NITROGEN EXPORT FROM FORESTED AND AGRICULTURAL
WATERSHEDS OF SOUTHERN CHILE*EXPORTACION DE NITROGENO EN CUENCAS BOSCOSAS Y AGRICOLAS
EN EL SUR DE CHILE*

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ABSTRACT

Measuring nutrients fluxes in watersheds with different landuse is important for evaluating the effects of conversion of native forests to agricultural land, and for establishing guidelines for land management. Nitrogen (N) concentrations and fluxes were studied over a 12-month period in four watersheds in the Lake Rupanco basin in the Andean Cordillera and four watersheds located in the Lake Huillenco basin in the Coastal Cordillera of southern Chile. Two watersheds in either lake basins were covered mainly by native rainforests, and the other two had mixed landuse (livestock pastures, subsistence agriculture and shrub-pasture mixtures). In the Lake Rupanco area, the annual transport of $\text{NO}_3\text{-N}$ from forested and agricultural watersheds was 4.9 and 11.0 $\text{kg ha}^{-1} \text{yr}^{-1}$, respectively. Inorganic-N ($\text{NO}_3\text{-N} + \text{NH}_4\text{-N}$) accounted for 53% and 74% of N transport in forested and agricultural watersheds, respectively. In the Lake Huillenco area, the annual transport of $\text{NO}_3\text{-N}$ was 1.4 and 0.8 $\text{kg ha}^{-1} \text{yr}^{-1}$, respectively, with nitrogen organic forms (DON), prevailing and exported mainly from native forests. The impact of the replacement forests by livestock pasture was clearly reflected in the streamwater $\text{NO}_3\text{-N}$ concentrations and fluxes in the watersheds at the Lake Rupanco basin, probably due to fertilization practices.

KEYWORDS: Landuse, native forest, nitrogen fluxes, non-point pollution.

RESUMEN

Establecer las concentraciones y flujos de nutrientes en cuencas con diferentes uso del suelo nos permite evaluar los efectos del reemplazo de bosques nativos por tierras agrícolas y entregar recomendaciones para un mejor uso de la tierra. En este trabajo se estudiaron las concentraciones y los flujos de nitrógeno (N) durante un período de 12 meses, en cuatro cuencas localizadas dentro del sistema de drenaje del Lago Rupanco en la Cordillera de los Andes y cuatro cuencas localizadas en la cuenca del lago Huillenco en la Cordillera de la Costa, en el sur de Chile. Dos cuencas, en ambas cordilleras, están caracterizadas principalmente por bosques nativos y otras dos cuencas tienen un uso mixto del suelo con praderas ganaderas, agricultura limitada y praderas-matorrales. En el área del Lago Rupanco, el transporte anual de $\text{NO}_3\text{-N}$ en las cuencas forestadas y agrícolas fue de 4,9 y 11,0 $\text{kg ha}^{-1} \text{a}^{-1}$, respectivamente. El transporte de N-inorgánico ($\text{NO}_3\text{-N} + \text{NH}_4\text{-N}$) representó el 53% y 74%, en las cuencas forestadas y agrícolas. En el área del lago Huillenco, el transporte anual de $\text{NO}_3\text{-N}$ fue de 1,4 y 0,8 $\text{kg ha}^{-1} \text{a}^{-1}$, respectivamente, prevaleciendo el N-orgánico, exportado principalmente desde los bosques nativos. El impacto del reemplazo de los bosques, principalmente por praderas ganaderas, se reflejó claramente en las concentraciones y flujos de $\text{NO}_3\text{-N}$ en las cuencas del área del lago Rupanco, probablemente debido a las prácticas de fertilización.

PALABRAS CLAVES: Bosque nativo, contaminación difusa, flujos de nitrógeno, praderas agrícolas.

INTRODUCTION

It is well known that land use, and in particular the replacement of forests by agriculture, strongly influences watershed nutrient fluxes (Omernick *et*

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al. 1981; Beaulac & Reckow 1982; Jordan *et al.* 1997; Castillo *et al.* 2000). Increased leaching of nitrogen and phosphorus from catchments due to conversion of from forests to cropland or pasture contributes to changes in water quality and eutrophication processes (Kaste *et al.* 1997). Nitrate is considered to be the main pollutant of aquatic ecosystems, and is typical of non-point source pollution by agricultural activities, as a result of the intensive use of chemical fertilizers and the increasing application of animal manure (Van Herpe & Troch 2000). In areas with low atmospheric deposition, the inorganic-N transport in streams draining natural forests usually is $< 1 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ (Godoy & Oyarzún 1999) but can be $25\text{--}30 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ in agricultural areas with high atmospheric deposition (Van Herpe & Troch 2000).

The assessment of nutrient loading from different sources to surface waters is important for the implementation of control measures to check eutrophication processes. Loading from nonpoint sources is by definition the most difficult to evaluate

(Vighi *et al.* 1991). Lakes and rivers receive nitrogen from several sources, e.g. as atmospheric deposition, natural background runoff, agricultural practices, diffuse runoff from agricultural fields, point sources from humans, industrial point sources and from nitrogen fixation within the waterbodies (Berge *et al.* 1997).

Few studies have examined the influence of landuse on watershed nitrogen exports in southern Chile. Oyarzún *et al.* (1997) reported on the effects of agricultural land use on streamwater nutrient concentrations in catchments of the Andean Cordillera, and recently, Uyttendaele & Iroume (2002) have measured solute fluxes within exotic plantations and native forest in the Coastal Cordillera, near Valdivia. The present paper reports nitrogen concentration and fluxes in watersheds encompassing a range of landuses, all located within a region where atmospheric deposition from anthropogenic origin, especially of nitrate, is very low (Godoy *et al.* 2001; Hedin *et al.* 1995).

TABLE I: Landuse characteristics (in %) of watersheds of Lake Rupanco.

Watersheds	Size (km ²)	Forest	Pasture	Cropland	Shrubland
Frutillar	8.29	98.4	0.0	0.0	1.6
Taique	1.58	100.0	0.0	0.0	0.0
Encanto	9.11	17.0	72.5	6.9	3.6
Trafún	5.57	31.0	67.5	1.5	0.0

MATERIAL AND METHODS

STUDY AREAS

Four watersheds were selected within the drainage system of the Lake Rupanco, Andean Cordillera ($40^{\circ} 45' - 41^{\circ} 00' \text{ S}$ and $72^{\circ} 25' - 72^{\circ} 45' \text{ W}$, 1110–145 m above sea level) (Table I). Two watersheds (Frutillar and Taique) were located in mountainous areas and they have native forests occupying 100% of their surfaces. The forested watersheds are dominated by species such as *Nothofagus dombeyi*

(Mirb.) Oerst., *Laurelia philippiana* Looser and *Weinmannia trichosperma* Cav. Two watersheds (Encanto and Trafún) were located in flat areas where landuse is mainly grassland farming (72.5% and 67.5%) with permanent fertilized pastures (Table I), suggesting a potential for nonpoint-source pollution. The soils of the watersheds are derived from volcanic ash (Hydric dystrandept), and the bedrock is of volcanic origin in mountainous areas and fluvio-glacial sediments in flat areas. The climatic regime can be considered as humid temperate, with a mean annual rainfall about

3,000 mm in mountainous areas and 1,500 mm in flat areas. Precipitation is highest in the fall and winter (May till August) due to the frequency of fronts from the Pacific Ocean.

The four other watersheds were located in the Lake Huillenco basin, Coastal Cordillera (42° 30' - 42° 45' S and 73° 45' - 73° 55' W, 750-50 m a.s.l.) (Table II). Two watersheds (Llin and Dongo) have an old-growth forest dominated by evergreen broad-leaved species, such as *Drimys winteri* J. R. et G. Forster, *Pilgerodendron uviferum* (D. Don) Pic. Ser. et Bizz, *Nothofagus nitida* (Phil.) Krasser, *Weinmannia trichosperma* Cau. and

Laurelia philippiana Looser. Two catchments (Cudehue and Notuco) have mixed landuse, mainly pastures (31.5% and 56.4%) and shrubland (52.4% and 13.3 %, respectively). Apparently, these pastures are not fertilised. Soils are trumaos, derived from volcanic ash, covering fluvioglacial sediments and the solifluxion strata of the late glacial age (Veit & Garleff 1995). The climate is humid temperate with a mean annual rainfall about 4,000 mm in forested watersheds and 2,000 mm in agricultural watersheds. Precipitation is high all year round, with a peak in fall and winter.

TABLE II: Landuse characteristics (in %) of watersheds at Lake Huillenco.

Watersheds	Size (km ²)	Forest	Pasture	Cropland	Shrubland
Llin	10.9	84.2	4.9	0.0	5.1
Dongo	24.1	96.9	0.0	0.0	2.2
Cudehue	9.7	16.1	31.5	0.0	52.4
Notuco	22.2	27.0	56.4	0.0	13.3

ANALYSES

Streamwater discharges were recorded by a water level recorder installed in the main streams. Water samples were collected monthly, transported to laboratory in 1000 ml plastic bottles and chemical analyses were performed usually within 24 hours of sampling. NO₃-N was determined colorimetrically using the sodium salicylate and Seignette salt method. NH₄-N was determined by the solorzano method and organic-N by Kjeldahl digestions (APHA-AWWA-WPCF 1975). Nutrient export was calculated for each sampling interval, by multiplying daily water discharge by interpolated daily nitrogen concentrations.

RESULTS

In forested and pastures watersheds of the Lake

Huillenco basin, the mean annual concentration of total-N was 153 and 194 µg L⁻¹ (Fig. 1). Organic-N concentrations were greater in forested (79 µg L⁻¹) and pasture watersheds (115 µg L⁻¹), than the concentrations of NO₃-N and NH₄-N. Concentrations of NO₃-N were slightly greater in pasture (74 µg L⁻¹) than in forest dominated watersheds (68 µg L⁻¹), whereas NH₄-N concentrations were similar and very low in forest and pasture streams (Fig. 1).

In the forested watersheds of the Lake Rupanco basin, the mean annual concentration of total-N was 157 µg L⁻¹, against 319 µg L⁻¹ in the pasture watersheds (Fig. 2). Concentrations of NO₃-N represented the greater values of all forms of nitrogen, especially in the pasture streams (245 µg L⁻¹), compared with the forested streams (109 µg L⁻¹). DON concentrations were similar in both forested (82 µg L⁻¹) and pasture (83 µg L⁻¹) streams (Fig. 2).

FIGURE. 1: Comparison of the nitrogen concentration ($\mu\text{g L}^{-1}$) between forested and pasture watersheds in the Lake Huillanco basin, Coastal Cordillera.

FIGURE. 2: Comparison of the nitrogen concentration ($\mu\text{g L}^{-1}$) between forested and pasture watersheds in the Lake Rupanco basin, Andean Cordillera.

FIGURE. 3: Comparison of the total nitrogen fluxes ($\text{kg ha}^{-1} \text{yr}^{-1}$) of forested and pasture watersheds in the Lake Huillanco basin, Coastal Cordillera.

The annual export of total-N from forested and pasture watersheds of the Lake Huillanco basin was 3.5 and 1.8 $\text{kg ha}^{-1} \text{yr}^{-1}$, respectively (Fig. 3). $\text{NO}_3\text{-N}$ fluxes were smaller, especially from pasture watersheds (0.8 $\text{kg ha}^{-1} \text{yr}^{-1}$) compared with forested watersheds (1.4 $\text{kg ha}^{-1} \text{yr}^{-1}$) and organic-N fluxes have similar patterns (1.0 and 2.0 $\text{kg ha}^{-1} \text{yr}^{-1}$, respectively). The annual export of total-N in forested watersheds of the Lake Rupanco basin was 7.9 $\text{kg ha}^{-1} \text{yr}^{-1}$, $\text{NO}_3\text{-N}$ of 4.9 $\text{kg ha}^{-1} \text{yr}^{-1}$ and organic-N of 2.9 $\text{kg ha}^{-1} \text{yr}^{-1}$ (Fig. 4). In agricultural watersheds, the annual fluxes were greater: total-N 13.9 $\text{kg ha}^{-1} \text{yr}^{-1}$ and especially $\text{NO}_3\text{-N}$ with 11.0 $\text{kg ha}^{-1} \text{yr}^{-1}$. Among the four Andean watersheds, $\text{NO}_3\text{-N}$ export rates appeared to be related to the percentage of the catchments area converted to agricultural grasslands, but there was no such trend for the Coastal Cordillera catchments (Fig. 5).

FIGURE. 4: Comparison of the total nitrogen fluxes ($\text{kg ha}^{-1} \text{yr}^{-1}$) between forested and pasture watersheds in the Lake Rupanco basin, Andean Cordillera.

FIGURE. 5: Relation of $\text{NO}_3\text{-N}$ fluxes with percentage of agricultural land (pasture + cropland) in the watersheds of the coastal and Andean ranges, southern Chile.

DISCUSSION

Most studies of N leaching from natural or semi-natural ecosystems have been carried out in forests. An examination of 65 forested plots and catchments in Europe indicated that below an atmospheric deposition of about 10 kg N ha⁻¹ yr⁻¹ no significant N leaching occurred from the forests (Dise & Wright 1995). Recently, Perakis & Hedin (2002) and Van Breemen (2002) reported that the nitrogen loss from unpolluted temperate South American forests is mainly *via* dissolved organic (DON). Perakis & Hedin (2002) estimated that N losses from pristine forests in regions with minimal human impact range from 0.2 to 3.5 kg N ha⁻¹ yr⁻¹ (maximum 7.5 kg N ha⁻¹ yr⁻¹) as a function of precipitation amount. According to Pérez *et al.* (1998), in the Coastal Cordillera forests in southern Chile, inorganic N (mainly nitrate) is strongly retained within the forest, immobilised either in plant or microbial biomass. Also, Oyarzún *et al.* (1998) have reported that in the Coastal Cordillera of southern Chile, atmospheric deposition of inorganic nitrogen is very low, especially for nitrate (< 1 kg ha⁻¹ yr⁻¹), which would explain the smaller concentrations of ammonium and nitrate in these watersheds, compared with watersheds located in the Andes (Fig. 1 and Fig. 2).

Higher pasture stream water DON (dissolved organic nitrogen) concentrations has been related to autochthonous production by aquatic grasses on pasture stream banks and in the channel (Neill *et al.* 2001). This effect could explain the higher streamwater DON concentrations in the pasture (115 mg L⁻¹) than forests (80 mg L⁻¹) of the Lake Huillinco basin (Fig. 1). Pasture streams located in this basin occupied very flat areas permanently flooded with a high cover of aquatic grasses inside the drainage channels.

The NO₃-N concentrations found in the forested Andean watersheds are higher than the data reported by Godoy *et al.* (2001) for smaller streams. They found very small concentrations of NO₃-N in streams draining undisturbed *Nothofagus pumilio* (6 µg L⁻¹) and *Nothofagus betuloides* (6 µg L⁻¹) forests located at the Puyehue National Park (40° S), near of the study sites. The N concentration levels in the forested watersheds of the present study showed some effects of the wood extraction, biomass burning and introduction of cattle inside the catchments.

Land use changes in the watersheds of the Lake Rupanco basin appear to have resulted in a significant increase in nitrogen fluxes to the lake (Fig. 4). The input of the fertilizers to the pastureland in this region has increased in the last years. For this region of the southern Chile, with *ca.* 3.64 x 10⁶ hectares, it was estimated that anthropogenic N contributes 7,087 tonnes yr⁻¹, 3,528 tonnes yr⁻¹ from pastures, 1,729 tonnes yr⁻¹ from croplands and 1,830 tonnes yr⁻¹ from cattle (Salazar *et al.* 2003). NO₃-N leaching from pasture streams was the most important nitrogen flux, due to the impact of fertilizer application and cattle production. Therefore, in the agricultural catchments loss of N from soils is determined by the supply mainly from external sources. In the forested catchments, leaching of N from soils probably is determined by both internal and external sources.

The effect on nutrient levels of the conversion of native forests to pasture and croplands was evident only in the watersheds of the Andean Cordillera (Fig. 5). In the watersheds of the Coastal Cordillera this impact was not evident probably due to the low use of fertilizers.

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