Mycorrhizal Fungi: Impact of Commercial Products in Nursery Propagation

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INTRODUCTION

Mycorrhizal fungi are specialized organisms that live on plant roots in a relationship that is mutually beneficial. The host plant supplies the fungus with carbohydrates produced during photosynthesis. In return, the fungus grows an extensive network into the soil, transferring water and nutrients to the roots and providing a protective environment.

Mycorrhizal fungi are very common in natural soils. They are less common in nursery growing media or in urban soils. From 2001 to 2005, our company tested commercial formulations of mycorrhizal products in nursery production and urban plantings. This article reviews trial results in plant propagation at Byland's Nurseries Ltd., Kelowna, British Columbia.

ABOUT MYCORRHIZAL FUNGI

Types of mycorrhizal fungi

"Mycorrhiza", or fungus roots, describes the association between a plant root and a specialized soil fungus. Mycorrhizal associations are prevalent in nature and found on 90 to 95% of land plants (Marx 1999).

Endomycorrhizal fungi are the most widely distributed. "Endo" refers to the fungi penetrating into the root. It cannot be seen except for some hyphae growing near feeder roots. Vesicular-arbuscular mycorrhizae (or VAM) are the most abundant and commonly associated with turfgrasses, vegetables, flowers, fruit trees, and many ornamental shrubs and trees. Over 80% of all plant species associate with a few genera such as *Glomus*. Specialized endomycorrhizal fungi are found on Ericaceous plants such as *Rhododendron*, *Vaccinium* and *Viburnum*, or on Orchidaceous plants (Peterson *et al*, 2004).

Ectomycorrhizal fungi occur on about 10% of world plants. They are found on conifer trees (*Picea* and *Pinus*) and hardwoods such as *Betula, Carya, Fagus* and *Quercus*. "Ecto" refers to the fungal growth forming a thick sheath around feeder roots. The structures of many ectomycorrhizal fungi can be seen with the naked eye and some species produce mushrooms or puffballs, including gourmet truffles and edible mushrooms such as chanterelles (Maronek *et al*, 1981).

Some plants are capable of forming both endo and ectomycorrhizal associations, for example, *Chamaecyparis, Juglans, Juniperus, Salix* and *Tilia*.

No mycorrhizal association is a situation found on a few plants typical of early ecological succession, including weeds such as Shepherd's-purse, stinkweed, bittercress, bindweed and buckwheat (Maronek *et al*, 1981).

Benefits of mycorrhizal fungi

Nutrient uptake. Mycorrhizal roots usually grow faster, are larger, and are more physiologically active than non-mycorrhizal roots. The improved nutrient uptake is more obvious in low fertility soils, "tired" land, and disturbed landscape sites (Maronek *et al*, 1981).

Mycorrhizal association improves phosphorus uptake by plant roots. The impact is greater for organic nutrient sources than for synthetic sources, indicating mycorrhizal roots can out compete soil microorganisms for phosphorus liberated from decomposing organic matter. Mycorrhizal roots also stimulate the activities of naturally occurring phosphorus-solubilizing bacteria such as *Pseudomonas putida* and *Enterobacter agglomerans*. Similar comments can be made to explain improved nitrogen uptake by mycorrhizal roots (Hamel 2004).

Disease tolerance. Mycorrhizal roots have an increased tolerance to infection by soil-borne diseases caused by *Pythium*, *Phytophthora*, *Rhizoctonia* and *Fusarium*. One level of protection comes from the secretion of antibiotics by some fungi. Another level of protection comes from the stimulation of beneficial soil microorganisms in the rhizosphere (the region in the soil around the root). Finally, there is a physical barrier on the outside of the root created by the mantle of ectomycorrhizal fungi. In all cases, prior root colonization by mycorrhizal fungi is necessary to obtain protection from soil-borne diseases (Quarles, 1999).

Stress tolerance. Mycorrhizal plants exhibit higher survival in cold temperatures and more tolerance of soil problems such as low pH or high salt content. Specific mycorrhizal fungi provide the host plant with competitive advantage in these stress situations (Trappe, 1977).

Drought tolerance is of particular interest. Mycorrhizal plants generally perform better than non-mycorrhizal plants during drought conditions. Host plants colonized by drought-adapted mycorrhizal fungi exhibit improved growth and survival during drought and more rapid recovery after rewatering, when compared to non-mycorrhizal plants (Mudge *et al*, 1987). For example, in a study with the endomycorrhizal fungi *Glomus intraradices*, maize seeds were exposed to three weeks of drought 45 to 65 days after sowing, followed by three weeks of water recovery. Mycorrhizal plants maintained higher leaf water potential during the three weeks of drought and took 50% less time than non-mycorrhizal plants to recover to the level of well-watered plants (Subramanian *et al*, 1997). Similar observations were made in another study with the fungus *Glomus deserticola* and pepper plants subjected to drought cycles (Davies *et al*, 1992).

A number of mechanisms help mycorrhizal plants overcome drought conditions. The most obvious explanation is the larger root system and increased phosphorus uptake in mycorrhizal plants, contributing to higher water uptake. However, a more important mechanism is the impact on leaf activities by maintaining stomatal opening and carbon fixation during drought periods. Finally, mycorrhizal roots are better at extracting soil water because of improved soil structure and more soil surface explored by fungi hyphae (Augé, 2004).

Recent research in nursery propagation

Rooting of Taxus. A team from the U.S. Department of Agriculture in Oregon placed propagules of *Glomus intraradices* into a rooting substrate of coarse perlite, peat moss and sand. Hardwood cuttings of *Taxus X media* 'Hicksii' were collected from previous year's growth on field-grown plants, trimmed to 15 cm length, disinfected then dipped into 1.03% IBA.

At 108 days after sticking, root mycorrhizal colonization was higher when cuttings were placed in a rooting substrate containing mycorrhizal inoculum from root fragments or fungal hyphae. At 108 and 152 days after sticking, the number of roots per cutting was significantly higher in the presence of mycorrhizal fungi when compared to control, with a similar observation for total root dry weight. For both measures, results were equal or better than using only a rooting hormone (Scagel *et al*, 2003).

Rooting of Rosa. The same team in Oregon placed 3 ml of *Glomus intraradices* inoculum into 10-cm (4-in) pots filled with 80% perlite and 20% peat. Two-node cuttings of different *Rosa* cultivars were bleach disinfected then stuck into pots with or without the inoculum. Cuttings were harvested 28 days later for measurements.

Untreated controls showed no sign of mycorrhizal colonization whereas results varied from cultivar to cultivar for cuttings rooted in inoculated media. Where root colonization did occur, results were as good or better than using a rooting hormone for percentage of rooted cuttings, number of roots per cutting and root weight per cutting. Where only rooting hormone was used, there were also plant cultivar differences in root weight per cutting (Scagel, 2001).

Flowering of Freesia. At the time of planting, the USDA team in Oregon placed mycorrhizal inoculum under corms of *Freesia X hybrida* cultivars. The inoculum was made of *Glomus intraradices* inoculated soil, hyphae and spores, and colonized *Allium* root segments. The control was a sterilized inoculum.

Results indicate that addition of mycorrhizal inoculum increased root colonization, decreased the number of days to shoot emergence and increased the number of flowers produced. Mycorrhizal plants also had larger daughter corms than non-inoculated plants. The beneficial effects were generally increased when mycorrhizal inoculum was applied in pasteurized soil (Scagel, 2003).

Rooting of junipers. A team at Laval University, Québec, placed a commercial formulation of *Glomus intraradices* into rooting media for hardwood cuttings of *Juniperus sabina* 'Blue Danube'. Presence of inoculum in the rooting media gave no significant effect during the rooting stage. However, when rooted cuttings were potted into 6-L containers, growth after one season was 50% greater for mycorrhizal plants (Trépanier and Rioux, 1997).

TRIAL RESULTS AT BYLAND'S NURSERIES

Impact on shrub growth

In July 2001, rooted liners of *Cornus alba* 'Bailhalo', *Spiraea bumaldi* 'Froebeli' and *Juniperus sabina* 'Monna' were potted in standard 1-gallon containers filled with regular growing media (75% composted conifer wood plus 25% composted plant residue, amended with standard rates of slow-release Osmocote 19-5-8 fertilizer, lime, gypsum and micro-nutrients) (B.C. Ministry of Agriculture, 2002). The trial examined variations in the growing media compared to the standard recipe. One treatment (20 plants over 4 replications) was the addition at label rate of the commercial product "Mycorise Pro Endo" containing *Glomus intraradices*.

In September 2002, fifteen months after potting, root samples were collected and analyzed for mycorrhizal colonization by an outside laboratory. Each sample was approximately 200 grams of younger roots manually removed from random locations inside the root ball of one plant.

For *Cornus*, there was a significant increase in number of roots colonized and root surface colonized when plants were grown in growing media amended with the commercial mycorrhizae product. Plants grown in the absence of inoculant had very low root colonization (see table 1).

The plants were cut at soil line, oven-dried for 24 hours and measured for top dry weight. The growth difference was not significant between control plants (40 grams per plant) and plants colonized with mycorrhizal fungi (41 grams per plant). Similar results were obtained for *Spiraea* and *Juniperus* (data not shown). Likely, there was no difference in top growth because the plants were grown under optimum fertilizer and water conditions.

Table 1. Mycorrhizal root colonization [1] and impact on top growth fifteen months after potting of *Cornus alba* 'Bailhalo' (8 root samples and 20 top samples per treatment)

Treatment	Root colonization [3]	Surface colonized [4]	Top dry weight
Regular media (control)	0.13	0.13	39.59 grams
Regular + 'Pro Endo' [2]	2.13	1.88	41.20 grams
Standard error	0.324	0.227	2.165
Significance [5]	$p<0.01$	$p<0.001$	not significant $p<0.05$

1: analysis at Premier Horticulture, Québec, www.premiertech.com
2: granular 'Mycorise Pro Endo', 1 propagule *Glomus intraradices* / gram (Premier Tech Biotechnologies, Québec)
3: percent of sub-sample roots showing colonization, 1-unit increment scale from 0 (none) to 5 (100% of roots)
4: percent space occupied by mycorrizal fungi, incremental scale from 0 (none) to 4 (100% of space)
5: for mean root colonization: $F(1,14)=19$, MSE=0.84. For mean root surface occupied: $F(1,14)=30$, MSE=0.41

Thus, mycorrhizal fungi successfully colonized the roots, yet there was no impact on top growth. So why add mycorrhizal products during nursery plant propagation? As most growers already know, top growth is only one of many factors that are important for plant health.

Impact on rooting of juniper cuttings

In September 2001, unrooted softwood cuttings of *Juniperus squamata* 'Blue Star' and *J. sabina* 'Monna' were planted in 36-cell trays with a standard rooting media (40% composted Douglas-fir, 30% perlite, 20% pumice, 10% composted plant residue). Commercial mycorrhizal products were applied at label rate, with treatments replicated four times. At intervals, 36 plants were lifted in each treatment and a count made of cuttings showing root emergence.

For 'Blue Star', after ten and twenty weeks when compared to control, using Premier's 'Pro Endo' and Root's water soluble 'endoRoots' resulted in more cuttings with roots emerging from the stem, but using Root's granular 'endoRoots' resulted in fewer cuttings with root emergence (see table 2). Results were generally similar for 'Calgary Carpet'.

Table 2. Number of cuttings showing roots for *Juniperus squamata* 'Blue Star' cuttings grown in media with various commercial formulations of mycorrhizal fungi (36 samples per treatment)

Treatment	Application rate	10 weeks	20 weeks
Regular rooting mix (control)	---	67 %	75 %
Regular + 'Pro Endo' at planting on media [1]	3.75 ml per cell	75 %	89 %
Regular + 'endoRoots' 14 days post-plant [2]	0.2 g / 50 ml / cell	72 %	92 %
Regular + 'endoRoots' mixed into media [3]	10 lbs / yd^3	33 %	78 %
Standard + 'endoRoots' at planting on media [3]	3.75 ml per cell	19 %	31 %

1: granular 'Mycorise Pro Endo', 1 propagule *Glomus intraradices* / gram (Premier Tech Biotechnologies, Québec)
2: water-soluble 'endoRoots Inoculant', six *Glomus* species, 44 dry spores and hyphae / gram (Roots Inc., MO)
3: granular 'endoRoots', six *Glomus* species, 8 spores and propagules / gram, also 3-3-4 nutrients (Roots Inc., MO)

After 20 weeks, results indicate a significant impact on number of root breaks per rooted cutting at $p<0.001$, with more roots on cuttings grown in a media amended with Premier's 'Pro Endo' and Root's water-soluble 'endoRoots' (see table 3). Average dry weight per root was significantly higher for the same treatments at $p<0.01$.

Table 3. Impact on root growth of *Juniperus squamata* 'Blue Star' cuttings grown 20 weeks in media with various commercial formulations of mycorrhizal fungi

Treatment	Application rate	Roots per cutting *	Weight per root **
Regular rooting mix (control)	---	5.29 b	2.94 grams b
Regular + 'Pro Endo' at planting on media	3.75 ml per cell	15.00 a	4.17 a
Regular + 'endoRoots' 14 days post-plant	0.2g / 50ml / cell	12.71 a	4.11 a
Regular + 'endoRoots' mixed into media	10 lbs / yd^3	4.43 b	2.35 b
Regular + 'endoRoots' at planting on media	3.75 ml per cell	0.71 b	1.23 c
Standard error		1.813	0.286

*: means followed by the same letter are not significantly different at $p<0.001$, ANOVA ($F(4,30)=10.9$, MSE=23)
**: means followed by the same letter are not significantly different at $p<0.01$, ANOVA ($F(4,30)=18.7$, MSE=0.57)

Thus, two commercial mycorrhizal products improved root emergence and root growth from unrooted cuttings, while another product resulted in poor root growth. Further trials with the same products helped clarify possibly reasons for the different results.

Impact on rooting of shrub cuttings

In July 2002, unrooted softwood cuttings of *Aronia meloncarpa* 'Autumn Magic', *Cornus alba* 'Argenteo Marginata' and *Euonymus alata* 'Compacta' were planted in 36-cell trays with a standard rooting media as described above. Treatments were the same commercial products described above for juniper cuttings, with one important difference: the application was made four weeks after sticking, thus on newly rooted cuttings. In June 2003, one year after treatments, plants were harvested to measure root colonization and dry weight.

For all plants combined, there was a significant treatment impact on top dry weigh ($p<0.001$) but not on root dry weight ($p<0.001$ ($F(3,385)=38$, MSE=0.005)). For *Aronia meloncarpa*, there was significantly more top growth for cuttings grown with Root's granular 'endoRoots' (see table 4). Similar results were obtained with *Cornus* and *Euonymus* (data not shown).

A composite sample of growing media was prepared for each treatment and analyzed for nutrient content by an outside laboratory. Results indicate nutrient content was modified by addition of Root's granular 'endoRoots' but not for the other products. The addition of Root's granular 'endoRoots' resulted in higher electrical conductivity (see E.C. in table 4), nitrate (1.09 mg/L vs. 0.37 for control), phosphate-P (5.94 mg/L vs. 4.28 for control), sulphate-S (10.6 mg/L vs. 7.5 for control) and calcium (35.4 mg/L vs. 29.1 for control).

Table 4. Impact after 12 months of commercial products applied four weeks after sticking unrooted *Aronia meloncarpa* cuttings (36 plant samples and one soil sample per treatment)

Treatment	Rate of application	Top dry weight (g)	E.C. [4] dS/m
Regular rooting mix (control)	---	0.344 b*	0.36
Regular + 'Pro Endo' spread on media [1]	3.75 ml per cell	0.321 b	0.29
Regular + 'endoRoots' drenched on media [2]	0.1 g / 25 ml / cell	0.375 ab	0.32
Regular + 'endoRoots' spread on media [3]	3.75 ml per cell	0.409 a	0.40
Standard error		0.011	

*: within treated column, means followed by the same letter are not significantly different at $p<0.05$, ANOVA
1: granular 'Mycorise Pro Endo', 1 propagule *Glomus intraradices* / gram (Premier Tech Biotechnologies, Québec)
2: water-soluble 'endoRoots Inoculant', 44 dry spores and hyphae of six *Glomus* species / gram (Roots Inc., MO)
3: granular 'endoRoots', 8 spores and propagules of six *Glomus* species / gram, 3-3-4 nutrients (Roots Inc., MO)
4: analysis at Norwest Labs, Alberta, www.norwestlabs.com, NWL samples ID 987239 to 987242

Thus, when comparing the trials with juniper cuttings and shrub cuttings, the commercial products that helped root initiation of unrooted juniper cuttings had no impact on root growth of rooted shrub cuttings. A third commercial product, Root's granular 'endoRoots', had a negative impact when applied to unrooted juniper cuttings but a positive impact on rooted shrub cuttings. This product contains a nutrient charge of 3-3-4 derived from composted poultry manure, ferrous sulfate and potassium sulfate. Possibly, the salinity charge had a negative impact on initial root emergence but a positive impact on later root growth.

Impact on growth of hosta

In October 2001, rooted cuttings of *Hosta* 'Royal Standard' were potted in standard 1-gallon containers filled with a growing media as described above, but with a different package of slow-release nutrients (13-13-13). There were five treatments comparing commercial products at label rates, each replicated over 24 containers. Plants were over wintered, grown under normal conditions in the spring, and cut at the soil line on June 26 for oven drying.

Results indicate a significant treatment impact for top dry weight at $p<0.01$ but no significant difference for root dry weight at $p>0.05$. Plants grown with Root's granular 'endoRoots' at label rate had higher root mycorrhizal colonization (86% vs. 0% for control) and significantly more top weight (4.03 grams per plant vs. 1.68 grams for control) (see table 5).

Table 5. Impact of commercial mycorrhizal products on root colonization, root dry weight and top dry weight of *Hosta* 'Royal Standard' after 8 months of growth (23 plants per treatment)

Treatment	Rate in 1-gal container	Mycorrhizal colonization [z]	Root dry weight (g)	Top dry weight (g)
Regular growing media (control)	---	10 %	5.83 a*	1.68 c**
Regular + 'Pro Endo' in media [1]	30 ml	0 %	6.25 a	1.70 c
Regular + 'endoRoots' drench [2]	0.6g / 500ml	12 %	4.98 a	1.36 c
Regular + 'endoRoots' in media [3]	15 ml	0 %	6.23 a	3.16 b
Regular + 'endoRoots' in media [3]	30 ml	86 %	6.86 a	4.03 a
Standard error			0.596	0.209

z: percent endomycorrhizal colonization of sub-sample roots, Mycorrhizal Applications Inc., Oregon
*: means followed by the same letter are not significantly different at $p<0.05$, ANOVA ($F(4,107)=31.3$, MSE=7.8)
**: means followed by the same letter are not significantly different at $p<0.01$, ANOVA ($F(4,107)=31.3$, MSE=0.96)
1: granular 'Mycorise Pro Endo', 1 propagule *Glomus intraradices* / gram (Premier Tech Biotechnologies, Québec)
2: water-soluble 'endoRoots Inoculant', 44 dry spores and hyphae of six *Glomus* species / gram (Roots Inc., MO)
3: granular 'endoRoots', 8 spores and propagules of six *Glomus* species / gram, 3-3-4 nutrients (Roots Inc., MO)

Thus, the three different commercial products increased root mycorrhizal colonization, but only one product impacted top growth. The addition of a low nutrient charge at the time of mycorrhizal inoculation may have favored root colonization and subsequent plant growth.

Impact on branching

On July 4, 2001, rooted cuttings of *Linum pernenne* 'Saphyr' were potted into standard 6-inch containers. There were five treatments of growing media amendments replicated over 21 containers. One potting mix was augmented with the commercial product 'Mycorise Pro Endo' described above.

Results indicate a significant difference between treatments at $p<0.001$. Plants grown with mycorrhizal fungi produced more branches breaking from the main stem than any of the other treatments. The impact was significant 4 weeks after potting and continued until the last rating 13 weeks after potting (see table 6). The improved branching was likely because of improved nutrition in the root zone.

Table 6. Number of branches breaking from the central stem on *Linum pernenne* at 1-month intervals after potting rooted cuttings into different growing media (21 samples per treatment)

Treatment	At 4 weeks	At 9 weeks	At 13 weeks
Regular perennial mix (control)	13.2 c *	15.9 c	21.5 c
Regular mix but no 34-0-0 no 0-45-0	7.4 c	15.2 c	22.0 c
Propagation mix with fertilizers	10.4 bc	18.3 bc	26.5 bc
Byland's regular mix with fertilizers	11.5 b	20.7 b	30.3 b
Byland's regular mix no 34-0-0 no 0-45-0 plus 'Pro Endo' in media at label rate [1]	18.2 a	30.6 a	44.9 a

*: means followed by the same letter are not significantly different at $p<0.001$, ANOVA ($F(8,190)=10.85$, MSE=21)
1: granular 'Mycorise Pro Endo', 1 propagule *Glomus intraradices* / gram (Premier Tech Biotechnologies, Québec)

Impact on post-planting survival
In April 2002, over 5000 bare-root trees were potted in 10, 15, 20 and 25-gallon standard containers with the regular potting mix, as described above. The two treatments were no inoculation (control) or manual application of a commercial product directly on the root system at the time of potting (inoculated). In July, the trees were visually rated for quality of top growth.

For all plants combined, there was no treatment impact on plant growth at $p>0.05$. Many plant genera grew well after replanting and showed no impact from inoculation (*Acer*, *Gleditsia*, *Juglans*, *Malus* and *Syringa*, data not shown). For other genera that regularly suffer losses after replanting, addition of mycorrhizal fungi generally improved survival and growth (see table 7).

Table 7. Impact of mycorrhizal inoculation at the time of tree potting evaluated 3 months later as "growing" (shoot extension), "alive" (green leaves, no growth) or "dead" (wilting, did not grow)

Tree type	Treatment [1]	Number of trees	% growing	% alive	% dead
Celtis occidentalis	Control	40	60	18	23
	Inoculated	148	86	5	9
Crataegus m. 'Snowbird'	Control	29	41	59	0
	Inoculated	122	53	47	0
Quercus ellipsoidalis	Control	19	42	42	16
	Inoculated	81	43	35	25
Sorbus aucuparia 'Skinner's'	Control	70	56	1	32
	Inoculated	92	85	1	15
Tilia cordata 'Greenspire'	Control	57	60	11	30
	Inoculated	215	75	6	19
Tilia mongolica 'Harvest Gold'	Control	40	43	18	40
	Inoculated	243	58	18	24
All trees	Control	1630	63 a *	15 a	23 a
	Inoculated	4062	65 a	12 a	23 a

1: 'Inoculated' was 125 ml applied on roots at the time of planting of 'Mycorise Pro Endo' (*Glomus i.*) or 'Mycorise Pro Ecto' (*Pisolithus t.*, *Rhizopogon* sp., *Laccaria* sp., and *Scleroderma* sp.), Premier Tech Biotechnologies
*: means followed by the same letter are not significantly different at $p>0.05$, ANOVA ($F(1,2)<1.0$, MSE>39)

Impact of rates used

In September 2002, rooted liners of *Juniperus sabina* 'Broadmoor', *Physocarpus opulifolius* 'Diablo' and *Yucca filamentosa* 'Adam's Needle' were potted in standard 1-gallon containers with regular growing media as described above. There were four treatments, replicated into 20 containers each, with variations in application rate of the commercial product "Mycorise Pro Endo". Plants were grown for one year then harvested for measurements.

Results indicate a significant difference between treatments for top dry weight at $p<0.05$ but not for root dry weight. Plants grown in a mix amended with twice the label rate had significantly more top dry weight than other mycorrhizal treatments (see table 8).

Table 8. Impact after one year of different rates of a commercial mycorrhizal product on combined growth of container-grown *Juniperus*, *Physocarpus* and *Yucca*

Treatment	Rate per 1-gal container	Root dry weight (g) *	Top dry weight (g) **
Regular media (control)	---	26.99 (SE 1.896) a	34.10 (SE 1.449) ab
Regular +'Pro Endo' ½ rate	15 ml	21.96 (SE 2.040) a	30.16 (SE 1.559) b
Regular +'Pro Endo' 1X rate	30 ml	24.55 (SE 2.037) a	33.08 (SE 1.557) b
Regular +'Pro Endo' 2X rate	60 ml	26.87 (SE 2.187) a	37.73 (SE 1.672) a

*: means followed by the same letter are not significantly different at $p<0.05$, ANOVA ($F(3,109)=1.3$, MSE=119)
**: means followed by the same letter are not significantly different at $p<0.05$, ANOVA ($F(3,109)=3.7$, MSE=69)

Root samples were analyzed at two outside laboratories to assess mycorrhizal colonization. The laboratories use different reporting methods but results are similar (see table 9).

Table 9. Root mycorrhizal colonization reported by two laboratories for samples of *Yucca filamentosa* 'Adam's Needle' (samples from 4 plants per treatment)

Treatment	Rate per 1-gal container	Root colonization at lab #1 [1]	Root colonization at lab #2 [2]
Regular media (control)	---	0 %	0
Regular +'Pro Endo' ½ rate	15 ml	41 %	2.75
Regular +'Pro Endo' 1X rate	30 ml	42 %	2.75
Regular +'Pro Endo' 2X rate	60 ml	52 %	2.50

1: % endomycorrhizal colonization of sampled roots, Soil Foodweb Inc., Oregon, www.soilfoodweb.com
2: mean of four sub-samples for percent space occupied by fungi, incremental scale from 0 (none) to 4 (100%), Premier Horticulture, Québec, www.premiertech.com

Thus, the 50% label rate was as effective as label rate for root colonization, but only the 2X rate resulted in improved plant growth.

SUGGESTED APPROACHES FOR NURSERY PROPAGATION

#1 Commit to in-house testing

There are many factors to consider with commercial use of mycorrhizal fungi. The benefits are mostly underground and often not obvious aboveground. Differences in growing media can impact plant root colonization. Different commercial formulations work best at different plant production stages.

Researchers at the University of California tested four commercial products at recommended application rates. They found significant differences between products on the growth of *Liquidambar styraciflua* rooted seedlings. They concluded that "nurseries test both the infectivity and effectiveness of mycorrhizal inoculants for the successful application of mycorrhizal technology in horticultural practices" (Corkidi *et al*, 2005).

#2 Select the mycorrhizal association appropriate for the crop

Mycorrhizal associations tend to be host-specific. Conifers and many hardwood trees associate with ectomycorrhizal fungi. Most flowers and shrubs associate with endomycorrhizal fungi. Propagators must select a commercial product matching the crop to obtain measurable benefits.

Researchers with the U.S. Department of Agriculture in Oregon examined different fungi for rooting of *Arctostaphylos uva-ursi* cuttings. They found significantly higher number of cuttings with roots and increased root growth per rooted plant where the inoculum was made of the ectomycorrhizal fungi *Lacaria laccata*. There was no measurable impact from using the endomycorrhizal fungi *Glomus intraradices* (Scagel, 2004b).

#3 Use a mixture of mycorrhizal fungi

Different species of mycorrhizal fungi have different competitive abilities. Propagators increase their chances of success by using commercial products that contain a variety of fungus species.

Researchers in Spain examined different mycorrhizal species for their impact on drought tolerance of *Lactuta sativa* (lettuce). They concluded that *Glomus deserticola* was the most efficient during drought to colonize roots, maintain plant growth and allow efficient use of water, followed by *G. fasciculatum* and *G. mosseae* (Ruiz-Lozano *et al*, 1995).

#5 Use early in plant production

Mycorrhizal associations will last as long as growing conditions allow. Using commercial products early in propagation reduces the amount of product required per soil surface and increases the time of exposure for successful root colonization.

Researchers at Pennsylvania State University inoculated annual bedding plants (*Coleus*, *Impatiens*, *Petunia*, *Salvia*, *Tagetes* and *Viola*) with *Glomus intraradices*. Inoculation at sowing required less inoculum and was generally as effective in promoting colonization than inoculation at transplanting. The best results came from inoculation at sowing and again at transplanting (Koide *et al*, 1999).

#6 Do not use on stressed or sick plants
Successful mycorrhizal colonization requires a transfer of photosynthesis materials from the plant to the fungus. Healthy plants can sustain the loss of photosynthates. For sick or dying plants, transferring resources to the mycorrhizal fungi may be enough to trigger further plant decline.

Researchers with the U.S. Department of Agriculture in Oregon placed mycorrhizal inoculum under corms of *Brodiaea laxa* 'Queen Fabiola' at the time of planting. Inoculation altered aspects of plant morphology and biomass partitioning. Many reports describe an initial lag-phase after inoculation where non-inoculated plants are larger than inoculated plants (Scagel, 2004a).

#7 Use other approaches for Ericaceous and Orchidaceous
There is currently no commercial product containing specialized mycorrhizal fungi for Ericaceous plants such as *Rhododendron*, *Vaccinium* and *Viburnum*, or for orchids. Stimulation of root growth and biocontrol of root diseases must be obtained by other methods.

Researchers at the University of Vermont colonized the roots of *Pieris floribunda* by growing seeds in peat moss. Effective root colonization with ericoid mycorrhizal fungi was obtained in ten of the 13 commercial peat products tested. The authors conclude that peat moss harvested from regions with native ericaceous plants can be used to colonize nursery plants, provided the peat contains colonized root debris or is harvested in late summer to fall (Gorman and Starret, 2003).

#8 Avoid detrimental practices
Propagators using mycorrhizal fungi must avoid over-fertilization. Mycorrhizal association is encouraged where soil phosphorus supply is adequate or low, because the fungus can mobilize soil phosphorus that is chemically bound with calcium or iron. However, when phosphorus concentration is high in plant tissue, mycorrhizal association tends to decline (Grant *et al*, 2005).

Propagators using mycorrhizal fungi must be careful with pesticide applications. Negative impact from various products depends on the type of mycorrhizal fungi. Possible inhibitory (negative) effect is greatest for pesticides applied in a soil drench rather than on the foliage, and during the first 3 weeks of root mycorrhizal colonization (Davies, 2000).

Propagators using mycorrhizal fungi must be careful with growing media composition. Different peat moss products can suppress or enhance root colonization, depending on the type of mycorrhizal fungi (Linderman and Davis, 2003).

#9 Expect most benefits to occur in the hand of the customer.
The benefits of mycorrhizal fungi seldom include increased plant growth. The benefits include improved plant nutrition in poor quality soils, reduction of root diseases in poorly-drained soils, and higher tolerance to stress situations such as transplanting, high salts, high pH or drought. Few of these conditions exist in a greenhouse or a nursery. Most of these conditions exist in landscapes and street plantings, where nursery plants are destined.

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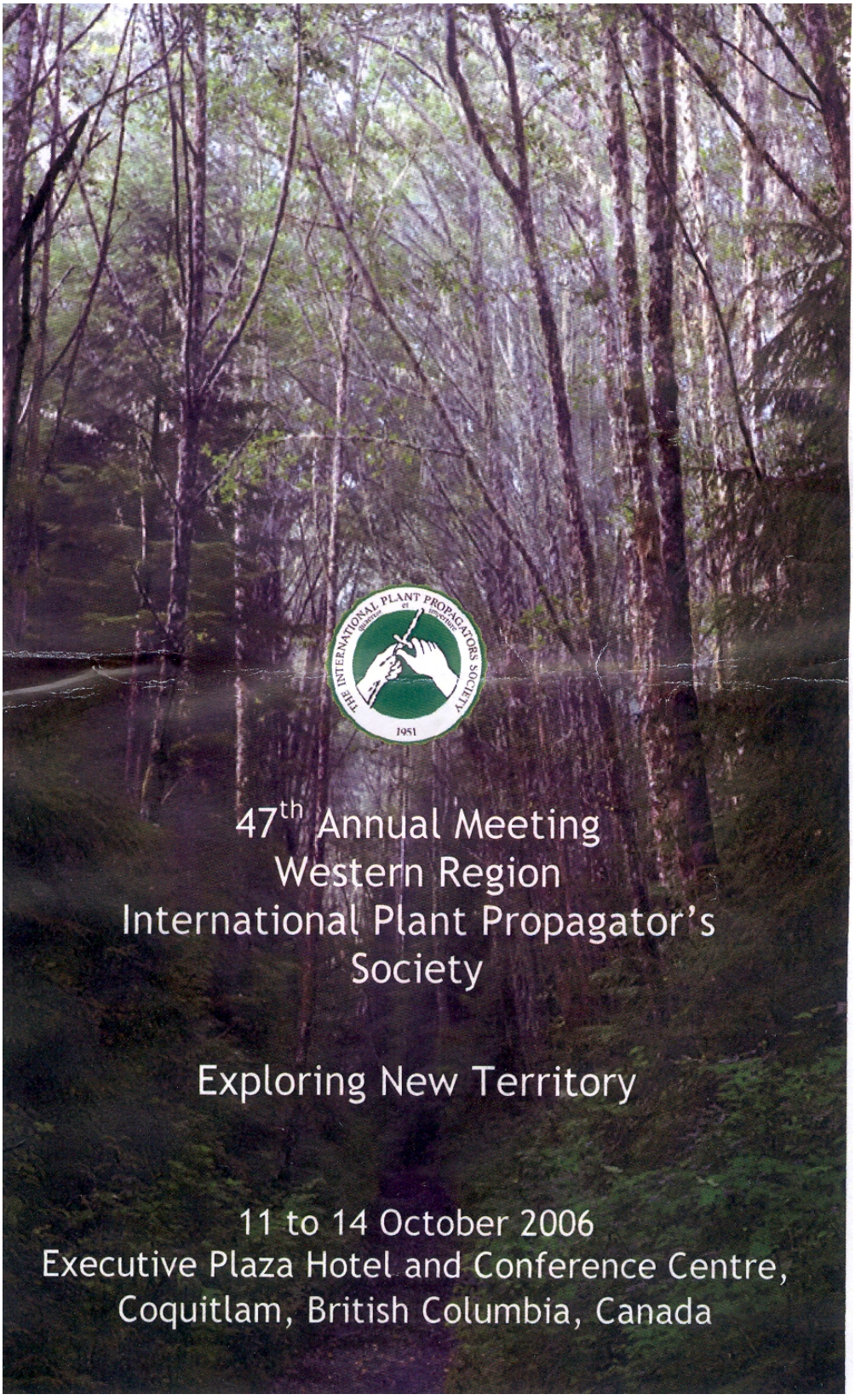

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