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Impact of nitrogen cycling on stream water quality in a basin associated with forest, grassland, and animal husbandry, Hokkaido, Japan

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Abstract

The direct discharge of wastes from agricultural fields and livestock feedlots increases the concentration of nitrogen (N) in streams. This study was conducted to determine the impact of farm N budgets on stream water quality. In 1999–2000, we investigated an experimental livestock farm of 457 ha in the Kepau River watershed in Shizunai, Southern Hokkaido, Japan, where grasslands and maize fields account for 33% of the farm's total area. Annual N flow was calculated on the basis of the farm's land management records. Livestock was supplied with 15.2 t N yr^{-1} from agricultural lands, which made the farm 81% self-sufficient. Livestock excreta produced 17.2 t N yr^{-1}, of which 4 t N yr^{-1} was lost, probably by ammonia volatilization during decomposition. Apart from manure, the major N inputs were 9.1 t N yr^{-1} of chemical fertilizers, 6.4 t N yr^{-1} of atmospheric deposition, and 12.6 t N yr^{-1} biological N fixation. The major outputs were uptake by forest vegetation of 11.0 t N yr^{-1}, denitrification of 1.5 t N yr^{-1}, and livestock feed production. Consequently, the annual surplus N on the whole farm was estimated to be 12.7 t N yr^{-1}, which corresponds to 28 kg N ha^{-1} of agricultural land.

The annual N load from the farm to the Kepau River was measured at 14.4 t N yr^{-1}. Ninety percent of this load, however, occurred during rainfall and spring snowmelt. Within one 2-week snowmelt period, 5.0 t N was discharged, which corresponds to 35% of the annual load. Although the average N concentration of stream water below the farm was 2.8 mg N L^{-1}, the maximum concentration recorded during the snowmelt season was 13.5 mg N L^{-1}. The N concentration of the stream water increased and the silica (Si) concentration decreased as the stream flow rate increased. Consequently, the molar ratio of Si/N frequently dropped below 2.7, the critical level for the occurrence of eutrophication. The large N load during rainfall and snowmelt could be ascribed to open ditches, which collect tile drainage and surface runoff from the fields, discharging it directly to the river, bypassing the forested riparian zone.

Keywords: N cycling; N load; Direct discharge; Eutrophication; Livestock farm

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1. Introduction

There is increasing concern about the impacts on both regional and global environments of the alteration of N cycling by human activities (Vitousek et al., 1997). Discharges of N from urban waste, arable land, and animal excreta result in N pollution of ground water and stream water. There is a significant amount of human-discarded N associated with food consumption, of field surplus N associated with chemical fertilizers, and of animal-disposal N associated with the consumption of purchased feed (Nagumo and Hatano, 2000). The N concentration in stream water was significantly correlated with the proportion of upland fields in a catchment (Jordan et al., 1997; Woli et al., 2002) and livestock density (Shimura and Tabuchi, 1997). N budget methods to estimate field surplus N have been studied on a field to farm scale (Fried et al., 1976; Barry et al., 1993). The estimation of field surplus N is used to predict N concentration in drainage water and stream water (Goss and Goorahoo, 1995). Zebarth et al. (1999) showed that the amount of field surplus N needed to maintain optimal N cycling was 50 kg N ha^{-1} in British Columbia, Canada. Woli et al. (2002) showed that regression slopes of the relationship between nitrate-N concentration in stream water and the proportion of upland fields measured in six basins in Hokkaido were significantly correlated with the amounts of field surplus N and animal-disposal N in the whole basin. These facts indicate that the impact of regional agriculture on stream water quality is related to the proportion of upland fields, the rate of N fertilizer use, and the amount of purchased feed N.

On the other hand, the riparian zone is a buffer zone protecting stream water quality from agricultural activity. Lowrance (1992) showed that nitrate-N concentration in ground water flowing from an upland field into an adjacent forested riparian zone with a width of 50 m decreased from 13 to 1.8 mg N L^{-1} within the first 10 m, and to 0.8 mg N L^{-1} in the following 40 m. Clausen et al. (1993) showed that denitrification activity was depressed in a cropped riparian zone converted from riparian forest. These facts indicate that forested riparian zones are responsible for significant denitrification and N uptake. Ettema et al. (1999) showed that denitrification activity was higher in forested riparian zones with higher soil water and labile C and N contents. Cooper et al. (1987) showed that more than 80% of sediment discharged from upland fields in a basin with an upland field ratio of 50% was trapped by forested riparian zones. Jordan et al. (1997) showed that less than 1/3 of N applied was discharged in 17 basins in Chesapeake Bay, USA. David et al. (1997) showed that 25–85% of field surplus N was discharged through tile drainage in the Embarras River basin in east-central Illinois, USA.

The objective of this study was to determine the impact of the N budget of a livestock farm located in a basin associated with forest, grassland, and animal husbandry on stream water quality.

2. Materials and methods

2.1. Livestock farm

The study was conducted on an experimental livestock farm of Hokkaido University, located at Shizunai town, which lies 150 km south-east of Sapporo, Hokkaido (42°25′N, 142°29′E; Fig. 1). The altitude ranges from 100 to 360 m. The mean annual temperature is 7 °C, and the annual precipitation is 1200 mm. Snow cover and soil freezing occur from December to March. The geography is an alluvial fan constructed by the Kepau River, and the soil is a Vitric Andosol (FAO, 1988) derived from mainly US-c supplied by the eruption of the Usu volcano. The total area of the farm is 457 ha, which consists of 12% grassland, 19% grazing pasture, 2% corn field, and 67% forest. Forest shares 50% of the riparian zone, but is concentrated in the upper part of the stream. The farm feeds 140 head of beef cattle, 70 native Hokkaido horses, and 14 race horses. All feed produced on the farm is supplied to the livestock, supplemented with purchased feed. The manure is stocked in a barn, and applied to the farm fields.

2.2. Estimation of N budget

Annual N flow was calculated on the basis of the farm's land management records for the 12 months from the beginning of April 1999 to the beginning of April 2000. Inputs for livestock were feed purchased and produced on the farm, and outputs from livestock were excreta and products sold. Inputs in the field and forest were atmospheric deposition, N fixation, chem-