Effects of clear-cutting on nitrogen leaching and fine root dynamics in a cool-temperate forested watershed in northern Japan

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Abstract

Stream and soil solution chemistry, fine root biomass and soil nitrogen processing before and after clear-cutting of trees and subsequent strip-cutting of understory vegetation, dwarf bamboo (*Sasa senanensis*), were investigated to understand the effect of these disturbances on biogeochemical processes on forested watershed in northern Japan. Tree-cutting did not cause a significant increase of nitrate (NO_3^-) concentration in stream water during the growing season after the cutting. Subsequent *Sasa*-cutting caused significant increase of stream NO_3^- concentration to ca. 15 μmol L^{-1}. There was no significant change of stream pH following both cuttings. NO_3^- concentration in soil solution increased after both cutting, but the change of concentration was higher (>100 μmol L^{-1}) after the *Sasa*-cutting than after the tree-cutting. In a riparian conserved area, on the other hand, NO_3^- in soil solution remained low after tree-cutting, suggesting the riparian area acted as a NO_3^- sink after the tree-cutting. There was no significant change in total biomass of fine roots after the tree-cutting because of an increase in *Sasa* root biomass despite a decrease in tree roots. The subsequent *Sasa*-cutting caused a 50% decrease of fine root biomass compared to that in the un-cut *Sasa* site. These results suggested that nitrogen uptake by *Sasa* was very important in preventing nitrogen leaching after tree-cutting, and decline of this nitrogen uptake after *Sasa*-cutting lead to marked NO_3^- leaching to the stream.

1. Introduction

Clear-cutting disturbs N cycling by hindering nitrogen uptake and/or producing large episodic inputs of fresh litter to soil, which leads to NO_3^- leaching and acidification of stream water (Likens et al., 1970; Vitousek and Melillo, 1979; Swank et al., 2001). However, the magnitude of increase in stream NO_3^- associated with clear-cutting has largely varied among ecosystems, ranging from about 20 μ mol L^{-1} (Swank et al., 2001) to about 1000 μ mol L^{-1} (Likens et al., 1970).

The response of N cycling to cutting varies among sites, depending on a variety of factors that stimulate N mineralization and inhibit N loss (Vitousek and Melillo, 1979; Vitousek et al.,

1982). The different biotic (including vegetation and micro-organisms) and abiotic (climate, geology, hydrology and so on) factors create different responses of N cycling to clear-cutting.

In forest ecosystems in northern Japan, dense dwarf bamboo (*Sasa senanensis* and *Sasa kurilensis*) grows as understory vegetation. Although it has been well established that *Sasa* often inhibit forest regeneration and succession (Noguchi and Yoshida, 2004), the role of *Sasa* on biogeochemical cycles has not been well-clarified. In particular, nutrient uptake of *Sasa* has not been quantified due to the technical difficulties in field investigation. Since fine root dynamics are closely related to nutrient uptake and detritus supply in soil, the investigation of fine root dynamics, especially of *Sasa*, is important when understanding the change of nutrient uptake of vegetation after the clear-cutting in Japanese forested ecosystems.

In northern Japan, trees are mainly cut when there is a snowpack for ease of the logging operation. As a result, *Sasa*

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is protected from disturbance. *Sasa* is often strip-cut to allow for seedlings plantations after cutting. These disturbance regimes affecting *Sasa* would cause unique characteristics of ecosystem response after clear-cutting and *Sasa* strip-cutting.

The purpose of this study was to clarify the effects of clear-cutting and subsequent removal of *Sasa* on N leaching in cool-temperate forested watershed with dense *Sasa* understory vegetation. We expected the decrease of N uptake by plants would be compensated with an increase of *Sasa* growth after tree-cutting. More specifically, our research questions were: (1) how does NO_3^- concentration in stream and soil solution respond to clear-cutting and subsequent *Sasa* strip-cutting? (2) Do clear-cutting and *Sasa*-cutting alter fine root biomass of tree species and *Sasa*?

2. Materials and methods

2.1. Site description

The study was conducted in a cool-temperate forested watershed (8 ha) in Teshio Experimental Forest of Hokkaido University in northern Japan (45°03′N, 142°06′E). Prior to clear-cutting, predominant overstory species were fir (*Abies sachalinensis*), birch (*Betula ermanii* and *Betula platyphylla* var. japonica) and Mongolian oak (*Quercus mongolica* var. grosserrata) (Koike et al., 2001). The forest floor was covered with dense understory vegetation, dwarf bamboo (mainly *S. senanensis* at flat area and partly *S. kurilensis* at steep riparian slope). Bedrock is sedimentary rock of the Cretaceous period. Soil is gleyic Cambisols (FAO, 1988) and Typic Dystrochrepts (USDA Soil Taxonomy, 1994), with about 10 cm of O horizon, 20 cm of A horizon and about 30 cm of B horizon. Mean annual air temperature was 5.6 °C while mean annual precipitation was 1170 mm, of which 30% was snow. Inorganic N deposition was ca. 5 kg N ha^{-1} year^{-1} in the studied watershed (unpublished data).

2.2. Clear-cut and Sasa strip-cut treatment

From January to March 2003, all trees were clear-cut in the entire watershed except for the riparian area and slope (about 13 m width from stream). *Sasa* were conserved as a result of the cutting treatment in the snowpack season. Logs were transported outside of the basin and detritus (including shoots, twigs and leaves) were left in the basin. In October 2003, *Sasa* were strip-cut into 4-m rows by crushing and spreading. The area with the *Sasa* strip-cut was ca. 50% of the total tree-cut area in the watershed. Larch seedlings were then immediately planted in the *Sasa* strip-cut line.

2.3. Stream water and soil solution

Stream water was sampled at the weir located at the outlet of the watershed every 2 weeks during 2002–2004. Soil solution was sampled using tension-lysimeters with ceramic porous cups at 10, 20 and 40 cm depth at the clear-cut area (un-cut *Sasa*) and riparian slope area on the same date as the stream water collection.

After the measurement of pH using a glass electrode, water samples were filtered through a 0.7 μm GF/F filter and kept below 4 °C prior to further chemical analysis. Ion concentrations of major anions (Cl^-, NO_3^-, SO_4^{2-}) and cations (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}) were analyzed using ion chromatography (DX-500, Dionex Inc., USA) after the additional filtering with a 0.2 μm membrane filter. Dissolved inorganic carbon (DIC) was analyzed using a total carbon analyzer (TOC-5000, Shimadzu Inc., Japan). HCO_3^- concentration was calculated from the DIC concentration and pH (Buurman et al., 1996).

2.4. Fine root biomass

Fine roots (<5 mm) were collected from surface soil (0–15 cm depth) using a soil auger in June, September and October 2003 and October 2004, washed using water to exclude soil material, dried (70 °C) and weighed to determine the fine root biomass at three plots; the cut *Sasa* and un-cut *Sasa* sites in the cut watershed and control site (no clear-cutting) near the cut watershed. Sampled roots were discriminated by vegetation (*Sasa* and trees) and diameter (<0.5, 0.5–5 mm). Fine root biomass was quantified for trees and *Sasa* separately with different diameters.

2.5. N mineralization and nitrification rate

Since *Sasa* was strip-cut in fall, the analysis of nitrogen processing in soil during the dormant season is important in understanding N leaching to the stream after the strip-cutting. Net N mineralization and nitrification rate during the dormant period were determined using the in situ buried-bag method as mentioned below. Soils of 0–15 and 15–30 cm depth was collected at the same three plots for fine root investigation (cut *Sasa*, un-cut *Sasa* and the control site) in October 2004, 1 year following the strip-cut of *Sasa*. Soils were sieved (2 mm) and roots and coarse organic matter were discarded. The fresh soil (10 g) was extracted using 2 M KCl (50 mL). NH_4^+ and NO_3^- in the extracted solution were analyzed using an auto analyzer (AACS-4, BL-TEC Inc., Japan). For net N mineralization and nitrification measurements, soils were packed into vinyl bags and buried again for incubation in situ. The buried bags were sampled in May 2005 when snow disappeared. Net ammonification and net nitrification rate were calculated as the difference of NH_4^+ and NO_3^- pool between before and after in situ incubation, respectively.

3. Results and discussion

3.1. Stream water chemistry

Before tree-cutting, mean NO_3^- concentration in stream water was very low (<1.0 μmol L^{-1}). After tree-cutting, it remained at a low level, and there was no discernible difference in NO_3^- concentration in stream water before and after the clear-cutting of trees. Just after the *Sasa*-cutting, however, stream NO_3^- concentration began to increase and the mean concentration in 2004 was significantly higher ($P < 0.001$) than that in
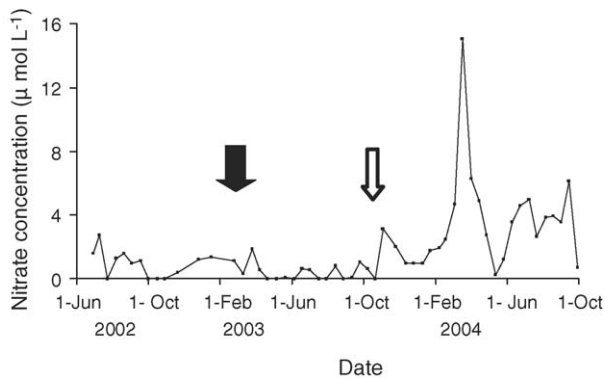
Fig. 1. Temporal fluctuation of NO_3^- concentration in stream water before and after clear-cutting of trees and subsequent *Sasa* strip-cutting. Solid and open arrow denote the period of clear-cutting of trees and *Sasa* strip-cutting, respectively.

2003 (Fig. 1), suggesting that the *Sasa*-cut treatment induced NO_3^- leaching to the stream. Stream NO_3^- concentration peaked (15 μmol L^{-1}) during the next snow-melting period (March 2004) and had subsequent higher values during the 2004 growing season compared to that observed before strip-cutting of *Sasa*. NH_4^+ in steam water was almost below the detection limit. The stream pH was almost neutral, and concentrations of HCO_3^- and major cations were relatively high during entire study period with 6.76 (±0.36S.D.) for pH, 368 (±308S.D.) μmol L^{-1} for HCO_3^- and 53 (±28S.D.) μmol L^{-1} for Ca^{2+}, respectively. There were no significant change in the pH and concentrations of HCO_3^- and cations in stream water after both cuttings (data are not shown) despite an increase in stream NO^{3-} concentration after *Sasa*-cutting (Fig. 1), indicating that the ecosystem had enough capacity to neutralize protons produced through NO_3^- production in soil even after *Sasa*-cutting.

3.2. Soil solution chemistry

Although the tree-cutting did not induce an increase in stream N leaching (Fig. 1), NO_3^- concentration in soil solution increased to a maximum of about 30 μmol L^{-1} after the tree-cutting of 2003, showing that the elimination of nutrient uptake by trees enhanced nitrification in the soil. In 2004, after the *Sasa*-cutting, there was a further increase in NO_3^- concentration in the solution (Fig. 2), suggesting that the *Sasa*-cut treatment promoted further nitrification in soil.

In the slope area surrounding the riparian zone, there was no increase in NO_3^- concentration in 2003 after tree-cutting, suggesting N is retained in the riparian area by plant uptake and denitrification in this anaerobic environment. However after the strip-cut of *Sasa*, NO_3^- concentration in soil solution in the riparian slope increased and reached a similar level as was observed in stream water (Figs. 1 and 2).

3.3. Fine root dynamics

Sasa root biomass in surface soil increased, while tree root biomass decreased after the tree-cutting (Fig. 3). As a result, *Sasa* made up 95% of the fine root biomass in the clear-cut area compared with 50% of *Sasa* in the control (uncut) area,
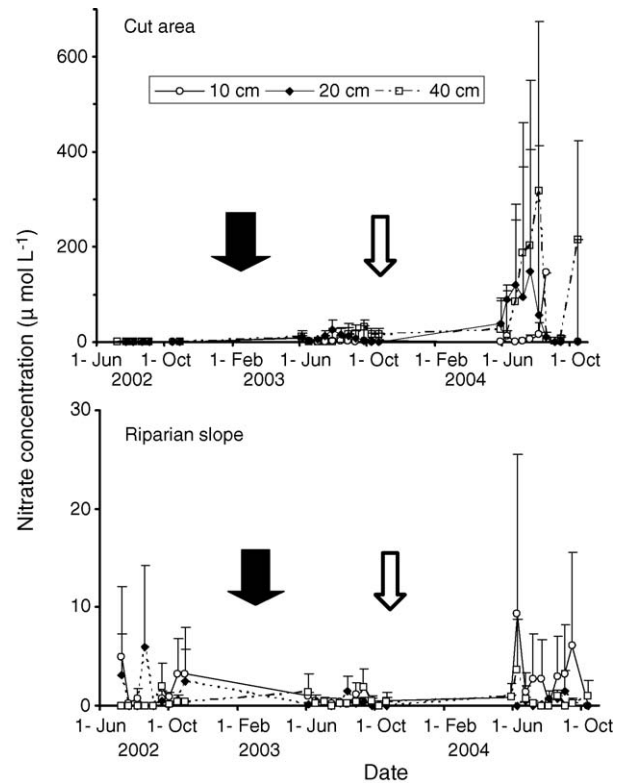

Fig. 2. Temporal fluctuation of NO_3^- concentration in soil solution before and after clear-cutting of trees and subsequent *Sasa* strip-cutting. Solid and open arrow denote the period of clear-cutting of trees and *Sasa* strip-cutting, respectively. Bars indicate S.D. (n = 4 for cut area, 3 for riparian slope, respectively).

indicating that fine root production of *Sasa* was stimulated by tree-cutting. The *Sasa*-cut treatment resulted in a 50% decrease in fine root biomass compared to that of the un-cut *Sasa* site (Fig. 4). These results show that N uptake by understory vegetation buffered N leaching after tree-cutting, however, N leaching after *Sasa*-cutting was due to a reduction of vegetative uptake.

3.4. N mineralization and nitrification

Net nitrification rate during the dormant period in surface soil (0–15 cm) in the cut *Sasa* plot and un-cut *Sasa* plot were 104 (±153S.D.) and 0.5 (±1.2S.D.) μg N kg $soil^{-1}$ day^{-1}, respectively, although there was no significant difference due to the large spatial heterogeneities (Fig. 5). In deeper soil, there was no difference in net N mineralization and nitrification between the cut *Sasa* and the un-cut *Sasa* site. In the cut *Sasa* plot, large input of fresh leaves and culms of *Sasa* with low C/N ratio might enhance N mineralization and nitrification in surface soil. Input of root detritus due to *Sasa*-cutting also might contribute to the N mineralization and nitrification by providing a labile source of organic material (Tripathi et al., 2005). Since the trees were cut in winter, there was not a large input of fresh litter from deciduous tree species. So the results of the buried bag experiment show that net nitrification was stimulated even in the dormant period by the *Sasa*-cutting rather than the tree-cutting, supporting that *Sasa*-cutting enhanced the NO_3^- leaching to the stream (Figs. 1 and 5).
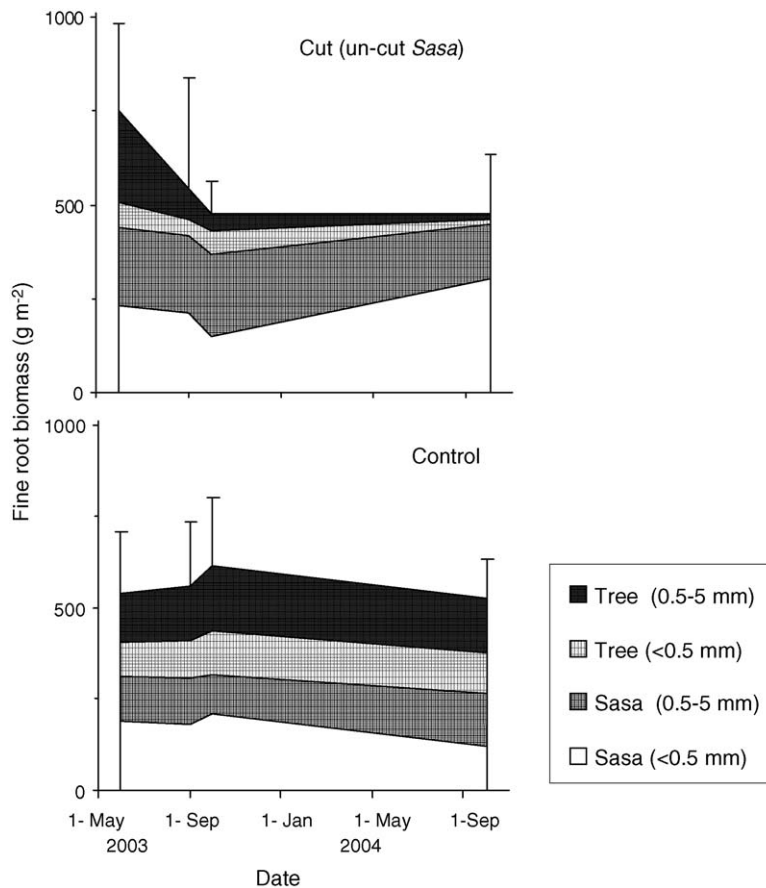
Fig. 3. Temporal fluctuation of fine root biomass in control site and clear-cut site (un-cut *Sasa*) after clear-cutting of trees. Bars indicate S.D. of whole fine root biomass ($n = 6$–8).

3.5. Role of understory vegetation on N retention

Our results show that N leaching was prevented after tree-cutting due to *Sasa* N uptake, while NO_3^- was leached from the soil to the stream after *Sasa*-cutting due to a decrease of N
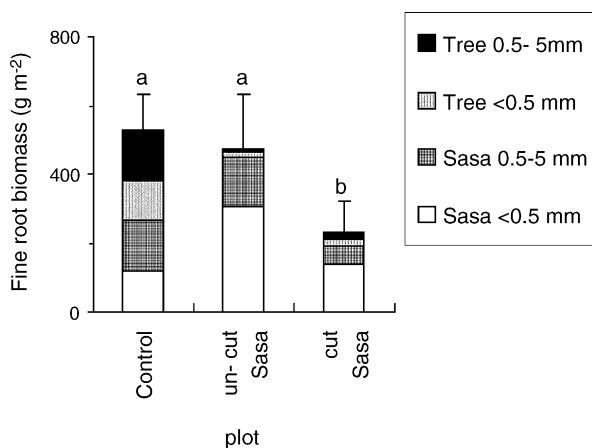

Fig. 4. Surface soil (0–15 cm) fine root biomass of trees and *Sasa* in each diameter class in the cut *Sasa*, un-cut *Sasa* and control (uncut) site 1 year following *Sasa*-cut treatment. Bars indicate S.D. ($n = 3$–8). Different alphabets denote statistical significance ($P < 0.05$) of total biomass among treatments (Scheffe's multiple comparisons).
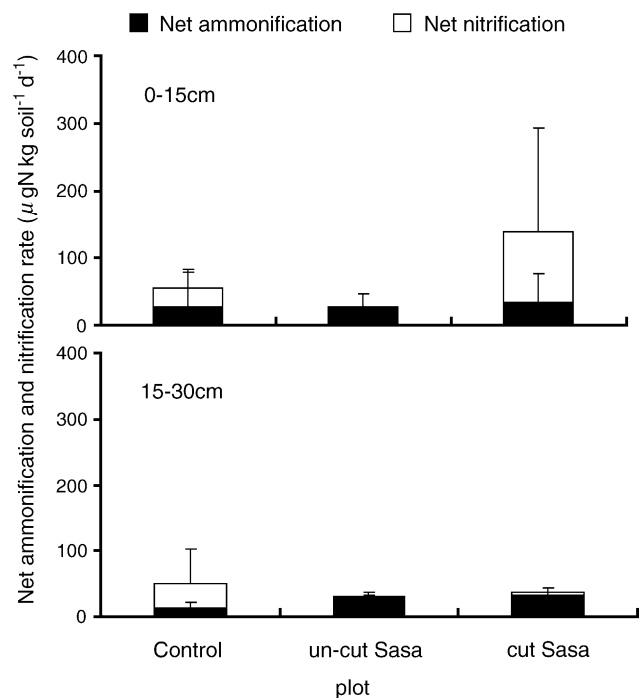

Fig. 5. Net ammonification and nitrification in soil in cut *Sasa*, un-cut *Sasa* and control (uncut) site 1 year following *Sasa*-cut treatment. Bars indicate S.D. ($n = 6$).

uptake by *Sasa*. Previous studies have indicated the importance of nitrogen uptake by sprouting trees or recovered herbaceous vegetation as a means of preventing nitrogen leaching after disturbance (Boring et al., 1988; Vitousek and Melillo, 1979; Likens et al., 1970). Weston and Attiwill (1996) also indicated that uptake of N by regrowing vegetation was essential in reducing NO_3^- concentration in soil water after the clearfelling in old-aged Eucalyptus regnans forests. In this study, it was suggested that the increased N was taken up by understory vegetation roots just after tree-cutting in this *Sasa* dominated ecosystems. To show the N retention by *Sasa* quantitatively, the N leaching from soil was roughly estimated in each year after the cutting. Assuming that: (i) mean concentration of NO_3^- in deeper soil solution (40 cm) was 10 and 106 μmol L^{-1} after tree-cutting (with *Sasa*) and after subsequent *Sasa* strip-cutting, respectively (Fig. 2) and (ii) water discharge from soil was 500 mm during growing season in both years (based on the mean stream discharge during 2003–2004, unpublished data), the N leaching from soil was 0.7 and 7.4 kg N ha^{-1}, respectively. These N leaching correspond to about one to two times of current atmospheric N deposition, implying that those values would not be large relative to the rest of ecosystem N cycling.

Although our results show that *Sasa*-cutting caused significant increase of NO_3^- leaching to the stream, there are still some uncertainties in understanding the cause of the 7-month delayed response. Further detailed studies involving the analysis of water flow-pass and residence time of N in the groundwater (Ohte et al., 2003) are necessary to address these uncertainties.

4. Conclusion

Our results show that the remaining *Sasa* prevented N leaching after the clear-cutting of trees by inducing N uptake by *Sasa*, but *Sasa* cutting promoted N leaching due to a reduction in N uptake by *Sasa*. Understory vegetation played a role to buffer the effects of tree clear-cutting on N leaching to the stream in this northern Japanese ecosystem.

Acknowledgements

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