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LEACHING OF NITRATE FROM SHEEP-GRAZED PASTURES

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Abstract

An indirect method has been used to estimate losses of nitrate nitrogen from sheep-grazed pastures on a free-draining soil. The drainage component of a soil water balance was assumed to move nitrate, at the concentration of the soil solution between 30 and 45 cm depth, to below the zone of uptake by plants.

Losses of between 60 and 80 kg N/ha were calculated to be leached from control ryegrass-clover pastures in each of the winter drainage seasons studied. More than 85% was lost by early August, even though 40% of drainage occurred after this date. Extra leaching losses in the first season appeared to account for the equivalent of 45% of either the 110 or 450 kg N/ha added in the two fertiliser N treatments. In the second season losses were less than 25%. Removal of clovers from the sward reduced leaching estimates to little more than half those below the control pasture.

Estimates confirm the large size of leaching losses under intensive grazing. These have implications for agricultural production and groundwater quality.

Keywords: Leaching, nitrate, sheep-grazed, pastures, fertiliser, nitrogen, clover-free, water balance, drainage.

INTRODUCTION

Loss of nitrogen (N) through leaching from grass-clover swards has been shown to be small where grazing animals have been excluded from the system (Karraker *et al*, 1950; Garwood et *al*. 1980). Grass plants in New Zealand (NZ) pastures are under N stress for most of the year (Field and Ball 1978) and appear to absorb N from the upper layers of the soil almost as fast as it becomes available from mlneralisation, except during drought. However, if mineral N is aggregated by sheep and cattle into excreta, urine patches in particular, pulses of nitrate move to below the zone of root uptake (Ball and Ryden 1984). Under wet conditions a large proportion of this N may be lost as nitrate in drainage water (Field and Ball 1982).

Estimates of nitrate leaching losses from NZ pastures, ranging from 90 kg N/ha/yr upwards, have been made by collecting leachate deep in the soil profile using suction devices (Goh *et al.* 1979; Steele *et al.* 1984). The study described here has taken a similar approach, but using repeated measurements of nitrate and water in soil cores combined with theoretical estimates for drainage to determine the dynamics and absolute amounts of nitrate leached from sheep-grazed pastures.

METHODS

Experimental Layout

Measurements were obtained from an experiment investigating N relationships in an established ryegrass-white clover pasture located on Manawatu fine sandy loam. The experimental layout and procedures have been described in detail elsewhere (Ball 1979; Ball *et al.* 1978). Four replicates of each treatment, in small paddocks, were periodically mob grazed by sheep. Treatments were: 1) “Control” = mixed ‘Grasslands Ariki’ ryegrass—‘G. Huia’ white clover sward; 2) “N110” and 3) “N450” = control sward receiving 110 or 450 kg fertiliser N/ha/yr, applied in split dressings of lime-ammonium nitrate (21-26% N) between late autumn and early summer; and 4) "Grass" = control sward with clovers removed.

Soil Water and Nitrate Measurements

Soil water was measured gravimetrically throughout the experiment, on average every 16 days. Eight soil cores were removed per paddock with a 25 mm diameter sampler to a depth of 300 mm from May 1972 until April 1974; and to 450 mm thereafter, until August 1975. From May 1974 sub-samples were taken from the bulk sample for mineral N analyses prior to drying. Each nitrate measurement used in this analysis was derived from 32 cores.

Estimation of Drainage

Drainage was estimated from a soil water balance for a level area of Manawatu silt loam, following the methods described by Kerr and Clothier (1975; Appendix 1). Soil water in the top 300 mm was used to evaluate water balance estimates, as measured values were available for 3 years. Drainage events from below 450 mm were identified for leaching estimates for the last 15 months of the experimental period, from May 1974 onwards, using a water balance to 450 mm depth. It was assumed here that drainage carried nitrate to below the root zone, under leaching conditions, solely by mass flow. Laboratory tests indicate no potential for immobilisation or denitrification at depth in this soil (Ball, unpubl. data). Although research on this point is still ongoing, there is no evidence for appreciable uptake of nitrate by plants from a depth greater than 450 mm in a productive pasture.

Estimation of Nitrate Leached

The quantity of nitrate leached was calculated as that contained in the water draining below 450 mm at the concentration measured in the soil solution at 300-450 mm by Ball (1979). Nitrate levels for any drainage event were interpolated between successive samplings allowing for cumulative drainage.

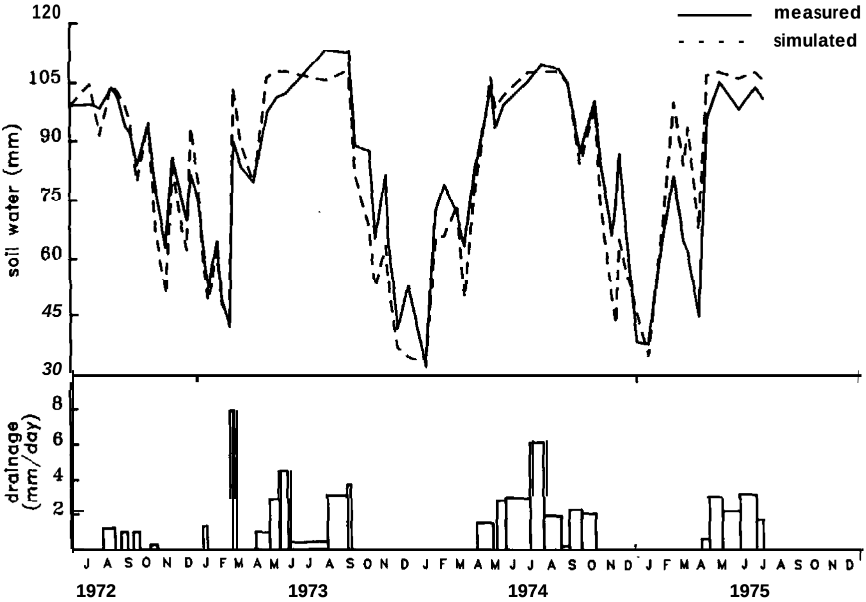

Figure 1: Measured (solid lines) and simulated (dashed lines) soil moisture to 300 mm depth (mm) and estimates of drainage (period means in mmlday).

RESULTS

Soil Water Balance and Drainage

Measured and simulated soil water contents (Fig. 1) were similar (R^2 = 0.83). Simulated values indicated more rapid drying and rewetting of the soil to 300 mm than was measured. Water balance estimates assume that during drying all water for evapotranspiration is extracted from above 300 cm depth, whereas pasture plants extract water from below this depth on this soil type (Evans 1978), and that during rewetting water is retained above 300 mm until field capacity is attained. Uneven infiltration of incident water in the field results in early movement to below 300 mm because of surface redistribution (Cook 1983) and movement through macropores (Scotter 1978).

The yearly pattern of drainage (derived from the water balance) varied with rainfall. The main drainage period from the top 300 mm commenced in May each year, with minor drainage indicated in March of 1973 (when 133mm rain fell in the week ending 15 March) and 1974. One drainage event occurred in late December 1972, but drainage would normally be expected to finish in September (1973) or October (1974). Total drainage predicted for the complete years of 1973 and 1974 was 350 mm and 485 mm, respectively, in years of 890 and 1170 mm total water receipt. Drainage from 450 mm showed minor differences from the pattern described for 300 mm only during the first leaching period in 1975, when the 300-450 mm layer was being recharged.

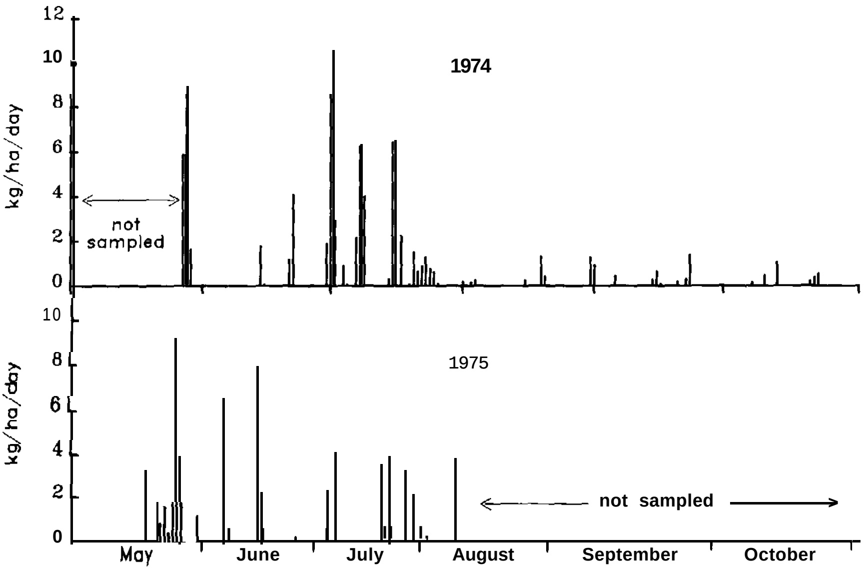

Figure 2: Estimates of occurrence and quantities of nitrate leaching from the root uptake zone in control pasture (kg N/ha/day).

Estimates of Nitrate Leached

The pattern of nitrate leaching from the top 450 mm of soil below the control pastures is shown in Fig. 2. In both years losses of nitrate were steady until the end of July. Some 280 mm of drainage would have flushed the topsoil by early August 1974 and 250 mm by the last sampling in early August 1975. Therefore it is likely that the same leaching pattern would have recurred in August-September 1975, with only an additional 10-15% of nitrated leached in all treatments before drainage ceased.

Table 1: ESTIMATED MEAN NITRATE LEACHING (kg N/ha) FROM CONTROL PASTURE AND THREE MANAGEMENT TREATMENTS.

Control	N110	N450	Grass
	22 May – 1 November 1974		
77.5	128.9	279.3	36.6
	5 May – 4 August 1975		
67.7	72.4	163.8	46.3

Addition of fertiliser N increased estimated leaching loses (Table 1). In 1974, at both fertiliser rates, leaching increased by the equivalent of about 45% of added N. In 1975, a year with lower winter rainfall (370 vs 530 mm, May-August), there was little increase in N loss from N110, and an estimated additional loss equivalent to only around 25% of applied N in N450. By contrast, removal of clovers from the sward substantially reduced the quantity of nitrate leached in both years, to little more than half that below the control pasture.

DISCUSSION

Water Balance Model

The total amount of drainage estimated for the full years was in the typical range measured with a lysimeter near the experimental site. While some discrepancies were encountered (Fig. 1), agreement between simulated and field values was good during the early winter period of both years. It was then that we have estimated the main leaching events took place.

Main Treatment Effects

Under conditions of N shortage, the amount of N lost by leaching should be proportional to the quantity cycling within the ecosystem, especially through the animal. Taking herbage N yields as an indicator of N ingested, the proportion of N cycling through the animal estimated to have been lost by leaching from the clover-free pasture was within 1% of that from the control (14%).

Addition of fertiliser N to grass-clover systems both increases production and the N concentration in herbage (Ball 1979). Nitrogen becomes more loosely held in the ecosystem and more susceptible to loss. Field and Ball (1982) estimated from a N model for dairyfarming that following fertiliser application (100 kg N/ha in split dressings) leaching losses increased by 28 kg N/ha, which is intermediate to the increases estimated here for N110 (Table 1). Neither of these studies was able to separate the indirect effect of increased N flow through urine resulting from increased N concentration in herbage (Henzell and Ross 1973) from the direct effect of soil mineral N enrichment, as causes of nitrate leaching.

Results from the present study for the N450 treatment (and for N110 only during the wetter winter) show that leaching losses are less directly tied to stocking rate when soil and herbage N levels are substantially increased by fertiliser N. Relative to control, sheep grazing days increased by less than 20% in N450, while leaching estimates increased by up to 360% (Table 1). Similarly, large leaching losses were estimated from beef-grazed pastures (Steele et *al.* 1984), where 105 extra kg nitrate-N was reported leached following application of 170 kg fertiliser N/ha in three dressings, even though stocking rate was unchanged between treatments. However, nitrate is not generally found in water draining below cut swards, even where substantial quantities of fertiliser N have been applied (Ryden et *al.* 1984). So we must conclude that grazing animals indirectly cause these exaggerated leaching losses.

Cur estimates for leaching from a ryegrass-white clover pasture without fertiliser N (60 to 80 kg nitrate-N/ha/yr) lend support to the annual loss of 90 kg nitrate-N/ha/yr reported by Steele et *al* (1984) from a similar pasture in Northland. Limitations in the data available to us have meant that our estimates are conservative, perhaps by 10% or more. Nevertheless, results from either study are cause for considerable concern. They are very much larger than annual values of 10 to 25 kg N/ha being used by the Ministry of Works and Development planners for assessing the impact of alternative agricultural practices on nitrate contamination of underground water supplies (Burden 1982).

Patterns of Leaching

Most nitrate was leached to below the plant uptake zone in late autumn and winter. This nitrate had accumulated in the soil profile under dry conditions, during summer and early autumn. Nitrate concentrations below fertiliser N treatments were two-(N110) to four-fold (N450) those below the control, at individual samplings over the May-June period in 1974 (Ball 1979). Little difference persisted among these treatments from August through to November. In 1975, nitrate levels in the soil solution were similar below both control and N110 pastures.

The pattern of leaching from control pastures, predicted here, is similar to that observed in the study by Steel and co-workers in Northland, where leaching from the control pastures peaked in June-July. However, nitrate concentrations in drainage below their N-topdressed pasture peaked later, during August-September, and high levels persisted through to November, despite drainage in each of these months. We conclude that most of the nitrate leached over the August-November period in the Northland study must have arisen almost directly from fertiliser applied in two dressings in late winter and early spring. By contrast, even at the highest fertiliser rate (225 kg N applied between May and August) in the data used here from Ball's (1979) experiment, little nitrate found its way into the soil solution below 300 mm in the spring.

CONCLUSIONS

These results confirm that leaching of nitrate is an important avenue for N loss from pastures on free-draining soils. As soil fertility improves and farming intensification increases, greater leaching seems inevitable; removal of clovers decreased, while application of fertiliser N increased, the loss of 60 to 80 kg N/ha/yr leached below the control, ryegrass-white clover pasture.

There are two important practical implications of these findings. First, leaching losses are depleting available soil N in intensively managed pastures, thereby contributing to a nitrogen-dependent, upper limit to herbage production. Second, much more nitrate is leached from intensively-farmed grasslands than is generally recognised. It is contaminating freshwaters, so could compromise water quality in important aquifers or endanger fragile aquatic environments, in some areas of NZ.

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APPENDIX

Estimation of Drainage

Drainage was estimated from a simple soil water balance for the top 450 mm of a level area of Manawatu silt loam, following the methods described by Kerr and Clothier (1975):

$$S = R + I - D - ET \quad (1)$$

where S is the change in soil water, R is rainfall, I is irrigation, D is drainage and ET is evapotranspiration. Infilatration is rapid in this soil so surface runoff wasassumed to be neglible. Rainfall and other climatic variables were measured at a meteorological station within 500 m of the experimental site. Irrigation was only occasional and was recorded at time of application. From recorded soil water changes and estimated daily ET, drainage from the root zone was calculated for conditions when water input exceeded the soil water holding capacity (taken here as 153 mm in the top 450 mm).

ET was calculated from estimated daily maximum evapotranspiration, ETmax, then applying reduction factors to account for pasture and soil effects. The steps used in the model were:

1. Estimation of ETmax: ETmax was expressed in terms of mean daily temperature (T) and incoming solar radiation (Kv):

   $$ETmax = 1.21\ (0.434 + 0.012\ T)\ (0.62\ Kv\ -0.24) \quad (2)$$

   For this application Kv was estimated from bright sunshine hours by the method of de Lisle (1966).
2. Accounting for pasture effects on ET: ET was estimated from ETmax using the relationship:

   $$ET = kl\ ETmax \quad (3)$$

   where kl accounts for pasture effects reducing ET below potential. ET from a closed canopy can be restricted when soil water in the root zone falls below 60% available soil water with kl falling linearly to zero at 37 mm soil water. Although water is extracted by plants from below 450 mm, nitrate was assumed to be lost from plants once below this level.
3. Accounting for effects of soil evaporation on ET: When soil water is low, pasture cover may be sparse and the effectiveness of rainfall and evaporation is reduced by a high soil surface evaporation component of ET. Surface evaporation (E) was assumed to fall as a function of the square root of days since any rainfall or irrigation event exceeding 3 mm (t).

   $$E = 5.5\ R/i- \quad (4)$$

   E cannot exceed ETmax.
4. Finally ET is taken as the larger E calculated from (3) or E from (4).