LEACHING LOSSES OF NITRATE FROM CATTLE URINE APPLIED TO A LYSIMETER

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ABSTRACT

Nitrate leached from cow urine was measured in the drainage water collected from a 2 square meter lysimeter located in a rygrass-white clover pasture. Freshly-collected cow urine was applied to the sward at rates of 88, 57, and 70 g N/m² on 23 June, 18 August and 29 September, 1983 respectively. Drainage was collected from the lysimeter twice weekly during 1983 and 1984. Transformations and movement of urine-N were followed in plots adjacent to the lysimeter during winter and spring of 1983.

Applied urine-N was present in the soil mainly as ammonium-N for three weeks following the June 23 application, and penetrated to all soil depths sampled (to 45 cm). Four weeks after the first application and within two weeks of later applications most of the mineral N present was nitrate.

Nitrate (18.7 g N/m²), equivalent to about 20% of the first urine-N application, was leached out of the 1 m deep soil column during winter-spring 1983. By the end of the 1984 drainage season the equivalent of 48% of all urine-N applied had been collected.

Using a previously developed model it was estimated that nitrate equivalent to 67 g N/m² passed below 45 cm during the 1983 drainage season. This estimate of leaching was based on calcuations of drainage, using a water balance, and on nitrate concentrations measured in the soil solution. It agreed closely with the combined total of nitrate collected in drainage and that remaining in the soil between 45 cm and 1 m depth after drainage from the lysimeter ceased, a total of 70 g N/m².

Additional Key Words: Mineral nitrogen, transformations of N, ammonium, pH, drainage

INTRODUCTION

Nitrate losses are estimated to form a substantial part of the outgoings of nitrogen (N) from intensive agricultural systems (Khana, 1981). The magnitude of such losses determine the relative importance of this process in limiting potential pasture production and as a source of pollution of freshwater systems.

As part of a research programme investigating mass balances for N in intensively-managed pastures (Ball, 1982), Ball and co-workers have inferred that substantial leaching losses occur from urine patches. This inference was drawn from experiments where volatilisation losses of ammonia and recovery of urinary N in herbage were measured from urine-treated plots (Ball et al., 1979; Ball and Keeney, 1983). Indirect estimates for the same plot using measured soil nitrate concentrations together with the estimated drainage components of the water balance indicated that, in the short term, between 5 and 15% of urinary N was leached as nitrate (Ball and Field, unpubl. data).

In New Zealand pastures, previous estimates of annual losses of nitrate have ranged from 70 kg N/ha from an irrigated, sheep-grazed pasture in Canterbury (Quin, 1982) and 80 kg N/ha using a water balance with soil nitrate data for pastures mob-stocked by sheep (Field and Ball, 1981), to 110 kg N/ha collected in drainage below pasture heavily stocked with weaner steers in Northland (Steele and Shannon, 1982). In the latter case, high chloride levels in the drainage suggested that the nitrate originated from urine patches. By contrast, Hogg (1981) failed to detect any increase of N in the drainage from urine applied in spring to small lysimeters at Ruakura.

This study was initiated to follow transformations of, and to determine leaching from, cow urine. Measurements were carried out on a lysimeter to enable the indirect water balance method for estimating leaching to be evaluated.

METHODS

Site

The experiment was conducted on a ryegrass-white clover pasture at the Massey University No. 1 Dairyfarm at Palmerston North. Plots consisted of a 2 m² lysimeter and 3 areas, each 0.5 m², located in pasture adjacent to the lysimeter. The lysimeter was 1 m deep and had been packed in 1970 to closely resemble soil in the surrounding area (Clothier et al., 1977). The profile consisted of 50 cm of Manawatu fine sandy loan (Dystric Fluventic Eutrochrept) overlying 40 cm of fine sand and 10 cm of gravelly coarse sand.

As part of the farm fertiliser programme, 50 kg urea-N/ha was applied to the experimental site on 14th November, 1983.

Urine applications

On three occasions, freshly-collected cow urine was sprinkled uniformly onto pasture trimmed to 3 cm, on both the lysimeter and adjacent plots. Urine was collected at the evening milking and applied fresh to the plots at a rate of 12

l/m² to simulate a cow urine patch. This resulted in N applications of 88, 57, and 70 g N/m² on 23 June, 18 August and 29 September 1983 respectively. Potassium bromide was added to the urine to provide a marker for interpreting leaching patterns (Mohammed *et al.*, 1984), at a concentration of 375 ppm in the first application and 3750 ppm in the two subsequent applications. Concentrated sulphuric acid was added (1%) to subsamples of the fresh urine which were then stored 4 °C until analysed for total N. Soil moisture at 0-7.5 cm was 32% w/w at each time of urine application and soil temperatures (0900 h at 10 cm) were 8 °C, 6.6 °C and 9.3 °C in June, August and September respectively.

Soil sampling

In 1983, soil samples to 45 cm depth were taken weekly from the plots adjacent to the lysimeter for gravimetric soil water determination, pH, urea and mineral N analyses. Each sample consisted of 10 cores, divided into 0-7.5 cm, 7.5-15 cm, 15-30 cm and 30-45 cm depths. They were broken up in the laboratory and thoroughly mixed. Subsamples (10g) were extracted for 1 h in 100 ml 2 M KCl containing phenyl mercuric acetate (PMA) to inhibit microbial transformations (Douglas and Bremmer, 1970) before being filtered through Whatman No. 42 filter paper. The filtrate was sealed in plastic containers and stored at 4 °C pending chemical analyses. Automated methods were used. Urea was determined using the method of Evans (1968); ammonium by Brown (1973); and nitrate by Henzell *et al.* (1968). Subsamples (50g) were dried for 16 h at 105 °C for soil water determination. Soil pH was determined on 1:2.5 soil:water suspensions. Bulk density was also calculated from these soil samplings.

Drainage collection

Drainage was drawn twice weekly from the lysimeter in the winters of 1983 and 1984, under a negative pressure of 2 kPa. Samples for analyses were forced through a 0.45 um millipore filter. Those kept for nitrate analysis were diluted with 4 M KCl(containing PMA) to give a final KCl concentration the same as in the soil extracts. Bromide concentration was determined with a selective ion electrode using samples previously stored in a deep freeze.

Environmental monitoring

Rainfall receipt between drainage samplings was measured using a tipping bucket guage adjacent to the lysimeter. These measurements agreed closely with those made at the Grasslands Division climatological station, approximately 1 km East of the lysimeter site. Sunshine hours and temperature records from this station were used for estimation of evapotranspiration.

Prior to the first urine application, collection beakers were used to monitor irrigations applied through rotary sprinklers at the rate of less than 10 mm/hour. During the 1983 measurement period irrigation was sprinkled onto the plots at about monthly intervals. Each application, designed to meet any shortfalls in an expected water receipt of 2.7 mm/day calculated from long term records, consisted of 20 to 30 mm applied with a watering can over a period of one hour.

RESULTS AND DISCUSSION

In the four weeks prior to 23 June 1983, 197 mm rainfall was recorded and 6 irrigations totalling 130 mm were applied. A further 122 mm of irrigation water was applied between June and November 1983. The first urine application followed the first drainage event in 1983.

Cumulative totals for water receipt and drainage recorded after the three urine applications in 1983 are shown in Figure 1. From mid July until early September, drainage closely followed water receipt and averaged 18 mm/week. As evapotranspiration rates increased in spring, drainage rates declined to average 9 mm/week from October to December and the difference in slope between cumulative water receipt and drainage totals became more pronounced (Figure 1). No drainage was recorded between 1/12/83 and 7/6/84. In 1984, drainage ceased on 10 September.
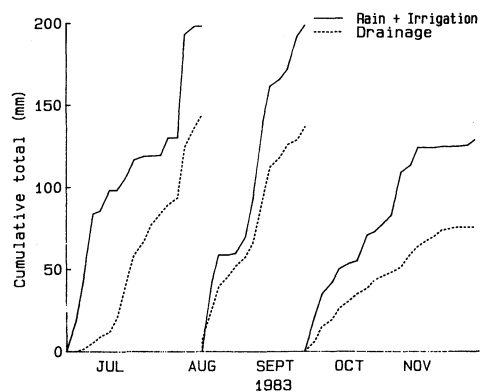

Figure 1: Water receipt and drainage in the three periods after successive urine applications.

Mineral N in the soil profile

One week after each urine application the total of urea plus mineral N in the profile to 45 cm depth was 65, 21 and 18 g N/m² respectively. After allowing for mineral N present at application time and nitrate leached to below 45 cm in the interim, these totals represented 78, 43 and 28% of the urinary N applied. This progressive decline in accountability within the soil most probably reflected a greater efflux by ammonia volatilization as the season progressed. Such losses would be expected to increase as soil surface temperatures rose. The volatilization ratio (Sherlock and Goh, 1983) computed from mean air and 10 cm soil temperature, indicates that losses by this avenue would be expected to increase by 26% from the first to the second application period, with the ratio increasing by 66% from the first to the third periods. Seasonal differences in urine infiltration into the soil, plant uptake and immobilisation of N could also have contributed to this pattern of results.
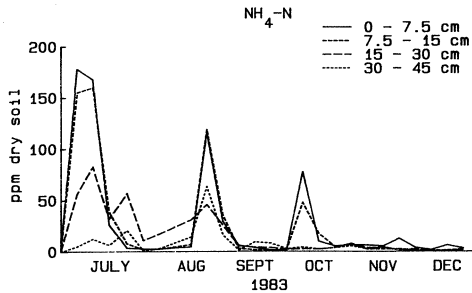
Figure 2: Ammonium distribution throughout the soil profile (sampled to 45 cm depth) during 1983 when urine was repeatedly applied.
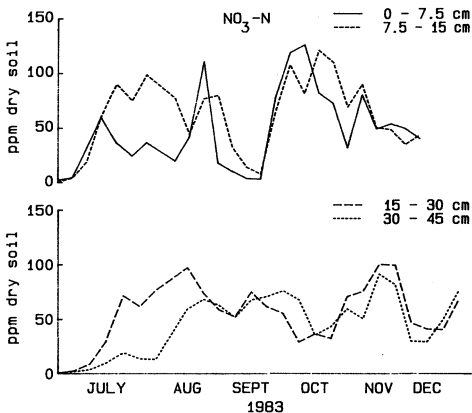
Figure 3: Nitrate distribution throughout the soil profile (sampled to 45 cm depth) during 1983 when urine was repeatedly applied.

Urea: Urea-N was detected in the soil only once; one week after the first urine application. Distribution of the 22.4 g urea-N/m² present then was 42, 18, 30 and 10% in the 0-7.5, 7.5-15, 15-30 and 30-45 cm depths respectively.

Ammonium: Ammonium-N in the top 15 cm of soil increased dramatically in the first week following each application of urine (Figure 2). Significant quantities of ammonium were measured at greater depths, in association with the first and second urine applications, indicating significant penetration of urine into the soil. Drier conditions at the time of the third application appears to have minimised such preferential flow (Scotter, 1978). As soil temperatures rose, ammonium at depth was progressively nitrified with the result that only low levels of ammonium-N persisted below 15 cm for the remainder of the study. The application of 50 kg urea-N/ha on 14/11/83 led to an observable increase in ammonium level in the topsoil at the mid November sampling (Figure 2).

Nitrate: Nitrate increased slowly relative to ammonium after the first urine application with increasing levels observed within the profile in successive weeks as

nitrification proceeded (Figure 3). After the first N application, the only time that nitrate levels approached zero in the surface soil was immediately before the third application. Greater biological activity with increasing soil temperature was reflected in more rapid appearance of nitrate in the profile following the second and third urine applications.

Soil pH

Initial soil pH was 6.2, to 7.5 cm depth, and 6.1 between 7.5 and 45 cm. Within 7 days following the first and second urine applications, the pH in the top 15 cm rose on average 0.8 pH units. While pH quickly returned to near starting levels in the 0-7.5 cm layers and remained there for the duration of the experiment, pH gradually declined in the lower layers, with final values of 5.3, 4.9 and 5.1 in the 7.5-15, 15-30, and 30-45 cm layers respectively when measured on 21 February 1984. Acidification of the soil profile is expected with nitrification and subsequent leaching of nitrate (Helyar, 1976).

Nitrate-N in leachate

Prior to the first urine application, the drainage water contained an average concentration of 11.5 ppm nitrate-N; a relatively high value under an ungrazed sward reflecting both a previous spring urea application and mineral N accumulation in the soil profile during the preceding warm, dry weather (Ball and Field, 1982). Although leachate volume increased after the initial urine application, nitrate concentration remained the same or lower until mid-September when it began to rise to reach a maximum level in December in excess of 400 ppm N (Figure 4).
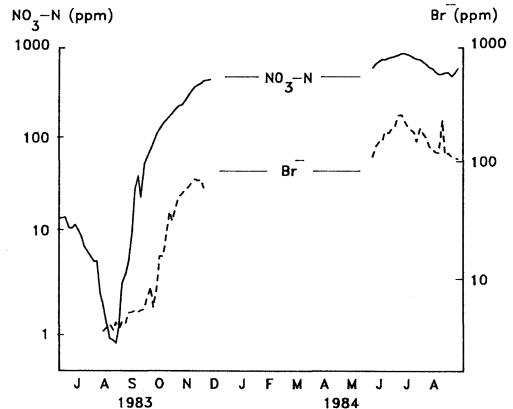
Figure 4: Nitrate and bromide concentrations in water draining from the lysimeter during 1983 and 1984.

Bromide concentration in the leachate (Figure 4) increased gradually from early September. Bromide preceded nitrate because of the delay in appearance of nitrate following the first urine application (Figure 4). A concentration of one-tenth that in the applied urine was achieved only after October 20 indicating that some bromide was moving more rapidly than the main front of

urine-derived nitrate within this monolith. Bromide concentrations remained well below input levels during 1983 as the main front would have mixed with, and been diluted by, water perched above the coarse sand-gravel junction in the lower levels of the lysimeter (Clothier *et al.*, 1977). As the bromide concentrations were still high and increasing at the start of the 1984 drainage season, we can infer that the main body of nitrate from the second urine application appeared at this time and had also been well mixed in the lower layers of the lysimeter. The phase lag of about 2 months for nitrate movement to 45 cm, indicated by the rate of movement of fronts in Figure 3, confirms that nitrate derived from an application in late September would not be collected in drainage in the 1983 season.

Nitrate concentration in drainage remained at or above 500 ppm N throughout the 1984 leaching season, peaking in early-mid July at greater than 850 ppm N. However, the patterns for emergence of both bromide and nitrate-N (Figure 4) indicate that the entities leached from all urine applications the previous year were by then well mixed.

Total nitrate-N leached during the two years was 102 g N/m^2, with the greater proportion (83.8 g N/m^2) in the second year. The total N leached represented 48% of the urine-N applied to the lysimeter. Very high concentration in the final drainage for 1984 indicated that the profile had not been cleared of nitrate arising from urine applications the previous year. If all water in the profile was engaged in drainage, rather than being separated into preferential flow and immobile phases, there had been sufficient excess water receipt to have effected a clearance of nitrate in the profile. Further measurements of leachates obtained during the current drainage period will be required to establish whether significant quantities of nitrate are still appearing in drainage, either diffusing back from the immobile water into the mobile drainage from this monolith or as a result of delayed release of urine N previously immobilised in the soil organic fraction. However, we would not place great stock on the quantitative aspect of nitrate in this year's drainage because other effects could be interfering and we are no longer able to cross-reference measurements with mineral N accountability from adjoining small plots. Heavy doses of potassium, which are a feature of urine patches, are known to accelerate the breakdown of soil organic matter (Campino, 1980).

CONCLUSIONS

Obviously, large amounts of nitrate were leached following multiple applications of cow urine to this lysimeter. A classical pattern of transformations (Ball *et al.*, 1979; Carran *et al.*, 1982) was observed. Much of the urinary N was hydrolysed quite quickly to ammonia with an accompanying rise in pH of the topsoil then much of the ammonium was nitrified with an accompanying decline in soil pH as nitrate was leached. The rate of these transformations quickened markedly as seasonal temperatures rose. Urea persisted in the soil for only one week under cold, wet conditions. Overall, nitrate-N equivalent to almost 50% of the applied urinary N was collected in drainage from the lysimeter during 1983 and 1984.

We have previously estimated leaching losses indirectly using nitrate levels in the soil profile combined with an estimate of the drainage component of the water balance (Field *et al.*, 1984). It was hoped that data gathered from this lysimeter study would provide a test of this approach. The peculiar properties of this soil, particularly the tendency for the lysimeter to retain a perched water table at depth thereby mixing percolates, provided an unwanted complication. However, a water balance was computed from the date of the first urine application, with drainage thereafter assumed to contain nitrate at the concentrations measured in the 30 to 45 cm depth, interpolated from soil samplings in the adjacent plots. A total equivalent to 67.2 g nitrate-N/m^2 was calculated to have passed through the 45 cm plane by the end of the 1983 drainage season. Nitrate-N collected from the lysimeter totalled only 18.7 g N/m^2 up to the cessation of drainage in 1983. A deep sampling of the plots on February 21, 1984, accounted for 50.8 g nitrate-N/m^2 resident in the profile between 45 and 100 cm. So together, recovery in the sub-soil to 1 m depth plus leaching below 1 m indicate a total movement of approximately 69.5 g nitrate-N/m^2 through the 45 cm plane. These considerations provide support for the approach of estimating nitrate leaching by use of soil nitrate concentrations at depth and assuming piston flow of the soil solution out of the 30-45 cm depth. This approach gave a realistic estimate of the net passage of nitrate from the zone of interest. Our study also indicates that there was very little removal of nitrate from below this depth (uptake by plants, immobilisation or denitrification) over the summer period.

ACKNOWLEDGEMENTS

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