Grazing Management and Soil Salinization in Two Pampean Natraqualfs[1]

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ABSTRACT

Soil salinization is the result of the combined effect of several site characteristics. They can be reduced to three different factors: a)environment, b) soil properties and c) land use impact. In order to study the effect of grazing on topsoil salinization, two Natraqualfs located in two basins of the Flooding Pampa (Argentina) were monitored during 30 months. Natraqualfs are the secondmost important great group of soils of the region, and are covered by grazed natural grasslands. The experiment had three treatments: continuous grazing, no grazing, and rotative grazing. The soils, located between the towns of Veronica (northeast) and Rauch city (southwest), showed different properties and water table regimes. Salts ascend to the soil surface by pulses, under continuous grazing conditions. It is concluded that topsoil salinization due to grazing can be considered a generalized process, which occurs regardless of characteristics of the soil, water table regime and other environmental features. Rotative grazing showed no heavy salt fluxes toward soil surface, and resembled the no-grazing treatment. Potentially, this could be a non-deteriorating grazing management technique in similar soils.

RESUMEN

La salinización de los suelos es el efecto combinado de diferentes características que se pueden agrupar en tres niveles diferentes: medio ambiente, propiedades del suelo e impacto del uso de la tierra. Se controlaron dos natracualfes en dos cuencas de La Pampa deprimida (Arg.), durante 30 meses, con el fin de estudiar el efecto del pastoreo en la salinización del suelo superficial. Los natracualfes son el segundo gran grupo de suelos de la región en orden de importancia y están cubiertos por pastizales naturales pastoreados. Se plantearon tres tratamientos: pastoreo continuo, no pastoreo y pastoreo rotativo. Los suelos, cerca de Verónica (noreste) y de Rauch (suroeste), presentaban diferentes propiedades y un régimen de agua freática propio. Las sales ascendieron a la superficie de los suelos por pulsos, bajo la condición de pastoreo continuo. Se concluyó que la salinización de los horizontes superficiales por el pastoreo puede considerarse como un proceso generalizado, independientemente de algunas propiedades de los suelos, del régimen de agua freática y de otras características del ambiente. El pastoreo rotativo no presentó importantes flujos de sales hacia la superficie del suelo, por lo que se asemejó al tratamiento no pastoreado. Esto podría ser la base para una técnica de manejo del pastoreo sin deterioro de tales suelos.

INTRODUCTION

Soil salinization, which takes place under many condition, has been the object of intense research for years. Salinization is the result of the combined effect of several site characteristics (10,14). They can be grouped into three different categories: **environment**, which includes the regional geology and geomorphology; climate (rainfall intensity, distribution, and evapotranspiration), and hydrology (the water table regime, the main supplier of salts to the soil); **soil properties**, which include components such as clay and organic matter, pore-size distribution, and lithologic discontinuities; and **the impact of land use**. For the last, grazing has been reported to be a causal factor of the salinization processes in different ecosystems, including marshes (1, 4), shrublands and woody areas (7, 15, 22, 24), and grasslands (3). In grasslands at the center of the flooding pampa in Argentina, the salinization process was studied in a Natraquoll (13).

The flooding pampa is large (about 9 000 000 ha), with a predominance of salt-affected soils, generally resulting from a high water table (11, 17). Most of the salt affected soils of the region have natric horizons, Natraquolls being the most extensive and widespread soils throughout the region. Natraqualfs are next great group, covering more than 1 000 000 ha. Over such a large area, the Natraqualfs show variations in their properties and components (8).

The region is still mostly covered by native grasslands rich in halo-hydrophilous species. Soil halomorphism was found to be the a major factor affecting natural grasslands, and it was found to be responsible for the areal distribution of herbaceous communities, as well as their composition and properties (2). These grasslands are devoted to production of beef cattle and subjected to continuous grazing year-round (23). The

1 Received for publication 9 September 1992
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continuous grazing promotes salt rise toward the upper soil horizons through a decrease in soil cover and an increase in soil water evaporation (13). The salts rise by a combination of diffusion in deep horizons and convection in the upper ones (14). There are attempts to improve grazing management in the area, including rotative grazing (18). However, no previous accounts relating this technique to soil salinization are registered.

The aims of this paper were to study 1) the effects of grazing on the salinization and alkalization of two Natraqualfs located in two different basins of the flooding pampa presenting contrasting physical and hydrological properties and 2) to evaluate an alternative grazing management technique in relation to these processes.

MATERIALS AND METHODS

Study Sites

The study was carried out in two flooding pampa sites 210 km apart. The first was located near the town of Veronica, to the northeast (upthrown block basin), and the second near the city of Rauch, in the southwest (calcareous crust basin). Both sites and their geomorphological unite are located are shown in Fig. 1. The soils were a typic Natraqualf in the northern site and a mollic Natraqualf in the southern site. Some properties of both soils, and the analytical methods used, are shown in Table 1.

In the upthrown block basin, most Natraqualfs have vertic characteristics in deep horizons, and show an average slope of 0.2% - 0.3%; they are also periodically waterlogged and exhibit some sheet erosion. The annual rainfall (average of 80 years) is around 950 mm. It followed the usual pattern in the temperate Pampean region: uneven distribution with no seasonality. Sala *et al.* (19) found that the phreatic water discharges toward Samborombon Bay (Fig. 1), but that evapotranspiration was considered the main discharge factor.

Gonzalez and Laurencena (16) and Sala *et al.* (19) found that this discharge area showed few fluctuations in its water table. The occurrence of soluble sodium carbonates and a high pH is characteristic of phreatic waters, and is the cause of the high sodicity of most soils of the area (11). In the calcareous crust basin, the soils have no vertic features and show average slopes of 0.1% - 0.2%. They are developed over a *caliche* crust located 1.0– 1.5 m deep. Most of the area is subjected to short-term waterlogging during winter. No erosion is observed. Annual rainfall (average of 80 years) is around 830 mm. There is no accurate information on the behavior of the water table. Sala *et al.* (20) reported regional underground fluxes toward the eastern part of the flooding pampa.

Table 1. Characteristics of both Natraqualfs.

Site	Horizon	Depth (cm)	pH[A]	Organic[B] C (%)	Clay[C] (%)	Silt (%)	Sand (%)	Lime[D] (%)
Veronica	A1	00- 16	8.5	0.95	24.1	65.2	10.7	0
	B1	16- 23	9.3	0.44	42.9	51.4	5.7	0
	B21	23- 36	9.3	-	61.9	32.4	6.6	0
	B22	36- 69	9.2	-	49.4	41.8	8.8	0
	B31	60-115	8.8	-	39.8	50.3	9.8	0
Rauch	A1	00-09	8.2	1.67	18.8	29.0	54.1	0.03
	B1	10-19	8.9	0.55	17.4	40.7	41.9	0.63
	B21	19-42	9.0	-	55.0	20.1	24.9	0.97
	B22	42-56	9.0	-	39.6	34.0	26.4	1.11
	B31	56-+	9.3	-	21.6	30.0	48.4	4.82
	Caliche crust:	103 cm						

A) pH in paste (16). B) Organic carbon by Walkley & Black method (16).

C) Particle size analysis by pipette method (9). D) Lime by Allison method (16).

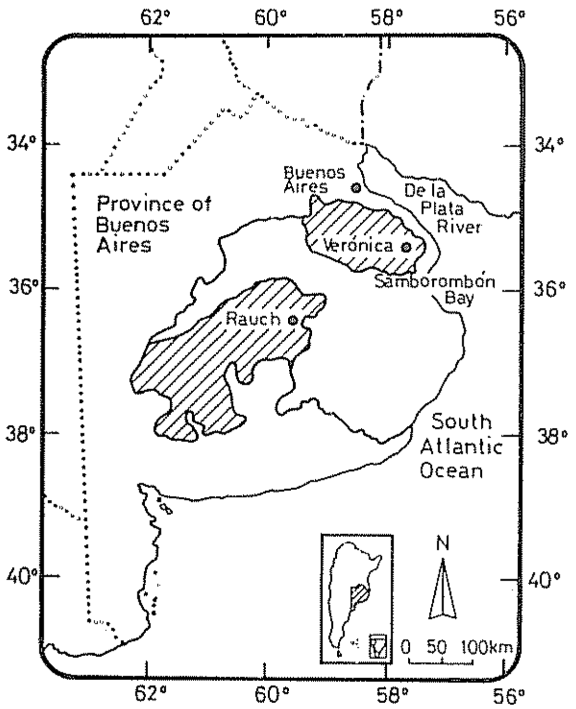

Fig. 1. Limits of the flooding pampa. Locations studied, areal distribution of each basin.

Sampling and Analysis

In each location, the A1 horizon (where most grass roots are located, according to Doll and Deregibus) (15) and the B21t horizon, the more clayey natric one, were sampled seasonally. An average of eight samples in the top horizon and four in the subsoil were taken on each date. Other soil horizons were sampled with less frequency.

Three treatments were applied in both sites:

a) Continuous grazing. This is the usual way livestock is raised in the region. This treatment began in an undefined past, as with the European settlements pushed the frontier toward the south in the last century.

b) No grazing; enclosure of 2 ha. After several years of grazing exclusion, these grasslands tend to show attributes of the original cover (21). It could be considered to resemble the behavior of the original soil.

c) Rotative grazing. This consists of short periods of high grazing pressure, followed by long periods of grassland rest. The grazing pulse is applied four times a year.

Treatments b) and c) started from a continuously grazed field. In both sites, plowing data ave unknown. In Veronica, the study began in July 1986 and in Rauch April 1987, lasting 30 months in both sites.

The following analyses were performed: soil water content (gravimetric), pH in paste, and electrical conductivity (EC) in soil saturation extract. Soluble cations by atomic absorption spectrophotometry and soluble anions by titrimetry were also determined (16). Sodium adsorption ratio (SAR) was calculated from soluble Ca, Mg and Na data (16). For both locations water infiltration rate (IR), double ring method, was determined (9) and processed using the Kostiakov equation. The depth of the water table was recorded and samples were extracted. In the groundwater, pH, EC and soluble anions and cations were also determined. The results were statistically analyzed by ANOVA. Rainfall and the potential evapotranspiration (Thornthwaite) data were obtained from records of the National Meteorological Service.

RESULTS

Water dynamics

Annual rainfall was below average in Veronica during 1986 (874.0 mm), but was normal in 1987 (958.0 mm). Precipitation was well above average (1418.5 mm) during 1988, but within recorded extremes. In Rauch, rainfall in 1987 and 1988 was above the historical mean (1128.0 mm and 948.0 mm, respectively), but in 1989 it was below the average (722.0 mm). The potential evapotranspiration followed a more regular yearly pattern. The maximum values were 124 mm and 126 mm in January, and the minimum were 21 mm and 18 mm in June, in Veronica and Rauch respectively.

In Veronica, the water table was found at a relatively shallow depth (average 1.15 m) as in other discharge areas in this part of the region. There was no direct relation between rainfall and water table depth (Fig. 2). Electrical conductivity of this water was almost constant (average 1.20 dS/m). In Rauch, the water table depth and salt content showed extreme variations above the shallow impervious *caliche* crust; as of September 1988, the observation well did not show water (Fig. 2).

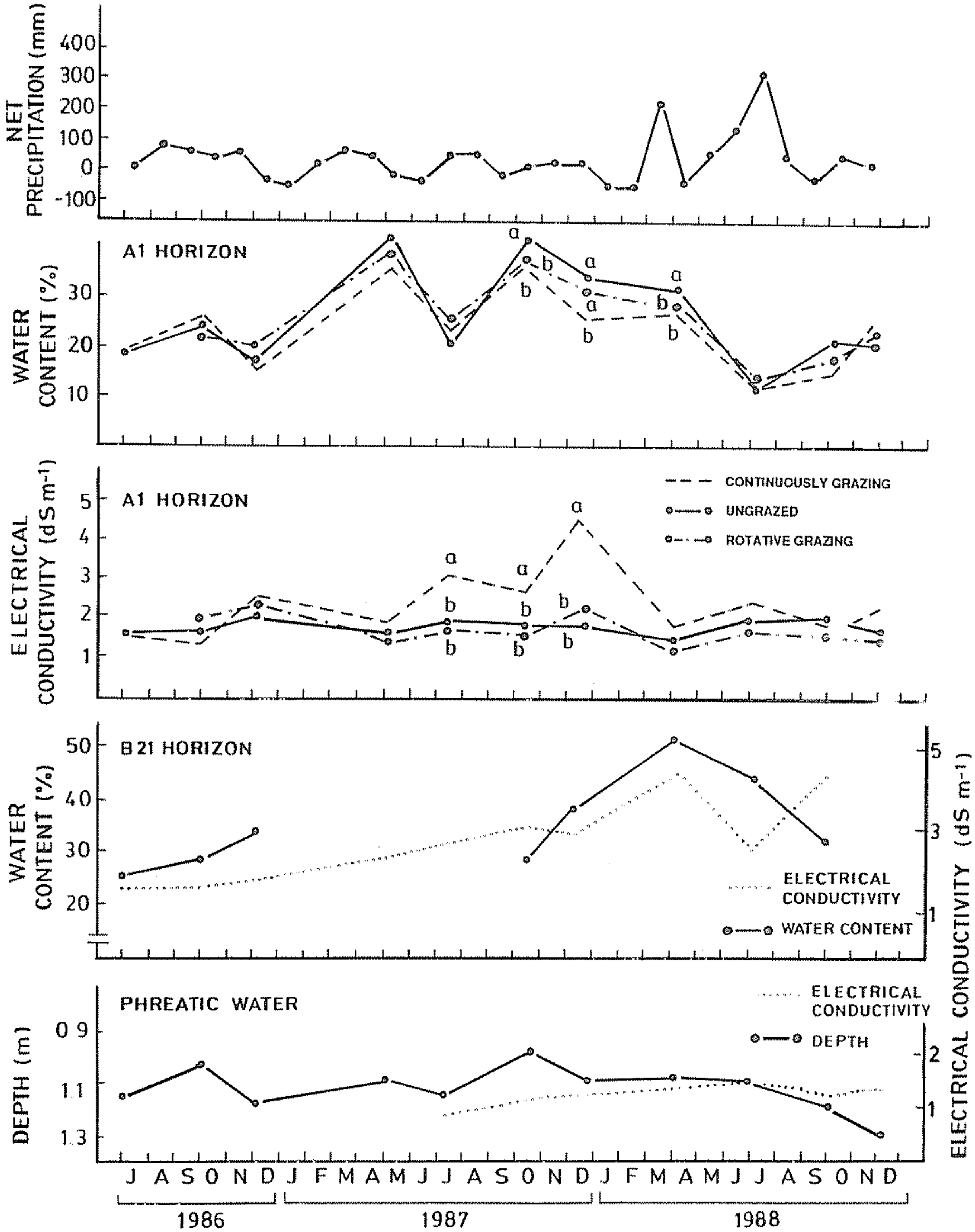

Fig. 2. Net precipitation (mm); water content (%) and electrical conductivity (dS/m) in A1 in the three treatments; average water content (%) and electrical conductivity (dS/m) in the B21 horizons; depth (cm) and electrical conductivity (dS/m) in the water table, through the study period. Location: Veronica.
Letters mean statistical differences among treatments, at each date.

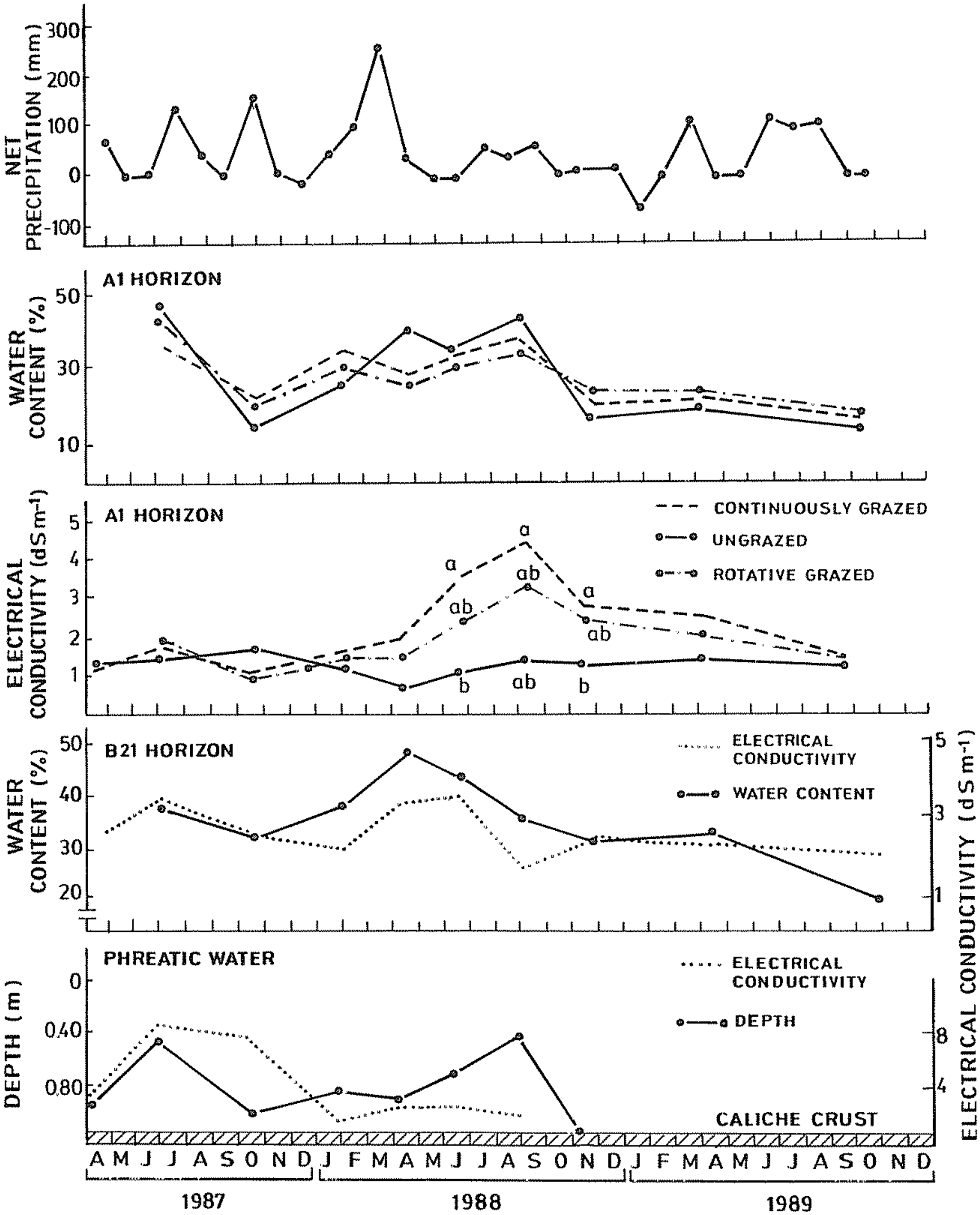

Fig. 3. Net precipitation (mm); water content (%) and electrical conductivity (dS/m) in A1 in the three treatments; average water content (%) and electrical conductivity (dS/m) in the B21 horizons; depth (cm) and electrical conductivity (dS/m) in water table, through the study period. Location: Rauch. Letters mean statistical differences among treatments, at each date.

At Veronica, soil water content was not generally related to either the rainfall or the net precipitation (difference between rainfall and potential evapotranspiration (Fig. 2). For instance, the lowest soil water content was observed during the wet 1988 winter. The low IR found in this site (averaging 0.29 cm/h during the study period) could justify the absence of such relationship. On three continuous sampling dates (October 1987 to April 1988), significant differences in soil water content for the treatments were found, the grazed one having the lowest values. The rotative grazing was close to no-grazing treatments (Fig. 2). In Rauch, the annual evolution in soil water content (Fig. 3) was not related to the net precipitation. No significant differences in water content between the three grazing treatments were found in this location. In this site, the IR showed large variations within treatments (ranging from 0.07 cm/h to 0.61 cm/h). The B21 horizon also did not show differences in water content between treatments (Fig. 3).

Salinization processes

Considering the A1 horizon of the soil at Veronica, only the Ec of the grazing treatment showed significant variations between dates (Fig. 2). On three dates, the EC under grazing was significantly higher than in the no-grazing treatment. In the rotative grazing treatment, there were also no salt fluxes to the soil surface. The EC of the B21 horizon (Fig. 2) showed no differences between treatments, though a trend to increase was found during the studied period. The cause of this increase, however, is not clear at present.

In the Rauch site, the A1 horizon under the no-grazing treatment showed no changes in EC with time, but the top-soil of the area under continuous grazing showed increases in EC on some dates (Fig. 3). Rotative grazing was intermediate between the other two treatments. The B21 horizon did not show differences between treatments, but showed variations in EC, with no definite trend (Fig. 3).

Alkalinity characteristics

The phreatic water at Veronica is rich in bicarbonates and sodium (average 14.79 mEq/l and 16.26 mEq/l, respectively) and contains soluble carbonates (average 0.84 mEq/l). Other anions and cations were found in small concentrations. In agreement with its chemical composition, the ground water showed high SAR (52.8), and pH was also high, usually around 8.4 - 8.5. At Rauch, the chemical composition average of samples taken in 1988 showed no predominance among HCO3-, CO3= and SO4= (4.75 mEq/l; 4.43 mEq/l and 5.23 mEq/l, respectively). Sodium predominated among cations (16.26 mEq/l). The rest of the ions were found in small concentrations. The SAR average was 27.20 and the pH of this groundwater varied between 8.2 - 8.4.

Table 2. Sodium adsorption ratio (SAR) in A1 horizons, through the study period.

	Veronica				Rauch		
Date	Cont. grazed	Ungrazed	Rotat grazed	Date	Cont. grazed	Ungrazed	Rotat. grazed
10-86	30.5 a	30.4 a	———	04-87	7.8 a	8.6 a	———
12-86	51.5 a	49.1 a	48.8 a	07-87	19.9 a	11.9 a	———
05-87	65.6 a	47.8 b	38.2 b	02-88	39.5 a	24.2 ab	16.2 b
07-87	68.9 a	51.9 b	34.7 b	06-88	28.0 a	13.3 b	20.7 ab
10-87	62.3 a	40.8 b	35.6 b	04-89	17.4 a	13.8 ab	11.4 b
12-87	82.5 a	49.2 a	38.2 a	10-89	8.1 a	5.2 a	7.6 a
04.88	41.6 a	44.2 a	48.4 a				
07-88	50.6 a	50.0 a	44.7 a				
10-88	47.4 a	42.4 a	39.6 a				
12-88	37.7	38.9	36.8				

Different letters mean statistical differences ($P < 0.05$) among treatments (at each location), at each date.

In Veronica, the SAR values of the A1 horizon were very high, Table 2). In the grazing treatment, there were statistically significant peaks parallelling those of EC, and the correlation between both parameters was high (r: 0.79 P: 0.05). The SAR and pH values in all the deep horizons were high. In Rauch, SAR of the A1 horizon showed lower absolute values (Table 2), and it was less related to EC. All the B horizons had higher pH values (around 9.0), similar to Veronica, but with lower SAR values (average 24). At both sites, the SAR values of the A1 horizons under rotative grazing was close to that of the no grazing treatment (Table 2).

DISCUSSION

At Veronica, salinity increased in the top-soil of the grazed treatment in spring 1987, and was coincident with soil water content differences between treatments in that season, low net precipitation and the increasing salt content in the bottom of the profile (Fig. 2). In a parallel study on the effect of grazing on the grassland vegetation, differences in accumulation of litter and standing dead material among treatments were found (Deregibus and Ansin, in preparation). On average, bare soil accounted at that time for 5% and 35% of the surface in the non-grazed exclosure and in the grazed field, respectively. There were some seasonal variations in soil cover, and the lower figures were recorded in autumn.

These results are in agreement with other local studies, which show large differences in soil coverage according to the grazing history. Lavado and Taboada (13) compared a grazed *versus* a non–grazed situation, and observed that water evaporation was ten times that

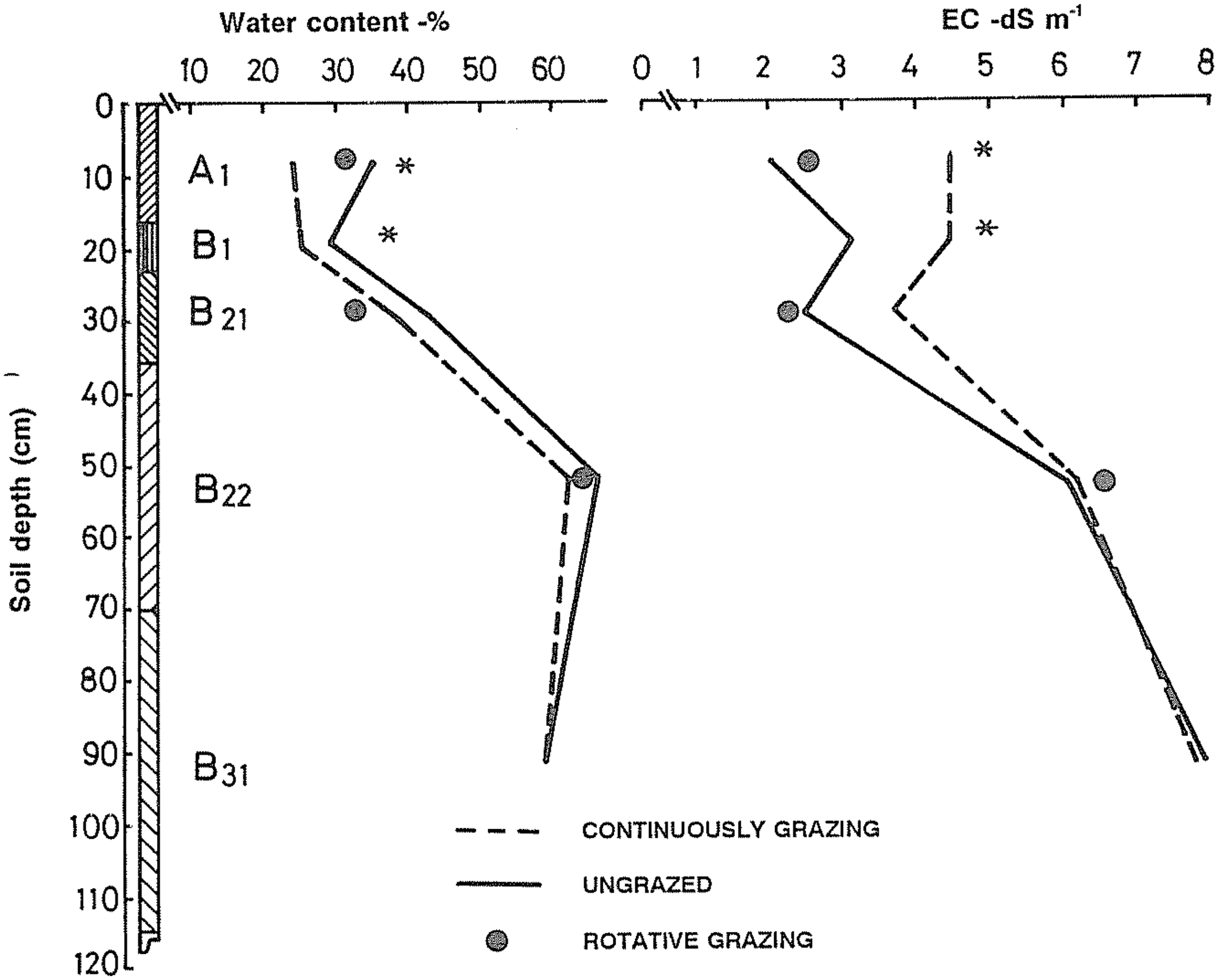

Fig. 4. Soil water and salt changes at Veronica, summer 1987. Letters mean statistical differences among treatments.

of a non-grazed soil. A direct consequence of this was an increase in the flux of water and salts from deeper horizons. Fig. 4 shows changes in the water and salt regimes along the whole soil profile. The decrease in water content in the top horizons of the grazed field is related to a higher evaporation rate. These results indicate a movement of water towards the upper soil horizons and the deposition of salts in top-soil under grazing. In summer 1987, horizons below the B21t horizon in the three treatments had the same water and salt content.

At Rauch, on two dates (July 1987 and September 1988), The water table in the observation wells was near the surface (Fig. 2). However, the water table in the field was confined by the B2 horizons, which acted as a barrier, as it was found in other soils of the region (14). In a parallel study, Rossi *et al.* (18) found changes in live and dead biomass between the grazed and ungrazed treatments.

The resultant percentage of bare soil was 30% in the grazed field and 7% in the exclosure. This represents a seasonal variation similar to that observed in Veronica, where salty peaks also appeared in the less-covered soil. However, it can not be related to the soil water content, since it was equivalent in both treatments. The salt ascent was found in winter-spring in this soil, but the salt ascent period coincided with a period of lower or even negative net precipitation (Fig. 3). Topsoil salinization took place in a period with very shallow phreatic water, but with low salt content. Salts transported by upward moving water came from the salinized deep horizons (Fig. 3) which were more saline than the phreatic water on this date (Fig. 2). In both locations, the IR played no important role and the water evaporation from bare soil was the main cause of soil salinization. The rotative grazing area behaved similarly to the no-grazing treatment, or was intermediate between it and the continuous grazing.

In both locations, differences in SAR among treatments were observed earlier, than differences in EC; no explanation is for this offered. The large changes in SAR found in Veronica top-soil did not affect soil pH; it averaged 8.4. In Rauch, the average pH of the A1 horizon was 8.2. In this location, no differences were found in the soil for different dates and treatments. In both locations, the SAR in rotative grazing was also close to the values observed for the no-grazing treatment.

CONCLUSIONS

In Veronica, salt ascended to the soil surface by pulses. The mechanism of salt movement was convection from the deep horizons, under a permanent shallow water table. The increase in salt content in the grazed topsoil was related to a decrease in water content. In Rauch, salts rose from salinized deep horizons, but only when the water table was near the soil surface. There were no differences in water content between treatments in this location.

Despite environmental and soil differences, grazing was a key factor affecting top soil salinization. In both soils, the salt content of the A1 horizon in areas under continuous grazing showed episodical increases in salt content. Grazing initiates the process through the reduction of the soil cover and the increase of water evaporation. These salt pulses, together with those previously found in a Natraquoll in a nearby basin and those resulting from the soil salinization process, allow us to conclude that salinization of the top horizons could be generalized as another effect of grazing on soils.

The rotative grazing area behaved similar to than the no– grazing treatment or was intermediate between it and continuous grazing. This is an important finding because, seen from the aspect of salinity, rotative grazing could be the basis of an ecologically sound grazing management technique.

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