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Carbon and nitrogen release from tree stumps in boreal clear-cut forests

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ABSTRACT

Stumps are the biggest coarse woody debris component in managed forests. Their role in nutrient cycling is, however, poorly understood. Recently the request for such information has grown since the use of stumps as energy wood increases rapidly. We studied C and N dynamics in Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), and silver birch (*Betula pendula* Roth.) stumps, which had decomposed for 0, 5, 10, 20, 30 and 40 years after clear-cutting in southern Finland. We found that in 40 years conifer stumps lost 80 % and birch stumps 90 % of their initial C. The amount of N in stumps increased during decomposition. After 40 years of decomposition, the amount of N was 1.7 and 2.7 times higher than the initial amount in pine and spruce stumps, respectively. Nitrogen was released from birch stumps, but not until they had decomposed for 20 years or longer. The increase of N amount in stumps could result from the translocation of N by fungi from the surrounding soil and from the fixation of atmospheric N by bacteria living in stumps. The results indicate that the stumps of the major tree species in Fennoscandian forests are long-term C and, especially, N pools, and they act as N sinks potentially diminishing N leaching into ground water and watercourses after clear-cutting. This suggests that the removal of stumps may markedly affect the nutrient status and nutrient cycling of boreal forests.

KEYWORDS: carbon, coarse woody debris, decomposition, energy wood, nitrogen, stump

INTRODUCTION

Stumps are the biggest coarse woody debris (CWD) component, which is normally left to decompose in Fennoscandian forest stands after clear-cutting. In mature stands stumps account for 15-20 % of carbon (C) and 8-15 % of nitrogen (N) found in tree biomass (Mälkönen 1975, Kubin 1977, Finér et al. 2003). The use of stumps as energy wood has increased rapidly (Röser et al. 2008). For example in Finland, the area of stump harvesting increased by 50 per cent from year 2006 to 2007 (Peltola 2008). Currently, 0.3 million m^3 of stumps are harvested annually in Finland. The importance of stumps as a nutrient source during stand development and their role in ecosystem C budget and nutrient cycling are largely unknown. Consequently, the effects of the removal of stumps on soil carbon and nutrient pools, site fertility and nutrient cycling cannot yet be predicted with confidence. Stumps can be important C pools and long-term sources of nutrients because they decompose slowly (Shorohova et al. 2008a, 2008b). Nitrogen generally limits the decomposition of wood. Therefore, N is immobilised by microbes, and concentrations and amounts of N in CWD generally increase during decomposition (Laiho and Prescott 2004). The accumulation of N may be due to translocation from soil by fungal hyphae (Berg 1988, Boddy and Watkinson 1995), the fixation of N_2 by nonsymbiotic micro-organisms (Granhall and Lindberg 1980, Jurgensen et al. 1987), and the immobilization of mineral N from rainwater (Downs et al. 1996). Nitrogen accumulation in CWD has been suggested to be an important mechanism of nutrient retention which may diminish N leaching after disturbances and maintain site fertility and productivity (e.g. Harmon and Hua 1991, Brais et al. 2006). Our aim was to study C and N release from decomposing Scots pine, Norway spruce and silver birch stumps, and find out whether they act as N sinks.

METHODS

Samples were collected from 0, 5, 10, 20, 30 and 40 years old clear-cut areas located in Orivesi, Längelmäki, Kuorevesi and Evo-Vesijako (61 ºN, 25 ºE) in southern Finland. The mean annual air temperature is + 3.1 ºC, the length of growing season 160 days, and the amount of precipitation 670 mm. The bedrock consists of orogenic granitoids and is covered with a till. The sites are medium rich *Vaccinium myrtillus* type according to the classification of Cajander (1949). The dominant tree species before clear-cutting was Norway spruce (*Picea abies* (L.) Karst.) mixed with Scots pine (*Pinus sylvestris* L.) and birches (*Betula pendula* Roth. and *B. pubescens* Ehrh.). Sites were mechanically prepared and planted with Norway spruce after clear-cutting. The height, base and top diameters of stumps were measured and their volumes were calculated. Average diameter of stumps varied from 18.6 cm to 38.0 cm. Samples of regular shape were taken from stump wood (n = 8-12 for pine, n = 15-22 for spruce, and n = 3-13 for birch), and their height, length and thickness were measured. The samples were oven-dried at 103°C for 48 h, weighed and their bulk density was calculated. The mass of stump wood was calculated by multiplying volume with bulk density. The decomposition of bark was analyzed as following. The lateral surface area of stumps *(S)* was calculated by the formula:

$$S = \pi L (R+r), \qquad (1)$$

where L is the slant height of a cone in metres and R and r are the maximum and minimum radii, in metres, respectively. Bark fragmentation was taken into account by visually estimating the percent cover of bark remaining on a stump (f). Total area of remaining bark (Sf) was determined by multiplying S with f. Bark samples (n = 4-12 for pine, n = 4-22 for spruce and n = 3-13 for birch) were taken from each stump and their height, width and mass were determined. The specific mass of bark (M_b) was calculated by dividing the dry mass of bark sample by the area of the sample. The total mass of stump bark was calculated by multiplying the total area of remaining bark (Sf) with the specific mass of bark (M_b). The concentrations of C and N were determined from milled samples with a LECO CHN-1000 analyzer (LECO Corporation, St. Joseph, Michigan). The amounts of C and N in stump wood and stump bark were calculated by multiplying concentrations at the time t by dry mass at time t. Total C and N amouts in stumps was calculated as the sum of wood and bark C and N amounts and were expressed as a percentage of the initial amount (average of the stumps that were sampled 0 years after clear-cutting). Differences in the amounts of C and N between tree species were analysed with a general linear model. The study sites, sampling and data processing are described in more detail by Shorohova et al. (2008a, 2008b).

RESULTS AND DISCUSSION

Carbon and N were released significantly faster ($p < 0.05$) from birch stumps than from conifer stumps (Figure 1). In 40 years, conifer stumps lost 78 % and birch stumps 90 % of their initial C. In contrast, the amount of N in stumps increased during decomposition. After 40 years of decomposition, the amount of N was 1.7 and 2.7 times higher than the initial amount in pine and spruce stumps, respectively. Nitrogen was released from birch stumps, but not until they had decomposed for 20 years or longer. On average, 59 % of N stored in birch stumps was released during 40 years. The increase of N content in stumps could result from the translocation of N by fungi from the surrounding soil (Berg 1988, Boddy and Watkinson 1995) and from the fixation of atmospheric N by bacteria living in stumps (Granhall and Lindberg 1980, Jurgensen et al. 1987).

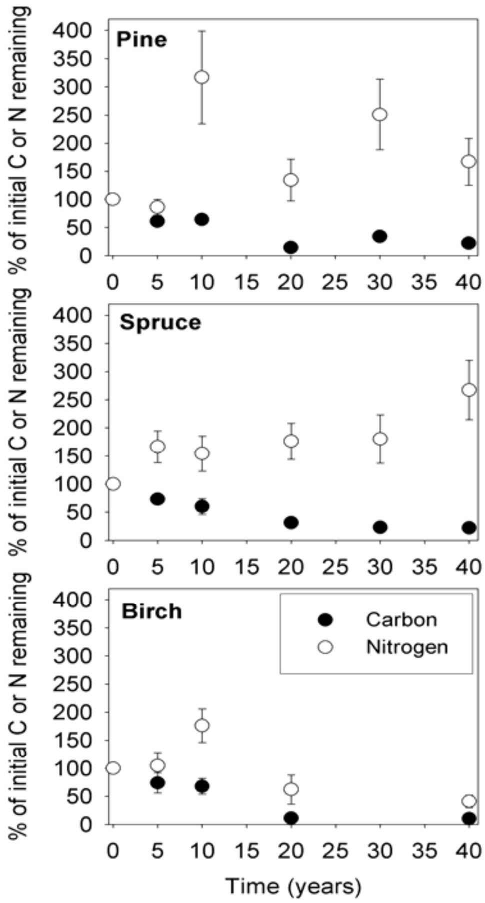

Figure 1. The amount of carbon and nitrogen as a percentage of initial amount in Scots pine, Norway spruce, and silver birch stumps after various periods of decomposition. Values are means ± SE.

The results showed that stumps are like branches accumulating external N during decomposition, but different from fine roots which release C and N rapidly after clear-cutting (Palviainen et al. 2004). The results indicate that Scots pine, Norway spruce and silver birch stumps are long-term C pools and potential sources of N for the next tree generation, and they act as a N sink for a long time possibly diminishing N leaching after harvesting. Stumps may thus markedly affect the nutrient status and nutrient cycling of boreal forests and this should be considered when the ecological effects of stump harvesting is evaluated.

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