three random, 30-cm segments of each treatment during 7 weeks are shown in Fig. 1. The greatest number of emerged seedlings was obtained when Enersol was incorporated in the gel at seeding, followed by treatments using Ergostim or Agro-Lig in the gel. Although the gel-seeded treatments lost 25% or more of the emerged seedlings, more total harvested roots were produced than in the untreated control. Overcrowding of seedlings may have contributed to the high mortality. A combination of factors, including seedling survival, stand establishment, health of the crop, and plant spacing, contribute to high carrot yields.

Similar results in carrot weights and root numbers were obtained in Fall 1984 (Table 2). Seed germinated in water and seeded in gel again produced about twice as many carrots as using raw, untreated seed. Seeds germinated with biostimulants and then gel-seeded produced 16% more carrots than gel-seeded without a biostimulant. The use of biostimulants also resulted in greater average root weights compared to when no biostimulant was used.

In contrast to other studies (Austin et al., 1969), seeds subjected to alternate imbibition and then drying (hardening) produced even fewer roots than seeds left untreated. Untreated and hardened seed did not differ significantly in average weight, total number of roots produced, or in plant vigor 21 days after seeding (Table 2). Seedling vigor was increased significantly by hardening the seed relative to untreated seed, but only up to 14 days after seeding. In addition, either gel-seeded or biostimulant-treated seedlings were much more vigorous than untreated seed. There were highly significant differences in seedling emergence when untreated seed was compared to gel treatments and when use of biostimulants was compared to untreated seed (Table 2). Enersol and Agro-Lig treatments consistently produced more seedlings than the other treatments. There were significantly more roots when the seed was gel-seeded without a biostimulant. The use of biostimulants resulted in greater average root weights compared to when no biostimulant was used.

Results of this study indicate gel-seeding combined with biostimulants can have a beneficial effect on carrot stand establishment and root growth, especially under stressful environmental conditions. Overseeding may be unnecessary when biostimulants are used due to the increased seedling emergence.

**Literature Cited**


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**The Use of Vesicular-Arbuscular Mycorrhizae in Boston Fern Production: I. Effects of Peat-based Mixes**

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**Additional index words.** peatmoss, VAM formation, Boston fern, Glomus intraradices, Glomus vesiculiferum, growth enhancement

**Abstract.** The horticultural Boston fern [Nephrolepis exaltata (L.) Schott cv. Verona] was micropropagated in vitro using commercial techniques. Rooted plantlets were transferred into pots containing one of three test substrates made of peat and vermiculite and subsequently inoculated with one of two species of Glomus. Survival of uninoculated control plants growing on a black peat-based mix was less than that on a brown peat-based mix. Vesicular-arbuscular mycorrhizal (VAM) inoculation significantly increased survival on the former, but not the latter, substrate. The growth of roots was enhanced in brown peatmoss, but VAM colonization was faster with black peatmoss. Compared to uninoculated controls growing under the same fertilization regime, inoculated plants had significantly higher frond P and N concentration and also showed better frond and root growth. On a growth-increment basis, our results suggested that the brown peat-based mix was more suitable for fungal activity and fern growth.

Beneficial interactions between vesicular-arbuscular mycorrhizal (VAM) fungi and various woody ornamental plants (Nemec, 1987) or horticultural crops (Menge, 1983) are, in general, well-documented. Most of the experiments supporting these conclusions have been conducted in greenhouses using pot cultures and sterilized soils. The use of mineral-type substrates was often preferred over organic substrates (Dehne and Backhauss, 1986; Plenchette et al., 1982). We found only a few investigations dealing with the potential use of peat-based substrates for VAM formation (Biermann and Linderman, 1983a; Biermann and Linderman, 1983b; Caron and Parent, 1988; Graham and Timmer, 1984; Graham and Timmer, 1985; Johnson and Hummel, 1986; Parent and Caron, 1987)

Little is known about the response of ferns to VAM inoculation (Cooper, 1975; Cooper, 1977; Stamps and Johnson, 1984), even though they are often mycorrhizal in the field (Berth and Kendrick, 1982; Bouillard, 1957; Cooper, 1975). The VAM inoculation of ferns has been successful in various steam-sterilized mineral soils that contain organic inclusions (Cooper, 1975) and in a steam-sterilized potting medium containing equal parts of sand, peat, and perlite (Stamps and
Fig. 1. Spread of Boston fern root system inoculated with Glomus intraradices (Gi) or G. vesiculiferum (Gv) in the three peat-based mixes. Measurements were made 6 weeks (a), 12 weeks (b), and 18 weeks (c) after inoculation. Non-inoculated controls were of type L or H, which, respectively, had received low- and high-P fertilization. For each set of measurements, values with the same letters are not significantly different (Scott-Knott test, P < 0.05).

Table 1. Hydrophysical properties of three amended peat-based mixes.

<table>
<thead>
<tr>
<th>Mix</th>
<th>BD (kg·liter⁻¹)</th>
<th>TPS</th>
<th>EA</th>
<th>AIR</th>
<th>EAW</th>
<th>WBC</th>
<th>Residual [% (w/v)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.18 a</td>
<td>89.7 b</td>
<td>1.5 b</td>
<td>6.2 c</td>
<td>24.8 a</td>
<td>5.8 c</td>
<td>51.4</td>
</tr>
<tr>
<td>2</td>
<td>0.16 ab</td>
<td>90.6 ab</td>
<td>3.4 b</td>
<td>11.8 b</td>
<td>23.6 a</td>
<td>7.6 a</td>
<td>44.2</td>
</tr>
<tr>
<td>3</td>
<td>0.15 b</td>
<td>91.5 a</td>
<td>10.4 a</td>
<td>15.1 a</td>
<td>26.7 a</td>
<td>6.7 b</td>
<td>32.6</td>
</tr>
</tbody>
</table>

For each property, values with the same letters are not significantly different (Duncan’s multiple range test, P < 0.05). BD = Bulk density; TPS = total pore space; EA = entrapped air = TPS, 1 cm; AIR = air capacity = TPS, 5 cm; EAW = easily available water = 5–50 cm; WBC = water buffering capacity = 50–100 cm; Residual = TPS – (EA + AIR + EAW + WBC).

Table 2. Striate fertility levels after 6, 12, and 18 weeks, according to guidelines for greenhouse growth media.

<table>
<thead>
<tr>
<th>Ions</th>
<th>Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>NH-N</td>
<td>Low</td>
</tr>
<tr>
<td>NO-N</td>
<td>Low</td>
</tr>
<tr>
<td>Potassium</td>
<td>Low</td>
</tr>
<tr>
<td>Calcium</td>
<td>Low</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Low</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Low</td>
</tr>
<tr>
<td>Soluble salts</td>
<td>Low</td>
</tr>
</tbody>
</table>

'NH-N low—0.3 ppm; NO-N low—0.39 ppm; potassium low—0.59 ppm; calcium low—0.79 ppm; magnesium low—0.29 ppm; phosphorus low—0.3 ppm; acceptable—4-7 ppm soluble salts low—0.75 ds·m⁻¹; acceptable: 0.75-1.49 ds·m⁻¹ [from Warncke (1980)].

Johnson, 1984). Observations by Boullard (1957) suggested that organic matter was essential to VAM formation in Pteridophytes, but no reports mention further observations of fern media preference for VAM inoculation. Boullard (1957) also studied seasonal variations in VAM infection of ‘Rooseveltii’ Boston fern, but no attempts were made to study fern growth responses due to VAM colonization.

Boston fern is a common household ornamental fern that has numerous cultivars prized for their variety of foliage shapes. Peat moss substrates are suitable for commercial production of Boston ferns in greenhouses, and inoculation with VAM might increase production. The objectives of this study were to determine: 1) whether VAM formation on ‘Verona’ fern is influenced by peat moss type, and 2) whether VAM colonization has an effect on host development.

Growth conditions for ferns. ‘Verona’ was micropropagated (at the CEGEP of Rivière-du-Loup, Qué.) using in vitro techniques described by Henny et al. (1981). Rooted plantlets were transferred to 60-cm pots containing test substrates and VAM inocula. Before introduction to greenhouse conditions, plantlets underwent 2 weeks of acclimatization under a mist with relative humidity of 75% black peatmoss, 25% brown peatmoss, and 25% vermiculite; mix 3 consisted of 50% black peatmoss and 25% brown peatmoss and 25% V; mix 3: 75% brown peatmoss and 25% V.

Table 2. Substrate fertility levels after 6, 12, and 18 weeks, according to guidelines for greenhouse growth media.

<table>
<thead>
<tr>
<th>Ions</th>
<th>Harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>NH-N</td>
<td>Low</td>
</tr>
<tr>
<td>NO-N</td>
<td>Low</td>
</tr>
<tr>
<td>Potassium</td>
<td>Low</td>
</tr>
<tr>
<td>Calcium</td>
<td>Low</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Low</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Low</td>
</tr>
<tr>
<td>Soluble salts</td>
<td>Low</td>
</tr>
</tbody>
</table>

'S NH-N low—0.3 ppm; NO-N low—0.39 ppm; potassium low—0.59 ppm; calcium low—0.79 ppm; magnesium low—0.29 ppm; phosphorus low—0.3 ppm; acceptable—4-7 ppm soluble salts low—0.75 ds·m⁻¹; acceptable: 0.75-1.49 ds·m⁻¹ [from Warncke (1980)].

Type L controls received low-P fertilization consisting of the basal nutrient solution that also was given to inoculated plants. Type H controls received high-P fertilization consisting of the basal nutrient solution supplemented with 114 mg of 0N-44P-0K/liter (Sudbury Laboratory, Sudbury, Mass.).

Experimental design. A randomized complete-block (six blocks) design was used to study the effect of VAM and peat-based substrates on Boston ferns. Each plant was an experimental unit. There were four treatments for each substrate: inoculated with mycorrhizal roots of leek containing chlamydospores of G. intraradices (Gi), inoculated with G. vesiculiferum (Gv), type L (low-P) uninoculated controls, and type H (high-P) uninoculated controls. There were three replicates of each treatment in each block.

Harvesting and measurements. One ran-
Table 3. Percent survival of Nephrolepis exaltata plantlets in several substrate mixes.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mix 1</th>
<th>Mix 2</th>
<th>Mix 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survival of uninoculated plantlets (%)</td>
<td>73</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>Survival of inoculated plantlets (%)</td>
<td>93</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>Probability that inoculation did not enhance survival (χ², n = 80)</td>
<td>0.02</td>
<td>0.04</td>
<td>0.40</td>
</tr>
</tbody>
</table>

See Table 1 for description of mixes.

Table 4. Analysis of variance of the percent root segments containing arbuscules.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df squares</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>5</td>
<td>146</td>
</tr>
<tr>
<td>Harvests (H)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>H Lin</td>
<td>1</td>
<td>9282</td>
</tr>
<tr>
<td>H Quad</td>
<td>1</td>
<td>404</td>
</tr>
<tr>
<td>Substrates (S)</td>
<td>2</td>
<td>35330</td>
</tr>
<tr>
<td>substrat 1 vs. 3</td>
<td>1</td>
<td>23920</td>
</tr>
<tr>
<td>substrat 2 vs. 1 and 3</td>
<td>1</td>
<td>11410</td>
</tr>
<tr>
<td>Fungi (F)</td>
<td>1</td>
<td>63</td>
</tr>
<tr>
<td>H lin × S</td>
<td>2</td>
<td>5144</td>
</tr>
<tr>
<td>H quad × S</td>
<td>2</td>
<td>1945</td>
</tr>
<tr>
<td>H lin × F</td>
<td>1</td>
<td>172</td>
</tr>
<tr>
<td>H quad × F</td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>S × F</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>H lin × S × F</td>
<td>2</td>
<td>54</td>
</tr>
<tr>
<td>H quad × S × F</td>
<td>2</td>
<td>125</td>
</tr>
<tr>
<td>Error</td>
<td>85</td>
<td>2132</td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>54880</td>
</tr>
</tbody>
</table>

Fig. 2. Percentage of Boston fern root segments containing arbuscules of Glomus intraradices (a) and G. vesiculiferum (b) in the three peat-based mixes. For each harvest and each fungus, values with the same letters are not significantly different (Duncan’s multiple range test, P < 0.05).

Fig. 3. Frond P content of Boston fern inoculated with Glomus intraradices (Gi) or G. vesiculiferum (Gv) in the three peat-based mixes. Measurements were made 6 weeks (a), 12 weeks (b), and 18 week (c) after inoculation. Non-inoculated controls were of type L or H, which, respectively, had received low- and high-P fertilization. For each set of measurements, values with the same letters are not significantly different (Duncan’s multiple range test, P < 0.05).
Table 5. Analysis of variance of the root system spread and the frond dry weight.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Sum of squares (millions)</th>
<th>Pr &gt; F</th>
<th>Sum of squares</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>5</td>
<td>4.826                     &lt;0.0070</td>
<td>0.62</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Harvests (H)</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H Lin</td>
<td>1</td>
<td>420.7                     &lt;0.0001</td>
<td>283.4</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H Quad</td>
<td>1</td>
<td>45.31                     &lt;0.0001</td>
<td>0.80</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Substrates (S)</td>
<td>2</td>
<td>298.8                     &lt;0.0001</td>
<td>88.68</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>substr 1 vs. 3</td>
<td>1</td>
<td>277.7                     &lt;0.0001</td>
<td>87.19</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>substr 2 vs. 1 and 3</td>
<td>1</td>
<td>22.12                     &lt;0.0001</td>
<td>1.49</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Fungi (F)</td>
<td>3</td>
<td>45.31                     &lt;0.0001</td>
<td>13.70</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>fungi 3 vs. 4</td>
<td>1</td>
<td>1.472                     &lt;0.0007</td>
<td>0.09</td>
<td>&lt;0.0045</td>
<td></td>
</tr>
<tr>
<td>fungi 1 vs. 3 and 4</td>
<td>1</td>
<td>15.62                     &lt;0.0001</td>
<td>5.60</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>fungi 2 vs. 1, 3, and 4</td>
<td>1</td>
<td>2822.8                    &lt;0.0001</td>
<td>8.01</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H lin × S</td>
<td>2</td>
<td>184.0                     &lt;0.0001</td>
<td>1.01</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H quad × S</td>
<td>2</td>
<td>29.06                     &lt;0.0001</td>
<td>1.24</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H lin × F</td>
<td>3</td>
<td>65.56                     &lt;0.0001</td>
<td>3.46</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H quad × F</td>
<td>3</td>
<td>18.83                     &lt;0.0001</td>
<td>0.85</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>S × F</td>
<td>6</td>
<td>19.37                     &lt;0.0001</td>
<td>1.07</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H lin × S × F</td>
<td>6</td>
<td>15.33                     &lt;0.0001</td>
<td>1.95</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>175</td>
<td>89.00                     ---</td>
<td>3.57</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>215</td>
<td>1252                      ---</td>
<td>404.1</td>
<td>---</td>
<td></td>
</tr>
</tbody>
</table>

Fungi 1: control type L (low-P); fungi 2: control type H (high-P); fungi 3: *Glomus intraradices*; fungi 4: *Glomus vesicularum*.

Table 6. Analysis of variance of the frond P concentration and the frond N concentration.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Sum of squares (millions)</th>
<th>Pr &gt; F</th>
<th>Sum of squares</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvests (H)</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H Lin</td>
<td>1</td>
<td>22.25                     &lt;0.0001</td>
<td>3.28</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H Quad</td>
<td>1</td>
<td>0.9328                    &lt;0.0001</td>
<td>0.11</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Substrates (S)</td>
<td>2</td>
<td>0.9237                    &lt;0.0001</td>
<td>0.92</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>substr 1 vs. 3</td>
<td>1</td>
<td>0.6922                    &lt;0.0001</td>
<td>0.90</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>substr 2 vs. 1 and 3</td>
<td>1</td>
<td>0.2315                    &lt;0.0001</td>
<td>0.03</td>
<td>&lt;0.0052</td>
<td></td>
</tr>
<tr>
<td>Fungi (F)</td>
<td>3</td>
<td>54.82                     &lt;0.0001</td>
<td>1.30</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>fungi 3 vs. 4</td>
<td>1</td>
<td>0.01507                   &lt;0.0072</td>
<td>0.06</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>fungi 1 vs. 3 and 4</td>
<td>1</td>
<td>1.890                     &lt;0.0001</td>
<td>1.05</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>fungi 2 vs. 1, 3, and 4</td>
<td>1</td>
<td>52.91                     &lt;0.0001</td>
<td>0.20</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H lin × S</td>
<td>2</td>
<td>4.898                     &lt;0.0001</td>
<td>0.72</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H quad × S</td>
<td>2</td>
<td>0.1021                    &lt;0.0001</td>
<td>0.09</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H lin × F</td>
<td>3</td>
<td>0.07374                   &lt;0.0030</td>
<td>0.90</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H quad × F</td>
<td>3</td>
<td>0.2989                    &lt;0.0001</td>
<td>0.31</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>S × F</td>
<td>6</td>
<td>1.174                     &lt;0.0001</td>
<td>0.24</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H lin × S × F</td>
<td>6</td>
<td>0.9284                    &lt;0.0001</td>
<td>0.39</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>H quad × S × F</td>
<td>6</td>
<td>0.7368                    &lt;0.0001</td>
<td>0.28</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>48</td>
<td>0.2218                    ---</td>
<td>0.15</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>83</td>
<td>88.85                     ---</td>
<td>8.77</td>
<td>---</td>
<td></td>
</tr>
</tbody>
</table>


Table 4: Analysis of variance of the root system spread and the frond dry weight.

Rositaly on normal watering conditions (AIR) (Table 1).

Finally, the substrate solution analysis revealed that NO3-N and NH4-N levels were low for the complete duration of the experiment, while PO4-P in solution varied from low to acceptable conditions. In general, there was little difference between treatments and mixtures for all ions shown in Table 2. At the end of the experiment, the solution pH ranged from 6.5 to 6.9, with higher values in mix 3 and lower ones in mix 1, but with no significant differences between treatments for a given substrate.

Percentage of root segments containing arbuscule. No real assessment was made on the extent of colonization during the acclimatization, but some plantlets were removed to check for the presence of the endophyte. Presence of the endophyte was noted only in mixes 1 and 2. Percent root segments colonized by VAM mainly depended on the substrate, to a lower extent on the harvest, but not on the fungal inoculation (Table 4).

Lowest values were consistently observed in mix 3 and similar patterns of VAM colonization were observed in mixes 1 and 2 (Fig. 2). In mixes 1 and 2, VAM colonization occurred rapidly during the first 6 weeks and 70% of root segments contained arbuscules after 18 weeks. In mix 3, VAM colonization was initially slow, but increased rapidly after week 12 to achieve 60% colonization at week 18. Vesicle development in all mixes remained low, with <20% of root segments containing vesicles after 18 weeks.

Effects on root growth. Root system spread mainly depended on the harvest and the substrate (Table 5). In accordance with the low value of the sum of squares, the fungi had only a small effect on root growth (Table 5). In comparing the respective treatments, there were no significant differences between mix 1 and 2 at the first harvest, but root system spread was thereafter consistently lower in mix 1 (Fig. 1). Root system spread was consistently greatest in mix 3. At the third harvest, mycorrhizal treatments generally showed values of root system spread lower than those of control type H but higher than those of control type L in each of the substrates (Fig. 1c).

Effects of frond development. According to the sum of squares values of the treatments, P concentration in fronds was mainly dependent on fungal inoculation and harvest (Table 6). It increased with time, and mycorrhizal treatments yielded lower values than
Table 7. Analysis of variance of the growth increment between the second and third harvest.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Sum of squares (millions)</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>5</td>
<td>0.3198</td>
<td>&lt;0.2065</td>
</tr>
<tr>
<td>Substrates (S)</td>
<td>2</td>
<td>38.48</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>substrat 1 vs. 3</td>
<td>1</td>
<td>36.27</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>substrat 2 vs. 1 and 3</td>
<td>1</td>
<td>2.213</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Fungi</td>
<td>3</td>
<td>19.24</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>fungi 3 vs. 4</td>
<td>1</td>
<td>0.1554</td>
<td>&lt;0.0619</td>
</tr>
<tr>
<td>fungi 1 vs. 2</td>
<td>1</td>
<td>19.08</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>fungi 1 and 2 vs. 3 and 4</td>
<td>1</td>
<td>0.0019</td>
<td>&lt;0.8338</td>
</tr>
<tr>
<td>S × F</td>
<td>6</td>
<td>3.554</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Error</td>
<td>55</td>
<td>2.353</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>63.94</td>
<td></td>
</tr>
</tbody>
</table>

Fungi 1: control type L (low-P); fungi 2: control type H (high-P); fungi 3: Glomus intraradices; fungi 4: Glomus vesiculiferum.

Frond dry weight (mg/plant) of Boston fern inoculated with Glomus intraradices (Gi) or G. vesiculiferum (Gv) in the three peat-based mixes. Measurements were made 6 weeks (a), 12 weeks (b), and 18 weeks (c) after inoculation. Noninoculated controls were of type L or H, which, respectively, had received low- and high-P fertilization. For each set of measurements, values with the same letters are not significantly different (Duncan’s multiple range test, P < 0.05).

Frond dry weight mainly depended on the harvest and the substrate (Table 5). All the interactions for this characteristic were of little importance in the model due to their low values of sum of squares. While the effect of fungi in mixes 1 and 2 (Fig. 5b) was evident after 12 weeks, this effect in mix 3 was only conclusive after 18 weeks (Fig. 5c).

The growth increment in terms of dry weight of fronds between the 12th and 18th weeks for all treatments is presented in Fig. 6. It depended mainly on substrate and fungal treatment (Table 7). Growth increment was generally lowest on mix 1 and highest on mix 3 (Fig 6). In comparison with control H and control L, mycorrhizal effects were evident in mixes 2 and 3, but not in mix 1. Growth increments in control H were significantly higher than those in mycorrhizal treatments.

In our experiment, the positive effect of endomycorrhizae on plant survival was more evident in substrate mixes 1 and 2, where there was less root aeration than in mix 3 (Table 1). Although survival of uninoculated plants in mixes 1 and 2 was good, the results nevertheless suggest that aeration is limiting in these two mixes. Barrows and Roncadori (1977) reported that poinsettia (Euphorbia pulcherrima Wind.) cuttings inoculated with a VAM fungus survived better than uninoculated controls, but that this relationship tended to disappear when culture conditions were made from more favorable for the plant.

Under our conditions, peat-based mix 3 appeared more suitable for root respiration, which, in turn, may have stimulated fern root development (Fig. 1). Stolzy et al. (1961) have demonstrated that the size of a root system generally increases with increasing oxygen availability. Root aeration may also be responsible for the relatively better survival of noninoculated plantlets in mix 3 (Table 3).

Saif (1981) stated that O concentration in the soil atmosphere generally has a stronger effect on physiological activity of mycorrhizae than on the degree of infection. He also demonstrated that soil aeration must be at a certain level before benefits from endomycorrhizal symbioses are maximized (Saif, 1981; Saif, 1983). Based on fern growth (Figs. 5 and 6), our results suggested that VAM fungi are indeed more efficient in a well-aerated substrate.

In addition to root development, soil conditions can also influence the ability of VAM fungi to infect and stimulate fern plants. In P-deficient soils, Cooper (1975, 1977) showed significant growth enhancement of various Leptosporangiate ferns by VAM. It is therefore possible that the delayed increase of VAM infection with mix 3 was due to changes in P availability (Fig. 2). Plants in mix 3 grew well during the first 12 weeks, despite relatively poor VAM colonization. This growth may have exhausted available P, thereby favoring increased VAM colonization after week 12. This colonization subsequently provided excellent fern growth (Fig. 6).

VAM colonization progresses in a sigmoid manner, similar to the growth of many biological populations (Saif, 1977; Sutton, 1973). Our data suggest that the lag phase of mycorrhizal colonization is greatly prolonged in the most-aerated substrate (mix 3). An analogous study reported that VAM in-
fection on crop plants maybe delayed if their root system is extending too rapidly (Black and Tinker, 1979). Furthermore, high P concentration in the host plant also leads to reduced VAM infection (Menge et al., 1978; Sanders, 1975), and P status seems to be the main factor determining VAM formation on plants (Moss, 1973). In light of these considerations, rapid root development (Fig. 1a) and high P concentration (Fig. 3a) in plantlets grown on mix 3 could explain the relatively few root segments containing arbuscules at first harvest (Fig. 2).

The influence of VAM on N nutrition has received little attention (Smith et al., 1985). In our experiment, mycorrhizal treatments yielded a higher frond N concentration than that in control. Depending on the substrate and the harvest, control H fronds had lower or higher N concentration than fronds of mycorrhizal plants. Under the low levels of nutrient concentration of substrate solutions, particularly N, in our experiment (Table 2), the plants would use nearly all the available N sources. The predominant form of assimilable N was the readily mobile NO\textsubscript{3}, but NH\textsubscript{4} is supposed to also be present. Furthermore, ammonium salts are readily produced during microbial digestion (Brady, 1984). However, NH\textsubscript{3} may be less available because various organic matter is known to fix ammonium into forms that are relatively unavailable to higher plants (Brady, 1984). Recent findings indicated that VAM fungi are able to assimilate NH\textsubscript{3} (Barea et al., 1987; Smith et al., 1985), but it is unlikely that NO\textsubscript{3} uptake is increased by VAM (Rhodes and Gerdemann, 1980). A contribution of VAM to plant growth may therefore include making NH\textsubscript{4} more available to the plant. Ames et al. (1984) have suggested that VA mycorrhizal plants could derive N from a source that was less available to non-mycorrhizal plants.

In terms of frond development and root growth, G. vesiculosum was more effective than G. intraradices in mix 3 only (Figs. 1c, 3c, 5c, and 6). Significant interactions between fungal strains and soil have also been reported previously (Johnson, 1977; Moss, 1972; Powell, 1982), suggesting that specific inoculants may have to be chosen for different soil types. Glomus vesiculosum seems to be more adapted to the well-aerated conditions of mix 3 than G. intraradices.

Future use of VAM fungi in greenhouse production of ferns requires potting media that are compatible with the appropriate fungus and host. Our results indicate that a brown peat-based mix can greatly prolong the lag phase of VAM colonization, as compared with a black peat-based mix. Better growth results for ferns ‘in mix 3 indicate that the brown peatmoss was more favorable for fern growth and for the physiological activity of VAM. We compared mycorrhizal treatments with two types of uninoculated controls to evaluate the growth effects of VAM on Boston fern plantlets. We observed that inoculated plantlets from P and N concentration, higher frond dry weights and a larger root system spread than uninoculated plantlets growing in the same low-P fertilization regime. These results re-emphasized the benefit of VAM inoculation to plants growing under stress conditions, such as a low-P fertilization regime. In general, for all growth characteristics tested, uninoculated plants in a P-supplemented fertilization regime grew better than the mycorrhizal treatments. It would be of interest under critical stress conditions (low air humidity, low soil moisture, and soil pathogens) to determine if the supplemented P fertilization regimen could be as effective as mycorrhizal treatments.

**Literature Cited**


Saif, S.F. 1977. The influence of stage of host

HortScience, Vol. 25(2), February 1990
Abstract. The effect of constant 16°C and noncontrolled soil temperature on flowering of four Alstroemeria cultivars grown in a greenhouse was studied over 3 years. Soil temperature regime did not influence either the start or cessation of flowering. During spring/summer, production was 15% lower under constant soil temperature, irrespective of cultivar. During fall/winter, the effect of constant soil temperature was cultivar-dependent; yield of ‘Red Sunset’ was increased by 150%, while that for ‘Rio’ decreased by 2270 relative to the noncontrolled. Annual production was not affected, but the ratio between the production of spring/summer and fall/winter decreased from 3.1 to 2.2 for noncontrolled and constant soil temperature, respectively.

Alstroemeria has developed worldwide importance as a cut flower crop due to excellent vase life, low energy growing requirement, and high productivity. Rhizomes are normally planted October through December in northern-latitude greenhouses. Production commences the following March-April and continues until June–July, when rhizomes cease to flower and produce primarily vegetative shoots. A fall flush can be expected during October-November at lat. 56°N (Powell and Bunt, 1986; Vonk Noordegraaf, 1975a). This cropping pattern usually continues for 2 to 4 years.

The control of flowering is biphasic (Wilkins et al., 1980; Vonk Noordegraaf, 1981). Plants require a cold induction treatment (thermophase) as a prerequisite to flowering. This can be fulfilled by a short (4-week) period at 5°C or by progressively longer periods at higher (16 weeks at 13°C) temperatures (Healy and Wilkins, 1982). Relatively high soil temperatures (17°C) have also been shown to induce flowering (Vonk Noordegraaf, 1975b), while 22°C stops flowering (Healy et al., 1982). The mechanism that triggers a flush once the thermophase has been fulfilled is still unclear. However, exposure to a long-day regime (photophase) induces earlier flowering production than short days (Heins and Wilkins, 1979), but does not always increase total production (Vonk Noordegraaf, 1975b).

Cessation of flowering after a flush is believed to be due to high soil temperatures, lack of plant growth substances (Heins and Wilkins, 1979; Healy and Wilkins, 1982), and/or long photoperiod (Healy and Wilkins, 1985).

Our study investigated the effects of soil temperature, maintained at an inductive level year-round, on start and cessation of flowering and total production. Flower production of four alstroemeria cultivars was compared using an uncontrolled and a constant 16°C soil temperature year-round over 3 years.

Two adjoining 50-m² computer-controlled glass greenhouses, each with four ground beds, were used. The soil of one compartment was maintained at 16°C set-point year-round by mixing and circulating either cold or warm water through 18-mm-diameter polybutylene lines; the soil temperature in the other compartment was not controlled. Soil temperatures were recorded at 15-cm depth using ‘T’ thermocouples and a Kaye Digistrip datalogger (Bedford, Mass.). In both compartments, bed areas were mulched with polystyrene beads, and the pathways were covered with straw. Air temperature was set according to commercial practices at a minimum.

Table 1. Annual yields in marketable stems/m² for noncontrolled (NST) and constant (CST) soil temperature during two seasons averaged over 3 years.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Spring/summer CST</th>
<th>Fall/winter CST</th>
<th>Annual CST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Sunset</td>
<td>144</td>
<td>24</td>
<td>168</td>
</tr>
<tr>
<td>Rio</td>
<td>120</td>
<td>64</td>
<td>184</td>
</tr>
<tr>
<td>Rosario</td>
<td>103</td>
<td>25</td>
<td>128</td>
</tr>
<tr>
<td>Rosita</td>
<td>133</td>
<td>45</td>
<td>179</td>
</tr>
<tr>
<td>Mean</td>
<td>125</td>
<td>40</td>
<td>165</td>
</tr>
</tbody>
</table>

Source

| ST × cultivar | NS |

Spring/summer (1 Apr.–30 Sept.): Fall/winter (1 Oct.–31 Mar.).

NS: Nonsignificant or significant at P = 0.05 or 0.01, respectively.