Simulation of salt leaching in grazed grassland soils using bromide as a tracer

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Abstract

Lowering of soil salinity is important in improving the productivity of grasslands in parts of Argentina. Under rainfed conditions, it is very difficult to reduce soil salt content. Soil cover can be modified by means of grazing management to test the effects on the salinisation process in soils. Grasslands on 3 soils in the Flooding Pampa were grazed or ungrazed and subjected to natural variable rainfall conditions.

Salt leaching was simulated by using bromide (Br) as a tracer. Its concentration was measured using a specific bromide ion electrode.

The tracer was leached from the soils in the ungrazed treatment at different rates, reaching the background level within 2 years. Conversely, in soils under grazing the tracer moved more slowly.

These results support the hypothesis that the rate of salt leaching can be accelerated through grazing management. The effect of soil type on the benefits obtained is discussed. It is concluded that, whenever grazing is managed to control the soil salt content, soil properties must be considered.

Introduction

Saline soils are usually subjected to two opposite processes: upward and downward flows of water and salts (Szabolcs 1979). Changes in the soil water balance, mainly resulting from changes in water infiltration or soil water evaporation, lead to changes in soil salinity levels. Under rainfed conditions, it is very difficult to increase salt leaching by increasing the downward movement of water. Reduction in soil salt content is important to improve grassland productivity, such as in the millions of hectares of grasslands developed on halomorphic environments in subtropical Argentina (Lavado 1988). Soil halomorphism in these regions is a major factor affecting the distribution and composition of native grasslands (Berasategui and Barberis 1982).

Previous observations showed that covered soils were less saline than uncovered ones (Doering *et al.* 1964; Sandoval and Benz 1966, 1973). Similarly, Lavado and Taboada (1987) and Lavado *et al.* (1990) found that the topsoil in ungrazed areas in the Flooding Pampa, Argentina had lower salt content than continuously grazed areas. This is largely a result of decreased water evaporation from the taller, denser canopy (green and standing dead material) and increased litter. Salinisation of soils under grazing operates in pulses occurring at irregular and recurrent times. The average salt content is not high, but, during salt pulses, electrical conductivity reaches extreme values as high as 14 dS/m (Lavado and Luconi 1988). After a while, salts are leached by the rainfall (Lavado and Taboada 1988), but the sodicity of most soils (measured as Exchangeable Sodium Percentage) remains high (Lavado and Luconi 1988; Lavado *et al.* 1990). Using that information, soil cover was manipulated through grazing management (short periods of high grazing pressure followed by long periods of rest) to check experimentally the salinisation process in soils of the area (Lavado *et al.* 1990). It was important to learn about the edaphic conditions affecting salt leaching in halomorphic environments in grazed pastures.

Salt leaching can be simulated by the use of tracers. Bromide (Br) has been used to study

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water and salt dynamics in soils (Ahuja *et al.* 1983; Germann *et al.* 1984; Smith *et al.* 1984). This anion is conservative in nature, has generally low background levels and its movement is similar to Cl^- (Bowman 1984). Chloride is a main anionic component of the soluble salts in soils (Lavado and Taboada 1988).

This study aimed to simulate salt leaching (using Br as a tracer) in 3 soils that represent a taxonomical gradation within the halomorphic soils of the Flooding Pampa. The soils were subjected to natural rainfall and were both grazed and ungrazed. The following hypothesis was tested: salt leaching depends not only on the properties of a soil but also on its interaction with grazing.

Materials and methods

The 3 soils studied were located in the Flooding Pampa (Argentina), a region of about 9 million ha, with a predominance of halo-hydromorphic complexes and associations. Most of those soils, with a high water table, have a natric horizon and Natraquolls are the most extensive and widespread soils. Natraqualfs are the next most common Great Groups (INTA 1990). The region is virtually flat. The area and its soils have been described elsewhere (Berasategui and Barberis 1982; Lavado and Taboada 1987, 1988; INTA 1990; Lavado *et al.* 1990). The studied soils were classified following the U.S. Soil Taxonomy, as a Typic Natraquoll (near the town of Casalins), a Typic Natraqualf (near the town of Verónica) and a Mollic Natraqualf (near the town of Colman). They do not fall on the same transect, but are representative of the predominant sequence of halo-hydromorphic soils of the region. Their main properties are shown in Table 1.

The region is mainly devoted to cow-calf operations on natural grasslands, composed of a mixture of C3 and C4 grasses (Burkart *et al.* 1990). Major species are: *Bothriochloa laguroides*, *Danthonia montevidensis*, *Carex* sp., *Paspalum dilatatum*, *Sporobolus indicus* and *Panicum* sp. (Casalins); *Paspalidium paludivagum*, *Leersia hexandra*, *Distichlis* sp., *Hordeum pusillum*, *Carex* sp. and *Lolium multiflorum* (Colman); and *Distichlis spicata*, *D. scoparia*, *Sporobolus pyramidatus*, *Paspalum vaginatum*, *Hordeum stenostachys* and *Chaetotropis elongata* (Verónica).

To simulate salt movement 3 small plots (2 m × 2 m) were laid down at random for each treatment on each soil. There were 2 treatments: continuously grazed and ungrazed. The first treatment represented normal grazing management with the typical cattle stocking rate for the area (between 0.8–1.1 units/ha). The ungrazed treatment was located in adjacent areas where

Table 1. Some characteristics of the 3 soils.

Soil type	Horizon	Depth	pH[1]	EC[2]	SAR[3]	Clay[4]	Organic[5] carbon
		(cm)		(dS/m)		(%)	(%)
Typic Natraquoll	A1	00–11	6.2	1.5	9.5	23.6	3.24
	B1	11–17	7.4	1.8	13.0	29.5	1.46
	B21	17–40	8.1	2.3	20.5	37.3	0.87
	B22	40–58	8.3	2.4	28.5	61.4	—
	B31	58–64	8.0	2.9	30.1	23.4	—
Mollic Natraqualf	A1	00–08	8.3	1.4	18.4	18.5	1.38
	B1	08–21	8.8	1.2	20.9	17.5	0.53
	B21	21–34	9.1	2.4	25.7	55.7	—
	B22	34–50	9.1	3.0	33.9	39.4	—
	B31	50–67	9.2	2.2	17.5	21.9	—
Typic Natraqualf	A1	00–07	8.6	2.1	30.7	24.0	1.11
	B1	07–34	9.4	1.8	33.8	42.5	0.35
	B21	34–54	9.2	2.1	43.2	62.3	—
	B22	54–65	9.1	3.8	49.6	49.2	—
	B31	65–86	8.7	6.4	58.4	39.6	—

[1] pH in paste (Page *et al.* 1982).
[2] Electrical Conductivity in saturation extracts (Page *et al.* 1982).
[3] Sodium Adsorption Ratio, from soluble Ca, Mg and Na (Page *et al.* 1982).
[4] Particle size analysis by pipette method (Klute 1986).
[5] Organic carbon, by Walkley and Black method (Page *et al.* 1982).

cattle were excluded for more than 12 years. Each plot was treated with 8 L of a 100 g/L solution of KBr. In each plot, duplicate samples were collected from the A1, B1, B21, B22 and B31 horizons (see depth in Table 1) with an auger, in autumn of 1988 (before tracer application), 1989 and 1990.

Tracer concentration was measured directly using a specific bromide ion electrode (Page *et al.* 1982). Determinations were made on 1:1 soil:water extracts (Germann *et al.* 1984), using an ionic strength adjustor. Data were statistically analysed by ANOVA. In each soil, 2 observation wells (2 m deep) were set up. In autumn 1990, infiltration rate (IR) was determined 3 times for each treatment using a cylinder infiltrometer (Klute 1986). The bulk density of each horizon was also determined (Klute 1986) and used to calculate the Br mass balance.

Results

When the study started, water tables at the 3 sites were within 1 m of the surface. On the next 2 sampling dates, none had a water table within 1 m. Mean IRs for each site (Table 2) show high variability among determinations. However, there is generally an inverse relationship between IR and parameters of sodicity (pH and sodium adsorption ratio (SAR); Table 1). IR was always lower in grazed than in ungrazed treatments.

The annual rainfall varied between 750–1200 mm in the different places and years. In general, it was around the long-term average during the first year, below average at the beginning of the second, and average for the rest of the experiment. The potential evapotranspiration followed a more regular pattern. Maximum values were around 4.5 mm/day in summer and the minimum around 0.8 mm in winter. Tschapek and Barrera (1962) determined in lysimeters that an average of 100 mm of water percolates yearly in well-drained soil in this area.

A considerable variation in Br concentration can exist at a given soil depth and treatment (Agus and Cassel 1992), with CVs exceeding 100%. In this study, the lowest CV was 0.2% in the A1 horizon under grazing in the Typic Natraquoll and the highest was 66.7% in the B21 horizon in the ungrazed treatment in the Mollic Natraqualf. In the ungrazed Typic Natraquoll (Figure 1a), during the first year of the experiment, the Br contents were similar to background levels (the concentration of Br in the soil before the experiment started) in the top (A1 and B1 horizons) and bottom (B22 and B31 horizons) of the profile. Br concentration in the B21 horizon was higher than background levels. This Br distribution showed that, in the ungrazed treatment, the tracer was leached but some still remained around the middle of the soil profile a year after Br application. In the grazed treatment, Br concentrations were significantly higher than background levels in all horizons sampled and higher than the ungrazed treatment in 3 horizons (Figure 1b). Two years after the tracer was applied, the Br was leached from the soil since the Br concentrations in both treatments were not different from background levels, except in the B22 horizon under grazing, in which some tracer still remained.

Figure 2 shows data for the Mollic Natraqualf. One year after the tracer was applied, Br concentrations in the B1, B21 and B22 horizons of the ungrazed treatment were statistically higher than background. On the last sampling date, the tracer concentration was similar to background, except in the B21 horizon. Under grazing, the Br concentrations were higher in the whole profile. In the second year, the 3 deeper horizons under grazing had a significantly higher Br concentration than background.

Figure 3 shows that, for the Typic Natraqualf, the tracer behaved similarly in both grazed and ungrazed treatments one year after application, the Br concentration being significantly higher than background in the top 3 sampling depths.

Table 2. Mean infiltration rate (cm/h) and (standard deviation) for 3 soil types and 2 grazing regimes.

Treatment	Soil type		
	Typic Natraquoll	Mollic Natraqualf	Typic Natraqualf
Grazed	0.31 (0.290)	0.21 (0.219)	0.17 (0.144)
Ungrazed	0.85 (0.797)	0.38 (0.281)	0.27 (0.283)

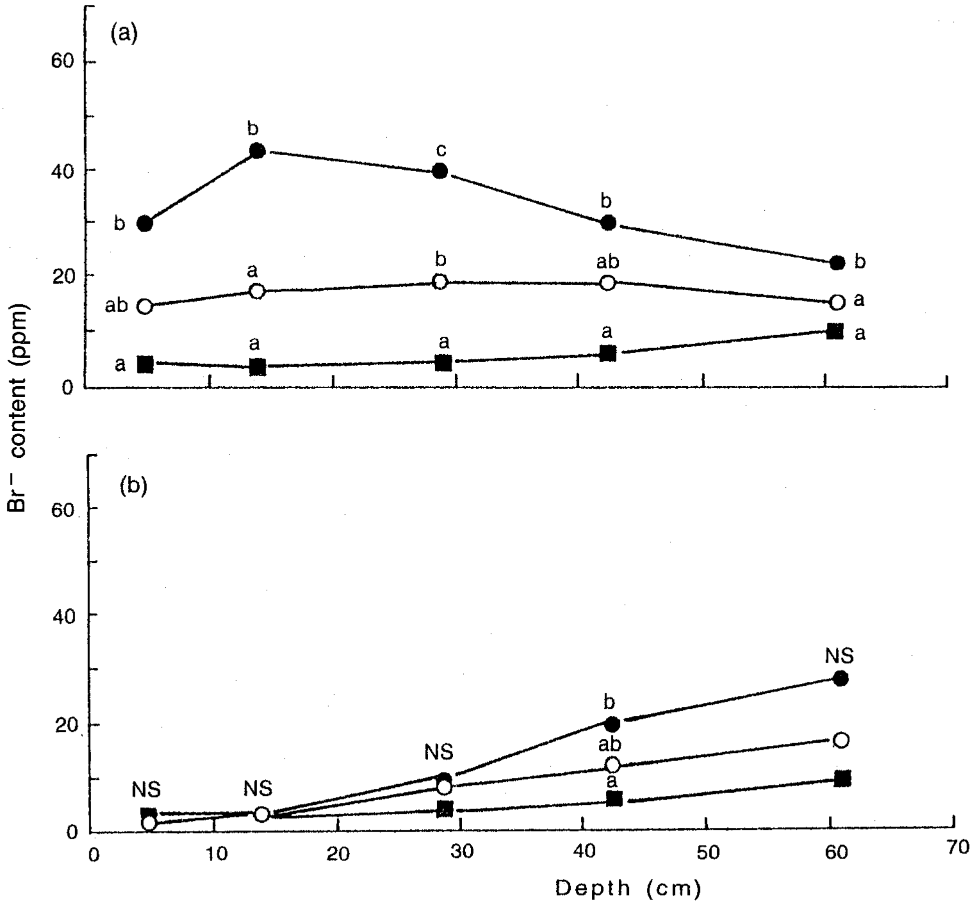

Figure 1. Bromide distribution in the profile of the Typic Natraquoll, (a) 1 year and (b) 2 years after Br application. ■ Background (data at the start of the experiment); o ungrazed treatment; and ● grazed treatment.

Two years after the experiment had started, the two treatments were different: the Br concentration was similar to background levels in the ungrazed treatment, but significantly higher in the B21 and B22 horizons in the grazed treatment.

A simple mass balance of Br (Table 3) shows that the pattern of Br output was similar for the Typic Natraquoll and the Mollic Natraqualf. At the end of the experiment, the highest Br leaching was found in the Typic Natraquoll with no grazing and the lowest in the Mollic Natraqualf under grazing. The Typic Natraqualf showed the lowest Br output in the first year. During the second year, the ungrazed treatment behaved in a similar way to the other soil types with a total Br loss of 70.2% while the grazed treatment showed an overall increase in Br level in the profile (Table 3). Br output (%) was calculated using the following equation:

$$\text{Br output (\%)} = \frac{\text{Br in the soil at the start} + \text{Br added} - \text{Br measured}}{\text{Br in the soil at the start} + \text{Br added}} \times 100$$

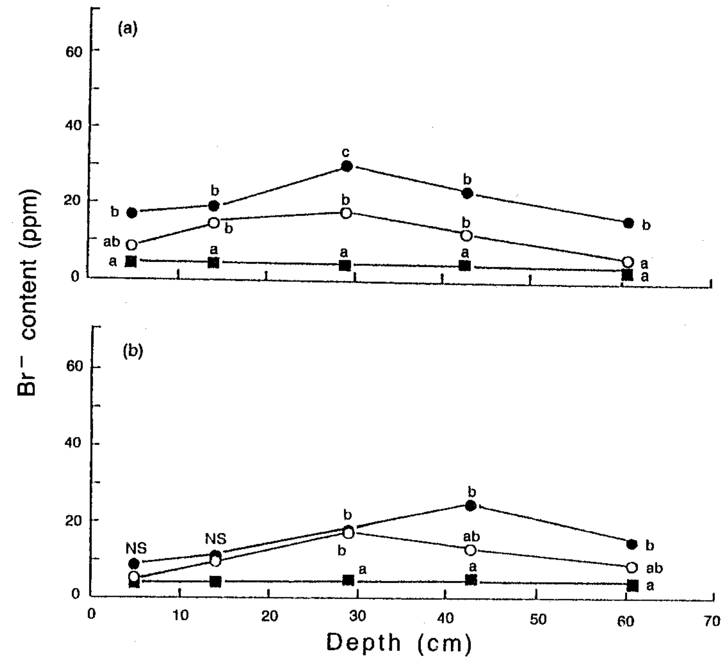

Figure 2. Bromide distribution in the profile of the Mollic Natraqualf, (a) 1 year and (b) 2 years after Br application. ■ Background (data at the start of the experiment); o ungrazed treatment; and ● grazed treatment.

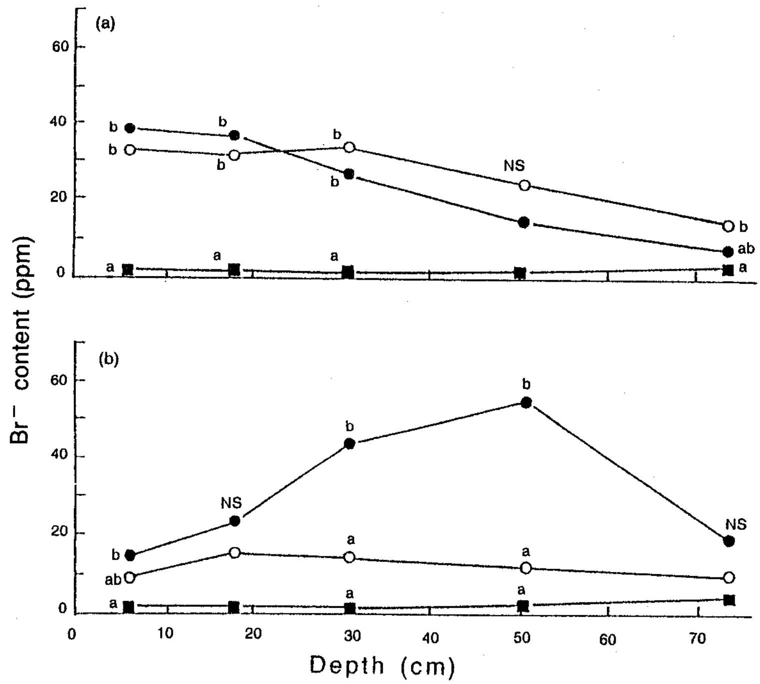

Figure 3. Bromide distribution in the profile of the Typic Natraqualf, (a) 1 year and (b) 2 years after Br application. ■ Background (data at the start of the experiment); o ungrazed treatment; and ● grazed treatment.

Discussion

The tracer behaved differently in the 3 soils under investigation. Smith *et al.* (1984), studying the Br fluxes in 3 growing seasons, found the velocity of pore water varied from soil to soil and year to year. However, they found velocity of pore water, and thus Br movement, was more related to soil differences than variations in water content. Bruce *et al.* (1985) found the efficiency of rainfall in transporting Br through the soil profile was related to the clay content of the B horizon and other physical differences. The 3 ungrazed soils showed lower Br concentrations in the soil profile, which reflects higher output rates (around 70–75% of the applied Br within 2 years (Table 3)). Under our conditions, uptake by plants and lateral movement of the tracer were considered minimal (limited green biomass and low slope) and similar at the 3 sites, so Br output was attributed mainly to leaching. In our grazed treatments, Br leaching in the Typic Natraquoll was similar to that of the Mollic Natraqualf and the tracer moved more slowly in these soils than under no grazing (Br output lower than 70% — Table 3). The Br concentration in the Typic Natraqualf under grazing was higher than that found in the other soils. This result agrees with the finding of Williams *et al.* (1990) on the effect of the physical condition of the soil surface on Br leaching. They also found a lower Br leaching in soils compacted by grazing animals. Jabro *et al.* (1991) found a significant correlation between infiltration rates and amount of Br measured in the soil. The general pattern of decrease of IR under grazing found in this study was expected from the literature. The reduced water infiltration rate as a result of grazing led to a higher tracer content in the profile, especially after the first year.

Agus and Cassel (1992) found that Br redistribution was related to soil characteristics, rainfall infiltration and the effect of tillage. Considering the ungrazed treatment maintained the properties of each soil without interference, the tracer leaching followed very weakly the clay content of the B horizons, the sodicity level (pH and SAR) (Table 1) and the differences in average IR (Table 2). Other factors that affect tracer movement must be taken into account. Smith *et al.* (1984) emphasised the highly variable sequence of water flow velocities in the field, as soil moisture contents and water uptake by plants vary. According to these authors, in the presence of a growing crop, the uptake of water by roots results in a non-uniform soil water content and reduced water and tracer flux with depth. In our case other factors may have also affected the Br movements, including changes in the grassland under grazing. Decrease in green aerial biomass, as well as in standing dead and litter biomass increase evaporative losses from the soil surface, as well as reducing IR (Sala *et al.* 1986; Sala 1988). Comparing grazed and ungrazed situations, the evaporation rate was as much as 10 times higher in grazed soils which led a significant capillary rise from salinised deep horizons (Lavado and Taboada 1987; 1988). The increase in salinity at the bottom of the Typic Natraqualf under grazing during the second year (data not shown), could be the reason for the Br increase in that treatment (Figure 3b).

The results obtained show different patterns of Br leaching in grazed and ungrazed situations. This suggests that, through grazing management (which modifies water infiltration rate and evaporation), it is possible to accelerate the degree of salt leaching and control soil salinisation. It appears that this may be more important on the more halomorphic soils (Typic Natraqualf, in our

Table 3. Bromide levels in the soil profile (mg Br/kg soil) during the experiment and (bromide output from the profile) (%).

Soil type	Sampling time	Ungrazed	Grazed
Typic	Autumn 1988	4.16	5.38
Natraquoll	Autumn 1989	15.75 (60.8)	31.70 (23.5)
	Autumn 1990	9.78 (75.7)	13.38 (67.7)
Mollic	Autumn 1988	4.17	4.48
Natraqualf	Autumn 1989	12.99 (65.9)	22.25 (42.1)
	Autumn 1990	11.74 (69.3)	15.51 (59.6)
Typic	Autumn 1988	2.61	2.26
Natraqualf	Autumn 1989	25.52 (12.1)	23.73 (17.3)
	Autumn 1990	11.24 (70.2)	31.04 (+8.2)

case) which may be more affected by grazing. It can therefore be concluded that grazing management aimed at soil salinisation control must take into account soil properties, since the more halomorphic the soil, the lower the salt leaching rate.

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