Research article

Influences of Riparian Land Use on Nitrogen Concentration of River Water in Agricultural and Forest Watersheds of Northeastern Hokkaido, Japan

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Abstract This study examines the relationship between nitrogen concentration in river water and agricultural land use in a large-scale upland farming region, with particular emphasis on the influences of riparian land use in agricultural watersheds on the nitrogen concentration in river water. In 21 watersheds in Northeastern Hokkaido nitrogen concentration was surveyed during normal river flow. Cropland (upland and grassland) accounted for 1% to 88% of each watershed, and forestland for 7% to 98%. The survey was conducted six times during the summer and autumn of 2006 and 2007. There was a close correlation between the percent of cropland in each watershed and nitrogen concentration in river water. Use of land for agriculture was shown to elevate the nitrogen concentration in river water. Next, using the buffering function of ArcGIS software, we set three buffer zones demarcated from the channel centerline outward: BZ_{20}, BZ_{60}, and BZ_{100}. The subscripts indicate the width of the zone in meters, with the riverbank as 0 m. The ratio of percent of forestland in BZ_{20} to the percent of cropland in the watershed was defined as the Land Use Index (*LUI*), and its relationship with nitrogen concentration was investigated. This revealed a strong negative correlation between *LUI* and total nitrogen concentration, a correlation that could be approximated by linear regression. This suggests that even when cropland area accounts for much of a watershed, establishment of much riparian forest can reduce the nitrogen concentration in a river.

Keywords riparian land use, nitrogen concentration, river water, watershed, Hokkaido

INTRODUCTION

Contamination of river water in agricultural watersheds has been evident in Japan since the 1980s. In particular, nitrogen contamination of rivers has become a major problem in Hokkaido. It is known that there is a high correlation between the nitrogen concentration of river water and land use (Tabuchi et al., 1995; Woli et al., 2002 and 2004). Land use is defined as cropland (upland and grassland) or forestland as a percentage of the total watershed area in agricultural regions. Okazawa et al. (2003) showed that rivers in watersheds consisting primarily of upland and grassland in Hokkaido contain a high concentration of nitrate nitrogen and that a large part of excess nitrogen (i.e., nitrogen contained in chemical fertilizer or compost that has not been absorbed during crop growth) discharged by agricultural fields flows into river water via base flow runoff. This high correlation between the nitrogen concentration in river water and agricultural land use in watersheds in upland farming regions highlights the importance of managing land use to protect the quality of river water.

Since the 1980s riparian buffers have attracted interest mainly in North America and Europe as a means of protecting water quality (Johnston et al., 1984; Lowrence et al., 1984; Hill et al., 2000).

Riparian buffer zones are areas surrounding rivers where forests, marshes and vegetation are preserved in order to help reduce the level of nitrogen discharged by agricultural fields through plant nitrogen fixation and denitrification. Many studies have been reported on the preservation of water quality using riparian buffers in Europe and North America, but there are few studies on the same topic conducted in Asia, which is distinguished by Asia monsoon climates.

This study explains the relationship between agricultural land use and the nitrogen concentration in river water in a large-scale upland-farming region in the northeastern part of Hokkaido. In particular, a unique definition of the *LUI* for river basin areas is used to show the relationship between the nitrogen concentration in rivers and land use.

METHODOLOGY

Study site

The hydrological investigation was conducted in the Shamou and Abashiri region of northeastern Hokkaido (N43° 54’ - N43° 56’, E144° 19’ - E144° 21’). In this region, the annual mean temperature is 5.8 ℃, the annual low is -7.9 ℃ (February) and the annual high is 17.6 ℃ (August). The annual mean precipitation is 753 mm/yr, much less than the national mean of 1,700 mm/yr. The mean snowfall during November to March is 373 mm/yr. Soil is mainly peat, volcanic and heavy clay, and most cropland is volcanic ash soil.

From the 1960s until recently the region saw large-scale land development for upland, grassland, pastureland and forestland. Residential plots are scattered. Sugar beets, beans, potatoes and grains are cultivated in the cropland. Riparian buffers of wetland and forestland are maintained along many of the rivers in the eastern part of the region, and the channels of these rivers remain in their natural and meandering condition. In the western part, cropland was developed on a large scale and rivers were straightened from their natural and meandering condition.

River water sampling and water quality analysis

In the Shamou and Abashiri region 36 watersheds were chosen for this study. Near the river mouth in each watershed river discharge observations and water sampling were conducted during normal river flows. The field survey was conducted six times each in August, September and October in 2006 and 2007. Water samples were analyzed for quality in the laboratory in terms of total nitrogen (T-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonium nitrogen (NH_4-N) and total organic nitrogen (TON).

Land use analysis

Land use was analyzed using a 1:25,000 topographic map. GIS software loaded with the topography was used for area determination of cropland, forestland and other land. Table 1 summarizes the land use in each watershed. The percent of cropland ranges from 1% to 88% and that of forestland from 7% to 98%. Cropland and forestland account for the majority of land use in most watersheds.

For the purpose of describing land use for each river, each watershed was divided into three zones. Using the buffering function of ArcGIS software, we set three buffer zones demarcated from the channel centerline outward: BZ_{20}, BZ_{60}, and BZ_{100}. The subscripts indicate the width of the zone in meters, with the riverbank as 0 m. Then, we established the *LUI*, which is derived from Eq. 1 to examine the relation between *LUI* and the nitrogen concentration in river water. The *LUI* is a ratio of the area of forestland in BZ_{20} to the cropland area of the entire watershed.

$$Land\ Use\ Index\ (LUI) = \frac{Forest\ Land\ Area\ in\ BZ_{20m}\ [km^2]}{Cropland\ Area\ in\ the\ Watershed\ [km^2]} \qquad (1)$$

Table 1 Characteristics of investigated watershed

No.	Watershed	Area (km^2)	*Landuse (%) Cropland	Forest	Other	River length (km)	River density (km/km^2)
1	Mokoto	166.8	41	56	3	130.1	0.78
2	Mokoto(Upper)	102.6	39	58	3	80.0	0.78
3	Chigusa-mokoto	46.3	39	59	2	39.3	0.85
4	Maruman	42.2	32	66	2	48.3	1.14
5	Onnenai	21.1	36	62	2	16.5	0.78
6	Ukarusyubetsu	10.3	77	18	5	3.0	0.29
7	Urashibetsu	57.7	27	72	1	58.5	1.01
8	Urashibetsu(Upper)	38.8	15	84	1	39.7	1.02
9	Tsutupochi	9.1	86	10	4	6.6	0.73
10	Miwak-kansen	3.3	76	13	11	2.0	0.59
11	Yambetsu	138.9	19	78	2	127.0	0.91
12	Panakusyubetsu	14.1	7	93	0	13.7	0.97
13	Yambetsu(Middle)	61.7	11	88	1	53.7	0.87
14	Yambetsu(Upper)	13.3	1	97	2	12.3	0.92
15	Odono	11.2	28	72	1	8.2	0.73
16	Pon-shibetsu	30.6	3	95	1	32.8	1.07
17	Chuo-kansen	5.0	86	9	4	3.9	0.78
18	Higashi-kansen	3.2	88	7	5	1.5	0.46
19	Uenbetsu	44.0	81	12	8	18.8	0.43
20	Syari	529.5	21	78	2	364.2	0.69
21	Ikushina	73.1	9	90	1	60.7	0.83
22	Ikushina(Upper)	57.0	2	98	0	49.0	0.86
23	Akino	46.4	32	67	1	26.1	0.56
24	Akino(Upper)	9.9	12	87	0	2.8	0.28
25	Toyosato	8.9	11	89	0	2.0	0.22
26	Saruma	45.5	51	47	2	23.5	0.52
27	Syari(Mid)	352.5	16	83	1	242.0	0.69
28	Kakurenosawa	26.3	9	90	0	21.8	0.83
29	Kakurenosama(Upper)	24.5	4	96	0	18.3	0.75
30	Chiesakuetonbi	22.1	44	54	2	7.7	0.35
31	Etonbi	12.9	38	61	1	9.5	0.73
32	Pehmen	16.4	11	89	0	9.8	0.60
33	Syari(Upper)	241.6	6	94	1	169.9	0.70
34	Onnebetsu	50.7	10	89	0	40.9	0.81
35	Umibetsu	14.7	9	91	1	8.6	0.58
36	Makushibetsu	4.2	48	51	1	4.2	1.00

** Land use: the percent of cropland (upland plus grassland), forest and other in each watershed*

RESULTS AND DISCUSSIONS

Mean nitrogen concentration of river water

The nitrogen concentration in river water is shown in Fig. 1 for each watershed as the mean and standard deviation of measurements obtained by six field surveys. The mean, minimum and the maximum T-N concentration are 1.61 mg/L, 0.18 mg/L (at watershed No.22) and 5.80 mg/L (at watershed No.18), respectively. In most watersheds, NO_3-N accounted for a large portion of the T-N. Because rivers near upland have higher concentrations of NO_3-N than concentrations of TON, NH_4-N and NO_2-N (Okazawa et al., 2004), it seemed that the investigated rivers were exposed to NO_3-N runoff from nearby uplands.

Influence of agricultural land use on nitrogen concentration of river water

Fig. 2 shows relationships between percent of cropland in each watershed and concentrations of T-N and NO_3-N in the rivers. The concentrations of T-N and NO_3-N increased with percents of cropland.

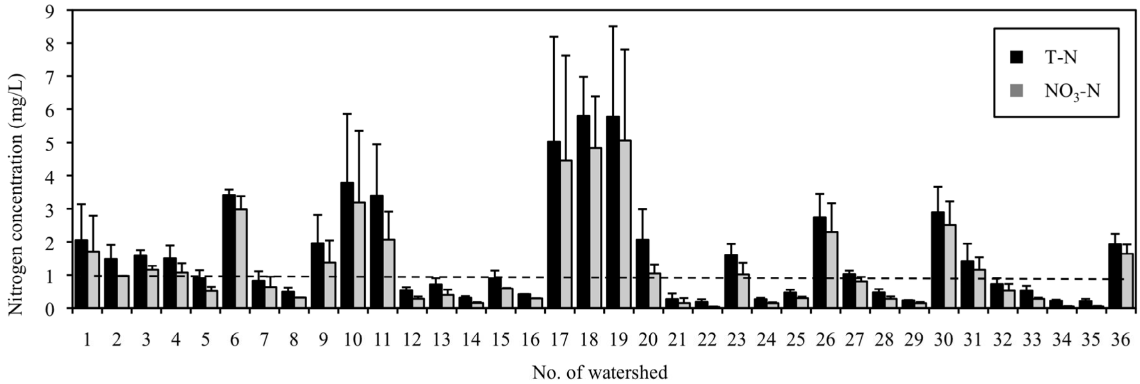
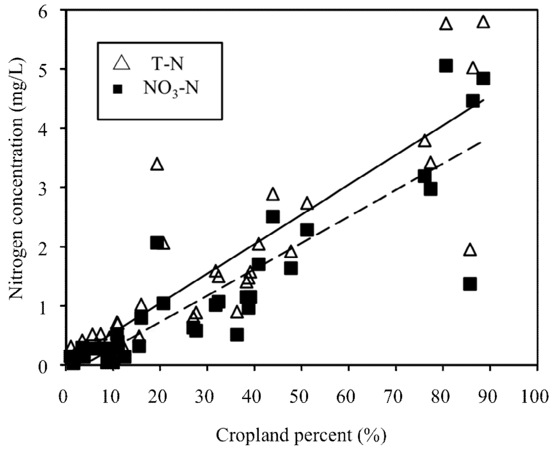


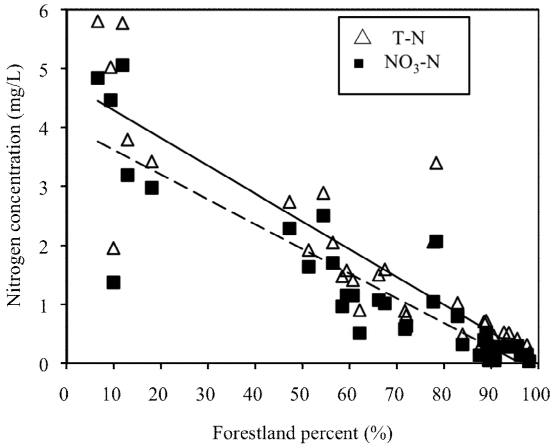
Fig.1 Mean and standard deviation of T-N and NO_3-N concentration

(*Broken line indicates 1 mg/L which is envronmental standard water quality.*)



Solid line (T-N) : $y = 0.05x + 0.05$, $R^2 = 0.75$**
Broken line (NO_3-N) : $y = 0.045x - 0.16$, $R^2 = 0.77$**

Fig.2 Relationship between percent of cropland and nitrogen concentration of river



Solid line (T-N) : $y = - 0.05x + 4.76$, $R^2 = 0.76$**
Broken line (NO_3-N) : $y = - 0.04x - 4.03$, $R^2 = 0.78$**

Fig.3 Relationship between percent of forst-land and nitrogen concentration of river

The correlation between the percent of cropland and the nitrogen concentration is very strong (R^2 = 0.75** for T-N and 0.77** for NO_3-N). This suggests that such agricultural land use contributes substantially to the variation in the nitrogen concentration in river water. However, even when the percent of cropland is more than 70%, there are high variations in T-N concentration (1.96-5.80 mg/L) and NO_3-N concentration (1.38-5.06 mg/L), indicating that other factors may affect the nitrogen concentration in river water.

Fig. 3 shows relationship between percent of forestland in each watershed and concentrations of T-N and NO_3-N. A strong inverse correlation between the percent of forestland and the nitrogen concentration demonstrated that forests reduce the concentration of nitrogen in rivers.

Relationship between riparian land use and nitrogen concentration in river water

We examined the percent of riparian forest area in relation to the nitrogen concentration in river water. Fig. 4 shows the relationship between percent of riparian forest area in BZ_{20}, BZ_{60} and BZ_{100} and T-N concentration. Regarding the three buffer zones, T-N concentration decreased with increases in the percent of forestland. Additionally, no significant difference was found between three approximate lines representing the relationship between T-N concentration and the percent of forestland in BZ_{20}, BZ_{60} and BZ_{100}. If the percentages of forestland in BZ_{20} and BZ_{100} are the same, then we conclude that forest area in BZ_{20} can neutralize more nitrogen runoff with less area. Thus, conservation of forest within 20m of the riverbank is important for river water quality control.

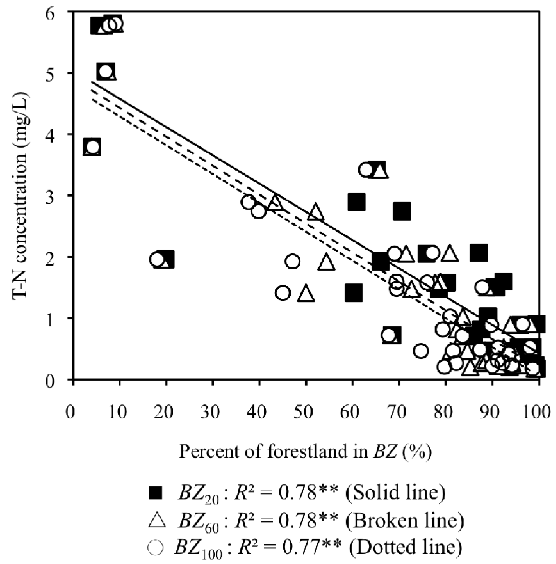


Fig.4 Relationship between forestland percent of BZ_{20}, BZ_{60}, BZ_{100} and T-N concentration

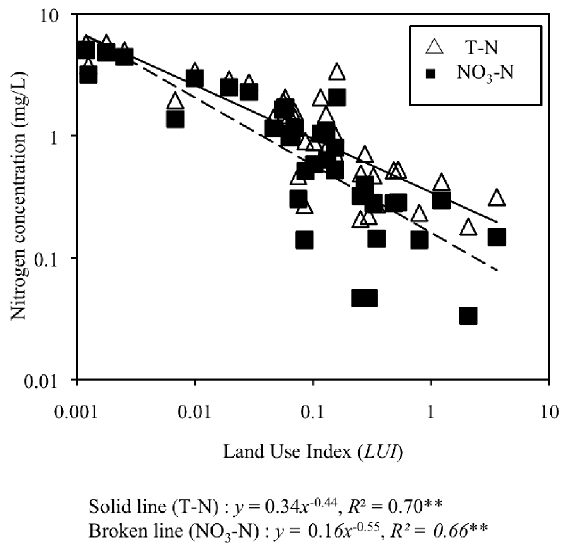


Fig.5 Relationship between *LUI* and N concentration

Land use and river water quality conservation

These results make it clear that conservation and regeneration of forestland in BZ_{20} was important for water quality control in this region. However, the area of cropland outside BZ_{20} varies widely between the watersheds. Even if the forestland in BZ_{20} is well conserved, the buffer zone will not be able to handle all the nitrogen from cropland beyond the zone if that cropland area is too large. For water quality conservation, agricultural land use must be determined while taking into account not only the size of the riparian forest but also the size of cropland area outside the buffer zone. In light of this, we examine that the relation between *LUI* and the nitrogen concentration in river water.

Fig.5 shows the relationship between the *LUI* and the concentrations of T-N and NO_3-N in river water. The investigation revealed a strong negative correlation between *LUI* and nitrogen concentration (R^2=0.70** for T-N and 0.66** for NO_3-N), a correlation that could be approximated by linear regression. Therefore, we found that the nitrogen concentration in river water in this region correlates with the *LUI*. In other words, measures for increasing the *LUI* are necessary to reduce the nitrogen concentration in rivers. The nitrogen concentration will be reduced by reducing the cropland area in the watersheds, or by regenerating forestland in the BZ_{20m}.

From the linear regression formula, we can estimate the minimum *LUI* necessary for reducing the T-N concentration in rivers to 1 mg/L or less. To keep the T-N concentration of rivers in the study region at 1 mg/L or less, we found that an *LUI* of at least 0.09 should be maintained. This means that forestland equivalent to 9% of the cropland needs to be maintained in the riparian land.

CONCLUSION

This study examined the relationship between the percent of cropland and the river nitrogen concentration in large-scale upland farming regions of eastern Hokkaido. The conclusions are: (1) the nitrogen concentration of rivers in 13 out of the 21 watersheds surveyed exceeded 1 mg/L, the maximum level specified in the environmental water-quality standard in Japan, thus confirming the presence of nitrogen contamination in those rivers; (2) as indicated in previous studies, a high correlation between the percent of cropland and the nitrogen concentration in rivers showed that agricultural land use is a major factor contributing to nitrogen contamination. At the same time, a strong inverse correlation between the percent of forestland and the nitrogen concentration demonstrated that forests reduce the concentration of nitrogen in rivers; (3) a correlation between the

LUI and the nitrogen concentration in river water revealed that the land use in river basin areas affects the concentration of nitrogen in rivers. This led to the conclusion that the *LUI* is an important indicator for evaluating the nitrogen concentration in river water. Furthermore, this study showed that in order to prevent the nitrogen concentration from exceeding 1mg/L, the level set as environmentally acceptable, the *LUI* must be kept at no more than 0.09. We conclude that *LUI* is strongly associated with the nitrogen concentration of river water. This suggests that even when cropland accounts for much of a watershed, establishment of much riparian forestland can reduce the nitrogen concentration in a river.

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REFERENCES

Hill, A.R., Devito, K.J., Campagnolo, S., Sanmugadas, K., (2000) Subsurface denitrofication in a forest riparian zone, interactions between hydrology and supplies of nitrate and organic carbon. Biogeochemistry, 51, 193-223.

Johnston, C.A., Bubenzer, G.D., Lee, G.B., Madison, F.W., McHenry, J.R. (1984) Nutrient trapping by sediment deposition in a seasonally flooded lakeside wetland. J. Environ. Qual, 13, 283-290.

Lowrence, R.R., Todd, R.L., Fail, J., Hendricson, J.O., Leonard, J.R. and Asmussen, L. (1984) Riparian forests as nutrient filters in agricultural watersheds. BioScience, 34, 374-377.

Okazawa, H., Inoue, T., Yamamoto, T., Nagasawa, T. and Unoki, K. (2003) Characteristics of stream water quality during rainfall runoff on an upland field area of eastern Hokkaido, Japan. Trans. of JSIDRE, 227, 33-40. (in Japanese)

Okazawa, H., Nagasawa, T., Yamamoto, T. and Inoue, T. (2004) Influence of near-river area's land use on river water quality during rainfall runoff in agricultural watersheds. Participatory Strategy for Soil and Water Coservation, Institute of Environment Rehabilitation and Conservation (ERECON), 39-44.

Tabuchi, T., Yoshino, K., Shimura, M., Kuroda, S., Ishikawa, M. and Yamaji, E. (1995) Relation between land use and nitrate concentration of outflow water from watersheds of agricultural and forest area. Trans. of JSIDRE, 178, 129-135. (in Japanese)

Woli, K.P., Nagumo, T. and Hatano, R. (2002) Evaluating impact of land use and N budgets on stream water quality in Hokkaido, Japan. Nutr. Cycle. Agroecosyst, 63, 175-184.

Woli, K.P., Nagumo, T., Kuramochi, K. and Hatano, R. (2004) Evaluating river water quality through land use analysis and N budget approaches in livestock farming areas. Sci. Total Environ., 329, 61-74.