Soil salinization as an effect of grazing in a native grassland soil in the Flooding Pampa of Argentina

Raul S. Lavado[1] & Miguel A. Taboada[1]

Abstract. The salt regimes in soil under grazed and ungrazed natural grassland were compared on a Natraquoll in the Flooding Pampa of Argentina. The salt concentration in the topsoil of the grazed land increased sharply and episodically after flooding, whereas in the ungrazed land it did not.

When the area was flooded groundwater rose and increased the salt content of the deep horizons. Thereafter the topsoil became salinized during drought when the atmospheric water demand was large. The evaporation from the soil surface in the grazed area was faster than in the enclosed field, being probably the cause of the accumulation of salts in the topsoil.

INTRODUCTION

THE SUBHUMID portion of the Pampean plain is fertile temperate cropland where only the Flooding Pampa (a subunit of 90000 km^2; Fig. 1) remains as natural grassland (León *et al.*, 1985; Sala, 1987). This very flat lowland has two important characteristics. First, large parts of it are covered by Natraquolls (US Soil Taxonomy): they have a high water table and most of the soils are affected to varying degrees by salts and sodium (INTA, 1977). Secondly, the region floods. Floods occur mainly in winter as a result of long periods of rain when the soil is already wet and the groundwater is near the soil surface. Due to the lack of a natural drainage network and the low hydraulic conductivity of most soils, particularly in the B2 horizon, the upper soil profile is quickly saturated with water and surface ponding occurs. Some of the flood water drains into the two rivers of the region (Samborombón and Salado rivers) and some to man-made channels that flow to the Atlantic Ocean, some infiltrates and some evaporates. In the area where this project was carried out floods occur in almost all years and last from a few days to several months. The vegetation of the region is a mosaic of grassland communities whose distribution is related to the soil properties (León, 1975), salinity and alkalinity being the most important (Berasategui & Barberis, 1982). The average annual rainfall for the Flooding Pampa is 900 mm, although it is more (1000 mm) in the area under study.

Since the introduction of cattle, sheep and horses by the Spaniards in the 17th century grazing has gradually increased. Most of the area is now devoted to the production of beef cattle which graze the natural pastures all year round. The effect of grazing on the original grassland has been considered by several authors (Ares & León, 1972; Sala *et al.*, 1986), but the effect on soil properties has only recently been studied. Grazing causes decreases in infiltration rate (PBA-CFI, 1980) and temporarily increases bulk density (Taboada & Lavado, unpublished work), but it does not influence other soil components such as organic matter, total nitrogen and available phosphorus (Lavado & Taboada, 1985). These results resemble those obtained elsewhere on grazed grassland soil (Parton & Risser, 1979). On the other hand, Lavado & Taboada (1985) observed that salinity, and to a lesser extent alkalinity, were less in the soil of the ungrazed area that in that of the grazed area.

Several years ago Jackson *et al.* (1956) found in Australia that different salt concentrations in the soil surface resulted from varying depths to groundwater and its different salinities. Soluble salts regularly moved upward through the soil profile during spring and summer and down during the rainy season. They also suggested that soil surface salinization is likely to occur in some temporarily waterlogged soils under heavy grazing. Taking into account the already mentioned environmental conditions of the Flooding Pampa, in which the halomorphic features of most soils are related to groundwater (INTA, 1977), and the previous observation of less salinity in ungrazed areas, we aim in this paper to consider the characteristics of salinization in grazed and ungrazed soils and to report the results of an experiment on the processes involved.

MATERIALS AND METHODS

Soil and vegetation

The experiment was performed on a typical Natraquoll, General Guido Series, located on a flat area 13 m above sea-level in the geographical centre of the Flooding Pampa (Pila county, Province of Buenos Aires; Fig. 1). This part of the region is floored by Quaternary marine sediments, and these are overlain by a thick layer of loess-like materials in which the soil is formed. The area is covered by a native grassland community characterized by *Piptochaetium montevidense, Ambrosia tenuifolia, Eclipta bellidioides* and *Mentha pulegium* (León, 1975). Both soil and vegetation are representative of the area.

[1]Departamento de Ecología, Facultad de Agronomía, Universidad de Buenos Aires, Avda. San Martín 4453, (1417) Buenos Aires, Argentina.

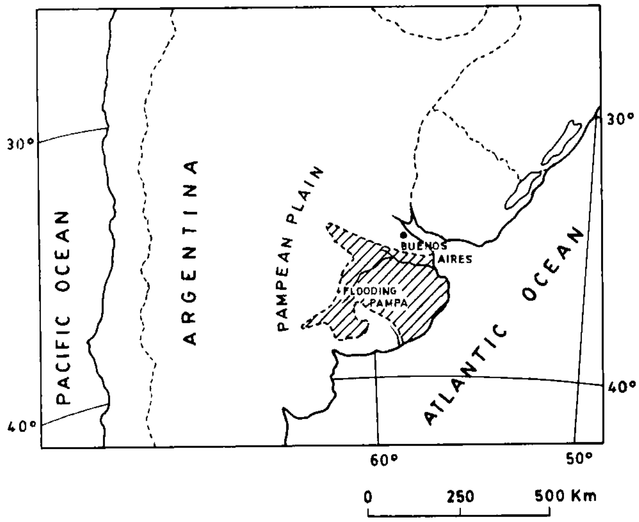

Fig. 1. Geographic location of the Flooding Pampa and the approximate extent of the Pampean Plain.

There were two treatments: (i) Grazed, in which the natural open grassland had been grazed all year round for more than a century at an usual stocking rate of 0.5 cattle ha^{-1}; and (ii) enclosed, which had not been grazed since 1976. The enclosure of 4 ha was surrounded by the grazed field. The grazed field and enclosure developed different plant community structures and species composition. The plant cover varied from 100% in the enclosure to 70% in the grazed area (Sala, 1987; Sala *et al.*, 1986). In the latter the bare soil surface was finely distributed and cattle trampled both the bare and covered soil.

Sampling and analysis

Sampling was performed monthly from April 1983 to August 1985, except July 1983 and January and June 1984. During this period there was a flood (from July to November 1984) and a summer drought (from December 1984 to March 1985). Five samples from the A1 horizon and two from the B horizons were taken at random each month from each treatment. In May of 1983, 1984 and 1985 10 samples from the B31 depth were also taken at random.

The soil profile was described and its main properties were determined by standard methods: clay (pipette), calcium carbonate (manometrically), organic carbon (Walkley & Black), pH (paste). The exchangeable sodium percentage (ESP) was calculated from the sodium adsorption ratio (SAR), which was obtained from the concentration of Na^+, Ca^{2+} and Mg^{2+} in saturation extracts (atomic absorption spectrometry). The monthly soil samples were analysed for salinity by measuring the electrical conductivity (EC) of the saturation extracts and for gravimetric water content. In January and February 1985 (full summer) the temperature of the soil at 4 cm depth was measured. The rate of evaporation from the surface of bare soil was measured using microlysimeters containing undisturbed soil cores that were taken immediately before measurements (Boast & Robertson, 1982).

The microlysimeters were 10 cm in diameter and 10 cm in depth and there were seven replicates in each treatment. They were placed in small areas free of plants in the grazed field, and among tussocks in the enclosure. The litter layers were maintained in both cases. Mean evaporation rates over 24 h were measured twice monthly. The depth of the water table was recorded monthly in two water table wells. One was located inside the enclosure and the other nearby in the grazed field. Water samples were taken bimonthly using a standard device and kept cold until their EC could be determined within 24 h.

RESULTS AND DISCUSSION

Soil profile description

The characteristics of the soil profile (soil horizons and their depths), colours, exchangeable sodium percentage (ESP), clay %, pH and organic carbon are shown in Fig. 2. Measurements of other properties of this soil have been

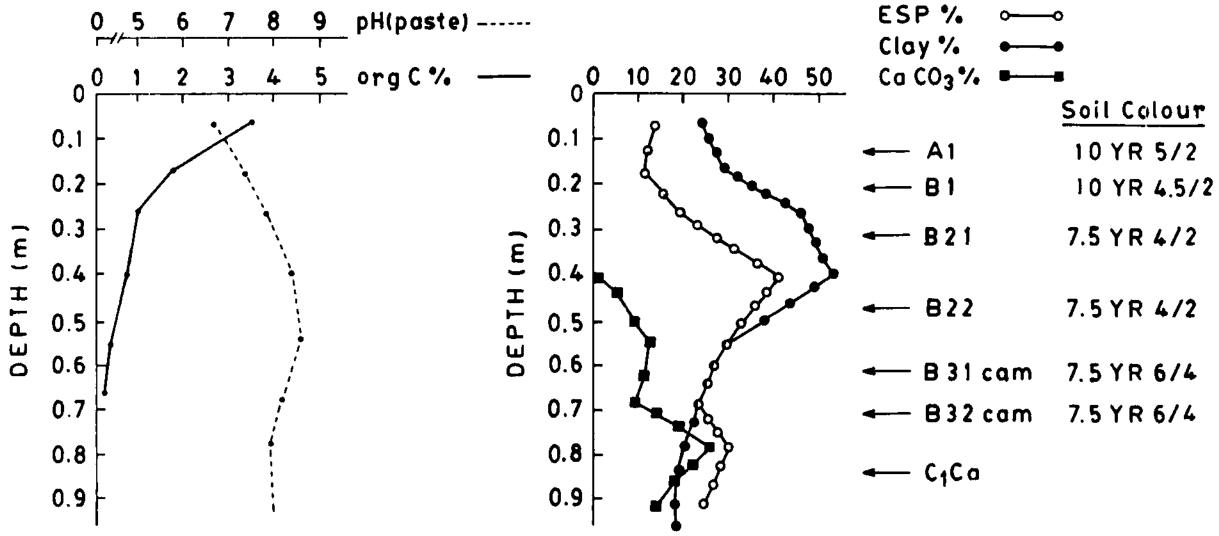

Fig. 2. Description of the soil profile and its main properties.

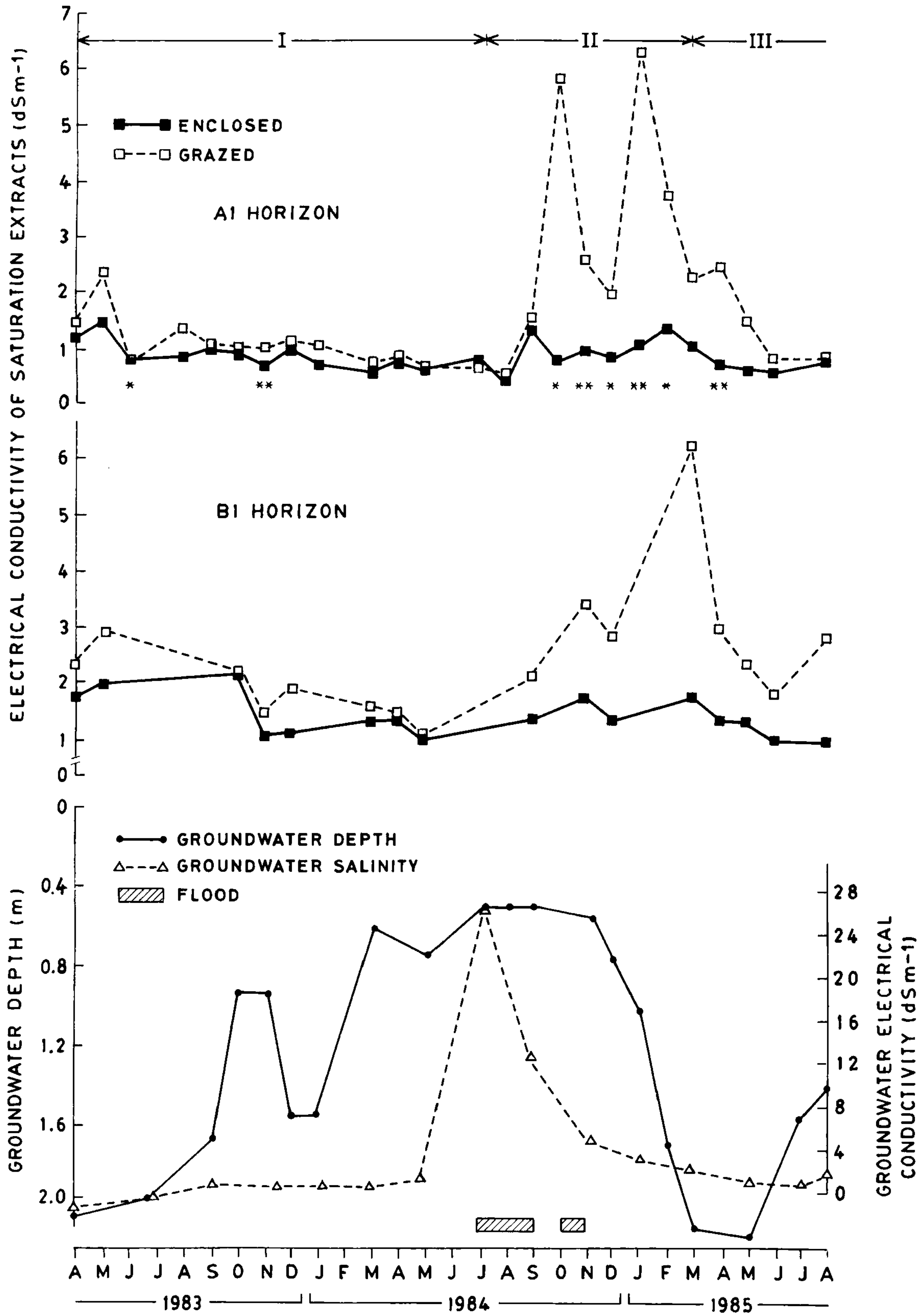

Fig. 3. Soil salinity measured as electrical conductivity (EC) in the A1 and B1 horizons, depth and EC of groundwater and flood periods. *: significant differences between treatments ($P \leq 0.05$). **: highly significant differences between treatments ($P \leq 0.01$).

published elsewhere by Berasategui & Barberis (1982), Lavado & Taboada (1985), and Taboada & Lavado (1986).

Topsoil salt regime

The electrical conductivity of the A1 horizon for both grazed and ungrazed fields is included in Fig. 3. The graph may be divided into three periods:

Period I. The values of EC during this period were generally small and declined under both treatments from April 1983 to May 1984. This decline was more than 100% in the grazed field and about 70% in the enclosure, and the overall change between the beginning and the end of this period was significant for both treatments. Salinity in the enclosure was less than that outside.

Rainfall during this period was 1555 mm, and the excess rain leached the salt by percolation through the soil. The differences in infiltration rate between a grazed and ungrazed field measured in another enclosure nearby (PBA–CFI, 1980) do not seem to affect the leaching of salts, as in both situations there was a similar decrease in the electrical conductivity of the soil.

The water content of the topsoil changed during this period. In the enclosure it ranged from 0.17 to 0.41 g g^{-1}, and in the grazed field from 0.14 to 0.36 g g^{-1}. Groundwater rose at the end of this period (Fig. 3), but its electrical conductivity was always small, averaging 1.05 dS m^{-1}.

Period II. A typical flood started in July 1984, covering the ground (both grazed and ungrazed fields) with 3 to 10 cm of water. It ended in September, but in October a second and shorter flood occurred which lasted until November 1984. Because the flood came directly as rain the EC of the flood water was small (0.47 dS m^{-1} on average). When the flood started the water table depth averaged 0.60 m in both wells and showed an abrupt increase in EC (Fig. 3). The changes in the height and the EC of the groundwater occurred over the whole area, the enclosed field being too small to affect the water table depth. Schlichter & Perelman (1985) showed that in this area the main cause of the rise in the water table is the local rainfall, but the sharp increase in its salt content during floods indicates the occurrence of other processes. It is possible that much of the salt derives from the deep marine sediments at these times, and it then increases the salinity of the deep soil horizons. For instance, the electrical conductivity in the B21 horizon averaged 2.10 dS m^{-1} in July, 4.80 dS m^{-1} in August, and 6.70 dS m^{-1} in September.

Table 1. Topsoil temperature and soil evaporation rate in January and February 1985. UG: ungrazed enclosure; G: grazed land

Months	Soil temperature range (°C) UG	Soil temperature range (°C) G	Evaporation rate (mm day^{-1}) UG $\bar{X}$	UG cv%	G $\bar{X}$	G cv%
January	22.8–25.5	26.4–32.7	0.19	93.12	2.13**	43.89
February	17.7–23.9	21.5–30.4	0.39	81.65	1.79**	30.11

$\bar{X}$: mean values, cv: coefficients of variation.
**: highly significant differences between treatments ($P \leq 0.01$).

During the flood the soil surface maintained its small salt content. When the first flood receded in September, however, the upper soil horizons under the two treatments behaved differently. In October the electrical conductivity of the topsoil in the grazed area increased, while the ungrazed soil showed no significant change in EC. It seems that some capillary flux may have occurred in the grazed field. This large salt content in the A1 horizon was partially diminished by the second flood caused by a further 226 mm of rain, and a later rainfall in the subsequent months (173 mm). However, because of the summer drought that followed, a new maximum in the EC was observed in the grazed field, but not in the enclosure. The salts did not come from the groundwater directly (the water table had dropped to a depth of 1.60 m) but from the salinized deep horizons. From January to March 1985, rainfall totalling 114 mm depleted the A1 horizon of salts.

In this very flat area (slope only 0.0016%) runoff is assumed to be almost negligible, and transpiration rates through the plant canopy were probably similar between treatments because the green leaf area index of this grassland is not affected at the usual stocking rate (Sala, 1987).

The topsoil temperature and evaporation rate measurements are shown in Table 1. Temperatures measured in the grazed field were always higher and had larger daily variations than those of the ungrazed area. Water losses by evaporation were also greater in the grazed field. Evaporation rates measured in the ungrazed area had very

Table 2. Soil water contents (g g^{-1}) during the drought period, from November 1984 to April 1985. UG: ungrazed enclosure; G: grazed land

Soil horizons	A1				B1				B21			
Treatments	UG		G		UG		G		UG		G	
	$\bar{X}$	cv%	$\bar{X}$	cv%	$\bar{X}$	cv%	$\bar{X}$	cv%	$\bar{X}$	cv%	$\bar{X}$	cv%
November 1984	0.452	5.20	0.419	10.10	0.511	0.89	0.371	13.90	—	—	0.475	0.57
December 1984	0.238	11.02	0.203	9.47	0.278	11.10	0.220	1.73	0.342	12.73	0.377	13.15
February 1985	0.113	10.19	0.093	11.90	—	—	0.122	0.86	—	—	0.177	13.81
March 1985	0.116	8.02	0.088	10.35	0.122	6.11	0.094	8.86	0.213	6.75	0.165	16.90
April 1985	0.342	10.35	0.272	10.08	0.290	0.16	0.243	1.93	0.427	7.70	0.402	6.20

$\bar{X}$: mean values, cv: coefficients of variation.

large coefficients of variation among replicates, nevertheless they were all significantly less ($P \leq 0.01$) there than in the grazed field. The differences in evaporation rate during the drought caused the water content of the topsoil in the grazed area to decrease by 0.09 g g^{-1} by March 1985 compared with 0.12 g g^{-1} in the enclosure (Table 2). Although the soil water content depends on several factors, the differences in evaporation rate can be regarded as one of the main causes for the differences in soil water content between treatments (Parton & Risser, 1979; Sokolenko, 1984). Relatively fast evaporation in the grazed field is probably the cause of the accumulation of salts in the topsoil.

The lack of salinization in the enclosure may be explained because the fenced field had an important surface litter layer plus standing dead material. For example, in a 5-year-old enclosure the litter amounted to 1300 kg ha^{-1}, compared with 600 kg ha^{-1} in the grazed area (Fonseca *et al.*, 1976). This layer acts as an effective mulch which reduces the upward flux of water. The influence of mulches on soil water movement and on the accumulation of salt at the surface has been shown in several papers (Benz *et al.*, 1967; Hillel, 1980; Smith & Stoneman, 1970). Some authors (cited by Bakker, 1985) found increases in salinity due to evaporation in grazed European salt marshes, and it therefore seems that the present case is another instance of this general process.

Period III. From April to August 1985 the total ranfall was 496 mm and further leaching of the soil occurred. The water table remained low and its salt content was small again, averaging 1.40 dS m^{-1}. In May 1985 the salt content was similar to that of April 1983 (beginning of the study), so this period represents a new leaching phase.

Soil profile salt regime

The salinization and leaching affected the whole profile. For instance, the sequence of salinization in the B1 horizon (Fig. 3) was similar to that of the A1 horizon, but displaced in time.

The electrical conductivity of saturation extracts from the topsoil to the B31 horizon depth for both treatments in May 1983, 1984 and 1985, are shown in Table 3. The decrease in EC throughout the profile in both areas between May 1983 and May 1984 reflected the salt leaching occurring along the Period I. The highly significant differences between treatments found in May 1985 reflected the remnants of the soil salinization that had developed in the grazed field in the previous months (Period II). The B31 horizon was not affected by grazing, as in any year there were differences in EC between treatments.

The salinization of the grazed land was not continuous but happened in pulses. Marine sediments are probably the original source of salts, but the accumulation of salt in the soil surface depends on two factors: the salinization of subsoil because of the rise of groundwater and its increase in salt content at the time of floods, and the upward movement of water carrying these salts to the surface when atmospheric water demand by evaporation is large. The two factors do not always combine, though they do follow more or less seasonal fluctuations. Then, the salinization seems to occur as pulses that depend on the successions of flood and drought rather than having a strict seasonal basis, as Jackson *et al.* (1956) found elsewhere. Although the subsoil of the ungrazed site also became salinized, salts were not carried into the soil surface because the litter layer checked the upward flux of water and salts. As a result only minor salinity fluctuations were detected in the topsoil.

Results suggest that soil salinization should be included as one of the effects of grazing that started when large domestic herbivores were introduced in the region. Research performed on the ecology of its grasslands (Sala, 1985) showed that the enclosure works like the primitive ungrazed ecosystem. Then, the occasional large concentration of salts observed under grazing may be one of the main effects on the natural herbaceous communities.

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Table 3. Electrical conductivities (DS m^{-1}) from the topsoil to the B31 horizon in the enclosure (UG) and in the grazed (G) areas

Soil horizons	May 1983					May 1984					May 1985				
	UG		G			UG		G			UG		G		
	$\bar{X}$	cv%	$\bar{X}$	cv%		$\bar{X}$	cv%	$\bar{X}$	cv%		$\bar{X}$	cv%	$\bar{X}$	cv%	
A1	1.48	20.35	2.38	21.24	ns	0.68	28.32	0.75	15.26	ns	0.73	7.82	1.79	47.66	**
B1	2.01	18.87	2.96	46.17	ns	1.26	25.72	1.08	23.68	ns	1.26	17.19	2.30	33.81	**
B21	2.65	20.62	3.60	37.32	ns	1.57	20.88	1.81	17.74	ns	1.31	16.67	2.54	39.65	**
B22	5.34	78.53	8.92	74.20	ns	2.64	33.77	3.23	22.99	ns	1.66	20.72	3.60	33.45	**
B31	7.98	50.15	9.13	25.08	ns	4.89	37.62	6.38	47.97	ns	2.99	41.65	4.70	37.65	ns

**: highly significant differences between treatments ($P \leq 0.01$).
ns: differences between treatments not significant ($P > 0.05$).

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Nitrogen inputs and outputs in a small agricultural catchment in the eastern part of the United Kingdom

G. Roberts[1]

Abstract. Nitrate concentrations measured in an ephemeral stream draining a 170 ha clay catchment in eastern England, with about 23% arable land, were greater than 11.3 mg N l^{-1} on the resumption of flow each autumn but then declined. There was also a spring peak in two years out of seven, 1978–1984, which depend on the length of time soils was at field capacity in the preceding winter. Mean annual load measured in rain was 19 kg N ha^{-1} and loss of nitrate in the stream 34 kg N ha^{-1}. A catchment nitrogen balance suggested that inputs, which averaged 130 kg N ha yr^{-1}, were generally more than outputs, average 108 kg N ha yr^{-1}, but gaseous losses were not taken into account.

INTRODUCTION

INCREASING nitrate–N concentrations have been evident in both surface and groundwater in many parts of the United Kingdom during the last 20 years or so (Royal Society, 1983). This deterioration in water quality has been most pronounced in the intensively farmed eastern part of the country and has occurred to such an extent that hitherto uncontaminated water supplies have had to be abandoned or else expensive treatment applied to conform to the World Health Organisation (1970) recommended limit of 11.3 mg l^{-1} of nitrate–N in potable water. The situation will be exacerbated when the UK adopts the new guidelines of the European Community (1980) which effectively halve the limit.

Although there are a number of possible reasons for these increasing concentrations, it is generally agreed that the intensification of agriculture that has occurred in many parts of the UK has been the major factor. Whilst pollution from point sources such as sewage effluents and industrial discharges is generally readily identifiable and remedial action taken, that from an agricultural source is diffuse and is not so easily controlled. Studies have shown (Young *et al.*, 1976) that ploughing old grassland releases appreciable quantities of nitrate. However, most of the conversion of grassland to arable land in the United Kingdom occurred during and immediately following the 1939–1946 war and, whilst losses from this practice are large, they are generally short-lived and are unlikely to be the cause of the recent increases in nitrate contamination. These are generally attributed to the massive increase in fertilizer usage.

The largest nitrate concentrations in streams draining agricultural land occur during the autumn and winter as the nitrogen demand of the crops is reduced and readily soluble material accumulated during the preceding summer is leached out of the soil profile. Particularly large concentrations have been observed during the first rainfall of any significance following very dry summers, the so-called

[1]Institute of Hydrology, Maclean Building, Wallingford, OX10 8BB, England.