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Rate of Woody Residue Incorporation into Northern Rocky Mountain Forest Soils

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RESEARCH SUMMARY

Research has shown organic matter, particularly decayed wood, imparts important properties to forest soils of the Northern Rocky Mountains. In order to maintain or reconstitute high quality soils in managed forests, the production time for incorporation of soil organic materials must be considered in the long-term management process.

The research contained in this report indicates lag periods of approximately 100 to 300 years between the time wood is produced on a forested site and the time it becomes incorporated into the soil organic mantle. Habitat type had a major influence on time period and on the tendency of an ecosystem to equilibrate with wood biomass concentrated as undecayed soil-surface residue or as extensively decayed materials incorporated into the soil profile. The cool-moist system accumulated residue. The warm-moist system accumulated decayed wood in the soil. Douglas-fir was the most common species of wood found in the soils of these experimental sites.

In order to reconstitute adequate supplies of decayed wood in soils depleted in this resource, lag periods in the 100- to 300-year range can be expected. Also, when managing harvest residue as parent materials for soil wood, Douglas-fir is a preferred species.

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INTRODUCTION

Maintenance of high organic matter levels in cultivated soils has long been recognized as important to site quality. In forest soils the rapid accumulation of organic litter and frequent requirement of a mineral seedbed for regeneration obscures the importance of long-term organic matter requirements.

Persistence of wood in forest soils has been recognized for some time (McFee and Stone 1966). Specific and quantitatively important contributions made by wood to forested ecosystems have been recognized only recently, however.

During the transition from solid to decayed wood, large residues support substantial nitrogen-fixing activity (Larsen and others 1978; Bormann and others 1977; Cornaby and Waide 1973). Once incorporated in the soil, decayed wood continues to support nitrogen-fixing activity (Jurgensen and others 1977). It becomes the primary site for nitrogen fixation during dry periods or on dry sites of the Northern Rocky Mountains (Harvey and others 1978b).

As a component of Northern Rocky Mountain forest soils, decayed wood also provides an important substratum for ectomycorrhizal symbionts. In one mature ecosystem, over 90 percent of the active ectomycorrhizal associations were supported by soil organic matter (Harvey and others 1976). As with nitrogen-fixing activity, decayed wood became the primary substratum for ectomycorrhizal activity during dry periods (Harvey and others 1978a) and on dry sites (Harvey and others 1978b, 1979).

The increasing importance of decayed wood in soils during dry seasons and on relatively dry sites is apparently related to the efficiency of the lignin matrix in highly decayed wood to retain moisture (Harvey and others 1978a, 1979).

Soil wood must be considered a primary factor governing soil quality of many forests. It is critical to moisture relations and, by way of the micro-organisms it supports, to nutrient input and availability. Therefore, how much wood is required on a site to support full growth potential and how long it takes to produce it if it is depleted are major considerations in the management of forests in which these contributions are important.

Requirements of decayed wood for high quality Northern Rocky Mountain soils are currently under study and will be reported separately. Here, we report a preliminary assessment of how long it may take to produce decayed wood in soils of three Northern Rocky Mountain ecosystems.

MATERIALS AND METHODS

This study was conducted on three sites within the boundaries of the Coram Experimental Forest located in Flathead County between Flathead Lake and Glacier National Park of northwestern Montana. The timber type is Douglas-fir/larch. Elevations range from 3,340 ft (1 018 m) to 6,370 ft (1 942 m) above sea level. Mean annual precipitation at the lower elevations averages 31 in (78.7 cm) and the mean annual temperature, 42.5° F (5.3° C). Mean annual summer temperatures average 61° F (16.1° C), see Klages and others (1976).

Three sites were chosen to represent a wide range of temperature-moisture conditions typical of Northern Rocky Mountain forests. Each supports a mature ecosystem approximately 250 years of age with no history of disturbance by man and includes at least 1 ha of uniform conditions.

These sites have been characterized in detail elsewhere (Harvey and others 1979). In summary, site 1 is a warm, dry south slope dominated by Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). Site 2 is a cool, moist east slope dominated by Douglas-fir, western larch (*Larix occidentalis* Mirr.), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), and Engelmann spruce (*Picea englemanni* Parry), and site 3 is a warm, moist north slope dominated by western hemlock (*Tsuga heterophylla* [Raf.] Sarg.). These sites are representative of *Pseudotsuga menziesii/Physocarpus malvaceus* (PSME/PHMA), *Abies lasiocarpa/Clintonia uniflora* (ABLS/CLUN), and *Tsuga heterophylla/Clintonia uniflora* (TSHE/CLUN) habitat types, respectively (Pfister and others 1977).

All major organic materials on these sites were characterized and measured as follows:

1. **Soil organic components:** Samples consisted of 4 x 12 in (10 by 30 cm) soil cores taken randomly from around 10 permanent plot centers evenly dispersed throughout each study site. Each core was divided into litter (0_1 horizon), humus (0_2 horizon), decayed soil wood (0_3 horizon), and charcoal (0_4 horizon) (Harvey and others 1979). The volume of each was determined by measuring its depth in the undisturbed core.

These samples were derived from a series of studies on these sites May to November 1975 and 1976. They represent a total of 1050 cores from site 2 and 160 each from sites 1 and 3.

2. **Down woody residues:** Random line intersect samples from around each of the permanent plot centers were used as a basis for calculating volume as described by Brown (1974). Residues were further characterized with respect to the general stage of decay as sound (no visible deterioration), solid decay (extensively discolored, but resistant to crumbling and breakage), and crumbly decay (easily broken and crumbled).

3. **Standing wood volume:** Site 2 volume measurements were based on a 100 percent inventory (Bensen and Schlieter 1980). Sites 1 and 3 were cruised according to Grosenbaugh (1952), and volume conversion factors were those provided in Faurot (1977).

4. **Radiocarbon dating:** Brown, cubicle decayed wood samples for dating were collected randomly from throughout the study sites. All samples selected were of crumbly decayed logs located on, partially buried in, or completely buried in the soil profile. Duplicate or triplicate samples of each decay type were dated at Washington State University according to procedures described by Sheppard (1975). All three sample types were dated for site 2. Samples from partially buried logs only were dated from sites 1 and 3. All materials of recent origin, such as roots and fungal strands were removed, insofar as possible, as a part of the sample preparation procedure. Each sample consisted of material from throughout a representative cross section and each was microscopically identified as to tree species.

5. **Lignin-carbohydrate analysis:** Samples for lignin and carbohydrate analysis were collected as above for radiocarbon dating. Ten to 15 samples from each sample type and site, as described above, were analyzed for content of lignin (Effland 1977) and carbohydrate, primarily cellulose and associated materials.[1] The species of each sample was also determined.

RESULTS AND DISCUSSION

Table 1 summarizes the results of the radiocarbon dating, lignin, and carbohydrate analyses of decayed wood residue samples from the three sites. The data for samples in various stages of incorporation into the soil show a progression in age from the position of lying on the surface of the soil ($\bar{x}$ 145 yr) to one of being fully incorporated in the soil profile ($\bar{x}$ 370 yr) of site 2 and also from the subalpine fir (site 2 — $\bar{x}$ 145 yr) to the Douglas-fir (site 1 — $\bar{x}$ 247 yr) to the hemlock (site 3 — $\bar{x}$ 473 yr) sites. Measurements derived from cross-section samples provided a maximum age estimate because of the inclusion of wood produced early in the lifespan of the tree. All 12 wood samples were identified as Douglas-fir. Present stands contain other tree species (table 2) and the fire frequency for these sites would not eliminate other species from the previous stands.

Data in table 1 show a significant loss of carbohydrates and persistence of lignin with increasing age (incorporation into the soil profile). Again, species identification of 90 random samples indicated all were Douglas-fir. This suggests Douglas-fir is the most persistent species of wood in these soils. Previous observations (Jurgensen and others 1977) have also suggested that brown, cubicle-decayed Douglas-fir wood is prevalent in these soils.

Table 1.—Radiocarbon age, lignin, and carbohydrate (percent dry weight) content of decayed soil wood from three undisturbed, mature forest stands in western Montana

Position	Species	Radiocarbon age	Lignin	Carbohydrate
		Years		
Site 1 (PSME/PHMA)[1]				
Partially buried	Douglas-fir	250 ± 100	[2]76.93(5.62)	[2]15.10(5.50)
		280 ± 95		
		210 ± 90		
Site 2 (ABLA/CLUN)[3]				
Surface	Douglas-fir	130 ± 90	64.9	27.1
		102 ± 90	73.3	18.8
Partially buried		190 ± 90	62.4	30.9
		100 ± 90	84.4	7.6
Buried		450 ± 95	80.9	11.3
		290 ± 90	78.8	11.9
Surface	Douglas-fir		[2]67.45(7.42)	23.87(8.17)
Partially buried			72.56(8.34)	18.57(9.16)
Buried			[4]78.13(3.86)	[5]12.64(4.44)
Site 3 (TSHE/CLUN)[6]				
Partially buried	Douglas-fir	510 ± 100	[2]75.13(3.35)	[2]16.56(3.38)
		550 ± 120		
		360 ± 90		

[1] *Pseudotsuga menziesii/Physocarpus malvaceus* habitat type.
[2] Mean and standard deviation determined from 10 to 15 random samples.
[3] *Abies lasiocarpa/Clintonia uniflora* habitat type.
[4] Significantly more lignin than surface sample, $\alpha = 0.01$, t-test.
[5] Significantly less carbohydrate than surface sample, $\alpha = 0.01$, t-test.
[6] *Tsuga heterophylla/Clintonia uniflora* habitat type.

[1] Moore, W.E., and D.B. Johnson. 1967. Procedures for the chemical analysis of wood and wood products (as used at the U.S. Forest Products Laboratory). USDA For. Serv., Madison, Wis. (unpubl.).

Table 2.—Mean stand volumes (m^3/ha) by tree species of three undisturbed, mature forests in western Montana; includes all stems

Species								
Douglas-fir	Western larch	Alpine fir	Engelmann spruce	Western hemlock	Western redcedar	Birch	Lodgepole pine	Total volume
Site 1 (PSME/PHMA)[1]								
271.5	6.2							242.7
Site 2 (ABLA/CLUN)[2]								
164.7	22.8	66.5	45.3		0.1			299.4
Site 3 (TSHE/CLUN)[3]								
152.7				255.3	17.3	9.0	4.6	438.9

[1] *Pseudotsuga menziesii/Physocarpus malvaceus* habitat type.
[2] *Abies lasiocarpa/Clintonia unifloraa* habitat type.
[3] *Tsuga heterophylla/Clintonia uniflora.*

Table 3.—Mean volumes (m^3/ha) of wood residues[1] in three undisturbed, mature forest stands in western Montana

	Species								
Condition	Douglas-fir	Western larch	Alpine fir	Engelmann spruce	Western hemlock	Western redcedar	Birch	Alder	Total volume
Site 1 (PSME/PHMA)[2]									
Sound	22.5	5.2							
Solid decay	45.4	7.2							
Crumbly decay	57.6	16.6							154.6
Site 2 (ABLA/CLUN)[3]									
Sound	82.3	42.4	27.10	1.5					
Solid decay	54.2	34.8	21.92	5.1					
Crumbly decay	105.4	46.0	7.46	1.8				0.1	430.3
Site 3 (TSHE/CLUN)[4]									
Sound	9.4	36.2			8.8	6.3			
Solid decay	6.6	54.0			43.5	5.4	4.7		
Crumbly decay	20.3	32.2			25.9	1.5			254.2

[1] Not considered as incorporated in the soil profile.
[2] *Pseudotsuga menziesii/Physocarpua malvaceus* habitat type.
[3] *Abies lasiocarpa/Clintonia uniflora* habitat type.
[4] *Tsuga heterophylla/Clintonia uniflora* habitat type.

A complete inventory of all woody materials on these sites is provided in tables 2, 3, and 4. Table 3 shows the greatest accumulation of downed woody residues, not incorporated in the soil profile, on the cool, moist site (site 2, ABLA/CLUN). Conversely, table 4 shows that the end products of the decay process (woody materials incorporated in the soil profile) are highest on the warm moist site (site 3, TSHE/CLUN). The greatest stand volumes occur on the warm moist site (table 2), but the tendency of the ecosystem to equilibrate with high wood residue volumes varies with site conditions. The apparent tendency to accumulate undecayed residue on the relatively productive growing site (site 2) with the coolest temperatures indicates decay is reduced by the cool temperatures.

Selected data from tables 2, 3, and 4 were used to calculate relative rates of wood accumulation and dispersion on these sites (table 5). These calculations show a tendency for the cool moist ecosystem (site 2, ABLA/CLUN) to accumulate woody residue at a relatively high rate. The difference between wood production, as reported in Pfister and others (1977), and the soil wood return rate, which is based on the difference[2] between total wood production over the 250-year stand age and total wood reserves measured on each site, was used to estimate the approximate time periods required to return wood reserves to the soil. A one-third loss of volume was estimated between the time fresh wood began the process of decay and disintegration and the time it began to function as soil. This estimate is based on field measurements by the authors.

[2] This figure (column 8, table 5) represents the volume of wood that can no longer be visually accounted for in the samples as intact wood; that is, it has been incorporated into the humus and mineral soil components or released to the atmosphere as CO_2. Microscopic observations by the authors indicate substantial quantities of this material have been incorporated into the humus components of these soils.

APPLICATIONS

Forest management actions should incorporate an awareness that depletion in site reserves of organic material, particularly decayed soil wood, can potentially reduce growth rates by reducing ectomycorrhizal and nitrogen-fixing activities. Replacement of the woody soil components lost due to harvesting or fire activity requires time periods from ca. 100 to 300 years. Therefore, harvesting plans, particularly those for dry sites, should be directed toward maintaining modest levels of organic matter, including large woody materials. Even where excessive depletion of woody residue has occurred (for example, sites that have been subjected to repeated and hot wildfires), the potential for soil improvement is considerable. Forest management should encourage the building of organic reserves and the rapid decay of available wood residues.

Table 4.—Mean volumes (m^3/ha/30 cm depth) of soil organic material in three undisturbed, mature forest stands in western Montana

Type of material				Total soil (wood materials only)
0_1 (litter)	0_2 (humus)	0_3 (decayed wood)[1]	0_4 (charcoal)	
Site 1 (PSME/PHMA)[2]				
60.9	304.8	365.8	7.6	373.4
Site 2 (ABLA/CLUN)[3]				
60.9	335.3	365.8	9.1	374.9
Site 3 (TSHE/CLUN)[4]				
152.4	457.2	426.7	2.9	429.7

[1]Considered incorporated in and functioning as soil.
[2]*Pseudotsuga menziesii/Physocarpus malvaceus* habitat type.
[3]*Abies lasiocarpa/Clintonia uniflora* habitat type.
[4]*Tsuga heterophylla/Clintonia uniflora* habitat type.

Table 5.—Derivation of woody residue dispersal rate (calculated by dividing wood production potential by persistent woody reserves) from three undisturbed forest stands in western Montana (m^3/ha)

Soil wood	Nonsoil wood residue	Stand volume	Wood reserves	Stand age	Yield capacity[1] per year	Wood production potential (250 yr)	Wood dispersed[2] (250 yr)	Dispersion (decay) rate[3] per year	Wood accumulation potential[4] per year	Soil wood production time[5]
				Years						*Years*
Site 1 (PSME/PHMA)[6]										
373.4	154.6	242.7	700.8	250	4.9	1224.5	523	2.1	2.8	192
Site 2 (ABLA/CLUN)[7]										
374.9	430.3	299.4	1104.6	250	6.3	1574.4	469.7	1.9	4.4	274
Site 3 (TSHE/CLUN)[8]										
429.7	254.2	[9]311.2	955.1	250	7.7	1924.2	929.1	3.7	4.0	172

[1]Pfister and others 1977.
[2]Dispersal of wood in soil to a point where it is classified as mixed in mineral soil or lost from the system as CO_2 (production potential minus reserves).
[3]Wood dispersed divided by stand age.
[4]Yield capacity minus dispersion rate.
[5]Wood production potential divided by dispersation rate (column 2) times 0.33.
[6]*Pseudotsuga menziesii/Physocarpus malvaceus* habitat type.
[7]*Abies lasiocarpa/Clintonia uniflora* habitat type.
[8]*Tsuga heterophylla/Clintonia uniflora* habitat type.
[9]Includes a 50 percent volume loss to live stem decay in hemlock stems.

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The important properties contributed to forest soils by decayed wood in the Northern Rocky Mountains make it desirable to determine the time required to reconstitute such materials in depleted soils. The ratio of fiber production potential (growth) to total quantity of wood in a steady state ecosystem provides estimates varying from approximately 100 to 300 years, depending on habitat type, for replacement of decayed soil wood. Radiocarbon dating of decayed wood in various stages of incorporation into the soil ranged from 100 to 550 years, depending on site and depth in soil. Species identification of decayed wood indicated that Douglas-fir residue is the most persistent woody material in these Northern Rocky Mountain soils.

KEYWORDS: decay, disintegration, decomposition, recycling, nutrients, fuels, wood residues, soils, ectomycorrhizae, nitrogen fixation, site quality, forest fire, organic reserves

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