The influence of nitrogen fertilisation and soil pH on the dry matter yield and forage quality of *Pennisetum purpureum* and *P. purpureum* × *P. glaucum* hybrids

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Abstract

The influence of soil acidity and nitrogen fertilisation on the DM yield of *Pennisetum purpureum* (napier grass) and two *Pennisetum* hybrids, known as Bana and Green-gold, was investigated on the Hatfield Experimental Farm of the University of Pretoria, Republic of South Africa. The pH(H_2O) of top soil on the experimental site was 4.2. Two other pH levels (5.6 and 6.5) were created by applying different rates of $Ca(OH)_2$. Four levels of N fertilisation (0, 100, 200 and 400 kg/ha) were compared using 3 replications per treatment combination. The results indicated that napier grass was not well adapted to the site, but both hybrids were persistent and drought-resistant and compared favourably with other pasture grasses adapted to this region. None of the pastures in this trial was sensitive to acidity in the top soil. The optimum level of N application was 150 kg/ha/yr, similar to that for other subtropical grass pastures in the region.

Introduction

Pennisetum purpureum, commonly known as elephant grass or napier grass, is endemic to the tropical regions of Africa, with a relatively high yield potential. It also has a high yield potential in subtropical regions. The species grows well on almost all soil types, but DM yield is positively correlated with soil fertility (Bogdan 1977). There are approximately 11 cultivars, including Merker, Capricorn and Gold Coast (Ghana) (Bogdan 1977).

In addition to napier grass, two hybrids of *P. purpureum* and *Pennisetum glaucum* (pearl millet), commercially known as Bana grass and Green-gold, are currently grown in South Africa. A key objective with the hybridisation has been to develop cultivars with higher quality than napier grass. These and several other hybrids have given higher yields than napier grass on light textured, acidic soils, under rainfed conditions in Zimbabwe (Gupta undated). However, they have not been evaluated on heavier textured soils in the subhumid or semi-arid subtropics. Hence, a trial was conducted to compare the productivity and quality of napier grass and the local 2 hybrids at 3 pH and 4 N levels.

Methods

Two *P. purpureum x P. glaucum* hybrids, Bana and Green-gold, and *P. purpureum* cultivar Gold Coast were planted as rooted segments, on the Hatfield Experimental farm of the University of Pretoria in the spring of 1987. Each plot covered an area of 6 m^2 with 6 plants per plot. The soil on the experimental site is a deep, red sand-clay-loam, classified as a Hutton form (Soil Classification Working Group 1991) with 25% clay, 14 mg/kg P, 23 mg/kg K, 140 mg/kg Ca and 14 mg/kg Mg. In the 1970s, the whole area was treated with heavy applications of $(NH_4)_2SO_4$ in order to create an acid soil for future trials (R.O. Barnard, personal communication). At the onset of this trial, the $pH_{(water)}$ of the topsoil was 4.2. The trial was a split-plot design with 3 replications of each treatment combination. There were 3 soil acidities: 4.2 (pH1), 5.6 (pH2) and 6.5 (pH3). These were achieved by applying $Ca(OH)_2$ at 0 kg/ha (pH1), 4192 kg/ha (pH2) and 7200 kg/ha (pH3), respectively, to the main plots. Each block was then subdivided into 12 plots to which the other treatment combinations

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(N fertilisation x forage type) were randomly allocated. The N levels compared were: 0, 100, 200 and 400 kg/ha/yr. In the first year of the trial, plots receiving 100 kg/ha/yr N received 57.5 kg/ha K, those receiving 200 kg/ha/yr N, 230 kg/ha K and those receiving 400 kg/ha/yr N, 576 kg/ha K. The plots that received 400 kg/ha N also received a P application of 44.65 kg/ha. The trial was not fertilised in the second season, but thereafter all plots received, in addition to the N fertilisation, an annual application equivalent to 250 kg/ha K and 30 kg/ha P. All fertiliser was applied as a single application in spring and the N was applied in the form of limestone ammonium nitrate (LAN)(28%N), which is produced locally by mixing dolomitic limestone and NH_4NO_3 at a ratio of 1:4.

The grasses were harvested twice each season when they reached a height of 1.5–2 m. Cut material was weighed in the field and subsampled for the determination of moisture content. The samples were dried to a constant mass at 65°C and used for the calculation of dry matter concentration.

On a number of occasions, the samples for each treatment combination were pooled, milled and analysed for *in vitro* digestible organic matter (IVDOM) (Tilley and Terry 1963) and chemical composition (N, P, K, calcium, magnesium, sodium, copper, manganese, zinc and iron).

Soil samples to a depth of 15–20 cm, to monitor soil fertility, were also taken at intervals. In the last season, the soil was sampled to a depth of 1.5 m, to investigate the possible leaching of NO_3^- and the P and K concentrations in the soil. The soil pH was also measured, but the measurement was $pH_{(KCl)}$ instead of $pH_{(water)}$. Although there is no fixed relationship between $pH_{(KCl)}$ and $pH_{(water)}$, it is accepted as a rule of thumb that the $pH_{(KCl)}$ is ≥ 0.5 units lower than $pH_{(water)}$ (Prof. A.S. Claassens, personal communication).

DM yield measurements were taken over a period of 8 years. The first year's results are already published (Pieterse *et al.* 1992) and the seventh year's results were lost because of human error.

Statistical analysis was done on the yield data with the GLM procedure, available in the SAS program.

Results

Soil acidity and DM yield

At the end of the first growing season (1987–88), the soil pH levels were 6.7 for pH3, 5.7 for pH2 and 4.6 for pH1. An analysis of soil samples, taken from the top 15 cm of the soil at the beginning of the 1991–92 growing season, showed no noticeable change in pH from levels at the end of the first season, but there was a noticeable increase in the K concentration in the soil (Table 1).

At the beginning of the last growing season (1995–96), the pH of the upper soil layers on the plots which received the highest N application was noticeably lower than those on the control

Table 1. Soil analysis data of the top 15 cm of soil, taken at the beginning of the 1991–92 growing season, from plots that were limed in 1987 and were then fertilised at different levels with N.

Treatment				Concentration (mg/kg)				
		$pH(H_2O)$	% AS[1]	P	K	Ca	Mg	Na
pH1[3]	N1[2]	4.8	15	11	37	227	60	20
	N2	4.6	21	18	63	164	37	18
	N3	4.8	15	18	87	243	29	17
	N4	4.2	43	23	75	99	40	17
pH2	N1	5.7	0	16	68	528	48	19
	N2	6.7	0	14	60	750	68	16
	N3	5.3	0	10	56	395	44	17
	N4	6.3	0	18	64	712	50	17
pH3	N1	7.4	0	15	57	1198	62	17
	N2	7.6	0	12	60	1522	48	19
	N3	5.7	0	11	117	487	50	23
	N4	6.6	0	32	54	809	65	19

[1]% acid saturation.
[2]N1 = nil kg/ha N; N2 = 100 kg/ha N; N3 = 200 kg/ha N; N4 = 400 kg/ha N.
[3]pH1 ≈ 4.2; pH2 ≈ 5.6; pH3 ≈ 6.5 in 1987.

plots (Table 2). The pH of the subsoil was approximately 5.2 (KCl) and did not differ between pH treatments.

During the first 4 years, the average DM yields from the neutral plots (pH3) were significantly (P≤0.05) higher than those from the acid (pH1) plots (Figure 1). The yields obtained on the neutral plots during the last 2 seasons were also higher than on the other treatments, but the differences were not significant (P>0.05). There were no significant interactions between soil pH and level of N application in terms of DM yield of the cultivars.

N fertilisation and DM yield

During 1989–90 and 1990–91, average yield at 400 kg/ha N was significantly (P≤0.05) higher than with the other 3 N levels (Figure 2), which did not differ significantly (P>0.05). In1991–92 and 1992–93, there was no significant response to N fertilisation, because of below average rainfall. The total DM response to the heaviest N application was only 0.73 t/ha (Figure 2). During 1993–94 and 1995–96, there were progressive significant (P≤0.05) responses in dry matter yield with each additional increment of N fertiliser (Figure 2).

Cultivars and DM yield

Results obtained with Bana grass in the establishment year have been published (Pieterse *et al.* 1992), and the rest of the data from this year unfortunately disappeared with the M.Sc. student who was responsible for the trial at the time. The DM yields with Bana, Green-gold and napier during the following growing season (1988–89) were extremely high (20.8, 26.9 and 23.3 t/ha, respectively), mainly because the material was harvested at a mature stage. During the following 2 growing seasons (1989–90 and 1990–91), when the area received an average precipitation of ≈ 750 mm/yr, the cultivars were harvested at an earlier stage and average yields were 15.11, 13.98 and 14.08 t/ha for Bana, Green-gold and napier grass, respectively (P>0.05). Highest yield (19.57 t/ha) during this period was obtained with napier at 400 kg/ha N, on the pH1 plots (Table 3). The highest yields with Bana (18.40 t/ha) and Green-gold (18.52 t/ha) were also obtained at 400 kg/ha, but on plots with the highest soil pH (pH3).

Table 2. Level of acidity and concentration of a number of essential nutrients in the topsoil from plots on which Bana was grown over a period of 8 years, fertilised at levels of 250 kg/ha/yr K, 30 kg/ha/yr P and 4 levels of N.

N rate (kg/ha)	ph1[1]					pH2					pH3				
	pH (KCl)	P	K	Ca	Mg	pH (KCl)	P	K	Ca	Mg	pH (KCl)	P	K	Ca	Mg
		(mg/kg)					(mg/kg)					(mg/kg)			
0	3.7	23	155	97	25	4.2	18	91	322	64	4.5	13	72	416	37
100	3.7	25	69	186	40	4.2	12	113	291	57	5.7	24	62	298	73
200	3.8	15	70	259	33	4.1	28	111	302	53	5.7	12	115	524	54
400	3.6	23	NA[2]	144	45	3.7	33	101	160	47	3.6	17	42	174	50

[1]Initial $pH_{(water)}$: pH1 ≈ 4.2; pH2 ≈ 5.6; pH3 ≈ 6.5.
[2]Not available.

Table 3. The influence of N fertilisation on the DM yield (average over 2 seasons) of Bana, Green-gold and napier grass.

N rate (kg/ha)	Bana			Green-gold			Napier		
	1989–90 & 1990–91	1991–92 & 1992–93	1993–94 & 1995–96	1989–90 & 1990–91	1991–92 & 1992–93	1993–94 & 1995–96	1989–90 & 1990–91	1991–92 & 1992–93	1993–94 & 1995–96
					(t/ha)				
0	13.47a[1]	7.54a	6.67a	12.71a	7.01a	5.34a	12.50a	7.19a	6.24a
100	15.12ab	8.94a	9.82b	13.13a	8.06a	10.17b	12.58a	6.62a	5.83a
200	15.25ab	8.35a	12.36c	13.47a	8.46a	11.96b	12.87a	6.53a	7.37ab
400	16.60b	8.70a	16.32d	16.59b	8.42a	16.35c	18.41b	6.78a	9.90b

[1]Values within columns followed by the same letter are not significantly different (P>0.05).

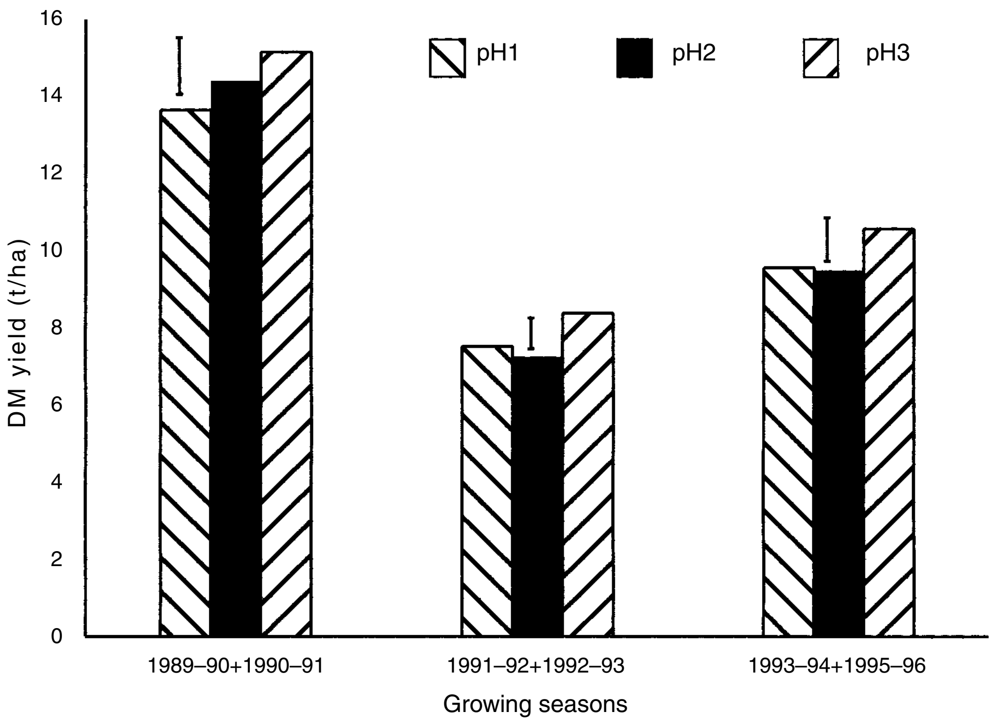

Figure 1. The average DM yields (average over 2 seasons, 3 forages and 4 N applications) of *Pennisetum* forages, at 3 topsoil pH levels (pH1 ≈ 4.2, pH2 ≈ 5.6 and pH3 ≈ 6.5). The vertical bars represent the necessary difference for significance (P≤0.05).

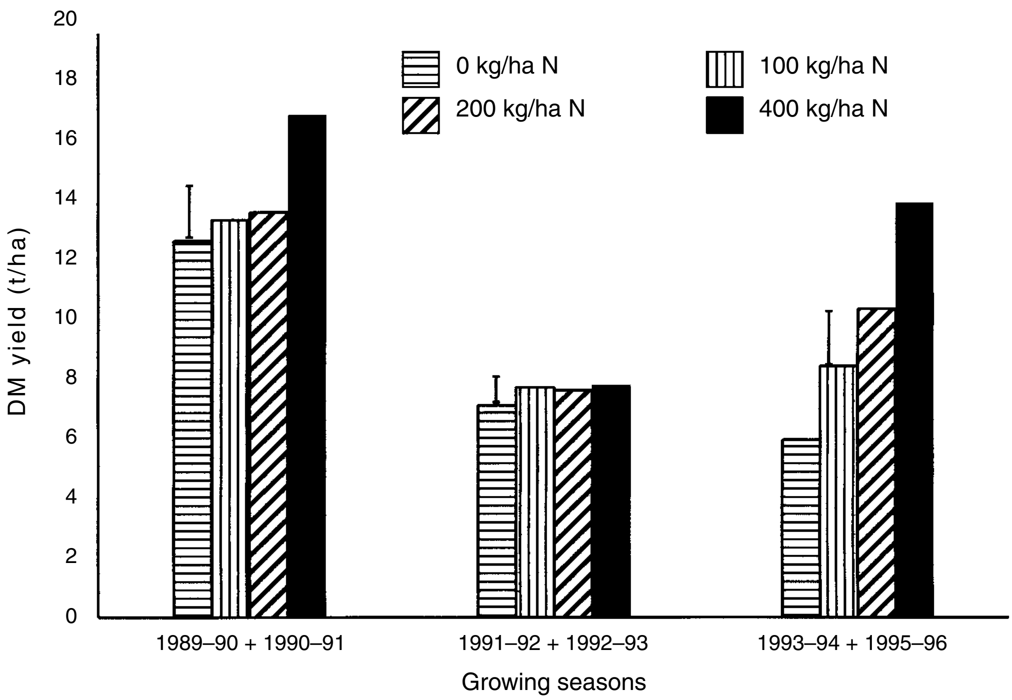

Figure 2. The average DM yields (average over 2 seasons, 3 cultivars and 3 pH levels in the topsoil) of *Pennisetum* forages, at 4 levels of applied N. The vertical bars represent the necessary differences for significance (P≤0.05).

The next two growing seasons (1991–92 and 1992–93) had below average rainfall (<400 mm/yr) and DM yields dropped correspondingly. Average yields of Bana (8.39 t/ha) and Green-gold (7.99 t/ha) were significantly ($P \leq 0.05$) higher than that of napier (6.78 t/ha). The highest DM yield was obtained from Bana (9.89 t/ha) at 400 kg/ha N, on plots with the highest soil pH (pH3). Green-gold gave maximum yield on the pH3 plots, but at 300 kg/ha N. By contrast, napier grass yield peaked at 0 kg/ha N (7.59 t/ha) on the high pH (pH3) plots (Table 3).

The 1993–94 and 1995–96 growing seasons had above average rainfall (>800 mm/yr) and the average yields from Bana (11.29 t/ha) and Green-gold (10.95 t/ha) were again significantly higher than that from napier (7.33 t/ha) (Table 3). The highest yield from Bana (17.91 t/ha) was again obtained at 400 kg/ha N on the pH3 plots. The highest yields from Green-gold (17.21 t/ha) and napier grass (10.88 t/ha) were also obtained at 400 kg/ha N, but on the pH2 plots (Table 3).

Influence of N fertilisation and soil acidity on quality of the fodder

N fertilisation affected crude protein concentration in the fodder, but not the concentration of other essential nutrients (Table 4). P, K and Ca concentrations in Green-gold were higher than in Bana. Neither N application nor pH had an effect on DM digestibility of the 3 cultivars (Table 5). The data presented in Table 5 are from analyses on material from the second harvest of the 1995–96 growing season. The yields from the Bana and Green-gold plots at this harvest, were approximately 2, 4, 6 and 11 t/ha with 0, 100, 200 and 400 kg/ha N, respectively.

Effect of N fertilisation on total N concentration in the soil

Analyses of soil samples, collected at different depths, showed the highest total N concentration was 518 mg/kg in the topsoil on treatments that

Table 4. The influence of N fertilisation on the chemical composition of Bana, Green-gold and napier grass from the second harvest of the 1990–1991 growing season, grown on plots with a $pH_{(water)}$ of ≈ 6.5 in the top soil.

Forage	N application (kg/ha)	CP	P	K	Ca	Mg	Na	Cu	Mn	Zn	Fe
		(%)						(mg/kg)			
Bana	0	9.88	0.13	1.31	029	0.51	0.02	8	200	12	157
	100	10.56	0.14	1.63	0.25	0.41	0.03	15	129	19	162
	200	11.31	0.13	1.94	0.28	0.42	0.03	17	200	21	224
	400	11.19	0.13	0.93	0.27	0.59	0.03	9	150	14	118
Green-gold	0	9.43	0.15	1.64	0.34	0.47	0.04	15	200	21	260
	100	9.13	0.18	2.22	0.32	0.35	0.02	17	150	20	209
	200	9.81	0.16	2.12	0.29	0.42	0.02	15	150	19	143
	400	10.75	0.17	1.21	0.29	0.52	0.02	13	200	17	177
Napier	0	9.62	0.15	1.82	0.32	0.39	0.02	12	250	18	202
	100	10.06	0.14	1.21	0.35	0.44	0.02	12	118	13	138
	200	10.31	0.12	1.67	0.27	0.37	0.02	12	119	15	195
	400	11.94	0.14	1.17	0.37	0.54	0.02	15	300	15	193

Table 5. The IVDOM concentration (%) in the DM from the second harvest from 3 forages, grown at 3 topsoil pH levels (pH1 ≈ 4.2, pH2 ≈ 5.6 and pH3 ≈ 6.5) and 4 N application rates (N1 = 0 kg/ha N, N2 = 100 kg/ha N, N3 = 200 kg/ha N and N4 = 400 kg/ha N) during the 1995–96 growing season.

Forage	pH1					pH2					pH3				
	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean
Bana	NA[1]	66	64	65	65	66	67	72	57	65.5	65	69	67	61	65.5
Green-gold	66	61	65	61	63.3	69	63	68	55	63.8	68	66	60	66	65
Napier	75	72	62	66	68.8	62	69	64	64	64.8	NA	72	NA	66	69
Mean	71	66	64	64		66	66	68	59		67	69	64	64	

[1]Not available.

received zero N. Total N concentration decreased with increase in soil depth with small differences between fertiliser treatments. The P concentration in the topsoil varied between 18–25 mg/kg, with highest levels on the N4 and lowest on the N1 plots. P concentration dropped to ≤5 mg/kg at depths of >30 cm, with very little difference between N application treatments. The K concentration in the topsoil varied between 65–105 mg/kg, with the lowest concentration on plots of the N4 treatment and highest concentrations on plots of the N1 treatment. The K concentration dropped to <40 mg/kg at depths of >30 cm with very little difference between N treatments.

Discussion

Four years after the start of the trial, there were no clear trends in soil pH or the concentration of nutrients in the soil, that could be ascribed to the effect of N fertilisation. After a further 4 years, there was a noticeable decrease in pH of the topsoil of plots fertilised at a rate of 400 kg/ha N, which is to be expected with high applications of ammonium-N. As a result, the differences in DM yield between the pH treatments declined over time.

At the start of the trial, there was little response to N fertilisation, with the result that the only significant increase in DM yield over the first two seasons, was achieved with 400/ha N. If the data are analysed in more detail it is clear that in the first season (1988–89) the significance of this increase is mainly due to a significant increase in yield with napier, while Bana and Green-gold showed almost no response to N fertilisation. In the second season (1990–91) there was again a significant response with napier at 400 kg/ha N, but response was not as large as during the first season. Green-gold also showed an increase in yield with an increase in N fertilisation in the second season, but there was still no response from Bana. The reason for this is not clear. It may be due to the fact that this particular area had received a heavy (about 1 500 kg) application of $(NH_4)_2SO_4$, about 20 years before the start of this trial. Thereafter, it was clean cultivated at regular intervals, but was not used for trial purposes before this trial. There might, therefore, have been high levels of free N in the soil at the onset of this trial, but unfortunately this was not monitored. The differences between the cultivars/species can be attributed to differences in root development and therefore exploitation of the soil profile, which was also not monitored. The reaction to N fertilisation during the first half of the trial is therefore very site specific and should not be taken into account in the calculation of the response of these three forages to N fertilisation. By the end of the trial, the DM yields on unfertilised areas had declined considerably and the increase in yield (over that of the unfertilised control) for the different applications (100, 200 and 400 kg/ha N) were 25.3, 22.4 and 20.2 kg DM/kg N applied, respectively. The decline in yield with time after sowing is well documented in tropical pastures; however, in this case, the decline on the 0 N plots can be attributed mainly to the removal of N through harvesting and to a lesser extent also to the tie-up of the nitrogen in below-ground parts (Robbins *et al.* 1986a; 1986b; 1989). The DM yield at 400 kg/ha N increased by 20.2 kg DM/ kg N applied over the unfertilised control and 15.65 kg DM/kg N applied, above the application of 200 kg/ha N. In 2001 the cost of good quality hay in South Africa was more than R440/t, whereas LAN cost R5.14/kg N. Using these cost figures, the financial benefit:fertiliser cost ratio at the highest N fertiliser level (400 kg/ha N) was 1.7:1. When the increase in crude protein concentration that resulted from the higher N application, is taken into account, the economics of high levels of N fertilisation (400 kg N/ha) become more favourable. It is, however, not possible to calculate N recovery rates, because of the lack of data on the N concentration of the plant material from the last couple of years of the trial. On sandy soils, leaching of NO_3^- may, however, be a danger when high levels of N fertilisers are applied. In this trial, on a soil with a clay content of approximately 25%and average rainfall of about 650 mm/yr, there was no evidence of leaching of NO_3^- at the high levels of N fertilisation, despite the fact that the last few seasons were characterised by above average rainfall.

During the two relatively dry years (1991–92 and 1992–93), the average DM yield of these forages was about 8 t/ha, which is about the maximum yield that can be expected from weeping lovegrass (*Eragrostis curvula*) and Smuts fingergrass (*Digitaria eriantha*) pastures, fertilised with 150 kg/ha N, in average rainfall years. This clearly illustrates the value of these forages in the semi-arid tropics.

Conclusions

According to these results, there is no significant difference in the DM yield potential of Bana and Green-gold. Both forages produced DM of good quality (digestibility and chemical composition) and exhibited drought-tolerance. However, the vigour and DM yield of napier grass decreased with age.

The optimum level of N fertilisation for Bana and Green-gold on this specific soil (red Hutton with a clay content of approximately 25%) and climatic conditions, will be in the vicinity of 150 kg/ha/yr, which is very similar to that for other summer grass pastures grown in the same region (Pieterse and Rethman 1995; Pieterse *et al.* 1997). However, economic increases in DM yields can still be obtained with N rates as high as 400 kg/ha N.

Bana and Green-gold responded to liming of acid soils, but only when the pH of the soil is increased to approximately 6.5. It must, however, be stressed that the extreme acidity in this study was limited to the top 30 cm of the profile.

Heavy applications of N fertiliser, in the form of limestone ammonium nitrate, lead to acidification of the topsoil. There was, however, no evidence of N leaching under local conditions (red soil with ±25% clay and rainfall of <800 mm/yr).

There was little or no movement of P and K through the soil profile on red Hutton soils with a clay content of ≈ 25%.

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