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NITROGEN FLUXES IN A *NOTHOFAGUS OBLIQUA* FOREST AND A *PINUS RADIATA* PLANTATION IN THE CENTRAL VALLEY OF SOUTHERN CHILE

FLUJOS DE NITROGENO EN UN BOSQUE DE NOTHOFAGUS OBLIQUA *Y UNA PLANTACION DE* PINUS RADIATA *EN EL VALLE CENTRAL DEL SUR DE CHILE*

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ABSTRACT

Forest structure and tree species can have a significant impact on total atmospheric nitrogen (N) deposition; for example, deciduous forests have higher N requirements than coniferous forests. However, knowledge about the effect of the conversion of native Chilean vegetation cover by exotic plantations on N cycling is scarce. The aim of this study was to determine the effect of the replacement of a *Nothofagus obliqua* native forest by a *Pinus radiata* plantation in southern Chile on the chemistry of throughfall, stemflow, soil water infiltration and percolation. *Pinus radiata* stemflow was more acidic (pH 4.7) than precipitation (pH 5.2) and throughfall (pH 5.6), while in the *Nothofagus* forest stemflow and throughfall pH were 6.3 and 6.1, respectively. In the *Nothofagus* forest, the soil water infiltration and percolation at 150 cm depth pH were 6.2 and 6.3, while in the *Pinus* plantation pH were 5.9 and 6.0, respectively. Throughfall and stemflow were enriched in DIN (NH_4^+-N + NO_3^--N) and DON in both forests. DIN fluxes were higher in throughfall in the *Nothofagus* forest (7.5 kg ha^{-1} yr^{-1}) than in the *Pinus* plantation (6.4 kg ha^{-1} yr^{-1}). DIN infiltration fluxes were much higher in the Pinus plantation (NH_4^+-N = 3.1 kg ha^{-1} yr^{-1}, NO_3^--N = 5.4 kg ha^{-1} yr^{-1}) than in the *Nothofagus* forest ($NH4^+$-N = 0.4 kg ha^{-1} yr^{-1}, $NO3^-$-N = 1.5 kg ha^{-1} yr^{-1}), suggesting a lower N immobilization and/or plant uptake in the *Pinus* plantation.

Keywords: Ammonium, infiltration, nitrate, soil percolation, throughfall.

RESUMEN

Es conocido que las especies arbóreas y la estructura de los bosques tienen un significativo impacto sobre la depositación de N, y que los requerimientos de nitrógeno de los bosques deciduos son mayores que los bosques de coníferas. Sin embargo, el conocimiento acerca de los efectos de la sustitución de vegetación nativa chilena por plantaciones exóticas sobre el ciclo del N es escaso. El objetivo de este estudio fue determinar los efectos del reemplazo de un bosque nativo de *Nothofagus obliqua* por una plantación de *Pinus radiata* sobre la química de la precipitación directa, escurrimiento fustal, infiltración y percolación del agua en el suelo. El agua del escurrimiento fustal en *Pinus radiata* fue más ácida (pH 4,7) que la precipitación directa (pH 5,6) y la precipitación (pH 5,2), mientras que en el bosque nativo de *Nothofagus* el pH del escurrimiento fustal y la precipitación directa fueron 6,3 y 6,1, respectivamente. En el bosque de *Nothofagus*, el pH del agua de infiltración y percolación a 150 cm de profundidad fueron de 6,2 y 6,3, respectivamente; mientras que en la plantación de pinos fueron de 5,4 y 6,0, respectivamente. La precipitación directa y el escurrimiento fustal fueron enriquecidos en nitrógeno inorgánico (DIN) y orgánico (DON) en ambos ecosistemas forestales. Los mayores flujos de DIN ocurrieron en la precipitación directa, tanto en el bosque de *Nothofagus* (7,5 kg ha^{-1} $año^{-1}$) como en la plantación de *Pinus* (6,4 kg ha^{-1} $año^{-1}$). En el agua de infiltración del suelo, los flujos de DIN fueron mayores en la plantación de *Pinus* (NH_4^+-N = 3,1 kg ha^{-1} $año^{-1}$, NO_3^--N = 5,4 kg ha^{-1} $año^{-1}$) que en el bosque de *Nothofagus* (NH_4^+-N = 0,4 kg ha^{-1} $año^{-1}$, NO_3^--N= 1,5 kg ha^{-1} $año^{-1}$), sugiriendo una inmovilización en el suelo o consumo por la vegetación.

Palabras Claves: Amonio, infiltración, nitrato, percolación, precipitación directa.

INTRODUCTION

Precipitation passing through forest canopies as throughfall or stemflow is enriched or depleted in certain ions depending on ion reactivity and on the nature of the canopy (Houle *et al.* 1999). Furthermore, when water infiltrates the forest floor and mineral soil, its chemistry is further modified depending on soil characteristics, litterfall quality and tree species. Throughfall and stemflow have been reported to have significant impacts on forest biogeochemical cycles (Parker 1983, Likens & Bormann 1995). Throughfall has been estimated at 60-86% of total precipitation for broadleaved temperate forests and 55-82% for conifer plantations in south-central Chile, and stemflow has been shown to account for 1 - 8% in the broadleaved forests and 1 - 13% in the coniferous stands (Huber & Iroumé 2001). A few studies of throughfall and stemflow chemistry were undertaken in forests of southern Chile, of which the majority is focusing at native temperate forests such as *Fitzroya cupressoides* (Molina) I.M.Johnst. located in the Coastal Range (Oyarzún *et al.* 1998) and *Nothofagus pumilio* (Poepp. & Endl.) Krasser and *N. betuloides* (Mirb.) Oerst. located in the Andes (Godoy *et al.* 1999, Oyarzún *et al.* 2004). Comparative studies with exotic plantations are scarce (Uyttendaele & Iroumé 2002), and consequently the effect of the substitution of *Nothofagus* forests by exotic plantations on soil water chemistry is unknown.

Research in the northern hemisphere (Cole & Rapp 1981) has reported that the uptake of nitrogen by temperate deciduous forests can be about 63% higher than by coniferous forests. Furthermore, forest structure, canopy density and tree species were reported to have a significant impact on total atmospheric nitrogen deposition onto forest stands (De Schrijver *et al.* 2004). Therefore, it is probable that the substitution of native vegetation cover by exotic plantations has an impact on the chemistry of throughfall, stemflow and soil water. Native forests in the Valdivian Eco-region (36º - 48º S) have been affected by human disturbances including degradation due to non-sustainable logging practices, and destruction due to human-set fires as well as conversion to agriculture and fast-growing plantations (Lara *et al.* 1996). It is estimated that between 1974 and 1992 around 11,000 ha y^{-1} of native forest was converted into exotic plantations of *Pinus radiata* D.Don and *Eucalyptus* spp., especially in the coastal range of south-central Chile. The *Nothofagus obliqua* (Mirb.) Oerst. forests of the central valley have suffered a particularly drastic reduction in land cover and original species composition (San Martín *et al*. 1991, Veblen *et al.* 1996b). Ecosystem remnants of this forest type are poorly represented in the Chilean system of national parks and reserves (SNASPE) (Armesto *et al*. 1998). These small areas located at the Central Valley in southern Chile have a great significance in biodiversity conservation (Veblen *et al*. 1996a), and based on research in other regions, likely also in the maintenance of groundwater water quality (e.g. De Schrijver *et al*. 2000).

This paper analyzes the effect of the replacement of a *Nothofagus obliqua* native forest by a *Pinus radiata* plantation on the concentrations and fluxes of nitrogen in the canopy and soil water. We hypothesized that the nitrogen fluxes in throughfall, soil water infiltration, and percolation water would be altered due to the different composition and structure of the vegetation.

MATERIALS AND METHODS

STUDY AREAS

The *Nothofagus obliqua* forest and the *Pinus radiata* plantation are located in the Central Valley (40º 07' S, 72º 51' W, 160 m above sea level) at a distance of 0.5 km of each other. The climate is classified as temperate with less than four dry months and the annual precipitation for the period June 2003-May 2004 was 1187 mm. Maximum precipitation occurred during the period April-September with 75% of the rainfall. Both soils originate from volcanic ash. Soils of the *Nothofagus* forest are denominated "trumaos", while in the plantation red clay soils occur, originating from older volcanic ash. The geological substrate is a metamorphic complex, mainly consisting of mica schist with quartz lenses.

The dominant tree species in the *Nothofagus* forest is *N. obliqua.* The stand has a subcanopy dominated by *Aextoxicon punctatum* Ruiz et Pav., and an understorey of the bamboo *Chusquea quila*

Kunth and the small tree *Rhaphithamnus spinosus* (A.L.Juss) Molina. The aspect of the stand is southerly and the mean slope is 35-40%. The growing season lasts from September till April. The *Pinus radiata* site is a fast-growing monoculture with an understorey of *Aristotelia chilensis* (Molina) Stuntz, *Chusquea quila* and *Rubus contrictus* P.F.Müll. et Lefèvre. The aspect of the stand is northerly and the mean slope is 35-40%. Tree density and basal area are much higher in the pine plantation than in the *Nothofagus* forest (Table I).

TABLE I. Characteristics of the *Nothofagus* and *Pinus radiata* stands sampled for canopy N fluxes in the central valley of southern Chile.

TABLA I. Características de los rodales de *Nothofagus* y *Pinus radiata* en los cuales se muestrearon flujos de N, en la depresión intermedia del sur de Chile.

Study site	Dominant tree species	Age (years)	Density (N ha^{-1})	Basal area (m^2 ha^{-1})	Height (m)
Native forest	*Nothofagus obliqua*	65-120	757	39	32
Pine plantation	*Pinus radiata*	30	1743	129	24

DATA COLLECTION

Bulk precipitation, throughfall, and stemflow water were collected monthly over a period of 18 months (June 2003 - November 2004). Bulk precipitation was measured with three funnel collectors, each with a surface area of 200 cm^2, attached to a plastic 2-l bottle. The bottles were set inside an opaque tube in order to avoid light penetration that could promote algae growth. The bulk precipitation was measured in a grassland about 50 m outside the *Nothofagus* forest. In addition to the rain collectors, a HOBO standard rain gauge was installed for measuring the amount of rainfall.

The throughfall collectors, their maintenance, and sample collection procedures were identical to those used for bulk precipitation, according to Kleemola & Soderman (1993). In both the *Nothofagus* forest and the pine plantation, 15 throughfall collectors were systematically located on a 0.1 ha plot. The stemflow collectors consisted of plastic collars attached to 25 L containers, for 4 trees that were representative of the tree diameter distribution.

Soil water infiltration was collected with 6 small zero-tension lysimeters (900 cm^2). These collectors were installed at 10 cm depth and were covered by an undisturbed soil layer. Percolation water was collected at 80 and 150 cm depth using a Pressure Vacuum Soil Water Sampler. Sixty centibars of soil suction was applied 24 hr before collection. Two replicates for each depth were located in the same plots as the throughfall, stemflow and infiltration collectors. Volume of water percolation at 150 cm depth was estimated using the water balance method, according to the references of Oyarzún & Huber (1999).

CHEMICAL ANALYSES

The samples were frozen, stored and analyzed within 2 weeks after collection. For each plot, the samples were pooled to one monthly sample of bulk precipitation, throughfall, stemflow, soil water infiltration and percolation before chemical analysis. After filtration of the water samples through a borosilicate glass filter (Whatmann) of 0.45 µm, pH and conductivity were determined using specific electrodes. NO_3-N was determined by a colorimetric method based on the reduction of cadmium (Clesceri *et al*. 1998). NH_4-N was measured by the phenate method (Clesceri *et al*. 1998). Organic-N was calculated by subtracting NH_4-N concentration of total Kjeldahl nitrogen (sum of organic nitrogen and NH_4-N) measured by the Kjeldahl method (Clesceri *et al.* 1998).

DATA ANALYSES

Element fluxes were calculated for the period June 2003-May 2004, by multiplying the measured amount of water in the different compartments of the forest and plantation with the element concentration (volume-weighted averages). Bulk deposition was subtracted from the sum of throughfall and stemflow to obtain net canopy exchange (NCE). Negative NCE values indicate uptake within the canopy (Houle *et al*. 1999). One-way ANOVA and LSD tests were applied to find differences in nutrient concentrations in precipitation, throughfall, stemflow and soil solution between the experimental sites.

RESULTS

PRECIPITATION CHEMISTRY

Volume-weighted bulk precipitation pH averaged 5.2 and average electrical conductivity was 11.6 µS cm-1 (Table II). Concentrations of NO_3--N, NH_4^+-N and DON in the precipitation were 26 µg L^{-1}, 180 µg L^{-1} and 121 µg L^{-1}, respectively.

TABLE II: Average volume-weighted values of chemical parameters in precipitation, throughfall, stemflow, infiltration and soil solutions in *Nothofagus obliqua* forest and *Pinus radiata* plantation (June 2003-November 2004). Different superscripts within a column indicate that means of the N concentrations differ significantly ($p < 0.05$) between the water fluxes of the two forest stands.

TABLA II: Valores promedio y rango de las características químicas del agua de precipitación, precipitación directa, escurrimiento fustal, infiltración y soluciones del suelo en un bosque de *Nothofagus obliqua* y una plantación de *Pinus radiata* (junio 2003-noviembre 2004).

Water flux	Value	pH (-)	Conductivity (µS cm^{-1})	NH_4^+-N (µg L^{-1})	NO_3^--N (µg L^{-1})	DIN (µg L^{-1})	DON (µg L^{-1})
Bulk precipitation	Mean	5.2	11.6	180^a	26^a	206^a	121^a
	Range	4.5 - 5.7	2.5 - 29.0	10 - 4389	4 - 127	16 - 4516	6 - 796
Throughfall							
Nothofagus	Mean	6.1	37.9	1213^b	199^b	1412^b	219^a
	Range	5.5 - 6.6	21.2 - 63.0	76 - 4793	42 - 544	140 - 5091	1 - 828
Pinus	Mean	5.6	24.5	861^b	192^b	1054^b	688^a
	Range	4.0 - 6.4	13.1 - 59.0	23 - 3835	31 - 471	73 - 4125	44 - 1762
Stemflow							
Nothofagus	Mean	6.3	82.8	1008^b	3389^b	4398^b	578^b
	Range	5.4 - 6.7	22.0 - 119.0	48 - 4108	75 - 9870	313 - 17402	41 - 2201
Pinus	Mean	4.7	60.5	398^a	316^a	714^a	346^a
	Range	4.6 - 4.8	32.0 - 80.0	20 - 2455	64 - 841	84 - 2802	298 -2135
Infiltration							
Nothofagus	Mean	6.2	44.5	180^a	591^b	771^a	497^a
	Range	5.9 - 6.5	28.1 - 77.0	16 - 3475	82 - 3176	145 - 4001	31 - 1083
Pinus	Mean	5.4	72.5	401^b	814^b	1216^b	376^a
	Range	5.0 - 6.0	36.1 - 164.0	66 - 5785	493 - 7887	558 - 13065	66 - 1034
Soil-80 cm depth							
Nothofagus	Mean	6.2	44.1	56	6	62	34
	Range	6.1 - 6.3	33.0 - 60.6	2 - 145	2 - 12	9 - 147	4 - 83
Pinus	Mean	5.9	55.6	39	10	48	46
	Range	5.8 - 6.1	48.8- 62.0	6 - 96	3 - 21	9 - 117	5 - 85
Soil-150 cm depth							
Nothofagus	Mean	6.3	44.9	11	6	17	13
	Range	6.0 - 7.1	32.0 - 56.0	1 - 18	2 -11	3 - 28	4 - 42
Pinus	Mean	6.0	37.1	2	8	10	25
	Range	5.8 - 6.3	35.0 - 42.0	1 - 7	3 - 16	3 - 26	6 - 97

Throughfall And Stemflow Chemistry

Average throughfall pH was 6.1 and 5.6 for the *Nothofagus* forest and 5.6 for the *Pinus* plantation, respectively (Table II). Electric conductivity increased from 11.6 µS cm^{-1} in bulk precipitation to 37.9 and 24.5 µS cm^{-1} in the *Nothofagus* and pine forest, respectively (Table II). In both plots the concentration of nitrate in throughfall was significantly higher than in bulk precipitation ($p < 0.05$) but not between the stands ($p > 0.05$). Ammonium concentration in the throughfall of the *Nothofagus* forest (1213 µg L^{-1}) was significantly ($p < 0.05$) higher than in bulk precipitation, but not significantly different from throughfall in the *Pinus* plantation (861 µg L^{-1}, $p = 0.29$) (Table II). There was a trend for DIN and DON concentrations to be higher in throughfall than in the bulk precipitation in both forest stands, particularly for nitrate, but the difference was not significant (Fig. 1). The enrichment concentration ratios of throughfall to precipitation were as follows: 6.7 and 4.8 for NH_4+-N, 7.7 and 7.4 for NO_3^--N, and 1.8 and 5.7 for DON in the *Nothofagus* and the *Pinus* stand, respectively (Table II).

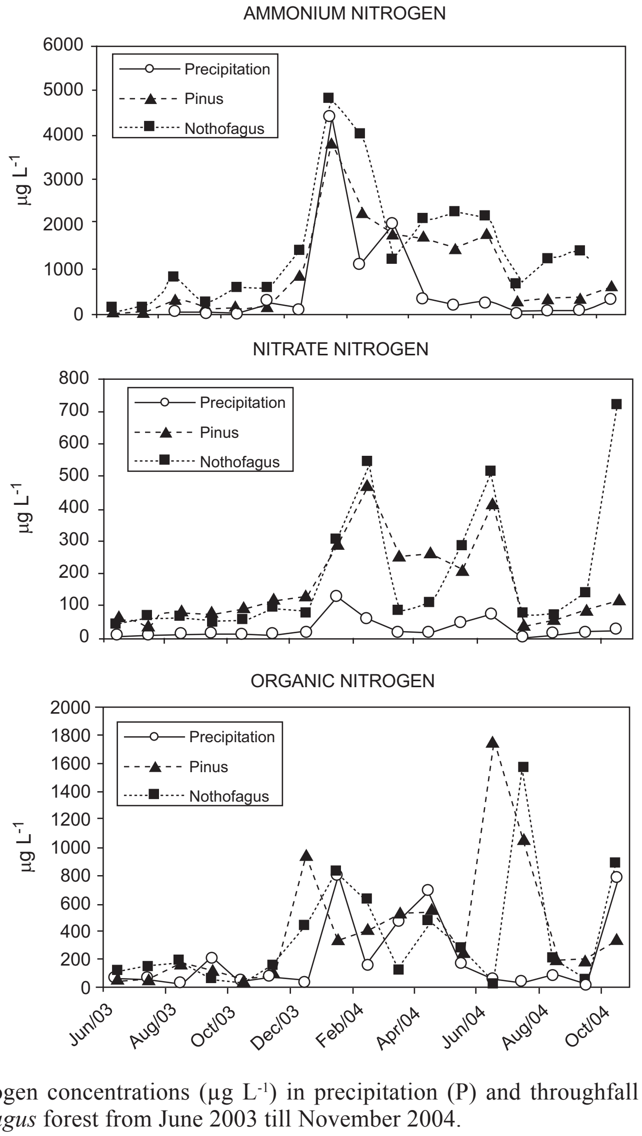


Figure 1. Monthly nitrogen concentrations (µg L^{-1}) in precipitation (P) and throughfall (TF) for a *Pinus radiata* plantation and a *Nothofagus* forest from June 2003 till November 2004.

Figura 1. Concentraciones mensuales de nitrógeno (µg L^{-1}) en la precipitación (P) y precipitación directa (TF) en una plantación de Pinus radiata y un bosque de Nothofagus, desde junio 2003 hasta noviembre 2004.

Stemflow pH was higher (6.3) in the *Nothofagus* stand and lower (4.7) in the *Pinus* plantation than in precipitation (Table II). In the two stands, electrical conductivity of stemflow was greater than in precipitation. *Nothofagus* stemflow concentrations of NO_3^--N, NH_4^+-N and DON were significantly higher than in precipitation ($p < 0.05$), but this was not the case in the pine plantation. The enrichment concentration ratios of stemflow to precipitation were as follows: 5.6 and 2.2 for NH_4^+-N, 13.0 and 12.2 for NO_3^--N, and 4.8 and 2.9 for DON in the *Nothofagus* and the *Pinus* stand, respectively (Table II).

SOIL SOLUTION CHEMISTRY

The pH of the soil water infiltration under *Pinus* (5.4) was similar to that of precipitation (5.2), whereas pH under *Nothofagus* was slightly higher (6.2). At 80 cm depth the soil solution pH had further risen to 5.9 under the *Pinus* plantation and had remained similar in *Nothofagus* forest (6.2). The difference between soil solution pH at 80 cm and at 150 cm depth was negligible in both plots (Table II). NO3--N concentrations in soil water infiltration were significantly higher in the *Pinus* plantation (814 µg L^{-1}, $p < 0.01$) and the *Nothofagus* forest (591 µg L^{-1}, $p < 0.05$) than in precipitation (26 µg L^{-1}). Ammonium concentrations were similar under *Nothofagus* (180 µg L^{-1}) and in precipitation (180 µg L^{-1}), but higher under *Pinus* (401 µg L^{-1}). In both plots, DON concentrations in soil water infiltration were not significantly different compared with precipitation (Table II). There was a general trend for NO_3^--N, NH_4^+-N and DON concentrations to be lower at 80 and 150 cm depth than in bulk precipitation (Fig. 2). Nitrate, ammonium and DON concentrations at 80 and 150 cm depth were lower than those in soil water infiltration.

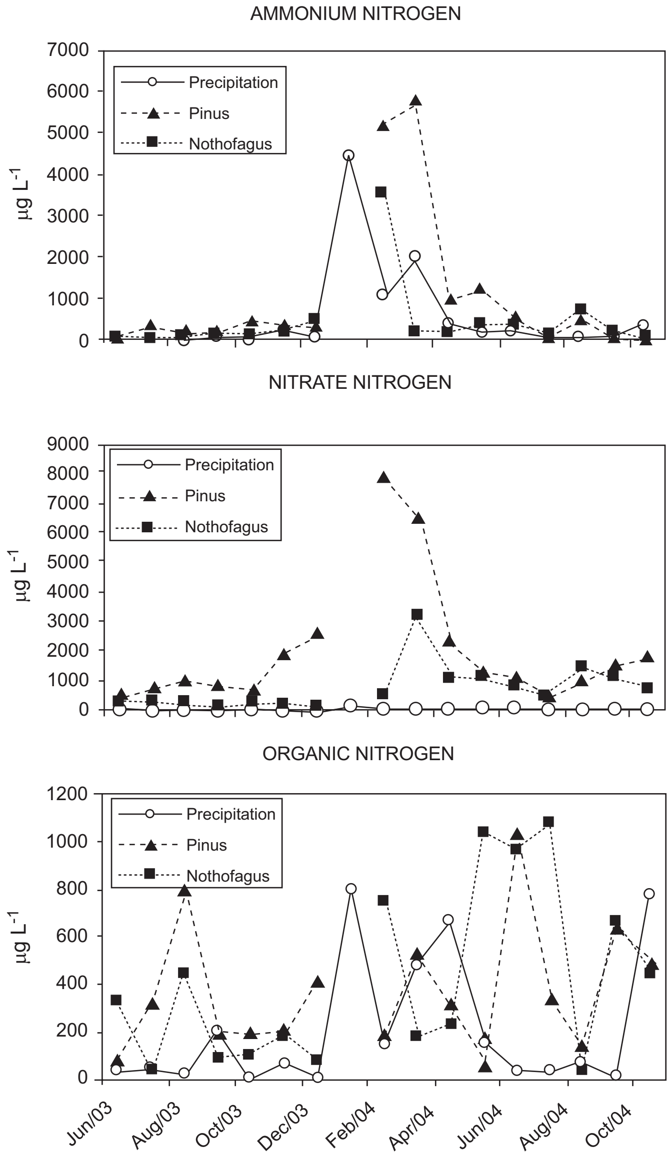
WATER AND NUTRIENT FLUXES

Net precipitation (throughfall plus stemflow) represented 73.1% of the gross precipitation in the *Nothofagus* stand and 86.9% in the *Pinus* stand (Table III). Therefore, canopy interception amounted 26.9 and 13.1% in the two stands, respectively. The soil percolation at 150 cm depth was estimated to be 20.3 and 23.5% of the gross precipitation in the *Nothofagus* forest and the *Pinus* plantation.

Bulk precipitation deposition of DIN and DON were 2.5 and 2.1 kg ha^{-1} yr^{-1}, respectively (Table III). In the two stands, NH_4^+ and NO_3^- throughfall fluxes were higher than bulk deposition. Stemflow fluxes of DIN and DON were very low in both stands due to the small quantities of water flowing down the trunks, especially in the Nothofagus forest (Table III). The highest fluxes of inorganic N in the soil water infiltration were found in the *P. radiata* plantation (NH_4^+-N = 3.1 kg ha^{-1} yr^{-1}, NO_3^--N = 5.4 kg ha^{-1} yr^{-1}), while the total DIN flux in the soil water infiltration in the *Nothofagus* stand was only 1.9 kg ha^{-1} yr^{-1}. The NH_4^+-N flux was reduced in both stands after passing through the humus layer, with the decrease being more pronounced in the *Nothofagus* stand. NO_3- fluxes in the soil water infiltration increased in both stands compared to net precipitation, with the increase in NO_3^--N amount being most clearly in the *Pinus* stand. Nitrogen fluxes at 150 cm depth were very low in both stands (Table III).

DISCUSSION

A few previous studies on the interaction of precipitation with forest canopies have been carried out in southern Chile (Godoy *et al.* 1999, 2001, 2003; Oyarzún *et al.* 1998, 2002, 2004; Uyttendaele & Iroumé 2002). The pH of bulk precipitation in the present study (Table II) was slightly lower (pH = 5.2) than those found at sites located in the Andean Range (pH = 5.7 - 6.1) (Godoy *et al*. 2001) and a site near Valdivia (pH = 6.1) (Uyttendaele & Iroumé 2002), probably because of moderate anthropogenic inputs. The study site is influenced by light industries and probably by a small town located approximately 2 km to the north. In regions subject to strong anthropogenic influence, rain generally has pH values lower than 5 (Likens & Bormann 1995). Electrical conductivity was similar (11.6 µS cm^{-1}) to the reports for forested sites located in the Andean Range (10.9 - 11.4 µS cm^{-1}) and slightly lower than found in agriculture-cattle sites at the Central Valley (13.7 - 22.9 µS cm^{-1}) (Oyarzún *et al.* 2002). Most coniferous canopies show a tendency toward net acidification of bulk precipitation inputs (Cronan & Reiners 1983, Edmonds *et al.* 1995). In our study, only the pH of stemflow in the *Pinus radiata* stand was slightly lower than the precipitation pH. Other studies in southern Chile (Uyttendaele & Iroumé 2002) and southeastern Australia (Crockford *et al.* 1996) have found similar results, suggesting that stemflow pH is strongly influenced by organic acids released by stem tissues.


AMMONIUM NITROGEN

NITRATE NITROGEN

ORGANIC NITROGEN

Figure 2. Monthly nitrogen concentrations (μg L^{-1}) in precipitation (P) and soil water infiltration (INF) for a *Pinus radiata* plantation and a *Nothofagus* forest from June 2003 till November 2004.

Figure 2. Concentraciones mensuales de nitrógeno (μg L^{-1}) en la precipitación (P) e infiltración de agua en el suelo (INF) en una plantación de Pinus radiata y un bosque de Nothofagus, desde junio 2003 hasta noviembre 2004.

TABLE III: Annual fluxes of water, and NH_4^+-N, NO_3^--N, DIN and DON in precipitation, throughfall, stemflow, infiltration and soil percolation at 150 cm depth in *Nothofagus obliqua* forest and *Pinus radiata* plantation (June 2003-May 2004).

TABLA III. Flujos anuales de agua, NH_4^+-N, NO_3^--N, DIN y DON en la precipitación, precipitación directa, escurrimiento fustal, infiltración y percolación a 150 cm de profundidad en un bosque de *Nothofagus obliqua* y una plantación de *Pinus radiata* (junio 2003 - mayo 2004).

	Water (mm)	NH_4^+-N (kg ha^{-1} yr^{-1})	NO_3^--N (kg ha^{-1} yr^{-1})	DIN (kg ha^{-1} yr^{-1})	DON (kg ha^{-1} yr^{-1})
Bulk precipitation	1186.6	2.4	0.1	2.5	2.1
Throughfall					
Nothofagus	856.5	6.9	0.7	7.5	1.6
Pinus	946.0	5.2	1.2	6.4	2.0
Stemflow					
Nothofagus	11.0	0.02	0.03	0.05	0.00
Pinus	85.3	0.09	0.05	0.15	0.20
Infiltration					
Nothofagus	558.7	0.4	1.5	1.9	0.4
Pinus	824.4	3.1	5.4	8.4	0.6
Soil-150 cm depth *					
Nothofagus	240.8	0.03	0.01	0.04	0.03
Pinus	278.7	0.01	0.02	0.03	0.07

* Estimated using the water balance method (see text).

In general, bulk precipitation deposition of N in southern Chile is considered to be among the lowest of the world. Bulk deposition of dissolved inorganic nitrogen (DIN= NH_4^+-N + NO_3^--N) ranged between less than 1 kg N ha-1 yr-1 in the Costal Range to about 5 kg N ha^{-1} yr^{-1} for the Andean Range (Godoy *et al*. 2003). In the agricultural region of Osorno, Central Valley (40 S), the annual bulk deposition was 6.9 kg N ha^{-1} yr^{-1} indicating the influence of livestock farming (Oyarzún *et al.* 2002). In our study site, the nitrogen bulk deposition was 2.5 kg N ha^{-1} yr^{-1} (Table II) suggesting a small anthropogenic influence. However, the present study does not consider the input from dry deposition, which may be important in the Central Valley of southern Chile (Godoy *et al*. this issue, Staelens *et al.* this issue). Data from forested sites in the USA and Europe (Lovett 1992) showed that net canopy exchange of N (throughfall plus stemflow minus bulk deposition) was negative for NH_4^+ and NO_3^- at all sites, indicating that canopies were clearly sinks for inorganic N. In our study both DIN and DON concentrations increased in stemflow and throughfall relative to precipitation, indicating a net N enrichment when passing through the forest canopies. This net enrichment is the result of two processes: the washing off of the unquantified N input by dry deposition, on the one hand, and the N uptake from wet, dry particulate and gaseous deposition by leaves, twigs, stem surfaces, and lichens, on the other hand (Staelens *et al.* this issue). Oyarzún *et al.* (2004) have shown the importance of the epiphytic lichen Sticta living in the canopies and branches of old-growth trees in the Puyehue National Park at the Andean Range.

The inorganic N concentrations in soil water infiltration at 10 cm depth (Table II) were 10-15 times higher than corresponding measurements in *Nothofagus pumilio* and *N. betuloides* forests located in Andean Range (Godoy *et al.* 2001). The throughfall and stemflow input of about 7 kg DIN ha^{-1} yr^{-1} decreased to almost 2 kg ha^{-1} yr^{-1} in the soil water infiltration in the *Nothofagus* stand and increased to more than 8 kg ha^{-1} yr^{-1} in the *Pinus* stand. Compared to net precipitation, the ammonium flux decreased and the nitrate flux increased in both stands by passing trough the humus and upper soil layer. This can be attributed to mineralization, nitrification and plant uptake occurring in the topsoil. The clear difference in nitrate soil water infiltration might be related to species-specific nitrogen uptake, because nitrate is often assumed to be a more important mineral N source for broadleaved trees than for conifers (De Schrijver *et al.* 2004). However, forest trees are able to use different organic and inorganic N compounds, depending on N availability in soil and the composition of the below-ground mycorrhizal community (Wallenda *et al.* 2000).

Inorganic and organic nitrogen concentrations were much lower in the soil percolation water than at the forest floor in both stands. Similarly, the nitrogen fluxes at 150 cm depth were negligible (Table III) in comparison with N fluxes at the forest floor. The low soil water fluxes at 80 and 150 depth reflect strong N retention due to abiotic and biotic immobilization (Johnson *et al.* 2000, Boeckx *et al.* 2004). Furthermore, inorganic nitrogen could be exported from the plantations via subsurface flow to streams, given the steep slope of both forest sites. However, this should be confirmed by further research.

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REFERENCES

ARMESTO, J.J., R. ROZZI, C. SMITH-RAMÍREZ & M.K. ARROYO. 1998. Conservation targets in south American temperate forest. Science 282: 1271-1272.

BOECKX, P., R. GODOY, C. OYARZÚN, J. BOT & O. VAN CLEEMPUT. 2004. Resolving differences in N cycling between more polluted and pristine forests using 15N isotope dilution. In: D.J. Hatch, D.R. Chadwick, S.C. Jarvis & J.A. Roker (Eds.). Controlling Nitrogen Flows and Losses. 143-144 pp. Wageningen Academic Publishers, The Netherlands.

CLESCERI L.S., A.E. GREENBERG & A.D. EATON. 1998. Standard Methods for the Examination of Water and Wastewater. 20th Edition. American Public Health Association, Washington. 1193 pp.

COLE, D.W. & M. RAPP. 1981. Elemental cycling in forest ecosystems. In: D.E. Reichle (Ed.), Dynamic Properties of Forest Ecosystems. University Press, Cambridge.

CROCKFORD, R.H, D.P. RICHARDSON & R. SAGEMAN. 1996. Chemistry of rainfall, throughfall and stemflow in a eucalyptus forest and a pine plantation in southeastern Australia. 3. Stemflow and total inputs. Hydrological Processes 10: 25-42.

CRONAN, C.S. & W.A. REINERS. 1983. Canopy processing of acid precipitation by coniferous and hardwood forests in New England. Oecologia 59: 316-223.

DE SCHRIJVER, A., G. HOYDONCK, L. NACHTERGALE, L. KEERSMAEKER, S. MUSSCHE & N. LUST. 2000. Comparison of nitrate leaching under silver birch (*Betula pendula*) and Corsican pine (*Pinus nigra* ssp. *Laricio*) in Flanders (Belgium). Water, Air, and Soil Pollution 122: 77-91.

DE SCHRIJVER, A., L. NACHTERGALE, J. STAELENS, S. LUYSSAERT & L. DE KEERSMAEKER. 2004. Comparison of throughfall and soil solution chemistry between a high-density Corsican pine stand and a naturally regenerated silver birch stand. Environmental Pollution 131: 93-105.

EDMONDS, R.K., T.B. THOMAS & R.D. BLEW. 1995. Biogeochemistry of an old-growth forested watershed, Olympic National Park, Washington. Water Resources Bulletin 31: 409-419.

GODOY, R., C. OYARZÚN & J. BAHAMONDES. 1999. Flujos hidroquímicos en un bosque de *Nothofagus pumilio* en el Parque Nacional Puyehue, sur de Chile. Revista Chilena Historia Natural 72: 579-594.

GODOY, R., C. OYARZÚN & V. GERDING. 2001. Precipitation chemistry in deciduous and evergreen *Nothofagus forests* of southern Chile under a low-deposition climate. Basic and Applied Ecology 2: 65-72.

GODOY, R., L. PAULINO, C. OYARZÚN & P. BOECKX. 2003. Atmospheric N deposition in central and southern Chile. An overview. Gayana Botánica 60: 47-54.

HOULE, D., R. OUIMET, R. PAQUIN & J. LAFLAMME. 1999. Interactions of atmospheric deposition with a mixed hardwood and a coniferous forest canopy at the Lake Clair Watershed (Duchesnay, Quebec). Canadian Journal Forest Research 29: 1944-1957.

HUBER, A. & A. IROUMÉ. 2001. Variability of annual rainfall partitioning for different sites and forest cover in Chile. Journal of Hydrology 248: 78-92.

KLEEMOLA, S. & G. SODERMAN. 1993. Manual for integrated monitoring. International Co-operative programme on integrated monitoring on air pollution effects. Environmental Report 5. Environment Data Centre, National Board of Waters and the Environment. Helsinki. 114 pp.

LARA, A., C. DONOSO & J.C. ARAVENA. 1996. La conservación del bosque nativo de Chile: problemas y desafíos. En: J. Armesto, C. Villagrán & M. Arroyo (Eds.). Ecología de los bosques nativos de Chile. 335-361 pp. Editorial Universitaria, Santiago, Chile.

LIKENS, G. & H. BORMANN. 1995. Biogeochemistry of a Forested Ecosystem. Springer Verlag, New York. 159 pp.

LOVETT, G.M. 1992. Atmospheric deposition and canopy interactions of nitrogen. In: D.W. Johnson & S. Lindberg (Eds.). Atmospheric Deposition and Forest Nutrient Cycling. 152-166 pp. Springer Verlag, New York.

OYARZÚN, C.E., R. GODOY & A. SEPÚLVEDA. 1998. Water and nutrient fluxes in a cool temperate rainforest at the Cordillera de la Costa in sourthern Chile. Hydrological Processes 12: 1067-1077.

OYARZÚN, C. & A. HUBER 1999. Water balance in young plantations of *Eucalyptus globulus* and *Pinus radiata* in southern Chile. Terra 17, 35-44.

OYARZÚN, C.E., R. GODOY & S. LEIVA. 2002. Atmospheric deposition of nitrogen in a transect from the Central Valley to Cordillera de los Andes, south-central Chile. Revista Chilena Historia Natural 75: 233-243.

OYARZÚN, C.E., R. GODOY, A. DE SCHRIJVER, J. STAELENS & N. LUST. 2004. Water chemistry and nutrient budgets in an undisturbed evergreen rainforest of southern Chile. Biogeochemistry 71: 107-123.

PARKER, C.G. 1983. Throughfall and stemflow in the forest nutrient cycling. Advances in Ecological Research 13: 58-121.

SAN MARTIN, C., C. RAMÍREZ, H. FIGUEROA & N. OJEDA. 1991. Estudio sinecológico del bosque de Roble-Laurel y Lingue del centro-sur de Chile. Bosque 12: 11-27.

UYTTENDAELE, G. & A. IROUMÉ. 2002. The solute budget of a forest catchment and solute fluxes within a *Pinus radiata* and a secondary native forest site, southern Chile. Hydrological Processes 16: 2521-2536.

VEBLEN, T., C. DONOSO., R. KITZBERGER & A. ROBERTUS. 1996a. Ecology of southern Chilean and Argentinean *Nothofagus* forest. In: Veblen *et al.* (Eds.). The Ecology and Biogeography of *Nothofagus* forests. 293-353 pp. Yale University Press.

VEBLEN, T.H., R. HILL & J. READ. 1996b. Commonalities and needs for future research. In: Veblen *et al.* (Eds.). The Ecology and Biogeography of *Nothofagus* forests. 387-397 pp. Yale University Press.

WALLENDA, T., C STOBER, L. HÖGBOM, H. SCHINKEL, E. GEORGE, P. HÖGBERG & D.J. READ. 2000. Nitrogen uptake processes in roots and mycorrhizas. In: E.-D. Schulze (Ed.). Carbon and Nitrogen Cycling in European Forest Ecosystems. 122-143 pp. Springer Verlag, Berlin.

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