# LIVESTOCK PRODUCTION AND DIFFUSE POLLUTION IN A VOLCANIC SOIL

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**Producción animal y contaminación difusa en un suelo volcánico**

**Key words:** Nitrogen, phosphorus, dairy production, beef production, environmental impact

## ABSTRACT

In developed countries, intensive grazing has been related to water pollution. The results of several projects carried out on a volcanic soil of the Osorno soil series on beef grazing production systems have shown that grazing management did not increase total nitrogen (N) and phosphorus (P) transfer and losses. Due to the high water infiltration capacity of the soil, runoff was <1% of total drainage, therefore, N and P losses in runoff were small. Nitrogen leaching losses were high (3 up to 71 kg N $ha^{-1}$ $yr^{-1}$). Nitrogen loss in runoff was mainly lost as DON (*c.* 50%) while N leaching losses were mainly as nitrate (*c.* 70%). Total P losses ranged between 1 and 22 g P $ha^{-1}$ $yr^{-1}$ and they increased with increasing field slopes. Phosphorus was mainly lost as reactive P (*c.* 70%). Total losses were greatly affected by incidental N and P losses associated to spring N and P fertilizer application, so that grassland managements should consider this constrain for grazed areas in southern Chile. Research should be carried out in more intensive production systems (e.g. dairy farms) where N and P rates used are higher and applied during different times of the year, with a potential impact for the wider environment.

**Palabras claves:** nitrógeno fósforo, producción de leche, producción de carne, impacto medioambiental

## RESUMEN

En países desarrollados, el pastoreo intensivo ha sido relacionado con la contaminación de aguas. Resultados de distintos proyectos llevados a cabo en un andisol de la serie Osorno, en sistemas de producción de carne bajo pastoreo, han demostrado que el manejo del pastoreo no incrementó la transferencia y las pérdidas de nitrógeno (N) y fósforo (P). Debido a la alta capacidad de infiltración de agua del suelo, el arrastre superficial fue menos del 1% del drenaje total, por lo que las pérdidas de N y P en arrastre superficial fueron bajas. Las pérdidas de N por lixiviación fueron altas (3 hasta 71 kg N $ha^{-1}$ $año^{-1}$). Las pérdidas de N en arrastre superficial fueron principalmente como NOD (*c*. 50%), mientras que las pérdidas de N por lixiviación fueron principalmente como nitrato (*c*. 70%). Las pérdidas totales de P variaron entre 1 y 22 g P $ha^{-1}$ $año^{-1}$ y se incrementaron con incrementos en la pendiente del terreno. El P se perdió principalmente en su forma disponible (*c*. 70%). Las pérdidas totales fueron fuertemente afectadas por las pérdidas incidentales de N y P asociadas a la aplicación de fertilizantes en primavera, de manera tal que el manejo de praderas debería considerar esta limitación en áreas bajo pastoreo en el sur de Chile. La investigación en este ámbito debería realizarse en sistemas más intensivos de producción (e.g. lecherías) donde las dosis de N y P usadas son mayores y aplicadas en distintas épocas del año, con un potencial de impacto para el medio ambiente.

## INTRODUCTION

The Lake and the River Regions of southern Chile (39º to 43º S, 71º to 74º W) have suitable climatic conditions and soil types for cattle production. Consequently, this area produces 65% of the country's milk and 45% of its meat, based on grazed on natural and improved pastures (INE, 2001). Volcanic soils are widespread in this area, being characterised by low nutrient availability and high phosphorus (P) fixation capacity (Escudey *et al.*, 2001), so that this fact has created the perception that low P losses to waters can be expected in the area.

The use of nitrogen (N) and P in fertilizers and animal feed in the area has increased over the last ten years (Alfaro & Salazar, 2005), being these elements the main cost of fertilizer application. This intensification has resulted in greater stocking rates being used in direct grazing and a higher demand for forage for grazing animals.

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). In countries of occidental Europe has been estimated that agriculture contributes with 37 to 82% of the N and with 27 to 38% of the P input into surface waters (Isermann, 1990).

Despite the importance of livestock production in southern Chile and that N and P are strategic for grassland production in the area, the potential effect of grazing systems on diffusse pollution in the area has not been estimated, even though other relevant economic activities in the southern region are aquaculture and tourism.

## MATERIALS AND METHODS

Over the last four years, INIA Remehue (40º35'S, 73º12'W) has carried out several research studies to estimate N and P transfer and losses from beef grazing systems based on permanent pastures in an andisoil of the Osorno soil series (Typic Hapludands; CIREN 2003). All experiment were tested on closed systems managed under rotational grazing on a 25 years old permanent pasture with Black and White Friesian steers (50-75% Holstein) with initial live weights for the three years of *c.* 220 ± 0.5 kg. The main species in the pasture were *Lolium perenne*, *Dactylis glomerata* and *Holcus lanatus*. Treatments were fertilized in autumn with 45 kg N $ha^{-1}$ (urea, 46% N or sodium nitrate, 16% N) and spring 22.5 kg N $ha^{-1}$ (sodium nitrate, 16% N) and 40 kg P $ha^{-1}$ (triple superphosfate, TSP, 46% $P_2O_5$).

**Nitrogen losses**

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 Alfaro & Salazar (2007). The accumulated runoff was measured three times per week and runoff samples were stored at 4ºC until analysis for available N. Nitrate was measured using the salicylic acid method (Robarge *et al.,* 1983), ammonium was determined through the indophenol methodology (Mulvaney, 1996) and total N was determined with the macro-Kjeldahl method (Mé thod 10071 test 'N Tube; ®Hach, 2000a). Organic N was calculated as the difference between total N and the sum of the available N forms.

Nitrogen leaching losses were determined using the ceramic suction cups technique described by Lord & Shepherd (1993), which has been shown to be suitable for freely draining soils (Webster *et al.*, 1993). Ceramic cups were placed at a depth of 60 cm in the soil (three replicates per surface lysimeter) at an angle of 30° to the vertical. Samples were stored at -15 ºC until analysis for available N ($N\text{-}NO_3^-$ and $N\text{-}NH_4^+$) in a Skalar autoanalyser. Total N losses were calculated as the product of drainage and N concentration in the respective samples. Drainage between the sampling periods was estimated by subtracting potential evapotranspiration figures from rainfall using meteorological data collected close to the experimental site (< 1 km) .

Evapotranspiration for the sward was calculated using the Penman-Monteith method (Penman, 1948). The amount of ammonium and nitrate leached over the period was then calculated according the trapezoidal rule proposed by Lord & Shepherd (1993).

**Phosphorus losses**

To quantify P losses in surface runoff, the three surface lysimeters were used following the methodology described for N determinations. Reactive P (RP) was measured using the ascorbic acid method (Clesceri *et al.*, 1998), and total P was determined through the digestion with acid persulphate (method 8190 ®Hach, 2000b). Organic P (OP) was estimated as the difference between TP and RP for each sample, so that this data may also include particulate P. Total P losses were calculated as the product of drainage and P concentration in the respective samples.

## RESULTS AND DISCUSSION

**Weather and rainfall**

During 2004, total rainfall was 1,231 mm, similar to that of the 30 years average for the area. Both 2005 and 2006 had a surplus equivalent to 195.3 and 176.0 mm of rainfall, respectively, in relation to a 30 years average. Average rainfall over the drainage period was 49% and 52% greater during 2005 and 2006 in relation to 2004, respectively. The greater rainfall of 2005 and 2006 had an impact on drainage values of those years, so that they were greater than drainage for 2004 (*c.* 600, 900 and 800 mm drainage for 2004, 2005 and 2006, respectively).

**Table 1:** Average nitrogen and phosphorus losses in surface runoff and leaching from grazed permanent pastures of southern Chile. Average of three years

**Cuadro 1:** Promedio de pérdidas de nitrógeno y fósforo en escorrentía superficial en la pradera permanente pastoreada del Sur de Chile. Promedio de tres años

| | Treatments characterisation | | | |
|---|---|---|---|---|
| Stocking rate | 3.5 steers $ha^{-1}$ | 3.5 steers $ha^{-1}$ | 3.5 steers $ha^{-1}$ | 5.0 steers $ha^{-1}$ |
| Rotational grazing | Every 3 days | Daily | Every 3 days | Daily |
| Field slope | 4% | 4% | 12% | 4% |
| Nitrogen (kg N $ha^{-1}$ $yr^{-1}$) | 67.5 | 67.5 | 67.5 | 67.5 |
| Phosphorus (kg N $ha^{-1}$ $yr^{-1}$) | 40 | 40 | 40 | 40 |
| Drainage in surface runoff (% of total) | <1% | <1% | <1% | <1% |
| Drainage in leaching (% of total) | 99% | 99% | 99% | 99% |
| | Nutrient losses | | | |
| Nitrogen in runoff (kg $ha^{-1}$ $yr^{-1}$) | 0.2 ± 0.02 | 0.3 ± 0.02 | 0.4 ± 0.03 | 0.4 ± 0.01 |
| Nitrogen leaching (kg $ha^{-1}$ $yr^{-1}$) | 13 ± 3.9 | 17 ± 5.7 | 8 ± 3.6 | 26 ± 3.3 |
| Total N losses (kg $ha^{-1}$ $yr^{-1}$) | 13 | 17 | 8 | 26 ± 12.8 |
| Total Phosphorus losses (g $ha^{-1}$ $yr^{-1}$) | 6 ± 3.1 | 5 ± 0.5 | 19 ± 2.9 | 14 ± 0.6 |

**Water pathways**

Results showed that the main pathway for water movement was leaching with 99% of total drainage, independently of the animal managent or the field slope (P≤0.05; Table 1), 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. Runoff results can be related to the low bulk density of the topsoil, favouring vertical infiltration capacity, in agreement with Dorel *et al.* (2000).

**Nitrogen losses**

Nitrate average concentration in surface runoff samples was higher than the 11.3 mg N $L^{-1}$ established by the European Union for water consumption (*i.e.* 91/676/EC). Ammonium concentration in surface runoff samples was over the Chilean Directive for quality of surface continental waters (*i.e.* DS 87/01) in more than 80% of the total samples analysed. Most of the sampling dates when nitrate and ammonium concentration in the surface runoff samples were high occurred during the winter period. This was probably related to the direct transport of nutrients, soil particles and faeces residues down the slope. Despite the high concentrations in runoff samples, total losses in runoff were low (<0.5 kg N $ha^{-1}$ $yr^{-1}$). However, these data stress the importance of best fertilizer managent practices, because they imply a risk for incidental N losses and thus, for surface water pollution in areas located closed by grazing paddocks.

Of total N lost in runoff, ammonium and nitrate losses represented on average *c.* 25% each, as the result of urine lost in runoff immediately after excretion in each grazing and N lost after nitrate fertilizer application in spring time. Dissolved organic N (DON) represented *c.* 50% of total N lost in runoff. This could be related to the high soil organic matter content in the topsoil and the expected high soil biomass activity, in agreement with Jarvis (2002) and Alfaro *et al.* (2006).

Concentrations of $NO_3^-$-N at each sampling date for leaching did not exceed the EC limit of 11.3 mg $L^{-1}$. Nitrogen leaching losses were variable for different years and ranged from *c.* 3 to 70 kg $ha^{-1}$ $yr^{-1}$. A high proportion (*c.* 70%) of the N was leached as nitrate with ammonium averaging less than *c.* 10% of the total inorganic N losses, in agreement with data reported by Webster *et al.* (1993) and Salazar *et al.* (2005). Dissolved organic N in leachates samples varied from 8 to 22.5 kg $ha^{-1}$ $yr^{-1}$, which represented *c.* 25% of total leaching losses. According to this, DON was the most important N form in N leaching losses after nitrate, as discussed previously.

**Phosphorus losses**

In all experiments, average P concentrations measured in runoff samples (RP and OP) were much greater than the 50 and 25 μg total P $L^{-1}$ established as eutrophication limit for rivers and lakes, respectively (Leinweber *et al.,* 2002). Peaks of RP concentration were measured associated to spring P fertilizer application during all years. The high RP concentrations after TSP addition was probably because of the direct transport of fertilizers granules in runoff after the application and because they were rapidly solubilized by surface runoff (Heatwaite *et al*., 1998). Peaks of OP concentration were measured during spring and they were probably related to the flush of organic matter mineralization produced at that time, in agreement with Turner & Haygarth (2000).

The main parameter affecting P losses was the field slope, so that P losses on a 4% slope field were 3 times lower than those on a 12% slope field (4 and 15 g P $ha^{-1}$ $yr^{-1}$, respectively). Animal management (stocking rate, grazing pressure) did not increase P losses in runoff. Overall P losses were low when compared with results of P transfer from grazed land in Europe

(Haygarth & Jarvis, 1997) and New Zealand (McColl *et al*., 1977). Total losses were mainly found as RP losses (70% on average), in agreement with Sharpley & Rekolainen (1997). Organic P losses represented only 30% of the total P lost in runoff.

Because of the high N and P concentrations measured in this study in runoff samples collected from a volcanic soil, best management practices (BMP) in relation to the timing of N and P fertilizer application should be adopted in the area, avoiding nutrients addition during the winter period or high rainfall events.

## CONCLUSIONS

Overall losses in surface runoff were low due to the low amount of runoff measured, because the high infiltration capacity of the Andisol in the topsoil layer. Nitrogen leaching losses were high, ranging from *c.* 3 to 70 kg N $ha^{-1}$ $yr^{-1}$. Nitrogen lost in runoff was mainly as DON (*c.* 50%). Nitrogen lost by leaching was mainly as nitrate (*c.* 70%). Phosphorus was mainly lost as reactive P (*c.* 70%).

These results showed that there is room for the intensification of beef grazing systems through grazing management, but that an adequate fertilizer management is required at all times during the year to reduce incidental N and P losses in runoff, especially in sloppy soils.

Research should be carried out in more intensive production systems where N and P rates used are higher and applied at different times of the year, representing a potential impact for the wider environment. In addition, we think that systems evaluation for cattle production should consider other losses as well, which includes gaseous emissions, that has been an important pathway of nutrient losses in these systems worldwide.

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