NITROGEN DYNAMICS POST-HARVEST: THE ROLE OF WOODY RESIDUES

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Abstract—The role of woody residues in N dynamics in harvested forests has not been fully elucidated. Woody residues have been found to be an N sink, N source, and N neutral in different studies. To understand the implications of each of these scenarios, post-harvest N dynamics in high- and no- woody residue treatments were modeled for a Douglas-fir ecosystem. Nitrogen mineralization in the combined forest floor, soil (to 15 cm depth), and root pools was 122 and 121, kg N/ha/year, in years 1 and 2 after harvest, independent of treatment. When wood was an N sink, 23 kg N/ha/year could be immobilized annually, and about 80 and 100 percent of the N available from forest floor, soil, and roots remained plant or leaching available in high- and no- woody residue treatments, respectively. When wood was a source of N, an additional 12 kg N/ha/year became available from wood in high residue, and 0 in no residue treatment. When wood was neutral, 100 percent of the N mineralized after harvest was plant and/or leaching available in both treatments. Empirical evidence is still necessary to confirm which scenario operates in various forest ecosystems. Implications of these different scenarios for N-saturated ecosystems of the central Appalachians are that as N sink, woody residues could potentially help decrease N exports as nitrate. As N source, woody residues could contribute to N exports. As neutral, woody residues would allow exports of N as they currently occur. This paper reflects on the dynamics of N and woody residues in the Appalachian hardwood forests and provide hypothetical comparisons between these dynamics in western coniferous forests and eastern hardwood forests.

INTRODUCTION

The role of woody residues in N dynamics in forests is not clear. Some of the obstacles to elucidating this role are the length of time involved in wood decomposition and lack of methods for taking into account changes in wood shape and volume over time (Krankina and others 1999). Wood decomposes over such time frames that chronosequences of pieces of unknown age are the only possibility to examine long-term decomposition of large wood. Age is presumed to be related to stage of decay, and stage of decay is described based on morphological characteristics (Fogel and others 1973). Comparison across species and environments is challenging if not impossible, as different conditions give the same morphological results at different lengths of decay. As wood decays, its original shape changes due to tissue subsidence and loss. Therefore assuming a circular shape of wood regardless of its stage of decay is inaccurate (Krankina and others 1999), but is routinely done and used in calculations of nutrient contents (volume X element concentration). Therefore, woody residues can be an N sink or N source, depending on how volume was calculated (Creed and others 2004). While others are resolving these important and difficult issues, this study was undertaken to better understand the implications of two divergent scenarios for post-harvest N dynamics.

Post-harvest N dynamics is of particular interest because of high rate of N turnover in disturbed and exposed soils, which leads to the formation of nitrate. Nitrate is a mobile anion easily leached to lower soil profiles in the presence of water, and exported to water courses where it is a potentially harmful contaminant (Driscoll and others 2003). Such export in the Douglas-fir forests of the Pacific Northwest further decreases ecosystem levels of a nutrient limiting forest productivity. In the north-eastern and central hardwood forests, some of which exhibit N saturation, N export increases total nitrate outputs to water sources. Nitrogen saturation describes a condition in which ecosystem N demand is lower than available N, and N is routinely exported (Aber and others 1989, 1998; Stoddard 1994). Should woody residues be a sink for N, then leaving branches, tree stumps, and other unwanted wood on sites after forest harvesting may be low-cost yet effective means for lowering the rates of N export and protecting water quality.

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Alternatively, if woody residues after harvest increase N exports by serving as an additional N source, then it may be advantageous to remove them for use for example as biomass-based fuels. Therefore, greater understanding of the implications of woody residues' role in different ecosystems will stimulate research in the direction of uncovering the biogeochemistry of nutrient dynamics with and without woody residues.

To accomplish this task, post-harvest N dynamics were modeled in two ecosystems – a Douglas-fir and a central Appalachian hardwood forest. This paper reflects on the dynamics of N and woody residues, and provides hypothetical comparisons between these dynamics in two ecosystems with widely differing N levels.

METHODS

Data from an extensive post-harvest biomass study in Pacific County, Washington were used for model development. A 40-year-old fertilized Douglas-fir/ western hemlock plantation was harvested in 1999 by cable-logging. The high-residue treatment contained all branches left after bole-only removal. The no-residue treatment contained almost no branches due to operational and manual removal. All residues were sampled including forest floor, buried slash, roots to 30 cm depth, and aboveground slash and large debris where present, and dry-weights and their nutrient concentrations were obtained (Piatek and Terry, unpublished).

The potential net N mineralization was estimated for the forest floor plus top 15 cm of soil (combined) using the equations developed by Yin (1992) for a range of forests growing along an environmental gradient from Massachusetts to Washington. The N processes in these equations are driven by average January and July air temperatures, and N content and mean extractable N of litter and soil. Because data on litterfall N was not available, we estimated this further by averaging the higher of the two Douglas-fir litterfall N values used to develop the model and the total N amount in our forest floor divided by 5 years (assumed length of time that litter had collected on the ground without complete decomposition). Nitrogen mineralization from roots was estimated by using percent N release in field- incubated fine roots of Douglas-fir as reported by Chen and others (2002).

Wood N dynamics for Douglas-fir residues from current harvest (older, mostly decayed woody residues were also present) were estimated according to the two possible and divergent scenarios. First, changes in wood mass from decay stage 1 to decay stage 2 were calculated from a known starting mass of fresh stumps and logging residues (75.2 t/ha; Piatek and Terry, unpublished data) by using an average annual decomposition constant for wood density (0.038; Edmonds and Eglitis 1989) applied for 2 years. Carbon content was estimated by multiplying mass by known C concentration (0.49; Piatek and Terry, unpublished data). The ratio of woody residue C, as calculated after 2 years of decomposition, to the original gave the percent C loss due to respiration alone. Second, to better understand woody residue N dynamics under the scenario of wood being a sink for N, N content was increased to 180 percent 2 years after harvest as described by Edmonds and others (1986), and annual N immobilization rate was calculated as the difference between "final" (after 2 years) and original N content divided by 2. Nitrogen concentration after 2 years was calculated by dividing N content by mass, and percent change by comparing to the original. To estimate possible N dynamics under the scenario of wood acting as N source, N content after 2 years was hypothetically lowered by 10 percent from the original, and N concentration and percent change was calculated as for N immobilization above.

A similar process was followed for a hypothetical Appalachian hardwood stand, using published data. Mass of logging residue used was 10 ton/ha, as reported for large residues only (Grushecky and others 1997). Carbon content was estimated by multiplying mass by 0.49 percent C (as for Douglas-fir). Nitrogen content was estimated by multiplying mass by 0.002 percent N, a value measured in Tucker County, WV 85-year-old hardwood forest (Adams and others 2004). A decomposition constant for yellow birch at 0.217 per year was used to estimate mass loss for 2 years (Creed and others 2004). Using the same procedure as above, N immobilization and "release" rates were obtained.

RESULTS AND DISCUSSION

Post-Harvest Potential N Mineralization Rates

Estimated potential net N mineralization rates from the forest floor, soil to 15 cm depth, and roots at the Douglas-fir site was 122 kg/ha in year 1 and 121 kg/ha in year 2 after harvest. There were no treatment differences, and that was most likely the result of using equations based on air rather than soil temperatures. Microbial processes, such as N mineralization, are driven by soil temperature among other factors, and soil temperatures are expected to be higher in the exposed soils of the no-residue compared to the high-residue treatment; therefore, it is highly likely that N mineralization rates in the no-residue treatment were higher during some parts of the year when soil moisture was not limiting.

Hardwood forests generally have higher rates of N turnover than coniferous forests due to the generally higher N content of leaf as compared to needle litter (Piatek and Allen 2001). Therefore Appalachian hardwood forests, especially under high surface soil temperatures of post-harvest sites, may mineralize at very high rates. In an N-saturated forest of central Appalachia these rates were estimated to be 374 kg N/ha/year (Adams and others 2004).

Post-Harvest Woody Residue Mass, and C and N Content

The Douglas-fir high residue treatment contained 75 tons/ha of fresh woody residues with 36 tons/ha of C, and 230 kg/ha of N with an average N concentration of 0.31 percent (Piatek and Terry, unpublished data). The no-residue treatment had none. After 2 years of decomposition, an estimated 71 tons/ha of wood and 35.5 tons/ha of C were still present in the high residue treatment.

When Douglas-fir wood acted as an N sink, an increase of 180 percent in N content over 2 years resulted in an estimated 92 kg/ha/year of N immobilization (table 1). However, this would only be possible if all woody residues were in direct contact with soil, as they were in the study that reported such an increase (Edmonds and others 1986). The soil is the main source of microbial inoculum for N immobilization

Table 1—Estimated N dynamics post-harvest based on 2 years of mass loss in Douglas-fir and Appalachian hardwood forests [a]

Scenario	Residue mass	C	N	N dynamics	N	Change in percent N
	- - - - - - - - - t/ha	- - - - - - - - -		*t/ha/yr*	*percent*	
Douglas-fir post-harvest conditions	75.2	36.9	0.23		0.31	
Wood = N sink	70.8		0.42	0.023[b]	0.59	89
Wood = N source	70.8		0.21	-0.012	0.29	(-) 6
Hardwood forest post-harvest conditions	10.0	4.9	0.02		0.2	
Wood = N sink	6.5		0.036	0.008	0.56	178
Wood = N source	6.5		0.018	-0.001	0.28	39

Wood = N sink represents N dynamics if N mass after 2 years increased 180 percent; Wood = N source represents N dynamics if N mass after 2 years were to decrease by 10 percent.

[a] Post-harvest conditions reflect conditions prior to decomposition.

[b] Estimated N dynamics for all wood in contact with soil was 0.092 t/ha/yr. Here, 25 percent is assumed in contact with soil where immobilization is possible.

in the Pacific Northwest forests as N inputs from atmospheric deposition are minor (Personal communication. 2000. Robert L. Edmonds, Professor, Department of Forest Resources, University of Washington, Seattle, WA 98195-2100). However, large-scale harvesting operations leave large amounts of woody residues that are intertwined with each other in a way that raises pieces at odd angles and often prevents them from lying flat against the soil surface. Woody pieces suspended above ground are assumed to be inert with respect to short-term N dynamics, and 25 percent of all residues present were taken to be in contact with the ground and capable of immobilization. Therefore, the rate of immobilization was adjusted to ¼ of the original estimate to 23 kg/ha/year (table 1).

Using the same procedures as for Douglas-fir, immobilization into hardwood woody residues was estimated at 8 kg N/ha/year. This rate was not further adjusted because the total amount of wood reported after harvest was only 13 percent of the total load of Douglas-fir residues, and individual pieces in a smaller load have greater chances for contact with the soil surface.

When residues acted as an N source, Douglas-fir residues released an estimated 12 kg N/ha/year, while hardwood released 1 kg N/ha/year.

N Immobilization or Release?

With a 90 percent increase in N concentration (a 180 percent increase in N content and including C loss due to respiration), 75 tons/ha of fresh woody residues in a post-harvest Douglas-fir site could potentially immobilize 20 percent of N available from the mineralization in the forest floor, soil, roots, and from atmospheric inputs. Therefore, in the absence of plant uptake, annually 80 percent of the available N could still leach through the soil and be eventually exported from site. By comparison, 10 tons/ha of woody residues in a clearcut in the Appalachian hardwood forest could immobilize only 2 percent of that site's estimated available N, with 98 percent potentially leaching without plant uptake.

When woody residue N dynamics were tested under the source scenario, the Douglas-fir residues contributed an additional 12 kg N/ha/year or almost 10 percent to the mineralization rates from the forest floor-soil-root complex in those treatments where residues were retained. In the no-residue treatments, no additional N would be present. In the Appalachian hardwoods, 1 kg N/ha/year would be added, a trivial proportion of the site's potential net N mineralization.

The large differences between these two sites in the capacity of woody residues to either immobilize or release N are due primarily to the different masses of residues which determined original N content used in these calculations, to wood N concentrations, and potential N mineralization rates from the forest floor-soil-root complex. Also, data accessed and used here for the Appalachian hardwood forest were not as exhaustive and site-specific as for the Douglas-fir forest.

While it may seem unconventional to compare different masses of woody residues, these conditions reflect some of the reality of each ecosystem in terms of growth rates for the species and sites, tree age and size at harvesting, harvesting systems, and wood utilization levels. Representing realistic conditions, given the limitations of data sources, was an objective of this work. At the same time, mass of hardwood residues used in this work included only coarse woody debris of 10 cm and above (Grushecky and others 1997), while the Douglas-fir data included all residues to 0.5 cm in diameter (Piatek and Terry, unpublished data). If mass of hardwood residues was hypothetically set to the same as in the Douglas-fir system (75 ton/ha) and all other parameters remained as in the previous hardwood calculation, then woody residues in the Appalachian hardwoods would be a source of 13 to 16 kg N/ha/year, and immobilization would not be possible.

While the residues' sink activity appeared higher than the source activity for both ecosystems in this modeling exercise, it is important to remember that the sink was estimated based on field data, while the source was somewhat arbitrarily set at 10 percent N release 2 years after harvest. A larger percent release than the one used would increase N release levels from woody residues, but N release would continue to lag behind potential immobilization levels over the same time period due to the smaller N pool for release (original wood N) than for immobilization into wood (the environment).

Woody residues in harvested Douglas-fir forests seem to have a potential capacity to contribute to N dynamics as a sink or a source of N, while woody residues in hardwood forests do not. Given that the Appalachian hardwood forests exhibit some of the highest mineralization rates reported for forested ecosystems, the estimated rates of either mineralization or immobilization by woody residues will not make a significant difference in the overall available N budget, even if residue loads were to increase 7-fold. Only lower rates of N mineralization could increase the relative importance of woody residues' role as an N sink or source.

It has been previously concluded from a review of nutrient dynamics for a range of coniferous forests that woody debris in standing forests plays a minor role in nutrient dynamics (Laiho and Prescott 2004). Estimates for Appalachian forests seem to support these conclusions and expand them into the N-saturated hardwood zone. In the Douglas-fir forests, however, woody residues after harvest appear to be potentially capable of immobilizing about 20 percent of the available N pool, or contribute additional 10 percent, depending on which model is operating. Therefore, for those forests, it will be beneficial to examine in greater detail the biogeochemistry of nutrients in post-harvest woody residues.

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