of species grew more vigorously in coarser mixes. In addition, a mix containing 50% sludge compost is a good starting point for beginning in-house experimentation.

With woody species consideration must be given to their long-term growth requirements. Therefore, fertilization would most likely be required with time. For plants which must be overwintered, coarse sand may be an appropriate substitute for perlite which tends to lose its structure over long periods of time and with freezing.

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Effects of *Glomus fasciculatum* or *Glomus mosseae* on Growth of *Liriodendron tulipifera* under High Fertility[1]

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Abstract

Liriodendron tulipifera L. seedlings were grown under greenhouse conditions and inoculated with the endomycorrhizal fungi *Glomus fasciculatum* (Thaxter) Gerdemann & Trappe or *G. mosseae* (Thaxter) Gerdemann & Trappe. Inoculated and non-inoculated plants were grown in highly fertile medium of perlite : sphagnum peat moss : loam soil (2:2:1, by volume with 120 mg/l NO_3, 53 mg/l P, 130 mg/l K, and 12 mg/l NH_4) and were watered as needed with nutrient solution (516.6 mg/l KNO_3, 367.6 mg/l NH_4NO_3, and 0.124 ml/l of 75% H_3PO_4). Both fungal species successfully promoted plant growth under these conditions, but *G. mosseae* tended to be more effective at promoting growth.

Index words: mycorrhizae, landscape plants

Introduction

Mycorrhizal fungi contribute to plant growth by expanding the root absorptive surface of the plant for uptake of soil nutrients and moisture in general, and by enhancing absorption of phosphorus. Nurserymen will be able to take advantage of this fungal-host relationship only if it can be manipulated to conform to production techniques employed for woody landscape plants.

Commercial production of woody landscape plants in containers generally employs pasteurized and/or soil-less media which may contain no mycorrhizal fungi. Under these conditions, mycorrhizal development can be expected to be considerably delayed, reduced, or absent. Mycorrhizal inoculation may therefore result in plants with accelerated growth and increased potential for establishment in the landscape.

Several reports have indicated the importance of mycorrhizal development in plant production (3, 6, 7, 12, 16, 22). These reports have generally stressed that mycorrhizal inoculation is well suited for production of plants in containers where the media is initially devoid of mycorrhizal

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fungi, and also suitable for field nursery crop production when soil phosphorus is abnormally low or when natural mycorrhizal levels have been eliminated by steam pasteurization or fumigation. Although nursery crop production in containers using sterile microbe-free media seems ideal for mycorrhizal inoculation, conventional plant production practices include use of moderate-to-high fertility levels, whereas most mycorrhizal research has been conducted under conditions of low fertility.

Gray and Gerdemann (5) found that *Glomus fasciculatum* significantly increased phosphorus uptake by tulip poplar (*Liriodendron tulipifera* L.), which indicates that mycorrhizal plants may be more competitive scavengers of phosphorus when this nutrient is limiting. Growth promotion due to mycorrhizae occurs readily under low fertility because plants have increased reliance on the fungi to absorb soil nutrients. Information on growth of mycorrhizal plants under low fertility is useful for situations such as stripmines or highway construction sites, but provides no indication of the practicality of mycorrhizal inoculation for normal production or landscape use of woody plants when soil fertility is increased.

There is evidence that minimum nutrient levels must be met before mycorrhizal promotion of growth can occur (23). This research indicated no promotion of growth of *Liriodendron tulipifera* occurred following mycorrhizal inoculation of a low fertility soil without fertilizer. However, when plants were fertilized with 2 or 4 g/l (0.07 or 0.14 oz) nitrogen as 19N-4.9P-5.2K (19-6-12) slow-release fertilizer, there were significant growth increases attributed to mycorrhizal development by *Glomus fasciculatum*. Fertilization of endomycorrhizal magnolia seedlings with slow-release fertilizer at the manufacturer's recommended rate did not inhibit a growth response (13). Johnson et al. (8) also found significant growth increases of *Podocarpus*, *Pittosporum*, and *Rhododendron* from mycorrhizae at high levels of fertilization. This information suggests that mycorrhizae may promote plant growth of certain plant species even with relatively high soil fertility. The objective of this study was to determine the effect of mycorrhizal inoculation on growth of *L. tulipifera* grown at high levels of soil fertility.

Materials and Methods

L. tulipifera seeds were stratified for 90 days at 4.4°C (39.9°F). Stratified seeds were soaked in 10% by volume HCl for 10 minutes and were sown in a medium of vermiculite:perlite (1:1, by volume) in a growth chamber at 24°C day/22°C night (75.2°F day/71.6°F night), with a 16-hour photoperiod. Seedlings 4-cm (1.6 in) tall and 30-days-old were transplanted into 3.28 l (#1) containers of medium which had been previously steam pasteurized at 121°C (249.8°F) for one hour. The growing medium consisted of perlite, sphagnum peat moss, and loam soil (2:2:1 by volume) and had a nutrient analysis of 164 mg/l soluble salts, 120 mg/l NO_3, 53 mg/l P, 130 mg/l K, 12 mg/l NH_4, and a pH of 6.2.

Plants were inoculated with *Glomus fasciculatum* or *G. mosseae* (initial source: Abbott Laboratories, Long Grove, IL), or not inoculated as a control treatment. The inoculum contained chlamydospores, hyphae, fragmented roots, and growing-medium from the previous culture of the fungus with *Lycopersicon esculentum* Mill. (tomato).

At transplanting, inoculum containing 400 spores (44,400 spores m^{-2} of container surface area) was inserted into the containers to a depth of 6 cm (2.4 in), in cores equi-distant from the plant and positioned just outside the root mass of the seedling to prevent root damage from the making of the cores. Inoculum was placed into cores to concentrate chlamydospores adjacent to roots.

Plants were transferred to a greenhouse at 24°C day/20°C night ± 3°C (75.2°F day/68°F night), with a 16 hour photoperiod and were irrigated as needed with nutrient solution containing 516.6 mg/l KNO_3, 367.6 mg/l NH_4NO_3, and solution containing 516.6 mg/l KNO_3, 367.6 mg/l NH_4NO_3, and 0.124 ml/l 75% H_3PO_4. After 16 weeks of growth, height and mycorrhizal condition of roots were determined. Roots were cleared and stained by the procedures of Phillips and Hayman (18) and the degree of mycorrhizal infection was evaluated by visually estimating the percentage of cortical cells which were infected in randomly selected roots (4, 2). Plants were arranged in a completely randomized design, and data were analyzed by analysis of variance with the Student-Newman-Keuls test of significance to determine differences between means.

Results and Discussion

Inoculation with *Glomus fasciculatum* or *Glomus mosseae* resulted in moderate mycorrhizal infection of 30–60% of root cells (Table 1). All plants appeared healthy and vigorous regardless of treatment. Inoculation with either fungal species significantly increased the height of *Liriodendron tulipifera* grown under highly fertile conditions (Fig. 1). These results are consistent with previous work by Verkade and Hamilton (23) in which mycorrhizal development increased growth of *Liriodendron* fertilized at moderate levels of N and K. However, in the present study, phosphorus also was raised to levels normally maintained during intensive container production, and significant promotion of growth by mycorrhizae still occurred.

Plants inoculated with *Glomus mosseae* tended to be taller than those inoculated with *G. fasciculatum* (Fig. 1). These results confirm those of Pope et al. (20) who observed a similar trend with *Liriodendron* and also found that inoculation with *Glomus macrocarpum* Tul. & Tul. resulted in an even greater growth promotion than either *G. mosseae* or *G. fasciculatum*. Lower fertility levels (20) may amplify the growth-promoting differential between *G. mosseae* and *G. fasciculatum* since the statistically-significant difference between the effects of these two fungal species found by Pope et al. (20) were not observed in our study. There are several reasons for variable fungal compatibility or mycorrhizal dependancy of plants (20), including plant genotype (10, 14), soil type (1), soil phosphorus (5, 14, 19, 23), and fungal species (1, 11).

Table 1. Estimate of the percentage of cortical cells infected by mycorrhizal fungi.

Treatment	% Cortical Cells Infected
Control	0–3
Glomus fasciculatum	30–60
Glomus mosseae	30–60

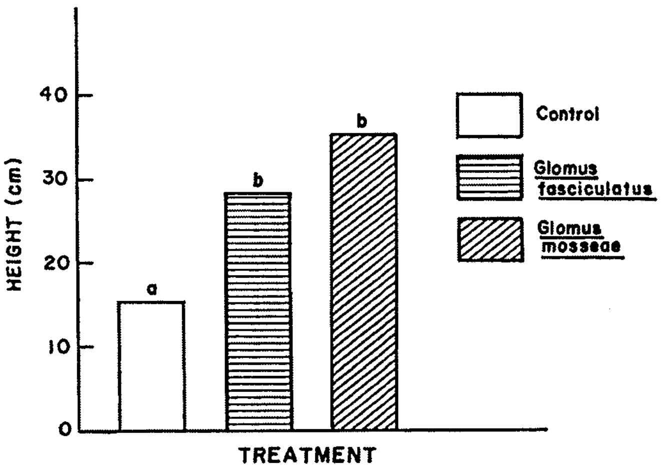

Fig. 1. **Effect of endomycorrhizal inoculation on height of *Liriodendron tulipifera* grown under high fertility. Mean separation between columns followed by the same letter are not significant using the Newman-Keuls Test at the 5% level. Means represent 12 values per treatment.**

Significance to the Nursery Industry

The results presented indicate that mycorrhizal inoculation may be feasible for production of *L. tulipifera* at levels of high soil fertility. This information is of importance to the nursery industry because use of mycorrhizal inoculation will require adaptation of production techniques, including moderate-to-high fertility. While these results indicate a potential for mycorrhizal inoculation under high fertility, the effectiveness of mycorrhizal inoculation will vary for each case depending on plant species, fungal species, and soil fertility.

Additional knowledge of the interactions of mycorrhizae with commonly-used nursery chemicals will be necessary before a mycorrhizal inoculation program can be initiated with confidence in the nursery. Primary among these is the use of fungicides. Although mycorrhizae generally are not pathogenic, they are fungi and the benefits of inoculation can be negated by the application of some fungicides. Furthermore, as more information regarding the practical and economic feasibility of mycorrhizal inoculation becomes available, nurserymen will be better able to assess which situations require mycorrhizal inoculation.

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