MOVEMENT OF NO_3^--N AND NH_4^+-N IN AN ANDISOL AND ITS INFLUENCE ON RYEGRASS PRODUCTION IN A SHORT TERM STUDY

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Movimiento de N-NO_3^- y N-NH_4^+ en un Andisol y su influencia sobre la producción de ballica en un estudio de corto plazo

Key words: Ammonium, leaching, nitrate, nitrogen, pasture.

ABSTRACT

In acids soils, the use of ammonium fertilizers accelerates the acidification processes and decreases both the production and persistence of the pastures. Nitrogen (N) is the most limiting factor for plant growth in most agricultural systems, but also it is one of the major environmental issues worldwide. In Chile, neither systematic studies in the first period of pasture growth and nor N leaching losses associated have been reported. The aims of this study were: (i) to evaluate the effect of the N sources at increasing rates of application on the yield and quality of ryegrass (*Lolium perenne*) and (ii) to quantify in the short-term the N potential leaching losses and the pH changes throughout the soil profile under field conditions. A field experiment was conducted during the spring-summer season 2000-2001 on an Andisol of Southern Chile under irrigation. Urea and sodium nitrate were applied at rates of 0, 150 and 300 kg N ha^{-1}. The pasture was cut thrice and dry matter (DM) production and shoot N concentration were determined. The soil pH and concentration of NH_4^+-N and NO_3^--N were also determined for the 0-10 cm, 10-20 cm and 20-40 cm depth, and the maximum N potential losses by leaching were estimated. Dry matter production increased by 128% as N supply increased from 0 kg N ha^{-1} to 300 kg N ha^{-1}. The N source did not show any effect on yield. Urea and sodium nitrate induced higher shoot N concentration as the N rate increased and non acidifying effect of urea on DM production and pasture quality were observed. The application of sodium nitrate and urea (300 kg N ha^{-1}) produced the highest NO_3^--N and NH_4^+-N concentration in the deepest soil layers. For the 20-40 cm of depth, the estimated maximum N potential losses downward the soil profile were about 90 kg N ha^{-1} and corresponded to the period of the lower rate of pasture growth.

Palabras claves: Amonio, lixiviación, nitrato, nitrógeno, pastura.

RESUMEN

En suelos ácidos, el uso de fertilizantes amoniacales acelera los procesos de acidificación y disminuye la producción y persistencia de las pasturas. El nitrógeno (N) es el principal factor limitante del crecimiento vegetal en la mayoría de los sistemas agrícolas, pero también es uno de los principales problemas ambientales del mundo. En Chile, no han sido reportados estudios sistemáticos en el primer período de crecimiento de la pastura ni las pérdidas de N por lixiviación asociadas. Los objetivos de este estudio fueron: (i) evaluar el efecto de la fuente de N a dosis crecientes de aplicación sobre el rendimiento y calidad de ballica (*Lolium perenne*) y (ii) cuantificar en el corto plazo las pérdidas potenciales de N por lixiviación y los cambios de pH a través del perfil del suelo bajo condiciones de campo. Se realizó un experimento de campo durante la temporada primavera-verano 2000-2001 en un Andisol del Sur de Chile bajo riego. Se aplicó urea y nitrato de sodio en dosis de 0, 150 y 300 kg N ha^{-1}. La pastura fue cortada tres veces y se determinó la producción de materia seca (DM) y la concentración de N foliar. Además, se determinó el pH del suelo y las concentraciones de N-NH_4^+ y N-NO_3^- para los 0-10 cm, 10-20 cm y 20-40 cm de profundidad, y se estimaron las máximas pérdidas potenciales de N por lixiviación. La producción de DM aumentó en 128 % a medida que el suministro de N se incrementó de 0 a 300 kg N ha^{-1}. La fuente de N no mostró ningún efecto sobre el rendimiento. La urea y el nitrato de sodio generaron una concentración de N foliar más alta a medida que la dosis de N aumentó, y no se observó un efecto acidificante de la urea sobre la producción de DM y la calidad de la pastura. La aplicación de nitrato de sodio y urea (300 kg N ha^{-1}) generó la mayor concentración de N-NH_4^+ y N-NO_3^- en las capas más profundas del suelo. Para los 20-40 cm de profundidad, las máximas pérdidas potenciales de N a través del perfil del suelo fueron alrededor de 90 kg N ha^{-1} y correspondieron al período de menor tasa de crecimiento de la pastura.

INTRODUCTION

In Chile there is an increasing need to improve the management of grazing systems and to reduce both the negative impact of nitrogen (N) leaching and the chemical reaction in acid soils. Intensive grazing systems are based on the use of highly productive forage species, especially ryegrass (*Lolium perenne*), alone or mixed with clover (*Trifolium repens* or *Trifolium pratense*).

At global scale, N is an essential element for plant nutrition being the most limiting factor of forage growth (Jarvis *et al.,* 1995) due to the large amounts harvested with crops, and because it can easily be lost through gaseous losses, leaching, runoff or erosion (Rufino *et al.,* 2006). The use of ammonium fertilizers increases the acidification process in Chilean Andisols. Ammonium fertilizers contribute to acidification after nitrification because of release free H^+. Due to the acid condition, which characterizes volcanic soils, acidic reaction of fertilizers applied continuously into the soil overcome their buffer capacity and the acidification process is accelerated (Mora *et al.,* 1999a). About 50 % of these soils present a high soil acidity level, the main factor limiting pasture production (Mora *et al.,* 1999b; Mora *et al.,* 2002, Mora *et al.,* 2004a; Mora *et al.,* 2006).

Mineral N is uptaken by plants in the forms of NO_3^--N and NH_4^+-N (Marschner, 2003). The differences in plant yield responses to the various forms of N fertilizer are due mainly to the differences in the N losses from the soil (Seidel *et al.,* 2007) rather than differences in the type of N form uptaken (Abassi *et al.,* 2005). With grass cutting or grazing, physiological factors, which determine roots N absorption, are strongly affected (Jarvis *et al.,* 1995).

Intensive agricultural practices comprise higher N use from fertilizer, even over pasture optimal demand. These excessive rates lead to enormous potential losses by leaching, with dangerous environmental effects. On the other hand, concerns about both the N use efficiency of pastures and the nitrate movement into the soil profile, make this kind of study necessary (Berg and Sims, 2000). The understanding of N uptake and its utilization as affected by different N doses will help to plan the best strategies of fertilization and water management, with high influence on N soil transformation and availability to the crops (Baligar and Bennett, 1986).

In Chile, there are few studies regarding N (NO_3^- and NH_4^+) leaching, but losses between 11 and 67 kg N ha^{-1} y^{-1} have been reported (Mora *et al.,* 2004b; Alfaro *et al.,* 2005; Alfaro *et al.,* 2006). In New Zealand, Ledgard *et al.* (1998; 1999), Di and Cameron (2004), Di *et al.* (2002) and de Klein and Ledgard (2001) reported losses by leaching between 74 and 200 kg N ha^{-1} y^{-1}.

The aims of this study were: (i) to evaluate the effect of the N source at increasing rates of application on the yield and quality of ryegrass (*Lolium perenne*) and (ii) to quantify in the short term the N potential leaching losses and the pH changes throughout the soil profile under field conditions.

MATERIAL AND METHODS

A field study was conducted at the 2000-2001 season. A grass crop of *Lolium perenne* cv. Nui, was established in September 2000 on an Andisol from Southern Chile (Table 1) by using a seed rate of 25 kg ha^{-1}.

The meteorological data for temperature and precipitation of the experimental site are showed in Table 2.

Table 1: Chemical properties of soil studied.
Cuadro 1: Propiedades químicas del suelo estudiado.

Soil analyses	**Value**
pH (H_2O)	5.63
Organic matter (%)	16.00
Olsen-P	17.00
K (cmol(+) kg^{-1})	0.98
Na (cmol(+) kg^{-1})	0.18
Ca (cmol(+) kg^{-1})	8.50
Mg (cmol(+) kg^{-1})	2.00
Al (cmol(+) kg^{-1})	0.08
Bases (cmol(+) kg^{-1})	11.66
CICE (cmol(+) kg^{-1})	11.74
Al Saturation (%)	0.68

Table 2: Meteorological data in the experimental period 2000-2001.
Cuadro 2: Información metereológica en el período experimental 2000-2001.

Month	Mean Temperature	Mean Precipitation
	ºC	mm
September	10.3	88.7
October	12.1	82.2
November	14.1	52.3
December	16.2	41.8
January	17.2	37.9
February	17.2	29.8

Urea and sodium nitrate (Chilean nitrate) were applied as N sources at a rate of 150 and 300 kg N ha^{-1}. Both N sources were broadcast with three equal split applications, (33 %) at the 3-4 leaves stage (October 5, 2000) and after the first and second cuts (December 9, 2000 and January 17, 2001). The fertilization base used was 180 kg P_2O_5 ha^{-1} as triple superphosphate and 44 kg K_2O ha^{-1}, 44 kg S ha^{-1} and 36 kg MgO ha^{-1} as potassium-magnesium sulphate and 2 kg B ha^{-1} as ulexite. Water was added by sprinkle irrigation, to even evapotranspiration, until soil field capacity was reached.

Pasture was cut thrice, when plants reached 25-30 cm of height (December 6, January 13 and February 3). A standing residue of 5 cm was left on each sampling date. Dry matter (DM) production and shoot N concentration were determined by Kjeldhal standard procedure (Binkley and Vitousek, 1989). The N use efficiency was calculated as the DM production of two consecutive N rates minus the DM of the control. These amounts were divided by the difference between two consecutive N rates (150 kg N ha^{-1}). An ANOVA test ($p < 0.05$) was performed with the data, using a factorial model on completely randomized design with nitrogen rates and fertilizers as treatments on three sampling dates with three replications. A Pearson correlation analysis was performed for dry matter yield and nitrogen fertilization ($p < 0.01$).

Soil samples were taken every fifteen days from October 15 at 0-10; 10-20 and 20-40 cm depth to determine NO_3^--N and NH_4^+-N on wet basis, for each treatment. The N potential losses were estimated from the data corresponding to the maximum peak of NO_3^--N and NH_4^+-N leaching in the layer 20-40 cm. The pH (1:2.5 H_2O) was determined on the control treatment and on the highest N fertilizer rate plot. These results were analyzed by using the modified Fourier Series regression model (Miranda, 1994) and a 95% of confidence interval was used to determine significant differences between treatments. The Spline cubic method was used for the interpolation of the estimated values from regression analysis.

RESULTS AND DISCUSSION

Dry matter production (DM) and shoot N concentration

Dry matter production significantly increased as the level of N application was increased ($p < 0.05$). At the lowest N rate (150 kg N ha^{-1}), DM yield was less than 4700 kg ha^{-1}, whereas at the highest N rate (300 kg N ha^{-1}), DM production was above 6200 kg ha^{-1}, significantly higher than DM production of the control treatment, 2720 kg ha^{-1} (Figure 1). These results are in agreement with those reported by Mora *et al.* (2002; 2006) for spring and summer seasons. On the other hand, no effect of N source on DM production was observed. In contrast, Mora *et al.* (1999a) showed that DM production of *Lolium multiflorum* pasture was 20 to 30 % lower when urea was applied compared with sodium nitrate. However, they worked on an Andisol with a higher acidity level than that here reported (Table 1).

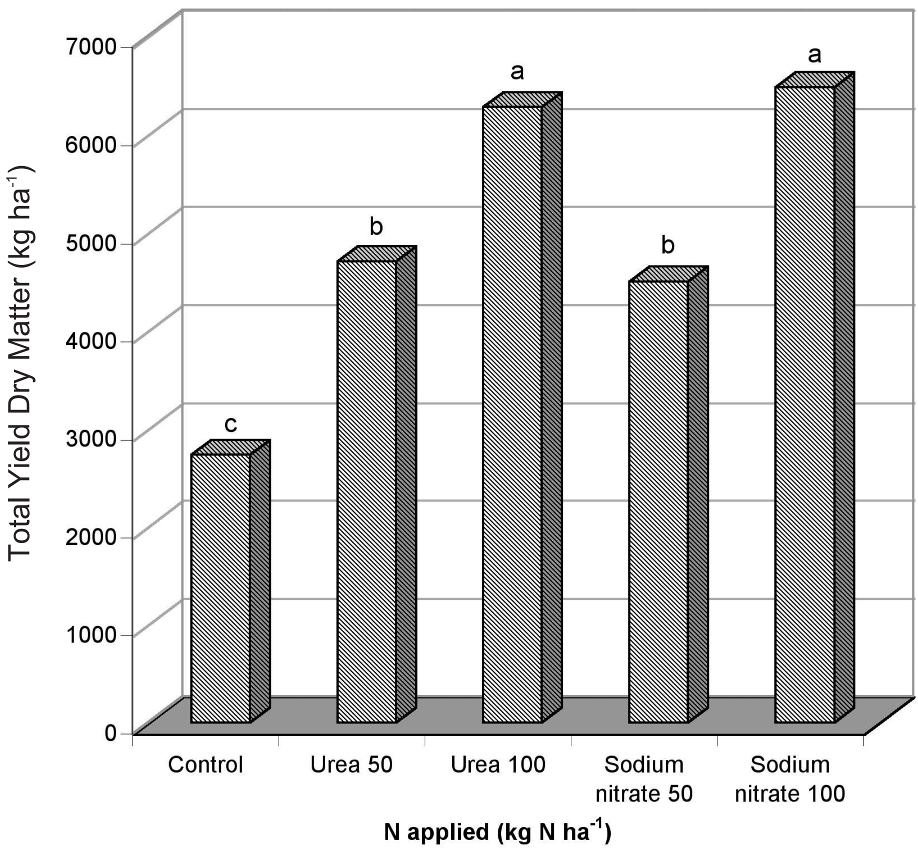

Figure 1: Total dry matter production of *Lolium perenne* cv Nui under different N fertilization treatment. Means followed by the same letter do not differ at the 0.05 significant level.

Figura 1: Producción total de materia seca de *Lolium perenne* cv Nui bajo diferentes tratamientos de fertilización nitrogenada. Promedios seguidos por la misma letra no difieren a un nivel de significancia de 0,05.

Figure 2 shows that the highest DM yields occurred early in the growing season, October, at the first cut date ($p < 0.05$). This could be explained by the favorable weather conditions (Table 2) and by the fertilization and irrigation practices, which promoted growth of soil microorganisms in the experimental site. Thus, the environmental conditions induced mineralization of organic matter, enhancing N availability to pastures during this period, which coupled with a high plant growth rate allowed to decrease NO_3^--N leaching.

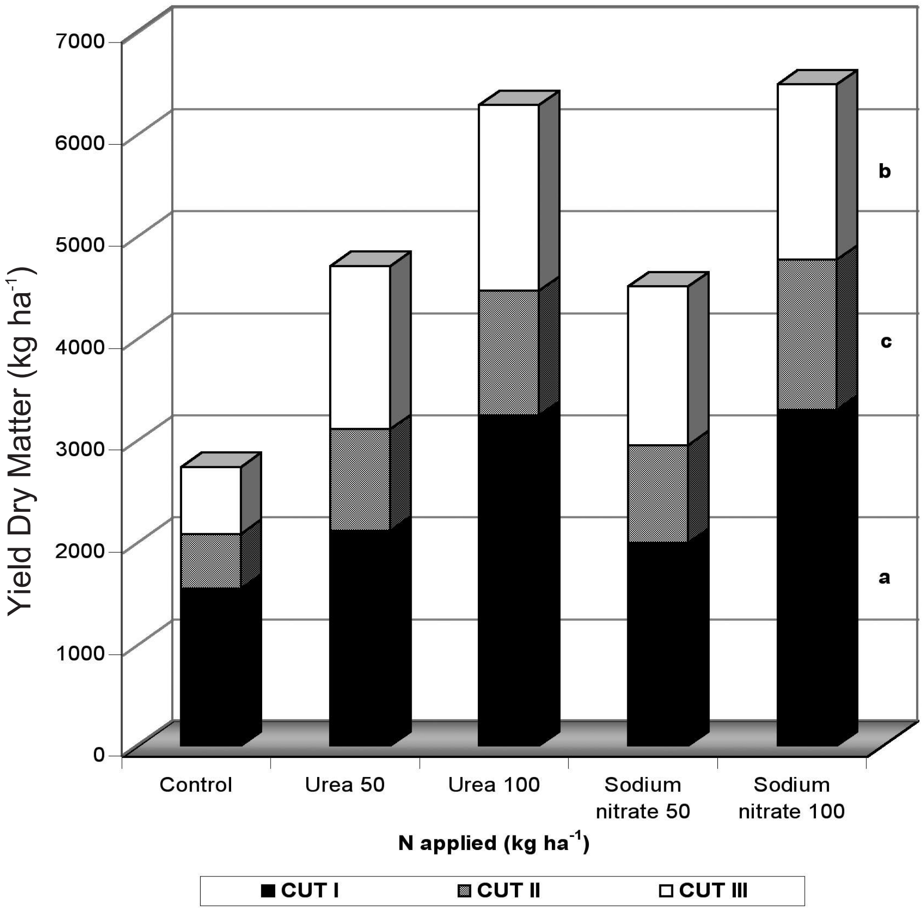

Figure 2: The effect of different rates and sources of N-fertilizer on dry matter production of *Lolium perenne* cv Nui on each sampling date. Means followed by the same letter do not differ at the 0.05 significantly level.

Figura 2: Efecto de diferentes dosis y fuentes de fertilizantes nitrogenados sobre la producción de materia seca de *Lolium perenne* cv Nui en cada fecha de muestreo. Promedios seguidos por la misma letra no difieren a un nivel de significancia de 0,05.

The delay of the last two N applications would explain the lowest DM yield on the second and third cuts. Brockman (1974) stated that N fertilizer must be applied soon after the cut, since a delay can decrease yield on the next cutting date. This yield decrease could be associated with a temporal reduction in the NO_3^--N uptake by defoliation after several cuttings during the growing period (Jarvis and Macduff, 1989) and a loss of regrowth capacity as the temperature increases in early summer (December-January).

Dry matter production was positively correlated with the amount of N applied (Figure 3; $p < 0.01$). In agreement with our results, t'Mannetje and Jarvis (1990) and Wilkins *et al.* (2000) found a linear response of DM production to N additions in the range 100 to 400 kg ha^{-1} and 250 to 700 kg N ha^{-1}, respectively. Nevertheless, in our study the N use efficiency slightly decreased from 13 to 10 kg DM kg^{-1} N when the rate of N application was increased from 150 to 300 kg N ha^{-1}. In fact, Whitehead (2000) indicated that the actual N use efficiency at a particular location depends on soil and weather factors, showing a point of decrease between 250 and 400 kg N ha^{-1} y^{-1} applied. These results show an adaptability and persistence of *Lolium perenne* to a wide range in N managements (Whitehead, 1995), and a higher N fertilizer recovery efficiency when N is applied during the stages with the higher plant growth rate at the proper rate of fertilizer and timing (Hoekstra *et al.,* 2007). This effect was also showed by Demanet *et al.* (1999) in ryegrass forage and seed production in Chilean Andisols.

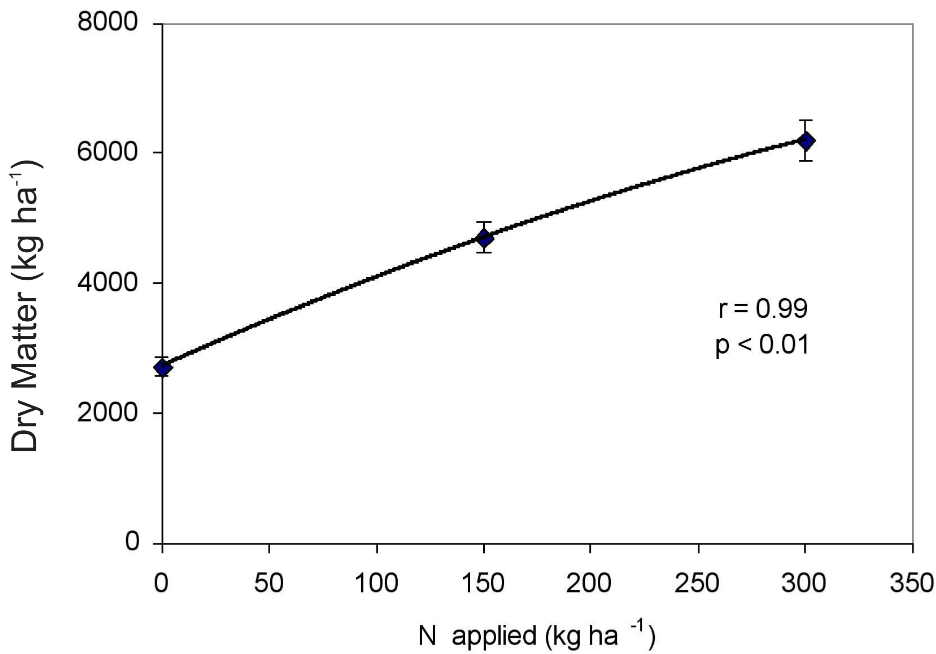

Figure 3: Pearson correlation between dry matter production and N rates applied to *Lolium perenne* cv Nui pasture.

Figura 3: Correlación de Pearson entre la producción de materia seca y las dosis de N aplicado a una pastura de *Lolium perenne* cv Nui.

Table 3 indicates that addition of N increased pasture quality by increasing N concentration of shoots ($p < 0.05$). Shoot N concentration was the highest in the third cut, and varied according with the DM production because of a dilution effect.

Furthermore, the concentration of N in the shoots was slightly higher with N broadcast as urea than as sodium nitrate because of pasture often exhibits higher NH_4^+-N uptake than NO_3^--N, when both ions are evenly supplied to soil (Clarkson *et al.,* 1986). According to Lycklama (1963) NO_3^--N uptake increases with temperature from 5 to 35°C with a peak at pH 6.2, whereas higher NH_4^+-N uptake is reached at about 22°C, and it is pH independent. Other studies have also indicated an important effect of temperature on the N uptake by plants (Room, 1986; Svenning and Macduff, 1996; Glass, 2003). All the previous factors could influence a higher ammonium uptake rather than nitrate, with all the urea and sodium nitrate rates used ($p < 0.05$) under temperature and pH conditions in the experimental site.

Table 3: Shoot nitrogen concentration on each cut of *L. perenne* pasture. 2000-2001.
Cuadro 3: Concentración de nitrógeno foliar en cada corte de una pastura de *L. perenne.* 2000-2001.

	Cut I[1]	**Cut II**	**Cut III**
		g kg^{-1}	
Control	16.4Bb	24.1Ac	26.0Ac
50 urea	19.8aCb	33.2Bb	38.2Aab
100 urea	22.5Ca	38.1Ba	42.0Aa
50 S nitrate	17.3Cb	31.7Bb	35.2Ab
100 S nitrate	21.9Ca	32.7Bb	41.0Aa

[1] Cut I, Cut II and Cut III means harvest dates for December 6, January 13 and February 3, respectively.
Row followed by the same capital letter are not significantly different at 0.05 probability level.
Column followed by the same lower-case letter are not significantly different at 0.05 probability level.

Changes in the N content of the soil profile

In late spring (November) the addition of N fertilizer raised soil NO_3^--N concentration in the 0-10 cm top layer, with higher values with the addition of 100 kg N ha^{-1} as sodium nitrate than with the other combinations (Figure 4a). An increase of the NO_3^--N concentration was observed on the second soil sampling date, on every plot that received N fertilizer, but not in the control treatment. During the first half of November, a large decrease in soil NO_3^--N concentration in the 0-10 cm (Figure 4a), 10-20 cm (Figure 5a) and 20-40 cm deep (Figure 6a) was observed. For the upper soil layers (0 to 20 cm depth) the decrease in NO_3^--N concentration could be explained by both the plant uptake and the leaching produced by effect of irrigation and precipitation. NO_3^--N losses below 20 cm can be mainly influenced by the water flux downward soil profile (Pakrou and Dillon, 2004), since the negative charge of NO_3^--N anion avoids its adsorption by the soil exchange sites (McLaren and Cameron, 1990; Whitehead, 1995; McLaren and Cameron, 1996;

Whitehead, 2000). From the second half of December, soil NO_3^--N concentration readily increased by the application of sodium nitrate at 0-10 cm of depth. In contrast, the application of urea did not show an immediate increase in the levels of NO_3^--N which could be attributed to moderate rates of urea hydrolysis and nitrification by effect of the environmental conditions. It is noteworthy that, during this period N leached highly with all the treatments, increasing NO_3^--N in deeper layers. The increment of NO_3^--N to the 20-40 cm layers in the control treatment may be attributed to the leaching of mineralized N in the shallow soil. On the other hand, at 0-10 cm of depth, soil NH_4^+-N concentration increased only when 300 kg ha^{-1} urea were applied (Figure 4b) because of the scarce leaching of NH_4^+-N, since this occurs in coarse-textured soil and low CEC (Aulakh and Bijay-Singh, 1997). An increase of the NH_4^+-N concentration in deeper soil layers was also observed with the highest urea rate after each split of nitrogen urea fertilization (Figure 5b and 6b). For the other N-treatments, the lower NH_4^+-N concentration at the deeper layers may be explained by the high affinity of this cation by negatively charged surfaces, which diminish the NH_4^+-N losses (Scholefield and Oenema, 1997). Typical zero point charge (ZPC) of these Chilean Andisols is near 4.0-4.5 (Mora *et al.,* 1999b). Therefore, the soil used in this study had a net negative charge in the range of pH which NH_4^+-N dynamics was involved. This cation is adsorbed in soil colloids by cationic exchange or by soil organic matter (McLaren and Cameron, 1990; McLaren and Cameron, 1996). Any increase of NH_4^+-N concentration in depth after the second and third split of N might be the product of microorganism N transformations and leaching process.

Temporal decrease or fluctuations in soil NH_4^+-N in the shallow soil may be explained by plant uptake and nitrification process as shown by an increase in NO_3^--N concentration from the urea input treatments (Figure 4a). The immobilization, which is mainly the absorption of NH_4^+-N by soil biomass, could also explain the behavior of this cation.

In early summer, plant uptake decreased due to a lower growth of ryegrass, and the data clearly show that when sodium nitrate or urea are applied at rates of 300 kg N ha^{-1}, the higher N availability induces to a greater N potential for leaching. This coincided with slightly lower N fertilizer use efficiency. Thus, the maximum N potential losses by leaching from sodium nitrate and urea fertilizers were estimated as 88 and 91 kg N ha^{-1} respectively, from the maximum peak in January to 20-40 cm (Figure 6a and 6b), which represent about 30 % of the N applied to the soil. On the other hand, N leaching was about 35 % lower when 150 kg N ha^{-1} were supplied.

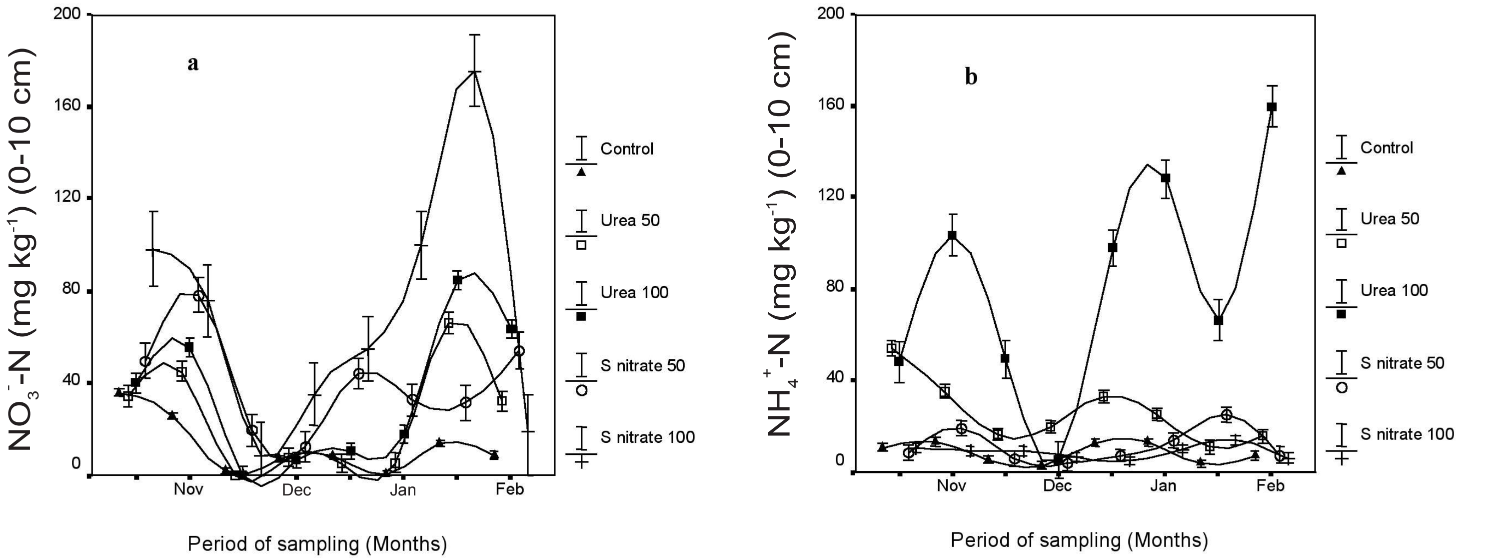

Figure 4: Variation of the (a) NO_3^--N and (b) NH_4^+-N concentrations in the soil at 0-10cm depth by effect of urea and sodium nitrate applications.

Figura 4: Variación de las concentraciones de (a) N-NO_3^- y (b) N-NH_4^+ en el suelo a una profundidad de 0-10 cm por efecto de las aplicaciones de urea y nitrato de sodio.

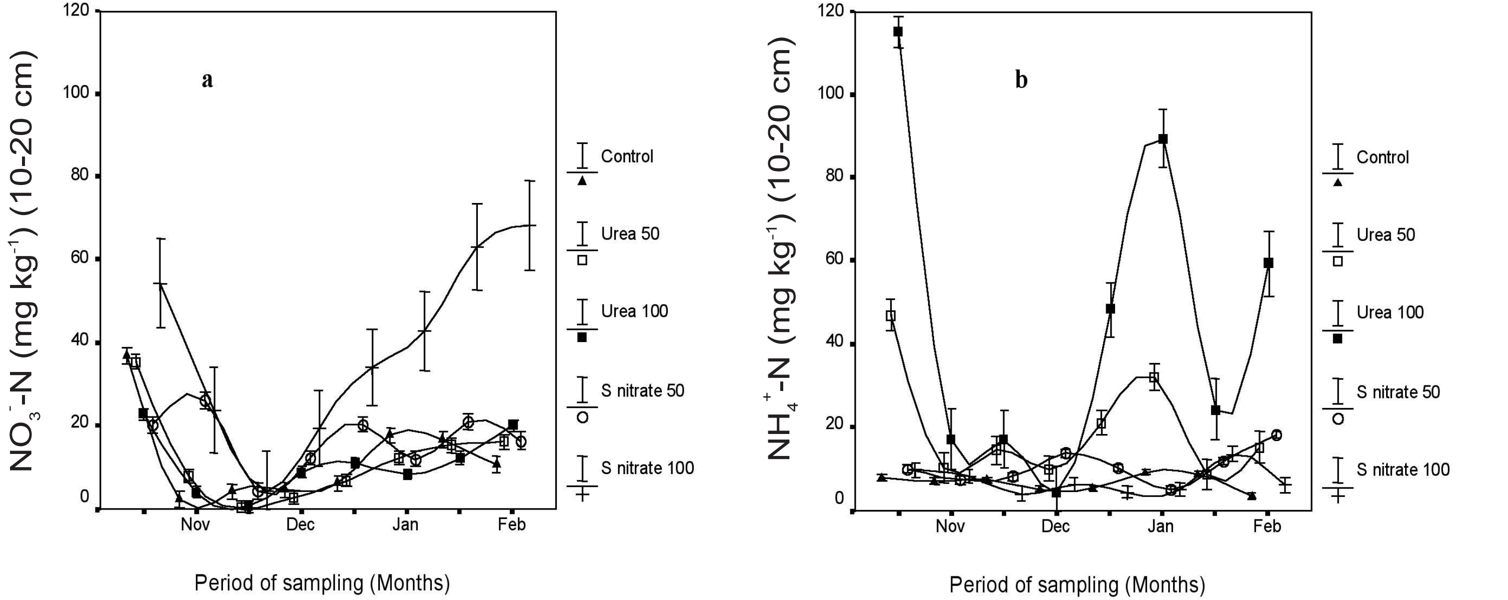

Figure 5: Variation of the (a) NO_3^--N and (b) NH_4^+-N concentrations in the soil at 10-20 cm of depth by effect of urea and sodium nitrate applications.

Figura 5: Variación de las concentraciones de (a) N-NO_3^- y (b) N-NH_4^+ en el suelo a una profundidad de 10-20 cm por efecto de las aplicaciones de urea y nitrato de sodio.

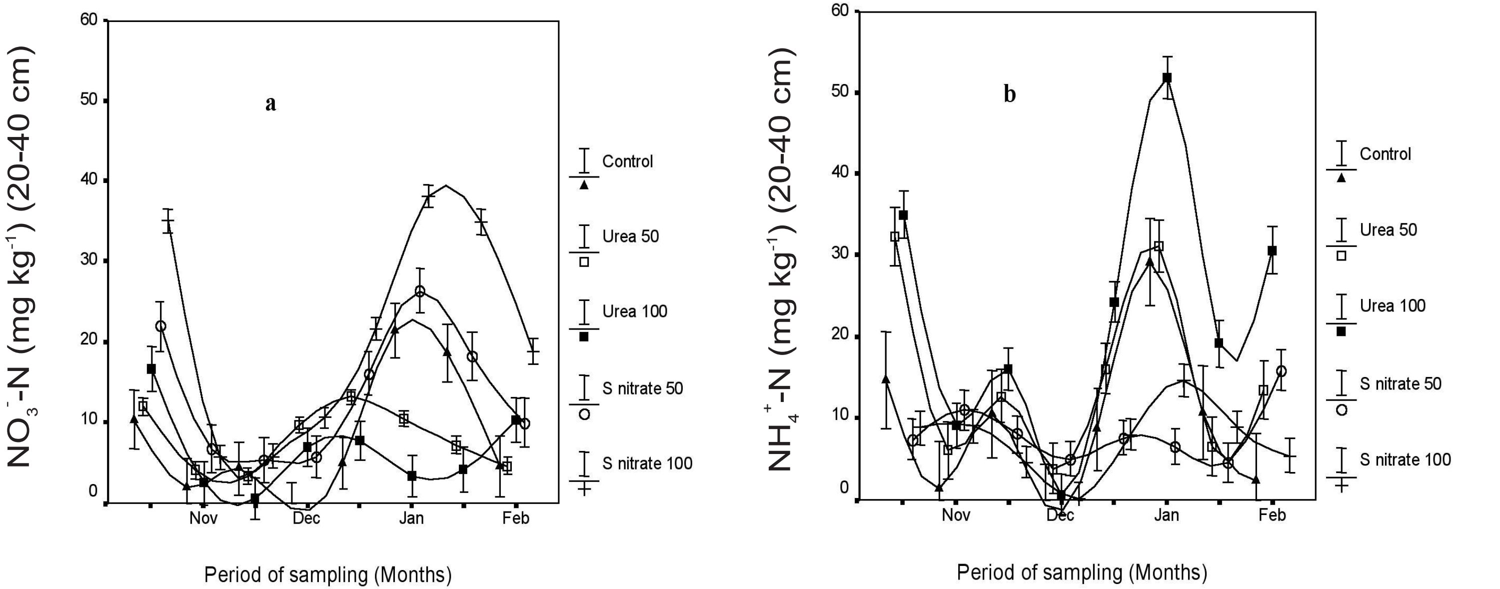

Figure 6: Variation of the (a) NO_3^--N and (b) NH_4^+-N concentrations in the soil at 20-40 cm of depth by effect of urea and sodium nitrate applications.

Figura 6: Variación de las concentraciones de (a) N-NO_3^- y (b) N-NH_4^+ en el suelo a una profundidad de 20-40 cm por efecto de las aplicaciones de urea y nitrato de sodio.

The maximum N potential losses here estimated are in the range previously reported by Alfaro *et al.* (2006) for urea application at a rate of 150 kg N ha^{-1} y^{-1}.

Therefore, the N rates rather than N sources, to some extent, affected the N use efficiency. Furthermore, it is well known that ryegrass is a specie adapted to temperate regions and its growth is limited in summer season by weather conditions. Then, to apply fertilizer to ryegrass in summer time to extend the growth period appears to be an alternative not profitable and also increase the risk of pollution in the environment.

Soil pH variations

For the treatments with the highest rate of sodium nitrate and urea, data analysis showed significant soil pH variations in the acid and basic range compared with the control treatment (Figures 7, 8 and 9).

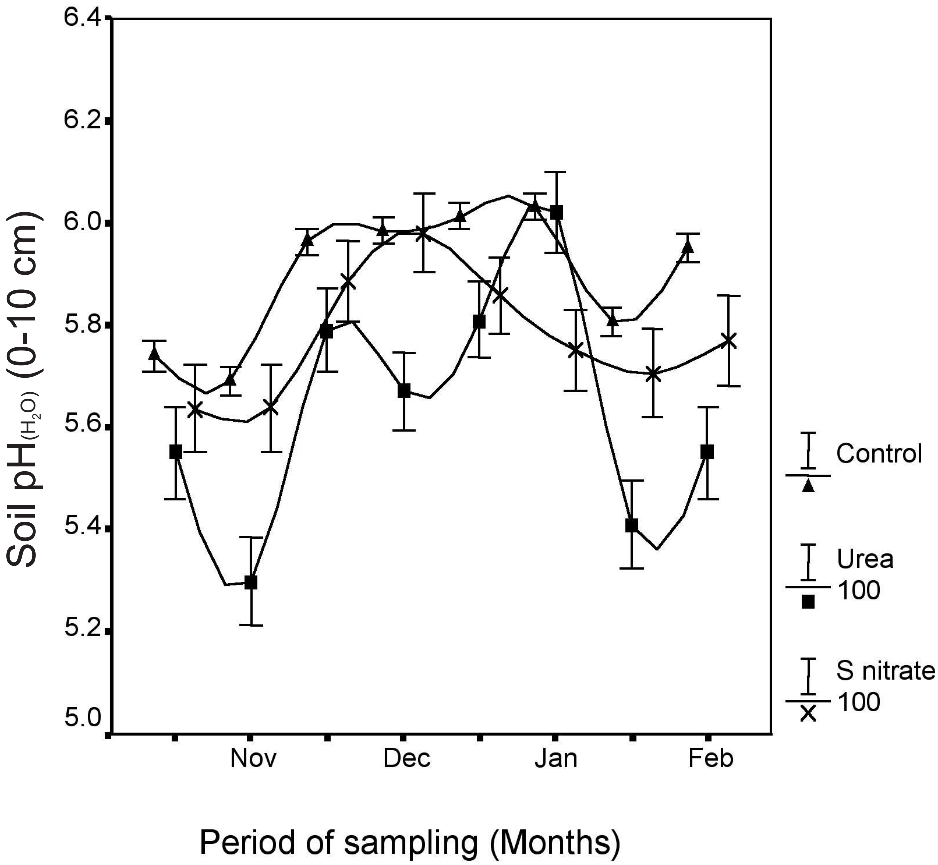

Figure 7: The effect of sodium nitrate and urea fertilizers on soil pH changes through the evaluation period at 0-10 cm depth.

Figura 7: Efecto de los fertilizantes nitrato de sodio y urea sobre los cambios de pH del suelo en el período de evaluación a una profundidad de 0-10 cm.

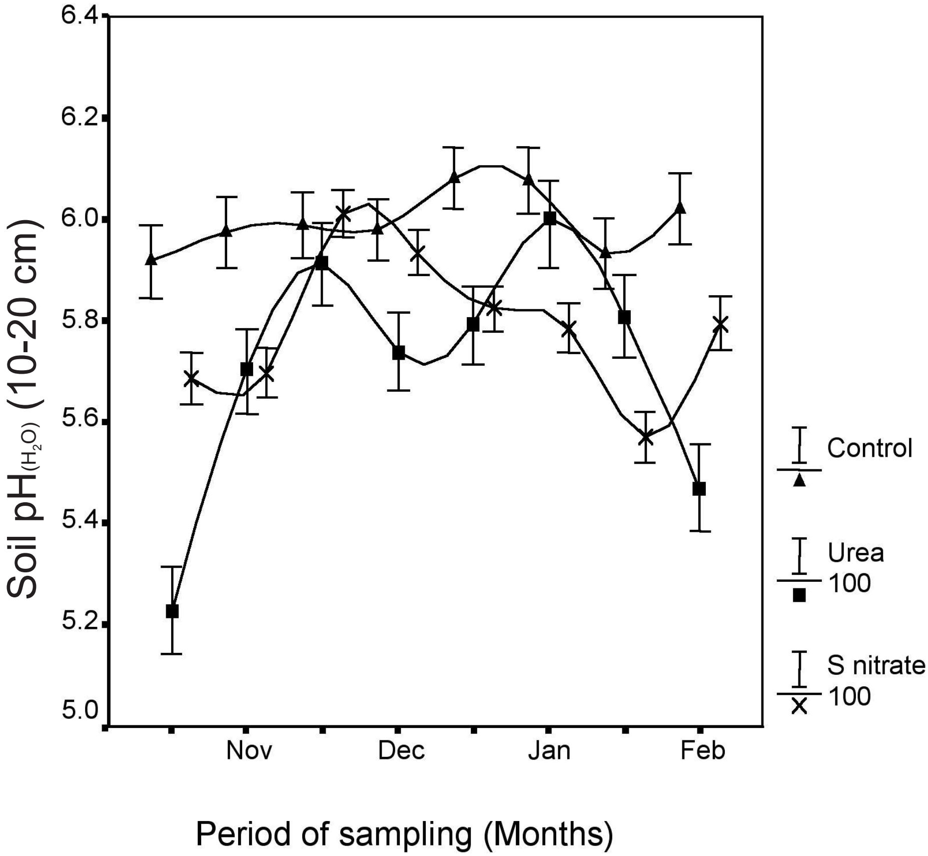

Figure 8: The effect of sodium nitrate and urea fertilizer on soil pH changes through the evaluation period at 10-20 cm depth.
Figura 8: Efecto de los fertilizantes nitrato de sodio y urea sobre los cambios de pH del suelo en el período de evaluación a una profundidad de 10-20 cm.

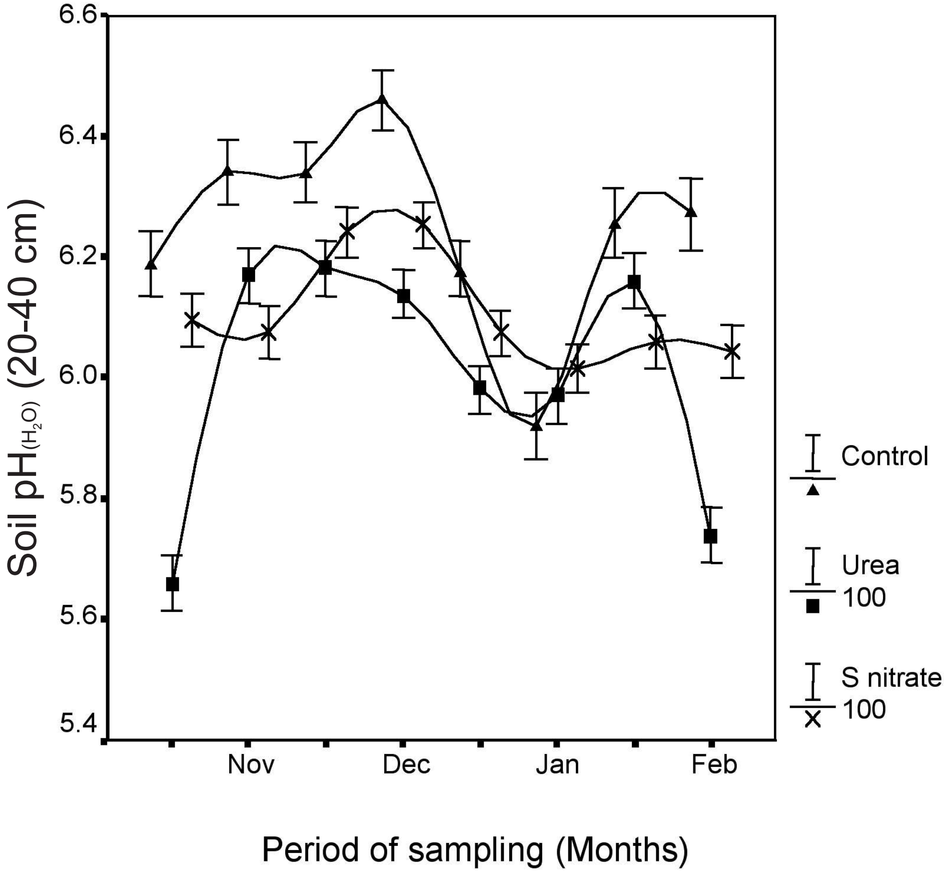

Figure 9: The effect of sodium nitrate and urea fertilizer on soil pH changes through the evaluation period at 20-40 cm depth.

Figure 9: Efecto de los fertilizantes nitrato de sodio y urea sobre los cambios de pH del suelo en el período de evaluación a una profundidad de 20-40 cm.

In our study, from late November to early January, there were changes of soil acidity values due to OH^- release from urea hydrolysis process. The highest pH fluctuations were observed with urea treatments, as the processes of hydrolysis and nitrification of this fertilizer occurred, leaving NO_3^--N available to plants. The decrease of pH values for the sodium nitrate treatments could be explained by leaching losses from the NO_3^--N soil pool during this period.

At the end of the experiment, the soil pH was about 0.4 units lower in the urea treatment compared with the control treatment. Despite the high N doses of urea applied (300 kg N ha^{-1}), during the first growth season of the pasture non detrimental effects of soil acidity on DM production or quality were observed in the short-term. However, after the first or second period of plant growth, an important negative effect of ammonium fertilizers on the pasture production is expected. Thus, our results suggest the need for pH evaluations in longer periods, to allow the expression of soil acidification caused by the use of ammonia fertilizers as it has been previously reported (Mora *et al.,* 1999a; Mora *et al.,* 2002; Mora *et al.,* 2006).

CONCLUSIONS

Dry matter production significantly increased by 128% as the N fertilizer rate was increased from 0 (control) to 300 kg N ha^{-1}. There was no effect of ammonia or nitrate N sources on grass yield. On the other hand, both N sources increased shoot N content, according to the increment of N fertilizer rate.

The pH fluctuations are directly associated with the dynamics of urea hydrolysis process in the soil. However, there was no acidifying effect of urea on DM production and pasture quality in this short-term assay. The application N (as sodium nitrate or urea) at dose of 300 kg N ha^{-1} yielded the highest NO_3^--N and NH_4^+-N concentration in the deepest soil layers. The higher N availability in soil during the period of lower growth rate of the pasture generated N leaching downward the soil profile. The maximum N potential losses by leaching estimated from 20-40 cm depth layer in January were around 90 kg N ha^{-1}. According to our results, we could estimate that the N leaching losses in a year would be more than 150 kg ha^{-1} if we apply 300 kg N ha^{-1}. This paper shown that the use of high rates of N in ryegrass under irrigation in Spring-Summer season have a very negative environmental impact.

ACKNOWLEDGEMENTS

This work was supported by the FONDECYT project 1061262 and by the Bicentenary Program of Science and Technology – PSD 26 CONICYT-UFRO.

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