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Nursery Floor Affects Containerized Plant Growth[1]

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Abstract

Rooted stem cuttings of 'Skogholm' cotoneaster (*Cotoneaster dammeri* 'Skogholm') potted into 14.2 liter (#5) containers in a pine bark:sand substrate were used to determine the effects of the nursery floor on plant growth, water use efficiency, substrate and plant canopy temperature, winter protection, and mineral nutrient efficacy. Four nursery floors were evaluated: black plastic, black ground fabric over black plastic, white plastic, and gravel from May 10, 2001, to April 23, 2002. Plants grown on gravel or ground fabric/black plastic had greater top and root dry weights compared to plants grown on white plastic. Water use efficiency was similar across all nursery floors, requiring an average 391 ml (13.2 oz) of water to produce a gram (0.04 oz) of plant material. Net photosynthetic rates of plants grown on black plastic, gravel, or ground fabric/black plastic were significantly greater than cotoneaster grown on white plastic. Plants grown on white plastic had significantly higher plant canopy [1 to 2C (1.8 to 3.6F)] and substrate temperatures [1 to 4C (1.8 to 7.2F)] daily from 1000 HR to 2000 HR throughout the summer months compared to all other nursery floors. Plant canopy and substrate temperatures were unaffected by the nursery floor during the winter months. Nitrogen efficiency was 42% on ground fabric/black plastic, 40% on gravel, 37% on black plastic and 33% on white plastic. Phosphorus efficiency was 53% on gravel, 52% on ground fabric/black plastic, 49% on black plastic and 43% on white plastic.

Index words: growing surface, effluent, nitrogen, phosphorus, nutrient budgets, water.

Significance to the Nursery Industry

The nursery crop growing area, specifically the surface (nursery floor) where containers are placed during nursery production, varies from gravel, white clam or oyster shell mulch, black plastic, to ground fabric over black plastic. In our study 'Skogholm' cotoneaster was grown on four nursery floors: black plastic, black ground fabric over black plastic, white plastic and gravel to determine if the nursery floor influenced production. Plants grown on white plastic were smaller with reduced N and P efficiencies compared to all other nursery floors in this study. These differences may be accounted for by increased canopy and substrate temperatures in plants grown on white plastic. White plastic or other white surfaces should be avoided as a nursery floor. Except for mineral nutrient efficiencies, there were few differences in growth and water usage when plants were grown on gravel, black plastic or ground fabric/black plastic. 'Skogholm' cotoneaster grown on gravel and ground fabric/black plastic had the highest N and P efficiency.

Introduction

The nursery crop growing area, specifically the surface (nursery floor) where containers are placed during production, varies from gravel, white clam or oyster shell mulch, black plastic, to ground fabric over black plastic (1). Which raises the question does the nursery floor play a role in plant production or is it simply a matter of convenience and costs? There has been little research to determine if or how the nursery floor affects containerized plant growth. Also, the choice of nursery floor is not addressed in the current 'best management guidelines' (21).

Growers have reported various impacts of the nursery floor on plant response (2). Some growers believe the nursery floor has a significant impact on water use, temperature of the plant canopy, and winter protection. Newman and Davies (9) grew four woody ornamental species in Texas on polypropylene ground covers with either black or white surfaces. Plant response varied from negative to neutral to positive. The white surface increased container substrate temperature by 2C to 4C (3.6F to 7.2F) compared to the black ground surface (9). However, container temperatures were only measured at 1200 HR on September 5 and 6. Temperature in combination with exposure time determines plant response (7). Therefore, the objective of this research was to determine the effects of the nursery floor on plant growth, water use efficiency, substrate and plant canopy temperature, winter protection, and mineral nutrient efficacy.

Materials and Methods

A split plot experiment in a randomized complete block design with four replications was conducted at the Horticulture Field Laboratory, North Carolina State University, Raleigh, from May 10, 2001, to April 23, 2002. Main plots were four nursery floors (growing surfaces): 0.15 mm thick (6 mil) black plastic (Armin Plastics, Torrance, CA), black ground fabric (polypropylene cloth, Baycor Horticultural Fabrics, Pendergrass, GA) over 0.15 mm (6 mil) thick black plastic, 0.15 mm (6 mil) white plastic (Armin Plastics, Torrance, CA), or gravel (#67, gray color) at a depth of 7.5 cm (3 in). Within each main plot were two subplots consisting of plants that were covered for winter protection or not covered.

Rooted stem cuttings of *Cotoneaster dammeri* 'Skogholm' were potted May 10, 2001, into 14.2 liter (#5) containers in a pine bark:sand (8:1 by vol) substrate amended with 0.9 kg cu m (2 lbs cu yd) dolomitic limestone. Each plant was topdressed at potting with 18 g N (0.6 oz) from an 18N–2.6P–9.8K controlled release fertilizer (18–6–12 with minors, 8 to 9 month, Pursell Technology, Sylacauga, AL) re-

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sulting in 2.6 g (0.09 oz) P per container. Plants were grown in a plant production area subdivided into 16 separate plots that allowed for collection of all effluent water leaving each plot. Plots were 8 × 1 m (25 × 3 ft) with a 2% slope. Twelve containers [25 cm (10 in) between containers] were placed in a plot for a total of 48 containers in each treatment. Half of the plants (total of six containers) in each plot were overwintered under white row covers (Pak Unlimited, Inc., Cornelia, GA) from December 14, 2001, to March 14, 2002. The remaining six containers in each plot were left uncovered. A single fallow container (no plant, no fertilizer) was also placed on each plot at initiation of the experiment. These containers were treated the same as the other containers on each plot except the leachate was not collected.

Irrigation was applied via pressure compensated spray stakes {Acu-Spray Stick 35; Wade Mfg. Co., Fresno, CA [11.4 liters/hr (3 gal/hr)]}. Leaching fraction (LF) was monitored daily and irrigation volume was adjusted twice weekly to maintain a leaching fraction of 0.2. The total daily volume of water was divided into three equal parts and applied at 0300, 0500, and 0700 HR. Rainfall ≤ 0.6 cm (0.25 in) was captured in the collection vessel. When rainfall was > 0.6 cm (0.25 in) water volume flowing to the collection vessel was estimated. When rainfall was ≥ 1.2 cm (0.5 cm) irrigation was not applied during that day or the following day depending upon the timing of the rain event. Volume of effluent from each plot (four per treatment) was measured from May 10 through September 4, 2001, at 0900 HR daily. A sub-sample of the effluent was collected, filtered, and analyzed for NO_3-N (3), NH_4-N (4), and P (11) using a spectrophotometer (Spectronic 1001 Plus, Milton Roy Co., Rochester, NY).

Irrigation was reduced to once a week for all plants after covering the plants for winter protection (December 14, 2001). Daily irrigation as described previously began after the winter protection cover was removed March 14, 2002.

Substrate temperature and canopy temperature were measured in one container in every subplot (total of eight thermocouples/nursery floor/location) for the entire study. One copper-constantan thermocouple was positioned in the substrate halfway down the container profile, 2.5 cm (1 in) from the container wall on the southern exposure. For canopy temperature, one copper-constantan thermocouple was positioned in the middle of the canopy by gluing (DAP Weldwood Contact Cement, DAP Inc., Dayton, OH) the thermocouple to the bottom of a leaf. Thermocouples were connected to a 23X micrologger via a AM-32 multiplexer (Campbell Scientific, Logan, UT). Temperature data were recorded every 5 min and averaged over each 60-min interval. Maximum, minimum, and average temperature along with time of maximum, and time of minimum were recorded every 60 min.

On July 17 and August 20 between 1030 to 1130 HR and 1330 to 1430 HR, leaf gas exchange was measured using a LI-COR 6200 closed portable infrared gas-exchange system (LI-COR, Lincoln, NE) on one plant from each subplot (eight plants/treatment). Photosynthetically active radiation (*PPF*), air and leaf temperatures, and relative humidity inside the leaf chamber were measured concurrently with gas exchange. *PPF* values averaged 1130 ± 143 and 1985 ± 75 $\mu mol \cdot s^{-1} \cdot m^{-2}$ from 1030 to 1130 HR and 1330 to 1430 HR, respectively. Net leaf photosynthetic rates (P_n) and stomatal conductance (g_s) were calculated using the LI-COR 6200 measurements. Data were recorded on the terminal 8 cm (3.2 in) of growth using a 0.25-liter chamber for 30 sec. Measurements commenced immediately after CO_2 concentration decreased in the chamber.

Tops (aerial tissue) from one randomly chosen container per subplot (total of eight containers/nursery floor) were removed on September 4, 2001. Roots were placed over a screen and washed with a high pressure water stream to remove substrate. Tops and roots were dried at 65C (150F) for 5 days and weighed. After drying, roots and tops were ground separately in a Cyclotec grinder (Analytical Instruments, LLC, Golden Valley, MN) to pass a 40-mesh (0.635 mm) screen. Tissue samples (1.25 g) were combusted at 490C (914F) for 6 hr. The resulting ash was dissolved in 10 mL (0.03 oz) 6 N HCl and diluted to 50 mL (1.5 oz) with deionized water. Phosphorus concentrations were determined using an inductively coupled plasma emission spectrophotometer (Model 2000DV, Perkin-Elmer, Norwalk, CT). Nitrogen was determined using 10 mg (0.03 oz) samples in a CHN elemental analyzer (PE 2400, Perkin-Elmer). Mineral nutrient content was determined by multiplying plant part dry weight by nutrient concentration expressing each nutrient in grams. Mineral nutrient content of tops and roots were combined for total plant mineral nutrient content.

At harvest, all fertilizer prills from the randomly chosen container per subplot were removed and a sample of the substrate was collected. A substrate sample from the fallow container was also collected. Fertilizer prills were mixed in a blender with 100 ml (3.5 oz) deionized water for 1 min. After blending, this solution was diluted to a total volume of 500 ml (17.5 oz) with deionized water. Nitrate-N, NH_4-N, and P analyses were conducted as described for effluent analysis. Substrate samples were dried at 62C (144F) for 5 days, ground in a hammer mill, and sieved through a 18-mesh (1 mm) screen. Each substrate sample (1.25 g) was combusted at 490C (914F) for 6 hr. The resulting ash was dissolved in 10 ml (0.03 oz) 6 N HCL and diluted to 50 ml (1.5 oz) with deionized water. Nitrogen and P concentrations were determined as described previously. The difference in N and P content between the fertilized and unfertilized containers was contributed by the fertilizer.

A second harvest was conducted April 23, 2002, tops (aerial tissue) from one randomly chosen container per subplot (one from winter protected and one from non-protected) were removed. Plants were harvested as described previously. Prior to harvest, tops of all plants were evaluated visually for winter injury (poor color, poor spring growth, etc.). Plants were rated from 1 = dead to 5 = no visual injury.

At treatment initiation, 10 representative plants were harvested and separated into tops and roots, dried, weighed, and ground for N and P analysis as described previously. These initial weights and mineral nutrient contents were subtracted from the final dry weight and mineral nutrient content prior to statistical analysis.

Total plant dry weight, root:top ratio, mineral nutrient content, mineral nutrient efficiency, and water use efficiency were calculated according to the following formulas:

Total plant dry weight = top dry weight (g) + root dry weight (g) [1]

Root:top ratio = root dry weight (g) ÷ top dry weight (g) [2]

Mineral nutrient content = plant part dry weight (g) × plant nutrient concentration (%) [3]

Nutrient efficiency = plant mineral nutrient content (g) ÷ recovered nutrient (g) [4]

Table 1. Effect of nursery floor on dry weight and root:top ratio of *Cotoneaster dammeri* 'Skogholm' on two dates.

Nursery floor	Dry weight (g) Top	Root	Total	Root:top ratio[z]
	September 4, 2001			
Black plastic	80b[y]	9.2b	89b	0.12c
Gravel	92a	11.6a	103a	0.13b
Ground fabric/black plastic	86a	11.7a	98a	0.14a
White plastic	68c	8.0b	76c	0.12c
	April 23, 2002			
Black plastic	284ab[y]	105a	390a	0.37a
Gravel	288a	97a	385a	0.34a
Ground fabric/black plastic	249b	93a	342b	0.37a
White plastic	211c	71b	282c	0.34a

[z]Root:top ratio = root dry weight ÷ top dry weight.

[y]Means separation within columns for a date by Fisher's protected LSD, $P = 0.05$.

Table 2. Effect of nursery floor on total irrigation volume applied, total irrigation volume leached, average experiment leaching fraction (LF), and water utilization efficiency, for the first 116 days after treatment initiation. All data presented on a 14.2 liter (15 qt.) container basis.

Nursery floor	Water applied (L)	Water leached (L)	Leaching fraction[z] (mL)	Water efficiency[y]
Black plastic	45.1a[x]	8.6	0.19	409a
Gravel	45.3a	8.4	0.19	357a
Ground fabric/black plastic	48.7a	8.7	0.18	408a
White plastic	36.8b	7.0	0.19	390a

[z]Leaching fraction = volume irrigation water leached ÷ volume irrigation water applied.

[y]Water use efficiency = water retained in the substrate ÷ total plant dry weight in grams.

[x]Means separation within columns by Fisher's protected LSD, $P = 0.05$.

Water use efficiency = water volume retained in substrate (ml) ÷ total plant dry weight (g) [5]

Recovered nutrient was defined as nutrient contained in effluent, substrate, and plant. Nutrient content of fertilizer prills was not included in mineral nutrient efficiency as it does not describe the efficiency of fertilization but is related to the remaining nutrient supplying power of the fertilizer. All data were subjected to analysis of variance procedures (ANOVA) (14). Treatments means were separated by Fisher's protected least significant difference (LSD), $P = 0.05$.

Results and Discussion

All data except canopy and substrate temperature when the containers were covered were unaffected by winter cover regardless of the nursery floor. Therefore, all data (except for canopy and substrate temperature when the containers were covered) were averaged over subplots and reanalyzed as a randomized complete block design with four replications.

On September 4, 2001, 'Skogholm' cotoneaster grown on gravel and ground fabric/black plastic had greater top and root dry weights compared to plants grown on black plastic or white plastic (Table 1). In addition, top dry weight of plants grown on black plastic was significantly greater than plants grown on white plastic, whereas root dry weight was similar for plants grown on black or white plastic. Total plant dry weight of cotoneaster grown on black plastic, gravel, and ground fabric/black plastic was 17 to 35% greater than cotoneaster grown on white plastic. Root:top ratio was greatest for ground fabric/black plastic followed by gravel with black plastic and white plastic having the lowest values.

After one year (April 23, 2002), 'Skogholm' cotoneaster grown on black plastic, gravel, or ground fabric/black plastic had greater top and root dry weights compared to plants grown on white plastic. Similar to the fall harvest, total plant dry weight of cotoneaster grown on black plastic, gravel, and ground fabric/black plastic was 21 to 38% greater than cotoneaster grown on white plastic. In contrast to the September harvest, all plants had similar root:top ratio regardless of the growing surface.

Top dry weight increased from 189% to 255% from September 2001 to April 2002, whereas root dry weight increased from 675% to 1066%. This supports the hypothesis proposed by Ivy et al. (8) that most root growth in container production occurs during the cooler months in the southeastern United States.

'Skogholm' cotoneaster grown on white plastic required significantly less water to maintain a 0.20 LF compared to the other floors (Table 2). This was probably due to the smaller plants on the white plastic nursery floor. Even though there were differences in applied water volume, water use efficiency was similar across all nursery floors, requiring an average of 391 ml (13.2 oz) of water to produce 1 g (0.04 oz) of plant material. Warren and Bilderback (18) reported a range of 300 to 700 ml (10.1 to 23.7 oz) of water to produce 1 g (0.04 oz) dry mass of 'Skogholm' cotoneaster. Thus, even though there were differences in plant dry weight, plants grown on the different floors required a similar quantity of water to produce a gram of plant dry weight.

After the covers were removed in March, there was a small difference in visual evaluations between covered and noncovered plants regardless of the nursery floor (data not presented). The visual rating of noncovered plants averaged 4.1, whereas covered plants averaged 5.0. Covered plants were a darker green as compared to noncovered plants in all nursery floors. However, within 2 weeks the visual quality of all plants on all nursery floors averaged 5.0. The winter of 2001–2002 was very mild with the lowest temperature of –7C (19F) recorded on January 4, 2002. This might have accounted for minimal differences between noncovered and covered plants and among the nursery floors.

Photosynthesis and stomatal conductance. Results from the morning and afternoon measurements were similar on both dates so only afternoon measurements from July 17 are

Table 3. Effect of nursery floor on net CO_2 assimilation and stomatal conductance of *Cotoneaster dammeri* 'Skogholm'.

Nursery floor	CO_2 assimilation (CO_2·□mol·m^{-2}·s^{-1})	Stomatal conductance (mol·m^{-2}·s^{-1})
Black plastic	8.9a[z]	0.18a
Gravel	9.2a	0.19a
Ground fabric/black plastic	9.3a	0.18a
White plastic	7.8b	0.14b

[z]Means separation within columns by Fisher's protected LSD, $P = 0.05$.

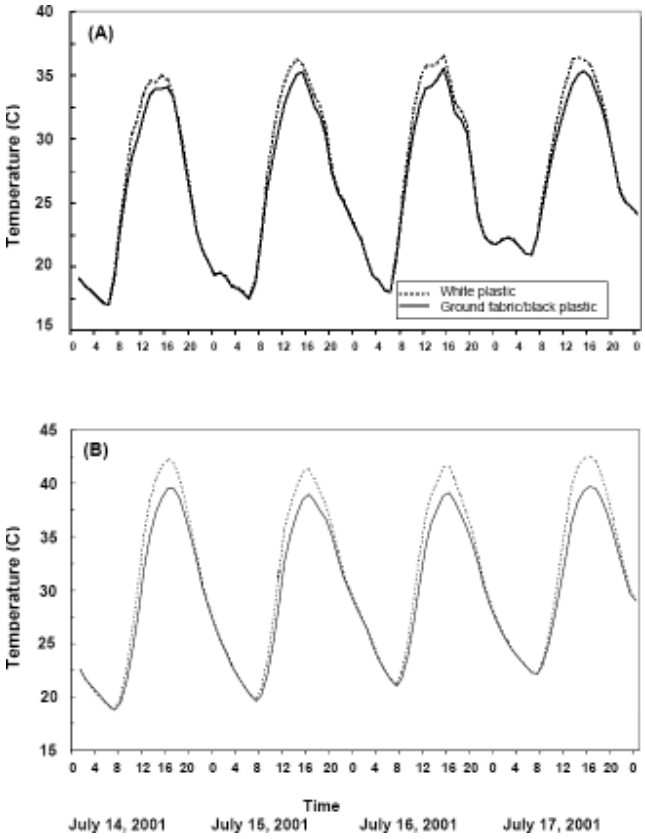

Fig. 1. Effect of white plastic and ground fabric/black plastic on (A) plant canopy and (B) substrate temperatures recorded from July 14 through July 17, 2001. Legend in (A) applies to (B).

presented (Table 3). P_n of plants grown on black plastic, gravel, and ground fabric/black plastic were 15 to 20% greater than cotoneaster grown on white plastic. This correlates with the reduced dry weight found with plants grown on white plastic. Compared to P_n, g_s had similar trends suggesting that reductions in g_s were limiting photosynthesis (Table 3).

Substrate and canopy temperature. 'Skogholm' cotoneaster grown on black plastic, gravel, and ground fabric/black plastic had similar canopy and substrate temperatures throughout the study period (data not presented). Therefore, only data for white plastic and ground fabric/black plastic are presented (Fig.1). 'Skogholm' cotoneaster grown on white plastic had significantly higher plant canopy [1C to 2C (1.8F to 3.6F)] and substrate temperatures [1C to 4C (1.8F to 7.2F)] daily from 1000 HR to 2000 HR throughout the summer months compared to all other nursery floors. While differences in maximum temperatures are important, exposure duration to those temperatures are just as critical. Ingram (7) reported critical root temperatures for direct injury decreased linearly as exposure duration increased exponentially. In the present study, canopy and substrate temperatures were significantly higher with 'Skogholm' cotoneaster grown on white plastic for 10 hr/day compared to the other nursery floors. Data for ground fabric/black plastic and white plastic from July 14 to July 17, 2001, are presented in Fig. 1 to illustrate the typical daily summer cycle for canopy and substrate temperature, respectively. These differences in temperature could explain reduced levels of photosynthesis for plants growing on white plastic resulting in decreased plant growth (13). Top and root growth of several woody plant species have been decreased by exposing roots to ≥ 40C (104F) compared to growth at lower root temperatures (6, 7, 17, 22). Martin et al. (10) reported a 50% increase in stem diameter growth of *Magnolia grandiflora* 'St. Mary' when maximum daily temperature was reduced by 3C (5.4F) [48C to 45C (118F to 113F)]. Canopy and substrate temperatures of all nursery floors were similar daily from 2000 HR until 1000 HR.

Nursery floor affected canopy and substrate temperatures during the summer months, however all nursery floors had similar canopy and substrate temperatures during late fall, winter, and early spring (data not presented). This suggests

Table 4. Grams of N recovered in effluent, substrate, cotoneaster tops and roots, and fertilizer prills for each nursery floor, 116 days after treatment initiation. All data are presented on a 14.2 liter (15 qt) container basis.

Variable	Nursery floor							
	Black plastic		Gravel		Ground fabric/ black plastic		White plastic	
	g	%	g	%	g	%	g	%
Effluent								
NH_4-N	1.46a[z]	22[y]	1.40a	21	1.33a	22	1.60a	24
NO_3-N	2.71a	41[y]	2.69a	39	2.28a	37	2.85a	43
Substrate	0.014a	0[y]	0.012a	0	0.013a	0	0.013a	0
Cotoneaster								
Tops	2.30ab	35[y]	2.52a	37	2.37ab	38	2.00b	30
Roots	0.16ab	2[y]	0.20a	3	0.20a	3	0.15b	2
N efficiency[x]	37b		40a		42a		33c	
Fertilizer prills								
Total N	6.36a		6.03b		5.92b		5.77c	
Recovered N[w]	13.00	72[v]	12.85	71	12.11	67	12.38	69

[z]Means separation within rows by Fisher's protected LSD, $P = 0.05$.

[y]Percentage based on N (g) recovered in effluent + substrate + plant.

[x]N efficiency = [g N in plant ÷ (g N in effluent + plant)] × 100.

[w]Recovered N (effluent + substrate + plant + fertilizer prill) (N in rainfall included).

[v]Percentage based on total N (18 g) applied.

Table 5. Grams of P recovered in effluent, substrate, cotoneaster tops and roots, and fertilizer prills for each nursery floor, 116 days after treatment initiation. All data are presented on a 14.2 liter (15 qt) container basis.

Variable	Nursery floor							
	Black plastic		Gravel		Ground fabric/ black plastic		White plastic	
	g	%	g	%	g	%	g	%
Effluent								
P	0.253a[z]	38[y]	0.224a	33	0.225a	35	0.244a	41
Substrate	0.175a	26[y]	0.186a	28	0.183a	28	0.171a	29
Cotoneaster								
Tops	0.217ab	33[y]	0.240a	36	0.217ab	34	0.168b	28
Roots	0.020ab	3[y]	0.023a	3	0.022a	3	0.016b	3
P efficiency[x]	49b		53a		52a		43c	
Fertilizer prills	0.63		0.61		0.56		0.56	
Recovered P[w]	1.30	50[v]	1.28	49	1.21	47	1.16	45

[z]Means separation within rows by Fisher's protected LSD, $P = 0.05$.

[y]Percentage based on P (g) recovered in effluent + substrate + plant.

[x]P efficiency = [g P in plant ÷ (g P in effluent + plant)] × 100.

[w]Recovered P (effluent + substrate + plant + fertilizer prill) (P in rainfall included).

[v]Percentage based on total P (2.6 g) applied.

the nursery floor would not aid in winter protection. Canopy and substrate temperatures of covered plants were significantly warmer by 2C (3.6F) during the winter months as compared to uncovered plants, regardless of nursery floor (data not presented). This is similar to that reported by Warren et al. (19).

Nitrogen and P budgets. Of the 18 g of N applied to each container, 67 to 72% was recovered (Table 4), whereas only 45 to 50% of the 2.6 g of applied P was recovered (Table 5). Tyler et al. (16) and Warren et al. (20) also reported low P recovery percentages. Nursery floor did not significantly affect N or P losses in the effluent; losses ranged from 21 to 24%, and 33 to 41% of the recovered N and P (effluent, substrate, and plant), respectively. Nitrogen losses can range from 13 to 46% (5, 12, 16). Likewise, N and P remaining in the substrate were unaffected by nursery floor with < 1% of the recovered N found in the substrate. There was 26 to 29%, however, of the recovered P found in the substrate. (Table 4).

Nitrogen and P content of tops and roots of cotoneaster grown on gravel was significantly greater than cotoneaster grown on white plastic (Tables 4 and 5). Reduced mineral nutrient content may be a reflection of elevated root temperatures when grown on white plastic. Yeager et al. (22) reported mineral nutrient uptake of *Ilex crenata* Thunb. 'Rotundifolia' decreased with increasing root temperature from 28C to 40C (82F to 104F). Tops of cotoneaster contained 12 to 15 times N and 10 to 11 times P found in the roots. Nitrogen and P content of tops and roots of cotoneaster grown on black plastic, gravel, and ground fabric/black plastic were similar. Plants grown on gravel and ground fabric/black plastic had the highest N and P efficiency, 40 and 42%, and 53 and 52%, respectively followed by black plastic (N = 37%, P = 49%) and white plastic (N = 33%, P = 43%) (Tables 4 and 5). Tyler et al. (16) growing cotoneaster with controlled-release fertilizers (CRFs) reported N efficiencies ranging from 56 to 69% depending upon rate of N application and LF, whereas Warren et al. (20) growing 'Sunglow' azaleas (*Rhododendron* sp. 'Sunglow') with CRFs found N efficiencies of 56%. However, using our definition of N efficiency and data collected by Stewart et al. (15), a 15% N efficiency was calculated when Japanese privet (*Ligustrum japonicum*) was grown with liquid fertilization.

'Skogholm' cotoneaster grown on white plastic was smaller with reduced N and P efficiencies compared to all other nursery floors. These differences may be accounted for by increased canopy and substrate temperatures. These data suggest white plastic should be avoided as a nursery floor. Except for mineral nutrient efficiencies, there were few differences in growth and water usage when plants were grown on gravel, black plastic or ground fabric/black plastic. 'Skogholm' cotoneaster grown on gravel and ground fabric/black plastic had the highest N and P efficiency.

Literature Cited

1. Appleton, B.L. 1986. Container Nursery Design. Amer. Nurseryman Publishing Co., Chicago, IL.

2. Bilderback, T. 1999. Maximize production. NMPro 15(6):37-46.

3. Calaldo, D.A., M. Haroon, L.E. Schrader, and V.L. Youngs. 1975. Rapid colorimetric determination of nitrate in plant tissue. Commun. Soil Sci. Plant Anal. 6:71–80.

4. Chaney, A.L. and E.P. Marbach. 1962. Modified reagents for determination of urea and ammonia. Clin. Chem. 8:130–132.

5. Fare, D.C. 1993. The influence of irrigation practices on nitrate-nitrogen leached form container-grown ornamentals Ph.D. Dissertation. Auburn Univ., Auburn, AL.

6. Harrison, R.H., T.H. Yeager, and D.L. Ingram. 1988. Growth response and nutrient uptake by *Photinia* x*fraseri* at supraoptimal root-zone temperatures. Proc. Southern Nurserymen's Assn. Res. Conf. p.68–70.

7. Ingram, D.L. 1986. Root cell membrance heat tolerance of two dwarf hollies. J. Amer. Soc. Hort. Sci. 111:270–272.

8. Ivy, R.L., T.E. Bilderback, and S.L. Warren. 2002. Effect of potting date on plant growth, nutrient content and substrate EC. J. Environ. Hort. 20:104–109.

9. Newman, S.E. and F.T. Davies, Jr. 1988. Influence of field bed position, ground surface color, mycorrhizal fungi, and high root-zone temperature in woody plant container production. Plant and Soil 112:29–35.

10. Martin, C.A., D.L. Ingram, and T.A. Nell. 1991. Growth and photosynthesis of *Magnolia grandiflora* 'St. Mary' in response to constant and increased container volume. J. Amer. Soc. Hort. Sci. 116:439–445.

11. Murphy, J. and J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. 27:31–36.

12. Rathier, T.M. and C.R. Frink. 1989. Nitrate in runoff water from container grown juniper and Alberta spruce under different irrigation and N fertilization regimes. J. Environ. Hort. 7:32–35.

13. Ruter, J.M. and D.L. Ingram. 1990. ^{14}Carbon-labelled photosynthesis partitioning in *Ilex crenata* 'Rotundifolia' at supraoptimal root-zone temperatures J. Amer. Soc. Hort. Sci. 115:1008–1013.

14. SAS Institute, Inc. 1985. SAS User's Guide: Statistics. Version 6.09. SAS Institute, Inc., Cary, NC.

15. Stewart, J.A., L.J. Lund, and R.L. Branson. 1981. Nitrogen balances for container-grown privet. J. Amer. Soc. Hort. Sci. 106:565–569.

16. Tyler, H.H., S.L. Warren, and T.E. Bilderback. 1996. Reduced leaching fractions improve irrigation use efficiency and nutrient efficacy. J. Environ. Hort. 14:199–204.

17. Walden R.F. and R.D. Wright. 1995. Supraoptimal root-zone temperature influences the medium solution and growth of 'Helleri' holly. HortScience 30:1020–1025.

18. Warren, S.L. and T.E. Bilderback. 2002. Timing of low pressure irrigation affects plant growth and water utilization efficiency. J. Environ. Hort. 20:184–188.

19. Warren, S.L., K.B. Perry, and R.E. Bir. 1990. Overwintering container-grown nursery crops: Plant, air, and medium thermal response to porous row covers. J. Environ. Hort. 8:49–55.

20. Warren, S.L., T.E. Bilderback, and H.H. Tyler. 1995. Efficacy of three nitrogen and phosphorus sources in container-grown azalea production. J. Environ. Hort. 13:147–151.

21. Yeager, T.H., C.H. Gilliam, T.E. Bilderback, D.C. Fare, A.X. Niemiera, and K.M. Tilt. 1997. Best Management Practices Guide for Producing Container-Grown Plants. Southern Nurserymen's. Assoc., Marietta, GA.

22. Yeager, T.H., R.H. Harrison, and D.L. Ingram. 1991. 'Rotundifolia' holly growth and nitrogen accumulation influenced by supraoptimal root-zone temperatures. HortScience 26:1387–1388.