CONTRIBUTION OF STUMPS TO CARBON AND NITROGEN POOLS IN SOUTHERN APPALACHIAN HARDWOOD FORESTS

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Abstract.—Decomposing stumps are prevalent in managed forest ecosystems although the impact of these microsites on nutrient retention and cycling is relatively unknown. In this study, stumps were defined as the aboveground and belowground (i.e., root system) left over from previous harvests. The objective of this study was to quantify the total soil volume occupied by stumps and compare total soil carbon (C) and nitrogen (N) between the bulk soil and soil directly influenced by decomposing stumps. Six randomly established 10 m x 10 m plots were evaluated. These sites were located in mature hardwood stands on the Jefferson National Forest in the Ridge and Valley Physiographic region of southwest Virginia. Approximately 26 percent and 36 percent of the total soil nitrogen and carbon, respectively, were estimated to be contained within the soil influenced by decomposing stumps. These results suggest that decomposing stumps are influential in forest nutrient cycling.

INTRODUCTION

Soil nutrient availability is variable both temporally and spatially (Nye and Tinker 1977). Plants have evolved to maximize nutrient acquisition by exploiting soil heterogeneity via changes in root proliferation, uptake kinetics and mycorrhizal infections (Drew 1975, Drew and Saker 1975, Fitter 1994, Gile and Carrero 1917, Jackson and others 1990, Robinson 1994). There is tremendous inter- and intra-species variation in root growth as nutrients become available either periodically during the growing season or as roots randomly encounter nutrient-rich microsites. Forest soils are particularly heterogeneous for several reasons. First, the effect of tree species on soil nutrient cycling and soil genesis and the mutual effect of soils on tree development and species composition cause both coarse- and fine-scale heterogeneity (Stone 1975). These changes are difficult to quantify because forests are dynamic entities, often requiring centuries or millennia to produce profound changes on the underlying soil. Secondly, land use history and the anthropogenic impacts (e.g., logging and agriculture) on soil often accelerate changes in soil fertility and soil structure. Lastly, actively managed forests typically occur on land unsuitable for agriculture because of steep slopes, high soil stoniness, and low inherent soil fertility due to underlying parent material. These three factors—species composition, land use history, and various landscape attributes—all contribute to forest soil heterogeneity.

A particular source of heterogeneity that has received little attention is the impact of decomposing stumps have on nutrient storage and availability (Van Lear and others 2000), fine root growth, and microbial biomass. Old root channels, for example, have been known to increase spatial heterogeneity in the soil, which provides optimum conditions for root growth due to: 1) increased transfer of water, nutrients, gases, and humus (Kostler and Bruchner 1968); 2) greater aeration and moisture relations (Lutz and Chandler 1947, Van Rees 1984); and 3) decreased soil strength, which can be extremely important in high density and compacted soils (Bennie 1983). Similarly, it would be expected that decomposing tree stumps and their associated root systems also provide a microsite rich in available nutrients and organic

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matter. Decomposing stumps essentially create an extension of the nutrient-rich O- and A-horizons when compared to the surrounding bulk soil.

The lack of information regarding the impact of stumps on nutrient cycling illustrates the need for more detailed research on these relic features. As most stumps are often remnants of past logging operations, a clearer understanding of the contribution and release of nutrients over time could reduce the use of soil amendments (i.e., fertilizer use) by forest managers as stump frequency increases. Therefore, the objectives of this study were twofold: 1) determine the proportion of total soil volume occupied by remnant stumps in a second-growth hardwood forest; and 2) compare total soil C and total soil N between areas directly under decomposing stumps and the bulk soil (A- and B-horizons).

STUDY AREA

This study was installed on the Jefferson National Forest in the Ridge and Valley physiographic region approximately 8 km west of Blacksburg, VA, in Montgomery County (37°17′38″ N, 80°27′27″ W). The elevation is approximately 670 m and the average annual precipitation is approximately 101.5 cm. Average annual temperature is 10.8 °C, ranging from 0.3 °C in the winter to 20.7 °C in the summer. The forest cover type is predominately white oak (*Quercus alba* L.), black oak (*Q. velutina* Lamb.), and scarlet oak (*Q. coccinea* Muenchh.) with red maple (*Acer rubrum* L.) and several species of hickory (*Carya* sp.) as associates in this mixed hardwood community. Forest soils in this region are often derived from a combination of sandstone and/or shale in residuum or colluvial parent materials. The soil in this study is classified as a Clymer soil series (coarse-loamy, siliceous, active, mesic typic hapludult) with an average soil depth of 68 cm. The forests are second-growth forests approximately 80 to 100 years in age as a product of extensive clearcutting and high-grading practices during the late 19th and early 20th centuries.

MATERIALS AND METHODS

Experimental Design

Six, 10 m x 10 m plots were randomly established on soils classified as the Clymer series. At each plot, the entire forest floor (i.e., leaf litter) was removed so that all decomposing stumps could be easily identified. For this experiment, stumps were classified as the aboveground and belowground (i.e., associated rooting system) portions of the tree remaining after previous harvests or as a result of stochastic events (e.g., disease, insects, etc.) that resulted in a standing stump-like feature. Windthrow or tip-up mounds were not evaluated. At each plot, one bulk soil sample by horizon (i.e., A- and B-horizons) was taken for every decomposing stump identified. The location for each bulk soil sample was determined by dividing each 10 m x 10 m plot into 1 m x 1 m cells labeled 1 to 100. An appropriate number of bulk soil sample locations were randomly selected from this pool based on the number of decomposing stumps identified for a given plot. If a tree, decomposing stump, or other feature resided within a randomly chosen cell then another cell was selected as a replacement. Of primary interest regarding the decomposing stumps is the soil directly underneath, which has been churned and modified by root growth and turnover.

Estimation of Soil Volume Influenced by Decomposing Stumps

A soil push-tube sampling device was used to estimate the extent of soil material influenced by decomposing stumps. Four depth measurements were collected at each cardinal direction to determine the relative extent of soil influenced by the associated root system. Pressure was applied to drive the soil sampler through the stump as deep as possible. If the stump was not highly decomposed to warrant the use of the push-tube through its center, then the sampler was angled at the edge of the stump so that it could be driven into the soil directly under the center of the stump. Qualitative attributes such as changes in soil color were used to determine the extent of the soil influenced by each stump's decomposing root system. In conjunction with the depth measurements, two cross-sectional diameter measurements of the stump were collected. Together, these two measurements, diameter and depth, were inserted into an equation for an elliptical cone which represented the assumed shape of the underlying root system:

$$V = \frac{\pi D^2 S_D}{6} \qquad (1)$$

where

V = volume of soil influenced by a decomposing stump
D = mean diameter of a decomposing stump
S_D = average depth or extent of soil influenced by a decomposing stump

We recognize that all soil is somewhat influenced by roots. In this study only the areas highly affected by decomposing stumps were considered (i.e., major coarse root portion). As the coarse roots decompose, a pronounced coloring of the soil occurs, allowing for an easily identifiable boundary between the decomposing stump and the adjacent bulk soil.

Soil Sampling and Analysis

Bulk Density Determination

A soil bulk density corer was used to obtain samples for determining bulk density (D_b) for each sampling location (n = 2). For the bulk soil, bulk density samples were taken by horizon. All samples were oven dried at 105 °C for 48 hrs and separated into the >2-mm and <2-mm fractions using a 2-mm sieve.

Total C and N Determination

The combustion method was used to determine the concentration of N and C present in the fine-earth fraction (<2-mm) for the bulk soil and decomposing stump samples (Nelson and Sommers 1982) using an Elementar CHNS analyzer (Elementar, Hanau, Germany). Total N and C were expressed in kilograms (kg) and megagrams (Mg) per hectare as follows for the bulk soil:

$$\text{Total N (kg} \bullet \text{ha}^{-1}\text{) or C (Mg} \bullet \text{ha}^{-1}\text{)} = D_b(g \bullet cm^{-3}) * depth(cm) * [\%N\_or\_\%C] * 1000 \qquad (2)$$

Equation 2 is the traditional method for converting concentrations of C and N to a kilogram per hectare basis, where an average horizon thickness (i.e., depth) is used in conjunction with measured soil physical and chemical data. On the other hand, extrapolating C and N concentration data from decomposing stumps required slight modifications because stumps are three-dimensional, have irregular boundaries, and occur intermittently across the landscape. Consequently, total stump volume is used along with bulk density (D_b) and C and N concentration data on a per plot basis (100 m^2) and then extrapolated to a per hectare basis (10,000 m^2). Since carbon totals were extremely high, values were converted to a megagram per hectare basis.

In addition to the examination of total C and N between the bulk soil and soil beneath decomposing stumps, research goals also include examining differences in major macronutrients such as available Mg^{2+}, Ca^{2+}, and K^+, inorganic species of N (NO_3^- and NH_4^+), fine root dynamics, and microbially derived N and

Table 1.— Bulk density and percent carbon and nitrogen soil physical and chemical data for the A- and B-horizons of the bulk soil and decomposing stumps

Soil Sampling Area	Bulk Density (g cm^{-3})		% Carbon		% Nitrogen	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
A-Horizon	1.20A	0.26	2.33B	0.9	0.113B	0.014
B-Horizon	1.55A	0.13	2.01B	0.85	0.116B	0.024
Decomposing Stumps	0.63B	0.21	16.4A	0.15	0.534A	0.095

*Significant differences denoted by different capital letters using Tukey's LSD ($\alpha = 0.05$) for each physical and chemical measurement(s).

Table 2.—Total soil volume of A- and B-horizons and decomposing stumps as well as the proportion of total soil volume, percent C, and percent N comprised by the measured soil sampling areas

Soil Sampling Area	Soil Volume (m^3 ha^{-1})	Total Percent Contribution		
		Soil Volume	Carbon	Nitrogen
A-Horizon	1125	14%	6%	10%
B-Horizon	7100	85%	57%	63%
Decomposing Stumps	103	1%	37%	27%

C. Furthermore, the impact of these stumps on poor versus high-quality sites characterized by different soil types will also be examined.

Statistical Analysis

Paired t-test was used to test for differences in total C and N between the bulk soil and decomposing stumps using an alpha-level of 0.05. Tukey's LSD procedure was also used as a multiple comparisons procedure to test for differences between percent N, percent C, and bulk density for individual horizons within the bulk soil and soil influenced by decomposing stumps using an alpha of 0.05 as well. SAS JMP version 6.0.2 statistical software (SAS Institute Inc., Cary, NC, 2006) was used to analyze these data.

RESULTS

Soil physical and chemical data varied between the bulk soil A- and B-horizons and the decomposing stumps; soil percent C and N were higher for the decomposing stumps, while bulk density was less (Table 1). Only 1.2 percent of the total soil volume was occupied by decomposing stumps (Table 2). However, decomposing stumps account for approximately 36.5 and 27.0 percent of the total soil C and N analyzed, respectively (Table 2).

When total megagrams C and total kilograms of N per hectare were examined, two different C and N pools were estimated. One pool included the total C and N found collectively in the A- and B-horizons only, and the second pool included the total C and N found in both the stumps and the A- and B-horizons, respectively (Figs. 1 and 2). When stumps were included in C and N estimations, total soil volumes for the A- and B-horizons were adjusted based on the soil volume influenced by stumps using Eq. [1].

Total soil C estimates for the A- and B-horizons were approximately 281 megagrams of C per hectare, where the A-horizon contained 31 Mg of C and the B-horizon 250 Mg of C per hectare, respectively

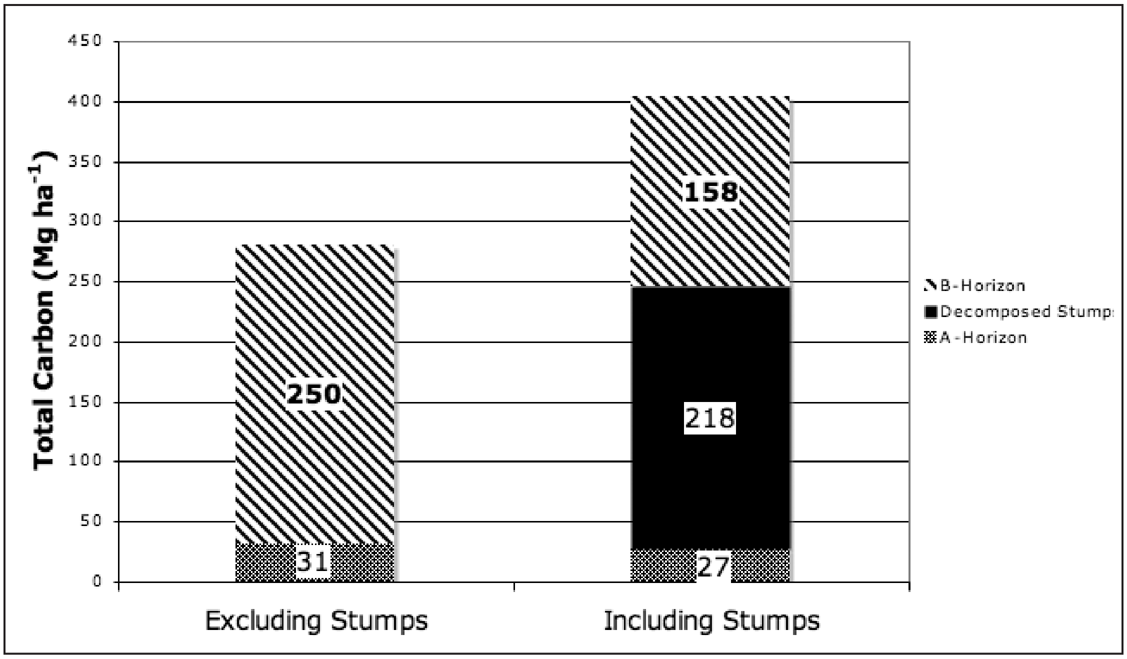

Figure 1.—Total soil carbon pools for estimates excluding and including decomposing stumps for soils on the Jefferson National Forest, Blacksburg, VA.

(Fig. 1). Conversely, when soil volume was adjusted to include the stumps in addition to the A- and B-horizons, total soil C was 403 Mg per hectare (Fig. 1). When examined individually, the A-horizon contained 27 Mg of C and the B-horizon 158 Mg of C. Stumps contained 218 Mg of C per hectare, which was significantly greater than C values that excluded soil influenced by decomposing stumps ($p = 0.03$).

For soil N estimates the A- and B-horizons contained approximately 13,622 kg of N per hectare with the A-horizon containing 1795 kg of N and the B-horizon 11,827 kg of N per hectare (Fig. 2). On the other hand, when soil volume was adjusted to include stumps in addition to the A- and B-horizons total soil N was 16,897 kg of N per hectare (Fig. 2). When examined individually, the A-horizon contained 1570 kg of N, the B-horizon 10,343 kg of N. Stumps contained 4984 kg of N per hectare, which was also significantly more than estimates that excluded soil influenced by decomposing stumps ($p = 0.03$).

DISCUSSION

Decomposing stumps accounted for 36.5 percent of the total soil C (Table 2), which suggests that global C stocks for forested ecosystems may be significantly underestimated if these relic features are not included. The decomposition stage of these stumps could also have an effect on the amount of labile C. For example, stumps that have undergone very little decomposition will likely have higher C:N ratios and lower potential N mineralization rates, whereas older more heavily decomposed stumps would likely have lower C:N and thus higher N mineralization rates and N availability (Van Lear and others 2000). Decomposing stumps accounted for 27.0 percent (4984 kg ha^{1}) of the total N (Table 2 and Fig. 2) found within the A- and B-horizons, which is a substantial amount of N when this nutrient often limits productivity in many forested ecosystems. These findings show that significant amounts of N and C are present in stumps. Perhaps other major nutrients such as Mg, Ca, P and K may also be contained within these stumps (Van Lear and others 2000).

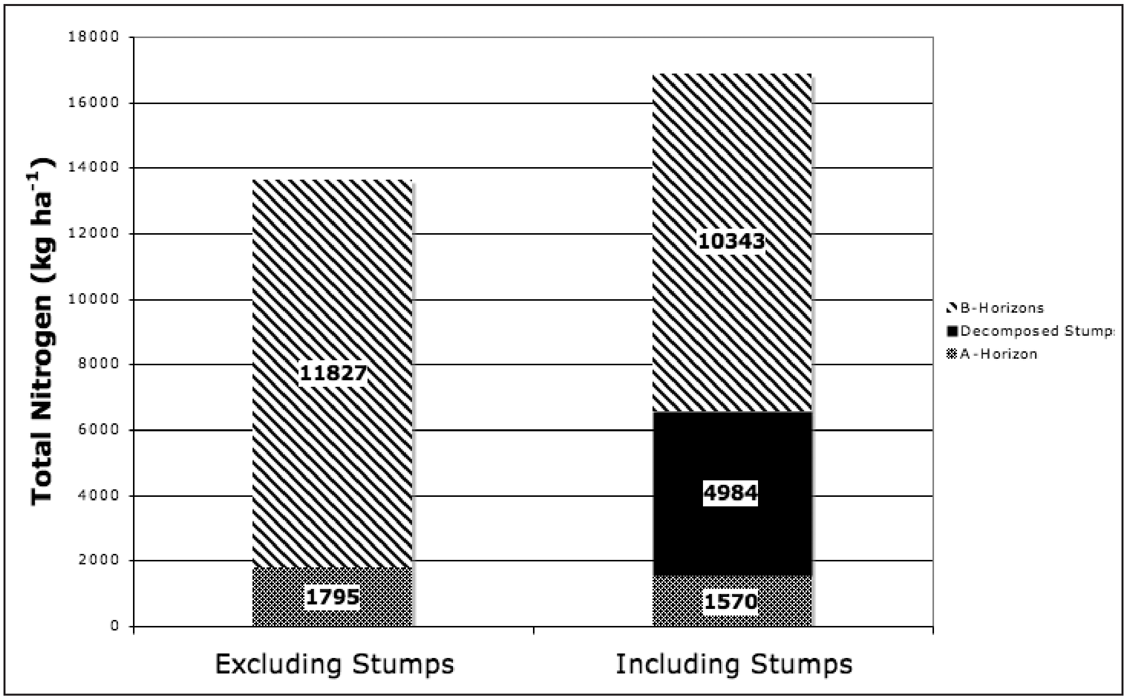

Figure 2.—Total soil nitrogen pools for estimates excluding and including decomposing stumps for soils on the Jefferson National Forest, Blacksburg, VA.

Van Lear and others (2000) examined the impacts decaying stumps have on site productivity of loblolly pine (*Pinus taeda* L.). This particular study showed that loblolly pine productivity and rooting density increased for trees in closer proximity to old decaying stumps. Elemental concentrations of C (C), N, Mg, Ca, and P were seven to 40 times higher in decomposing root systems/stumps than in the root/soil interface and soil matrix, respectively. Tree roots often extend to lengths two to seven times greater than the height of the tree; however, the area directly surrounding the tree stump provides the majority of beneficial attributes associated with decomposition processes (Van Lear and others 2000). In addition, these rich microsites provide a habitat ideal for microorganisms. In the early phases of decomposition, there is an increase in C which results in high C:N ratios and lower nutrient availability; however, as decomposition progresses and the C:N ratio declines, nutrient availability increases due to rapid mineralization (Van Lear and others 2000). This pattern emphasizes the importance of examining decomposing stumps following harvest or mortality.

Decomposing stumps represent microsites rich in nutrients. Plants in close proximity to these stumps may have a competitive advantage over other plant species that are farther away (Van Lear and others 2000). Plant communities adapted to sites with either high or low nutrient availability may benefit differently from decomposing stumps. Plants occurring on poor quality sites are often adapted to taking advantages of short pulses of increased resource availability (e.g., decomposing stumps), but are not as adapted to exploiting increases in nutrient availability when supplied for long periods (Campbell and Grime 1989, Crick and Grime 1987, Grime and others 1986). This adaptation to heterogeneous environments for plants occurring on low quality sites can be attributed to: 1) the overall low nutrient demand to obtain optimal growth; and 2) the relatively slow root turnover rate and lower risk of nutrient loss (Crick and Grime 1987). On the contrary, plants adapted to fertile environments are more responsive to a sustained supply of nutrients (i.e., relatively homogenous soil environments) and often have higher tissue turnover, dry mass allocation, and nutrient absorption rates than plants occurring on infertile sites (Campbell and Grime 1989), but these values are lower when the plants are grown on infertile sites. Therefore, decomposing stumps may be more important on sites with lower site quality where plants are adapted to taking advantage of heterogeneous supplies of nutrients than plants found on high quality sites.

CONCLUSIONS

Tree stumps and the underlying root systems can contain as much biomass as the overstory portion of trees. These results initially suggest that decomposing stumps are influential in forest nutrient cycling and that a stratified sampling scheme versus conventional random sampling may help forest scientists better understand the role of soil heterogeneity. Thus, more comprehensive research investigating the influence of stumps is required.

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