RELATIONSHIPS BETWEEN SOILS, CURRENT NUTRIENT STATUS AND PERSISTENCE OF GREENLEAF DESMODIUM AT TINANA IN SOUTH-EASTERN QUEENSLAND

G. E. RAYMENT*, B. L. COMPTON* and R. C. MCDONALD*

ABSTRACT

Two groupings of soils were made, based on local observations of persistence of Desmodium intortum *cv. Greenleaf in grass-legume pastures at Tinana, south-eastern Queensland. Soils classified as coarser surface textured (CST) were mostly yellow podzolics with minor yellow earths and were considered to exhibit some degree of legume persistence. A finer surface textured (FST) grouping of soloths, solodics and red-yellow podzolics appeared to be associated with poor legume persistence. Potential availability of soil moisture may be the most significant physical feature likely to influence legume persistence in these soils.*

Current fertility status of four soils from each grouping, ranging in age from virgin to seven years under fertilized pasture, was then assessed under glasshouse conditions.

In their virgin state, soils from both groupings responded to phosphorus, sulphur and molybdenum. A yield increase to lime was also recorded in the virgin FST soil. Deficiencies of these nutrients were still apparent in many soils after variable periods under pasture, molybdenum and lime responses occurring in all FST soils irrespective of past fertilizer history or pasture age. A response to copper occurred on one CST soil after seven years under pasture but no soil responded to zinc. Despite inputs of potassium fertilizers, a pasture phase also appeared to induce potassium deficiency on most soils. However, a yield depression was recorded following potassium chloride treatment on a FST soil which was strongly sodic and had received 120 *kg K ha^{-1} as potassium chloride over two years prior to sampling. Implications for pasture fertilizer programs in the Tinana area have been discussed.*

The data suggest that molybdenum deficiency and/or lower residual molybdenum availability on FST soils could have been the most important nutritional factor influencing legume growth and persistende in Tinana pastures.

INTRODUCTION

During recent years, pasture development in excess of 10,000 ha has taken place in an area north-east of Gympie, near Sandy and Tinana Creeks. Grass-legume pastures have been used extensively, most common grasses being *Setaria anceps* cvv. Narok and Nandi, and *Pennisetum clandestinum* cv. Whittet with *Desmodium intortum* cv. Greenleaf the preferred tropical legume. Despite use of considerable quantities of both establishment and maintenance fertilizers, local reports suggest legume loss from these pastures has become a serious problem, with a decline phase commencing after about three years and increasing in severity with time.

Hutton and Gray (1967) attributed lack of persistence of *D. intortum* to one or more factors including attack by Amnemus weevil, extended hot, dry periods and susceptibility to 'legume little leaf' virus while Thompson (1966) gave lowered soil fertility as a further reason for decline in pasture quantity and quality. Local graziers at Tinana have also observed some degree of correlation between legume persistence in older pastures and soil surface texture. Sufficient examples were shown to the authors to warrant investigation of possible causes.

---

* Department of Primary Industries, Agricultural Chemistry Branch, Indooroopilly, Qld. 4068.

Due to absence of a detailed physical and nutritional assessment of Tinana soils, it was not known whether apparent differences were due to variations in nutrient status of principal soils, to soil physical conditions or a combination of both. Variable inputs of fertilizers were an additional complication.

To obtain preliminary information on these aspects, soil profiles at various sites were described and a series of glasshouse nutrient experiments undertaken. In this paper, some soil morphological characteristics have been defined and current nutrient status, as influenced by soils and pasture age, evaluated. Implications for legume growth and persistence are discussed.

SOILS

Land used for pasture about Sandy and Tinana Creeks consists chiefly of a moderately undulating plain with nearly level to convex interfluves and local relief of 15–20 m. Soils appear to be derived primarily from Upper Triassic to Lower Jurassic sandstone. Location of area and sites sampled are shown in Figure 1.

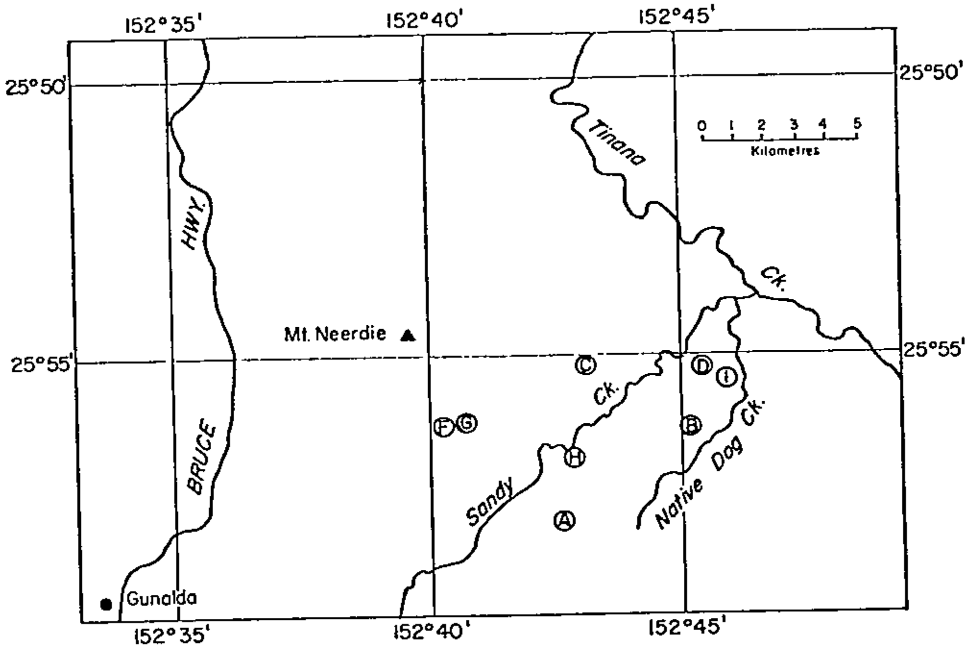

FIGURE 1
Map showing location of area and sites sampled.

Because of its link with legume persistence, surface soil texture was used as the principal selection criteria. Two soil groupings were then established. In the first, which was comprised of coarse surface textured (CST) soils, legumes had shown some degree of persistence. The second grouping consisted of finer surface textured (FST) soils. These had been associated with poor persistence of legumes, especially *D. intortum.*

CST soils were mostly yellow podzolics with minor yellow earths. These had A horizons of either sandy-loam or sandy-clay-loam ranging in depth from 45–80 cm. Surfaces of both soils were weakly hard setting. Mottling in B horizons of the yellow podzolics and ironstone nodules at depth in the yellow earths suggested seasonal waterlogging below 70–90 cm.

FST soils were comprised of soloths, solodics and red-yellow podzolics. In comparison with the CST group, these soils had shallower (20–30 cm), finer textured (clay-loam or clay-loam, sandy), harder A horizons and finer textured, harder, usually less mottled B horizons. The red-yellow podzolics were an exception, being strongly mottled below 40 cm. Relatively shallow A horizons of these FST soils, conspicuously bleached A_2 horizons and general lack of mottling in sodic B horizons of soloths and solodics suggested lower permeability with moisture retention confined principally to the A horizons.

METHODS AND MATERIALS

Site and soil selection

Four sites from each soil grouping were selected in April, 1977 and representative samples of surface (0–10 cm) soil taken for chemical analysis and glasshouse experimentation. The range of pasture ages and past fertilizer histories were similar for each group (Table 1).

Glasshouse experimentation

Each soil was passed through a 1.25 cm stainless steel sieve and potted in 15 cm diameter polystyrene pots fitted with a polyethylene liner. Potting weights on each soil were varied to give a uniform watering weight at 60 per cent of water holding capacity to all pots.

A half replicate of a 2^6 factorial design was run concurrently on each soil. The six factors were presence or absence of lime, sulphur, potassium, copper, zinc and molybdenum, all with basal phosphorus (Table 2). No responses to boron, magnesium, manganese and iron were obtained in an earlier pilot trial on virgin sandy soil from the same area, so these nutrients were not included.

For a concurrent series of phosphorus rate experiments involving all soils, four phosphorus rates equivalent to 0, 10, 20 and 40 kg P ha^{-1} (nil, 70.9, 141.9 and 283.8 mg pot^{-1} as $Ca(H_2PO_4)_2.H_2O$) were used. In addition, both virgin soils received two additional rates, equivalent to 60 and 80 kg P ha^{-1} (425.8 and 567.6 mg pot^{-1}). All nutrient treatments used on the factorial experiments were supplied as a basal dressing.

Lime was mixed throughout each pot as required. Following liming, all other chemicals were applied in solution form to the soil surface, phosphorus being added last. Thorough incorporation to a depth of 1 cm was achieved when sowing, which took place immediately afterwards.

Soils from factorial and phosphorus rate trials were arranged in separate blocks and within each, soils and treatments were allocated to random positions on an automatic pot watering machine. Double deionized water was used in preparation of all nutrient solutions and for routine watering of pots.

Test species used throughout was *D. intortum*, inoculated with *Rhizobium* strain CB 627 prior to planting on April 26, 1977. Seedlings in each pot were thinned to five after early disease problems in some soils were sufficiently controlled by an application of 0.25 g pot^{-1} of Captafol 80% W.P. (cis N- 1,1,2,2, tetra chloroethyl thio-4-cyclohexene 1,2 di carboximide). *Pythium middletonii* was isolated from diseased plants. All pots were harvested on August 3, 1977 and plant tops dried at 70°C prior to weighing to determine dry matter production.

Glasshouse environment was controlled throughout. Day length was fixed at 13.5 hours by the use of incandescent bulbs to increase day length. Mean daytime maximum and night-time minimum temperatures were 28 and 17°C respectively.

Chemical analyses

Soil analyses were performed on air-dry (40°C) samples. Methods used are defined in Table 3. Plant analyses were conducted on oven dry (105°C) samples.

TABLE 1

Details of experimental soils and pasture histories

Site Code	Great soil group†	Principal profile form*	Surface soil texture group	Pasture age (years)	Total fertilizer nutrients applied					Years since last application				
					P (kg ha^{-1})	K (kg ha^{-1})	S (kg ha^{-1})	Ca (kg ha^{-1})	Mo (g ha^{-1})	P	K	S	Ca	Mo
A	YP	Dy 2.41	Coarser	Virgin	—	—	—	—	—	—	—	—	—	—
B	YE	Gn 2.24	Coarser	1	46	30	50	50	135	1	1	1	1	1
C	YP	Dy 2.41	Coarser	2.5	109	90	62	62	185	1	1	1	1	2
D‡	YP	Dy 3.41	Coarser	7	128	136	81	81	235	2	2	2	2	3
F	SD	Dy 2.43	Finer	Virgin	—	—	—	—	—	—	—	—	—	—
G	SH	Db 1.31	Finer	1	46	30	50	50	135	1	1	1	1	1
H	SH	Dy 3.41	Finer	2	105	120	112	112	210	1	1	1	1	1
I‡	RYP	Dy 3.41	Finer	7	128	136	81	81	235	2	2	2	2	3

† Stace *et. al.* (1968) * Northcote (1971) ‡ Received 1.1 kg ha^{-1} of CuO and ZnO at pasture establishment

YP yellow podzolic, YE yellow earth, SD solodic, SH soloth, RYP red-yellow podzolic

TABLE 2

Nutrient forms and rates for factorial trials

Nutrient	Source†	mg pot^{-1}‡	Approximate field equivalent: compound (kg ha^{-1})	Approximate field equivalent: element (kg ha^{-1})
Lime	$CaCO_3$	885	500	N.A.§
S	Na_2SO_4	314	177	40
K	KCl	168	95	50
Cu	$CuCl_2.2H_2O$	9	5.1	1.9
Zn	$ZnCl_2$	9	5.0	2.4
Mo	$Na_2MoO_4.2H_2O$	0.59	0.333	0.132
Basal P	$Ca(H_2PO_4)_2.H_2O$	284	161	40

† AR grade chemicals; basal P was LR grade
‡ 1 mg pot^{-1}=0.565 kg ha^{-1} for 15 cm dia. pot
§ not applicable.

Nitrogen and phosphorus were measured on an Auto Analyzer, potassium on a flame photometer and calcium and magnesium by atomic absorption, after Kjeldahl digestion in the presence of sodium sulphate with selenium as catalyst. Procedures were as defined by R. Roofayel (unpublished). Plant sulphur, copper, zinc and manganese determinations were by X-ray fluorescence spectrometry.

RESULTS

Soil chemical properties

Data for all soils are given in Table 3.

Acid and bicarbonate extractable phosphorus levels were low in virgin soils A and F. Higher levels were found in soils with a history of phosphorus fertilization, which is confounded with pasture age. In contrast, several other soil chemical properties, including exchangeable calcium and potassium, were higher in virgin soils than in those under pasture, despite inputs of calcium and potassium fertilizers.

Phosphorus rate experiments

Mean yields on soil H were not significantly different ($P < 0.05$) at any phosphorus rate, but yield increases to phosphorus were recorded on remaining soils. Virgin soils were most responsive, maximum yields occurring at the equivalent of 60 and 80 kg P ha^{-1} for soils A and F respectively.

Compared across all phosphorus treatments, more growth occurred on FST soils (means of 4.87 and 5.72 g pot^{-1} for coarser and finer textured soils respectively; LSD for $P < 0.01$ of 0.71 g). However when yield of the nil phosphorus treatment is expressed as a percentage of maximum yield for the same soil, it is apparent that as a group, CST soils tended to be more responsive to freshly applied phosphorus than their counterparts of equivalent age. Percentage yields for CST soils were 2.4, 36.2, 36.1, 34.8 for ages virgin, one, two-three and seven years respectively, as against 8.2, 42.7, 64.1 and 53.1 per cent for corresponding FST soils.

Factorial experiments

Mean yields for each soil, significant main effects and interactions based on yield data are presented in Table 4. A yield ratio expression has been included with main effects to provide an estimate of the magnitude of response within each soil.

Zinc failed to increase yields on any soil but all other nutrients were associated with responses on one or more soils. Copper was only important on soil I. There it influenced the magnitude of response to molybdenum (greater in presence of copper)

TABLE 3

*Surface (0–10 cm.) soil chemical properties*Χ *of selected Tinana soils*

Site Code	Acid extractable* P (ppm)	Bicarbonate extractable** P (ppm)	Exch. cations†					Organic carbon‡ (%)	Total N¶ (%)	1:5 soil/water			DTPA trace elements¶¶				Extractable B§ (ppm)	Exch. Al§§ (ppm)
			Ca^{++} (m equiv. 100 g^{-1})	Mg^{++}	Na^{+}	K^{+}	CEC"			pH	NO_3-N (ppm)	Cl (ppm)	Fe	Cu (ppm)	Mn	Zn		
A	4	5	2.1	1.3	0.15	0.19	7	1.83	0.06	5.8	2	34	34	0.1	6	0.6	0.35	203
B	14	14	1.5	0.6	0.12	0.07	3	1.31	0.05	5.7	2	37	50	0.1	5	0.4		101
C	28	24	1.7	0.5	0.08	0.09	3	1.56	0.05	5.7	3	29	77	0.1	5	0.3		131
D	20	14	0.6	0.3	0.12	0.07	3	1.07	0.04	5.6	2	35	84	0.1	1	1.1		151
F	5	8	5.9	3.9	0.60	0.29	11	2.13	0.12	6.2	4	65	122	0.3	37	2.1	0.46	56
G	15	22	6.0	2.5	0.15	0.14	10	1.93	0.11	6.0	2	46	100	0.4	45	1.3		76
H	21	14	1.0	0.9	1.11	0.19	6	1.67	0.06	5.4	2	61	107	0.1	2	0.7		431
I	20	23	1.3	0.7	0.30	0.11	5	1.87	0.07	5.7	2	47	153	0.1	4	1.2		279

Χoven dry (105^{0}C) basis
*Kerr and von Stieglitz (1938)
**Colwell (1963)
"Cation exchange capacity
†extracted with neutral molar NH_4Cl
‡Walkley and Black method (Piper 1950)
¶Kjeldahl digestion
¶¶Lindsay and Norvell (1969)
§Hot water soluble
§§extracted with molar KCl at pH 4.5

TABLE 4

Significant dry matter yield responses and yield ratios† for the various nutrients used in the glasshouse factorial experiments

Effect	Coarser surface textured soils				Finer surface textured soils			
	A	B	C	D	F	G	H	I
Mean yield (g pot^{-1})	3.10	6.06	8.53	3.62	8.19	9.08	3.36	4.57
Main effects			(Yield ratios and significance)					
$CaCO_3$				1.45**	1.20**	1.10*	1.89**	1.39**
S	1.47**		1.77**	1.19*	1.35**			1.16**
K		1.61**	1.32**	1.32**		1.40**	0.67**	
Mo	5.09**			1.46**	2.87**	1.14*	1.41**	1.70**
Interactions				(Significance)				
$CaCO_3$ x K				*				*
$CaCO_3$ x Mo				**				**
S x K			**					*
S x Cu								**
S x Mo	**		**		**			
K x Mo				**				
Cu x Mo								*

† D.M. yield with nutrient/D.M. yield without nutrient (for main effects).
* Significant at $P<0.05$
** Significant at $P<0.01$

and modified the effect of sulphur (significant increase only in presence of copper). Potassium caused the only yield depression ($P < 0.01$), which was recorded on soil H.

All FST soils responded to molybdenum and lime, irrespective of pasture age or past fertilizer history. On CST soils, responses to sulphur and potassium were common but not universal.

Plant analysis

Plant phosphorus concentrations in Greenleaf increased with increasing phosphorus treatment in virgin soils A and F but not in soils H and I. Slight increases occurred in plants from the remaining soils. The critical level of 0.22 per cent established by Andrew and Robins (1969a) for this species was not exceeded in any soil.

Nutrient levels in plant tops from selected treatments of all factorial experiments helped confirm most yield response trends. For example, without added potassium, concentrations of this nutrient in plants from responsive soils ranged from 0.39 to 0.72 per cent. In those which did not respond, levels ranged from 0.72 to 1.28 per cent while for soil H (yield depressed by potassium chloride) it was 0.93 per cent. Andrew and Robins (1969c) gave 0.72 per cent as the critical concentration of potassium in *D. intortum*.

With sulphur, significant yield responses ($P < 0.05$) were associated with plants containing from 0.07 to 0.14 per cent sulphur, whereas plants from non-responsive soils contained 0.14, 0.24 and 0.25 per cent. Addition of sulphur usually raised sulphur status above the critical concentration of 0.17 per cent (Andrew 1977) and increased nitrogen concentrations in plants on deficient soils from an average of 1.80 to 2.24 per cent. Molybdenum additions to molybdenum deficient soils also increased plant nitrogen concentrations (mean of 1.73 per cent when deficient compared to 2.32 per cent with molybdenum present).

Copper concentration in plants from soil I (which showed some response to copper) was 4.0 ppm in the absence of added copper. However 3.0 ppm was recorded for the identical treatment on soil C which gave no significant response. Levels of

4.0 ppm were also recorded on soils D and F, neither of which required copper to attain maximum yield. Zinc levels averaged 21 ppm across all soils in the absence of this non-responsive nutrient.

Addition of lime generally resulted in increased plant calcium concentrations but there was no apparent link between these levels and response. As a group, plant calcium levels in FST soils, all of which responded to lime, were higher than those in CST soils (1.10 and 0.90 per cent respectively in the absence of added lime).

DISCUSSION

Soil morphology and legume persistence

Soil groups associated with specific profile characteristics have not previously been linked with persistence of *D. intortum* in grass-legume pastures in south-eastern Queensland.

When the two soils groups are compared, soils which appeared to be associated with poorer legume persistence had shallower, finer textured, harder setting A horizons and usually less mottled B horizons. With sodic B horizons, soloths and solodics would be less permeable, shed water laterally more readily, have lower moisture accession (confined primarily to the A horizon) and therefore have less moisture available to plants. Because of their shallow A horizons (to 30 cm) red-yellow podzolics may also retain less moisture than those soils (yellow podzolics with minor yellow earths) which showed some degree of legume persistence. Further, the red-yellow podzolics had finer textured B horizons and shallower depth to strong mottling (40 cm c.f. 70–90 cm) than did the yellow podzolics, suggesting shallower impedance to water movement.

Potential availability of soil moisture between soil groupings may be the most significant physical feature as far as persistence of *D. intortum* is concerned. Its sensitivity to hot, dry periods (Hutton and Gray 1967) and limited tolerance to drought (Barnard 1972) support this contention. The CST group would normally be expected to have a better ability to respond to light falls of rain. By promoting water shedding, the harder setting nature of surface soils of the FST group would further accentuate differences in available water holding capacities between the two soil groupings.

Soil fertility and legume persistence

Based on the pattern of yield responses obtained (Table 4), molybdenum and lime appeared to be the only nutrients likely to have influenced legume persistence in Tinana soils.

Irrespective of pasture age and the amount and timing of previous fertilizer applications, additions of molybdenum and lime to FST soils always resulted in yield increases. In comparison, a lime response on CST soil did not appear until seven years under pasture, while responses to molybdenum were less frequent. Although initially molybdenum deficient, it took three years for this deficiency to re-emerge following applications of molybdenum fertilizer. On FST soils, molybdenum deficiency reappeared one year after treatment.

In view of the importance of molybdenum in legume nutrition, the different pattern of response between soil groupings and sensitivity of *D. intortum* to molybdenum deficiency (Johansen *et al.* 1977), it is suggested that this nutrient could have markedly influenced *D. intortum* growth and decline in Tinana pastures. This is especially so on FST soils which appear to have a lower residual molybdenum availability than CST soils. Higher rates and/or more frequent molybdenum applications should offset this apparently low residual availability.

Beneficial effects of lime on soils D and I could be linked to release of molybdenum although not exclusively in soil I, where a positive interaction with potassium was also apparent. On remaining FST soils, lime responses obtained were not significantly linked to interactions with other elements under test. As calcium deficiency symptoms (Andrew and Pieters 1972) were not observed and plant calcium concentrations compared favourably with those in healthy *D. intortum* reported by Andrew and Robins (1969*b*), some other factor appeared to be involved.

High tolerance of the related species *D. uncinatum* to aluminium excess (Andrew *et al.* 1973) together with generally satisfactory aluminium soil test levels and low aluminium availability at the pH of FST soils (Pratt 1966) suggest aluminium toxicity was not a factor. Plant manganese levels (data not reported) were also well below the toxicity threshold level for *D. uncinatum* (Andrew and Hegarty 1969). This appears to dissociate manganese toxicity from the lime response.

In the absence of any apparent soil structural improvements, most likely reason for the higher yield is that lime promoted mineralization of nitrogen, stimulating early growth of *D. intortum* seedlings. These are known (Hutton and Coote 1972) to establish rather slowly due to relatively low nodulating ability of some lines. Alternatively, the increased growth following liming could have resulted from improved nitrogen fixation (Munns *et al.* 1977). Further experimentation would be required to determine whether response continues past the seedling stage to an extent sufficient to influence legume persistence.

As good growth of Greenleaf was achieved on soils from both groupings when necessary plant nutrients were applied, it would appear that soil fertility need not be a factor in legume decline at Tinana.

Implications for fertilizer programmes

While greater attention must be given to molybdenum applications, especially on FST soils, changes in some other fertilizer practices also appear to be warranted.

Absence of a response to potassium in both virgin soils suggests potassium can be omitted from fertilizer mixtures at Tinana when planting into new land. Indications of a higher initial phosphorus requirement in virgin FST soils requires confirmation under field conditions.

Despite sizable inputs of potassium fertilizers, a pasture phase appeared to induce potassium deficiency in soils from both groupings. While higher and/or more frequent applications of potassium fertilizer are necessary, care is required on some FST soils as indicated by the yield depression due to potassium chloride treatment on soil H. This followed a total field application of 120 kg K ha^{-1} as potassium chloride in the two year period prior to sampling. Induced chloride toxicity (Andrew and Robins 1969 *c* and *d*, Jones 1973) and the highly sodic nature of this soil may have been contributing factors.

Previous superphosphate applications have generally been unable to satisfy the phosphorus and sulphur requirements of desmodium seedlings in potted surface soils from Tinana. Because sulphate-sulphur can occur at depth (Reisenauer *et al.* 1973, Probert and Jones 1977) and because established desmodium has smaller requirements for phosphorus (Fox *et al.* 1974), field experimentation is required to clarify maintenance fertilizer requirements for both these nutrients.

Absence of a response to zinc is in keeping with an unpublished soil test calibration of K. A. Verrall (personal communication) which indicates yield responses are probable on acid soils with D.T.P.A.—Zn levels of less than 0.2 ppm. By similar standards, copper levels in soils B, C, D, H and I are marginal, but yield responses were restricted to one soil. The strong tolerance of *D. intortum* to low copper situations (Andrew and Thorne 1962) undoubtedly influenced this result. If more copper sensitive species are to be grown, some copper fertilizer additions may be necessary.

ACKNOWLEDGEMENTS

We are indebted to Tinana Developments Pty. Ltd. of Gympie who assisted with site selection, soil collections and supplied details on pasture age and fertilizer history.

Within the Department of Primary Industries we are grateful for help given by various officers of Agriculture, Plant Pathology, Biometry and Agricultural Chemistry Branches, particularly B. G. Cook, P. E. Luck, J. A. G. Irwin, H. Mulder, N. G. Christianos and R. C. Bruce.

REFERENCES

Andrew, C. S. (1977)—The effect of sulphur on the growth, sulphur and nitrogen concentrations and critical sulphur concentrations of some tropical and temperate pasture legumes. *Australian Journal of Agricultural Research* **28:** 807–20.

Andrew, C. S., and Hegarty, M. P. (1969)—Comparative responses to manganese excess of eight tropical and four temperate pasture legume species *Australian Journal of Agricultural Research* **20:** 687–96.

Andrew, C. S., Johnson, A. D., and Sandland, R. L. (1973)—Effect of aluminium on the growth and chemical composition of some tropical and temperate pasture legumes. *Australian Journal of Agricultural Research* **24:** 325–39.

Andrew, C. S., and Pieters, W. H. J. (1972)—Foliar symptoms of mineral disorders in *Desmodium intortum*. Division of Tropical Pastures Technical Paper No. 10. (Commonwealth Scientific and Industrial Research Organization, Australia).

Andrew, C. S., and Robins, M. F. (1969a)—The effect of phosphorus on the growth and chemical composition of some tropical pasture legumes I. Growth and critical percentages of phosphorus. *Australian Journal of Agricultural Research* **20:** 665–74.

Andrew, C. S., and Robins, M. F. (1969b)—The effect of phosphorus on the growth and chemical composition of some tropical pasture legumes II. Nitrogen, calcium, magnesium, potassium and sodium contents. *Australian Journal of Agricultural Research* **20:** 675–85.

Andrew, C. S., and Robins, M. F. (1969c)—The effect of potassium on the growth and chemical composition of some tropical and temperate pasture legumes. I. Growth and critical percentages of potassium. *Australian Journal of Agricultural Research* **20:** 999–1007.

Andrew, C. S., and Robins, M. F. (1969d)—The effect of potassium on the growth and chemical composition of some tropical and temperate pasture legumes. II Potassium, calcium, magnesium, sodium, nitrogen, phosphorus and chloride. *Australian Journal of Agricultural Research* **20:** 1009–21.

Andrew, C. S., and Thorne, Peggy M. (1962)—Comparative responses to copper of some tropical and temperate pasture legumes. *Australian Journal of Agricultural Research* **13:** 821--35.

Barnard, C. (1972)—"Register of Australian Herbage Plant Cultivars" (C.S.I.R.O.: Canberra).

Colwell, J. D. (1963)—The estimation of the phosphorus fertilizer requirements of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3:** 190–97.

Fox, R. L., Nishimoto, R. K., Thompson, J. R., and de la Pena, R. S. (1974)—Comparative external phosphorus requirements of plants growing in tropical soils. Transactions of the 10th International Congress of Soil Science, Moscow **4:** 232–39.

Hutton, E. M., and Coote, J. N. (1972)—Genetic variation in nodulating ability in Greenleaf desmodium. *The Journal of the Agricultural Institute of Agricultural Science* **38:** 68–9.

Hutton, E. M., and Gray, S. G. (1967)—Hybridizaton between the legumes *Desmodium intortum*, *D. uncinatum* and *D. sandwicense*. *Journal of the Australian Institute of Agricultural Science* **33:** 122–23.

Johansen, C., Kerridge, P. C., Luck, P. E., Cook, B. G.. Lowe, K. F. and Ostrowski, H. (1977)—The residual effect of molybdenum fertilizers on growth of tropical pasture legumes in a sub-tropical environment. *Australian Journal of Experimental Agrculture and Animal Husbandry* **17:** 961–68.

Jones, R. M. (1973)—Seedling death of *Desmodium intortum* in the Queensland Wallum with special reference to potassium chloride fertilizer. *Tropical Grasslands* **7:** 269–75.

Kerr, H. W., and von Stieglitz, C. R. (1938)—The laboratory determination of soil fertility. Bureau of Sugar Experiment Stations, Queensland, Technical Communication No. 9.

Lindsay, W. L., and Norvell, W. A. (1969)—Development of a DTPA micronutrient soil test. *Agronomy Abstracts* p. 84.

Munns, D. N., Fox, R. L., and Koch, B. L. (1977)—Influence of lime on nitrogen fixation by tropical and temperate legumes. *Plant and Soil* **46:** 591–601.

Northcote, K. H. (1971)—"A Factual Key for the Recognition of Australian Soils". Third Edition (Rellim Technical Publications: Glenside, South Australia.)

Piper, C. S. (1950)—"Soil and Plant Analysis". (University of Adelaide Press: Australia).

Pratt, P. F. (1966)—Aluminium. Chapter 1 *In*: "Diagnostic Criteria for Soils and Plants" (Ed. H. D. Chapman), University of California: Riverside. U.S.A.

Probert, M. E., and Jones, R. K. (1977)—The use of soil analysis for predicting the response to sulphur of pasture legume in the Australian Tropics. *Australian Journal of Soil Research* **15:** 137–46.

Reisenauer, H. M., Walsh, L. M., and Hoeft, R. G. (1973)—Testing soils for sulphur, boron, molybdenum and chlorine. Chapter 12 *In* "Soil Testing and Plant Analysis". Revised Edition. (Ed. L. M. Walsh and J. D. Beaton), Soil Science Society of America, Inc.: Madison, Wisconsin, U.S.A.

Stace, H. C. T., Hubble, G. D., Brewer, R., Northcote, K. H., Sleeman, J. R., Mulcahy, M. J., and Hallsworth, E. G. (1968)—"A Handbook of Australian Soils." (Rellim Technical Publications: Glenside, South Australia).

Thompson, C. H. (1966)—Soils and soil problems of the Wide Bay district. The Tropical Grassland Society of Australia, Proceedings No. 6, 7–12.

(Accepted for publication January 5, 1979).