Changes in Root IAA Content and Growth of Bareroot Conifers Treated with Plant Growth Regulating Substances at Planting[1]

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Abstract

Growth and survival of bareroot plants after transplanting is partially a function of the plant's capacity to produce new roots. We conducted an experiment to determine whether application of plant growth regulators (PGRs) or moisture retention materials could modify IAA concentration in roots, new root growth, and above ground plant growth. Bareroot western larch, Englemann spruce, lodgepole pine, and Douglas-fir were treated with Stimroot, ethrel, Hormogel, or Alginate immediately before planting into a raised bed in a greenhouse. All treatments increased IAA content in roots of western larch, Englemann spruce, and Douglas-fir, but only treatments containing IBA increased free IAA in roots of lodgepole pine. Stimroot and Hormogel treatment increased height growth of western larch, lodgepole pine, and Douglas-fir, but only ethrel treatment increased height growth of Englemann spruce. All treatments increased stem diameter growth of western larch. Stimroot increased stem diameter growth rate of Englemann spruce and Douglas-fir, but stem diameter of lodgepole pine was unaffected by all treatments. Our results indicate that application of PGRs or other root-promoting materials to the roots of bareroot conifers before planting has the potential to be a cost-beneficial method for increasing root growth and decreasing transplant shock.

Index words: IBA, ethylene, auxin, alginate, root, transplant.

Species used in this study: Douglas-fir (*Pseudotsuga menzesii* (Mirb.) Franco.); Englemann spruce (*Picea englemannii* Parry); western larch (*Larix occidentalis* Nutt.); lodgepole pine (*Pinus contorta* Dougl.).

Chemicals used in this study: Hormogel, Stimroot, Calcium Alginic Acid, Ethephon.

Significance to the Nursery Industry

Efficient initiation and growth of roots after transplanting can increase plant survival and decrease production costs of woody landscape and nursery crops. Understanding how to maintain optimal conditions for initiation and growth of roots can increase the efficiency of nutrient and water uptake during plant production and allow plants to tolerate more stressful environmental conditions. Our study showed that application of different plant growth regulators (PGRs) or alginate to the roots of bareroot *Larix occidentalis*, *Picea englemannii*, *Pinus contorta*, or *Pseudotsuga menzesii* modified endogenous root hormone concentrations, root growth, and above ground growth of bareroot conifers. Although changes in root growth and above ground growth resulting from the different treatments were specific to the conifer species, PGR materials that stimulated increases in root IAA concentrations generally provided the best stimulation of plant growth. We also found that application of a moisture retention gel to roots can increase root growth, possibly by mechanisms associated with changes in root IAA levels. Application of PGRs to roots of conifers may increase root growth and plant quality and potentially decrease losses from root damage and stress associated with transplanting.

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Introduction

In production of woody perennials, the rapid resumption of root growth after transplanting is one of the principle processes responsible for plant establishment, growth, and survival. Transplanting bareroot plants invariably results in root damage and transplant shock that can affect the subsequent growth and survival of the plant (14). Developing methods to decrease transplant shock and increase the subsequent growth and establishment of transplants is important for increasing survival and quality of bareroot plants.

Plant growth regulators (PGRs) influence many aspects of root growth and development. Any number of factors may influence root formation, but, in most cases, the primary trigger that initiates root growth is auxin. Indole-3-acetic acid (IAA) is the natural form of auxin found in most plants. The response of plants to changes in IAA levels is dependant on absolute concentration and the amount relative to other plant growth regulators. Several researchers have applied auxins to root systems of tree seedlings (5, 6, 8, 15, 17, 24, 28, 29, 38, 41). The effect of exogenously applied auxins on root growth, however, has been variable. Kelly and Moser (17) found that root application of IBA to *Liriodendron tulipifera* increased root regeneration in both spring- and fall-planted seedlings. Struve and Moser (37) and Struve and Arnold (36) increased root regeneration of oak seedlings up to six-fold by application of auxins to roots. Simpson (33) increased lateral root production of Douglas-fir seedlings by soil drench application of auxins to seedlings. We (30, 31) found species specific responses in root growth and tree survival of container-grown Douglas-fir (*Pseudotsuga menzesii*), *Pinus contorta*, and *Picea englemannii* to application of auxins. Certain reports have also suggested similar increases in root growth of different conifer species resulting from ethylene application (13, 27, 30, 31). In contrast, Zaerr (41) and Lavender and Hermann (19) showed no effect of exogenous auxin on new root growth of conifers.

The responses of trees to plant growth regulator applications have been examined, but very little is known about changes in IAA content of tissues as a result of exogenous application of PGRs. In previous papers, we described the growth and survival of container grown conifers three years (30) and ten years (31) after application of PGRs and moisture retention gels to the roots prior to cold storage or immediately before planting. In this paper, we describe the changes in root IAA and plant growth resulting from application of PGRs to bareroot conifers just prior to planting in a greenhouse. Our objective was to answer the following questions: (1) Does exogenous application of plant growth regulators and moisture retention compounds to roots of bareroot conifers change the IAA content in roots after transplanting? (2) Do changes in root IAA content of bareroot conifers increase root growth after transplanting? (3) Do increases in root growth after transplanting increase the above ground growth of bareroot conifers?

Materials and Methods

Stock attributes and culture. The British Columbia Ministry of Forests Nursery in Surrey, B.C., Canada, provided nursery grown bareroot stock of four tree species: Interior Douglas-fir (*Pseudotsuga menzesii* (Mirb.) Franco.), Englemann spruce (*Picea englemannii* Parry), western larch (*Larix occidentalis* Nutt.), and lodgepole pine (*Pinus contorta* Dougl.). Bareroot trees (2+0) were taken from cold storage, thawed, treated, and planted in a greenhouse-raised bed containing pasteurized soil mix. Trees were grown for 4 months under conditions of 20C (72F), 18 hr days, and 16C (64F), 6 hr nights at the USDA-ARS, Horticultural Crops Research Laboratory, Corvallis, OR.

Treatments. Treatments consisted of submerging tree root systems for 10 sec either in one of Hormogel, Stimroot, ethrel, Stimroot in alginate, ethrel in alginate, or alginate. Hormogel treatment was an experimental combination of 0.5 g l^{-1} indolebutyric acid (IBA) and 0.5 g l^{-1} naphthaleneacetic acid (NAA) in a gel based carrier. Stimroot treatment consisted of a commercial preparation of IBA at 0.5 g l^{-1} applied to the roots as a powder. The combination treatment of alginate and Stimroot treatment consisted of a commercial preparation of IBA at 0.5 g l^{-1} applied to roots in a carrier of Calcium Alginic Acid (Protanal SF, Multichem Corp.). Ethrel (Wilbur Ellis Corp.), a commercial formulation of Ethephon (2-chloroethyl phosphonic acid), is a slow-release ethylene compound that was applied at 0.05 mg l^{-1} in water. The combination treatment of alginate and ethrel consisted of a commercial formulation of Ethephon applied at 0.05 mg l^{-1} in a carrier of Calcium Alginic Acid. Alginate treatment consisted of a commercial formulation of Calcium Alginic Acid.

Above ground and below ground measurements. We measured tree height and root collar diameter at planting and at harvest two weeks and four months after treatment. Stems and roots excluded from IAA analysis were subsampled and dried at 60C (152F) for 72 hr, and their weight was determined.

Samples for root growth assessment were taken from five experimental seedlings per conifer species-treatment combination (4 species × 5 treatments) 2 weeks and 4 months after planting. The percentage of the root system initiating new roots was used to estimate root growth potential. Root systems were visually divided into four sections, and the percentage of new roots estimated for each section. A ranking of 1 was given for 0–25% of roots with new white root tips, 2 for 25–50%, 3 for 50–75% and 4 for 75–100%. Total root system ranking was determined by averaging the four ratings of the root subsections. During this procedure, the percentage of root tips colonized by mycorrhizal fungi was also determined as described in Scagel and Linderman (28). Mycorrhizae formation was determined by counting the number of primary laterals on a seedling and the number that were mycorrhizal. Representative mycorrhizae were examined for Hartig net development.

IAA analyses. Samples for IAA analysis were taken from five experimental seedlings per conifer species-treatment combination (4 species × 5 treatments) 2 weeks and 4 months after planting. Immediately after harvest, samples were immersed in liquid nitrogen and then stored at –20C in the dark. All tissue was freeze dried before extraction. Extraction was performed using a modified method of Cohen et al. (9) and Miller (21), as previously described (28, 29).

Experimental design and statistical analyses. For each of the four tree species, the five treatments (control, alginate, Hormogel, ethrel, and Stimroot) were replicated 20 times in two blocks (10 plants/block) in a randomized block design. For each tree species, data were analyzed for differences within species by one-way Analysis of Variance (ANOVA) with blocking using the Statistica statistical package (35). Categorical data for estimates of new root growth were analyzed using Kruskal-Wallis ANOVA by Ranks and treatments compared to controls using the Mann-Whitney U-Test. Where necessary, data was square root transformed to equalize variances; in these cases, untransformed means are reported. Contrast analyses were used for planned comparisons of means to address the following questions: (1) Do PGR-treated plants differ from controls? (2) Do plants treated with IBA differ from plants treated with both IBA and NAA? (3) Do plants treated with an auxin differ from plants treated with an ethylene-releasing material? (4) Do plants treated with an auxin and alginate differ from plants treated with only alginate?

Results and Discussion

Comparisons between controls and PGR treatments. Root IAA concentrations are related to root formation and growth in some species (4). In our study, we modified root IAA concentrations by external application of PGR treatments containing IBA, ethylene, or NAA to roots of four different conifer species before planting. Changes in root growth and above ground growth resulting from the different treatment were specific to the conifer species.

When compared to controls, all PGR treatments increased free IAA content in roots of western larch, Englemann spruce, and Douglas-fir two weeks after planting, but only PGR treatments containing IBA increased free IAA in roots of lodgepole pine (Fig. 1E). When all four tree species were treated with PGRs containing IBA, the IAA conjugates in roots two weeks after planting were higher than those found in controls (Fig. 1F). Ethrel application also increased IAA conju-

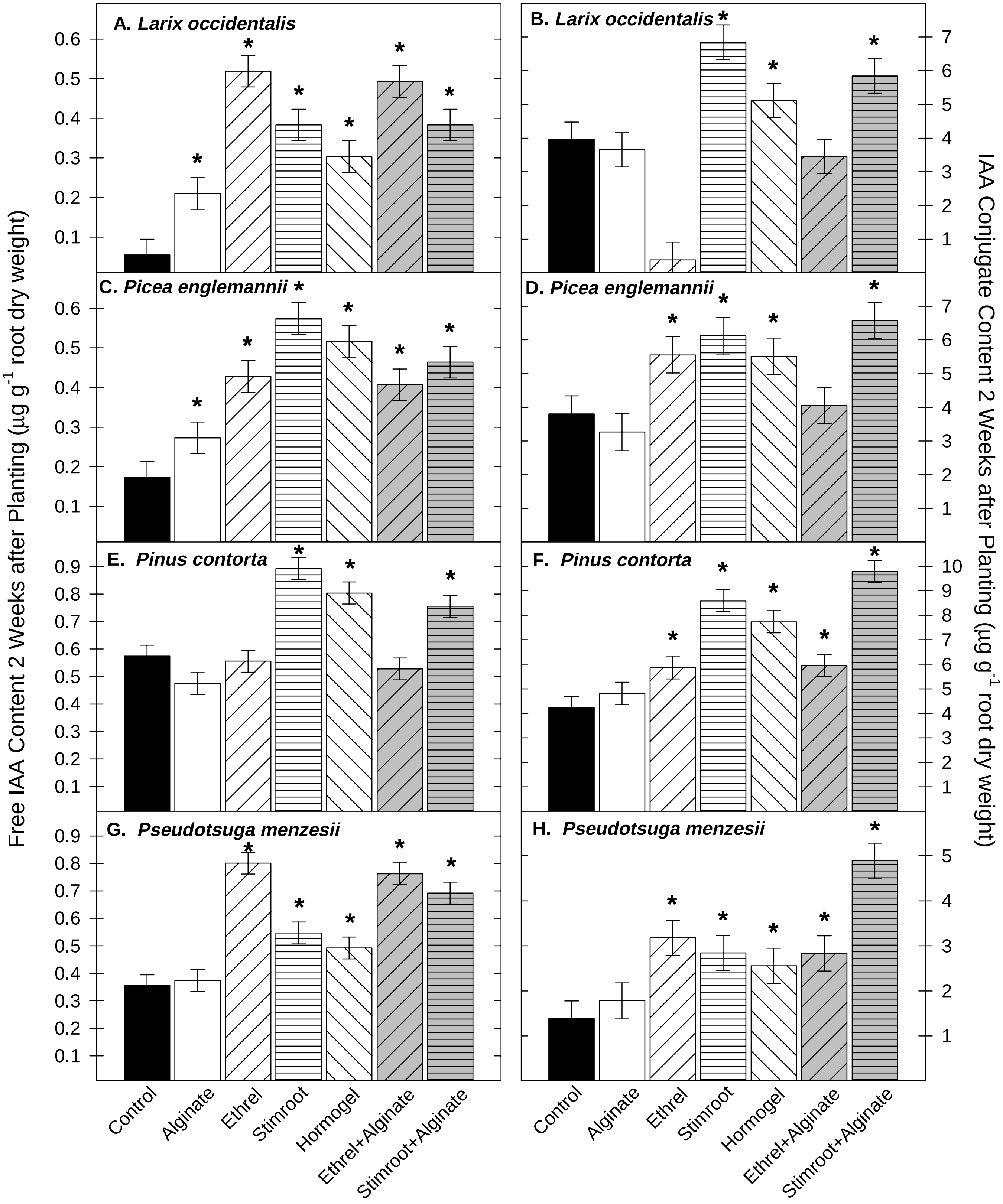

Fig. 1. **Influence of PGR treatments on IAA conjugates and free IAA in roots of bareroot conifers two weeks after PGR treatment and planting. Asterisks represent means significantly greater than control ($p < 0.05$) based on contrast analysis. Control = no treatment, Alginate = Calcium Alginic Acid, Ethrel = Ethylene, Hormogel = IBA and NAA, Stimroot = IBA.**

gates in roots of Englemann spruce (Fig. 1D), lodgepole pine (Fig. 1F), and Douglas-fir (Fig. 1H) when compared to controls. Four months after planting, levels of root IAA from western larch and lodgepole pine treated with PGRs were higher than controls for most treatments, whereas only Englemann spruce and Douglas-fir treated with Stimroot had higher levels of root IAA than controls (data not shown).

All PGR treatments increased new root growth of western larch (Fig. 2A) and Douglas-fir (Fig. 2G) two weeks after planting when compared to controls. Treatment with ethrel, Stimroot, or Hormogel increased new root growth of Englemann spruce two weeks after planting when compared to controls, but only when alginate was excluded as a carrier for the PGR (Fig. 2C). Treatment with all PGRs except Hormogel increased new root growth of lodgepole pine two weeks after planting when compared to controls (Fig. 2E). Four months after planting, new root growth of western larch (Fig. 2B), lodgepole pine (Fig. 2F), and Douglas-fir (Fig. 2H) was greater on PGR-treated trees than controls.

Stimroot and Hormogel treatment increased height growth rate of western larch (Fig. 3A), lodgepole pine (Fig. 3E), and Douglas-fir (Fig. 3G) when compared to controls, but only ethrel treatment increased height growth of Englemann spruce (Fig. 3C). When compared to controls, all PGR treatments increased diameter growth rate of western larch, Stimroot increased diameter growth rate of Englemann spruce (Fig. 3D) and Douglas-fir (Fig. 3H), and PGR treatments had little influence on diameter growth of lodgepole pine (Fig. 3F).

Different responses of tree species to PGR materials could be a result of differences in the relative initial IAA content of the trees at the time of treatment, variations in environmental conditions at the planting site, tissue sensitivity to the concentration applied (12), tissue receptivity to the type of PGR applied (25), or differences in initial tree quality. In a field trial (30), Stimroot application before planting increased the free IAA content in roots of container-grown Douglas-fir, Englemann spruce, and lodgepole pine and increased root growth and subsequent height and diameter growth during the three years after planting. We (30) found that ethrel application failed to increase free IAA content in roots but did increase subsequent height and diameter growth of plants during the three years after planting. Under the more controlled and less stressful conditions in a greenhouse, our results indicated that PGR application to roots of bareroot conifers induced similar increases in root IAA concentrations and plant growth as seen under field conditions.

The form of IAA present in root tissue also plays an important role in the regulation of root growth (16). In some species, the level of IAA conjugates is inversely correlated with growth rate (2), and the relative content of IAA conjugates and free IAA depends on the age and growth rate of root cells. Auxin available for uptake by plants is usually converted either through oxidation or conjugation (10). Conjugation of free auxin is a reversible inactivation, which allows future release of free auxin from the conjugated form (34). The results of our study showed that PGR application influenced both the IAA conjugates and free IAA in roots of treated trees, but often to a different extent. In a previous study (30), application of Stimroot, Hormogel, or ethrel before planting increased the IAA conjugates in roots of container-grown Douglas-fir, Englemann spruce, and lodgepole pine planted in a clearcut. Under more controlled and less stressful conditions in a greenhouse, our results indicated that PGR application to roots of bareroot conifers increased IAA conjugates in roots, similar to results seen under field conditions. Based on the results from this study and field trials, we believe that when screening materials for their stimulatory effects on root growth, the results obtained under controlled conditions can give researchers and growers an idea of the potential effects PGR application will have on modifying root IAA, new root growth, and subsequent above ground growth.

Comparisons of PGR applications with or without alginate. Hormone levels do not solely regulate root growth and tree survival after planting. Application of a hydrophilic gel to the root system prior to planting can increase moisture availability around the newly planted root system (18, 22) and may increase the activity of rhizosphere microbial populations or root growth-promoting substances which stimulate tree growth through mechanisms different from those associated with PGRs (23). In our study, we applied alginate and PGRs alone and in combination to assess their individual and combined effects on modifying root IAA concentrations and plant growth. Changes in root IAA, root growth and above ground growth resulting from the different alginate treatments type were specific to the conifer species.

Trees treated with alginate had similar levels of IAA conjugates in their roots as untreated control trees (Fig. 1). However, western larch and Englemann spruce treated with alginate had higher free IAA content in roots than controls, whereas free IAA concentrations in lodgepole pine (Fig. 1E) or Douglas-fir (Fig. 1G) roots were unaffected by alginate. Alginate also increased the new root growth of western larch (Fig. 2A), lodgepole pine (Fig. 2E), and Douglas-fir (Fig. 2G), but new root growth of Englemann spruce was unaffected by alginate (Fig. 2C). Height and diameter growth rate of western larch (Fig. 3A) and lodgepole pine (Fig. 3E) were greater for plants treated with alginate than controls. Douglas-fir diameter growth rate was increased by alginate application (Fig. 3H), but height and diameter growth rate of Englemann spruce were unaffected by alginate (Fig. 3C, D).

Increased free IAA content in roots of western larch and Englemann spruce could be a result of increased activity of microbes capable of PGR production in the rhizosphere (7, 28, 29). In previous studies, we (30, 31) found that application of alginate to roots increased root growth and plant survival sometimes without a concomitant increase in root IAA concentrations. This result indicates that alginate is capable of increasing root growth and survival by a mechanism not directly associated with the IAA content of the roots.

Free IAA and IAA conjugates in roots, new root growth, and height and diameter growth rate of all four tree species were unaffected or slightly decreased by combining alginate with either ethrel or Stimroot (Table 1).

In a previous field study (31), roots from trees treated with Stimroot had higher IAA conjugate and free IAA content than roots from trees treated with a combination of alginate and Stimroot. Using alginate as a carrier for the IBA-containing material decreased tree response to the Stimroot. Perhaps the alginate carrier decreased the active concentration of PGRs available to the root through increased oxidation, microbial breakdown, or enzymatic conversion. Based on the results from this study and field trials, we believe that although application of alginate alone can stimulate plant growth and increase survival, the benefits of PGR application in combination with alginate is not additive and under

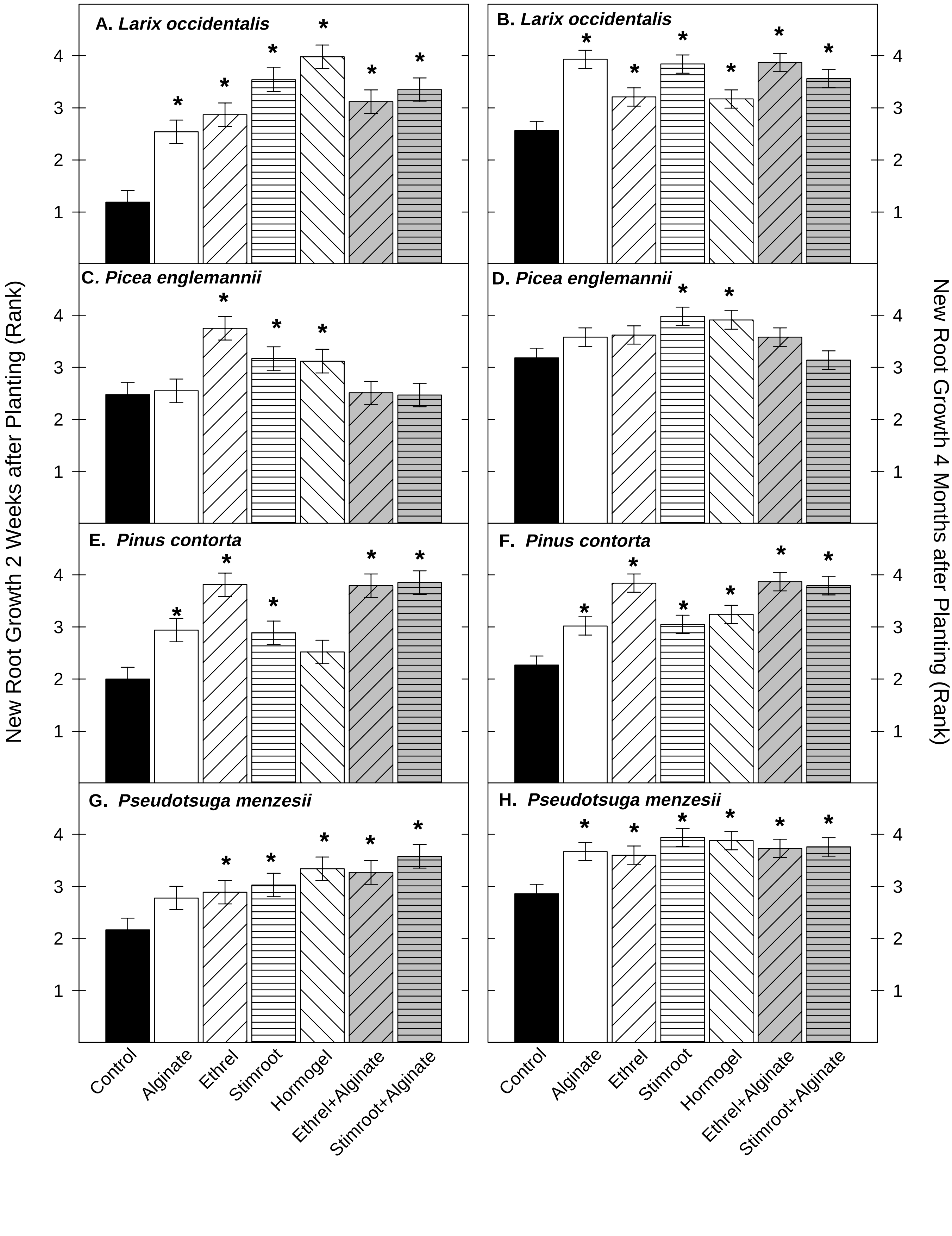

Fig. 2. Influence of PGR treatments on new root growth of bareroot conifers two weeks and four months after PGR treatment and planting. Asterisks represent means significantly greater than control ($p < 0.05$) based on Mann-Whitney U-Test. Control = no treatment, Alginate = Calcium Alginic Acid, Ethrel = Ethylene, Hormogel = IBA and NAA, Stimroot = IBA. Ranking: 1 = 0–25%, 2 = 25–50%, 3 = 50–75%, and 4 = 75–100% of roots with new white root tips.

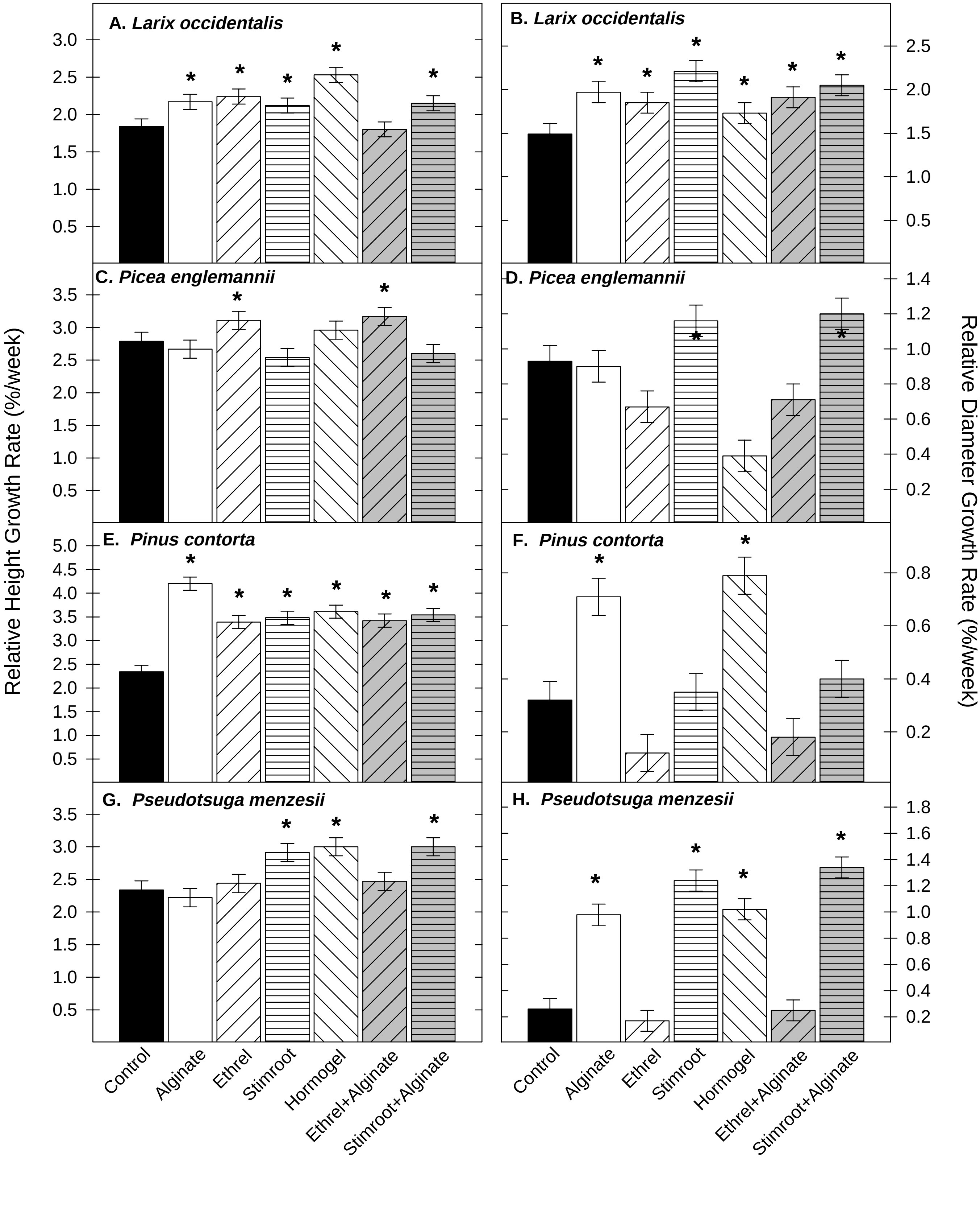

Fig. 3. Influence of PGR treatments on height and diameter growth rate of bareroot conifers during the four months after PGR treatment and planting. Asterisks represent means significantly greater than control ($p < 0.05$) based on contrast analysis. Control = no treatment, Alginate = Calcium Alginic Acid, Ethrel = Ethylene, Hormogel = IBA and NAA, Stimroot = IBA.

Table 1. Significance levels (p-values) from contrast analysis on the free IAA and IAA conjugate content of roots from bareroot larch (*Larix occidentalis*), Englemann spruce (*Picea englemanii*), lodgepole pine (*Pinus contorta*), and Douglas-fir (*Pseudotsuga menzesii*) two weeks and four months after PGR treatment and planting.[z]

	IAA content of roots[y] (μg g^{-1} root dry weight)				New root growth (Rank)		Relative growth (%/week)	
	Free		Bound					
Treatments	**2 Weeks**	**4 Months**	**2 Weeks**	**4 Months**	**2 Weeks**	**4 Months**	**Height**	**Diameter**
Larch								
Stimroot vs Ethrel[x]	0.000	0.000	0.000	0.000	0.000	0.000	0.826	0.000
Stimroot vs Hormogel	0.027	0.189	0.005	0.004	0.002	0.295	0.947	0.000
Stimroot vs Stimroot + Alginate	0.088	0.075	0.035	0.141	0.262	0.000	0.197	0.447
Ethrel vs Ethrel + Alginate	0.003	0.000	0.000	0.000	0.339	0.000	0.640	0.101
Englemann Spruce								
Stimroot vs Ethrel	0.000	0.000	0.000	0.000	0.000	0.000	0.177	0.642
Stimroot vs Hormogel	0.002	0.007	0.004	0.003	0.000	0.051	0.470	0.487
Stimroot vs Stimroot + Alginate	0.000	0.050	0.034	0.000	0.737	0.009	0.884	0.259
Ethrel vs Ethrel + Alginate	0.230	0.324	0.018	0.012	0.001	0.000	0.495	0.741
Lodgepole Pine								
Stimroot vs Ethrel	0.000	0.000	0.000	0.003	0.000	0.000	0.132	0.306
Stimroot vs Hormogel	0.002	0.000	0.003	0.012	0.129	0.000	0.818	0.573
Stimroot vs Stimroot + Alginate	0.000	0.000	0.000	0.181	0.000	0.000	0.779	0.127
Ethrel vs Ethrel + Alginate	0.323	0.587	0.034	0.006	0.001	0.129	0.149	0.319
Douglas-fir								
Stimroot vs Ethrel	0.000	0.000	0.000	0.000	0.345	0.478	0.933	0.053
Stimroot vs Hormogel	0.031	0.004	0.024	0.029	0.706	0.000	0.959	0.636
Stimroot vs Stimroot + Alginate	0.000	0.021	0.000	0.000	0.028	0.000	0.942	0.994
Ethrel vs Ethrel + Alginate	0.111	0.236	0.006	0.011	0.000	0.515	0.355	0.840

[z]Significance levels (p-values) comparing PGR types.

[y]Free = Free IAA, Bound = IAA Conjugates.

[x]Alginate = Calcium Alginic Acid, Ethrel = Ethylene, Stimroot = IBA, Hormogel = IBA + NAA.

certain conditions may decrease the potential benefits from PGR application.

Comparisons between ethrel and Stimroot. Stimulation of root growth by application of ethrel as a source of ethylene has been reported previously (1, 3, 13, 30). In some plants, ethylene has been found to enhance tissue sensitivity to auxin (39). In our study, we compared the root IAA content and plant growth responses of trees treated with ethrel, a slow release ethylene compound, or Stimroot, an auxin containing material. Changes in root IAA, root growth and above ground growth resulting from ethrel or Stimroot treatment were specific to the conifer species. Roots of ethrel-treated western larch had higher free IAA content than plants treated with Stimroot, but IAA conjugates and new root growth was higher in plants treated with Stimroot than plants treated with ethrel (Table 1). Roots of Stimroot-treated Englemann spruce and lodgepole pine had higher free IAA and IAA conjugates than plants treated with ethrel, but root growth and height growth rate were greater for plants treated with ethrel than plants treated with Stimroot (Table 1). Roots of ethrel-treated Douglas-fir had higher free IAA and IAA conjugates than plants treated with Stimroot, but new root growth was similar for plants treated with ethrel and Stimroot (Table 1).

Scagel and Linderman (30, 31), reported that exogenously applied ethrel influenced root initiation indirectly by increasing levels of free IAA in roots, a phenomenon generally reported only for plants exposed to extreme stress from flooding (40). These results may explain the earlier results (1, 3, 13) that reported exposure of seedling roots to relatively low levels of ethylene gas stimulated root growth. Although our results showed that ethrel generally failed to stimulate diameter growth, longer-term field trials (30, 31) indicated that ethrel application increase diameter growth and survival of Englemann spruce and lodgepole pine. Based on the results from this study and field trials, we believe that the mechanisms through which application of Stimroot or ethrel to roots of conifers increase root IAA and plant growth are similar, but have distinct species and environmental differences that warrant further study.

Comparisons between Stimroot and Hormogel. The effects of PGR application on root growth are often a function of the concentrations and forms of PGR applied (12). In our study, we compared the root IAA content and plant growth responses of trees treated with Stimroot, a material containing 500 ppm IBA, or Hormogel, a material containing 500 ppm IBA and 500 ppm NAA. Changes in root IAA, root growth and above ground growth resulting from Hormogel or Stimroot treatment were specific to the conifer species. Western larch treated with Stimroot had higher free IAA and IAA conjugates in roots than plants treated with Hormogel, however new root growth two weeks after planting and height growth rate were higher in plants treated with Hormogel than plants treated with Stimroot (Table 1). Englemann spruce, lodgepole pine, and Douglas-fir treated with Stimroot had higher free IAA and IAA conjugates in roots than plants treated with Hormogel, however new root growth and plant

Table 2. **Probability values (p) for correlations between root IAA concentrations and growth parameters of bareroot conifers two weeks and four months after PGR treatment.**

Species	Parameter	IAA content of roots[z]		New root growth	
		Free	Bound	2 Week[y]	4 Month
Larch					
	Bound IAA	0.124			
	New root growth				
	2 Weeks	0.075	0.000		
	4 Months	0.005	0.348	0.000	
	Relative growth rate				
	Height	0.017	0.086	0.000	0.484
	Diameter	0.629	0.000	0.103	0.353
Englemann Spruce					
	Bound IAA	0.000			
	New root growth				
	2 Weeks	0.488	0.012		
	4 Months	0.796	0.099	0.000	
	Relative growth				
	Height	0.313	0.103	0.026	0.000
	Diameter	0.878	0.771	0.000	0.472
Lodgepole Pine					
	Bound IAA				
	2 Weeks	0.000			
	New root growth				
	2 Weeks	0.196	0.809		
	4 Months	0.036	0.921	0.091	
	Relative growth				
	Height	0.498	0.336	0.032	0.431
	Diameter	0.318	0.766	0.000	0.185
Douglas-fir					
	Bound IAA				
	2 Weeks	0.000			
	New root growth				
	2 Weeks	0.000	0.000		
	4 Months	0.756	0.061	0.000	
	Relative growth				
	Height	0.383	0.441	0.291	0.025
	Diameter	0.099	0.832	0.110	0.720

[z]Free = Free IAA, Bound = IAA Conjugates.

[y]2 Weeks = two weeks after planting, 4 Months = four months after planting.

height and diameter growth were similar between the two treatments (Table 1).

Scagel and Linderman (30), showed Hormogel application to container-grown Englemann spruce, lodgepole pine, and Douglas-fir failed increase root growth to the same extent as Stimroot application and actually decreased survival of transplanted conifers. Although auxin is required to induce roots on cuttings, it can also inhibit the extension and emergence of root primordia and root growth (11). We believe that under certain conditions the concentration of Hormogel applied to the plants may have been inhibitory to root growth. Another possibility is the gel carrier used in Hormogel may have had a similar effect as alginate on the active concentrations of PGRs in the root zone.

Relationship between root IAA content, new root growth, and above ground growth. Some researchers (20, 26) believe root initiation and growth is not the sole predictor of seedling quality and survival after transplant. In our study, we looked for relationships between root IAA content, root growth, and above ground plant growth. Changes in root IAA concentrations related to changes in root growth and above ground growth were specific to the conifer species. The free IAA content in roots of western larch two weeks after planting was correlated with new root growth and plant height growth rate (Table 2). IAA conjugates in western larch roots correlated with new root growth two weeks after planting and diameter growth rate (Table 2). The free IAA content in roots of Englemann spruce two weeks after planting was related to new root growth but was correlated to height growth rate (Table 2). IAA conjugates in roots of Englemann spruce correlated with new root growth and height growth rate (Table 2). The free IAA content in roots of lodgepole pine two weeks after planting was correlated with new root growth four months after planting and diameter growth rate (Table 2). IAA conjugates in roots of lodgepole pine were not related to new root growth but correlated with height growth rate (Table 2). IAA conjugates and free IAA content in roots of Douglas-fir two weeks after planting was correlated with new root growth two weeks after planting and height and diameter growth rate (Table 2). New root growth two weeks after planting correlated with height and diameter growth in all tree species except Douglas-fir (Table 2).

In field trials, we (30, 31) examined correlations between root IAA content, new root growth, and height and diameter growth. We found that IAA content in roots of container-grown Douglas-fir and Englemann spruce correlated to new root growth, and above ground growth, whereas IAA content in roots of lodgepole pine was poorly correlated to root growth and above ground growth. We believe that field studies have a better a potential for finding a high correlation between root IAA and plant growth because the less controlled environment in the field study increases the trees' dependence on new root growth to decrease transplant shock.

This study confirms the validity of applying root growth stimulating compounds to increase the growth of trees after planting. The results presented here were similar to those resulting from field trials (30, 31) and inoculation of trees with ectomycorrhizal fungi possessing differential capability to produce IAA and ethylene (28, 29). Rhizosphere microorganisms, such as ectomycorrhizal fungi, are known to produce plant growth regulators (PGRs), including IAA and ethylene, and can influence morphological changes in root growth of conifers (28, 29). With refinement, treatment of plants with either PGR materials or inoculation with PGR-producing or -inducing fungi or bacteria (7) can easily be incorporated into horticultural practices. Although the results of this study, and the results reported in Scagel and Linderman (30, 31), indicate plant response to PGR treatment varies based on plant species, and environment, we believe PGR application can be refined with regard to adjusting concentrations and timing to reduce some of the variability.

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