Influence of field bed position, ground surface color, mycorrhizal fungi, and high root-zone temperature in woody plant container production

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Key words: *Buxus microphylla*, *Berberis thunbergii* ‘Atropurpurea’, *Glomus fasciiculatum*, *Glomus etunicatus*, *Pinus elderica*, *Pittosporum tobira* ‘Wheeler’s dwarf’, root stress

Abstract
High root-zone temperatures can stress plants and reduce nursery productivity of container produced crops. Field studies were conducted to study position of containers in field beds, ground surface color, mycorrhizal fungi and high root-zone temperatures in the production of selected woody plants. Root-zone temperature profiles in containers were established to determine nursery production conditions for white and black ground bed surfaces. White surfaces increased container medium temperatures in beds of plants with open canopies by 2–4°C compared to full canopied plants. Under field conditions with container medium temperatures as high as 40–50°C, the open canopied *Berberis thunbergii* DC. ‘Atropurpurea’, *Pinus elderica* Medd. and *Buxus microphylla* Seibold and Zucc. were more susceptible to temperature stress compared to the more close canopied *Pittosporum tobira* (Thunb.) Ait. ‘Wheeler’s dwarf’. When compared to controls, *P. tobira* colonized with mycorrhizal fungi [(*Glomus etunicatus* Baker and Gerd. and *Glomus fasciiculatum* (Thax. sensu Gerd.) Gerd. and Trappe] had increased shoot growth in all bed areas except the western exposure, and increased root growth in western and eastern bed regions. Greatest root damage generally occurred in containers of colonized and noncolonized *B. thunbergii* in southern and western bed exposures. Mycorrhizal colonization did not improve plant growth of the more high temperature susceptible *B. thunbergii*.

Introduction

Dark colored plastic containers traditionally used in commercial production of ornamental nursery crops can adversely increase root-zone temperatures (Fretz, 1971; Ingram, 1981; Wong et al., 1971; Young and Hammett, 1980). High container medium temperatures cause root damage, decrease plant quality and marketability, and can increase plant production time (Whitcomb, 1980). In the field bed surfaces on which containers are placed can also contribute to root damage. Many nursery growers in the Southern US place their containers on black polypropylene fabric for weed and erosion control, while others use crushed limestone rock or white shells (Davidson et al., 1988).

Nursery growers minimize heat load on susceptible plant roots with intermittent irrigation cycles for evaporative cooling, shading with saran, bordering containers of susceptible species with high temperature resistant species, intermixing larger shade producing plants among production beds of understory shrubs, or by closely spacing containers (can-tight).

Natural systems exist that may offer some protection from high temperature root stress in black containers. One potential system is use of mycorrhizal fungi which form a symbiotic relation-
ship with plant roots (Maronek et al., 1981). Improved plant health and vigor due to this association has been attributed to greater nutrient efficiency, drought resistance, pathogen protection, and high temperature root stress resistance (Maronek et al., 1981; Marx and Bryan, 1971; Marx et al., 1970). Mycorrhizal plants have a much greater chance for survival than non-mycorrhizal plants in harsh sites, such as surface mine spoils and waste sites (Allen and Allen, 1980). Pinus taeda seedlings, colonized with Pisolithus tinctorius, can survive and grow with medium temperatures of 34°C (Marx and Bryan, 1971). Glycine max colonized with Glomus mosseae tolerated high root-zone temperature of 36°C (Schenck, 1982). Hence, mycorrhizal fungi may be of potential use for alleviation of high temperature root stress in containerized production systems.

Objectives of this research were: 1) to establish root-zone temperature patterns and plant growth responses of selected nursery plants grown in black polyethylene containers on field beds simulating souther US nursery conditions, and 2) to determine growth responses of high root-zone temperature susceptible and moderately susceptible woody plants colonized with mycorrhizal fungi under high root-zone temperature nursery production conditions.

Materials and methods

Study I: Root-zone temperature patterns and plant growth

Plant culture Four economically important nursery crops were evaluated for their response to high root-zone temperatures under simulated commercial container production conditions. Berberis thunbergii DC. 'Atropurpurea', red pygmy barberry, Buxus microphylla Seibold and Zucc. japonica, Japanese boxwood, and Pittosporum tobira (Thunb.) Ait. 'Wheeler's dwarf', Wheeler's dwarf pittosporum were obtained as rooted liners from a commercial nursery. Seedlings of Pinus elliottii Medw., Afghan pine, were germinated and grown in a glasshouse in 0.5 liter containers (Spencer LeMair Inc., Edmonton, Alberta, Canada).

Liners of the four plant species were shifted into 3.8 liter black polypropylene containers with a commercial container medium of 3 composted pine bark; 1 builder's sand (v/v), amended with 2.95 kg m⁻³ dolomitic limestone, 2.95 kg m⁻³ gypsum, 1.77 kg m⁻³ superphosphate, 4.72 kg m⁻³ 18N-2.6P-10K slow release fertilizer (Osmocote®, Sierra Chemical Co., Milpitas, CA) and 75 g m⁻³ of fritted trace elements (FTE, WR Grace and Co., Fogelsville, PA).

Each field bed was composed of 16 containerized plant units (1 plant unit = one 3.8 liter container and plant) of a given species and containers were placed on woven polypropylene ground covers with either black or white surfaces. Container beds were spaced 1 m apart to prevent mutual shading. Average minimum and maximum daily air temperatures during the experimental period were 20°C ± 0.3°C and 34.1°C ± 0.3°C, respectively, and 37.8°C was the highest air temperature recorded during this period.

Plants were harvested 4½ months after planting. Container medium was hand washed from the roots of each plant as described by Bohm (1979). Shoots and roots were graded, separated, and dried at 60°C for 48 hours and weighed.

Medium temperature measurement. To determine temperature isotherms representing root-zone profiles of the 16 containerized plants per bed, medium temperatures were measured using dial type thermometers (Weston Model 4363, Weston Instruments, Newark, NJ) inserted 15 cm into the container medium. Temperatures were recorded September 5 and 6, 1982 at 1200, and a series of isotherm lines were calculated from the temperatures of each species, ground cover color, and position within the field bed.

Statistical analysis. The 4 plant species were analyzed as separate experiments in a randomized complete block design (Snedecor and Cochran, 1967) with factorial combinations of 2 ground cover surface colors (black or white) and 5 container positions within a bed (south, west, east, north or center exposures). There were 3 replicate beds within two blocks per species and treatment combination. Each replication was composed of a field bed containing 16 containerized plants of a given species which were arranged in a square configuration 0.7 by 0.7 m (Fig. 1).

Fig. 1. Diagram of experiment 16 containers used for a center bed position.

Study II: Mycorrhizal root temperatures and plant growth

Plant selection and bed positions and non-mycorrhizal B. thunbergii and P. elliottii plant species from susceptible and moderately susceptible root-zone temperatures, rooted into 3.8 liter black pasteurized medium (no superphosphate 18N-2.6P-10K slow release fertilizer, Sierra Chemical Corp.) along with after pasteurization.

Mycorrhizal colonized root/soil blend of S. sitchensis roots colonized with G. fasciculatus Gerd. and G. fasciculatus Gerd. and Trappe and non-colonized plants of non-colonized S. sitchensis and Davies, 1984). Each field bed had black ground covers with or west exposures. Of
medium of 3 composted pine
and (v/v), amended with
limestone, 2.95 kg m⁻³ gauge
phosphate, 4.72 kg m⁻³
fertilizer (Osmocote®,
Milpitas, CA) and 75 g m⁻³
FTE. WR Grace and Co.

posed of 16 containerized
it = one 3.8 liter container
species and containers were
polyethylene ground covers with
success. Container beds were
prevent mutual shading.
maximum daily air tem-
perimental period were
respectively, and
air temperature recorded in
4½ months after planting.
was washed from
the described by Bohm (1979).
拆, separated, and dried
weighed.

Measurement. To determine
representing root-zone
containerized plants per bed,
were measured using dia-
Model 4303, Weston
inserted 15 cm into the
were recorded
at 1200, and a series of
iments from the tem-
, ground cover color, and

4 plant species were
ments in a randomized
(Snedecor and Cochran,
combinations of 2 ground
and (or white) and 5 con-
bed (south, west, east, 
es). There were 3 replicated
per species and treatment
laction was composed of a
containerized plants of a 
arranged in a square con-
(Fig. 1).

Container bed, mycorrhizae, high temperature effects

![Diagram of experimental bed unit indicating position of containers used for analysis of south, west, east, north, and center bed](image)

**Study II. Mycorrhizal fungi, high root-zone temperatures and plant growth**

**Plant selection and culture.** To test container field bed positions and mycorrhizal fungi colonization, *B. thunbergii* and *P. tobira* were selected as test plant species from the previous study as highly susceptible and moderately resistant to high root-zone temperatures, respectively. Liners were planted into 3.8 liter black containers containing steam pasteurized medium as previously described except that no superphosphate was added and 2.34 kg m⁻³
N₂O-2.6P-10K slow release fertilizer (Osmocote®,
Sierra Chemical Co., Milpitas, CA) was incorporated along with other standard amendments after pasteurization.

Mycorrhizal colonized test plants had 100 g of a
root soil blend of *Sorghum sudanense* (Piper) Stapf.
roots colonized with *Glomus etunicatus* Baker and
and *G. fasciculatum* (Thax. sena Gerd.)
Gerd. and Trappe added to each container and
non-colonized plants had 100 g of a root soil blend
of non-colonized *S. sudanense* roots added (Sweatt
and Davies, 1984).

Each field bed had 100 containers placed on
black ground covers with north, south, east, center
or west exposures. Of the 120 containerized plants
per bed, 24 were colonized with mycorrhizal fungi
and 24 were non-colonized. The remaining 72
plants were non-colonized and to provide an infec-
tion barrier were placed between colonized and
non-colonized plants. Supplemental fertilizer was
applied as soluble 20N-8.6P-16.6K at 100 mg l⁻¹ N
during the production period at 30 day intervals.
The average daily minimum and maximum con-
tainer temperatures were 20.0°C ± 0.4°C
and 32.5°C ± 0.3°C, respectively. The highest tem-
perature was 41°C.

Plants were harvested after 4½ months, and shoot
and root data were analyzed as previously described.
The percent mycorrhizal fungi colonization of
roots was determined using the techniques of
Phillips and Hayman (1970). Colonization levels of
*B. thunbergii* and *P. tobira* colonized and non-
colonized roots were 20.6% and 5.2%, and 51.5%
and 1.7%, respectively.

**Statistical analysis.** The 2 plant species were
analyzed as separate experiments in a completely
randomized design (Snedecor and Cochran, 1967)
with factorial combinations of 2 mycorrhizal levels
(colonized or non-colonized) and 5 container
positions within a bed (south, west, east, north or
center exposures). There were 2 beds per species
and treatment with each bed representing a
replication. A total of 48 plants per species and per
treatment were analyzed.

**Results**

**Nursery study I**

**Medium temperature.** Ground cover color influ-
enced the temperature of the container medium
within the field beds. White ground surfaces
nearly increased the container medium temperatures
in beds by 2° to 4°C compared to black ground
surfaces (Fig. 2). Medium temperature was not
affected by ground cover color for *B. microphylla*,
except for a high temperature peak of 48°C in the
southern row on black ground surfaces (Fig. 2B).
Highest medium temperatures were found in con-
tainers with southern and western exposures. The
open plant canopies of *B. thunbergii*, *B. micro-
phylla*, and *P. eldarica* (Fig. 2A–2C) permitted
higher media temperatures than the denser canopy of
*P. tobira* (Fig. 2D).
Plant growth analysis. White ground surfaces reduced both shoot and root dry weights of *P. eldarica* and increased shoot dry weight of *B. microphylla* (Table 1). *B. thunbergii* and *P. tohira* were not affected by ground and surface color.

Container position in beds did not affect shoot and root dry weights of *B. thunbergii* and *P. tohira* (Table 2). The southern bed exposure reduced shoot and root dry weights of *P. tohira* and shoot weight of *B. microphylla* (compared to western and center exposures).

**Nursery study II**

Plant growth analysis. Root and shoot growth of *B. thunbergii* were not enhanced by mycorrhizal colonization (Table 3). Both colonized and non-colonized *B. thunbergii* exposed to southern and western exposures had lower root dry weights compared to more protected center and northern exposures. Colonization generally increased shoot dry weight and shoot quality of *P. tohira* in all bed positions except the western exposure, when compared to non-colonized plants (Table 3). Root dry weight was also enhanced by colonization in the eastern and western bed exposures.

**Discussion**

Root-zone temperatures in nursery containers were dependent upon the ground cover surface color and canopy surfaces generally. Temperatures 2° to 4° higher. The mutual plants and canopy were the primary factors. A grower product susceptible species...
Table 2. Effects of container bed position on shoot and root weight of Berberis thunbergii, Atropurpurea, Baccharis micrantha japonica, P. eldarica, and Pittosporum tobira. Shoots were pooled from containers placed on white and black ground surfaces.

<table>
<thead>
<tr>
<th>Species</th>
<th>Bed position</th>
<th>Dry weights (g)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Shoot</td>
<td>Root</td>
</tr>
<tr>
<td>B. thunbergii</td>
<td>South</td>
<td>0.60 ± 0.10</td>
<td>0.26 ± 0.06</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>0.70 ± 0.12</td>
<td>0.34 ± 0.08</td>
</tr>
<tr>
<td></td>
<td>East</td>
<td>0.70 ± 0.09</td>
<td>0.32 ± 0.07</td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>0.73 ± 0.14</td>
<td>0.38 ± 0.11</td>
</tr>
<tr>
<td></td>
<td>Center</td>
<td>0.68 ± 0.09</td>
<td>0.33 ± 0.07</td>
</tr>
<tr>
<td>B. micrantha</td>
<td>South</td>
<td>7.12 ± 0.21</td>
<td>4.34 ± 0.40</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>7.68 ± 0.29</td>
<td>5.27 ± 0.53</td>
</tr>
<tr>
<td></td>
<td>East</td>
<td>7.54 ± 0.51</td>
<td>4.54 ± 0.51</td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>7.44 ± 0.24</td>
<td>5.18 ± 0.69</td>
</tr>
<tr>
<td></td>
<td>Center</td>
<td>7.90 ± 0.23</td>
<td>5.30 ± 0.62</td>
</tr>
<tr>
<td>P. eldarica</td>
<td>South</td>
<td>3.32 ± 0.44</td>
<td>2.36 ± 0.55</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>4.20 ± 0.34</td>
<td>3.25 ± 0.82</td>
</tr>
<tr>
<td></td>
<td>East</td>
<td>4.25 ± 0.60</td>
<td>2.62 ± 0.48</td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>4.30 ± 0.69</td>
<td>3.16 ± 0.68</td>
</tr>
<tr>
<td></td>
<td>Center</td>
<td>3.88 ± 0.42</td>
<td>2.69 ± 0.44</td>
</tr>
<tr>
<td>S. tobira</td>
<td>South</td>
<td>17.59 ± 1.57</td>
<td>5.09 ± 0.34</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>23.06 ± 1.47</td>
<td>3.47 ± 0.41</td>
</tr>
<tr>
<td></td>
<td>East</td>
<td>24.45 ± 1.81</td>
<td>3.80 ± 0.45</td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>25.00 ± 1.92</td>
<td>3.90 ± 0.46</td>
</tr>
<tr>
<td></td>
<td>Center</td>
<td>22.11 ± 1.22</td>
<td>3.73 ± 0.73</td>
</tr>
</tbody>
</table>

Means of 36 observations ± standard error of the mean.

Means of 24 observations ± standard error of the mean.

Means of 48 observations ± standard error of the mean.

Greater penetration of reflected light from the white ground surfaces into the denser plant canopy of B. micrantha (compared to B. thunbergii and P. eldarica) may have been responsible for increased shoot dry weight, as reported in other plant species. Conversely, when containers of the sparsely cano-pied P. eldarica were placed on white ground surfaces, the shoot and root dry weight decreased due to supraoptimal medium temperatures caused by greater reflected solar radiation on container side walls.

High medium temperatures in the southern bed exposure ranged from 42°C for P. tobira, 44°C for B. thunbergii, 48°C for B. micrantha and 50°C for P. eldarica, which approached or exceeded lethal temperatures established for roots of other woody plant species (Ingram and Buchanan, 1981 and 1984; Ingram et al., 1986). Medium temperatures of 40°C during day periods were reported to reduce shoot and root growth, root carbohydrate levels, and photosynthetic rates for P. tobira (Johnson and Ingram, 1984). The southern exposure reduced shoot and root dry weights of P. tobira and reduced shoot weight of B. micrantha. The more protected center region of the beds had lower root-zone temperatures and a more favorable micrometeor for plant growth and water use as a result of mutual shading.

Mycorrhizal fungi colonization did not enhance growth of B. thunbergii. These plants did not tolerate high temperature stress and most were dead at plant harvest.

Mycorrhizal fungi improved shoot and root growth of P. tobira. Mycorrhizal enhancement of shoot dry weight and quality was most pronounced in the protected east, north and center bed positions. Medium temperature profiles for containerized P. tobira on a black ground surface in the southern plot position averaged from 37°C compared to 28°C for the protected plot positions (i.e., center, north, east exposure). Thus, medium temperatures in the southern bed exposure were equal or greater than those reported in mycorrhizal temperature studies (Marz and Bryan, 1971; Schenck and Schroder, 1974). It should be noted that both mycorrhizal isolates of G. etunicatum and G. fasci-
Table 3. Effects of mycorrhizal fungi colonization and container bed position on shoot and root dry weight, and shoot quality of *Berberis thunbergii*, *Atropurpurea* and *Pittosporum tobira* - *Wheeler*.

<table>
<thead>
<tr>
<th>Species</th>
<th>Colonization level</th>
<th>Bed position</th>
<th>Plant weights (g)</th>
<th>Shoot</th>
<th>Root</th>
<th>Shoot quality*</th>
</tr>
</thead>
<tbody>
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<td></td>
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<tr>
<td><em>B. thunbergii</em></td>
<td>Non-colonized</td>
<td>South</td>
<td>1.03 ± 0.15</td>
<td>0.45 ± 0.03</td>
<td>1.25 ± 0.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>West</td>
<td>1.22 ± 0.19</td>
<td>0.47 ± 0.10</td>
<td>1.21 ± 0.15</td>
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<tr>
<td></td>
<td></td>
<td>East</td>
<td>1.05 ± 0.29</td>
<td>0.48 ± 0.11</td>
<td>1.29 ± 0.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>North</td>
<td>1.36 ± 0.20</td>
<td>0.83 ± 0.15</td>
<td>1.20 ± 0.20</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Center</td>
<td>1.34 ± 0.18</td>
<td>0.83 ± 0.12</td>
<td>1.41 ± 0.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Colonzied</td>
<td>South</td>
<td>1.11 ± 0.25</td>
<td>0.43 ± 0.06</td>
<td>1.08 ± 0.06</td>
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<tr>
<td></td>
<td></td>
<td>West</td>
<td>0.92 ± 0.15</td>
<td>0.39 ± 0.04</td>
<td>1.00 ± 0.00</td>
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<tr>
<td></td>
<td></td>
<td>East</td>
<td>1.00 ± 0.28</td>
<td>0.48 ± 0.14</td>
<td>1.50 ± 0.29</td>
<td></td>
</tr>
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<td></td>
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<td>North</td>
<td>0.86 ± 0.25</td>
<td>0.48 ± 0.22</td>
<td>1.20 ± 0.20</td>
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<td>Center</td>
<td>1.10 ± 0.14</td>
<td>0.57 ± 0.07</td>
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<tr>
<td><em>P. tobira</em></td>
<td>Non-colonized</td>
<td>South</td>
<td>22.84 ± 1.93</td>
<td>1.78 ± 0.31</td>
<td>2.83 ± 0.21</td>
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<tr>
<td></td>
<td></td>
<td>West</td>
<td>16.64 ± 1.55</td>
<td>1.64 ± 0.28</td>
<td>2.50 ± 0.24</td>
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<tr>
<td></td>
<td></td>
<td>East</td>
<td>18.98 ± 1.73</td>
<td>1.61 ± 0.21</td>
<td>2.75 ± 0.27</td>
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<td>North</td>
<td>23.16 ± 1.82</td>
<td>2.12 ± 0.25</td>
<td>2.80 ± 0.20</td>
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<tr>
<td></td>
<td></td>
<td>Center</td>
<td>22.60 ± 1.35</td>
<td>1.45 ± 0.14</td>
<td>3.37 ± 0.13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Colonzied</td>
<td>South</td>
<td>26.38 ± 2.25</td>
<td>1.90 ± 0.32</td>
<td>3.33 ± 0.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>West</td>
<td>18.59 ± 2.11</td>
<td>2.21 ± 0.23</td>
<td>2.79 ± 0.29</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>East</td>
<td>35.59 ± 2.65</td>
<td>3.14 ± 0.22</td>
<td>4.17 ± 0.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>North</td>
<td>32.64 ± 2.71</td>
<td>2.00 ± 0.14</td>
<td>3.90 ± 0.19</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Center</td>
<td>29.11 ± 1.58</td>
<td>1.66 ± 0.17</td>
<td>4.17 ± 0.14</td>
<td></td>
</tr>
</tbody>
</table>

* Plant quality ratings from one to five, one being poorest and five being best.
* means of 6 observations ± standard error of the mean.
* means of 7 observations ± standard error of the mean.
* means of 5 observations ± standard error of the mean.
* means of 3 observations ± standard error of the mean.

*Cuscuta* were from more northern ecotypes; therefore, future mycorrhizal selections from regions of higher root-zone temperatures may be more beneficial for alleviating high temperature root stress.

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