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Fate of Urea-nitrogen from Cattle Urine in a Pasture–Crop Sequence in a Seasonally Dry Tropical Environment

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Abstract

The fate of urea-N in cattle urine applied during the dry season (in August) to the pasture phase of a pasture–crop sequence at Katherine, N.T., was investigated. Cattle urine labelled with ^{15}N-urea was applied to three sets of microplots to measure the following parameters: (*a*) amount and distribution of ^{15}N remaining in the microplots during the remainder of the dry season with 0, 0·5, 1·0 and 5·0 t ha^{-1} of pasture residues present initially; (*b*) the effect of placing the urine 5 cm below the soil surface on the amount of ^{15}N remaining during the dry season; (*c*) uptake of ^{15}N by the pasture during the early part of the wet season (October to December) and uptake by sorghum sown directly into the killed pasture in January. Residual ^{15}N in the surface soil (0–15 cm) after the sorghum crop was also measured.

Of the applied ^{15}N, 26% was lost after 1 day, 32% after 7 days and 46% after 63 days. Losses were not affected by the amount of pasture residues on the microplots when the urine was applied. Almost all of the ^{15}N remaining in the microplots was in the 0–7·5-cm layer of soil, and 65–75% of this was mineral N. The dry-season losses of ^{15}N were presumably through volatilization of ammonia, because leaching was absent and no loss of ^{15}N occurred when the urine was placed 5 cm below the soil surface.

Pasture growth killed at the end of December contained 6·2% of the applied ^{15}N, the sorghum crop recovered only a further 2·1%, and after harvest of the sorghum crop the 0–15·0-cm layer of soil contained 23%. Thus about half of the ^{15}N remaining in the soil–plant system to the 15·0 cm soil depth at the end of the dry season disappeared during the following wet season, either as a gaseous loss or by leaching deeper into the soil.

Introduction

Research at Katherine to develop crop and animal production systems for the monsoonal areas of Australia was pursued actively in the 1950's and 1960's (Norman 1966; Norman and Begg 1973), and research on integration of grain cropping and beef cattle production in the area was re-initiated in the late 1970's (McCown *et al.* 1983). The main elements of the system are: (i) cattle grazing native pastures during the wet season and legume leys and crop residues in the dry season; (ii) a legume pasture in a short rotation with maize or sorghum, with the pasture producing most of the nitrogen (N) for the crop; (iii) crops planted directly into chemically killed pasture; (iv) pasture regenerated naturally from legume seed that remained hard during the crop phase plus seed produced from volunteer legumes allowed to grow as an intercrop. A key factor in the above system is the effectiveness of transfer of N from the legume ley to the subsequent maize or sorghum crops.

The relative importance of cattle excreta and plant litter as avenues for transfer of N is not known at present, but dry-season grazing will be managed so that a high proportion of the ley pasture is eaten, leaving just enough residues to protect the

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soil from summer storms. More than 90% of the herbage N ingested by the cattle can be expected to be excreted in faeces and urine, with 50% or more in the urine (Henzell and Ross 1973). If the legume ley provides a diet with an adequate level of protein, urea would account for the largest fraction of urinary N — about three-quarters (Church 1969). Experiments in Australia and in New Zealand have shown that 5–65% of the urine N applied to soils under pastures is commonly lost from the soil–plant system and that apparent recovery of the urine N by the pasture plants ranges from 15 to 50% (Watson and Lapins 1969; Ball *et al.* 1979; Carran *et al.* 1982; Vallis *et al.* 1982; Ball and Ryden 1984; Vallis and Gardener 1984).

The present experiment was conducted at the Katherine Research Station during 1981–82 to investigate the fate of ^{15}N-labelled urea-N in cattle urine applied during the dry season to a ley pasture with various densities of plant residues, and the availability of the N to a subsequent sorghum crop. Residual ^{15}N in the surface soil after the sorghum crop was also measured.

Materials and Methods

The field experiment was conducted on Tindall clay loam (formerly Tippera clay loam), a red earth (oxic paleustalf) which has the following properties in the 0–10·0-cm layer of a typical profile: pH 6·2, organic matter 2·18%, total N 0·076%, cation exchange capacity 51 mmol kg^{-1} (Aldrick and Robinson 1972). Clay content ranges from 25% at the surface to 50% at 90 cm depth and the dominant clay mineral is kaolinite (Wetselaar 1967). The area had been under a mixed pasture of Townsville stylo, *Alysicarpus vaginalis*, *Brachiaria* spp. and *Digitaria* spp. for the previous 10 years. The pasture was cut for hay each season.

Design

The experiment consisted of two parts. Part A was designed to measure the distribution and total recovery in the soil–plant system of N from ^{15}N-urea in cattle urine added to the surface of ley pasture during the dry season, and part B was designed to measure the availability of this N to a sorghum crop grown in the following wet season in a simulated 'no till' system.

The treatments in part A were four levels of pasture residues (0, 0·5, 1·0 and 5·0 t ha^{-1}) at the time of urine application with six times of measurement (1, 3, 7, 21, 35 and 63 days after urine application). These were arranged in a completely randomized, unreplicated factorial design. There were also two supplementary treatments, both replicated four times. In one, urine was placed 5 cm below the surface of bare soil and the remaining ^{15}N measured after 35 days. This treatment was expected to minimize volatilization of ammonia (Terman 1979; Hauck 1983), and thus allow an assessment of the relative importance of this process in other treatments. In the other supplementary treatment, urine was applied to bare soil, then covered with residues (5·0 t ha^{-1}) and the remaining ^{15}N measured after 21 days. This treatment was designed to assess the influence of retention of the urine on pasture residues at the time of application on N losses.

The treatments in part B of the experiment were four factorial combinations of two levels of pasture residue at the time of urine application (0 and 5·0 t ha^{-1}) and two different qualities of pasture regrowth killed just before sowing the sorghum. Killed regrowth (^{15}N-labelled) was either cut and left *in situ* or removed and replaced by an equal amount of unlabelled regrowth. These four treatments were applied in a completely randomized design with five replications.

Field Procedures

The experiment was carried out with microplots of pasture laid out on a 1-m square grid and enclosed with open-ended galvanized steel cylinders (11·8 cm diameter by 16·5 cm long). Dry pasture residues were removed from the microplot sites and the cylinders driven 15 cm into the soil on 18 May 1981. Good contact between the soil and the cylinders was ensured by tamping any disturbed soil against the cylinder wall and watering around the inside and outside perimeters with 30 and 50 ml of water, respectively. A thermocouple was installed horizontally at 1 cm depth in each microplot. Pasture residues that had been collected previously were applied at the prescribed rates to the microplots and 45 cm wide border areas on 27 July. The microplots and their borders were then covered with plastic netting to hold the residues in place in windy conditions.

Urine collected from steers between 0700 and 1200 h was stored at 6°C and used next day. The urine contained 3·16 g N l^{-1}, of which 0·15 g l^{-1} was ammonium-N. Thus there was little hydrolysis of urea in the urine during overnight storage. The concentration of N in the urine was at the low end of the range reported for cattle: 2·5–13 g N l^{-1} (Whitehead 1970). Urea enriched with ^{15}N (*c.* 50 atom %) was added to the urine as a tracer for urinary urea. The added urea increased the N concentration in the urine by 0·13 g l^{-1}. A pipette was used to apply 50 ml of amended urine evenly over the surface of each microplot between 0900 and 0930 h, on 6 August. Each application took about 35 s, and was equivalent to 4·5 l m^{-2} and 150 kg N ha^{-1}, compared with 'average' values of 7 l m^{-2} and 575 kg N ha^{-1} for cattle urine (Whitehead 1970). From then until 8 October, when the last cylinders were removed from part A of the experiment, all microplots in both parts of the experiment were covered with plastic sheets when rain seemed imminent.

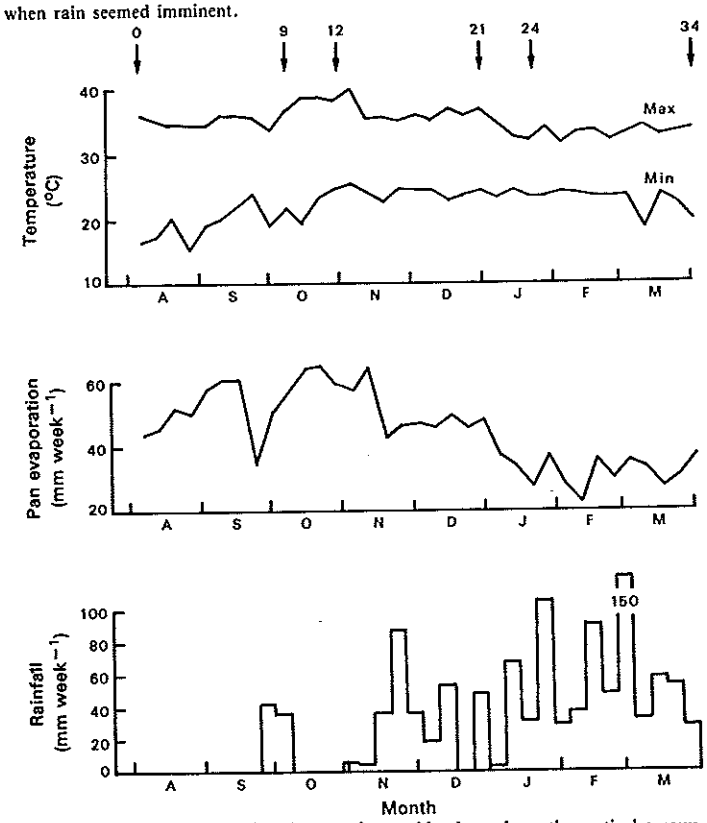

Fig. 1. Climatic data during the experiment. Numbers above the vertical arrows indicate weeks after urine application for the following operations: 9 weeks, last sampling in part A; 12 weeks, microplots of part B sown with *U. mosambicensis* and *A. vaginalis*; 21 weeks, pasture sprayed with herbicide; 24 weeks, sorghum sown; 34 weeks, sorghum harvested.

At each sampling in part A of the experiment, plant residues were collected from the microplots by hand before the cylinders and enclosed 0–15 cm depth of soil were extracted. Soil below each microplot was sampled by taking a 4 cm diameter core from the 15·0–22·5-cm layer on days 1 and 3, and from the 15·0–22·5- and 22·5–30·0-cm layers at later samplings. Six soil cores were also taken from around the perimeter of the experiment for determination of background values of nitrate content and ^{15}N abundance in the 0–7·5-, 7·5–15·0-, 15·0–22·5- and 22·5–30·0-cm layers of soil at the start of the experiment.

The microplots in part B of the experiment also received ^{15}N-labelled urine on 6 August, at the same rate as in part A. From then until 8 October they were treated similarly to those in part A. On 29 October they (including their borders) were planted with *Urochloa mosambicensis* and *Alysicarpus vaginalis*. Vegetation on the entire area was sprayed with glyphosate on 31 December and 1 week later the dead vegetation on the plots was cut at 1–2 cm height. The cut vegetation (assumed to be labelled with ^{15}N) was left *in situ* on half of the plots, and on the other plots it was replaced with a similar amount of dead legume and grass material (not labelled with ^{15}N) from the area adjacent to the experiment. These two treatments were included to estimate the contribution of N from killed pasture plants to a subsequent crop under a no-till system. Seven seeds of sorghum (cv. Monsoon) were planted 5 cm deep in each microplot on 10 January 1982 but germination was uneven, so the seedlings were removed and a second sowing made on 22 January. Water (14 mm) was applied after this sowing and again (7 mm) 2 days later. The plants were thinned to two plants per microplot on 11 February. The border area around each microplot was sown with sorghum on 28 January, and again on 26 February to fill in gaps. These plants were thinned on 3 March to leave six to eight plants spaced evenly on the circumference of a 66 cm diameter circle around each microplot. All thinnings from the microplots and borders were kept for analysis. The plots were sprayed as required to control insects and diseases. The microplots and borders were harvested on 31 March to obtain the following components: (1) sorghum tops (cut 2·5 cm above ground level), (2) stem bases and large roots and (3) soil and fine roots (inside microplots only).

Table 1. Water content of soil in urine-treated microplots of pasture during the dry season
Mean of four levels of pasture residues. Water retained at −1·5 MPa: 0–20 cm depth, 19·0%; 20–40 cm, 21·5%[A]. Water retained at −0·03 MPa: 0–20 cm depth, 27·6%; 20–40 cm, 29·6%

No. of days after urine application	Volumetric % at soil depth (cm) of: 0–7·5	7·5–15·0	15·0–22·5	22·5–30·0
1	6·0	13·2	17·5	—
3	5·8	12·4	15·2	—
7	5·3	12·8	17·0	17·7
21	4·6	12·0	15·9	18·1
35	4·5	12·0	15·5	17·4
63	16·0	22·0	25·6	24·7

[A] R. J. K. Myers, personal communication.

Laboratory Procedures

Plant material was dried (60°C), weighed and ground (<1 mm) before subsampling for chemical analysis. Soil from part A of the experiment was crushed (<2 mm), mixed and weighed before subsampling for moisture and chemical analysis. The subsamples for chemical analysis were stored at −15°C. Soil from part B was dried (40°C) and crushed (<2 mm) before subsampling. Total N, mineral N and isotopic composition were determined as described elsewhere (Vallis and Gardener 1984).

Results

Moisture and Temperature

Less than 1 mm of rain fell during the experiment until late September–early October, 53 days after the urine was applied (Fig. 1). Thus, in part A of the experiment, only those microplots sampled on day 63 were affected by rain (see below). Hot dry weather then returned until mid-November, and this was followed by sufficient rain through to mid-December for establishment and growth of the annual mixed pasture. After the second sowing of sorghum late in January, weekly rainfall equalled or exceeded pan evaporation until the crop was harvested at the end of March.

Soil water contents during part A of the experiment were very low except at day 63 (Table 1). If the soil moisture contents were 0·05 g cm^{-3} before urine was applied, and 0·27 g cm^{-3} afterwards (Table 1), the average depth of penetration of urine in bare soil would have been 23 mm. The penetration under a litter cover would have been less than this. The amount of water applied as urine (4·5 mm) was less than the daily pan evaporation (Fig. 1), and it seems likely that much of this water was quickly evaporated. The microplots were covered during the rain that fell just before day 63, and the increase in water content of the 0–15·0-cm layer was from water that moved below the lower end of the cylinders from adjacent soil and then upwards to within 4 cm of the soil surface.

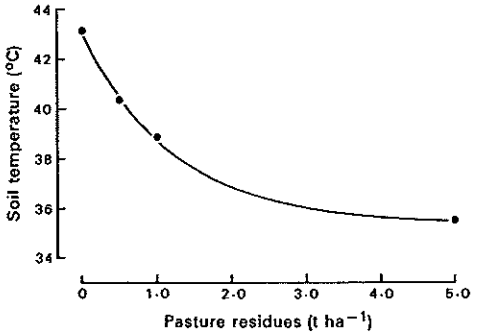

Fig. 2. Effect of quantity of pasture residues on soil temperature at 1 cm depth at 1 p.m. on 6. viii. 1981 (mean of six plots). The equation for the fitted line is $y = 35{\cdot}4 + 7{\cdot}69\,e^{-0{\cdot}80x}$.

Maximum soil temperature at 1 cm on the day of urine application was 43°C under bare soil and decreased exponentially with increasing cover of plant residues (Fig. 2). On the following day, the maximum soil temperatures ranged from 48°C in bare soil down to 40°C in soil under 5·0 t ha^{-1} of pasture residues. The lower temperatures on the first day were mainly due to the added urine, as maximum air temperatures on these two days were similar, viz 36 and 37°C, respectively.

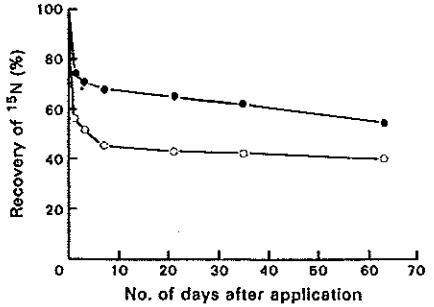

Fig. 3. Total recovery of ^{15}N in herbage residues and soil from microplots of pasture during the dry season after application of ^{15}N-urea in cattle urine. ● Total ^{15}N in herbage residues + soil. ○ Mineral ^{15}N in soil.

Nitrogen Balance during the Dry Season

Recoveries of ^{15}N in the soil and pasture residues indicate that labelled N was lost rapidly from the microplots during the first 3 days after urine application, and then the rate of loss slowed markedly (Fig. 3). The data in Fig. 3 are averaged over the amounts of pasture residues placed on the soil before the urine was applied, as

these had no significant effect on total ^{15}N recovery. Also, this recovery was not affected by whether pasture residues (5·0 t ha^{-1}) were on the soil when the urine was applied or were placed on the soil later (data not shown). On the other hand, when the urine was placed 5 cm below the soil surface the total recovery of ^{15}N after 35 days was 102% (s.e. ±1) compared with 62% (s.e. ±2) after surface application.

Most of the ^{15}N that was retained in the microplots during the dry season was in the 0–7·5-cm layer of soil. The range of recoveries up to day 63 was 48–73% in this layer, compared with 0–4% in the 7·5–15·0-cm layer, none below 15 cm, and 0–6% in the pasture residues. Approximately 65–75% of the ^{15}N recovered in the soil was in the mineral N fraction (nitrate plus exchangeable ammonium) (Fig. 3). No significant amounts of nitrate were present until day 63, when nitrate comprised approximately one-third of the mineral N.

Recovery of ^{15}N during the Wet Season

Pasture growth during November and December accumulated 2·2 t dry matter ha^{-1} and 28 kg N ha^{-1}, with little difference between the microplot and border areas. Sorghum yielded 3·0 t dry matter ha^{-1} and 46 kg N ha^{-1} in tops, with higher yields in the microplots than in the border areas, where the plants were pruned to encourage growth of the plants in the microplots.

Table 2. Recovery of ^{15}N in killed pasture before sowing the sorghum crop, and in the sorghum and soil plus roots at the end of the experiment

Killed pasture was removed on 7 January 1981, and sorghum, litter and soil + roots on 31 March 1982

Treatment		Recovery of ^{15}N (%)				
Amount of ley residues at time of urine application (t ha^{-1})	Amount of killed pasture removed before planting sorghum[A]	Killed pasture	Sorghum	Litter	Soil + roots[B]	Total
0	None	n.a.[C]	2·7	0·2	20·6	23·5
	All	5·3	2·7	0·0[D]	21·2	29·2
5	None	n.a.	1·8	0·4	21·1	23·3
	All	7·0	1·5	0·1	19·7	28·3
s.e.		0·2	0·3	0·2	1·0	1·0

[A] Replaced with equal amount of herbage not labelled with ^{15}N.
[B] To 15 cm depth.
[C] n.a., Not applicable.
[D] Less than 0·05%.

Uptake of ^{15}N by pasture between October and 31 December and by the subsequent sorghum crop was small (Table 2). Pasture growth early in the growing season was more vigorous and resulted in slightly higher uptake of ^{15}N in plots that were covered with 5·0 t ha^{-1} of ley pasture residues in August than in those that were bare at that time, but this treatment had the reverse effect on uptake of ^{15}N by the sorghum crop.

None of the treatments affected the recovery of ^{15}N in soil plus roots (0–15·0 cm) at the end of the experiment. ^{15}N in soil below the 15·0 cm depth was not measured, because the absence of any restriction on lateral movement of ^{15}N below this depth precluded accurate calculation of ^{15}N recovery.

Discussion

The apparent loss of 46% of the urea-^{15}N from cattle urine in the dry season in this experiment is at the upper end of the commonly reported range of 5–65% for losses of N from sheep and cattle urine in temperate areas (Watson and Lapins 1969; Ball *et al.* 1979; Carran *et al.* 1982; Ball and Ryden 1984), and is higher than the losses of 16–32% in similar experiments on a solodic soil in the seasonally dry tropics near Townsville, Qld (Vallis and Gardener 1984).

The pattern of a high rate of loss during the first 24 h followed by a marked decrease in the rate of loss over the next few days (Fig. 3) is characteristic of volatilization of ammonia from urine patches under warm conditions (Vallis *et al.* 1982), and this was confirmed as the main avenue of loss by the quantitative recovery of ^{15}N when the urine was covered with a 5-cm layer of soil, which would have minimized volatilization of ammonia (Terman 1979; Hauck 1983). Quantitative recovery of applied ^{15}N in this treatment is also considered to verify the laboratory procedures used.

The uptake of 6% of the applied ^{15}N by the pasture early in the growing season is low in comparison with the uptake of urine N by pasture plants in other studies. In south-western Australia, for example, where gaseous losses were of a similar order to those in the present study, 30% of the urine N applied at the start of the dry season was taken up by ryegrass in the following growing season (Watson and Lapins 1969). The causes of the poor uptake of ^{15}N from urine in the present experiment could not be identified. Scorching of the sward by urine in warm weather is considered to be an important cause of low uptake of urine N by pasture plants (Ball and Keeney 1983), but this was not possible in the present experiments. Oversupply of N or toxicity from nitrite were not implicated, as the rate of N application (150 kg ha^{-1}) was not excessive and nitrification had begun by 3 October. The most probable causes are losses of mineral N from the root zone by denitrification or leaching and further microbial immobilization of mineral N. While denitrification is thought not to occur at better-drained sites on this soil (Wetselaar 1967), an apparent loss of 14% of fertilizer N by denitrification has been observed at another site (Myers 1983). The present site is not considered to be well drained. Also, leaching of nitrate from the topsoil of Tindall clay loam during high-intensity summer rains is a well-known phenomenon (Wetselaar 1962; Day 1977; Myers 1983). Denitrification and leaching of nitrate are thought to be major pathways of N loss from urine-affected areas of pasture in New Zealand and the United Kingdom (Ball and Keeney 1983; Ball and Ryden 1984). Finally, increased microbial activity following wetting of the soil by summer storms could have caused some immobilization of mineral ^{15}N.

When the sorghum crop was sown in January, most of the residual ^{15}N in the microplot was probably in organic forms, either in residues of the killed pasture or in soil organic matter. Appreciable retention of N as non-exchangeable ammonium would not be expected in this soil, in which the dominant clay mineral is kaolinite (Wetselaar 1967). Availability of N from the pasture residues was very low, as removal of these residues had little effect on the uptake of ^{15}N by the sorghum. Thus, most of the ^{15}N taken up by the sorghum must have come from residual mineral ^{15}N or from remineralization of ^{15}N that had been immobilized in soil organic matter.

Because ^{15}N-urea was used as a tracer, the results of this experiment are considered to be directly applicable only to the urea- and ammonia-N of the urine. Ammonia is included because of the very rapid hydrolysis of urea to ammonia in urine patches under warm conditions (Vallis *et al.* 1982). The behaviour of N in other urinary compounds (mainly amino acids, hippuric acid, allantoin and creatinine) may have been quite different from that in urea. However, urea and ammonia usually account for 50–75% of the urinary N of ruminants (Church 1969), and the results of this experiment indicate that N returned in cattle urine during dry-season grazing of legume leys in this environment will result in little transfer of fixed legume N to a crop in the following wet season. It seems that the major transfer of N will be through the mineralization of organic N that accumulates in the soil during the ley phase. These conclusions are consistent with those drawn from other work in very different environments in the south-west of Western Australia (Watson 1964) and in New Zealand (Ball and Keeney 1983; Ball and Ryden 1984), where grazing ruminants are considered to cause considerable losses of N via ammonia volatilization, leaching and denitrification.

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