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Dynamics of mineral nitrogen in topsoil, during regrowth of pasture in two contrasting grassland systems

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Abstract

Changes in soil mineral nitrogen(N) were monitored during regrowth of pasture between consecutive grazings in two contrasting grassland systems; Grass-clover (the norm in NZ) and a more intensive system, Grass+N400 (pure grass + 400 kg fertiliser N/ha/year). The experiment was carried out during autumn at DSIR Grasslands, Palmerston North. Net mineralisation of N under field conditions was estimated in an ancillary experiment, using soil samples from undisturbed soil cores contained in PVC tubes. The dynamics of mineral N in soil were dominated by a 'pulse' of ammonium, observable soon after grazing. Nitrification proceeded rapidly thereafter. Mineral N in soil then progressively declined, much of it going into organic combination presumably through uptake by plants. Since nitrate formation in the soil is minimised by maximising the residence time of N in plant (organic) form, different management options (varying in frequency and intensity of defoliation) may have important influences, not only on pasture utilisation and production, but also on the management of mineral N in the soil-plant-animal complex. Tubes embedded in soil and incubated in the field have provided some additional, useful perspectives. There was only limited evidence for significant net mineralisation of organic N throughout the period of regrowth. Analyses of individual soil cores demonstrated a sharp contrast between the pasture at large and the 10 - 15% of total area influenced by urine from the previous grazing, in terms of mineral N content. 'Averaging' these by bulking numerous cores into a composite sample can provide an accurate quantitative estimate of mineral N, which can be related to herbage uptake of N over the whole area. But if losses of N (by leaching or volatilisation) are disproportionate to the concentration of mineral N in affected and unaffected volumes of soil, then bulking samples and averaging will not be the most appropriate way to estimate these losses. The results of this study point to the importance of the urine of grazing ruminants as a N substrate for pasture regrowth in the absence of fertiliser N. At the same time, urine patches provide the main avenue for N escape to the wider environment from developed pastures.

Keywords mineral N, N in pastures, N cycling by animals

Introduction

During the last decade it has been clearly recognised that:

1. Grassland productivity is severely limited by nitrogen (N) availability in soils (Ball & Field 1982; Meer & Lohuyzen 1986).
2. In the process of supplying adequate N to overcome this limitation (principally by fertiliser N in intensive grassland systems) a substantial proportion of the N applied can be lost from the system. This loss of N is important not only because of its agricultural significance, but also because of its potential impacts on the wider environment and human health (nitrate leaching to ground water and emission of oxides of nitrogen to the atmosphere: Ryden 1986; Ryden *et al. 1984)*.
3. Grassland management practices have also been reported to have large effects on N dynamics in pastures, thereby affecting productivity (Brock *et al.* 1983) and the extent and forms of N losses (Ball & Keeney 1983; Ball & Ryden 1984; Brock *et al.* 1990; Field & Ball 1982; Steele & Brock 1985).

To improve efficiency of N utilisation and reduce losses in grassland soils, a better understanding of N dynamics is required. In particular, net mineralisation of N requires further study, because of its relationship to the amount of N available for both plant nutrition and nitrification. Nitrification is a pre-requisite for potential losses.

Most studies of net mineralisation and nitrification have been carried out in the laboratory. However, agreement between laboratory experiments and field results is generally poor (Hofman *et al.* 1986). The major difficulties in measuring these processes in the field arise through the effects of immobilisation, especially plant uptake of N, and return of N in the excreta of grazing animals.

The objective of this study was to monitor changes in mineral N in soil during regrowth between consecutive grazings in two contrasting grassland systems under autumn conditions. This work will contribute to a better understanding of the short-term dynamics of N in pastures.

Materials and Methods

This experiment is part of a larger study of N dynamics in three contrasting grassland systems being carried out at DSIR Grasslands, Palmerston North, New Zealand. The main experiment consists of 3 treatments replicated 4 times and arranged in a randomised, complete block design. The experimental swards were sown in March 1989 on a recent alluvial soil (Manawatu fine sandy loam, Cowie, 1972; C:N=10, pH=5.9) in plots of 200 m^2. The pastures were periodically mob-stocked with sheep.

Intensive, sequential measurements of mineral N in the field

In the study reported here, mineral N was periodically measured during a regrowth period in autumn 1990 (March-April) in two grassland systems: a) Grass-clover (*Lolium perenne* L. cvv. 'Grasslands Nui' and 'Yatsyn' - *Trifolium repens* L. cv 'Grasslands Huia'); b) Grass (cvv. 'Grasslands Nui' and 'Yatsyn') receiving 400 kg of fertiliser N/ha per year (as urea, split into 8 dressings).

Soil samples from each plot comprised a bulked sample of 15 cores taken at random to 2 depths (0-7.5 cm and 7.5-15 cm) at the following times: 1 day before grazing then, 1, 2, 4, 8, 11, 15, 18, 22 and 28 days after grazing. Mineral N (ammonium and nitrate) were determined using standard, automated methods (Ball et *al.* 1979). Herbage regrowth was periodically measured by a standard technique, taking three quadrats of 0.5 m^2 per plot. Herbage samples were analysed for total N using a digestion by the Kjeldahl method with modification to include nitrate by addition of salicylic acid (Bremner 1965). Total N was determined colorimetrically on a 'Technicon Auto-Analyser'.

Net mineralisation measured in PVC tubes embedded into the soil

Net mineralisation under field conditions was also estimated by periodically analysing soil samples from undisturbed soil cores contained in PVC tubes embedded to 15 cm depth. The principles of this technique were described by Raison et al. (1987). This method avoids the effects of soil disturbance and altered environmental conditions in mineralisation studies of soil N.

Immediately after the area was grazed (27 March) each plot was allocated 20 tubes, inserted at random in 4 sets of 5 units. The tubes were PVC cylinders having an internal diameter of 5 cm and a capacity of approximately 147 cm^3 in each section of 7.5 cm depth. At weekly intervals (for 5 weeks) 4 tubes (one from each set) were removed from each plot and analysed for mineral N in separate sections of 0-7.5 cm and 7.5-15 cm depth. Each tube protruded 4 cm above the soil surface. The herbage was cut at ground level and removed before setting the tubes into the soil. To prevent any plant uptake of N, or nitrate leaching, each unit was adequately protected from rain and light effects with a reflective cover located 2 cm above the tube, and a plug of non-absorbent cotton wool was placed inside the exposed end of each cylinder.

Some meteorological conditions, soil moisture and soil temperature during the period of study (20 March-25 April, 1990)

Rainfall = 48.7 mm

Raised pan evaporation (Class A) = 95.9 mm

Variation of soil moisture conditions (0-15 cm depth) over 5 weeks:

- incubation tubes = 0.63 to 0.72 field capacity;
- field samples = 0.55 to 0.75 field capacity.

Soil temperature (°C daily average, 10 cm depth): week 1 = 16.7 ± 1.4; week 2 = 15.7 ± 0.7; week 3 = 16.0 ± 1.0; week 4 = 13.1 ± 2.2; week 5 = 16.1 ± 1.3.

Results and Discussion

Field measurements

The quantity of mineral N to a depth of 15 cm before grazing was 6.3 and 5.5 kg N/ha in the Grass-clover and Grass+N400 treatments, respectively (grazing began at time 0; Figures 1a, 1b). In the latter treatment, N fertilisation had been discontinued the previous January (because of poor responses in summer), after application of 400 kg N/ha during the previous year. This comparison demonstrates the short residual effect of fertiliser N on soil mineral N in grassland soils. Mineral N had declined to the same level as the treatment receiving no fertiliser N in less than 2 months.

Soil mineral N was measured 1 day after intensive grazing by sheep (up to 400 sheep/ha for four days)

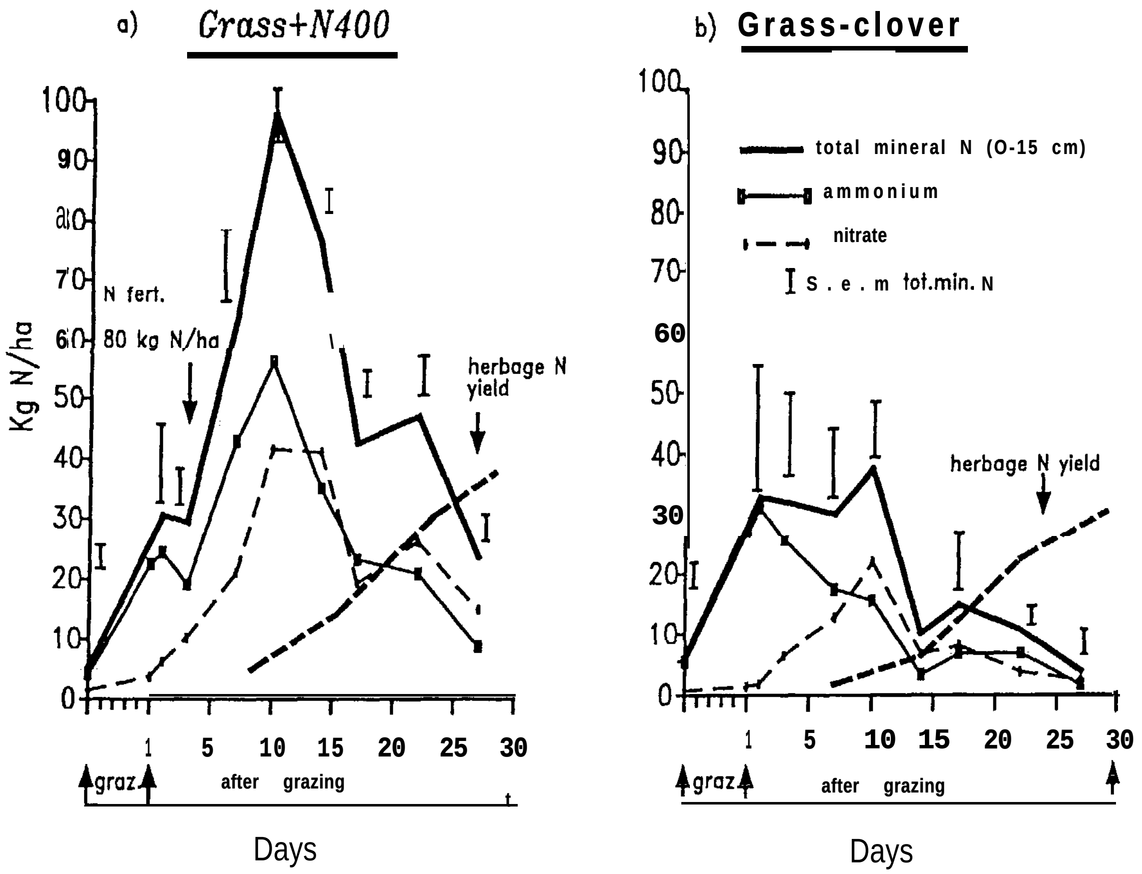

Figure 1 Dynamics of mineral N in soil, and yield of plants. during regrowth of pasture

(Figures la, lb), and both systems contained about 28 kg N/ha-15 cm. This value represents a weighted average of soil mineral N in areas unaffected and affected by returns of animal excreta. These results indicate that much of the organic N held in the herbage mass before grazing was returned to the soil, from where it was recoverable as ammonium despite concurrent losses by volatilisation of ammonia (Ball & Ryden 1984; Jarvis et al. 1989). The excreta of grazing animals in the soil after grazing is the most likely source of this ammonium; but decomposition of herbage residues, herbage tissue damage or reduced uptake of N by the recently defoliated sward could all be contributing to some extent. The net increment of soil mineral N immediately after grazing represented 51% and 68% of the amount of N in the herbage before grazing, for Grass-clover and Grass+N400 respectively.

During the next 3 or 4 days after grazing the nitrification rate increased markedly (Figures la, b), and nitrate accumulated, mainly because of less plant demand for N.

Nitrogen fertiliser (80 kg N/ha as urea) applied 4 days after the completion of grazing to the Grass+N400 treatment (Figure la) brought soil mineral N from 29 kg/ha- 15 cm (measured on day 4) to 98 kg/ha- 15 cm at day 10. This increase represents 86% of the fertiliser N applied.

From 10 days after grazing, soil total mineral N decreased in the two systems, most obviously as a result of vigorous plant growth and associated uptake of N by plants (Figures la, 1 b). The N yield is an average value from plants growing in areas unaffected and affected by excretal return; detailed comparison of soil and plant behaviour in both types of conditions have been reported in Ball *et al.* (1979), Ball & Ryden (1984), Thomas *et al.* (1990) and Whitehead & Bristow (1990). As plant growth proceeded, ammonium and nitrate were depleted quickly, and at the end of the regrowth period the amount of mineral N in the topsoil was similar to that present at the end of the previous regrowth period.

Measurements in tubes

Without the effects of plant uptake and leaching, net mineralisation resulted in the accumulation of 30 kg mineral N/ha- 15 cm in the system receiving no fertiliser N by the second measurement, 2 weeks after grazing (Figure 2b). This amount is similar to the soil mineral N measured in the sward shortly after grazing (Figure 1b). The smaller amount of mineral N during the first week, in relation to that measured in the grazed sward, could have been due to an enhanced microbial immobilisation within the tubes through breakdown of remaining root tissues, although such an explanation is only one possibility.

The results from the system receiving fertiliser N (Figure 2a) suggest that some net immobilisation of N may have occurred, because 80 kg fertiliser N/ha was applied before the sampling 1 week after grazing. There is excellent concurrence between results obtained in the N-fertilised sward (Figure 1a) and from the tubes (Figure 2a) one week after grazing, both in terms of total mineral N (70 kg N/ha) and NH_4-N:NO_3-N. However, in view of the 30 kg mineral N/ha-15 cm observed in the field before application of the fertiliser, much of the added N remained unaccounted for.

Nitrification became an active process during this field incubation, both with and without fertiliser N, so ammonium must have been quite freely available to nitrifiers. Because nitrifiers are known to be poor competitors for ammonium (Fisk & Fahey 1990), we can infer that microbial immobilisation is usually not too intense in temperate grasslands of this type, on soils with a low C:N ratio, but this provides no lead as to what happened to the 'missing' N in the Grass+N400 system. Clearly, however, ammonium accumulated in substantial quantity within the tubes in the absence of uptake by plants, as mineralisation proceeded (Figure 2).

Nitrification occurred quickly under the prevailing environmental conditions. Most of the ammonium was oxidised to nitrate during the first 2 weeks of

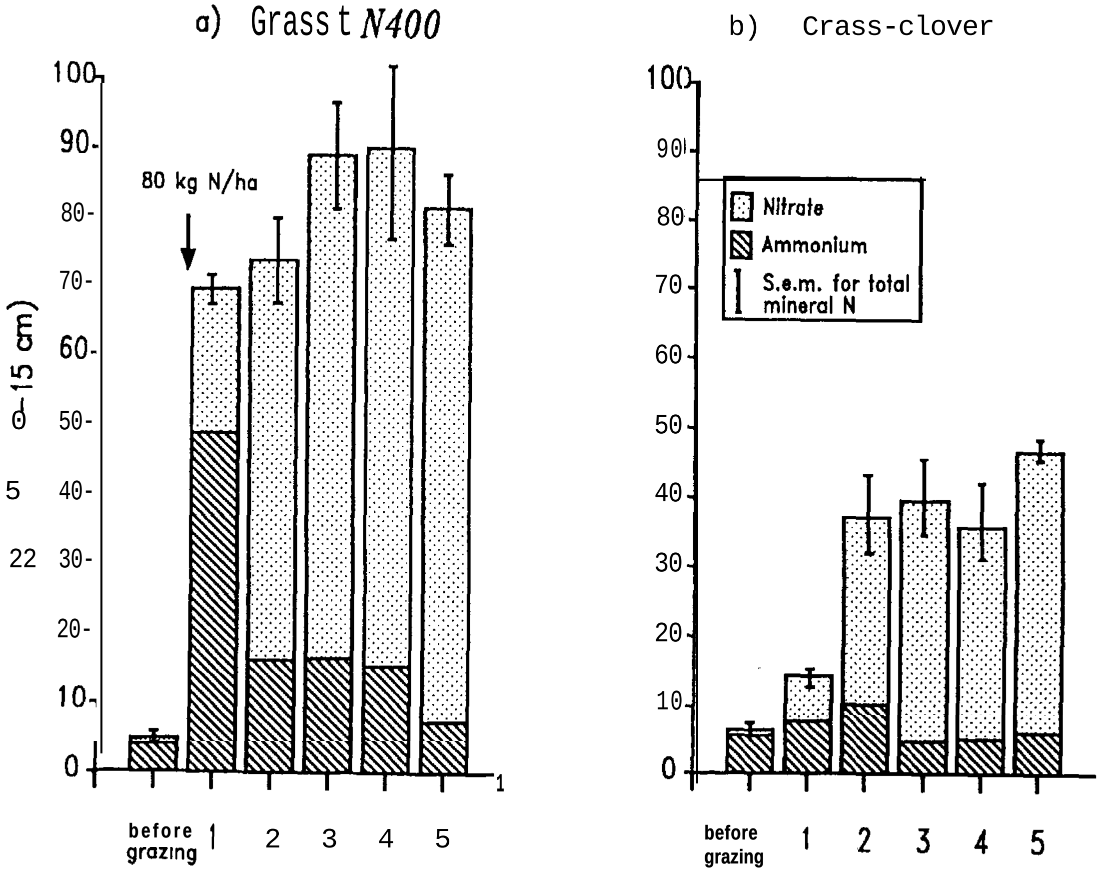

Figure 2 Recovery of mineral N from undisturbed soil cores contained in PVC tubes (15 cm deep). during mineralisation in the field

incubation. At the end of the incubation more than 80% of the mineral N was in nitrate form, in both soils with and without fertiliser N. Although the eventual decline in the rate of nitrate production might be attributed to several possible causes, the most likely explanation is the progressive exhaustion of ammonium substrate available to the nitrifiers.

Spatial variability in mineral N

The study and understanding of mineral N dynamics in pasture soils is bedevilled by spatial variability, stemming from the aggregation of excess dietary N into urine patches and dung pats by grazing ruminants (Thompson & Coup 1940). The result is a markedly skewed distribution of values for mineral N in individual soil cores (Figure 3) and large uncertainty associated with mean values (Figs 1, 2). The difficulties are profound, as the range in values among individual cores (15 cm depth) taken from an ostensibly uniform, grazed sward is generally lo-fold and can extend to 20-fold soon after grazing. By arbitrarily subdividing the frequency distributions of mineral N into two subpopulations, we estimated that about 10-15% of cores were displaying the effects of urine at the time of sampling to 15 cm depth. Current recommendations to meet this problem include intensive sampling and the bulking of cores before chemical analyses. Further, transformation to normalise the data before any statistical analysis is required (White et al. 1987).

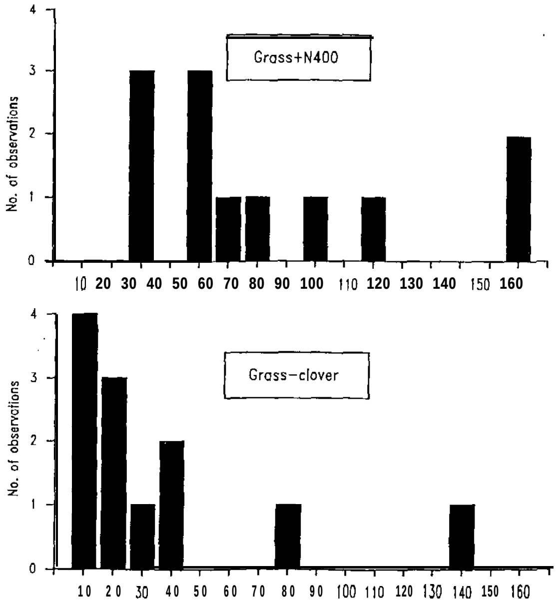

Figure3 **Frequency distribution for class values of total mineral N recovered from tubes. two weeks after grazing**

However, any form of ‘averaging’ is a moot procedure from a practical point of view. Depending on the objectives of any study, one may be better advised to concentrate on either the cluster of values arising from the major part of the sward unaffected by urine, or on the outlying values arising from recent urine patches. For instance, a farmer is interested in the quantity of fertiliser required to bring the whole area up to optimal production, so does not intentionally sample areas obviously affected by excreta. On the other hand, the environmentalist may be more interested in the urine-affected areas, from which the bulk of N escapes to the wider environment (Ball & Ryden 1984). Considerations like these point to the need for compartmentalised research to understand better the N dynamics in those parts of the sward either affected or unaffected by recent urinations.

Conclusions

The mineral N regime in this soil was obviously dominated by a ‘pulse’ input of N, observable soon after grazing, mainly as ammonium. This points to the importance of the urine of grazing ruminants as a N substrate for pasture regrowth in the absence of fertiliser N.

Nitrification proceeded rapidly after grazing in this well developed grassland soil.

Although immobilisation of N is commonly defined as a microbial process, this experiment indicates that in the grass-clover system most of the mineral N in soil was brought into organic combination through uptake by plants rather than microbial immobilisation. Field results showed a rapid decline in soil mineral N, coincident with the onset of sward regrowth (Figure 1), while mineral N levels remained unchanged during time in the tubes (Figure 2). Obviously, N uptake by plants has a dominant influence on the amount of nitrate accumulating in the soil. So a vigorously growing pasture or crop is the best insurance against losses of N, whether through leaching of nitrate or denitrification.

These results may be useful for improving the management of available N (importantly, nitrate) in grassland soils. Since nitrate formation is minimised by maximising the residence time of N in plant (organic) form, different management options (set stocking, rotational grazing, frequency and intensity of defoliation, etc) may have important influences, not only on pasture utilisation and production, but also on the management of mineral N in the soil-plant-animal complex. For instance, our results strongly indicate that it would be prudent to delay fertiliser N application until regrowth of the sward is well underway.

Use of tubes embedded in soil and incubated in the field provided some additional, useful perspectives. Analyses of individual soil cores indicated that some

10-15% of total area was influenced by animal urine at the previous grazing. But bulking soil cores into a composite sample, while providing a value for quantitative description of mineral N in the soil, will not be the most appropriate way to estimate N losses.

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