Nitrogen immobilization by wood-chip application: Protecting water quality in a northern hardwood forest

Peter M. Homyak [a],[*], Ruth D. Yanai [b], Douglas A. Burns [c], Russell D. Briggs [b], René H. Germain [b]

[a] Department of Environmental Sciences, University of California, Riverside, 900 University Avenue, Riverside, CA 92521, United States
[b] SUNY College of Environmental Science & Forestry, 1 Forestry Dr., Syracuse, NY 13210, United States
[c] US Geological Survey, 425 Jordan Road, Troy, NY 12180, United States

Abstract

Forest harvesting disrupts the nitrogen cycle, which may affect stream water quality by increasing nitrate concentrations, reducing pH and acid neutralizing capacity, and mobilizing aluminum and base cations. We tested the application of wood chips derived from logging slash to increase immobilization of N after harvesting, which should reduce nitrate flux to streams. In August 2004, a stand of northern hardwoods was patch-clearcut in the Catskill Mountains, NY, and four replicates of three treatments were implemented in five 0.2-ha cut patches. Wood chips were applied to the soil surface at a rate equivalent to the amount of slash smaller than eight inches in diameter ($1\times$ treatment). A second treatment doubled that rate ($2\times$), and a third treatment received no chips ($0\times$). Additionally, three uncut reference plots were established in nearby forested areas. Ion exchange resin bags and soil KCl-extractions were used to monitor nitrate availability in the upper 5–10 cm of soil approximately every seven weeks, except in winter. Resin bags indicated that the wood chips retained 30% or 42% of the nitrate pulse, while for KCl extracts, the retention rate was 78% or 100% of the difference between $0\times$ and uncut plots. During the fall following harvest, wood-chip treated plots had resin bag soil nitrate concentrations about 25% of those in $0\times$ plots ($p = 0.0001$). In the first growing season after the cut, nitrate concentrations in wood-chip treated plots for KCl extracts were 13% of those in $0\times$ treatments ($p = 0.03$) in May and about half those in $0\times$ treatments ($p = 0.01$) in July for resin bags. During spring snowmelt, however, nitrate concentrations were high and indistinguishable among treatments, including the uncut reference plots for resin bags and below detection limit for KCl extracts. Wood chips incubated in litterbags had an initial C:N of 125:1, which then decreased to 70:1 after one year of field incubation. These changes in C:N values indicate that the wood-chip application can potentially immobilize between 19 and 38 kg N ha^{-1} in the first year after harvesting, depending on the rate of wood-chip application. Our results suggest that the application of wood chips following harvesting operations can contribute to the protection of water quality and warrant additional research as a new Best Management Practice following cutting in regions that receive elevated levels of atmospheric N deposition.
© 2008 Elsevier B.V. All rights reserved.

Keywords: Water quality; Wood chips; C:N ratio; Nutrient cycling; Forest harvesting; Northern hardwood forest

1. Introduction

Intensive harvesting disrupts the nitrogen (N) cycle of forested ecosystems (Hendrickson et al., 1989; Aber et al., 2002), which can have negative impacts on stream water quality through reduced plant nutrient uptake and a resulting increase in the export of nitrate to streams (Hornbeck et al., 1986; Burns and Murdoch, 2005). Because nitrification is an acidifying process (Driscoll and Schaefer, 1989; Murdoch and Stoddard,

1992), intensive harvesting can cause other changes in water quality such as a lowering of pH and acid neutralizing capacity (ANC) and mobilization of aluminum and base cations from forest soils (Hornbeck et al., 1986; Martin et al., 2000; Burns and Murdoch, 2005).

Changes in stream chemistry after forest harvesting are of special concern in areas with elevated N deposition (Fenn et al., 1998), such as the Catskill Mountains in New York (NY), where N in wet deposition is among the highest in the US (6–7 kg N ha^{-1} year^{-1}) (NADP, 2006). Watersheds in this region are particularly sensitive to forestry operations; harvesting has been shown to induce high rates of nitrate leaching (Burns and Murdoch, 2005; Wang et al., 2006). In

---

* Corresponding author. Tel.: +1 951 827 3404.
  E-mail address: peter.homyak@email.ucr.edu (P.M. Homyak).

northern hardwoods, such water-chemistry changes are typically greatest during the first two years after forest harvesting (Hornbeck and Kropelin, 1982; Hornbeck et al., 1986; Martin et al., 2000).

Previous studies have documented the effects of forest harvesting in areas of elevated N deposition (Hornbeck and Kropelin, 1982; Hornbeck et al., 1986; Dahlgren and Driscoll, 1994). Following a 24-ha clearcut in the Catskill Mountains, stream water nitrate concentrations rose to 1400 μmol L^{-1} from background levels of 20 μmol L^{-1} during the first year after cutting (Burns and Murdoch, 2005). Not only did nitrate concentrations rise above EPA water quality standards of 710 μmol L^{-1} (EPA, 2002), but inorganic monomeric aluminum was mobilized from soils into stream water where it reached toxic levels and caused the death of brook trout held in bioassay cages (Baldigo et al., 2005). Likewise, at a nearby shelterwood cut, adverse changes in stream chemistry were detected despite the removal of only 33% of tree basal area (Wang et al., 2006). In this case, inorganic monomeric aluminum concentrations also rose briefly to toxic levels after the cut. Clearly, the design and implementation of post-harvest land management practices designed to minimize adverse water-chemistry changes are warranted.

Best Management Practices (BMPs) have been used to minimize the negative effects of harvesting on forested ecosystems and water resources (Martin and Hornbeck, 1994; Nyland, 2002). These practices have addressed water quality primarily by minimizing the export of sediments to streams through the protection of stream crossings, riparian areas, and forest soils (Martin, 1988). None of the well known and frequently practiced BMPs directly addresses the disruption of nutrient cycling that results in changes in nitrate, pH, ANC, and inorganic monomeric aluminum concentrations in streams.

Nitrate concentrations in forested streams in the Catskill Mountains generally range from 5 to 40 μmol L^{-1} during the summer, but can increase to 100 μmol L^{-1} or greater during snowmelt (Murdoch and Stoddard, 1992; Lovett et al., 2000). However, every October, coincident with leaf fall, stream water nitrate concentrations typically fall below detection ($\sim$1 μmol L^{-1}) (Murdoch and Stoddard, 1993). Dissolved organic carbon freshly derived from leaves is readily available to microbial communities and associated with microbial immobilization of nitrate (Sobczak et al., 2003). These observations suggest that a practice that increases the immobilization of N in the forest floor by adding material high in C:N after logging may reduce nitrate flux to streams and limit associated adverse water chemistry changes.

Many studies support the notion that high soil C:N ratios are correlated with low rates of nitrification and reduced N losses. At the Hubbard Brook Experimental Forest in New Hampshire, high C:N ratios in soil organic matter were inversely correlated with net nitrification rates, suggesting that nitrification was limited by low ammonium (NH$_4$$^+$) supplies or by factors such as low pH or tannins associated with a high C:N (Venterea et al., 2003). In another study in a Mediterranean shrubland, wood shavings mixed with the litter layer decreased the availability of mineral N in the soil, suggesting an increase in N

immobilization (Gallardo and Merino, 1998). In soils across a 100-year chronosequence of upland hardwood stands in Indiana, a high C:N ratio of woody debris was associated with increased rates of N immobilization (Idol et al., 2003). In a conifer plantation in Japan, sites with added slash had lower nitrate concentrations in soils than sites where slash was removed (Takahashi and Ikeda, 1994). Across New Hampshire, stream nitrate export was inversely related to the ratio of dissolved organic carbon to dissolved organic nitrogen (Goodale et al., 2000). Lastly, a study in the central Appalachians showed how two adjacent watersheds with similar N inputs differed in nitrate outputs because of differences in soil C:N ratios; the watershed with the lower C:N ratio exported more nitrate (Christ et al., 2002).

In this study, we used wood chips derived from logging slash to test whether the addition of organic material high in C:N to forest soils after harvesting would have potential as a new forestry BMP. We hypothesized that wood-chip treated sites would have lower nitrate and ammonium concentrations in the upper 5–10 cm of soil than those receiving no chips, in the year following forest harvest. To measure the success of the wood chips at reducing nitrate and ammonium, we used two levels of wood-chip application and compared them to sites with no chips and uncut reference sites. We monitored nitrate and ammonium with ion-exchange resin bags and soil-KCl extractions. Additionally, we monitored wood-chip decomposition rates with litterbags as a separate estimate of the potential of this material to immobilize N. We also measured nitrification rates in the wood chip mix in laboratory incubations. Finally, we measured soil temperature and moisture in treatment plots to assess whether these environmental variables explained changes in net N mineralization.

2. Materials and methods

2.1. Site description

The study site is located at the Frost Valley YMCA Model Forest in the Catskill Mountains, NY (Fig. 1). The Model Forest lies in the Neversink River basin, which is part of the New York City Catskill/Delaware water supply system. The research site is dominated by a northern hardwood forest with a basal area (BA) of 30.5 m^2 ha^{-1} and relative density of 107%. The study site is predominantly composed of yellow birch (*Betula alleghaniensis* Britton.; BA = 16.3 m^2 ha^{-1}), sugar maple (*Acer saccharum* L.; BA = 6.9 m^2 ha^{-1}), red maple (*Acer rubrum* L.; BA = 2.0 m^2 ha^{-1}), and American beech (*Fagus grandifolia* Ehrh.; BA = 1.0 m^2 ha^{-1}). The mean annual temperature at the Slide Mountain weather station in Ulster County, NY, approximately 2 km from our site, is 4.9 °C with an annual precipitation of 1565 mm (NRCC, 2005), of which 20–25% falls as snow. Average yearly runoff is estimated at 970 mm, of which 32% occurs during late winter – early spring (March–April), and only 28% occurs during May through September (Firda et al., 1995).

Soils are mapped as bouldery silt loams in the Arnot–Oquaga–Lackwanna association. These soils are lithic and