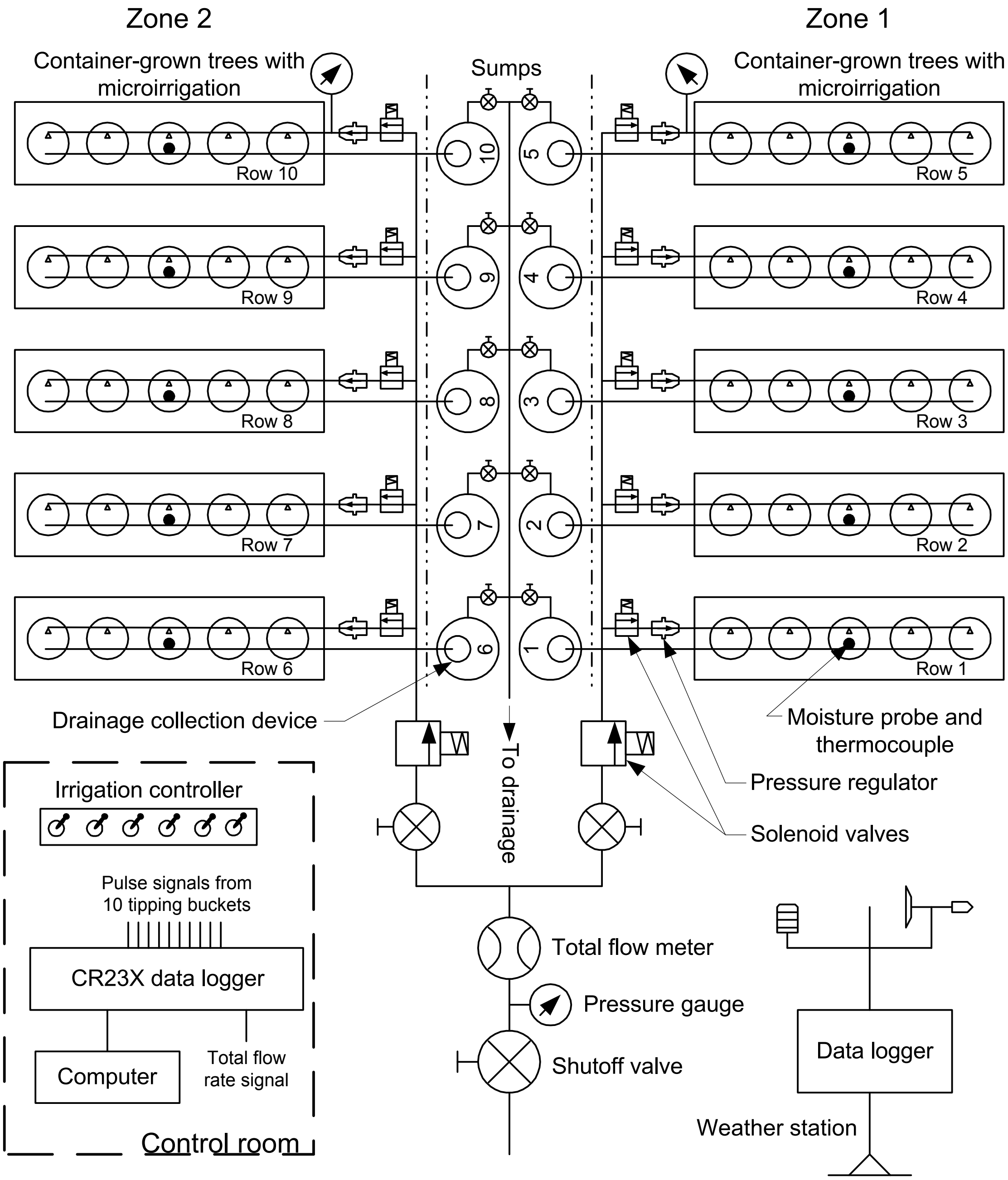

Fig. 1. **Schematic diagram of the experimental system for monitoring drainage water quantity and quality, and temperature and water content of container substrate in pot-in-pot nursery production.**

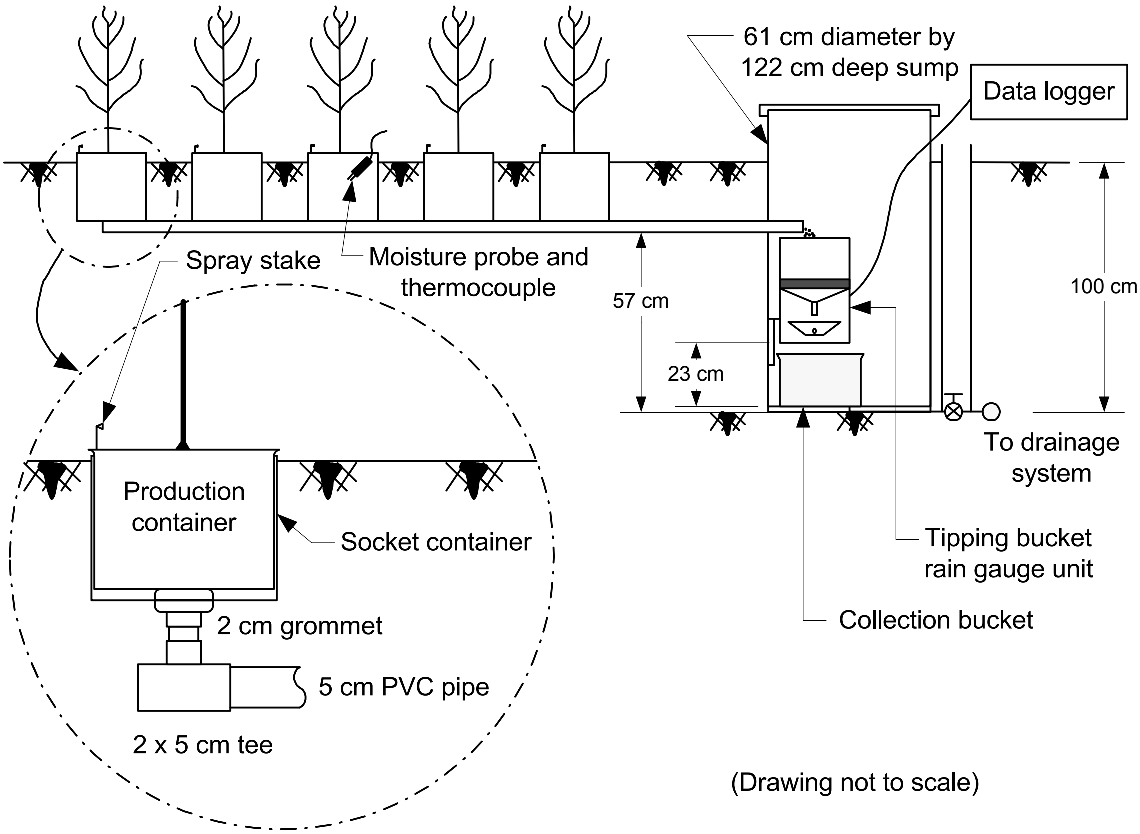

Fig. 2. Diagram of drainage water loss measurement from 5 pot-in-pot tree containers in a row.

duction. 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 in July 2003, 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 below.

Two adjacent zones were selected to install fifty #15 pot-in-pot containers for tree production. Each zone had five rows, each row having five container-grown trees (Fig. 1). Spacing between centerlines of two rows was 1 m (42 in), and spacing between two trees within a row was 1.5 m (60 in). The #15 tree container had a volume of 58 liters (15 gal) and a 43.2 cm (17 in) diameter, and was placed inside a socket container. The socket container was installed in the ground to the lip of the tree container (Fig. 2).

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 (7 in) above the ground was measured during the growing season. The average tree caliper of bare root trees was 1.4 cm (0.55 in) 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. The container substrate provided for natural suppression of pythium and phytophthora root rots (8).

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 (4.2 oz) 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.

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 liters/hr (3 gal/hr) at 70 kPa (10 psi). Each row had an irrigation supply line with a 70 kPa (10 psi) pressure regulator to minimize variations in application rate. An electric 24 VAC solenoid valve (model 12024E-10, Weather-Matic, Dallas, TX) was installed ahead of the regulator to control irrigation schedule on each row. A manual gate valve and a solenoid valve were installed in the water supply line to each zone. A Model 1200 inline vortex flow rate meter (Fluidyne, Longmont, CO) was used to measure flow rate and the amount of water applied to trees in the two zones. Irrigation management was manually controlled with micro-switches in a control room (Fig. 1).

The system was placed in use on August 6, 2003, with irrigation applied twice a day, once in the morning and once in the afternoon, until November 16 (total 14 weeks) under the conditions that there was insufficient rainfall to wet the container substrate during the same day. To verify the accuracy of the rain gauge units for measuring amount of drainage from container-grown trees, irrigation rate was controlled for five separate weeks during the growing season (16). During the five weeks of system accuracy verification, the 11.6 liters/hr (3 gal/hr) spray stakes were used twice a day in all 50 containers for four weeks and then spray stakes (Part Number 01SSABK-36, Netafim USA, Fresno, CA) with 27.1 liters/hr (7 gal/hr) at 70 kPa (10 psi) were used twice a day in the plot for another week. Total irrigation time with the 11.6 liters/hr (3 gal/hr) spray stakes was 6, 8, 12, and 16 minutes per day in weeks 1, 2, 3 and 4, respectively, and the total irrigation time with the 27.1 liters/h spray stake was 6 minutes per day for the week. Except for these five separate weeks, irrigation application rate during the rest of the growing season was managed with the 11.6 liters/hr (3 gal/hr) spray stakes following the production practice in a 18.2 ha (45 A) commercial pot-in-pot production area adjacent to the experimental system. Between August 6 and November 16, 2003, a total of 19.3 cm (7.6 in) irrigation was applied to the trees, and total precipitation received was 59.8 cm (23.5 in).

A Model 3665R electronic 'tipping bucket' rain gauge unit (Spectrum Technologies, Plainfield, IL) was installed 43 cm (17 in) below the soil surface in a 61 cm (24 in) diameter and 122 cm (48 in) deep sump (Fig. 2) to measure water drainage from five tree containers in each row. A 5 cm (2 in) PVC pipe was installed 7 cm (3 in) under the five containers in each row to guide drainage water to the rain gauge unit. Detailed information on the drainage measurement for this system was given by Zhu et al. (16). During winter, the rain gauge units were removed from the system and stored indoors to prevent ice damage.

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. In 2003, drainage water from the plot was collected until November 16 when irrigation was no longer applied for the growing season.

Container substrate moisture near upper root zones with majority of roots was measured with ten ML2X Theta probes (Delta-T Devices Ltd, Cambridge, England). Length of rods on probes was 60 mm (2.4 in). Each row had one probe placed at a 45° angle, 5 cm (2 in) below the container substrate surface, and about 5 cm (2 in) from the tree in the middle container. The probes were calibrated in the container substrate with both tap water and tap water containing 200 ppm of nitrogen at the moisture content ranging from 5 to 55%. The substrate was saturated at a moisture content between 52 and 56%. The substrate temperature was measured by a thermocouple (Thermo Electric Co., Saddle Brook, NJ) with galvanic effect prevention at 5 cm (2 in) 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, UT) was installed near the experimental plot to measure precipitation, air temperature, relative humidity, solar radiation, atmospheric pressure, and wind speed and azimuth. These data were collected every 15 minutes with a CR23X data logger (Campbell Scientific, Inc., Logan, UT) transferred to a network website for analysis.

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. Total irrigation flow-rate data were collected each second only during the irrigation period. The data logger was connected with two synchronous communication modules to allow multi-signal inputs simultaneously. During winter, substrate moisture and temperature were collected at 30-minute intervals, while drainage was not measured because of freezing.

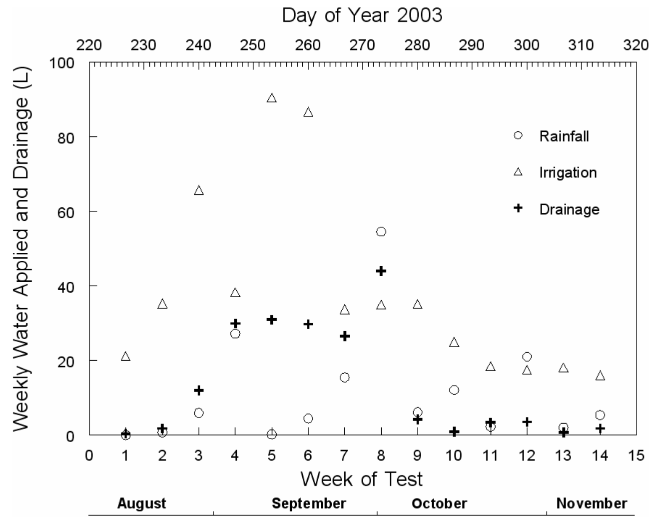

Fig. 3. Weekly total rainfall and irrigation applied to, and drainage from, 50 pot-in-pot production containers between August 6 and November 16, 2003.

Results and Discussion

Amount of drainage. Data in Fig. 3 show the comparison of weekly total amounts of irrigation, rainfall and drainage water collected from 10 rows of the 50 pot-in-pot system between August 6 and November 16, 2003. During the 14-week period, total volume of drainage water from 50 containers was 1900 liters (490 gal) while total irrigation water and rainfall to the 50 tree containers was 6,940 liters (1790 gal). About 38% of irrigation water and rainfall was lost through drainage during September and the first week of October 2003 because large amounts of irrigation were applied to maintain tree caliper growth during this dry period.

With the system, real-time data were acquired on drainage flow due to irrigation and rainfall (16). Onset of drainage following irrigation varied with application rate. The average drainage start time from the 10 rows was 22.3 minutes after irrigation started with11.6 liters/hr (3 gal/hr) flow rate applied for three minutes, and was 7.6 minutes with 27.1 liters/hr (7 gal/hr) flow rate applied for three minutes. Higher flow rate caused earlier drainage because of limited substrate capability of holding water in containers.

NO_3-N, P and K leachate and drainage water pH. Fig. 4 illustrates the average weekly amount of NO_3-N, P, and K

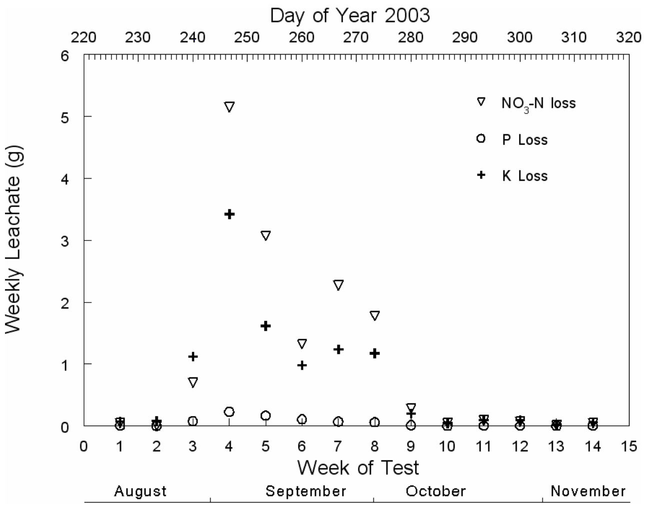

Fig. 4. Average weekly amount of NO_3-N, P, and K in drainage water from 10 rows of total 50 pot-in-pot containers between August 6 and November 16, 2003.

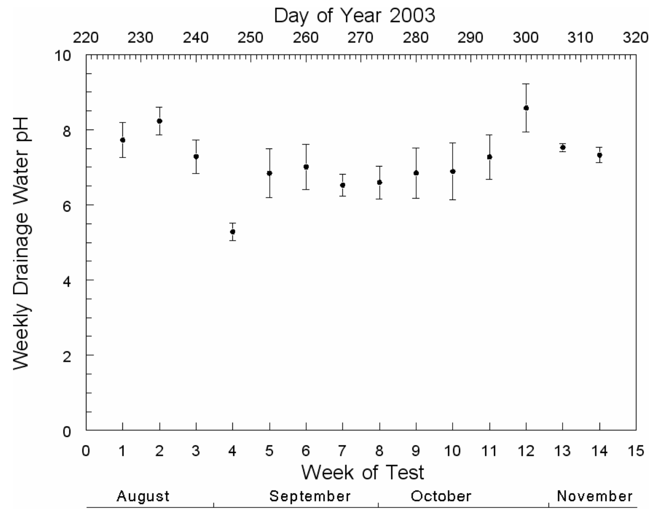

Fig. 5. Average weekly drainage water pH from 10 rows of total 50 pot-in-pot containers between August 6 and November 16, 2003.

leachate in drainage water from 10 rows between August 6 and November 16, 2003. The system detected that the total amount of NO_3-N, P and K lost through drainage from 50 containers during 14 weeks was 142.8, 7.2 and 97.8 g (5.04, 0.25 and 3.45 oz), 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. Therefore, the system enabled monitoring of fertilizer utilization efficiency for pot-in-pot production.

The mean pH of drainage water samples stayed within the range from 6 and 8 most of the time for all 10-row samples except for weeks 4 and 12 (Fig. 5). Unexpectedly, the average pH in week 4 was 5.3 and the average pH in week 12 was 8.6. High water pH could result in negative impact on tree uptake, substrate quality and drainage water quality.

Substrate moisture content. The system is capable of monitoring substrate moisture content near upper root zones in real time for pot-in-pot production during the four seasons throughout a year. Fig. 6 shows the response of substrate moisture content in rows 1, 3, 7, and 10 to 27.1 liters/hr (7 gal/hr) of irrigation applied for 3 minutes, twice a day, on September 9 and 10. 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. Fig. 7 shows the response of substrate moisture content in rows 1, 3, 7, and 10 to 19.8 mm (0.78 in) and 29.0 mm (1.14 in) of rainfall reached the area within 30 hours. 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 Figs. 6 and 7.

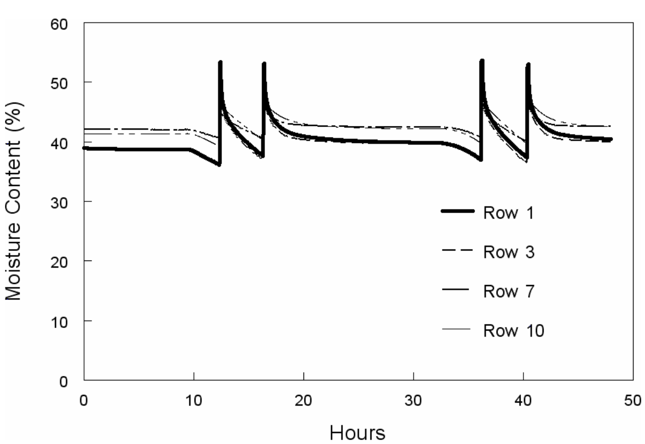

Fig. 6. Example of substrate moisture content near upper root zones for four rows when 27.1 liters/hr of irrigation was applied for 3 minutes, twice a day on September 9 and 10, 2003.

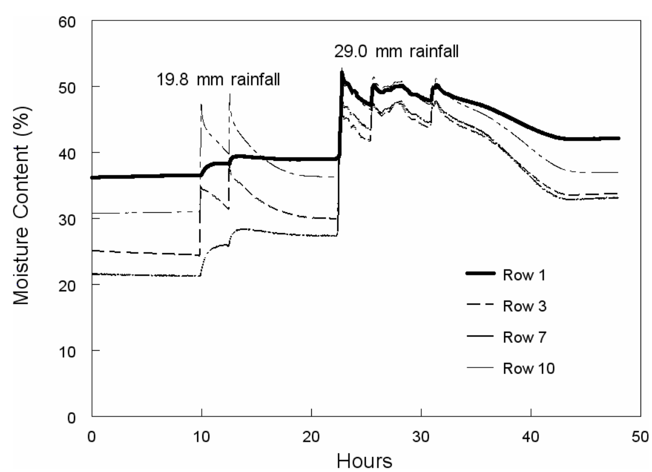

Fig. 7. Example of substrate moisture content near upper root zones for four rows when 19.8 mm (0.78 in) and 29.0 mm (1.14 in) of rainfall reached the test plot within a 30 hour period.

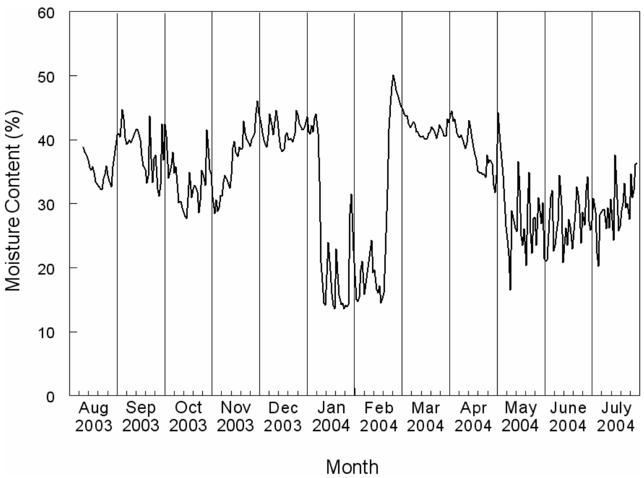

Fig. 8. Mean container substrate moisture content measured with 10 probes between August 6, 2003 and July 31, 2004.

Daily mean substrate moisture content near upper root zones fluctuated widely during four seasons, with the largest variation in January and February (Fig. 8). The substrate moisture content from the end of November through December was higher than 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. Figs. 9 and 10 show the mean substrate temperature, the daily maximum and minimum ambient air temperatures in September 2003 and February 2004, respectively. In September, the substrate temperature in 10 rows ranged from 11.7 to 25.4C (53 to 78F) while the ambient air temperature ranged from 5.1 to 28.9C (41 to 84F) (Fig. 9). Comparatively, in February the substrate temperature in 10 rows ranged from –4.4 to 0.4C (24 to 33F) while the ambient air temperature ranged from –19.7 to 15.7C (–3.5 to 60F) (Fig. 10). Fig. 11 shows the average daily substrate temperature of 10 rows and maximum and minimum daily ambient air temperatures between August 2003 and July 2004. The substrate temperature in the pot-in-pot system had much lower variation than the 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.

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. Fig. 12 shows the caliper of trees at 18 cm (7 in) above the ground between July 3 and November 5, 2003. Growth rate of trees was considerably higher in September than other months. Despite growth rate among the 50 trees was not consistent, average tree caliper was 2.5 cm (1 in) at the end of growing season, or 178% increase during the growing season.

The system operated satisfactorily during the 2003 growing season after it was established and the entire 2004 growing season to monitor amounts of irrigation, rainfall, drainage water loss, and substrate nutrient loss, and the substrate temperature and moisture content during four seasons.

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

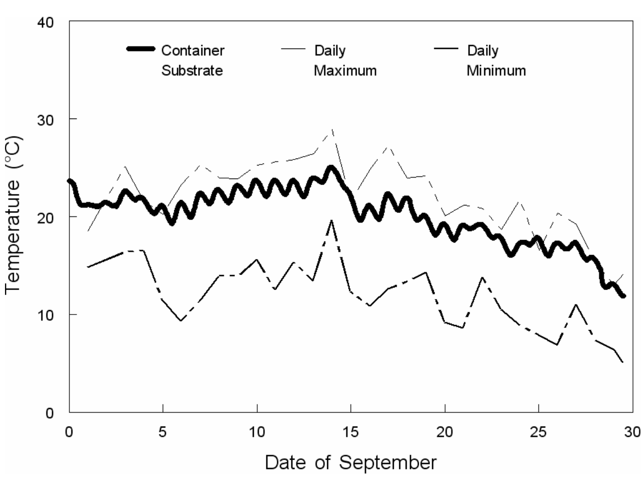

Fig. 9. Mean container substrate temperatures measured with 10 thermocouples and daily maximum and minimum ambient air temperatures during September of 2003.

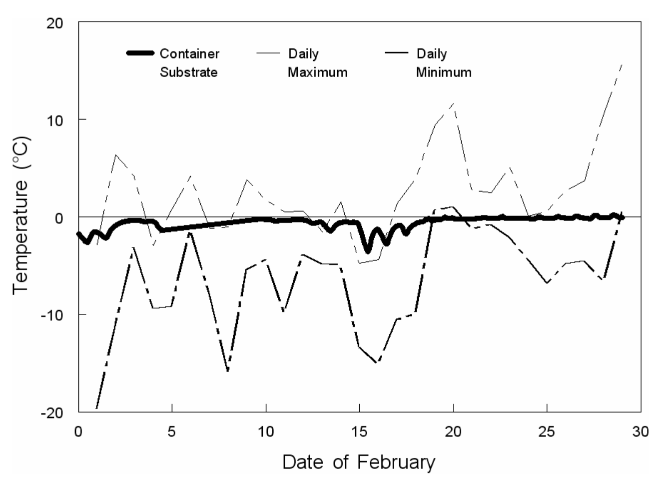

Fig. 10. Mean container substrate temperature measured with 10 thermocouples and daily maximum and minimum ambient air temperatures during February of 2004.

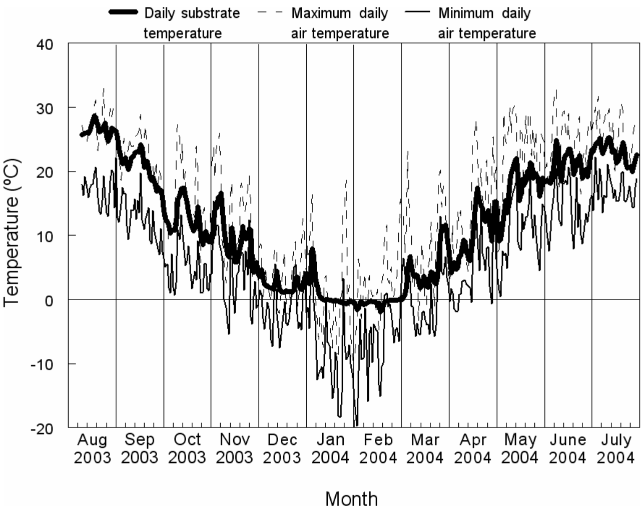

Fig. 11. Average daily substrate temperatures in 10 rows and daily minimum and maximum ambient air temperatures between August 6, 2003 and July 31, 2004.

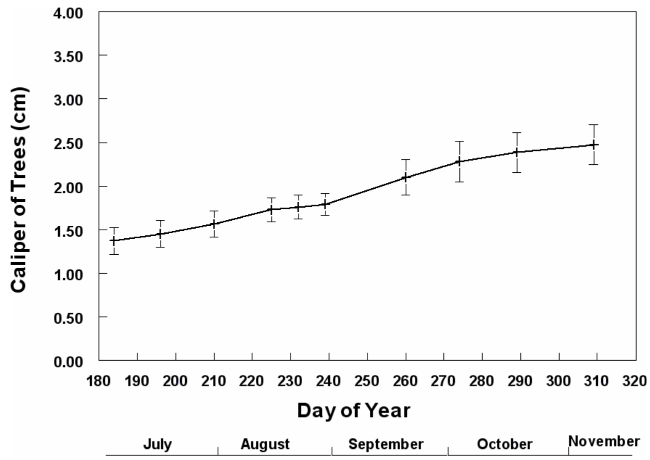

Fig. 12. Average trunk caliper of 50 trees at 18 cm (7 in) above the substrate between July 3 and November 5, 2003.

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; and (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.

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