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EFFECT OF LAND USE DISTRIBUTION PARTTERNS ON NITROGEN CONCENTRATION IN RIVER WATERS IN AGRICULTURAL CATCHMENTS, WESTERN HOKKAIDO, JAPAN

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Abstract

In this study, the relationship between the land uses for croplands and forests in 32 small-scale catchments in western Hokkaido, JAPAN was examined. The purpose of the study is to determine what land use distribution is beneficial for the maintenance of agricultural production and the conservation of river water quality.
River water sampling was done on 32 rivers in June, August and October 2011 and 2012, and nitrogen concentration was measured. Land-use analysis was done by using GIS, and the proportion of cropland to forestland, the spatial continuity (*SC*) of cropland and that of forestland, and the land use of riparian areas were obtained.
In catchments where the proportion of cropland is high, the nitrogen concentration in the river water is high. It was estimated that the area of current cropland would need to be reduced by up to 20% to reduce the nitrogen concentration of the river water to 1 mg/L. However, it was also clarified that decreases in the nitrogen concentration of the river water would be possible even without considerable reduction in the proportion of cropland, if the distribution of land uses was changed. Increasing the continuity of forests or changing croplands in the riparian zone to forests was found to be effective.
Key words: Nitrogen, River water, Upland field, Forest, Land use distribution pattern

Hokkaido's 1.15 million ha of agricultural land accounts for 25% of Japan's agricultural land, and most of that land in Hokkaido is cropland. Nitrogen used for croplands has caused river water contamination, because 50% of nitrogen input in the croplands flow out into rivers (Okazawa et al., 2003). Previous studies revealed a correlation between the nitrate nitrogen concentration in river water at normal flow and the proportion of cropland in the catchment (Ahearna et al., 2005; Muneoka et al., 2012). It can be thought that reduction in the proportion of cropland in a catchment is one way to resolve the problem of nitrogen contamination in river water. However, it is not practical to further reduce croplands. It is necessary to maintain the present level of agricultural production, because Japan is less than 50% self-sufficient in food production reported by the Ministry of Agriculture, Forestry and Fisheries, JAPAN. It has been reported that the nitrogen concentration in river water often differs in two catchments with similar proportions of cropland (Okazawa et al., 2013). The difference in the nitrogen concentration is known to be attributable to the distribution of forest areas along the river, such as riparian forest (Okazawa et al., 2010). It has been known that the presence of riparian forests changes the nitrogen concentration in river water (Lowrence et al., 1984; Hill et al., 2000); however, very few studies have further addressed this in the Eastern Asia.

Materials and methods

The hydrological investigation was conducted in 32 small catchments located in the Nukibetsu River basin and Shiribetsu River basin of western Hokkaido, JAPAN. In this region, the annual mean temperature is 6.1℃, and the annual low is -20.2℃(February) and the annual high is

29.7℃, (August). The annual precipitation (2012) is 1,181 mm/y, much less than the national mean of 1,700mm/y. During November to March, whole subject area has been covered by snow.

Table 1 A summary of the surveyed catchment areas

No.	River	Area (km^2)	Land use (%)			No.	River	Area (km^2)	Land use (%)		
			Cropland	Forestland	Other				Cropland	Forestland	Other
1	Pon-Nukibetu 1	10.92	41	40	19	**17**	No Name	11.42	32	55	13
2	Pon-Nukibetu 1	15.89	40	45	15	**18**	No Name	7.32	42	50	8
3	No Name	9.33	43	55	2	**19**	Shinosen	7.16	50	48	2
4	Oroen-nukibetu	22.14	10	75	15	**20**	Chiraibetu	7.42	54	40	5
5	Soutakibetu	9.48	22	72	6	**21**	Makkari	102.88	28	61	11
6	Soutakkinetu-oku	10.82	11	63	26	**22**	Rubeshibe	28.09	6	74	21
7	Maruyama	4.41	3	87	10	**23**	Nanasi	20.23	11	65	24
8	Ponbetu	29.79	9	74	17	**24**	Doro	7.49	21	42	37
9	Shin-yamanashi	9.43	14	78	8	**25**	Inufurebetu	8.88	1	81	18
10	Ohara	6.52	48	36	16	**26**	Katuranosawa	11.94	0	92	7
11	Nifusinai 2	2.01	91	1	8	**27**	Yahasinosawa	7.64	0	94	6
12	Nifusinai 1	1.30	91	1	8	**28**	Konbu 1	9.68	1	73	26
13	Nifusinai	13.87	79	17	4	**29**	Pirikanbetu	4.77	0	69	31
14	Obanai	10.55	42	52	7	**30**	No Name	3.44	3	47	50
15	No Name	24.39	23	67	10	**31**	Shintomi	6.54	25	47	28
16	Nambetu	5.90	66	30	4	**32**	Konbu 2	10.45	23	71	6

A summary of the surveyed catchment areas is given in Table 1. 32 catchments were chosen for this study. The proportions of cropland and forestland in each catchment area varied significantly, ranging from 0% to 91% and 1% to 94%, respectively. In all catchments, however, cropland and forested area together accounted for at least 50% of the total area, and the proportion of other land-use patterns (such as residential or industrial) was very small.

Water quality was surveyed on sunny days to avoid the effects of flood condition due to precipitation. The field survey was done six times each in June, August, and October of 2011 and 2012, respectively. Samples were taken from river water at the downstream end of each small catchment. The samples were taken back to the laboratory and their nitrogen content was analyzed using the Japanese Industrial Standard (JIS) method.

Determination of rivers and their respective catchment boundaries was made using a 1:25,000 topographic map. Additionally, a land-use map with a 100-m grid resolution, published by the Ministry of Land, Infrastructure, Transport and Tourism, was used to determine land use, such as cropland and forestland. Land-use ratios and agglomeration were analyzed using GIS software (ArcGIS 9.1, ESRI).

Three types of land-use index were used in this study;

(1) The percentage of forested land or cropland in a catchment.

(2) Using the buffering function of ArcGIS software, we set buffer zone demarcated from the channel centerline outward (BZ_{100}). The subscripts indicate the width of the zone in meters, with the riverbank as 0 m (Okazawa et al., 2010). The ratio of percent of forestland in BZ_{100} (km^2) to the percent of cropland in the catchment (km^2) was defined as the Land Use Index (*LUI*), and its relation with nitrogen concentration was investigated.

$$LUI = \text{Forest area in } BZ_{100} \,/\, \text{Cropland area in the catchment} \qquad \text{Eq. 1}$$

(3) Indices for the land-use agglomeration include those that show how “joined” or “clumped” land-use areas are, as well as the “spatial continuity” (*SC*) index of identical land use. In this study, *SC*, which can be simply derived from GIS, is employed as the index for land agglomeration. *SC* was proposed by Tsunekawa et al. (1991) and Okazawa et al, (2011). A land-use map with a grid resolution of 100 m was used to calculate *SC*. An example of *SC* calculation for cropland is shown

in Fig. 1. To obtain an *SC* index, grids representing cropland were grouped into “patch” units. A patch refers to a group of grid cells connected in a vertical, horizontal, or oblique direction. In Fig. 1, the cropland grid cells are grouped into 4 patches. After all subject grids were grouped into patches, *SC* was obtained using Eq. 2.

$$SC = k \,/\, C_{patch} \qquad \text{Eq. 2}$$

where k is the number of grid cells representing the cropland area in a catchment, and C_{patch} is the number of patches representing groupings of these cells. In the example given in Fig.1, the number of grid cells representing cropland, k, is 17, and C_{patch} is 4, so *SC* is 4.25. In other words, *SC* is equivalent to the average area of a patch in each catchment. The *SC* for forested land was calculated using the same method.

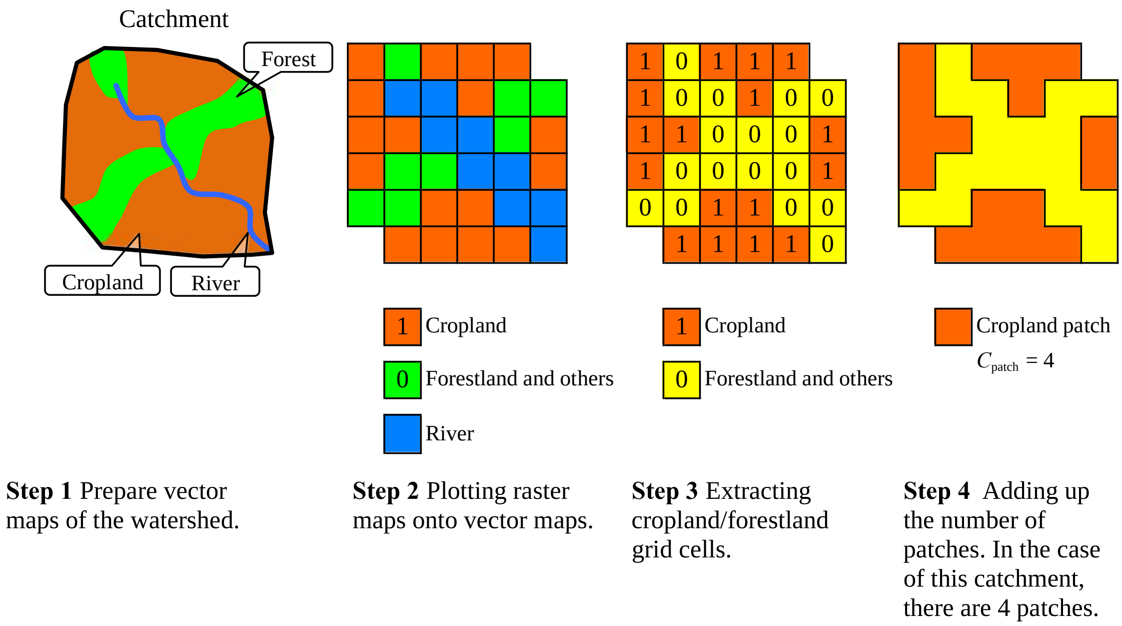


Fig.1 Land use and attribute values
(k = 17, C_{patch} = 4, SC = 4.25)

Results and discussion

The nitrogen concentration in the river water shown in Table 2 for each catchment is the mean and standard deviation of measurements obtained by six samples. The minimum and the maximum T-N concentration are 0.14 mg/L, 4.29 mg/L, respectively. T-N contamination in river water exceeding 1 mg/L, which is the environmental standard value, was found in the sample at 15 out of 32 locations. In most catchments, NO_3-N accounted for a large portion of the T-N.

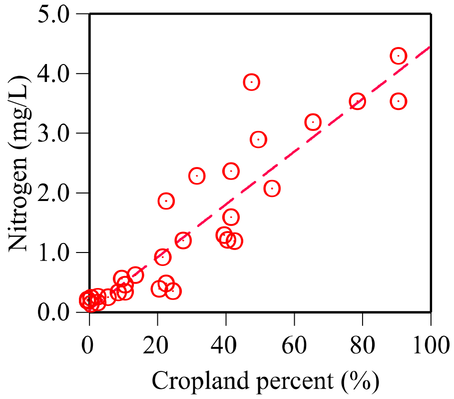
Fig.2 shows relationship between percent of cropland in each catchment and concentrations of T-N in the rivers. The higher is the percent of cropland, the higher are the concentrations of T-N. The correlation between the percent of cropland and the nitrogen concentration is very strong (r^2 =0.84**). This suggests that such agricultural land use contributes greatly to the variation in the nitrogen concentration in river water. It was also clarified that, in order to lower the nitrogen concentration in river water to within 1 mg/L, which is the environmental standard value in Japan, or lower, it was necessary to reduce the area of cropland to about 20% of the catchment.

Fig.3 shows the relationship between *LUI* and T-N concentration. T-N concentration decreased with increases in *LUI*. A negative correlation was obtained between *LUI* and T-N concentration. The above findings show that, in order to lower the nitrogen concentration in river

Table 2 Nitrogen concentration of investigated rivers

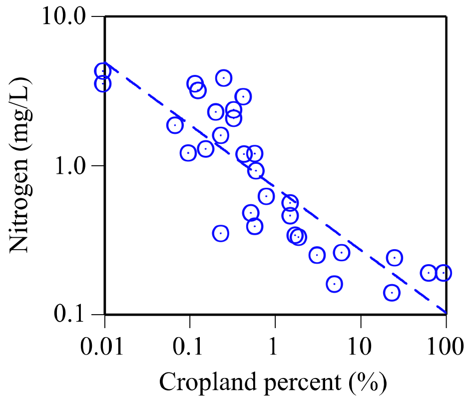
	①T-N(mg/L)		②NO_3-N(mg/L)		NO_2-N(mg/L)		NH_4-N(mg/L)		Org-N(mg/L)		
No.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	②/①
1	1.21	0.29	0.81	0.15	0.00	0.00	0.04	0.01	0.36	0.35	0.67
2	1.29	0.25	0.90	0.07	0.01	0.01	0.05	0.03	0.33	0.32	0.69
3	1.19	0.25	0.91	0.03	0.01	0.00	0.05	0.01	0.23	0.25	0.77
4	0.56	0.16	0.28	0.08	0.00	0.00	0.03	0.02	0.25	0.24	0.50
5	0.92	0.57	0.57	0.54	0.01	0.02	0.04	0.03	0.29	0.27	0.62
6	0.34	0.17	0.12	0.14	0.00	0.00	0.03	0.02	0.19	0.13	0.34
7	0.26	0.15	0.06	0.06	0.00	0.00	0.03	0.01	0.16	0.20	0.25
8	0.33	0.11	0.15	0.06	0.00	0.00	0.03	0.02	0.14	0.09	0.47
9	0.62	0.21	0.40	0.21	0.01	0.02	0.07	0.05	0.14	0.16	0.65
10	3.85	2.39	1.03	0.40	0.16	0.07	1.04	1.13	1.63	1.60	0.27
11	3.53	0.94	2.92	0.63	0.02	0.01	0.08	0.08	0.51	0.54	0.83
12	4.29	0.29	3.94	0.65	0.02	0.01	0.03	0.03	0.30	0.40	0.92
13	3.53	0.08	3.27	0.30	0.01	0.01	0.03	0.03	0.23	0.24	0.93
14	1.59	0.17	1.26	0.28	0.01	0.01	0.03	0.02	0.30	0.14	0.79
15	1.86	0.45	1.51	0.44	0.01	0.01	0.07	0.03	0.28	0.29	0.81
16	3.18	0.72	2.89	0.56	0.01	0.01	0.05	0.01	0.24	0.24	0.91
17	2.28	0.24	1.81	0.18	0.01	0.01	0.03	0.02	0.42	0.40	0.80
18	2.36	0.24	1.82	0.23	0.01	0.00	0.05	0.01	0.47	0.16	0.77
19	2.89	0.79	2.54	1.07	0.01	0.00	0.03	0.03	0.31	0.40	0.88
20	2.07	0.54	1.59	0.23	0.00	0.00	0.02	0.02	0.46	0.38	0.77
21	1.20	0.12	0.96	0.06	0.01	0.00	0.03	0.01	0.19	0.06	0.80
22	0.25	0.08	0.11	0.05	0.00	0.00	0.03	0.01	0.11	0.04	0.42
23	0.46	0.08	0.31	0.07	0.00	0.00	0.04	0.02	0.11	0.03	0.67
24	0.39	0.10	0.22	0.04	0.00	0.00	0.02	0.01	0.14	0.05	0.57
25	0.14	0.03	0.04	0.01	0.00	0.00	0.03	0.03	0.07	0.06	0.31
26	0.19	0.04	0.11	0.03	0.00	0.00	0.02	0.01	0.06	0.02	0.59
27	0.19	0.02	0.08	0.03	0.00	0.00	0.03	0.02	0.08	0.02	0.43
28	0.24	0.05	0.08	0.03	0.00	0.00	0.05	0.04	0.11	0.05	0.34
29	0.21	0.07	0.11	0.03	0.00	0.00	0.02	0.00	0.07	0.06	0.55
30	0.16	0.05	0.06	0.02	0.00	0.00	0.03	0.03	0.08	0.01	0.35
31	0.35	0.05	0.23	0.09	0.00	0.00	0.03	0.03	0.09	0.03	0.65
32	0.48	0.14	0.16	0.06	0.01	0.00	0.04	0.04	0.27	0.12	0.34

water, it is effective to increase forestland within BZ_{100m} or to reduce the overall area of cropland in the catchment.



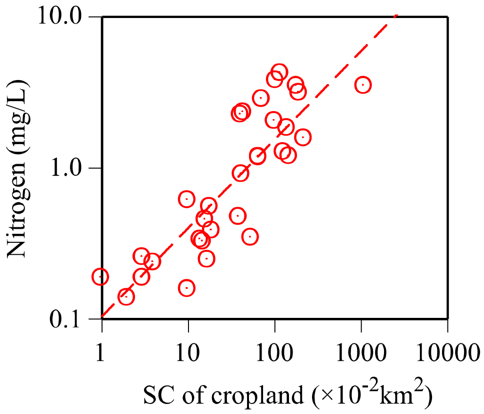
$y = 0.044x + 0.040$ ($r^2 = 0.84^{**}$)

Fig.2 Relationship between T-N and cropland percent



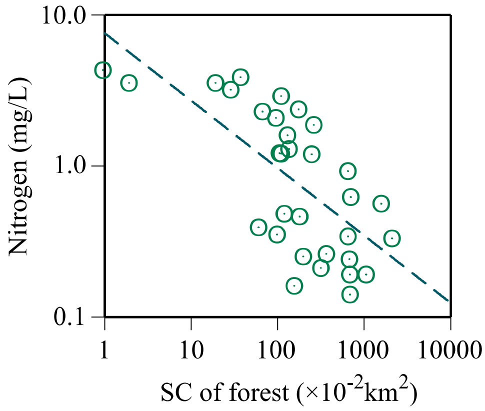
$y = 0.71x^{-0.41}$ ($r^2 = 0.71^{**}$)

Fig.3 Relationship between T-N and *LUI*



$y = 0.10x^{0.59}$ ($r^2 = 0.74^{**}$)

Fig.4 Relationship between T-N and SC of cropland



$y = 7.6x^{-0.45}$ ($r^2 = 0.47^{**}$)

Fig.5 Relationship between T-N and SC of forestland

Fig. 4 and 5 show the relationship between *SC* and T-N concentration. Positive correlation with 1% significance was found between the *SC* of cropland and T-N concentration. Negative correlation with 1% significance was found between the *SC* of forests and T-N concentration. Based on the above examination, it is thought to be possible to lower nitrogen concentration in river water by only decreasing the patch area of cropland or by increasing the patch area of forests without changing the total areas of cropland or forest in a catchment.

Conclusion

It was determined that the following land-use options would be effective in lowering the nitrogen concentration in river water.

1) Reducing the area of cropland to about 20% of the total catchment area; however, this reduction lowers agricultural productivity.

2) Increasing forests along the river without decreasing the area of cropland in the catchment. Reducing the patch area of the cropland. It is possible to lower the nitrogen concentration in river water by increasing the patch area of forests.

In Japan, forests are mainly owned by the national government and agricultural land by farmers. Agreement of the land owner is necessary in order to change the land use. Based on the above described conditions, it was determined that installation of riparian forests, in which land-use change and reduction in the area of cropland are minimum, is the most effective means for conserving river water quality.

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