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# Nutrition of Digitaria decumbens on two sandy soils in a humid tropical lowland environment

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## Summary

Fertiliser requirements of pangola grass *(Digitaria decumbens)* were studied on two sites representative of important land classes in the large tracts of infertile sandy soils in the humid tropical lowlands of Queensland, the first site being derived from granite, the second derived from beach sand. Nitrogen, phosphorus, potassium and calcium fertilisers were varied in a small plot clipping experiment at each site, and sources and rates of sulphur were studied in a third experiment on the beach sand.

Results highlighted the interdependence of different fertilisers in situations where multiple deficiencies occur. The quantity of fertiliser required and the size of the yield response to one element depended on the quantity of others applied. Indications were that initial inputs of 500 kg superphosphate, 50 kg muriate of potash and 500 kg ha$^{-1}$ lime plus an annual input of 200 kg ha$^{-1}$ N would largely satisfy the nitrogen, potassium, phosphorus, sulphur and calcium requirements of pangola grass on both soil types. However, there was evidence of sequential deficiency patterns for the range of elements on both sites.

## 1. INTRODUCTION

Large areas of infertile sandy soils, suitable for development with introduced pastures, occur in the humid tropical lowlands of Queensland. Glasshouse and field nutritional screening experiments with several pasture legumes revealed severe and widespread deficiencies of phosphorus and copper together with less frequent responses to potassium, calcium, zinc, molybdenum and boron (Teitzel and Bruce 1971, 1973). The work was extended by Bruce and Teitzel (1978) who found, in longer term studies with variable fertiliser rates, that *Stylosanthes guianensis* pastures grown in field conditions required 20 to 50 kg ha$^{-1}$ P and 56 kg ha$^{-1}$ K to achieve maximum growth rates on these soils. Bruce and Teitzel (1978) also suspected a sulphur deficiency.

Pangola grass *(Digitaria decumbens)* has been popular with farmers in the region. Although pangola has never formed a stable association with legumes under commercial conditions, it was recommended for use in nitrogen fertilised buffer pastures by Teitzel, McTaggart and Hibberd (1971). However, little is known of the nutrition of this grass grown on these sandy soils and an industry request for information on fertiliser requirements (particularly on the expensive nitrogen and potassium fertilisers) was anticipated. To provide some of this information, three small plot clipping experiments were undertaken. Two studied the effect of nitrogen and potassium application rates, their interactions and interactions with other elements, particularly phosphorus and calcium. A third experiment examined the sulphur deficiency suspected by Bruce and Teitzel (1978).

## 2. MATERIALS AND METHODS

Two representatives sites were chosen, one a granitic sand (Gn 2.81), the other a beach sand (Uc 4.2) (Northcote 1971). The granitic sand (Site 1) was situated 30 km west of Tully, and the beach sand (Site 2) was 1 km west of Cowley Beach. The soils and natural vegetation are the same as those described in detail previously (Bruce and Teitzel 1978). Site 1 was planted to pangola grass and fertilised with superphosphate, ammonium nitrate and muriate of potash at 500, 500 and 112 kg ha$^{-1}$ respectively, 1 year before beginning Experiment 1. Site 2 was newly cleared of natural vegetation.

### Experiment 1 (granitic sand)

Nitrogen (56, 112, 224 and 448 kg ha$^{-1}$ N as ammonium nitrate) and potassium (0, 29, 58 and 116 kg ha$^{-1}$ K as muriate of potash) levels were combined in a factorial array and arranged in two completely randomised blocks. The main plots were split in half so as to impose another factor, 'Others' (other elements thought to be deficient). One subplot received no further elements, and the other subplot received superphosphate (44.8 kg ha$^{-1}$ P), copper sulphate (2.8 kg ha$^{-1}$ Cu) and zinc sulphate (2.3 kg ha$^{-1}$ Zn).

The experimental area was mown to a height of 10 cm and the fertiliser treatments other than nitrogen were applied on 18 February 1971. Nitrogen treatments of 56, 112, 224 and 448 kg ha$^{-1}$ N as ammonium nitrate were applied as shown in Table 1.

**Table 1. Rates of nitrogen fertiliser application, and times applied (Experiment 1)**

| Date | Nitrogen (kg ha$^{-1}$) | | | |
|---|---|---|---|---|
| | 56 | 112 | 224 | 448 |
| 24 Mar 71 | 14 | 28 | 56 | 112 |
| 27 May 71 | 42 | 56 | 56 | 112 |
| 28 Aug 71 | .. | 28 | 56 | 112 |
| 26 Oct 71 | .. | .. | 56 | 112 |

Plots were sampled for dry matter yield on 20 May 1971, 24 August 1971, 22 December 1971 and 22 February 1972. A strip 2 × $10^{-4}$ ha was cut at 4 cm for each subplot using a Jari autoscythe. The cut grass was then oven dried, weighed, subsampled and ground for chemical analysis. After each sampling, the entire experiment was mown and the cut material removed.

Soil samples (0 to 10, 20 to 30 cm) were taken from each subplot on 1 June 1971 and 18 May 1972. Four 5-cm diameter cores were taken at random positions along the diagonals of a subplot. Subplot composite samples were sieved and air dried, before chemical analysis.

### Experiment 2 (beach sand)

Nitrogen (112, 224 and 448 kg ha$^{-1}$ N), potassium (0, 29 and 87 kg ha$^{-1}$ K), phosphorus (33.6 and 67.2 kg ha$^{-1}$ P) and lime (0 and 560 kg ha$^{-1}$) were combined in a factorial array and arranged in two completely randomised blocks. Nutrient compounds were the same as those used in Experiment 1.

The experimental area was disced twice, then planted with pangola grass runners on 1 and 2 March 1971. Fertiliser treatments together with a basal dressing of copper sulphate (2.8 kg $ha^{-1}$ Cu) were applied by hand on 6, 7 and 8 April 1971. Nitrogen was applied as shown in Table 2.

**Table 2. Rates of nitrogen fertiliser application and times applied (Experiment 2)**

| Date | Nitrogen (kg $ha^{-1}$) | | |
|---|---|---|---|
| | 112 | 224 | 448 |
| 12 May 71 | 56 | 56 | 112 |
| 3 Aug 71 | 28 | 84 | 168 |
| 27 Oct 71 | 28 | 84 | 168 |

Plots were sampled for dry matter yield on 2 August 1971, 11 October 1971, 17 December 1971, 3 February 1972, 4 April 1972, 7 August 1972 and 4 December 1972. Cutting height was 6 cm on the last two occasions and 4 cm on all others. Otherwise, sampling procedure was the same as that described for Experiment 1.

Soil samples were collected in the same manner as in Experiment 1 on 7 June 1971, 18 April 1972 and 16 April 1973.

## Experiment 3 (beach sand)

Sulphur was applied as elemental sulphur or gypsum, each at five application rates (0, 28, 56, 84 and 112 kg $ha^{-1}$ S). The 10 treatments were arranged in three completely randomised blocks. The experiment was adjacent to Experiment 2, and details of land preparation, planting and sampling were similar.

Pangola grass runners were planted on 3 March 1971 and sulphur treatments applied on 16 April 1971. The following basal fertilisers were used: $NaH_2PO_4$ (33.6 kg $ha^{-1}$ P) on 26 March 1971 and $Ca(H_2PO_4)_2$ on 25 May 1972; KC1 (58 kg $ha^{-1}$ K) on 26 March 1971 and 9 August 1972; $CuSO_4.5H_20$ (2.8 kg $ha^{-1}$ Cu) on 26 March 1971; $NH_4NO_3$ (224 kg $ha^{-1}$ $annum^{-1}$ N) split into applications of 56 kg $ha^{-1}$ N on 26 March 1971, 12 May 1971, 3 August 1971, 27 October 1971, 24 April 1972, 19 June 1972, 6 September 1972 and 16 December 1972.

The particle size distribution of the elemental sulphur used was: $>$ 0.2 mm, 1.4%; 0.1 to 0.2 mm, 10%; 0.05 to 0.1, 44.6% and $\leqslant$ 0.05, 44%.

## Soil and plant chemical analyses

Soil samples were analysed for pH (in a 1:5 suspension in water and in a 1:2 suspension in calcium chloride), extractable phosphorus (by the method of Kerr and von Stieglitz 1938), total phosphorus and potassium (by X-ray fluorescence spectroscopy), total nitrogen (by a Kjeldahl method), organic carbon (by the method of Walkley 1947), and cation exchange capacity and exchangeable cations (using 1 M ammonium chloride at pH 8.4).

Plant samples (plant parts above defoliation height) were analysed for nitrogen by a microkjeldahl method. After dry ashing the samples, phosphorus was determined by the colorimetric method of Cavell (1954), calcium and magnesium by EDTA titration, and potassium by flame photometry. Sulphur was determined by a turbidimetric method (Mottershead 1971) after oxidation of plant material with nitric-perchloric acid. Only selected harvests were analysed.

## 3. RESULTS

### General

Aphids (*Rhapalosiphum maidis* or *Schizaphis* sp.) and rust (*Puccinia oahuensis*) were observed at both sites during June, July and August 1971 and 1972, and virtually destroyed the pasture in Experiment 1 by December 1972. At Site 2 (beach sand) there was an infection of Striate virus in January and February 1972, and an infestation by nymphs of beetles (*Lygacidae* family) in April 1972. Both organisms killed large patches of pangola grass.

Rainfall recorded at stations within 4 km of the experiments is shown in Table 3. Abnormally dry conditions in the latter half of 1972 severely checked growth at Site 2.

**Table 3. Rainfall (mm) at the two sites during the experiments**

| Period | Granitic sand | Beach sand |
|---|---|---|
| 1971 | | |
| Mar-Apr | 2030 | 1468 |
| May-Jun | 164 | 234 |
| Jul-Aug | 112 | 97 |
| Sep-Oct | 125 | 69 |
| Nov-Dec | 243 | 159 |
| 1972 | | |
| Jan-Feb | 1606 | 1616 |
| Mar-Apr | 1001 | 912 |
| May-Jun | 449 | 538 |
| Jul-Aug | 35 | 40 |
| Sep-Oct | 127 | 88 |
| Nov-Dec | 104 | 98 |

### Plant growth

Added nitrogen fertiliser increased the yield of pangola grass in all harvests on both sites. There were significant responses to potassium in the second and fourth harvests of Experiment 1 on the granitic sand and in all except the fifth harvest of Experiment 2 on the beach sand. The 'Others' treatment produced positive significant growth increases in all four harvests in Experiment 1. In Experiment 2 on the beach sand, calcium increased pangola growth in Harvest 2 and phosphorus in Harvests 3, 4 and 6.

These responses were all significant at the 'main effects' level of the statistical analyses. Necessary differences for significance were generally too high for statistical significance to be carried through to the same treatments at the first order interaction level. However, these first order data show that, at most harvests on both sites, the response to one element depends on the status of others. This relationship has greater biological and economic significance than responses to individual elements so our presentation of data emphasises these first order relationships.

#### *Effect of N × K treatment combinations*

The interactions of nitrogen and potassium on both sites are shown in Figure 1. In Experiment 1 on the granitic sand, although there were significant growth increases from nitrogen in all harvests and from potassium in the second and fourth harvests, responses were erratic in all except the fourth harvest (February 1972) when it was reasonably clear that 29 kg ha$^{-1}$ K was sufficient for a maximum response to 224 kg ha$^{-1}$ N. However, to achieve a further increase from the 448 kg ha$^{-1}$ N treatment, either the 58 or 116 kg ha$^{-1}$ K treatments were required in association. There were no differences between these two higher potassium treatments at any nitrogen level.

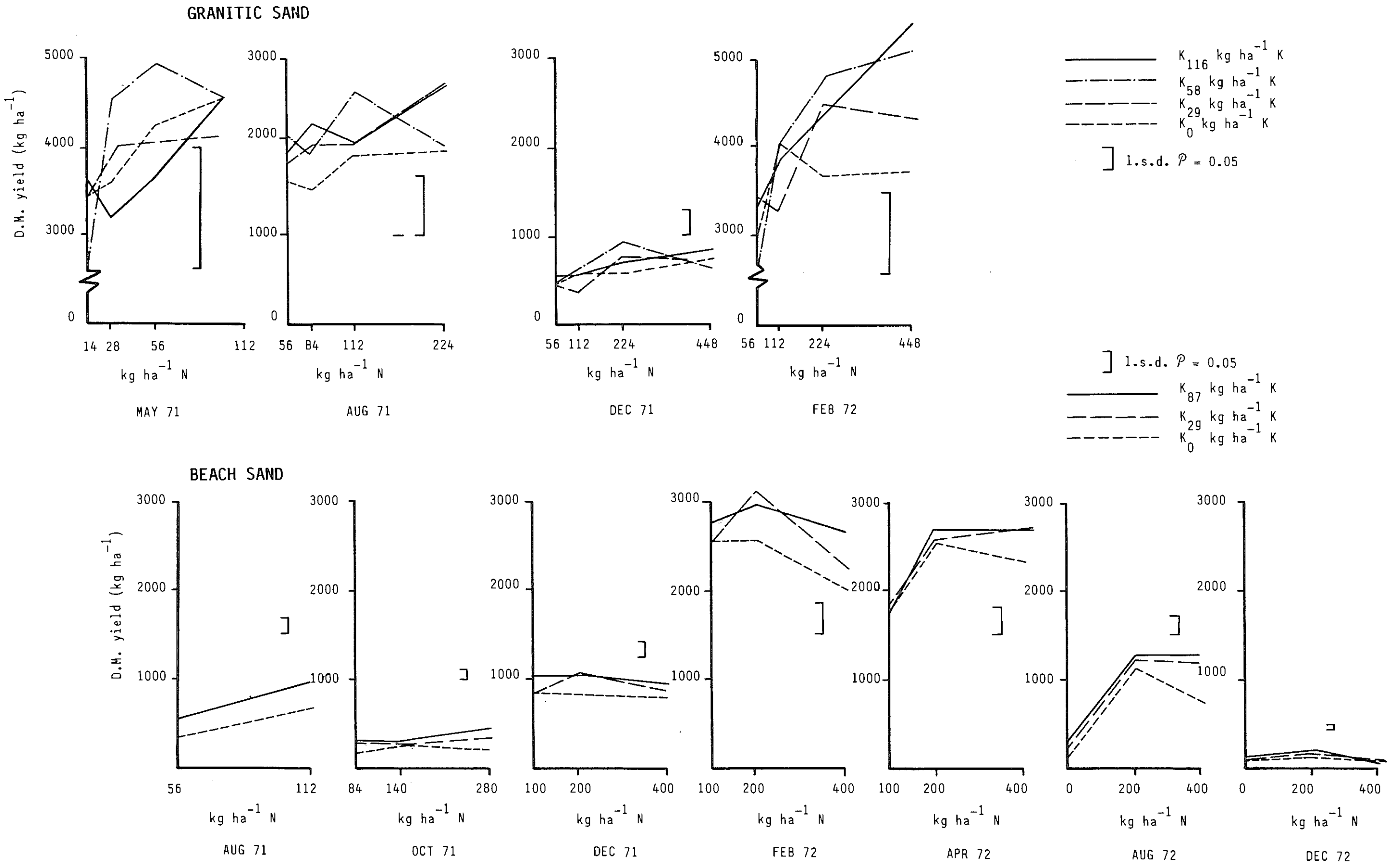

Figure 1. The effect of N × K interaction on pangola grass growth.

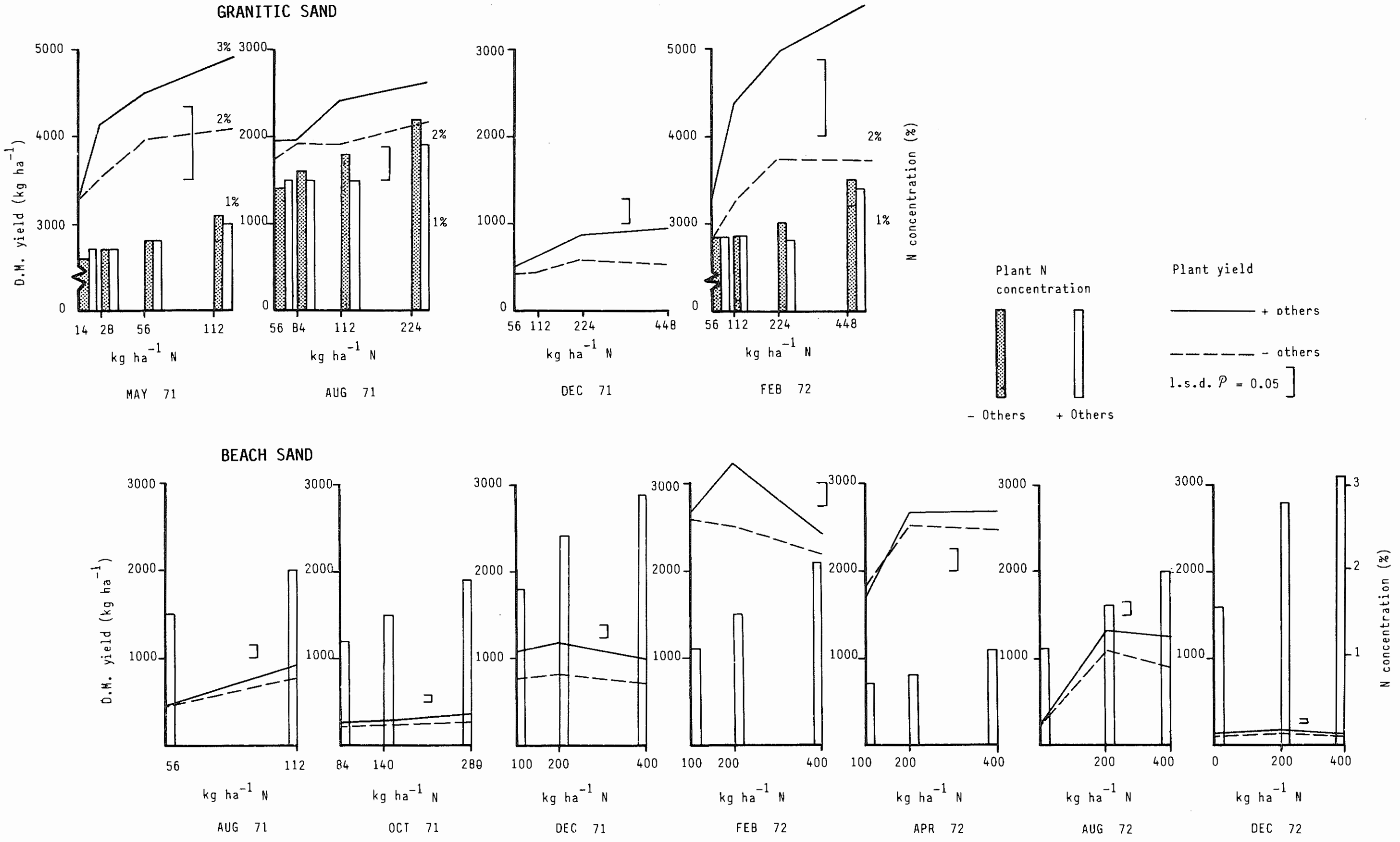

Figure 2. The effect of N × 'Others' interaction on pangola grass growth and plant N concentration.

Responses were more regular in Experiment 2 on the beach sand. At most harvests, best yields were generally achieved by the 29 kg K + 224 kg ha$^{-1}$ N treatment combination.

### *Effect of N × 'Others' treatment combinations*

Plant yields from these combinations are plotted in Figure 2. In all harvests on the granitic site, the 'Others' treatment was required in combination for a full expression of the responses to increasing nitrogen fertiliser rates. At the same time, the 'Others' response was higher at the higher nitrogen rates.

On the beach sand there were positive significant responses to the 560 kg ha$^{-1}$ treatment at the first two harvests and to the 67.2 kg ha$^{-1}$ P over the 33.6 kg ha$^{-1}$ P treatment at the five subsequent harvests. The response is uneven in the first sampling period, simply additive to each nitrogen level in the second and third, and occurs only in the presence of the two higher nitrogen treatments in the remainder.

### *Effect of K × 'Others' treatment combinations*

There was a regular additive response to elements other than nitrogen or potassium on both soil types. The effect was consistent over most potassium treatments in most harvests. However, the response to 'Others' was consistently non-significant in combination with the 116 kg ha$^{-1}$ K treatment on the granitic site. The functional 'Others' treatments on the beach sand were lime in the first two harvests and the higher phosphorus treatment in the remainder.

### *Effect of S rates and sources*

There were no significant differences between the two sources of sulphur at the 'main effects' level in the factorial data analysis.However at the individual treatment level there were responses ($P<0.05$) to the high rate of gypsum in Harvests 1, 2, 4 and 6 and to the low rate of elemental sulphur in Harvests 1 and 4. Yields (in kilogrammes per hectare dry matter) were of the order: no sulphur=800, plus sulphur (28 kg ha$^{-1}$ as sulphur or 84 kg ha$^{-1}$ as gypsum)=1400 in Harvest 1; no sulphur=350, plus sulphur (84 kg ha$^{-1}$ S as gypsum)=730 in Harvest 2; no sulphur=1560, plus sulphur (28 kg ha$^{-1}$ as sulphur or 84 kg ha $^{-1}$ as gypsum)=2075 in Harvest 4; and no sulphur=620, plus sulphur (84 kg ha$^{-1}$ S as gypsum)=1040 in Harvest 6. A good deal of variability was encountered in all sampling periods.

## Plant sulphur content

Plant sulphur content varied from 0.07 to 0.18%. There were no consistent differences between fertiliser treatments, sampling periods or between the three experiments.

## Plant phosphorus content

Selected treatment means from a number of sampling periods in the three experiments are shown in Table 4. Plants from the 67.2 kg ha$^{-1}$ P treatment consistently had a higher phosphorus content than those from the 33.6 kg ha$^{-1}$ P treatment in Experiment 2. Otherwise, there were no consistent treatment effects in any of the experiments. In all experiments differences between sampling periods were greater than differences between treatments.

## Plant calcium content

The only consistent treatment effect was a higher calcium content in the 'Others' treatment in Experiment 1. Corresponding treatments in Experiment 2 did not show this effect. Again, there were pronounced seasonal or sampling variations in all experiments. Selected treatment means are shown in Table 5.

**Table 4. Effect of selected treatments from the 3 experiments on the phosphorus content of pangola**

| Treatment | Phosphorus content (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| **Experiment 1** (Granitic sand) | | | | | | | |
| | May 71 | Aug 72 | Feb 72 | | | | |
| – 'Others' | 0.08 | 0.15 | 0.09 | | | | |
| + 'Others' | 0.11 | 0.15 | 0.09 | | | | |
| **Experiment 2** (Beach sand) | | | | | | | |
| | Aug 71 | Oct 71 | Dec 71 | Jan 72 | Apr 72 | Aug 72 | Dec 72 |
| 33.6 kg ha$^{-1}$ P | 0.13 | 0.12 | 0.15 | 0.14 | 0.12 | 0.13 | 0.17 |
| 67.2 kg ha$^{-1}$ P | 0.18 | 0.17 | 0.21 | 0.19 | 0.15 | 0.16 | 0.28 |
| **Experiment 3** (Beach sand) | | | | | | | |
| | Aug 71 | Oct 71 | Dec 71 | Jan 72 | Apr 72 | Aug 72 | Dec 72 |
| 0 | 0.16 | 0.11 | 0.13 | 0.12 | 0.10 | 0.24 | 0.25 |
| 112 kg ha$^{-1}$ S as sulphur | 0.15 | 0.12 | 0.11 | 0.11 | 0.10 | 0.23 | 0.21 |
| 112 kg ha$^{-1}$ S as gypsum | 0.17 | 0.10 | 0.11 | 0.10 | 0.10 | 0.21 | 0.23 |

**Table 5. Plant calcium (%)**

| | | | | |
|---|---|---|---|---|
| **Experiment 1** (Granitic sand) | | | | |
| | May 71 | Aug 71 | Feb 72 | |
| –'Others' | 0.17 | 0.28 | 0.18 | |
| +'Others' | 0.24 | 0.37 | 0.23 | |
| **Experiment 2** (Beach sand) | | | | |
| | Oct 71 | Dec 71 | Feb 72 | Apr 72 |
| 33.6 kg ha$^{-1}$ P | 0.39 | 0.30 | 0.16 | 0.16 |
| 67.2 kg ha$^{-1}$ P | 0.42 | 0.30 | 0.17 | 0.20 |
| **Experiment 3** (Beach sand) | | | | |
| | Oct 71 | Dec 71 | Feb 72 | Apr 72 |
| 0 | 0.32 | 0.20 | 0.13 | 0.17 |
| 112 kg ha$^{-1}$ S as sulphur | 0.41 | 0.19 | 0.14 | 0.11 |
| 112 kg ha$^{-1}$ S as gypsum | 0.35 | 0.23 | 0.15 | 0.18 |

## Plant nitrogen content

Nitrogen content data presented as histograms in Figure 2 show a close relationship between plant nitrogen content and nitrogen fertiliser addition in all harvest periods in Experiments 1 and 2. Addition of the 'Others' treatment had a regular dilution effect on nitrogen content in Experiment 1. In Experiment 2, chemical analysis of all treatments was carried out in Harvests 4 and 5 only. In Harvest 4 (February 1972), nitrogen content of the 448 kg ha$^{-1}$ N treatment was reduced from 2.2% to 2.0% ($P<0.05$) by potassium fertiliser addition. However, in Harvest 5 (April 1972) the only nitrogen dilution effect measured was from the higher phosphorus fertiliser treatment which reduced mean nitrogen content from 1.0% to 0.9% ($P<0.01$).

## Plant potassium content

Mean plant potassium content of a number of treatments is shown by histograms in Figure 3. In Experiment 1, addition of potassium fertiliser increased plant potassium content from between 0.6 and 0.8% to between 1.0 and 1.4% in the three sampling periods

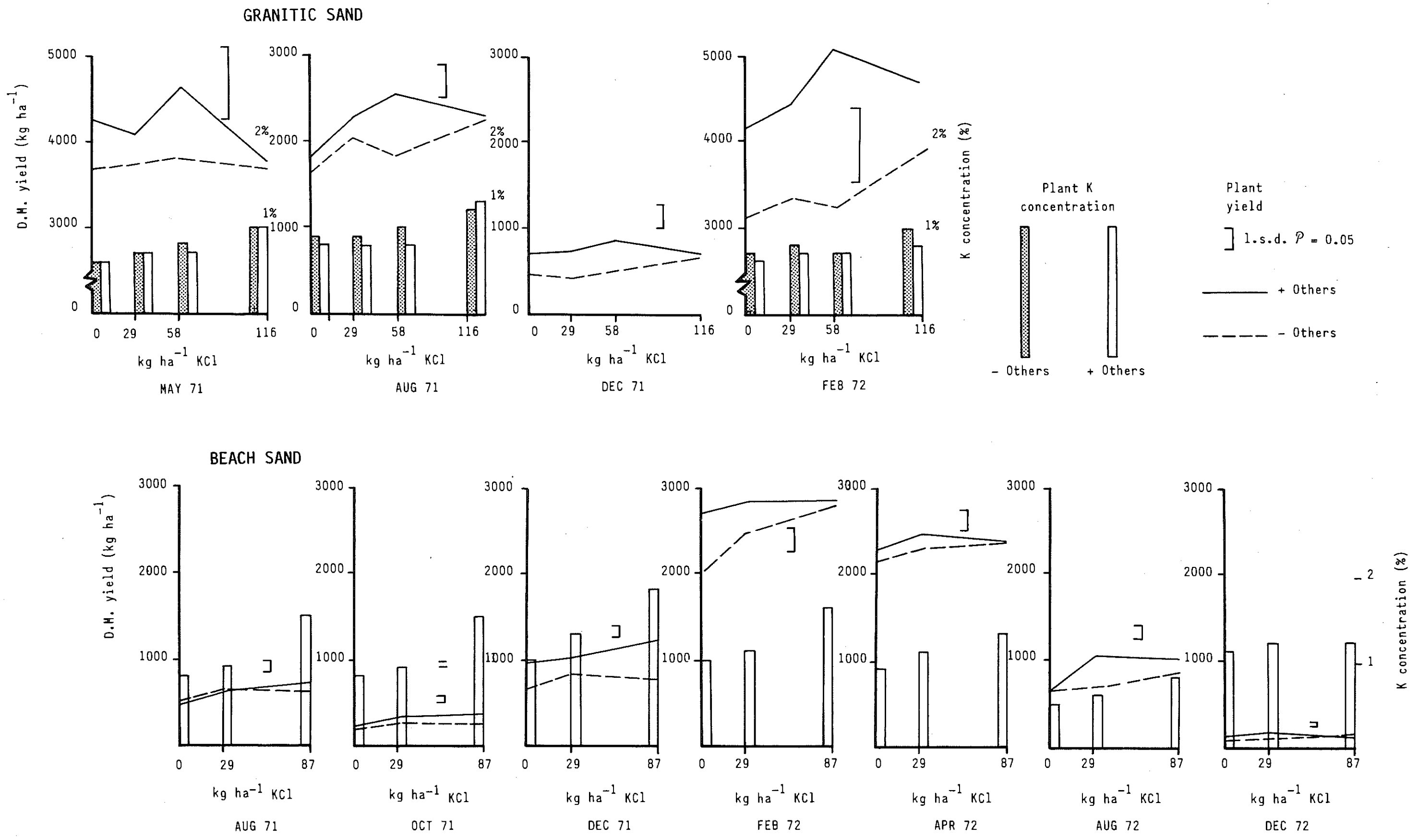

Figure 3. The effect of K × 'Others' interaction on pangola grass growth and plant K concentration.

in which it was analysed. The 'Others' treatment generally tended to reduce potassium content at each potassium treatment level. In Experiment 2 there appeared to be a close relationship between plant potassium content and potassium fertiliser addition in all except the last harvest, when a plateau occurred at the 29 kg $ha^{-1}$ K treatment level. The only other effect measured was a mean increase ($P<0.01$) in potassium content of 0.14% from the calcium treatment in Harvest 4 (February 1972). In the sulphur rates experiment, plant potassium content was not influenced by sulphur treatment.

## Soil analysis from the granitic sand

Extractable phosphorus and exhangeable potassium concentration at the 0 to 10 and 20 to 30 cm soil levels from potassium and 'Others' treatment units are presented in Table 6. Phosphorus content increased with phosphorus fertiliser addition in the 0 to 10 cm horizon only. Concentrations in this horizon declined with time but there was no apparent movement into the 20 to 30 cm horizon. Potassium concentration in the 0 to 10 cm horizon also increased with potassium treatment and decreased with time but in this case there also appeared to be an accumulation in the 20 to 30 cm horizon with time. The highest mean potassium concentration recorded was 0.12 meq%.

**Table 6. Selected soil analyses from the granitic sand**

| Soil sampling depth (cm) | Fertiliser treatment combination | Analysis<br>1971 | <br>1972 |
|---|---|---|---|
| 0-10 | Pre-trial<br>pH (in water) 4.9<br>P (ppm) 19<br>K (meq %) 0.08<br>Ca (meq %) 0.20<br>Mg (meq %) 0.10 | | |
| | | **Available P (ppm)** | |
| | −'Others' (initial P dressing) | 18 | 11 |
| 0-10 | +'Others' (initial + 44.8 kg $ha^{-1}$ P) | 38 | 29 |
| 20-30 | −'Others' | 6 | 4 |
| 20-30 | + 'Others' | 6 | 4 |
| | | **Exchangeable K (meq. %)** | |
| 0-10 | nil K | 0.08 | 0.07 |
| 0-10 | 29 kg $ha^{-1}$ K | 0.09 | 0.08 |
| 0-10 | 58 kg $ha^{-1}$ K | 0.11 | 0.08 |
| 0-10 | 116 kg $ha^{-1}$ K | 0.12 | 0.10 |
| 20-30 | nil K | 0.03 | 0.05 |
| 20-30 | 29 kg $ha^{-1}$ K | 0.03 | 0.07 |
| 20-30 | 58 kg $ha^{-1}$ K | 0.02 | 0.09 |
| 20-30 | 116 kg $ha^{-1}$ K | 0.04 | 0.08 |

## Soil analyses from the beach sand

Concentrations of dilute acid extractable phosphorus and exchangeable phosphorus and exchangeable potassium in soils from different phosphorus and potassium treatments, respectively, are shown in Table 7. As with the granitic site, phosphorus content declined with time and increased with increasing phosphorus fertiliser inputs, but on this site phosphorus obviously moved into the 20 to 30 cm horizon. Addition of potassium fertilisers increased soil potassium concentration to a maximum of 0.11 meq% in the 0 to 10 cm horizon but declined to 0.04 meq% after 3 years.

**Table 7. Selected soil analyses from the beach sand**

| Soil sampling depth (cm) | Fertiliser treatment combination | Soil mineral content | | |
|---|---|---|---|---|
| | | 1971 | 1972 | 1973 |
| 0-10 | Pre trial<br>pH (in water) 5.0<br>P (ppm) 4<br>K (meq%) 0.02<br>Ca (meq%) 0.29<br>Mg (meq%) 0.31 | | | |
| | | **Available P (ppm)** | | |
| 0-10 | 33.6 kg ha$^{-1}$ P | 20 | 9 | 13 |
| 0-10 | 67.2 kg ha$^{-1}$ P | 38 | 22 | 20 |
| 20-30 | 33.6 kg ha$^{-1}$ P | 8 | 4 | 4 |
| 20-30 | 67.2 kg ha$^{-1}$ P | 15 | 13 | 10 |
| | | **Exchangeable K (meq %)** | | |
| 0-10 | nil K | 0.02 | 0.03 | 0.03 |
| 0-10 | 29 kg ha$^{-1}$ K | 0.06 | 0.04 | 0.03 |
| 0-10 | 87 kg ha$^{-1}$ K | 0.11 | 0.06 | 0.04 |
| 20-30 | nil K | 0.02 | 0.01 | 0.02 |
| 20-30 | 87 kg ha$^{-1}$ K | 0.03 | 0.02 | 0.02 |

There were no detectable changes in soil organic matter or pH with either fertiliser treatment or time. Acid digestible phosphorus concentrations from 0 to 10 cm and 20 to 30 cm horizons ranged from 36 to 85 ppm in June 1971. Changes from 1971 to 1973 were of the same order as those for dilute acid extractable phosphorus shown in Table 7.

## Removal of nitrogen, phosphorus and potassium

The amounts of nitrogen, phosphorus and potassium removed in pangola grass are summarised in Table 8 for particular treatment means from August 1971 to April 1972 for Experiments 2 and 3. Highest inputs of nitrogen and potassium doubled nitrogen and potassium yields in cut grass and the higher rate of superphosphate increased phosphorus yields by about 50% in Experiment 2. Yields from Experiment 3 were comparable with those from Experiment 2. The apparent recovery of potassium at both application rates was 62%.

**Table 8. Comparison of nitrogen, phosphorus and potassium inputs and removal in pangola grass from 2 August 1971 to 4 April 1972 in Experiments 2 and 3**

| | Experiment 2 | | | Experiment 3* |
|---|---|---|---|---|
| Nitrogen | | | | |
| Application, kg ha$^{-1}$ | 112 | 224 | 448 | 224 |
| Removal, kg ha$^{-1}$ | 66.9 | 100.5 | 123.1 | 67.0-89.2 |
| (Removal ÷ Application) × 100 | 60 | 45 | 27 | 30-40 |
| Apparent recovery, % | | 30 | 17 | |
| **Phosphorus** | | | | |
| Application, kg ha$^{-1}$ | 33.6 | 67.2 | | 33.6 |
| Removal, kg ha$^{-1}$ | 8.2 | 12.6 | | 6.5-9.4 |
| (Removal ÷ Application) × 100 | 25 | 20 | | 19-28 |
| Apparent recovery, % | | 13 | | |
| **Potassium** | | | | |
| Application, kg ha$^{-1}$ | 0 | 29 | 87 | 58 |
| Removal, kg ha$^{-1}$ | 56.2 | 74.2 | 110.2 | 58.4-86.7 |
| (Removal ÷ Application) × 100 | | 252 | 125 | 99-147 |
| Apparent recovery, % | | 62 | 62 | |

*Range of all treatment means.

Apparent recovery of element, % $$\left\{\frac{\text{Yield at rate x} - \text{Yield at lowest rate}}{\text{Yield at lowest rate} - \text{Lowest rate}}\right\} \times 100$$

## 4. DISCUSSION

A very dynamic situation was found to exist on both soils: the response to one element depended on the status of another but, as the trial progressed and as seasons varied, the relationship between the elements seemed to alter, leading to a sequence of most important responses. There was never a clear cut response to a single treatment. For instance, certain other elements increased plant growth at high and low rates of nitrogen fertiliser. But, in most cases, the nitrogen response was steepest when other deficient elements were applied in association. This highlights some hazards inherent when interpreting experiments which study application rates of only one element to soils where multiple deficiencies are likely to occur.

Nitrogen was the most important fertiliser for growth on both soil types, with an apparent requirement of about 200 kg N $ha^{-1}$ $year^{-1}$ for close to maximum pangola yields. There was a marginal positive response to higher concentration on nitrogen on the granitic site, whereas on the marine site the effect was generally negative, particularly at low inputs of potassium. The final nitrogen application in October 1971 coincided with the long drought and was probably ineffective for the remainder of the season. Plants containing most nitrogen were most susceptible to moisture stress, aphids and rust at this time of the year. Highest nitrogen fertiliser rates gave highest plant nitrogen contents but addition of other elements that increased yields invariably diluted plant nitrogen.

Potassium fertiliser is required for both soil types. An application of 29 kg $ha^{-1}$ K was adequate for maximum yields with 224 kg $ha^{-1}$ N but 58 kg $ha^{-1}$ K may be required for responses to higher rates of nitrogen on the granitic soil. Despite the very low exchangeable potassium levels in the beach sand, pangola grass was able to extract 56.2 kg $ha^{-1}$ K in the first year when no muriate of potash was applied. It is generally believed that rapid leaching of potassium occurs in sands. The apparent recovery of 62% of applied potassium from the 29 and 87 kg $ha^{-1}$ K treatments contradicts this view. In Experiment 3 where 58 kg $ha^{-1}$ K was applied on 26 March 1971, exchangeable soil potassium analyses at 0 to 10 cm were marginally lower in June 1971 than those from plots receiving 29 and 58 kg $ha^{-1}$ K in Experiment 2. This difference could be partly attributable to movement down the profile when 369 mm of rain fell between 26 March and 8 April. In Experiment 3, potassium removal still exceeded application (Table 8). Low soil potassium concentrations in 1972 (Tables 6 and 7) and plant potassium analyses below 1% in Experiments 2 and 3 in August 1972 suggest a need for annual applications of potassium fertiliser at the end of each wet season.

From chemical analyses of the virgin soils, both sites were judged to be phosphorus deficient. However, responses were not expected following the pre-trial commercial application of superphosphate to the granitic soil before Experiment 1 began. Responses to more than 37.6 kg $ha^{-1}$ P in Experiment 2 were also not expected (Bruce and Teitzel 1978).

No response to the higher phosphorus concentration was found until December 1971 in Experiment 2. The apparent recovery of additional phosphorus in the 67.2 kg $ha^{-1}$ P treatment was 13% by April 1972.

There was an immediate response to the 'Others' treatment on the granitic site but we do not know whether phosphorus was the functional element. There is nothing to suggest that the optimum for pangola grass differs from the 50 kg $ha^{-1}$ P suggested for legumes on equivalent sites (Bruce and Teitzel 1978). Movement of phosphorus to the 20 to 30 cm horizon in Experiment 2 would be predicted from the low phosphate sorption shown by Cowley sand (Moody, personal communication). Acid extractable phosphorus analyses from the 67.2 kg $ha^{-1}$ P treatment were marginally higher in April 1972 than those from 33.6 kg $ha^{-1}$ P treatment in 1971 and were similar in April 1973 (Table 8), indicating an appreciable residual effect from the higher rate.

Responses to lime and sulphur were recorded on the beach sand but they were inconsistent. The granitic sand received calcium and sulphur from the previous commercial dressings of single superphosphate. A dressing of 500 kg ha$^{-1}$ superphosphate should satisfy the requirement of pangola grass for sulphur and calcium as well as phosphorus on both sites. The effect of a separate dressing of lime requires further study.

The chemical content of plants varied with the combinations of fertilisers, season and soil type. This behaviour highlights the problems associated with applying diagnostic criteria for one element when others may be deficient (as described by Andrew 1968).

Soil analyses also had limited diagnostic value. Exchangeable potassium concentrations increased with increased potassium fertiliser addition, but all levels measured on both soil types were well below the range (0.2 to 0.3 meq %) generally regarded as desirable for most soils in the region. Consequently, there must be doubt about the suitability of exchangeable potassium as an indicator of potassium status on these soils. We were also unable to measure any meaningful changes in soil organic matter or pH. The extractable phosphorus concentration in the soils at both sites ranged from 16 to 20 ppm, slightly above the concentration (15 ppm) thought adequate for grass/legume pastures on a granitic soil (Bruce 1972).

Results of these experiments suggest that pangola grass grown on these soils requires an initial fertiliser input of about 500 kg ha$^{-1}$ superphosphate and 50 kg ha$^{-1}$ muriate of potash plus an annual input of 200 kg ha$^{-1}$ N for close to maximum plant growth. Previous work (Teitzel and Bruce 1971 and 1973) had also shown the need for 10 kg ha$^{-1}$ copper sulphate. A dressing of 500 kg ha$^{-1}$ lime also has beneficial effects during the pasture establishment phase on the marine site but lime requirements are not clearly understood on the granitic site. There is evidence that phosphorus in particular is more mobile on the marine soil, suggesting a need for more frequent application. Further studies on depletion rates of all elements on both soil types are required before sequential fertiliser strategies can be formulated.

## 5. ACKNOWLEDGEMENTS

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