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NITROGEN RUNOFF AND LEACHING LOSSES IN BEEF PRODUCTION SYSTEMS UNDER TWO DIFFERENT STOCKING RATES IN SOUTHERN CHILE

PERDIDAS DE NITROGENO POR ARRASTRE Y LIXIVIACION BAJO DOS CARGAS ANIMALES EN SISTEMAS DE PRODUCCION DE CARNE DEL SUR DE CHILE

Marta Alfaro, Francisco Salazar, Sergio Iraira, Nolberto Teuber & Luis Ramírez

INIA Remehue, P. O. Box 24-O, Osorno, Chile. Phone:+56-64-233515. Fax:+56-64-237746. malfaro@inia.cl

ABSTRACT

The Lakes Region of Chile produces 60% of the country's milk and 45% of its meat. Production is expected to increase in the near future, yet there are few data on the environmental impact of local livestock systems. A field experiment was carried out during 2004 to measure nitrogen (N) runoff and leaching losses in beef cattle-grazing production systems near Osorno. Grazing was carried out with Holstein-Friesian steers of 220 kg of initial live weight, with stocking rates of 3.5 and 5 steers ha^{-1}. Water samples were collected during 6.5 months with surface lysimeters and ceramic cups, and were analyzed for nitrate and ammonium. Total losses were calculated as the product of N concentration and accumulated drainage at each sampling date. A significant difference in the total N loss was found between the two treatments (11.1 and 29.9 kg N ha^{-1}, respectively; $P < 0.05$). The main pathway of N loss was leaching, which contributed 99% of the total N loss. Nitrate was the main form of N loss in runoff (71%) and leaching (99%). Average nitrate concentration in leaching samples was always below the European Community Directive limit. However, nitrate concentration in runoff samples had maximum values of 116 ± 13.8 and 82 ± 22.4 mg L^{-1} for the 3.5 and 5 steers ha^{-1} treatments, respectively. For the experimental conditions tested, N losses from beef cattle production systems were low. This was related to the low N inputs in fertilizers used and to the physical and chemical properties of the volcanic soils.

KEYWORDS: Andisol, ammonium, nitrate, livestock production, leaching.

RESUMEN

En la Región de los Lagos de Chile se produce el 60% de la leche y el 45% de la carne del país, esperándose un aumento de la producción en un futuro cercano. Existe escasa información local sobre los impactos ambientales de esta creciente producción agropecuaria. Un experimento de campo fue llevado a cabo durante el 2004 para medir las pérdidas de nitrógeno (N) por lixiviación y arrastre superficial en sistemas de producción de carne de la zona basados en el pastoreo. Para el pastoreo se utilizó terneros Holstein-Friesian de 220 kg de peso vivo inicial, organizados en dos tratamientos con cargas de 3,5 y 5 terneros ha^{-1}. Las muestras de agua fueron colectadas durante 6,5 meses con lisímetros superficiales y cápsulas cerámicas, y analizadas para nitrato y amonio. Las pérdidas totales de N fueron calculadas como el producto de la concentración de N en las muestras y la cantidad de drenaje disponible, para cada fecha de muestreo. Se observó diferencias significativas en las pérdidas totales de N entre los dos tratamientos (11,1 y 29,9 kg N ha^{-1}, respectivamente; P=0.05). La principal vía de pérdida de N fue la lixiviación, la cual contribuyó con un 99% del total de N perdido (P=0.05). El nitrato fue la principal forma para la pérdida de N por arrastre (71%) y lixiviación (99%). La concentración promedio de nitrato en los lixiviados estuvo siempre bajo el límite de la Directiva de la Unión Europea. Sin embargo, la concentración de nitrato en muestras de arrastre tuvo un máximo de 116 ± 13.8 y 82 ± 22.4 mg L^{-1} para los tratamientos de 3.5 y 5 terneros ha^{-}, respectivamente. Bajo las condiciones experimentales estudiadas, las pérdidas de N desde sistemas de producción de carne fueron bajas. Esto fue relacionado con la baja cantidad de N aplicado como fertilizantes, y las propiedades físicas y químicas de suelos volcánicos.

PALABRAS CLAVES: Andisol, amonio, nitrato, producción ganadera, lixiviación.

INTRODUCTION

The Lake Region of southern Chile has suitable climatic conditions and soil types for cattle production. Consequently, 56% of the national cattle herd is concentrated in this maritime temperate climatic region, grazed on natural and improved pastures. These cattle produce 60% of the country's milk and 45% of the meat (INE 1997). In addition, 80% of Chile's dairy farmers are located in this region and they own 67% of the land dedicated to dairy production used nationally (Anrique 1999). It is expected that the production of this sector will increase in the near future because of the new commercial trade agreements between Chile and the European Union, the United States of America and South Korea. In addition, other important activities such as tourism, forestry, and fish farms also use the natural resources soil, water and air.

Volcanic soils of southern Chile have low nutrient availability and a high phosphorus fixation capacity (Campillo 1994), so that the use of nitrogen (N) and phosphorus (P) in fertilizers and animal feed has increased over the last ten years. This, in turn, has resulted in greater stocking rates being used and a higher demand for forage for grazing animals. Because of the need to increase the total production per hectare and the total number of animals, it is expected that the environmental damage by livestock production will increase. In developed countries the environmental impact of livestock systems has been widely studied, because of the important role of this activity on water, soil and air pollution (Jarvis & Oenema 2000). It has been estimated that agriculture contributes 37% to 82% of the N input into surface waters of Western Europe (Isermann 1990). Several studies have indicated that N loss due to nitrate leaching and denitrification is higher in arable crops than in grass managed under cutting. However, this situation is different when grass is grazed. The amount of nitrate leached below a grass sward grazed by cattle has been reported to be 5.6 times greater than that leached below a comparable cut sward, so that in grazing swards, nitrate leaching is likely to equal or exceed the range observed in arable production systems (Ryden *et al.* 1984). In addition, losses of N through ammonia volatilization and denitrification are much greater from grassland that is intensively grazed than from extensive grassland or grassland managed under cutting (Ryden 1986). The low value from animal production systems usually arises because of the inefficiency of the ruminant in converting ingested N into milk or protein and live weight gain. The excess N is excreted in dung and urine and is returned directly to the pasture during grazing or accumulated into farm manures (Jarvis 1993).

Despite the importance of livestock production in southern Chile and despite the fact that N is a strategic nutrient for grassland production, there is little information about the contribution of N to water sources from beef production systems in the region. Some lysimeter studies have been carried out under laboratory and field conditions (Dumont 2000; Salazar 2002) to evaluate N leaching losses after pasture cutting, but this does not mimic exactly the conditions created by grazing. In the Lake Region of Chile, watershed studies have shown that the annual export of total N on livestock pastures is greater than that from pastures and native forests watersheds (1510, 805, and 676 mg m^{-2} yr^{-1}, respectively) (Oyarzún *et al.* 1997).

We quantified N losses in runoff and leaching in beef production systems with two different stocking rates in southern Chile. We hypothesized that because of the soil characteristics and rainfall distribution at the experimental site, nitrate leaching would be the main pathway for N losses in the systems studied and that these would be greater when greater stocking rates were used.

MATERIALS AND METHODS

The experiment was carried out between the 12th of April and 31st of October 2004 at the National Institute for Agricultural Research (INIA), Remehue Research Centre (40º35'S, 73º12'W). The soil at the site is an Andisol of the Osorno soil series, which has 6% slope, more than 1 m depth, high organic matter and available phosphorus (Olsen P) concentrations, and a low aluminum saturation index (Table I). This index describes the relationship between Al and other cations in the soil solution (Ca+-Mg+K+Na). According to a weather station, placed within 1 km distance, the average rainfall for the area is 1260 mm yr^{-1} (30 years average).

In this study two stocking rates (3.5 steers ha^{-1} and 5 steers ha^{-1}) were tested on two closed systems (2 ha each). Grazing was carried out with

Holstein-Friesian steers with initial live weight of 220 kg, which were managed under rotational grazing on a permanent pasture of 25 years old that had been always used for grazing with beef cattle. The soil at the experimental site had adequate nutrient concentrations for grassland production (Table I). Treatments were fertilized in autumn 2004 (27th April) with 45 kg N ha^{-1} (urea, 45% N) and in the spring of 2004 (10th of September), with 25 kg N ha^{-1} (sodium nitrate, 16% N) and 29 kg P ha^{-1} (triple superphosfate, 45% P_2O_5).

TABLE I. Initial soil chemical analysis and bulk density at the experimental site for the 3.5 and 5 steers ha^{-1} treatments. 0-10 cm depth, 25th march 2004. Average of two replicates (± standard error of the mean).

TABLA I. Análisis químico inicial y densidad aparente del suelo en el sitio experimental para los tratamientos de 3,5 y 5 terneros ha^{-1}. 0-10 cm profundidad, 25 marzo 2004. Promedio de dos réplicas (± error estándar de la media).

Parameter	Treatment	
	3.5 steers ha^{-1}	5 steers ha^{-1}
P Olsen (mg kg^{-1})	28 ± 1.5	27 ± 0.8
pH (Water)	5.8 ± 0.01	5.6 ± 0.01
Organic matter (%)	18 ± 0.02	15 ± 0.24
Ca (cmol(+) kg^{-1})	7.6 ± 0.14	7.5 ± 0.08
Mg (cmol(+) kg^{-1})	1.7 ± 0.04	1.7 ± 0.05
CEC (cmol(+) kg^{-1})	10.3 ± 0.25	10.3 ± 0.16
S (mg kg^{-1})	2 ± 0.5	2 ± 0.03
Al saturation (%)	1.5 ± 0.01	2.0 ± 0.14
Bulk density 0-5 cm (g cm^{-3})	0.49 ± 0.005	0.49 ± 0.008

To quantify N losses in surface runoff, three surface lysimeters (5 x 5m) were established in each closed treatment, according to the methodology described by Scholefield & Stone (1995), and surface runoff was collected three times per week. The accumulated surface runoff was measured at each sampling date with the use of a graduated collector. Leaching losses at 60 cm depth were estimated through the use of ceramic cups (three replicates per surface lysimeter, n=9 per treatment). Samples were collected fortnightly and drainage for the period was calculated according to Lord & Shepherd (1993). In this methodology, drainage is calculated as the difference between rainfall and evapotranspiration, which in this case were measured by an automatic weather station, placed within 1 km distance. Runoff and leachates samples were collected in 125 ml polyethylene bottles, which were rinsed once with water sample before the final collection. All individual collections were chemically analyzed and no filtering was needed. Leaching samples were frozen until analysis for available N (N-NO_3^- and N-NH_4^+) in a Skalar autoanalyser, monthly. Runoff samples were stored at 4ºC until analysis for available N, within one week of collection. Nitrate was measured using the salicylic acid method (Robarge *et al.* 1983), and ammonium was determined through the indophenol methodology (Mulvaney 1996). Detection limits for the methods was 0.5 and 0.05 mg L^{-1}, for nitrate and ammonium, respectively. Total N losses were calculated as the product of drainage and N concentration in the respective samples. Total N losses for the experimental period were calculated as the sum of N losses in runoff and N losses by leaching.

In order to measure the effect of the grazing animals on the plant distribution in the paddock, the proportion of soil covered by the pasture was estimated. To do this, once during autumn (May) and once during winter (July), a grid of 0.4 x 0.4 m with 36 divisions was used to register at each sampling point (n=30) the number of divisions with no plants, so that this number in relation to the total number of squares available represented the proportion of soil uncovered by the sward.

Analysis of variance (ANOVA) was used to compare nitrate and ammonium concentrations between treatments, surface runoff losses, leaching losses and overall N losses between the two treatments tested, as well as differences in the proportion of soil uncovered by the sward in the two treatments.

RESULTS

Total rainfall for the experimental period (12th of April to the 31st of October 2004) was 868 mm and total drainage (surface runoff plus leaching) during the same period was 634 mm for both treatments. Of the total drainage collected, 99% was due to water moving down the soil profile (>60 cm depth). No difference in the contribution of surface runoff to the total drainage was found between the two treatments tested (P>0.05; Table II).

Leaching represented over 99% of the total N lost. Significant difference (P=0.05) was found between the two stocking rates for the total N leaching losses (10.8 and 29.7 kg N ha^{-1} for the 3.5 and 5 steers ha^{-1} treatments, respectively; Table II).

TABLE II. Drainage (% of the total drainage), average inorganic nitrogen (N) concentrations in surface runoff and leaching samples (mg L^{-1}) and N losses (kg N ha^{-1}) in paddocks grazed by 3.5 and 5 steers ha^{-1}, in the Lake Region of southern Chile (± standard error of the mean). Different letters in rows indicate significant differences (P=0.05) between stocking rates. Experimental period: 12th of April to the 31st of October 2004.

TABLA II. Drenaje (% del total), concentración promedio de nitrógeno (N) en muestras de arrastre superficial y lixiviados (mg L^{-1}) y pérdidas de N (kg N ha^{-1}) en potreros pastoreados con 3,5 y 5 terneros ha^{-1}, en la Región de los Lagos del sur de Chile (± error estándar de la media). Letras diferentes en filas indican diferencias significativas (P=0,05) entre cargas animales. Periodo experimental: 12 de abril al 31 de octubre del 2004.

Variables	Stocking rate	
	3.5 steers ha^{-1}	5 steers ha^{-1}
Drainage*		
Total drainage collected (mm)	633.8	634.0
Surface runoff	1% a	1% a
Leaching (> 60 cm)	99% a	99% a
Mean surface runoff concentrations and range (mg L^{-1})		
N-NH_4^+	37 ± 10.7 a	17 ± 5.0 b
	(1 – 64)	(1 – 33)
N-NO_3^-	52 ± 19.9 a	34 ± 11.4 b
	(1 – 116)	(1 – 82)
Mean leachate concentrations and range (mg L^{-1})		
N-NH_4^+	0.02 ± 0.006 a	0.03 ± 0.016 a
	(0.02 – 0.04)	(0.02 – 0.07)
N-NO_3^-	1.7 ± 1.20 a	4.7 ± 2.05 a
	(0.4 – 4.1)	(0.9 – 8.0)
N losses (kg ha^{-1})		
N-NH_4^+ in surface runoff	0.03 ± 0.002 a	0.01 ± 0.001 b
N-NO_3^- in surface runoff	0.06 ± 0.003 a	0.03 ± 0.002 b
N-NH_4^+ in leaching	0.2 ± 0.04 a	0.2 ± 0.10 a
N-NO_3^- in leaching	10.8 ± 7.63 b	29.7 ± 13.00 a
Total N losses	11.1 ± 7.63 b	29.9 ± 13.00 a

* Total rainfall for the period was 868 mm.

Nitrogen losses in runoff were low (<0.1 kg N ha^{-1}), but varied significantly between treatments (P=0.05). Nitrogen loss in surface runoff was more than 2 times greater in the treatment with the lower stocking rate.

For both stocking rates the highest N leaching losses were observed over three sampling dates during the winter period (June 23rd to July 27th, Figure 1), were the highest drainage values were obtained. The losses measured during these dates represented 79 and 53% of the total N lost in the experimental period for the 3.5 and 5 steers ha^{-1} treatments, respectively.

The proportion between ammonium and nitrate in the total losses varied according to depth. At the ground level, ammonium losses represented 33 and 25% of the total N lost in runoff, for the 3.5 and 5 steers ha^{-1} treatments, respectively. At 60 cm depth, ammonium losses were only a 1 ± 0.1% of the leaching losses, for both treatments (Table II).

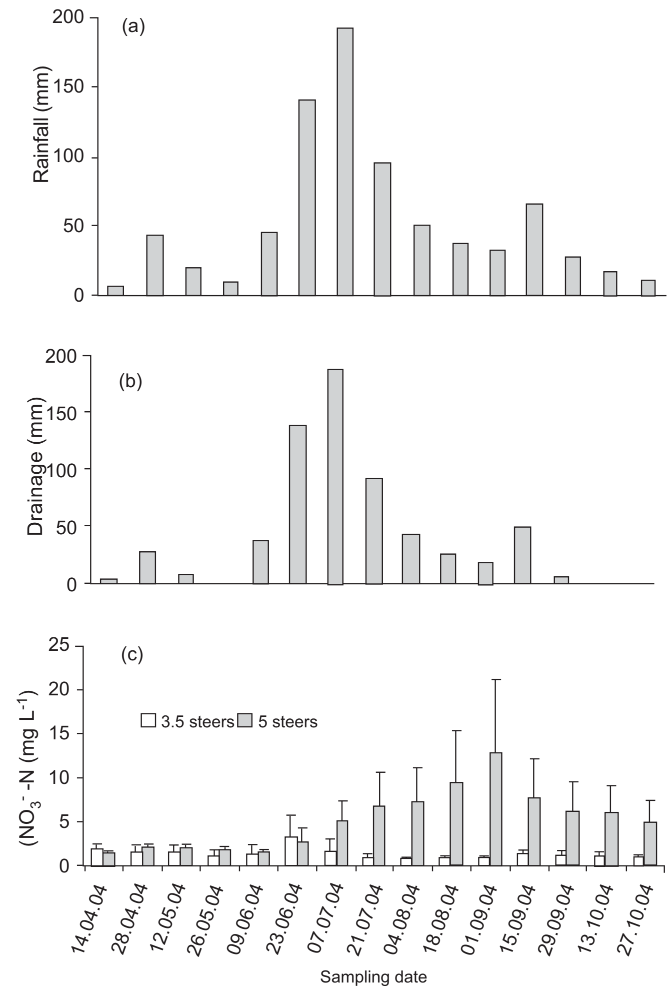

FIGURE 1. (a) Rainfall (mm), (b) drainage (mm) and (c) nitrogen concentration in leachate samples (mg NO_3^--N L^{-1}) collected at 60 cm depth in paddocks grazed by 3.5 and 5 steers ha^{-1} on an andisol of the Osorno soil series, in the Lake Region of southern Chile, for the experimental period between 12th April and 31st of October 2004. Average of three replicates.

FIGURA 1. (a) Precipitación (mm), (b) drenaje (mm) y (c) concentración de nitrógeno en muestras de lixiviados (mg NO_3^--N L^{-1}) colectados a 60 cm de profundidad en potreros pastoreados con 3.5 y 5 terneros ha^{-1} en un andisol de la serie Osorno, en la Región de Los Lagos del sur de Chile, para el período comprendido entre el 12 de abril y el 31 de octubre del 2004. Promedio de tres repeticiones.

Nitrate concentration in water samples collected at 60 cm depth was in most of the cases below the international directive for drinking water (*i.e.* European Union, 91/676/EEC), which establishes that the NO_3^- concentration in the water must be less than 11.3 mg N L^{-1} (Figure 1).

During the winter period, and as a product of the pouching caused by the animals, it was common to observe an increment of the proportion of soil uncovered by the pasture. This effect was greater in the treatment with 5 steers ha^{-1}, where the proportion of soil uncovered in winter went up to by 4 times that measured in autumn, reaching the 20% of the soil. In the 3.5 steers ha^{-1} treatment, this effect reached only a 12%, which was significantly different from that of the 5 steers ha^{-1} treatment (P=0.05; Figure 2).

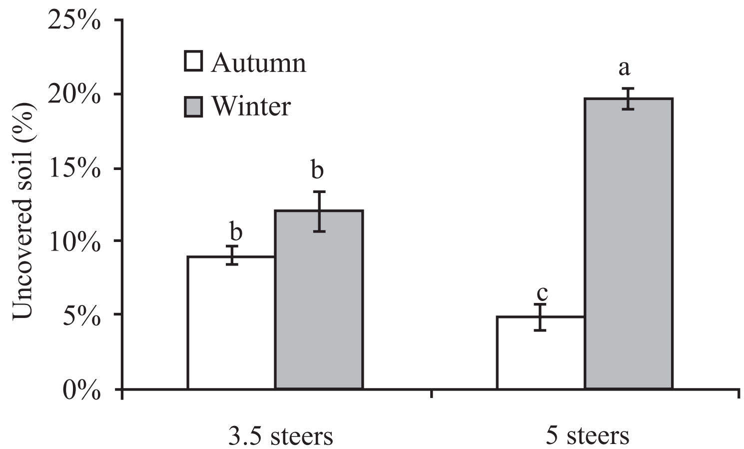

FIGURE 2. Proportion of uncovered soil (%) by pouching during autumn (March to May) and winter (June to September) in paddocks grazed by 3.5 and 5 steers ha^{-1} on an andisol of the Osorno soil series, in the Lake Region of southern Chile. Average of 30 replicates. P=0.05.

FIGURA 2. Proporción de suelo descubierto (%) por pisoteo animal durante el otoño (marzo a mayo) e invierno (junio a septiembre) en potreros pastoreados con 3.5 y 5 terneros ha^{-1} en un andisol de la serie Osorno, en la Región de Los Lagos del sur de Chile. Promedio de 30 repeticiones. P=0.05.

DISCUSSION

Total N losses obtained were low compared with those measured in dairy systems on similar soils in New Zealand, using ceramic cups (Ledgard *et al.* 1999). In that experiment, leaching losses varied between 20-74 kg N ha^{-1} yr^{-1} without N fertilizer application, and increased up to 101 kg N ha^{-1} yr^{-1} after the application of 200 kg N as mineral fertilizer. The difference in N loss between the present study and that with dairy cows studied by Ledgard *et al.* (1999) can be explained by differences in the amount of N recycled in urine and faeces by beef cattle and dairy cows. Cows usually have a greater N concentration in the diet so that N excretion in urine is greater. In addition, urine patches of dairy cows are less distributed in the paddock and patches are of a greater volume than that of beef cattle, so that leaching losses are greater in this case (Ledgard 2004, personal communication). Results obtained under Chilean conditions are also lower than those reported by Scholefield *et al.* (1993) for beef cattle production systems on old pastures in south West England, where average losses over seven years were 38 kg N ha^{-1} yr^{-1} after the application of 200 kg N ha^{-1} yr^{-1} in nine applications over the grazing season. In this case, differences in the soil type can explain differences in the amount of leaching losses. In the UK experiment, soil type was a clayey non-calcareous soil (4% organic matter) with poor drainage and an impermeable clay layer at 30 cm depth where mole drainage had been implemented, while in the present study the soil was permeable, had free drainage and high organic matter content (Table 1). Considering this information, it seems that Chilean beef cattle systems are not as intensive with respect to the amount of N fertilizer used and the N leaching losses as those managed under European or New Zealand conditions. The water pollution observed in livestock systems of these developed countries is an attention cal for the intensification of current Chilean livestock production systems.

Total N losses measured in this study were greater than those reported by Dumont (2000) for the same soil series, on a monolith lysimeter experiment managed under cutting. This author found that after the application of up to 140,000 L ha^{-1} of dairy slurry in spring time (157 kg total N ha^{-1}, of which 64 kg N ha^{-1} were immediately available to plants), N losses were 11 kg N ha^{-1}. Furthermore, no significant difference in N loss was found between this treatment and the control treatment that received no N application. This suggests that in andisols of the Osorno series, with high organic matter content, the soil biomass and the natural soil N mineralization processes could be a key factor in controlling the total N losses by leaching, by acting as a buffer for N losses, in agreement with results of the present study.

Recent studies have shown that organic N losses (DON) can be an important source of N transfer to surface water (Murphy *et al.* 2000). Leachate samples collected from intensively grazed pastures elsewhere have shown that DON could contribute with as much as 50% of the total N lost (Jarvis 2002). DON concentrations were not measured in the water samples collected during this study. However, in view of the high organic matter content of the Osorno soil series, DON concentrations in leachate can be expected to be high, increasing the overall N lost to water.

N leaching losses measured in the 5 steers ha^{-1} treatment were three times higher than those determined in the 3.5 steer ha^{-1} treatment. Differences can be related to the greater N soil availability, due to N recycling in dung and urine, in the treatment with the greater stocking rate. Thus, in this treatment more N was available to be lost by leaching once the soil was saturated (beginning of July) and this situation continued until the end of the drainage season.

Because of the low nitrate concentrations measured in the leachate samples, no major implications for the contamination of groundwater below grazed areas under the conditions represented in this experiment were found, in agreement with results of Nissen *et al.* (2000). These authors found low NO_3^- concentrations (<0.01 and 0.63 mg L^{-1}) in wells water used for human or animal drinking (45 to 118 m depth), collected in the region where the present study was carried out.

Nitrogen losses in surface runoff were less than 0.1 kg N ha^{-1}, because of the low flow of water moving in this pathway. Nevertheless, nitrate concentration in the surface runoff samples, was higher than the EU limit in 42 and 33% of the total number of sampling dates for the 3.5 and 5 steers ha^{-1} treatments, respectively. Ammonium concen-tration in surface runoff samples was over the Chilean Directive for quality of surface continental waters (DS 87/01) in more than 95% of the total samples analysed. This directive establishes a maximum limit of 1 mg L^{-1} for category 1 (good water quality). This situation represents a risk for incidental N surface water pollution of water bodies located closed by grazing areas in Southern Chile, with potential negative effects on other activities such as aquaculture and tourism.

Ammonium losses in surface runoff were 50 and 33% of those measured as N-NO_3^- in the 3.5 and 5 steers ha^{-1} treatments, respectively. At 60 cm depth, ammonium losses represented 1% of the total N lost in this pathway, for both treatments. This could be related to the quick transformation of urine-ammonium to nitrate and its subsequent leaching, as described by previous studies (*i.e.* Haynes & Williams 1993).

Drainage data confirmed that in andisols leaching is the most important pathway of N transfer and loss, which agrees with results of Ledgard *et al.* (1999) for leaching experiments carried out in dairy systems on similar soils to that of the present study, in New Zealand. It is expected that surface runoff will have a strong effect on nutrients losses only at critical times during the year such as those with heavy rainfall occurring after fertilizer application or when the soil is dry, i.e. the first rainfall of autumn or in summer, when a pool of available nutrients, particularly N, has accumulated in the soil because of favourable conditions for mineralization (Hatch *et al.* 2000). This agrees with results obtained by other authors for different soil types and nutrients such as N (Scholefield *et al.* 1993), phosphorus (Turner & Haygarth 2000) and potassium (Alfaro *et al.* 2004).

Most of the sampling dates when the nitrate concentration in the surface runoff samples was higher than the EU limit occurred during the period with more rainfall, i.e. between June and August 2004 (Figure 1). During this time of year also the highest ammonium and nitrate concentrations in the runoff water samples were measured. This was probably related to direct transport of nutrients, soil particles and faeces residues down the slope. These data stress the importance of matching farming management with heavy rainfall managements, as discussed below.

Higher N water samples concentrations in periods of heavy rainfall agree with results of the soil cover measurements (Figure 2), so that, the effect of the pouching caused by the grazing animals in this period, resulted in a greater proportion of the soil being uncovered by the grass (Figure 2), being equivalent to a fallow period. If greater stocking rates are used in the future in livestock systems of Southern Chile, and these are based on a all year grazing type, this problem will probably be increased over time. Therefore, best management practices (BMP) should be developed and adapted to reduce N transfer from the grazing areas to streams and surface waters. The maintenance of buffer areas with no grazing and fertilizer application around the water bodies, the use of feed supplements to reduce the pressure on the winter sward production, and the avoidance of fertilizer applications during periods of heavy rainfall could be of high relevance to reduce the loss of N and other nutrients by runoff in grazing systems of southern Chile, in agreement with Heathwaite *et al.* (1990).

This study has presented novel data about N loss in livestock production systems of southern Chile. Results showed that Chilean beef production systems are not as intensive as those in developed countries, considering N inputs in fertilizers and leaching losses as inorganic N. Nevertheless, according to recent studies (Murphy *et al.* 2000), organic N losses can be as important as those in inorganic forms, so that for Chilean conditions more studies are needed to fully understand N cycling and losses.

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