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Growing conifer seedlings in woodwaste-sewage sludge compost

by
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ABSTRACT

Seedlings from Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), lodgepole pine (*Pinus contorta* Dougl.), white spruce (*Picea glauca* (Moench) Voss), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and sub-alpine fir (*Abies lasiocarpa* (Hook.) Nutt.) were grown in sewage sludges or woodwaste-sewage sludge composts. In most cases, seed germination, seedling shoot and root growth, and general quality were not as good as for seedlings grown in the 3:1 limed peat-vermiculite mix presently used by forestry nurseries in British Columbia. Changes to nutrient regimes and addition of inert materials, such as vermiculite, should enable high-quality conifer seedlings to be produced for reforestation projects.

ACKNOWLEDGEMENTS

Woodwaste-sewage sludge composts were provided by the Waste Management Branch, B.C. Ministry of Environment. Technical assistance of Mr. K. Odlum, formerly of the Research Branch, B.C. Ministry of Forests, is greatly appreciated. Earlier drafts were reviewed by Dr. L.F. Ebell and Dr. C. Leadem, both of the Research Branch, B.C. Ministry of Forests.

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INTRODUCTION

Sludges produced by sewage treatment facilities have, in the past, been considered only as disposable wastes. Recently, numerous trials have shown sewage sludges to be a valuable resource to agriculture as well as forestry.

Two major areas of sewage-sludge use open to the forest industry include: sewage sludge as a forest fertilization alternative (Berry and Marx 1977; Cooley 1982; Domenowski 1980; Edmonds and Cole 1980; Koterba et al. 1979; Moza et al. 1979; Lepp and Eardley 1978); and woodwaste-sewage sludge composts as organic amendments for bareroot nursery soils (Govin 1977; Govin et al. 1978; Lepp and Eardley 1978; Korcak et al. 1979) or as growing media for containerized seedlings (Hoitink and Poole 1980; Krapfenbauer et al. 1981; Sanderson and Martin 1974).

Application of sewage sludges to forest land is presently limited to situations where the forests to be used as dumping sites are reasonably close to the source of sludge. The $2500 - 7500 /ha^{-1} estimated cost of fertilization with sewage sludge (Domenowski 1980) cannot be recovered by increased wood production (Edmonds and Cole 1980). For this reason, sewage sludge cannot be considered a cost effective alternative to chemical fertilizers unless the application costs are borne by the sludge producer as a sludge disposal cost.

Sewage sludges, and in particular, woodwaste-sewage sludge composts can be successfully added to nursery soils as an organic amendment. As the $6.35/m^{-3} cost (Stevens 1980) of woodwaste-sewage sludge compost is considerably less than the $24.20/m^{-3} paid for peat moss on average (J. Maxwell, pers. comm., B.C. Min. Forests, Silviculture Br., Surrey, B.C.) considerable annual savings could be made on the purchase of approximately 8000 m^{-3} of peat moss for Ministry of Forests nurseries.

Growing conifer seedlings directly in woodwaste-sewage sludge compost has been demonstrated, and if the cost or supply of the presently used standard limed peat-vermiculite mix should become limiting, woodwaste-sewage sludge composts may be alternative growing media for production of seedlings. The number and quality of seedlings produced by a container nursery can be greatly affected by the growing medium used, and it is therefore important to carefully evaluate any new growing media.

This experiment demonstrates that conifer seedlings can be grown in woodwaste-sewage sludge composts, and evaluates the growth and final quality of those seedlings relative to the standard limed peat-vermiculite mix used in forestry nurseries in British Columbia.

MATERIALS AND METHODS

Experiment 1

Seed to produce 600 germinants of white spruce (Picea glauca (Moench) Voss), lodgepole pine (Pinus contorta Dougl.), Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), and western hemlock (Tsuga heterophylla (Raf.) Sarg.), as well as 200 germinants of sub-alpine fir (Abies lasiocarpa (Hook.) Nutt.), was obtained from the B.C. Ministry of Forests Seed Centre in Duncan, B.C. (Table 1). The seed from each species was divided into 12 lots (four for sub-alpine fir), each estimated (from the most recent germination test results) to contain 50 viable seeds. The seed was stratified for 21 days at $+4^{o}C$ after soaking in distilled water for 24 hours and surface-drying.

TABLE 1. Origin of seedlots

Species	BCMF seedlot	Latitude (N°)	Longitude (E°)	Elevation (m)
White spruce	2658	54.4	126.3	824
Lodgepole pine	1806	52.4	122.7	945
Western hemlock	1837	55.2	127.7	701
Douglas-fir	1029	49.2	121.3	518
Sub-alpine fir	3334	49.2	115.7	1425

Four growing media (three woodwaste-sewage sludge composts [Growrich, PE-60, and CORD] and a standard limed 3:1 peat-vermiculite mix) were passed through a 5-mm sieve prior to being placed into 30 x 60 x 10-cm cedar flats. Three flats of each medium were prepared. The stratified seed was sown in rows so that each flat contained a row of each species, except that only one flat of each medium had a row of sub-alpine fir seed. The seed was covered with a 3- to 4-mm layer of granite grit and misted daily in a greenhouse maintained between 15 and 30°C.

To assess germination the number of germinants in each row was counted at frequent intervals until 60 days after sowing.

During the growing periods -- 116 days for Douglas-fir and lodgepole pine and 229 days for subalpine fir, white spruce, and western hemlock -- the flats were kept in a greenhouse maintained above 15°C. Supplemental light was provided by 400-W mercury vapour lamps which extended the natural photoperiod to 16 hours with a minimum of 35-μmoLm^{-2}S^{-1} photosynthetically active light. Soluble fertilizers were applied as 10-52-17 (N-P-K) at 750 mg L^{-1} twice weekly for three weeks, beginning after germination was complete. For the remaining growth period, 20-20-20 at 600 mg L^{-1} twice weekly and Fe_2SO_4 at 150 mg L^{-1} fortnightly were applied. All fertilizers were applied until the media were saturated and run-off occurred.

Shoot length of 20 individuals in each row was measured at 90 days and either 116 or 229 days since sowing. Shoot dry masses were determined on a bulked sample of all surviving seedlings.

Data were subject to analysis of variance (ANOVA) and multiple range testing where appropriate, with programs provided by the SAS Institute Inc., Cary, N.C.

Experiment 2

Stratified Douglas-fir and lodgepole pine seed was sown, two seeds per cavity, in styroblocks having 240 cavities 2 cm in diameter and 11 cm in depth (PSB 211). For both species, two styroblocks of the eight growing media being tested were sown (Table 2), and then randomly arranged in two blocks in an

TABLE 2. Growing media characteristics[a]

Media	Source	pH	Cation exchange capacity (meq 100 g^{-1})	Organic %	N (%)	P ($\mu g\ g^{-1}$)	K (meq 100 g^{-1})	Ca (meq 100 g^{-1})	Mg (meq 100 g^{-1})
Standard Peat-vermiculite[b]	Sunshine Peat and Horticultural grade vermiculite (3:1)	4.59-5.11	106	54	.46	331	2.25	31.67	20.21
CORD	Septic tank pumpings from Kelowna area composted with woodwaste	4.76-4.88	69	55	1.30	660	2.78	21.97	2.29
PE-60	Kelowna treatment plant sludge composted with woodwaste	5.18-5.21	46	28	.74	738	2.47	17.37	4.23
GVRD	Vancouver treatment plant sludge composted with woodwaste	4.40-4.71	32	24	.76	802	1.18	4.38	1.42
Vancouver sludge	Vancouver treatment plant sludge	4.59-4.75	20	11	.62	635	1.30	3.78	1.15
CORD-vermiculite	CORD compost and horticultural grade vermiculite (3:1)	4.82-4.85	61	45	1.18	595	2.02	20.8	3.47
PE-60-vermiculite	PE-60 compost and horticultural grade vermiculite (3:1)	5.18-5.23	43	27	.70	583	1.99	15.09	4.12
VS-vermiculite	Vancouver sludge and horticultural grade vermiculite (3:1)	4.75-4.93	19	10	.61	645	1.26	4.11	1.64

a All media were screened to pass a 5 mm sieve.
b The standard medium contained 3 Kg m^{-3} of 12 mesh and finer dolomitic lime.

unheated polyethylene-covered greenhouse. Seed germination, as a percentage of viable seed sown, was assessed at 2-day intervals between 12 and 28 days after sowing. Greenhouse air temperature during germination maintained between 15 and 25° with extremes of 10 to 30°C.

Between 4 and 7 weeks after sowing, all seedlings were fertilized twice weekly with 750 mg L^{-1} 10-52-17; between 7 and 14 weeks after sowing, three times weekly with 600 mg L^{-1} 20-20-20; and between 14 and 20 weeks after sowing, twice weekly with 750 mg L^{-1} 10-52-17. Iron was added fortnightly throughout the experiment as 150 mg L^{-1} Fe_2SO_4.

From germination until 14 weeks after sowing, six 150-W incandescent lights suspended 1.5 m above the seedlings were used to provide 18-hour photoperiods. Photoperiods after 14 weeks from sowing declined from 14 hours (Sept. 29, Victoria, B.C.).

To monitor shoot growth during the growing period 25 germinated seedlings in each styroblock were measured at approximately 1-week intervals between 7 and 17 weeks after sowing. At 20 weeks from sowing (mid-November), 25 seedlings were removed from each styroblock and used to determine shoot and root morphology. Each seedling used for the morphologic measurements was rated according to whether a root plug suitable for planting had been formed. The rating was subjective, but considered how well the plugs held their shape when dropped on the floor from a height of 1 m.

Eight seedlings from each styroblock were placed into +2°C cold storage for 90 days in mid-November. After the storage period, a 1-week root regeneration potential test was conducted. The method used to measure root regeneration was similar to that described by Burdett (1979), except that the number of new roots greater than 10 mm was recorded rather than his ranking scale being used.

Data were subject to ANOVA, with programs provided by the SAS Institute Inc., Cary, N.C. Treatment means were tested for significance at p 0.05 using Duncan's multiple range tests available from SAS.

RESULTS

Experiment 1

Generally, seed sown in the woodwaste-sewage sludge media had lower germination counts (Figures 1-5). Only lodgepole pine sown in Growrich, a commercial product made with sewage sludge from the Greater Vancouver Regional District (GVRD) sewage treatment facility, had significantly fewer germinants than when sown in the standard limed peat-vermiculite medium (Figure 6). Germination of the species with larger seed (Douglas-fir and sub-alpine fir) was not as adversely affected by the growing medium as were the species with smaller seed. Germination rate of white spruce and western hemlock, indicated by the slope of the linear portion of the germination curves (Figures 2 and 3), was not adversely affected by growing medium. Data were unavailable for the other species. There was no indication of a delay in germination with any medium; in fact, western hemlock began germinating sooner in Growrich than it did in the other media.

In all species, except sub-alpine fir, shoot length after 90 days (shaded portions) was greatest in the peat-vermiculite treatments (Figure 7). After 116 days, lodgepole pine and Douglas-fir seedlings grown in peat-vermiculite had reached a height large enough (150 - 200 mm) to be used for field planting. Shoot dry weights of seedlings harvested at this time (Figure 8) show that the peat-vermiculite medium produced the heaviest lodgepole pine and Douglas-fir seedlings. After 229 days from sowing, the white spruce, western hemlock, and sub-alpine fir seedlings were harvested. As with the species harvested after 116 days, the peat-vermiculite medium produced seedlings with the tallest and heaviest shoots. Of the three woodwaste-sewage sludge media tested, Growrich seems to produce larger seedlings than the PE-60 or CORD media. Because the seedlings were grown in undivided flats, root systems were extensively intertwined, and thus no measurement of root dry weight was attempted.

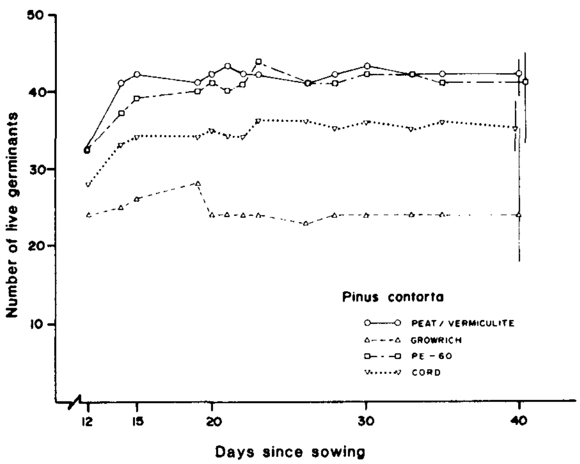

FIGURE 1. Germination curves of Pinus contorta seed sown in three woodwaste-sewage sludge composts and the standard peat-vermiculite growing media. 95% confidence intervals are indicated around the mean of three replications.

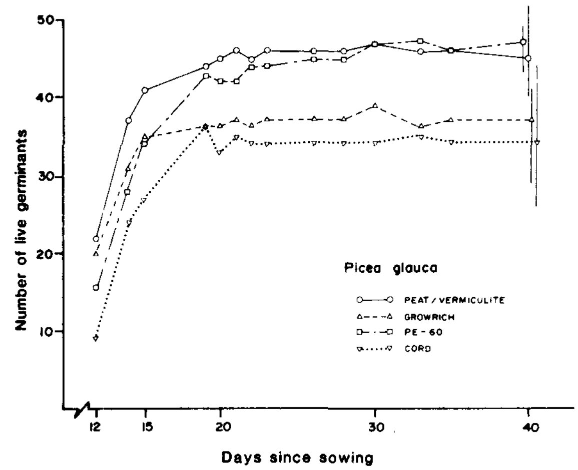

FIGURE 2. Germination curves of Picea glauca seed sown in three woodwaste-sewage sludge composts and the standard peat-vermiculite growing media. 95% confidence intervals are indicated around the mean of three replications.

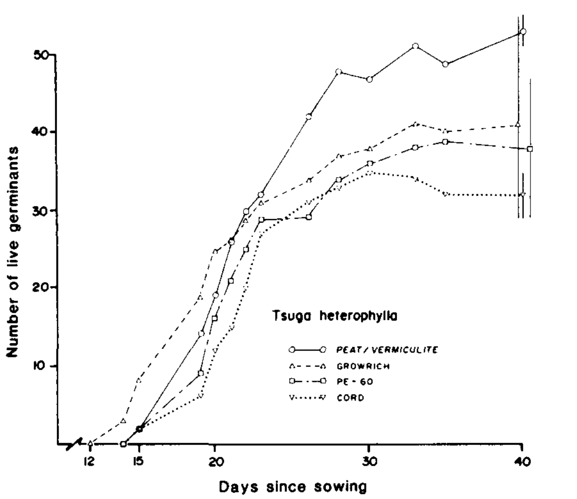

FIGURE 3. Germination curves of Tsuga heterophylla seed sown in three woodwaste-sewage sludge composts and the standard peat-vermiculite growing media. 95% confidence intervals are indicated around the mean of three replications.

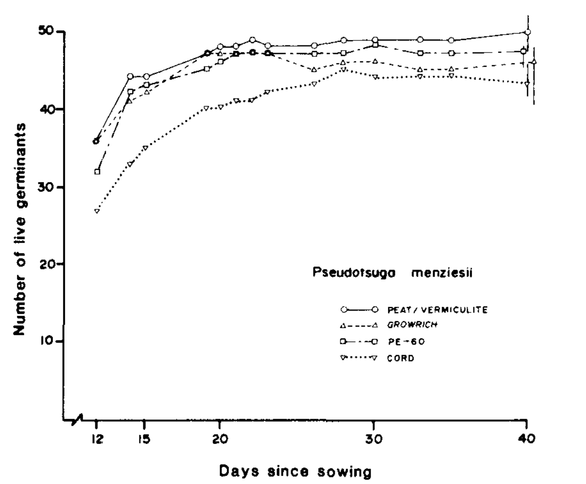

FIGURE 4. Germination curves of Pseudotsuga menziesii seed sown in three woodwaste-sewage sludge composts and the standard peat-vermiculite growing media. 95% confidence intervals are indicated around the mean of three replications.

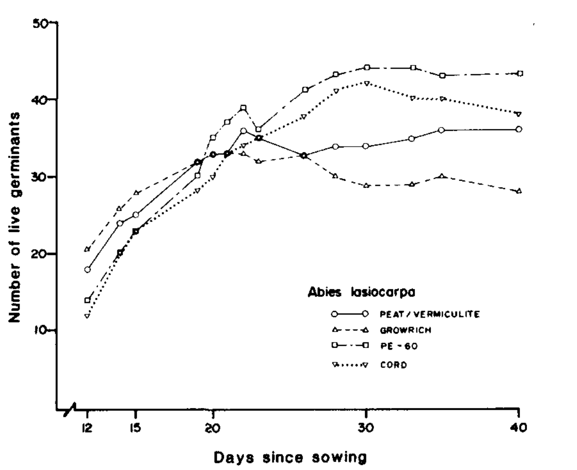

FIGURE 5. Germination curves of Abies lasiocarpa seed sown in three woodwaste-sewage sludge composts and the standard peat-vermiculite growing media.

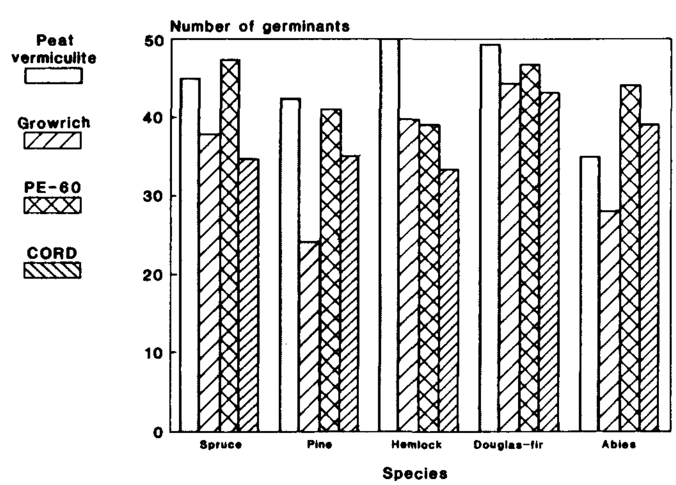

FIGURE 6. Growing media effects on seed germination. Total seed germination of five conifer species in Figures 1 to 5 after 40 days from sowing.

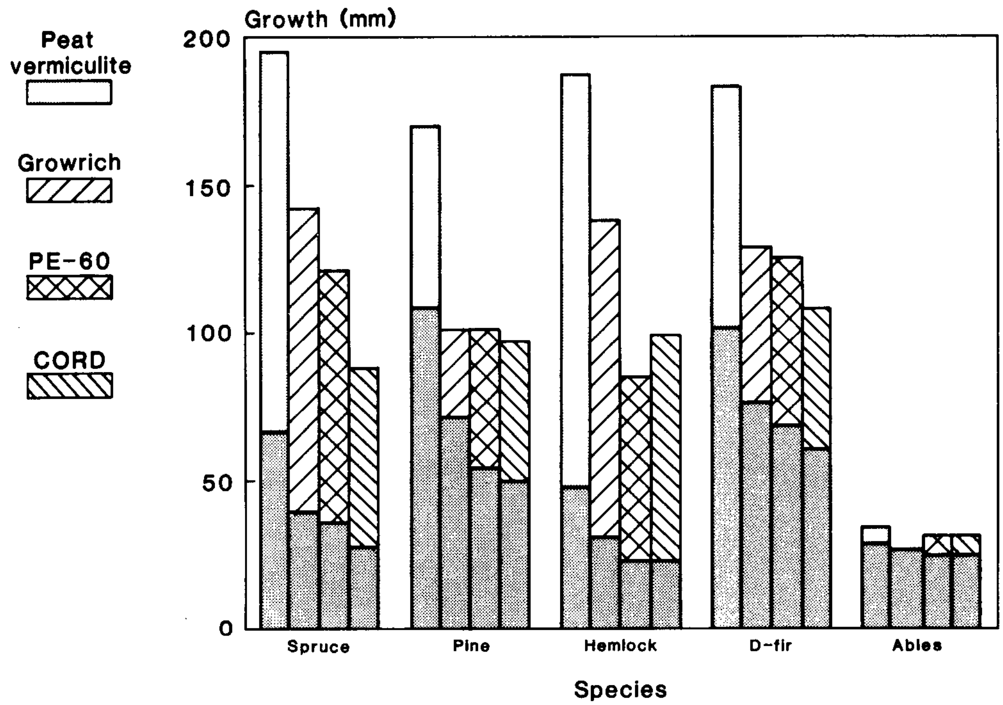

FIGURE 7. Shoot height of five conifer species at 90 days from sowing (shaded portions), 116 days from sowing (pine and Douglas-fir), and 229 days from sowing (spruce, hemlock, and sub-alpine fir). Each bar is the mean height of three replications of 20 seedlings.

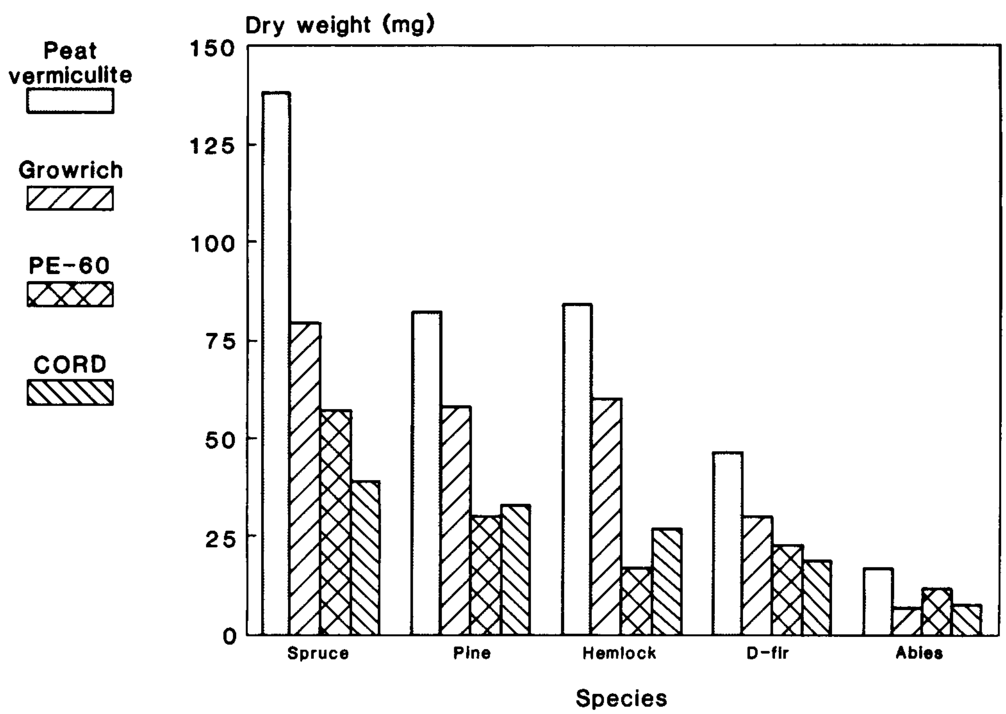

FIGURE 8. Shoot dry weight of five conifer species after 116 days (pine and Douglas-fir), and 229 days from sowing (spruce, hemlock, and sub-alpine fir). Each bar is the mean weight of three replications of up to 50 seedlings each.

Experiment 2

Approximately 75% of the viable lodgepole pine and Douglas-fir seed sown in the standard peat-vermiculite medium had germinated 28 days after sowing (Figures 9 and 10). With the exception of lodgepole pine seed sown in the PE-60 plus vermiculite, and Douglas-fir in the uncomposted Vancouver sludge with or without vermiculite, there were no reductions in germination (Figures 9 and 10). The addition of vermiculite to the woodwaste-sewage sludge media did not have consistent positive or negative effects on seed germination. Germination rate was unaffected by growing medium, and therefore, these data are not shown.

Shoot lengths measured in mid-November, 20 weeks after sowing, indicate that growth of Douglas-fir grown in the standard limed peat-vermiculite mix and in the CORD and PE-60 mixes, with or without added vermiculite, was similar (Figure 11). The media originating from the GVRD and the uncomposted Vancouver sludge (VS) produced seedlings substantially shorter than those in the peat-vermiculite standard. Lodgepole pine seedlings grew taller when vermiculite was added to any of the woodwaste-sewage sludge media (Figure 11). CORD compost and Vancouver sludge with added vermiculite produced lodgepole pine seedlings as tall as those grown in the peat-vermiculite standard. Root collar diameters of Douglas-fir seedlings were very small (less than 2.9 mm) and unaffected by the growing media (Figure 12). Lodgepole pine seedlings had somewhat larger root collar diameters, which were generally increased with the addition of vermiculite (Figure 12). Shoot, root, and total dry weights of both species' seedlings were usually increased with the addition of vermiculite to the growing media. Dry weights of Douglas-fir seedlings grown in all media were at least as great as for seedlings grown in the peat-vermiculite standard (Figure 13). In lodgepole pine, except for seedlings grown in the CORD and PE-60 media without vermiculite, and PE-60 with vermiculite, dry weights were similar to the peat-vermiculite grown seedlings (Figure 14).

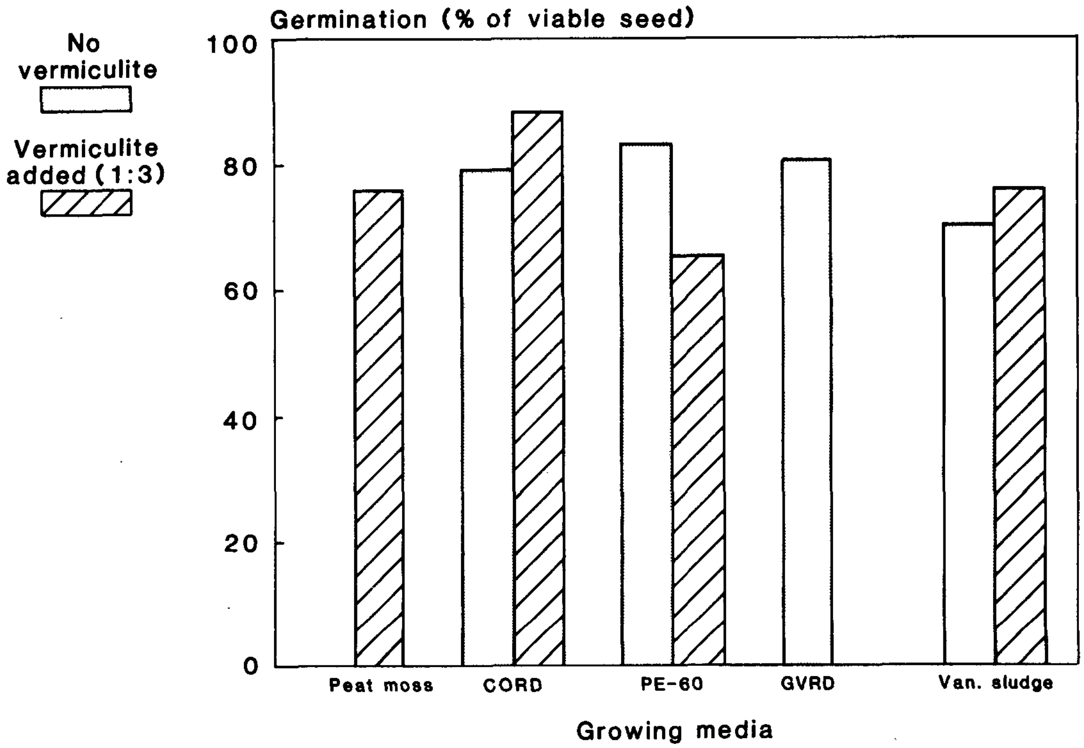

FIGURE 9. Germination of lodgepole pine in eight different growing media. Each bar is the mean of two replications of 100 viable seeds.

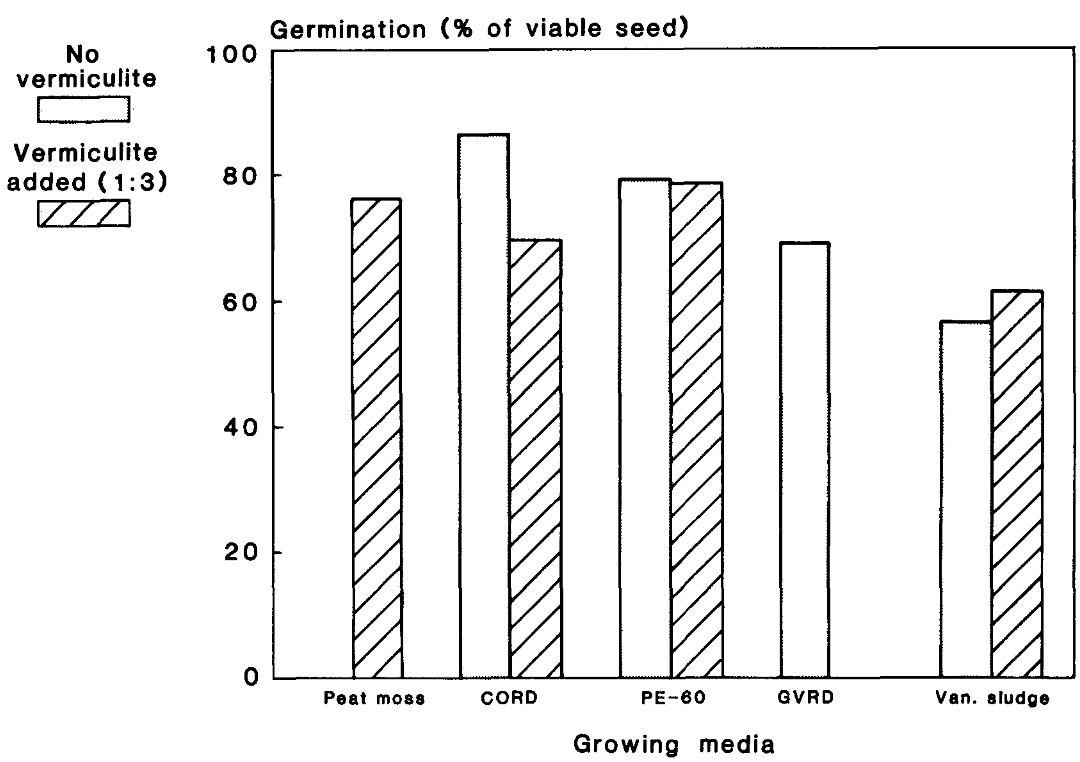

FIGURE 10. Germination of Douglas-fir in eight different growing media. Each bar is the mean of two replications of 100 viable seeds.

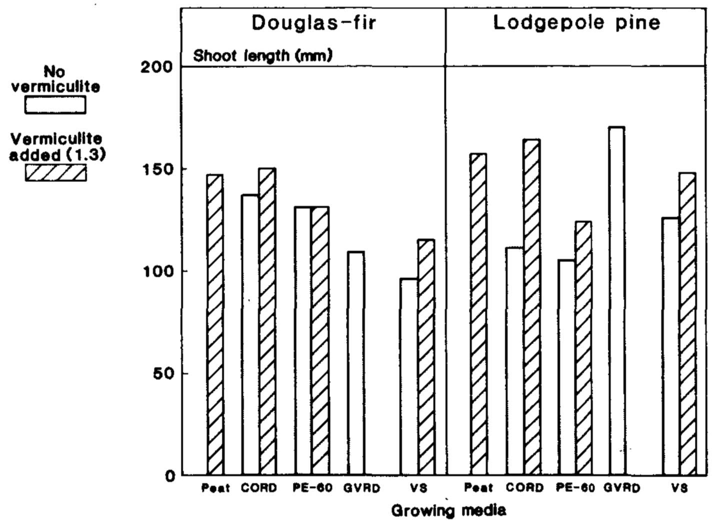

FIGURE 11. Shoot length of Douglas-fir and lodgepole pine in eight different growing media. Each bar is the mean of two replications of 25 seedlings.

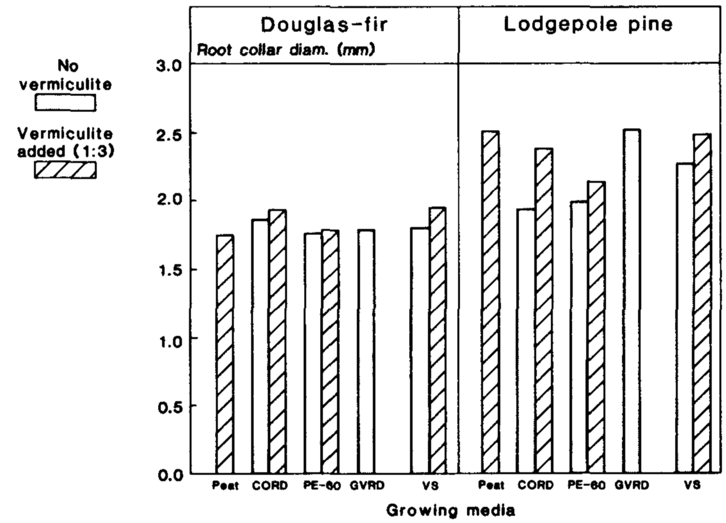

FIGURE 12. Root collar diameter of Douglas-fir and lodgepole pine in eight different growing media. Each bar is the mean of two replications of 25 seedlings.

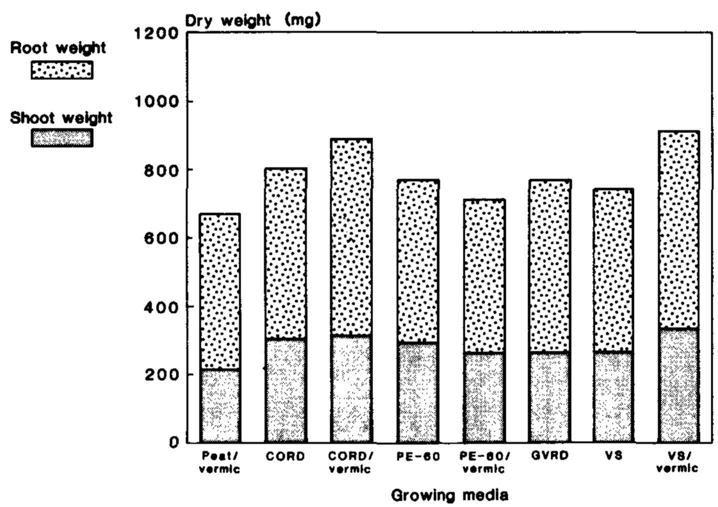

FIGURE 13. Douglas-fir seedling dry weight. Each bar is the mean of two replications of 25 seedlings.

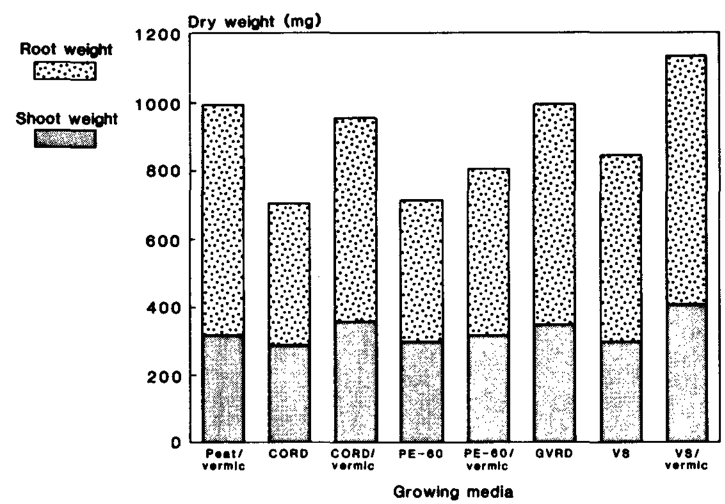

FIGURE 14. Lodgepole pine seedling dry weight. Each bar is the mean of two replications of 25 seedlings.

Subjective assessment of root plug formation suggested that only approximately 70% of Douglas-fir seedlings in standard peat-vermiculite mix were suitable for field planting (Figure 15). A similar proportion of Douglas-fir seedlings, grown in CORD media with or without vermiculite, also produced suitable root systems, but Douglas-fir seedlings grown in the other media had only 40-50% good plugs (Figure 15). More than 90% of the lodgepole pine seedlings grown in the peat-vermiculite medium had root systems suitable for planting. The other media produced between 75 and 85% of pine seedlings with suitable root systems.

Root regeneration potential of Douglas-fir seedlings after 90 days in $+2^{\circ}C$ storage was greater in all the woodwaste-sewage sludge media with added vermiculite. Root regeneration potential of lodgepole pine seedlings was greater than for Douglas-fir seedlings and was not significantly different between treatments (Figure 16). There was a general trend for a small improvement in root regeneration potential when vermiculite was added to the various media.

DISCUSSION

The limed peat-vermiculite (3:1) growing medium that is the standard mix for growing conifer seedlings in British Columbia forest nurseries was found to be a consistently better growing medium than any of the woodwaste-sewage sludge composts.

Reduced seed germination is speculated to be, at least in part, due to the following: 1) in the smaller seeded species, moisture stress occurring in the coarse-textured woodwaste composts; 2) pathogens in the unsterilized growing mixutres; 3) phytotoxic leachates from the woodwastes used in the composts; and 4) metals in the sewage sludges.

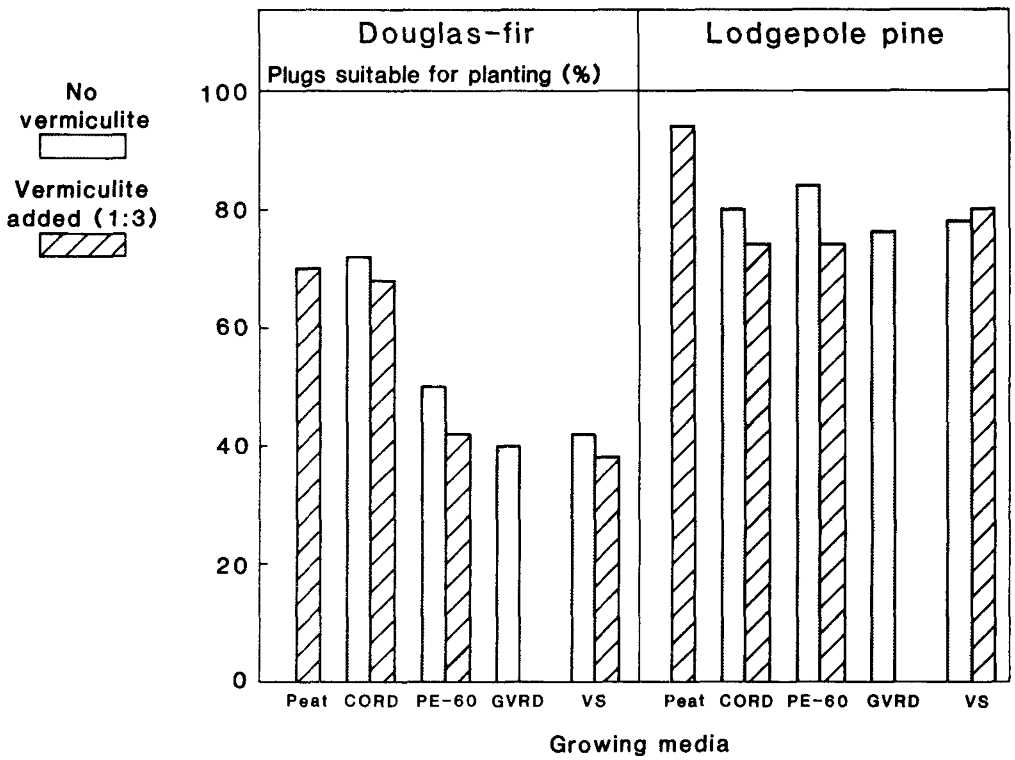

FIGURE 15. Formation of plugs suitable for planting in Douglas-fir and lodgepole pine seedlings grown in eight different growing media.

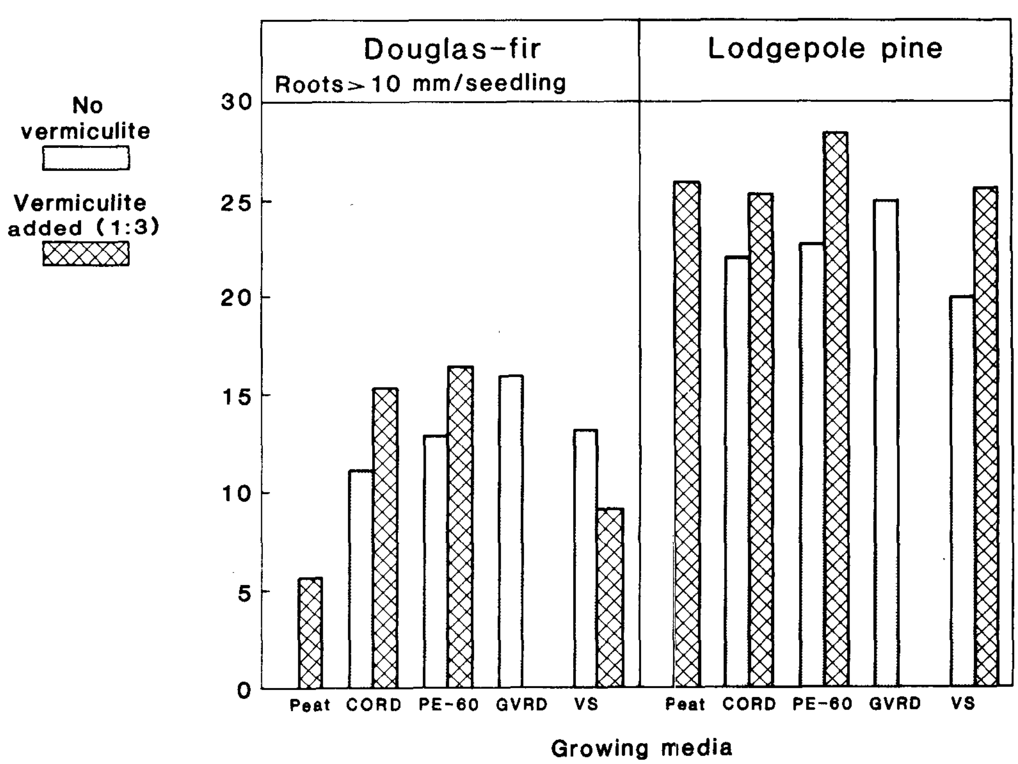

FIGURE 16. Growing media effects on root regeneration potential of Douglas-fir and lodgepole pine seedlings after cold (+2°C) storage for 90 days. Each bar represents the mean number of roots per seedling from two eight-seedling samples. Means followed by same letter are not significantly different at $p \leq 0.05$.

Measurement of the water potential in each growing medium was not made; however, the surface of the woodwaste-sewage sludge composts usually appeared drier than that of the standard peat-vermiculite mixture. No attempt to isolate pathogens from the media was made. If pathogens did contribute to germination reductions, they were of the type causing pre-emergence losses rather than damping off, as little damping off was noted in either experiment.

Phytotoxicity of phenols and phenolic compounds is well known (Fisher 1980). Levels of phytotoxic phenol compounds have been observed to be reduced by the composting process (Solbraa 1979). The composts used in both experiments were at least 1 year old, having been stored outside where leaching likely occurred. Therefore, phytotoxic compounds are unlikely to have caused germination to be reduced.

Seed sown in growing media originating from the GVRD (Growrich in experiment 1 and Vancouver sludge in experiment 2) had lower total germination. This germination depression may be linked to the higher heavy metal levels (Table 3) in a large city's sludge (such as Vancouver's), relative to the levels in a small non-industrial city's sludge (such as Kelowna's). Patterson and Olson (1983) report that solutions of copper, nickel, and cobalt as low as 1-5 mg L^{-1} can cause reduced root growth. Although heavy metals are relatively immobile, particularly in organic soils (Buckman and Brady 1969), the levels noted in Vancouver sewage sludges (Table 3) may be sufficient to raise soil water levels to the 1-5 mg L^{-1} range.

Superior growth of conifer seedlings in limed peat-vermiculite may be due to a higher cation exchange capacity (C.E.C.) in that mix (Table 2). The pH of all growing media were in the range normally considered suitable for growing conifer seedlings (Tinus and McDonald 1979). Because of the added soluble fertilizers, differences in nitrogen, phosphorus, and potassium levels among the growing media are not thought to be important. Calcium levels in the woodwaste-sewage sludge composts coming from Vancouver (GVRD and Vancouver sludge) were lower than levels in the other media. It is possible this difference may contribute to poorer height growth of seedlings grown in those mixes.

TABLE 3. Metal concentrations ($\mu g\ g^{-1}$) in Vancouver and Kelowna sludges (Wetter 1980)

	Cd	Cr	Ni	Zn	Pb	Cu
Vancouver						
Lions's Gate	5	153	28	763	250	1830
Iona Island	7	142	29	912	741	966
Annacis Island	5	147	32	1070	311	992
Lulu Island	29	906	83	1850	510	959
Kelowna	6	29	18	679	142	1380

Added vermiculite did not result in growth improvements by affecting the chemical characteristics of the growing media (Table 1). The positive effects of vermiculite addition are likely due to improved aeration and drainage in the mixtures. Further growth improvements, such as were seen when vermiculite was added to the woodwaste-sewage sludge composts, may be possible with changes in the fertilizer regime, the addition of other inert materials like perlite to the mixes, or the use of larger volume containers that may drain better.

Most conifer seedlings used for reforestation projects in British Columbia receive some cold (+2^{0}C) or frozen (-2^{0}C) storage prior to field planting. Root regeneration or root growth capacity, measured on samples of stock shortly before planting, has been shown to be related to survival and growth of field planted seedlings (Ritchie and Dunlap 1980; Burdett et al. 1983; Sutton 1983). The root regeneration improvements in Douglas-fir seedlings grown in PE-60, CORD, and GVRD mixtures may possibly have been due to higher levels of stored nutrients in those media. Higher levels of root regeneration potential might contribute to survival and growth improvements on outplanting of seedlings raised in these woodwaste-sewage sludge composts.

Future research in the use of woodwaste-sewage sludge composts should concentrate on (1) determining if heavy metals are being taken up by the seedlings and influencing growth; (2) correcting any deficiencies (particularly in calcium) in nutrient regimes; and (3) adding inert soil amendments, to improve root plug formation and, hence, the production of seedlings suitable for planting.

In conclusion, the standard peat-vermiculite growing medium used for conifer planting stock should not be replaced at present by any of the woodwaste-sewage sludge composts considered in these experiments. It may be possible, by soil structure and nutrient regime adjustments, to produce conifer seedlings of an improved quality in woodwaste-sewage sludge compost. Sewage sludges from domestic sources or smaller non-industrial cities should be favoured because of their lower heavy metal levels.

LITERATURE CITED

Berry, C.R. and D.H. Marx. 1977. Growth of loblolly pine seedlings in strip-mined kaolin spoil as influenced by sewage sludge. J. Environ. Quality 6:379-381.

Buckman, H.O. and N.C. Brady. 1969. The nature and properties of soils. MacMillan Publishing Co. Inc., New York, N.Y.

Burdett, A.N. 1979. New methods for measuring root growth capacity: their value in assessing lodgepole pine stock quality. Can. J. For. Res. 9:63-67.

Burdett, A.N., D.G. Simpson, and C.F. Thompson. 1983. Root development and plantation establishment success. Plant and Soil 71:103-110.

Cooley, J.H. 1982. Applying liquid sludge to forest land: a demonstration. In Proc. of the Fifth Annual Madison Conference of Applied Research and Practice on Municipal and Industrial Waste, Dept. of Eng. and Appl. Sci., Univ. of Wisconsin, Madison, Wis., Sept. 22-24, 1982. pp. 547-556.

Domenowski, R.S. 1980. A presentation of the Municipality of Metro Seattle Sludge Utilization Research. In Sludge disposal on land: it's future in British Columbia. B.C. Min. of Environ. and B.C. Water and Waste Assn., Vancouver, B.C. April 16, 1980.

Edmonds, R.L. and D.W. Cole 1980. Use of dewatered sludge as an amendment for forest growth. Vol. 3. Center for Ecosystem Studies, College of Forest Resources, Univ. of Wash., Seattle, Bull. No. 3.

Fisher, R.F. 1980. Allelopathy: A potential cause of regeneration failure. J. For. 78:346-348.

Govin, F.R. 1977. Conifer tree seedling response to nursery soil amended with composted sewage sludge. HortScience 12:341-342.

Govin, F.R., C.B. Link, and J.F. Kundt. 1978. Forest seedlings thrive on composted sludge. Compost Sci.-Land Utilization 19:28-30.

Hoitink, H.A.J. and H.A. Poole. 1980. Factors affecting quality of composts for utilization in container media. In Proc. of the Symposium: Using municipal waste for production of horticultural crops. HortScience 15:171-173.

Korcak, R.F., F.R. Govin, and D.S. Fanning. 1979. Metal content of plants and soils in a tree nursery treated with composted sludge. J. Environ. Qual. 8:63-68.

Koterba, M.T., J.W. Hornbeck, and R.S. Pierce. 1979. Effects of sludge application on soil water solution and vegetation in a northern hardwood stand. J. Environ. Qual. 8:72-78.

Krapfenbauer, A., E. Buchleitner, and M. Sieghardt. 1981. Pot trials with Norway spruce (*Picea abies*) and Scotch pine (*Picea silvestris*) for testing composted waste sewage sludge with different degrees of leaching. Diebodenkultur 32:105-115.

Lepp, N.W. and G.T. Eardley. 1978. Growth and trace metal content of European sycamore seedlings grown in soil treated with sewage sludge. Chemosphere 6:373-365.

Moza, P.N., I. Scheunert, W. Klein, and F. Korte. 1979. Long-term uptake of lower chlorinated biphenyls and their conversion products by spruce trees (*Picea abies*) from soil treated with sewage sludge. Chemosphere 6:373-365.

Patterson, W.A. and J.J. Olson. 1983. Effects of heavy metals on radicle growth of selected woody species germinated on filter paper, mineral and organic soil substrates. Can. J. For. Res. 13:233-238.

Riekerk, H. 1981. Effects of sludge disposal on drainage solutions of two forest soils. Forest Sci. 27:792-800.

Ritchie, G.A. and J.R. Dunlap. 1980. Root growth potential: it's development and expression in forest tree seedlings. N.Z.J. For. Sci. 10:218-248.

Sanderson, K.C. and W.C. Martin. 1974. Performance of woody ornamentals in municipal compost medium under nine fertilizer regimes. HortScience 9:242-243.

Solbraa, K. 1979. Composting of bark. IV. Potential growth-reducing compounds in bark. Medd. Norsk. Inst. Skogforsk 34:443-508.

Stevens, G.M. 1980. Composting of raw sludge with forest industry waste. *In* Sludge disposal on land: it's future in British Columbia. B.C. Min. Environ. and B.C. Water and Waste Assn., Vancouver, B.C. April 16, 1980.

Sutton, R.F. 1983. Root growth capacity: relationship with field root growth and performance in outplanted jack pine and black spruce. Plant and Soil 71:111-122.

Tinus, R.W. and S.E. McDonald. 1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv. Gen. Tech. Rep. RM-60.

Wetter, R.D. 1980. The future of sludge regulation in British Columbia. *In* Sludge disposal on land: it's future in British Columbia. B.C. Min. Environ. and B.C. Water and Waste Assn., Vancouver, B.C. April 16, 1980.