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The Growth of Three Woody Plant Species and the Development of their Mycorrhizae in Three Different Plant Composts[1]

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Abstract. **Composts of corn (*Zea mays* L.), eastern hemlock [*Tsuga canadensis* (L.) Carr.], and sugar maple (*Acer saccharum* Marsh.) were each used as the medium for container-grown hemlocks, sugar maples, and rhododendrons (*Rhododendron catawbiense* Michx.) over a 3-year period. Corn compost was high in available nutrients and the unamended hemlock and maple composts were relatively low in nutrients. No vesicular-arbuscular mycorrhiza (VAM) development was observed in a corn plant bioassay of corn compost while a moderate development was found in the hemlock compost and a high development found in the maple compost. Sugar maples showed the greatest plant growth and incidence of VA mycorrhizae in maple compost and also showed a positive growth response to fertilizer. Corn compost was lethal to 50% of the maples and produced a retarded growth and very low incidence of VAM in the survivors. Hemlocks showed the greatest plant growth and incidence of ectomycorrhizae in either unfertilized hemlock compost or unfertilized maple compost. A significant retarded growth response to fertilizer was found with hemlocks. Rhododendrons showed the greatest growth in corn compost and the fertilized composts. A negative correlation was found between growth and the incidence of ericoid mycorrhizae in rhododendrons. Differences in compost effects upon plant growth were probably due to differences in the content of plant nutrients and in the type and quantity of mycorrhizal propagules.**

An investigation was conducted to determine whether or not a species effect may exist in composted plant residues that would affect plant growth and mycorrhizal development. The broad differences in lignin quality may be a factor in a species effect since the decomposition of lignin from various plant sources results in the release of various biologically active phenols (4) or their derivatives in various concentrations in the soil (10, 11).

The differences in the lignin chemistry of plants lie within the phenolic units comprising the lignin polymer (8). Conifer lignins are generally composed of coniferyl alcohol (3 methoxy, 4 hydroxy phenylpropane) monomers. Hardwood lignins are polymers of sinapyl alcohol (3, 5 dimethoxy, 4 hydroxy phenylpropane) and p-coumaryl alcohol (4 hydroxy phenylpropane) monomers. Grass lignins are composed of the three monomers cited above with sinapyl alcohol being the major component (1).

In this study eastern hemlock, sugar maple, and field corn served as the representative source of each lignin group. The residues of these species were readily collectible, in volume, and in a homogenous state.

The test plant species selected were eastern hemlock, sugar maple and 'Roseum Elegans' rhododendron. These species permitted the observation of the response of plants (hemlock or maple) to composted organic matter of their own species as well as to that of two other species. In addition, the 3 test plant species represented a broad range in mycorrhizal associations. Hemlock is ectomycorrhizal, sugar maple is endomycorrhizal, of the vesicular-arbuscular type, and rhododendron is endomycorrhizal of the ericoid type.

Ectomycorrhizae of hemlock are readily identified by the presence of the fungal sheath and/or Hartig Net (7). The VAM of sugar maples are also readily identified by the characteristic arbuscules and fungal coils generally found in profusion within the cortical tissue (3).

The endomycorrhizae of rhododendron, however, are less readily determined. The lateral rootlets of rhododendron are less than 50 μm in diameter and the cortex is usually only one cell in thickness providing very little tissue upon which observations can be made. In addition, the fungal hyphae most frequently observed are extreme fine, septate strands which approach the resolution limit of the microscope. In this experiment, these strands restricted to the cortex of otherwise healthy roots were assumed to constitute the ericoid mycorrhizal system (5).

Materials and Methods

Recent leaf and branch litter from pure strands of eastern hemlock and sugar maple were collected in July, shredded and stockpiled outdoors in 1.9 × 1.9 m snow-fence enclosures to a height of 1.9 m. Field corn harvested at maturity in October by field chopper was treated similarly. All 3 stockpiles were watered down initially and then permitted to compost without amendment for nearly a year. On 2 occasions during the composting process the composts were aerated by moving each pile to an adjacent enclosure by bucker loader.

The concentration of VAM propagules in the composts was evaluated by bioassay utilizing corn as the test plant. Corn seeds

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were planted in containers of each compost, and as the plants grew, root samples were taken periodically for verification of VAM development by light microscopy of stained microsections.

Immediately prior to utilization and annually thereafter, compost samples were analyzed for pH and available plant nutrients. The pH was determined by glass electrode on a thick paste of the sample. Available nutrients were extracted by ammonium acetate solution at a 1:5 v/v compost extractant ratio. P in the extract was determined colorimetrically by the molybdate method, K and Ca by flame photometry and Mg colorimetrically by the magnesium blue method (2).

A fertilizer treatment consisting of 18N–2P–9K (18–5–11) Osmocote (14-month nursery fertilizer) at 3 kg/m^3 of compost, fritted trace elements at 150 g/m^3 and dolomitic, agricultural grade limestone at 7.15 kg/m^3 was an added variable to the hemlock and maple composts.

Hemlocks and rhododendrons were propagated by vegetative cuttings and maples were grown from seed collected from a single parent tree. The hemlock cuttings were rooted under mist in peat-perlite (sphagnum peatmoss-perlite) and were 16 months old and averaged 15 cm in height when placed into the compost treatments. Root development at this time, although adequate for transplanting, was not vigorous and top growth had not commenced.

The rhododendron cuttings were rooted under mist in peat-perlite and had been transplanted once into 7.6 cm pots of peat-perlite prior to treatment. Root development at the initiation of treatment was voluminous and top growth vigorous. The 17-month-old test plants selected for the test were very uniform showing two whorls of leaves and were 15 cm in height.

The maple seeds were stratified and germinated in peat-perlite. The plants were 3 months old when they were selected for uniformity and placed into the treatments. All test plants bore 8 leaves of very similar size and ranged between 10–13 cm in height.

Examination of representative stained root microsections of each species showed that no mycorrhizal involvement had occurred prior to the planting into the composts.

One plant of each species was planted in June in a 3.8 liter plastic container of each compost treatment and replicated 10 times. The plants were grown in a glasshouse from March through October at ambient temperatures in a randomized block experimental design. Plants were watered as required with well water. From November through February the plants were randomized likewise in a plastic-covered cold frame, mulched with hardwood sawdust, and root temperatures were maintained at just above freezing by heating cable under the containers.

With the exception of the 3rd year growth on hemlocks, the following growth data were taken on each plant each year: plant height and spread, and new shoot numbers and length. The 3rd year growth on hemlocks was evaluated by height and plant spread measurements only. Number of leaves was also counted in maples. Concurrently, compost samples were taken from each container for plant nutrient analysis and samples of healthy appearing roots were taken from each plant for mycorrhizal determination. The root samples were killed and fixed immediately in FAA (formalin-acetic acid-alcohol). A random subsample of the lateral rootlets of each species was embedded in paraplast, microtomed, stained with safranin and fast green, and then scrutinized for mycorrhizal development by light microscopy.

Results and Discussion

The initial compost analyses given in Table 1 show that the corn compost was much higher in pH, available Mg, P and K than the untreated hemlock and maple composts. The addition of fertilizer and limestone to the latter 2 composts increased the pH and available nutrient levels as would be expected.

Table 1. The pH and available plant nutrients in compost treatments prior to planting.

Compost	pH	Available nutrients (mg/liter compost)[z] Ca	Mg	P	K
Corn	6.5	625(M)[y]	>250(VH)	50(VH)	195(H)
Hemlock	3.9	510(M)	70(M)	6(M)	60(L)
Maple	4.6	810(M)	80(M)	7(M)	65(L)
Hemlock + fertilizer and limestone	5.4	940(MH)	>250(VH)	28(VH)	215(H)
Maple + fertilizer and limestone	5.9	1360(H)	>250(VH)	25(VH)	280(VH)

[z]Extractable with 1.25N acetic acid + 0.625N NH_4OH, pH 4.8.
[y]Interpretive soil fertility ratings: L=low, M=medium high, H=high, MH=medium high, VH=very high.

The bioassay conducted with corn plants was based upon the assumption that the effective quantity of VAM propagules in the composts would be reflected in the VAM development of corn. After 115 days of growth in corn compost, no corn roots sampled were found to be mycorrhizal. The corn compost was either devoid of VAM propagules or inhospitable to VAM development. The corn plants constituting the compost, however, were collected sans roots and would only have the few VAM fungal spores that may adhere to the phylloplane as a result of leaf-soil contact and rain-splash erosion. In maple compost, on the other hand, where ample quantities of propagules might be expected (6), 50% of the corn roots sampled were found to be VAM 66 days after planting and 75% were mycorrhizal 80 days after planting. VAM were not found in hemlock compost until 80 days after planting when 3% of the roots were found to be mycorrhizal. At 115 days after planting 50% of the roots grown in hemlock compost were VAM. These data may indicate that the hemlock compost had only moderate quantities of VAM propagules available.

Eastern hemlock. The relative growth data for hemlocks are given in Table 2. The first year's growth was minimal and showed no statistically significant differences. The plants averaged 15.6 cm in height and had 11 branches. The relative values presented in Table 2 for the first year reflect only the length of terminal growth measurement.

The 2nd year's growth also showed no statistically significant differences among treatments. Plants averaged 22 cm in height and had 63 branches. The data for the 2nd year of growth given in Table 2 reflect the total length of new branch growth.

Table 2. The relative growth of eastern hemlocks over 3 years.

Compost	Relative growth[z], Year after planting: 1	2	3
Corn	98	76	70B[y]
Hemlock	100	100	100AB
Maple	105	132	119A
Hemlock + fertilizer and limestone	95	100	83AB
Maple + fertilizer and limestone	106	91	49B

[z]Growth in hemlock compost taken at 100%. Year 1 = length of terminal growth. Year 2 = total length of new branch growth since year 1. Year 3 = increase in plant volume over year 2.
[y]Mean separation by comparisons among the treatment means, 1% level (9).

Table 3. The pH and available plant nutrients in composts at the 3rd year of hemlock growth.

Compost	pH	Available nutrients (mg/liter compost)[z]			
		Ca	Mg	P	K
Corn	5.2	1050(MH)[y]	183(H)	4(M)	17(VL)
Hemlock	4.8	890(M)	120(MH)	1(VL)	19(VL)
Maple	5.6	1264(H)	132(H)	1(VL)	21(VL)
Hemlock + fertilizer and limestone	6.3	1833(VH)	>250(VH)	7(MH)	23(VL)
Maple + fertilizer and limestone	6.6	1857(VH)	>250(VH)	11(H)	40(VL)

[z]Extractable with 1.25N acetic acid + 0.625N NH_4OH, pH 4.8.
[y]Interpretive soil fertility ratings: L=low, M=medium high, H=high, MH=medium high, VH=very high.

Table 4. The average annual shoot growth of sugar maples.

Compost	Annual shoot growth (cm) Year after planting		
	1	2	3
Corn	4	21B[z]	42C
Hemlock	12	73A	108B
Maple	8	69A	120B
Hemlock + fertilizer and limestone	7	31B	139B
Maple + fertilizer and limestone	9	102A	233A

[z]Mean separation within years by comparisons among the treatment means, 1% level (9).

After the 2nd year's growth data had been taken, each plant was pruned to a symmetrical shape common to ornamental nursery practice and consonant with the growth habit of each plant. Analysis of the statistical data on pruned plant volume showed no significant differences among treatments, which indicates that no bias was introduced by the pruning.

The relative data presented in Table 2 for 3rd year growth reflect the increase in volume gained in the 3rd year over the pruned volume from the 2nd year. The data show that hemlock plants grown in unfertilized hemlock and maple composts grew at a greater rate than in either the corn compost or the fertilized composts. There was, in fact, a statistically significant negative effect of fertilizer upon the growth of hemlocks. The average volume of conical space occupied by the hemlocks grown in hemlock compost was 41.8 liters, and the plants averaged 46 cm in height.

The percent of lateral rootlets found to be mycorrhizal at the end of the 3rd year of growth are given in Table 7. There were no statistically significant differences in quantity of ectomycorrhizae among hemlock plants grown in either the hemlock or maple composts. No ectomycorrhizae were found, however, in hemlocks grown in corn compost at the end of the 3rd year. The lack of mycorrhizal development on hemlocks grown in the corn compost may reflect an inhospitable medium. Hemlock root samples taken in the 2nd year did show some ectomycorrhizal development (20%) in corn compost. In the 2nd year there were 10% or less ectomycorrhizae in the other composts. No ectomycorrhizae were found in the first year in any compost. No significant correlation was found between the numbers of mycorrhizae and the volume of growth in the 3rd year.

The values for pH and available nutrients in the composts at the end of the 3rd year of hemlock growth are given in Table 3. Except for corn compost, the other composts under hemlock plants increased substantially in pH from original levels. In addition, there was a general increase in available Ca and, in the hemlock and maple composts, an increase in Mg. The most marked effect, however, was the extremely low values found for available K over all treatments and the diminished P levels even in the fertilized composts.

Sugar maple. The growth data for sugar maples given in Table 4 are the average annual shoot growth per plant. The first year's growth showed no significant differences among treatments. Maples grown in maple compost showed VAM in 10% of the roots examined. No mycorrhizae were found in the other composts.

In the 2nd year, maples grown in hemlock, maple, and maple plus fertilizer composts showed significantly greater growth than maples in either corn or hemlock plus fertilizer composts. Maple plants in both maple composts showed an average of 25% VAM while maples in the hemlock composts showed less than 1% VAM and no mycorrhizae were found in corn compost.

In the 3rd year, maples grown in fertilized maple compost showed significantly greater growth than in the other compost treatments. The positive effect of fertilizers upon growth was significantly different. Surviving maples in the corn compost showed statistically significant lesser growth. The mortality rate of maples grown in corn compost was severe as 50% of the plants either did not break dormancy or just sprouted leaves which soon wilted and desiccated. The survivors in corn compost averaged 54 cm in height which was significantly shorter than maples in the other treatments which averaged 152 cm in height.

The data given in Table 7 show that only 8% of the lateral rootlets from the live plants grown in corn compost were found to be VAM at the end of the 3rd year. The low incidence of VAM may be a result of an inadequate quantity of propagules. The high mortality rate in this treatment may be a function of this minimal mycorrhizal development. Roots of maples grown in maple compost were found to be over 80% mycorrhizal. There were fewer VAM found on maples grown in hemlock compost, but the differences were not statistically significant.

The values for pH and available nutrients in composts at the end of the 3rd year of maple growth are given in Table 5. These data show similar trends to those found for hemlocks but not to the same degree.

The pH of the corn compost dropped to the lowest level and the pH values of the other composts increased the least under maples. It would appear that maples have a greater acidifying effect upon composts than the other plant species tested. The available P and K levels are low but do not seem to be as depleted as those under hemlocks.

Table 5. The pH and available plant nutrients in composts at the 3rd year of maple growth.

Compost	pH	Available nutrients (mg/liter compost)[z]			
		Ca	Mg	P	K
Corn	4.4	650(M)[y]	135(H)	13(H)	20(VL)
Hemlock	4.2	560(M)	112(MH)	1(VL)	31(VL)
Maple	5.2	1030(MH)	122(MH)	1(VL)	41(VL)
Hemlock + fertilizer and limestone	5.4	1500(H)	>250(VH)	8(MH)	70(L)
Maple + fertilizer and limestone	6.1	1755(VH)	>250(VH)	5(M)	80(L)

[z]Extractable with 1.25N acetic acid + 0.625N NH_4OH, pH 4.8.
[y]Interpretive soil fertility ratings: L=low, M=medium high, H=high, MH=medium high, VH=very high.

Table 6. The average annual shoot growth of rhododendrons.

Compost	Annual shoot growth (cm)		
	Year after planting		
	1	2	3
Corn	18	148C[z]	666B
Hemlock	21	217B	392C
Maple	20	272A	410C
Hemlock + fertilizer and limestone	19	178B	841A
Maple + fertilizer and limestone	17	191B	643B

[z]Mean separation within years by comparisons among the treatment means, 1% level (9).

Rhododendron. The growth data for rhododendrons given in Table 6 are the average annual shoot growth per plant. The first year's growth showed no significant differences among treatments. To encourage multiple shoot breaks, vegetative terminal buds were removed annually prior to the onset of the growth period.

In the 2nd year rhododendrons in corn compost produced significantly less growth than in the other treatments. In maple compost, rhododendrons showed significantly greater growth than in all other treatments.

At the end of 2 years of growth the rhododendron roots had proliferated extensively and larger containers were required. After the growth data and appropriate samples had been taken, the plants were repotted into 7.5 liter containers with the appropriate compost added from the original stockpile.

In the 3rd year the rhododendrons grown in the unfertilized hemlock and maple composts had significantly less shoot growth than in the more fertile media. Plant heights showed no significant differences and averaged 70 cm among all plants.

In addition, rhododendrons grown in the unfertilized hemlock and maple composts produced no blossoms in the 3rd year. In the more fertile composts, however, 60% of the plants showed blossoms at an average of 2 blossoms per plant.

The data on lateral rootlets found to be mycorrhizal in Table 7 show significant differences among treatments. Rhododendrons had significantly fewer mycorrhizae when grown in corn compost and in the fertilized hemlock and maple composts than in the less fertile composts. A significant negative correlation at the 5% level ($r = -.392$) was found between numbers of mycorrhizae and growth. After the first year of growth 20% of the rootlets examined over all treatments were identified as mycorrhizae. In the 2nd year 54% of the roots were mycorrhizal and showed similar trends as in the third year.

The values for pH and available nutrients in the composts at the 3rd year of growth are given in Table 8. The data show that composts under rhododendrons had higher levels of available nutrients than under the other plants although the pH values were not much different than those found under hemlocks. Most notable are the higher values found for phosphorus and potassium.

Table 7. The percentage of lateral rootlets found to be mycorrhizal at the 3rd year of growth.

Compost	Mycorrhizal rootlets (%)		
	Hemlocks	Maples	Rhododendrons
Corn	0B[z]	8b	17C
Hemlock	83A	70a	54A
Maple	90A	87a	49A
Hemlock + fertilizer and limestone	77A	51a	35AB
Maple + fertilizer and limestone	69A	82a	29B

[z]Mean separation within plants by comparisons among the treatment means (arc sine transformation) at 5% (lower case) and 1% (upper case) level (9).

Table 8. The pH and available plant nutrients in composts at the 3rd year of rhododendron growth.

Compost	pH	Available nutrients (mg/liter compost)[z]			
		Ca	Mg	P	K
Corn	5.6	1893(VH)[y]	>250(VH)	13(H)	140(MH)
Hemlock	4.2	571(M)	137(H)	2(L)	75(L)
Maple	5.5	1400(H)	220(VH)	3(L)	116(M)
Hemlock + fertilizer and limestone	6.0	1912(VH)	>250(VH)	12(H)	96(M)
Maple + fertilizer and limestone	6.5	2000(VH)	>250(VH)	13(H)	145(MH)

[z]Extractable with 1.25N acetic acid + 0.625N NH_4OH, pH 4.8.
[y]Interpretive soil fertility ratings: L=low, M=medium high, H=high, MH=medium high, VH=very high.

Physical condition of the composts. Hemlock compost was coarse in texture and was consequently excessively well drained. The need for watering plants in this compost was frequent and may account for the low levels of available K found at the end of the experiment. The maple compost had a finer texture than hemlock and, therefore, a better water retention capacity, but could still be considered as well drained. The corn compost had the greatest amount of fine organic matter and the highest water retention capacity. The drainage of corn compost was only moderate, and the exposed surface tended to crust.

From this study it can be concluded that differences in compost effects upon plant growth were primarily due to differences in the content of plant nutrients and in the type and quantity of mycorrhizal propagules.

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