Runoff Nutrients from an Afforested Watershed of *Chamaecyparis Obtusa* during Rain Events

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ABSTRACT

In order to evaluate nutrient budget in an unmanaged artificial forest watershed, the flux budgets of total nitrogen (T-N) and total phosphorus (T-P) were measured in a small watershed covered by an artificial forest of Japanese cypress, *Chamaecyparis Obtusa*. One of the greatest problems in the forest and forestry in Japan is how to manage artificial forests covering 44% of the total forest area. In the unmanaged forests, the canopy becomes dense and thick, and the development of understory vegetation is disturbed. The output [kg/yr/ha] of T-N and T-P in drainage water has been usually estimated using interval-representative flux method (I-R method). However, the estimated output values of the watershed using I-R method were always less than the input [kg/yr/ha] of precipitation. On the other hand, the estimated output values using L-Q method were larger than the input of precipitation. The results show that L-Q method is better to evaluate nutrient output than I-R method because L-Q method considers changes of load [kg/10min./yr] during rain events. However, L-Q method still underestimates output of nutrients because it does not properly estimate large loads of particulate nutrients during peak discharges. Our results suggest that the unmanaged artificial forest watershed worked as a diffuse source of nutrients.

Keywords : small watershed; diffuse pollution; eutrophication; L-Q equation; storm event; water purification

INTRODUCTION

About 67% of Japanese archipelago is covered by forested hills. Recently, commercial uses of these forests have nearly ceased, but public functions of forests (e.g. controlling rising water level, water purification) have been highly evaluated. These functions are thought to work well as long as forest management is conducted sufficiently. In order to control proper tree density, several forest management operations, such as tree thinning and pruning, are required, because the seedlings were planted in quite high density at the initial stage. However, these operations have ceased in most of Japanese artificial forests, which cover about 44 % of the total forest area. In the unmanaged forests, the canopy becomes dense and thick, and the development of understory vegetation is disturbed. In such forests, soil erosion is easily occurred during storm events because of bare soil surface of the forest floor.

Japanese cypress, *Chamaecyparis Obtusa*, is one of the most typical afforested species in Japan. The litter leaves of Japanese cypress are decayed into smaller particulates within a few months and thus most of them are washed away from the forest floor by surface runoff soon after defoliation. Therefore, in unmanaged artificial forests of Japanese cypress, the tendency of soil erosion is strong because the litter layer, which protects soil surface from being eroded by rainfall impact, doesn't sufficiently develop and thus the forest floor is denuded (Yukawa and Onda, 1995). It is considered that nutrients such as nitrogen and phosphorus run off from the soil surface accompanied by soil erosion. Therefore, it is assumed that the unmanaged artificial forests of Japanese cypress are diffuse sources of nutrients that lead to eutrophication in the downstream regions, i.e. water purification as one of public functions of forests doesn't sufficiently work. When the source of flux [kg/yr/ha] of nutrients into the forest, i.e. input, was regarded as only from precipitation and the output of the flux from the forest was regarded as drainage waters (stream), it is assumed that the output may be larger than the input. However, there are few basic studies that demonstrate this assumption.

In most of former researches, forested areas in Japan have been regarded as sinks of nutrients such as nitrogen and phosphorus because the output was less than the input (Tabuchi, 1998; Kunimatsu, 1994). However, Kunimatsu (1994) pointed out that most of the estimation of the output values might be significantly underestimated because the interval-representative flux method (I-R method) was used in the estimation and this method lacks of continual discharge data. The I-R method does not evaluate the output flux during rain events. On the other hand, L-Q method, which is one of representative methods to estimate the output, can compensate the flux during rain events, though continual discharge data are needed. But there are few studies that estimate the output values using L-Q method.

In this study, in order to evaluate nutrient budget in an unmanaged artificial forest watershed, hydrological and hydrochemical survey was conducted in the small watershed covered by an unmanaged Japanese cypress forest. The flux budget for total nitrogen (T-N) and total phosphorus (T-P) was measured. In addition, from the aspect of evaluation of nutrient budget, the methods to estimate the output of nutrients were discussed.

METHODS

Study site and investigation

The studied watershed (Ochozu Experimental Watershed, OEW) is located in Fukuoka Prefecture, about 15 km east of Fukuoka city (33º 38'N, 130º 32'E). It is a mountainous watershed situated in the part of No.4 forest of the Fukuoka experimental forests of Kyushu University. The mountain stream originated from OEW flows into the enclosed sea, Hakata Bay, via Tatara River. The area of OEW is 9.5ha, the length of the main stream is 265m, the width of OEW is 179m, the slope of the stream is 0.22 and the average slope is 0.37 (Hiramatsu et al, 1987). The major bedrock is a chlorite schist and the major soil is a Yellow-Brown Forest soil. OEW is mostly covered by artificial forests of Japanese cypress. The Japanese cypress was planted 46 years ago. The forests have not been managed since 1993 except that a small portion was thinned. Thus the canopy of the artificial forest is dense and the vegetation of the forest floor is scarce.

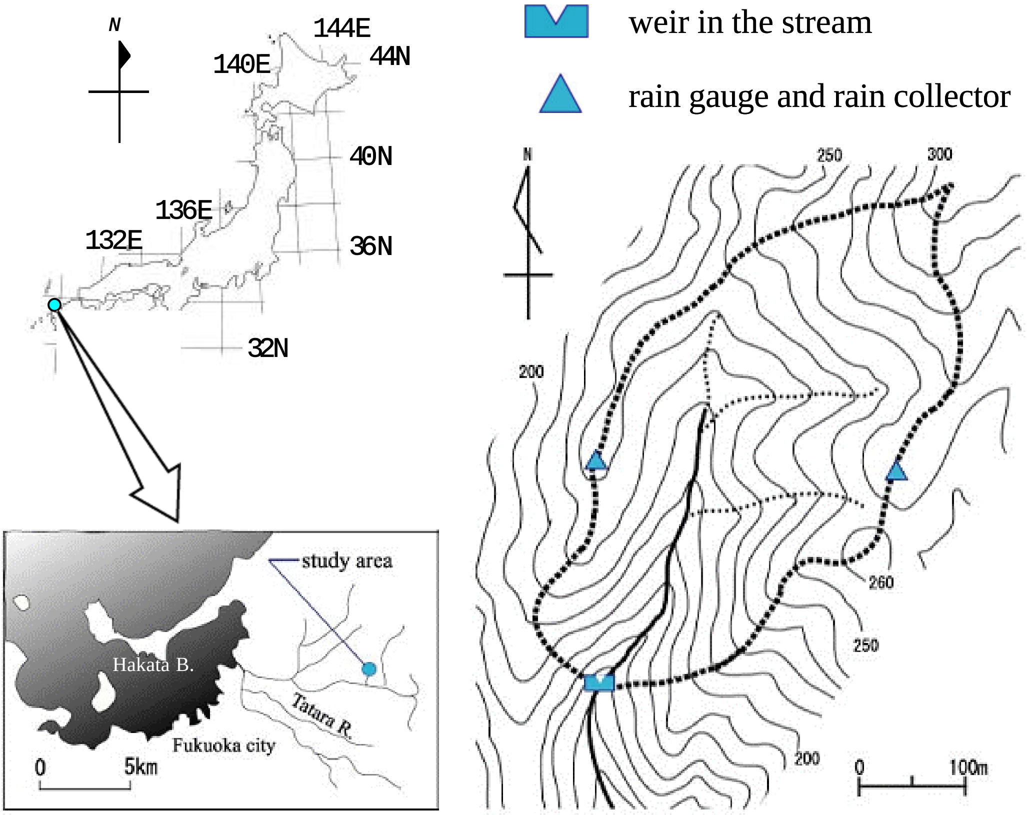

Fig.1 Location and map of Ochozu Experimental Watershed (OEW)

The weir was constructed at the end of OEW (Fig.1), and the water level has been measured at every 10 minutes by hydraulic pressure sensor (OSASI Tech.Inc., PC-001). Stream water was collected and analyzed in the laboratory. Stream water was collected regularly every week and also irregularly in rain events. And in addition, the stream water was collected continually (at 15min.- hourly intervals) in 3 rain events (Nov/29/2001, Jun/11/2002, Sep/16/2002) manually or using automatic sampler (ISCO Inc., ISCO-6712). The precipitation collected at both west and east ridges of OEW and those samples were collected once every two or three weeks. The amount of precipitation was also monitored by rain gauges at each site.

Chemical analysis

Total nitrogen (T-N) and total phosphorus (T-P) of the collected water were analyzed. For T-N analysis, water samples were decomposed using an alkaline solution of potassium peroxodisulfate. Then their T-N were measured using an ultraviolet absorptiometry (Shimadzu UVmini-1240). For T-P analysis, the samples were decomposed using potassium peroxodisulfate. Then their T-P were measured using the molybdenum blue (ascorbic acid) absorptiometry. For the samples collected continually in 3 rain events, dissolved nitrogen (DTN), particulate nitrogen (PTN), dissolved phosphorus (DTP) and particulate phosphorus (PTP) were measured in addition to T-N and T-P. For DTN and DTP analysis, the samples were filtrated through grass fiber filters (Whatman, GF/C), and the same method as T-N and T-P was used, respectively. PTN was the difference between T-N and DTN (= T-N - DTN), and PTP was the difference between T-P and DTP (= T-P - DTP).

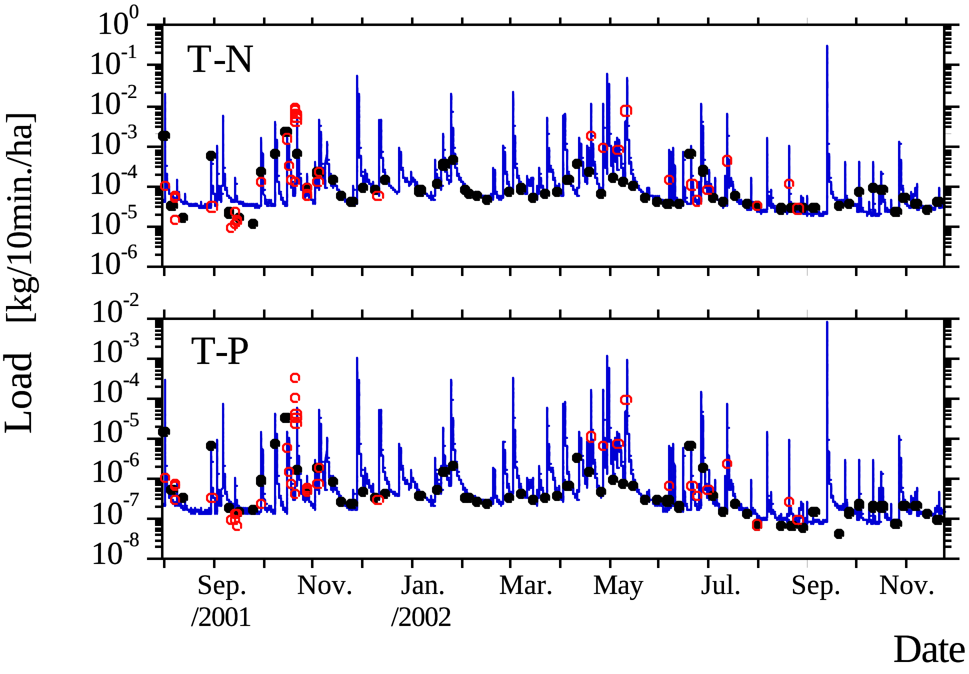

Fig.2 Loads of total nitrogen (T-N) and total phosphorus (T-P) during the observation period (Aug/1/2001-Nov/28/2002). Vertical axes are logarithmic scale. Each closed circle shows the load based on regular data obtained every week. Each open circle shows the load based on irregular data obtained in rain events. Each solid line shows the load calculated by L-Q equation.

Calculation of the input and output of the watershed

In order to evaluate nutrient budget in OEW, we assumed that all the input [kg/yr/ha] of nutrients (T-N, T-P) to the OEW was from precipitation and all the output [kg/yr/ha] from the OEW was in stream. The input was the value multiplied precipitation-weighted average concentration by precipitation per year. The output was estimated using two representative methods based on regular data observed every week. One is interval-representative flux method (I-R method), the other is L-Q method (Takeda, 2001). I-R method assumes that a load datum observed regularly represents the average load of half of pre-period and half of post-period, and the output estimated by this method is annual summation of each value multiplied a load datum (L_i) by half of both periods (T_i), i.e.

$$output = \sum_{i}^{n} L_i T_i \tag{1}$$

L-Q method is the method that calculates the output using correlation equation between observed load (L) and flow rate (Q), i.e. L-Q equation ($L = aQ^b$).

RESULTS AND DISCUSSIONS

The regular data of load [kg/10min./ha] for T-N and T-P were obtained by weekly observation (Fig.2, closed circles). Using the data, the output of T-N and T-P estimated by I-R method was 8.35 and 0.072 kg/yr/ha, respectively. In order to obtain the parameters of L-Q equations for T-N and T-P, the weekly observed data of flow rate [mm/10min.] and load were used. The calculated L-Q equations are as follows;

$$\text{T-N:}\quad L = 3.83\times10^{-2}Q^{1.16} \quad (r^2 = 0.92) \tag{2}$$

$$\text{T-P:}\quad L = 6.67\times10^{-4}Q^{1.38} \quad (r^2 = 0.91) \tag{3}$$

Using these equations, the output of T-N and T-P was calculated as 16.3 and 0.189 kg/yr/ha, respectively. When the output estimated by I-R method (O_{IR}) were compared with those estimated by L-Q method (O_{LQ}), O_{LQ} / O_{IR} ratio of T-N and T-P was approximately 2.0 and 2.6, respectively (Table1). The differences in the values between O_{IR} and O_{LQ} reflect the loads during rain events (Fig.2).

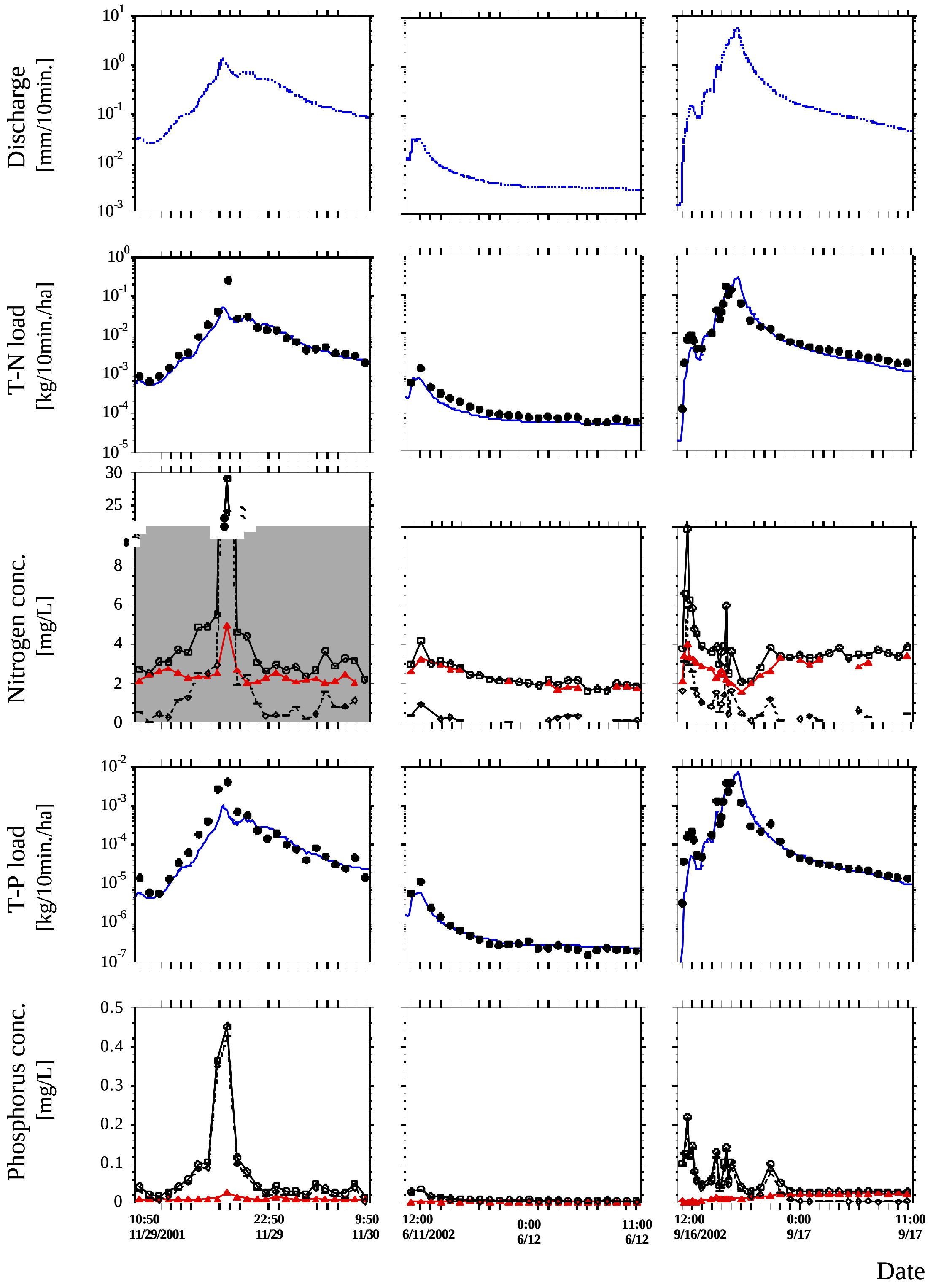

Fig.3 Changes in discharge, load and concentration of nitrogen and phosphorus in 3 rain events. Closed circles and solid lines in load graphs are the observed loads and the calculated loads using L-Q equations, respectively. Open circles, triangles and lozenges in concentration graphs are concentrations of total nutrient (T-N, T-P), dissolved nutrient (DTN, DTP) and particulate nutrient (PTN, PTP), respectively.

Table 1 The flux budgets of T-N and T-P

	T-N	T-P
Input	8.6	0.116
A: output by I-R method [a]	8.35	0.072
B: output by L-Q method [a]	16.3	0.189
Ratio for A	0.97	0.189
Ratio for B	1.9	1.62
B/A ratio	1.96	2.64

Both T-N and T-P, O_{IR} was less than the input, whereas O_{LQ} was larger than the input (Table1); i.e., I-R method evaluated OEW as a sink of nutrients, but L-Q method evaluated it as a source of nutrients. It was highly possible that O_{IR} was significantly underestimated as compared with true value of the output because O_{IR} did not include the peak loads during rain events when the loads increased drastically within a short time (Fig.3, closed circles). Therefore, O_{IR} is not appropriate to evaluate nutrient budget in OEW. On the other hand, the loads calculated by L-Q equations fitted well with the loads observed irregularly in rain events except some parts (Fig.2). O_{LQ} may be appropriate to evaluate nutrient budget in OEW. Therefore, OEW is a source of nutrients. However, the estimated loads for both T-N and T-P were much less than the loads observed on October 22nd, 2001 when a great amount of load was observed (Fig.2). This result suggested that the reliability of the loads estimated by L-Q method during such heavy rain events needed to be assessed.

In order to assess the validity of O_{LQ}, the loads calculated by L-Q equations were compared with the observed data that was continually measured (at 15 min. - hourly intervals) in 3 rain events (Nov/29/2001, Jun/11/2002, Sep/16/2002). In all cases, the results showed that the calculated loads using L-Q equations were significantly underestimated as compared with the observed loads during peak discharges (as shown in Fig.3). Furthermore, high levels of particulate nutrients (PTN, PTP) were running off during peak discharges (as shown in Fig.3). These suggest that L-Q equation fails to estimate the loads during peak discharges, especially when runoff of particulate nutrients is large. It was suggested that O_{LQ} was still underestimated as compared with true value of the output.

CONCLUSIONS

The results suggest that L-Q method is more appropriate to evaluate nutrient budget in watersheds than I-R method because L-Q method considers changes of nutrient load during rain events. However, output of nutrients estimated by L-Q method is still underestimated as compared with true value of the output because it does not properly estimate large loads of particulate nutrients during peak discharges. This shows that true value of the output is larger than the input in OEW, i.e. it is a source of nutrients, because O_{LQ} is larger than the input. This also shows that runoff characteristics of particulate nutrients need to be clarified in order to estimate proper value of the output.

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