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Nitrogen-fertilised grass in a subtropical dairy system 1. Effect of level of nitrogen fertiliser on pasture yield and soil chemical characteristics

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Summary. The effects of 5 levels of nitrogen (N) fertiliser on pasture yield and composition and soil chemical characteristics of Rhodes grass (*Chloris gayana*) cv. Callide pasture under grazing and cutting in a subtropical environment of 800 mm annual rainfall were studied over 6 years. Pasture received annual basal dressings of superphosphate (250 kg/ha) and potassium chloride (125 kg/ha for plots, 125 kg/ha.alternate year for grazed paddocks). Urea was applied in 3 equal dressings in September, December, and February, at rates equal to 0, 150, 300, 450, and 600 kg N/ha.year. Stocking rate was 2 Holstein–Friesian milking cows/ha throughout the year, and separate areas of grazing oats (0.4 ha/cow), cracked grain (0.8 t/cow.year), and hay or silage were used to supplement pasture.

Under both cutting and grazing, pasture dry matter (DM) yield increased linearly with applied N to about 300 kg N/ha.year, with little further increase at higher levels. Under grazing there was evidence of a decrease in yield at 600 kg N/ha.year, due to total death of the pasture following frosting in winter and the need for regeneration from seedlings in spring; this regeneration was slowed by the large amount of surface litter. Grass N content increased and phosphorus and potassium contents decreased with increasing levels of applied N. All 3 nutrients increased from year 1 to 6. Leaf content of grazed pasture was highest during spring (>30% DM) and declined through to autumn (<20% DM), with no consistent effect of N level. Leaf content was consistently higher under cutting (>50%) but was not altered by level of applied N.

Soil nitrate-N levels increased (P<0.05) with level of applied N, from 4 to 42 mg/L at 0 and 600 kg N/ha.year, respectively. After 6 years of fertilisation at 300 and 450 N/ha.year, nitrate-N levels were similar to those for 600 kg N/ha.year. Soil pH decreased (P<0.05) with applied N, by 0.15 and 0.28 units annually for 150 and 600 kg N/ha.year, respectively.

We conclude that in this environment large responses in pasture growth occur under both cutting and grazing to levels of applied N to about 300 kg N/ha.year, with little response beyond this level.

Introduction

Dairy systems based on grazed tropical pastures have low productivity compared with those on temperate pastures. For example, in tropical and subtropical Australia, average farm milk production, after adjustment for the amount of concentrates given, is about 1770 L/cow.year and 1420 L/ha.year (Kerr and Chaseling 1992). This is in contrast to the high potential for growth of tropical pastures and, therefore, the apparent high potential for milk production (Colman 1971).

The factors limiting productivity include low soil nutrient status, particularly nitrogen (N), which limits the growth of tropical grasses (Henzell 1963), and low intake characteristics of these pastures (Hardison 1966). Intake and production can be increased if animals have access to a high yield of accessible leaf (Chacon and Stobbs 1976; Cowan *et al.* 1986), or if pastures contain a high proportion of legume (Davison and Cowan 1978). Much research has involved developing legume-based pastures, but it has not been possible to maintain productive grass and legume mixed pastures under the levels of stocking used on commercial farms (Lowe and Hamilton 1985).

An alternative is the use of nitrogenous fertilisers on tropical grass pastures to increase pasture yield and to eliminate the effects of stocking rate on the persistence of pasture components. Use of these fertilisers results in consistent, large increases in dry matter (DM) yield (Colman 1971; Buchanan and Cowan 1990). Fertilised pastures can sustain 2–4 cows/ha (Colman and Kaiser 1974; Davison *et al.* 1985), and milk production per ha is above that achieved with grass and legume mixed pastures (Caro Costas and Vicente Chandler 1979; Davison *et al.* 1982).

In the subtropical environment of south-eastern Queensland several experiments have demonstrated increases in pasture DM yield, in the absence of grazing, of about 25 kg/kg applied N (reviewed by Buchanan and Cowan 1990). However, applying N to pastures is practised on only a small number of farms to overcome short-term deficiencies of pasture on offer. Use is restricted by concerns that the response in milk production may not warrant the cost of fertiliser, and that continued use of N fertiliser may have detrimental effects on pastures and soils. There is also concern about whether results from coastal areas of higher rainfall and longer growing seasons (Colman and Kaiser 1974; Davison *et al.* 1985) can be extended to areas with <1000 mm annual rainfall and substantial frosting during winter.

The use of nitrogenous fertilisers on kraznozem soils has also been shown to decrease soil pH and concentrations of some cations over 3 years (Davison *et al.* 1985). At low pH (e.g. <5), responses to N fertiliser can be limited (Awad *et al.* 1979). With high rates of N application soil nitrate may build up (Rayment and Helyar 1980). In subtropical dairying areas of Australia, soils often have a higher clay content than the kraznozems and may have more buffering capacity against pH changes with the use of applied N (Rayment and Helyar 1980).

We evaluated the responses in soil, pasture, and milk production when urea was used continually to maintain productivity of a tropical grass pasture in south-eastern Queensland. This paper reports changes in pastures and soils associated with the use of various levels of N fertiliser. Over 6 years, pastures were fertilised at 5 levels of nitrogenous fertiliser and grazed by milking cows at stocking rates similar to those used on farms.

Materials and methods

The experiment was conducted at Mutdapilly Research Station in south-eastern Queensland (27°45'S; 152°40'E; alt. 40 m) in a subtropical environment of predominantly summer rainfall. Rainfall during the experiment (1983–89) is shown in Table 1. Mean maximum and minimum temperatures are 31 and 18°C in December and 20 and 5°C in July. Frosts can occur from May to September but are most common during June, July, and August. During all 6 years of the experiment January–March rainfall was below average, and in 3 years, including the last 2, rainfall in April–May was well above average.

The experiment was on an area of mixed black and brown cracking clay soils, classified as Cyrus, with water-holding capacity of 12.6 cm (Powell *et al.* 1985). These soils are neutral on the surface and strongly alkaline at depth. A high clay content of 80% restricts internal drainage. Very slight slopes (<1%) result in poor surface drainage.

Pasture

Rhodes grass (*Chloris gayana*) cv. Callide was sown into a cultivated seedbed at 3 kg seed/ha in October 1992. Subsequent rainfall was abnormally low (Table 1) and the pasture was established over 12 months, with light grazings at infrequent intervals. The pasture was fenced into 2 blocks, and each block was further subdivided at random into five 1-ha and three 0.67-ha paddocks. At sowing, pasture received 250 kg superphosphate and 125 kg potassium chloride (KCl)/ha. Superphosphate was applied at this rate each spring and KCl in alternate springs. From September 1983, five 1-ha paddocks in each of the 2 blocks were fertilised with 0, 150, 300, 450, and 600 kg N/ha.year, and three 0.67-ha paddocks with 150, 300, and 600 kg N/ha.year. Urea was surface-spread in 3 equal applications in September, December, and February. Urea was applied on a predetermined date, and no attempt was made to relate the timing of the application to rainfall.

In December 1983 a separate area of 12.8 ha was divided into 2 blocks, each of which was subdivided into eight 0.85-ha paddocks. These paddocks were ploughed and fallowed in preparation for the sowing of oats at 50 kg seed/ha in late February or March each year. Two varieties, 1 quick-maturing (Minhafer or Stout) and the other slow-maturing (Camelia or Algerian), were sown each year. At sowing, paddocks received 250 kg superphosphate/ha and 50 kg N/ha as urea. A further 50 kg N/ha was applied after the first grazing.

Table 1. Rainfall during the experiment (1983–89) and means from 1883 to 1983 (LTM) at Mutdapilly, south-eastern Queensland

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1983	60	26	86	143	210	149	63	27	32	135	128	145	1204
1984	74	41	67	116	4	57	102	26	50	63	87	89	776
1985	93	29	78	49	25	36	36	31	26	104	29	138	674
1986	40	125	26	1	49	0	32	50	18	122	104	117	684
1987	121	27	64	11	77	24	25	35	2	137	41	89	653
1988	107	64	42	390	16	153	96	66	51	7	50	108	1150
1989	103	55	100	310	141	22	36	55	10	67	143	175	1217
LTM	115	103	91	43	46	47	38	27	37	64	78	115	804

Animals

Twenty-four Holstein–Friesian cows and 8 Holstein–Friesian heifers were grouped on parity and calving date into 4 blocks of 8, from which they were randomly allocated to 8 treatment groups to enter the experiment in October 1983. These treatments were an incomplete factorial combination of 5 levels of N fertiliser (0, 150, 300, 450, 600 kg N/ha.year) and 2 stocking rates (2 and 3 cows/ha on the Rhodes grass pasture). The lower stocking rate (2 cow/ha) was chosen to be similar to those used on this type of pasture on Queensland dairy farms (Anon. 1988). All animals were artificially mated to calve in October–December 1983, and late September–November in subsequent years. Animals were diagnosed pregnant by rectal palpation in June, and those that were not pregnant at the end of mating (December–February) were maintained in treatments throughout lactation and replaced with pregnant animals, usually heifers, in early September each year.

Management

Water and shade were available in each pasture paddock. Animals grazed the 2 blocks of Rhodes grass pasture on a 2-week grazing, 2-week spelling rotation throughout the year. When sufficient oats was available in winter, cattle grazed oats during the day and Rhodes grass at night. When green DM on offer in Rhodes grass pastures was visually assessed at <0.5 t/ha, second-quality lucerne (*Medicago sativa*) hay or maize silage supplements were given at about 9 kg DM/cow.day. Feeding ceased when the amount of green leaf and stem DM on offer was visually assessed at >1 t/ha. Dry cows were given 1 kg cracked sorghum or barley grain once daily; during lactation this was increased to 3 kg once daily.

Measurements

Data were obtained at the stocking rate on Rhodes grass of 2 cows/ha. The treatment nil applied N was discontinued after 3 years. Pasture on offer to cows was sampled for yield and botanical composition in spring (September–October), summer (December–January), autumn (March–April), and winter (June–July) of years 1, 2, and 3, and in summer and autumn of year 4. During year 6, pastures were sampled every 2 weeks from the opening rains of the wet season (January) to July. In the first 4 years, both pasture replicates were sampled on the same day, and the means used as a measure of pasture on offer. In year 6 (1988–89) pastures were sampled 2–3 days before cows re-entered the replicate. At each sampling, six 0.25-m^2 quadrats from each paddock were cut to a stubble height of about 3 cm, using hand shears, and bulked for each paddock. The bulked sample was weighed, then 2 subsamples were taken: one for determination of DM content (500 g); and one for physical separation into green leaf, green stem, dead material, and weeds (500 g). After sorting, samples were dried at 80°C in a forced draught oven for 24 h. Dried samples were ground through a 1-mm screen and retained for analysis of N (Kjeldahl), phosphorus (P), and potassium (K) in years 1 and 6, and for calcium (Ca), magnesium (Mg), and sulfur (S) in year 1 (AOAC 1975).

In September 1985 and January 1989, yield of ground litter was assessed by collecting dead and decaying grass on the soil surface. After cutting the standing pasture with hand shears, the litter was collected separately. This litter did not include the stubble of the standing pasture. As with pasture, the bulked sample was weighed and a subsample (800 g) taken, weighed, and dried at 80°C for 48 h, then ground through a 1-mm screen before ashing at 600°C for 4 h (AOAC 1975).

Soil samples were taken before the imposition of treatments, in spring (September) 1983, and again in September after years 3, 5, and 6. On each occasion 20 soil cores were taken to a depth of 10 cm from each treatment within each replicate, bulked, and subsampled for analyses of nitrate-N (1:5 soil:water), pH (1:5 soil:water), electrical conductivity (EC, 1:5 soil:water), water-soluble chloride (1:5 soil:water), P (bicarbonate-extractable, Colwell 1963), and K (exchangeable, 1:20 soil:1 mol NH_4Cl/L).

In spring 1989, soil samples were taken to a depth of 1.5 m using a sampling tube of 5 cm diameter. Ten samples were taken in each treatment within each replicate, divided on the basis of depth (0–10, 10–20, 20–30, 30–40, 40–50, 50–60, 80–90, 110–120, 140–150 cm), bulked, and analysed for nitrate-N as above, ammonium-N and organic carbon (AOAC 1975), and total N (Kjeldahl).

In winter 1988, 2 operators scored paddocks of Rhodes grass for frost damage, on a 0–10 scale: 0, no damage; 10, total death.

Cutting experiment

Within an enclosed area of the 2 paddocks receiving nil N fertiliser, plots of 2 by 2 m were fertilised with the 5 rates of N fertiliser used in the main grazing trial. There were 2 replicates in each paddock. The plots were mown in September 1983, and fertiliser was applied by hand at the respective rates. Superphosphate (250 kg/ha) was applied each September, and N as for grazed pasture. Potassium chloride (125 kg/ha) was applied in year 1 but not year 2. A reduction in DM response to level of N was observed in year 2 and foliar symptoms of K deficiency were noticed. Consequently, KCl was applied at the above rate each year. Grass was mown with a reciprocating mower to 4 cm stubble height each 6 weeks throughout the growing season, and the material from a strip 0.9 by 2 m was weighed then subsampled for determination of DM content and botanical composition as above.

Statistical analyses

Data from the grazing experiment were analysed by regression analysis using level of applied N as the independent variable. Soil nitrate-N data were analysed by analysis of variance, and soil pH by analysis of covariance using data from September 1983 (pretreatment) as the covariate. Data from the cutting experiment were analysed by analysis of variance and regression.

Results

Annual response to applied N was similar in the 5 years of measurement, being relatively large from 0 to 450 kg N/ha, with no further response beyond this level (Fig. 1). Also presented are mean responses from the cutting experiment and an associated experiment on several farms in south-eastern Queensland, in which pasture yields were measured before grazing (Buchanan and Cowan 1988). The form of the response was similar in each experiment, with a plateau at 300–400 kg N/ha. Greatest response was in the range 0–300 kg N/ha. Mean annual pasture yield on offer was very low at nil applied N. Figure 2 shows that pasture yield in this treatment was similar to treatments receiving applied N at the beginning of year 1, but rapidly decreased over the first 3 years of the experiment. In years 2 and 3, pasture yield at nil applied N was consistently very low.

Pasture DM response to N was evident in each season (Fig. 2). During spring, there was a reduction in DM yield on offer at 600 kg N/ha. This effect was associated with a change in the growth habit of the grass from clump-forming at lower rates of N to running at 600 kg N/ha, with rooting from the nodes. There was extensive death of the grass, especially at 600 kg N/ha, with severe frost during winter (Fig. 3) and a build-up of

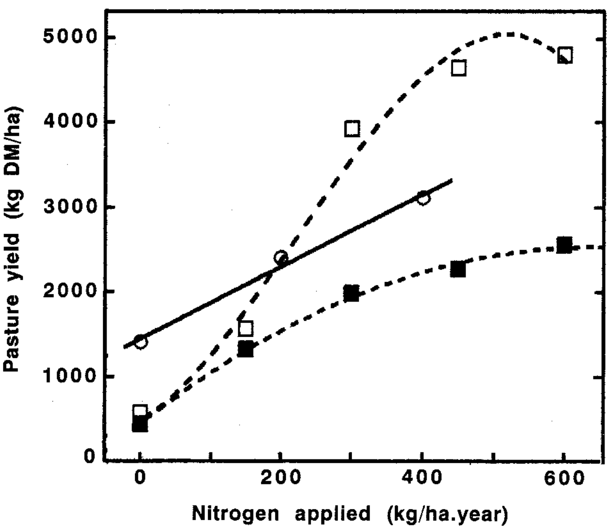

Figure 1. Relationship between the yield of Rhodes grass pasture and level of applied nitrogen under grazing and cutting. Grazing, present experiment (□), equation is $Y = 470 + 5.15X + 0.0313X^2 - 0.0000467X^3$ ($P<0.01$; $R^2 = 0.88$; r.s.d. = 202); cutting, present experiment (■), equation is $Y = 448 + 6.47X - 0.005X^2$ ($P<0.01$; $R^2 = 0.99$; r.s.d. = 65); grazed paddocks on farms (Buchanan and Cowan 1988) (○), equation is $Y = 1450 + 4.25X$ ($P<0.06$; $R^2 = 0.99$; r.s.d. = 122).

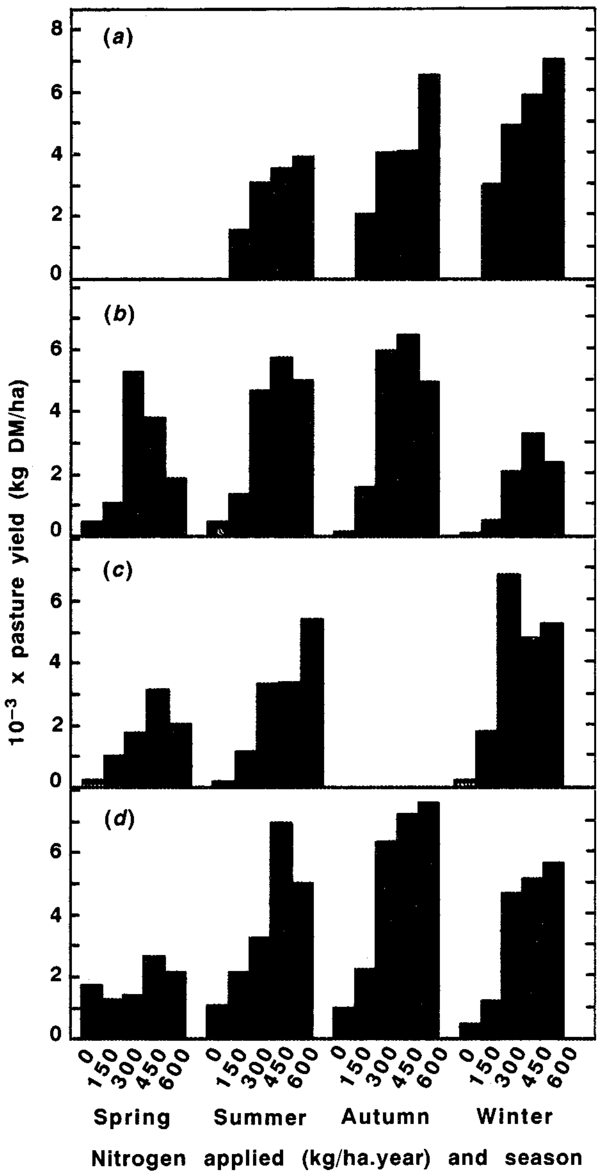

Figure 2. Effect of level of applied nitrogen on yield of a grazed Rhodes grass pasture in each season: (*a*) year 6 (1988–89); (*b*) year 3 (1985–86); (*c*) year 2 (1984–85); (*d*) year 1 (1983–84).

ground trash (Table 2). In summer year 6, the percentage of aboveground DM present as surface litter averaged 43, 57, 70, and 82% at 150, 300, 450, and 600 kg N/ha, respectively. Spring regrowth in the highest fertiliser treatment was very dependent on seedling regeneration, whereas at lower levels of applied N, grass regrowth was from the base of established clumps.

The N percentage in grass leaf and stem increased with level of fertiliser in spring and summer (Table 3). The concentration of N in leaf was higher than in stem, and values for both leaf and stem were significantly higher during summer and autumn in year 6 than in year 1. Phosphorus and K concentrations in leaf and stem decreased at higher levels of applied N in year 1, but this effect was less evident in year 6. As was the case for N, the concentrations of P and K in grass were higher in year 6 than year 1, particularly at high rates of applied N. Calcium, Mg, and S concentrations in year 1 were similar at 0 and 600 kg N/ha. Samples of total pasture taken 1 week after severe frost in July 1984 averaged 0.85% N, 0.08% P, and 0.26% K.

The percentage of leaf in pasture was relatively high during spring if rains occurred early enough to result in substantial pasture growth, and was consistently high during summer. Leaf percentage was reduced in autumn and winter (Fig. 4). Increased level of applied N had an inconsistent effect on leaf percentage in pasture on offer to cows. Content of standing dead

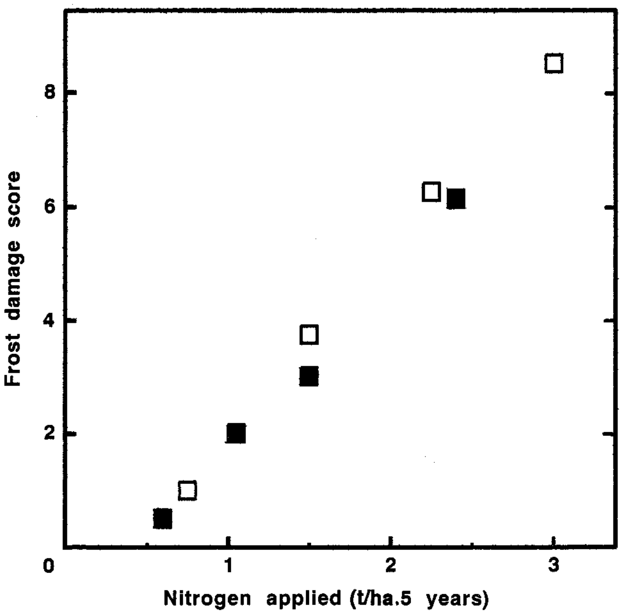

Figure 3. Relationship between the proportion of standing pasture killed by frost in winter 1988 and total level of applied nitrogen over the previous 5 years. Present experiment (□); adjacent pastures (■) used in the first 3 years of the present experiment.

matter was high in autumn, and extremely high following frost in winter (Fig. 4). After year 1, weeds were a significant percentage of the DM on offer only at nil applied N, comprising 70% of DM during summer of year 3.

The pattern of change in total standing DM on offer is shown in Figure 2. In year 6, summer rains were relatively late, and significant pasture growth did not commence until January. In spring of years 2 and 3 there was a curvilinear response ($P<0.05$) to applied N. As the season progressed, pastures receiving the highest level of applied N (600 kg N/ha) became the highest yielding, and over all years there was a linear ($P<0.01$) response to N level during autumn and early winter. Following heavy frost in late June there was no green leaf on offer during July. The stem proportion of the pasture increased substantially for all treatments from spring to winter (Fig. 4).

Soil nitrate-N levels increased ($P<0.05$) with level of applied N, from about 4 mg/L at nil N to 39 mg/L at 600 kg N/ha (Table 4). In 1989, after 6 years of fertilisation, values were similar at 300, 450, and 600 kg N/ha. Soil pH decreased with applied N, and the rate of decline was greater at the higher levels of application (Table 4). Concentrations of K, Cl, and P were increased ($P<0.05$) from initial values (mean ± s.e.) of 0.30 ± 0.05 cmol/kg, 14.8 ± 3.7 mg/L, and 12 ± 2 mg/L, to 0.55 ± 0.02 cmol/kg, 48 ± 4 mg/L, and 18 ± 3 mg/L in year 6. In years 3 and 6, K concentrations decreased ($P<0.05$) with increasing levels of applied N, the values after 3 years being 0.72, 0.58, 0.51, 0.44, and 0.48 cmol/kg at 0, 150, 300, 450, and 600 kg N/ha, respectively. Levels of Ca, Mg, S, and sodium (Na) averaged 22, 15, 8, and 1.2 cmol/kg, respectively, and were not affected by treatment. Electrical conductivity of soil solution was initially 0.039 ± 0.003 mS/cm, and this increased to 0.129 in year 3, 0.101 in year 5, and 0.312 in year 6. In year 3, there were significant

Table 2. Yield (kg/ha) of surface litter in grazed paddocks fertilised with five rates of nitrogen over six years

DM, dry matter; OM, organic matter

	Applied nitrogen (kg/ha.year)				
	0	150	300	450	600
	Year 2 (Sept. 1985)				
Surface litter DM	332	1187	2818	3717	6933
Surface litter OM	233	973	2452	2863	6378
Standing pasture DM	500	1126	5287	3825	1906
Total DM	832	2313	8105	7542	8835
	Year 6 (Jan. 1989)				
Surface litter DM	—	1296	4155	7769	13 283
Surface litter OM	—	984	3296	6081	9340
Standing pasture DM	—	1683	3184	3265	2919
Total DM	—	2979	7339	11 034	16 202

(P<0.01) differences between treatments, with values varying from 0.095 at nil applied N to 0.191 at 600 kg N/ha. However, in years 5 and 6 there was no significant difference in EC between 150, 300, 450, and 600 kg N/ha. In September 1989 the bulk density of dry soil was measured at 1.17 g/cm^3, with no significant difference between treatments.

Analyses of soils from the 10–20 cm depth in 1989 showed no significant (P>0.05) difference between treatments for the above measurements, with values similar to initial values for soils from 0–10 cm depth. Variation between treatments in the surface soil was confined to depths <60 cm (Fig. 5). Below 60 cm, nitrate, ammonium, and total N levels were very low. Organic carbon levels declined steadily from 60 to 150 cm depth.

Cutting experiment

Dry matter production (kg DM/ha) was curvilinearly related to level of applied N (kg N/ha) in each season and over the full year. Equations describing the mean yields were as follows:

Spring DM = 430 + 6.9N – 0.0026N^2 (R^2 = 0.99; r.s.d. = 53)
Summer DM = 1191 + 15.6N – 0.0132N^2 (R^2 = 0.99; r.s.d. = 75)
Autumn DM = 472 + 7.6N – 0.0076N^2 (R^2 = 0.95; r.s.d. = 123)
Annual DM = 2094 + 30.2N – 0.0235N^2 (R^2 = 0.99; r.s.d. = 214)

There was a strong incremental response to applied N up to 300 kg N/ha in each year (Fig. 6). The most consistent response was in summer (Fig. 6), with responses during spring being dependent on early rainfall. A significant response in autumn occurred only in year 5.

Table 3. Chemical analyses (% DM) of leaf and stem at selected rates of nitrogen fertiliser

Data for 150 and 450 kg N/ha.year are not presented for year 1; data for 150 kg N/ha.year are presented for year 6, as nil N applied was discontinued after 3 years

Component and N rate (kg/ha.year)	Year 1 (1983–84) N	P	K	Ca	Mg	S	Component and N rate (kg/ha.year)	Year 6 (1988–89) N	P	K
						Spring				
Leaf										
0	1.25	0.23	1.50	0.43	0.28	0.19				
300	1.35	0.18	0.93	—	—	—				
600	2.18	0.13	1.06	0.56	0.20	0.25				
Stem										
0	0.58	0.28	2.12	—	—	—				
300	—	—	—	—	—	—				
600	1.63	0.11	1.42	—	—	—				
						Summer				
Leaf							Leaf			
0	1.26	0.31	1.71	0.57	0.35	0.23	150	1.95	0.27	1.60
300	1.57	0.15	1.03	—	—	—	300	2.61	0.19	1.82
600	1.82	0.11	1.06	0.50	0.25	0.24	600	3.57	0.29	1.75
Stem							Stem			
0	0.58	0.41	1.86	—	—	—	150	1.23	0.31	1.97
300	—	—	—	—	—	—	300	2.03	0.20	2.72
600	1.16	0.07	1.18	—	—	—	600	2.64	0.21	2.09
						Autumn				
Leaf							Leaf			
0	2.17	0.51	1.72	0.54	0.32	0.32	150	2.78	0.25	2.33
300	2.11	0.20	1.39	—	—	—	300	2.72	0.18	—
600	2.09	0.12	1.11	0.68	0.33	0.26	600	2.45	0.16	1.27
Stem							Stem			
0	0.97	0.45	2.42	—	—	—	150	2.03	0.31	2.79
300	—	—	—	—	—	—	300	2.62	0.24	2.33
600	1.13	0.06	0.98	—	—	—	600	2.18	0.13	1.75
						Winter				
Leaf							Leaf			
0	1.76	0.24	1.61	0.65	0.50	0.42	150	1.57	0.28	1.59
300	1.22	0.11	1.09	—	—	—	300	1.92	0.28	1.45
600	1.87	0.11	0.74	0.87	0.46	0.38	600	1.17	0.23	1.53
Stem							Stem			
0	0.62	0.19	0.87	—	—	—	150	0.61	0.24	1.37
300	—	—	—	—	—	—	300	0.61	0.22	1.45
600	1.02	0.06	0.50	—	—	—	600	1.14	0.13	1.02

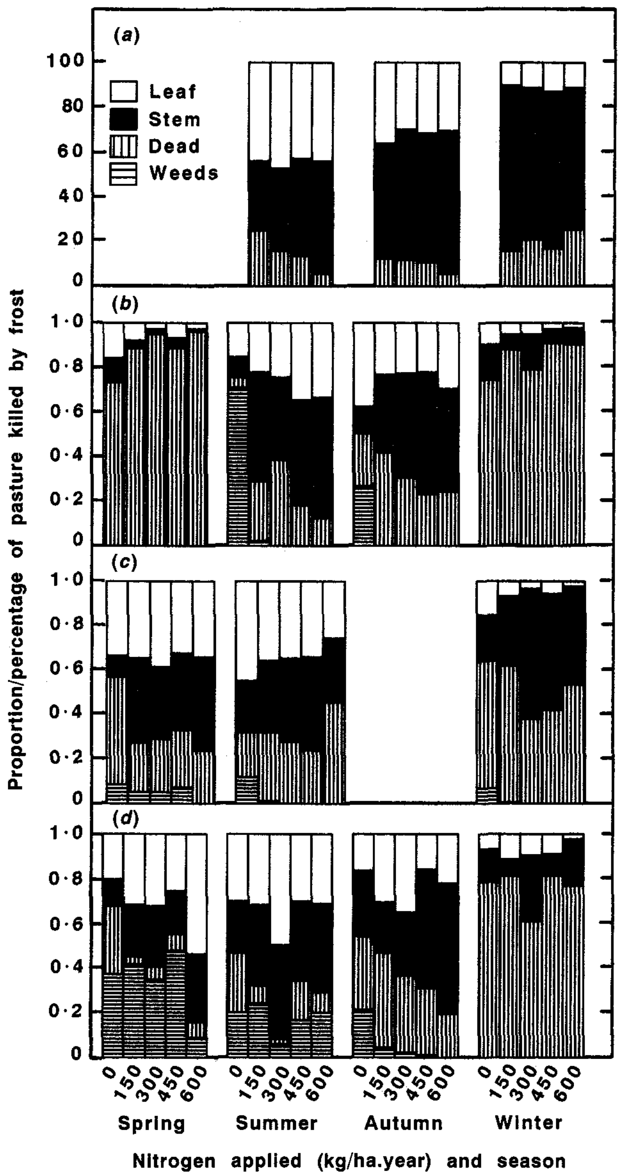

Figure 4. Effect of level of applied nitrogen on proportions of botanical components in a grazed Rhodes grass pasture in each season: (*a*) year 6 (1988–89); (*b*) year 3 (1985–86); (*c*) year 2 (1984–85); (*d*) year 1 (1983–84).

Leaf content of grass under regular cutting was consistently higher than for grazed grass, with leaf content in summer being >50% of DM (Fig. 7). The percentage of leaf in grass DM was not altered by level of applied N (Fig. 7).

Discussion

The response in pasture DM yield to level of applied N was curvilinear and of similar form in both cut and grazed swards. Greatest response occurred at 0–300 kg N/ha, and there was little or no response at >400 kg N/ha. Teitzel *et al.* (1991) reviewed cutting experiments conducted in Queensland and concluded that in areas with average annual rainfall of 750 mm, the main response in DM yield occurred from 0 to 300 kg N/ha, with no response above 400 kg N/ha. In higher rainfall zones the pasture response continued to higher levels of applied N.

We observed some negative effects of the highest level of applied N on pasture yield, largely associated with a high death rate of plant material after frosting in winter and the need for regeneration from seedlings in spring. Some depression in yield of grazed kikuyu pastures at 672 kg N/ha was also recorded by Mears and Humphreys (1974). Other than this specific effect on spring growth at the highest level of applied N, the regular application of N did not alter the seasonal distribution pattern of pasture growth. Murtagh (1980) observed no change in seasonal distribution of pasture growth with applied N in 3 coastal areas of higher rainfall.

There was rapid deterioration of pastures receiving no applied N. By contrast, at 150 kg N/ha the grass was vigorous and weed-free. Rayment and Helyar (1980) calculated the maintenance requirements for fertiliser N as 77 kg N/ha for pastures producing annual yields similar to those in our study. Robbins *et al.* (1989) demonstrated that tropical grass pastures receiving 58 kg N/ha showed a substantial decline in productivity during the 5 years following establishment, an effect attributed to the annual incorporation of about 15 kg N/ha into ground litter and the subsequent N deficiency in the grass. On the other hand, Gartner (1969) showed that N applied to a tropical grass pasture encouraged development of the introduced species. Since we applied no N and the soils had a very low nitrate-N content at the beginning of the experiment, a severe N deficiency probably caused the rapid

Table 4. Effect of level of nitrogen fertiliser on soil nitrate-N concentrations and pH in spring

1983 represents the pretreatment measurements

	Applied nitrogen (kg/ha.year)					
	0	150	300	450	600	s.e.m.
	Nitrate-N concentration (mg/L)					
1983	6.0	7.0	8.5	7.0	4.5	3.2
1986	3.5	10.5	15.5	42.5	49.0	5.7
1988	—	7.0	14.0	33.0	24.5	5.3
1989	—	11.0	45.0	41.0	42.0	8.3
	Soil pH					
1983	7.1	7.3	7.5	7.2	7.6	0.29
1986	7.0	6.9	6.9	6.5	6.1	0.06
1988	—	6.9	6.8	6.3	6.4	0.23
1989	—	6.4	6.3	6.0	5.9	0.08

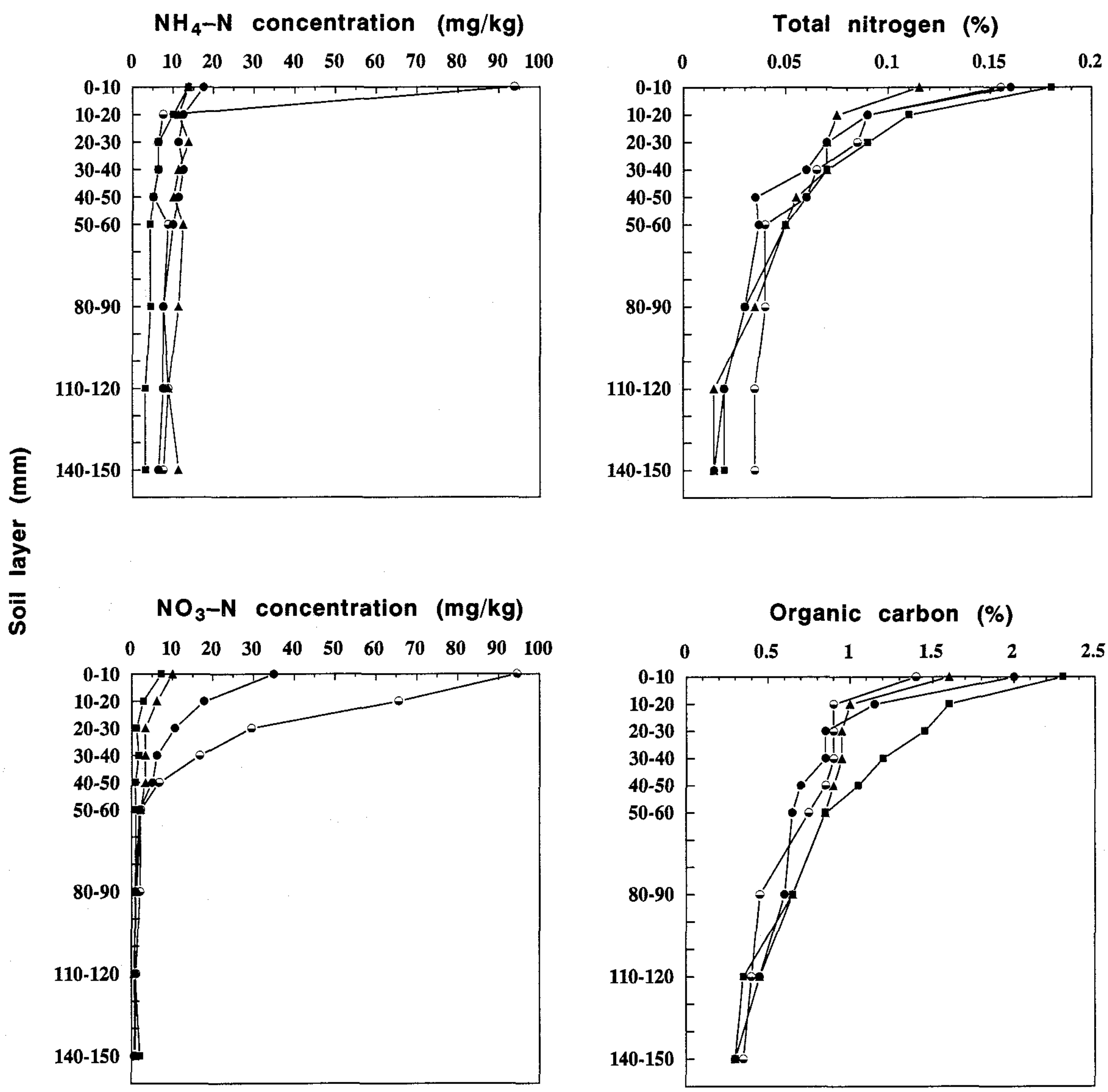

Figure 5. Changes in soil content of nitrate and ammonium nitrogen, total nitrogen, and organic carbon with depth following 6 years of nitrogen fertilisation (kg N/ha.year): 600 (◒), 450 (●), 300 (▲), 150 (■).

deterioration of the grass in our pastures. From the data it is not possible to determine a minimum level needed to maintain the grass, but evidence (our results and the above discussion) suggests about 80–150 kg N/ha.year.

The combination of high levels of applied N (600 kg N/ha.year) and large amounts of surface litter was associated with marked changes in the growth habit of Rhodes grass. Although our data are limited in describing this effect, Rhodes grass formed a sward rooted at the nodes through runners, with almost a complete absence of large stools of grass. These pastures were observed to wilt more rapidly in dry weather than those at lower N levels, and our data show they were more easily killed by frost. In early spring the paddock was covered with about 8 cm of litter, and most regrowth was through seedling re-establishment. R. J. Moss (unpublished data) subsequently observed this effect in paddocks receiving lower levels of applied N (300 kg N/ha) and stocked lightly (0.5 cows/ha) during summer and autumn. We conclude that this effect is related to the amount of standing, unutilised grass in the pasture when frosted in winter. In our environment there was an increase in the amount of surface litter with time. Modest amounts of surface

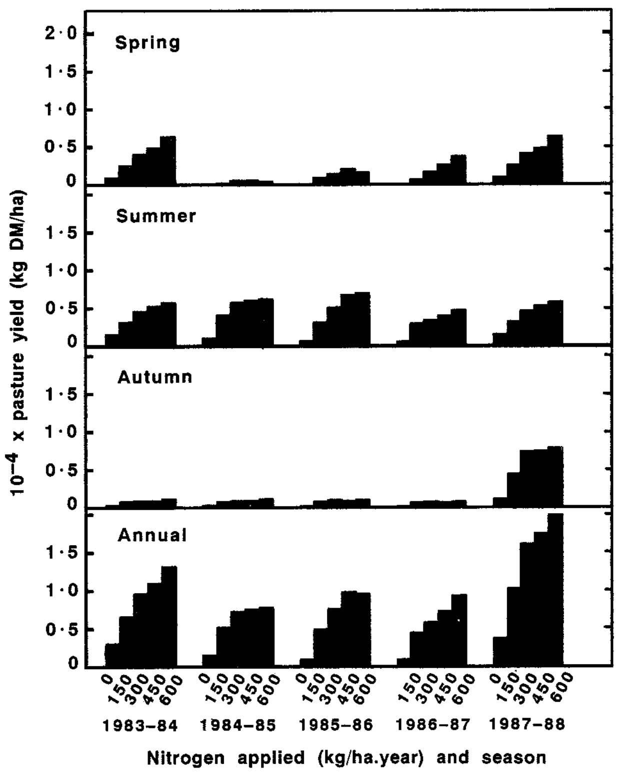

Figure 6. Effect of level of applied nitrogen to a Rhodes grass pasture harvested by cutting each 6 weeks on pasture yield in each season.

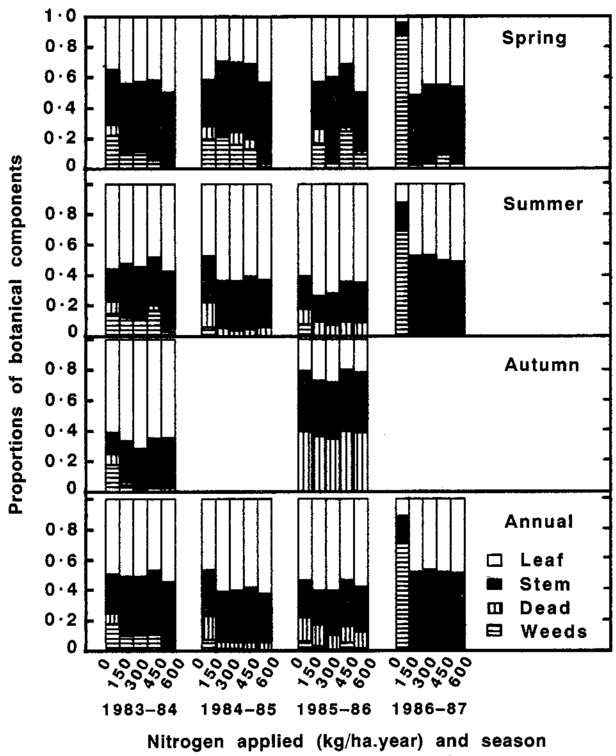

Figure 7. Effect of level of applied nitrogen to a Rhodes grass pasture harvested by cutting each 6 weeks on proportions of botanical components in each season.

litter are likely to be beneficial in moisture retention and as a source of recycled nutrients (Jarvis *et al.* 1989), but excessive amounts lead to the effects we observed at 600 kg N/ha. In our experiment, surface litter levels >4 t DM/ha were associated with reduced spring growth of pasture.

The increase in N concentration in grass leaf and stem with level of applied N was most evident during spring, while there was no consistent response during autumn and winter. Gartner and Everett (1970) and Buchanan and Cowan (1986) measured more pronounced increases in plant N concentration during spring than during summer and autumn. The decline in P concentration in grass leaf and stem is consistent with previous reports (Davison *et al.* 1985), and in our experiment was much more evident in year 1 than year 6. After 6 years of application of both N and P fertiliser, soil P concentrations had increased, and the P concentration in grass receiving 600 kg N/ha approached the concentrations in grass receiving 150 kg N/ha. The greatest effects in year 6 occurred in stem, rather than leaf, P concentrations. Similar effects were noted for K concentrations in leaf and stem, with strong negative effects of fertiliser N level in year 1 and no consistent effect in year 6. These effects further demonstrate the cumulative effect of fertiliser level on the soil–pasture system.

During autumn, pastures contain a low percentage of leaf. The diet of grazing cows often has a high stem content (Davison *et al.* 1985; Cowan *et al.* 1986) and, consequently, a low crude protein content (Moss *et al.* 1992). A large part of the standing stem needs to be removed to avoid the problems of regrowth in spring (referred to earlier in Discussion), and in practice, this material may be better used by less productive animals such as dry cows or heifers. Alternatively, a high yield of stemmy grass would be available for conservation in late autumn if a suitable use for the conserved material was available. The need to produce large amounts of stem in association with leaf leads to a build-up of ground litter and requires a higher level of applied N fertiliser than would be necessary to grow leaf alone. Both of these effects limit the sustainability of the system, through effects on pasture regrowth in spring and on soil acidification and nitrate levels.

The decline in soil pH with time is consistent with previous results (Davison *et al.* 1985; Reason *et al.* 1989; Teitzel *et al.* 1991). Our results suggest that the rate of decline on the heavily buffered clay soils in our experiment is similar to that on the lighter textured kraznozems used by Davison *et al.* (1985). On a wide range of soils in south-eastern Queensland supporting tropical grass pasture and receiving 200 and 600 kg N/ha.year, respectively, a mean rate of decline in soil pH of 0.12 and 0.25 units each year was measured (Reason *et al.* 1989). These values are comparable to ours (0.15 and 0.28, respectively) and the 0.12 reported by Davison *et al.* (1985) for pastures receiving 200 kg N/ha.year as ammonium nitrate. The rates of decline are considerably higher than those for soils of initial pH <5.5 (Teitzel *et al.* 1991). Reason *et al.* (1989) attributed some of the initial fall in pH to increasing ionic strength of the soil solution, and thought that changes in pH could exaggerate the change in hydrogen ion concentration in soil solution. The pattern of change in pH values in our experiment tends to support this, as we measured more rapid initial declines in pH at 600 kg N/ha than at lower levels of applied N, yet after 6 years of fertilisation, pH values were similar for soils receiving 150–600 N/ha.year.

The build-up of soil nitrate-N under these pastures was modest, with highest values of about 40 mg/L (equal to about 40 kg NO_3-N/ha). Some of the soils used by Reason *et al.* (1989) achieved up to 400 mg nitrate-N/L, with a mean value of 100 mg/L for 600 kg N/ha.year after 4 years. There was no evidence of leaching of nitrate in the heavy soils used in our experiment, and at 600 kg N/ha.year about 100 kg N/ha was present in surface litter and standing pasture. Assuming that this N is incorporated into the soil organic N fraction (Robbins *et al.* 1989), and that 25 kg N/ha is removed annually in milk, then about 70% of applied N was lost through volatilisation or surface runoff. At 300 kg N/ha, the value is about 50%. Clearly, practices that increase the efficiency of use of applied N would improve the economics of fertiliser use and avoid some of the associated effects, such as acidification, and the subject warrants further investigation.

We conclude that there are large responses in pasture growth to levels of applied N up to 300 kg N/ha.year, with much less response above this level. Responses were consistent in cut and grazed swards and occurred in both leaf and stem, with a large accumulation of stem during autumn. If not removed, this can have detrimental effects on spring regrowth. The net efficiency of N use was low, suggesting substantial opportunities for further research.

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