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Studies on solodic soils under *Acacia harpophylla-Eucalyptus cambageana* forests in central Queensland

2. Plant nutrient assessment in the glasshouse

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Summary

Nutrient experiments were conducted in the glasshouse on nine soils representative of solodised solonetz and solodic soils of *Acacia harpophylla* (brigalow)-*Eucalyptus cambageana* (Dawson gum) forests in central Queensland. Plant yield responses were obtained from the application of phosphorus, sulphur, potassium, lime, molybdenum and zinc.

1. INTRODUCTION

Chemical properties of the solodic soils occurring under *Acacia harpophylla-Eucalyptus cambageana* forests in central Queensland were described in Part 1 of this series (Webb, Dowling and Nugent 1982).

Effects of land clearing and development for pastures or cropping on total nitrogen and organic carbon contents of solodic soils in central Queensland are given by Graham, Webb and Waring (1981). They demonstrate marked yield response by buffel grass *(Cenchrus ciliaris)* to nitrogen applications at three sites on solodic soils. Glasshouse nutrient experiments on solodic soils (Webb, Maltby, Gill and Nugent 1977) indicate marked responses to sulphur and phosphorus by lucerne *(Medicago sativa)*. Unpublished studies (Dowling, personal communication) showed a marked phosphorus response with wheat on a solodic soil. These studies have given some insight into the fertility of this extensive group of soils. However, more information is required to help predict possible nutrient requirements, particularly since there is no depth of experience in fertiliser usage on these soils in the region.

The aim of this work was to investigate further the fertility of the solodic soils by conducting nutrient pot experiments on another nine sites in central Queensland.

2. MATERIALS AND METHODS

Nine soils were required for the glasshouse nutrient studies to cover a range of chemical properties and varying thicknesses of A horizon characteristic of the solodic soils in the region. Soils were numbered 1 to 9 with numbers 2, 5, 7 referring to Group 2, numbers 1, 3, 4, 6 to Group 3, and numbers 8, 9 to Group 4, as described in Part 1 of this series. Bulk surface (0 to 10 cm) samples were taken from pasture sites, sieved air dry through a 10 mm mesh and thoroughly mixed. For each soil a phosphorus rate experiment and a $\frac{1}{2} \times 2^6$ factorial nutrient experiment were carried out.

The phosphorus rate experiment comprised seven rates of phosphorus (0, 10, 30, 50, 70, 90 and 110 kg ha^{-1}P on an area basis as $NaH_2PO_4.2H_2O$) replicated three times. A basal application of all nutrients used in the factorial experiments was added to each pot.

For the $\frac{1}{2} \times 2^6$ factorial nutrient experiments, treatments were the presence or absence of lime, molybdenum, zinc, potassium, sulphur and copper plus boron. It was anticipated that on these soils phosphorus would have to be added as a matter of course to attain maximum yields. Hence, the effect of other nutrients should be examined in a situation where phosphorus is non-limiting to growth. For this reason, a basal application of phosphorus (58 kg ha^{-1}P) was added to all pots. Rates of application and nutrient compounds used are given in Table 1.

Table 1. Rates and chemical forms of nutrients used in pot experiments

Treatment	Compound applied	Rate of application	
		kg ha^{-1}	g per pot
P	$NaH_2PO_4.2H_2O$	237	0.42
Ca	$CaCO_3$	847	1.5
Mo	$(NH_4)_6Mo_7O_{24}.4H_2O$	0.6	0.001
Zn	$ZnCl_2$	15	0.026
K	KCl	100	0.177
S	Na_2SO_4	140	0.248
Cu	$CuCl_2.2H_2O$	15	0.026
B	$Na_2B_4O_7.10H_2O$	3	0.0053

Polystyrene 15 cm diameter pots holding 1 600 g soil were used for all $\frac{1}{2} \times 2^6$ factorial experiments and for the phosphorus rate experiments on soils 6 and 7. In the remaining seven phosphorus rate experiments, small aluminium pots (13 cm high × 6.5 cm diameter holding 450 g soil) were used to save glasshouse space.

Lucerne (*Medicago sativa* cv. Hunter River) inoculated with *Rhizobium* was grown as the test species. For each experiment, seedlings were thinned to seven plants per pot, watered daily to 'field capacity' with deionised water, and harvested at floral initiation. Oven dry weight (75°C) for each pot was recorded.

Dried plant material from selected treatments of the factorial experiments, and from bulked replicates of the phosphorus rate experiments, was ground in a stainless steel mill for tissue analysis. Following Kjeldahl digestion, nitrogen and phosphorus were determined colorimetrically and potassium by flame photometry. Sulphur, copper and zinc were determined by X-ray fluorescence spectroscopy.

The nine soils used were analysed using methods described in the previous paper (Webb *et al.* 1982).

3. RESULTS AND DISCUSSION

Soil analysis

Analytical data for the nine soils used in the pot experiments are shown in Table 2. Thickness of A horizons varied from 15 to 36 cm. Chloride levels were less than 20 ppm and are not shown. The low soluble salt content is evident from the EC values. Total nitrogen and organic carbon are very low in Soil 6. Other soil properties are discussed under the relevant sections below.

Phosphorus rate experiments

Pertinent yield and plant phosphorus concentration data, shown in Table 3, characterise the phosphorus response pattern for each soil.

Above ground dry matter production was significantly increased ($P<0.05$) by phosphorus addition in seven of the nine soils. Plant phosphorus concentrations also increased for all soils. However, plant percentage phosphorus levels for the seven soils tested in small (450 g) pots were all below the suggested critical phosphorus concentration of 0.24% (Andrew and Robins 1969a) even at the highest phosphorus rate. This suggests that the high phosphorus rate in the small pots was inadequate for luxury phosphorus uptake and probably also inadequate for maximum plant growth. For Soil 6 (the only phosphorus responsive soil tested in 1600 g pots) the critical phosphorus concentration was close to 0.24% (see Figure 1). The reflex curve for Soil 4 (Figure 1) is indicative of a 'Steenbjerg effect' (Steenbjerg 1951).

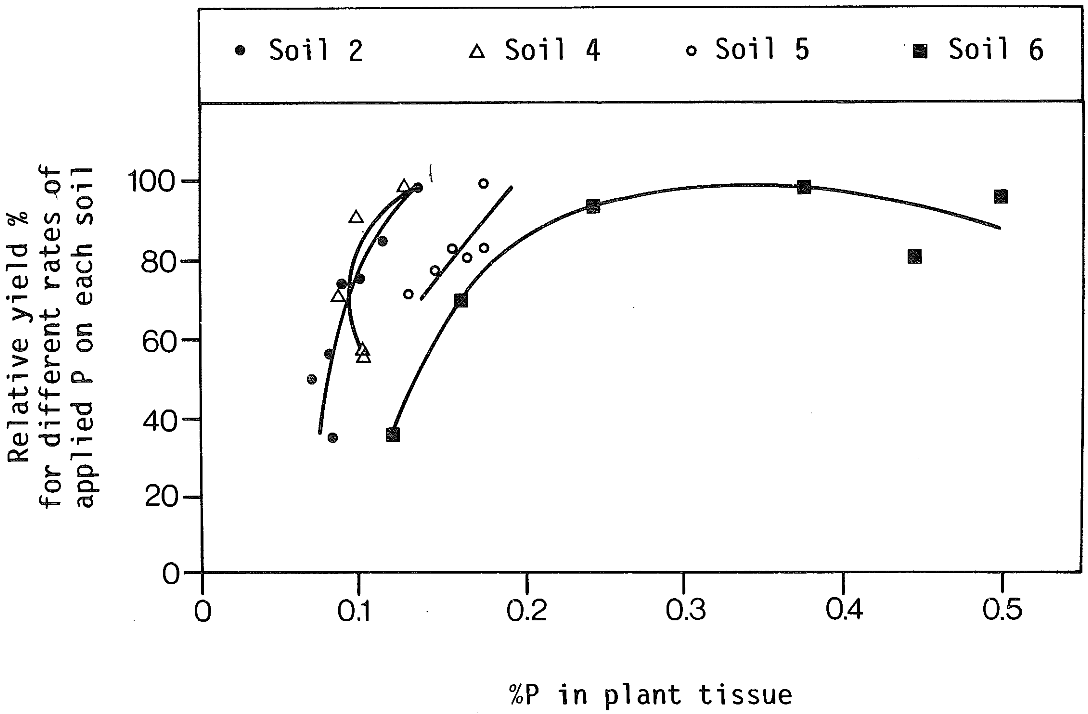

Figure 1. Hand fitted trend lines for the relationships between relative yield and plant phosphorus concentration on Soils 2, 4 and 5 (small pots) and Soil 6 (large pots).

Table 2. Analytical data for nine soils (0 to 10 cm) used in pot experiments

Attribute	Soil number								
	1	2	3	4	5	6	7	8	9
P.P.F.	Dy2.22	Dy2.43	Db1.43	Db1.43	Dd1.33	Db1.43	Dd1.43	Db1.43	Dy2.33
pH	7.2	6.6	7.0	7.3	6.2	6.8	7.0	7.6	6.9
* P_A ppm	24	9	15	12	26	10	60	58	13
† P_B ppm	14	8	14	8	16	7	37	34	10
Exchangeable cations meq per 100 g									
Ca^{++}	7.1	5.7	8.0	10.0	4.5	3.3	5.7	7.9	9.5
Mg^{++}	1.2	1.7	1.1	1.6	2.6	2.1	1.5	1.4	1.9
Na^{+}	0.09	0.06	0.06	0.10	0.23	0.17	0.40	0.04	0.03
K^{+}	0.50	0.20	0.35	0.36	0.52	0.16	0.59	1.02	0.85
C.E.C.	11	11	13	13	15	8	14	13	16
E.C. micro S cm^{-1}	105	28	70	60	34	20	45	122	52
Total N %	0.13	0.11	0.11	0.15	0.11	0.05	0.13	0.11	0.10
Organic C %	1.1	0.9	1.4	1.2	1.3	0.7	1.3	0.7	1.5
Total phosphorus %	0.056	0.029	0.051	0.045	0.041	0.024	0.048	0.062	0.046
Total potassuim %	0.29	0.35	1.63	0.28	0.20	0.34	0.16	0.86	1.14
Total sulphur %	0.026	0.026	0.020	0.024	0.028	0.013	0.020	0.020	0.020
D.T.P.A. Cu ppm	1.2	0.7	1.1	0.7	2.0	0.5	0.9	1.1	1.3
D.T.P.A. Zn ppm	0.8	0.2	1.1	0.4	1.5	0.2	1.3	1.4	0.6
Coarse sand %	39	37	38	42	44	57	46	22	33
Fine sand %	46	42	39	39	28	28	32	51	34
Silt %	6	7	12	6	9	7	9	13	14
Clay %	9	13	12	13	20	7	13	16	20
Air dry moisture %	1.3	1.6	1.5	1.5	2.1	1.0	1.7	1.6	2.6

*Acid extractable phosphorus ppm.
†Bicarbonate extractable phosphorus ppm.

Table 3. Yield and tissue phosphorus concentrations for *Medicago sativa* grown in phosphorus rate pot experiments

Soil	Control yield(P_0) (g per pot)	Maximum yield (P_{max}) (g per pot)	P rate giving maximum yield (kg ha^{-1} P)	Tissue % P of P_0	Tissue % P for 110 kg ha^{-1} P
1	0.82	1.01*	110	0.12	0.17
2	0.39	1.08*	110	0.08	0.14
3	0.70	0.96*	110	0.10	0.15
4	0.50	0.89*	110	0.10	0.14
5	0.83	1.15*	110	0.13	0.18
6†	1.24	3.33*	90	0.12	0.50
7†	3.46	3.61	50	0.22	0.46
8	0.97	1.21	90	0.16	0.20
9	0.56	0.99*	110	0.10	0.13

* Significant ($P<0.05$) yield increase due to phosphorus fertiliser.
† 1600 g soil per pot used. In all other cases 450 g soil per pot used.

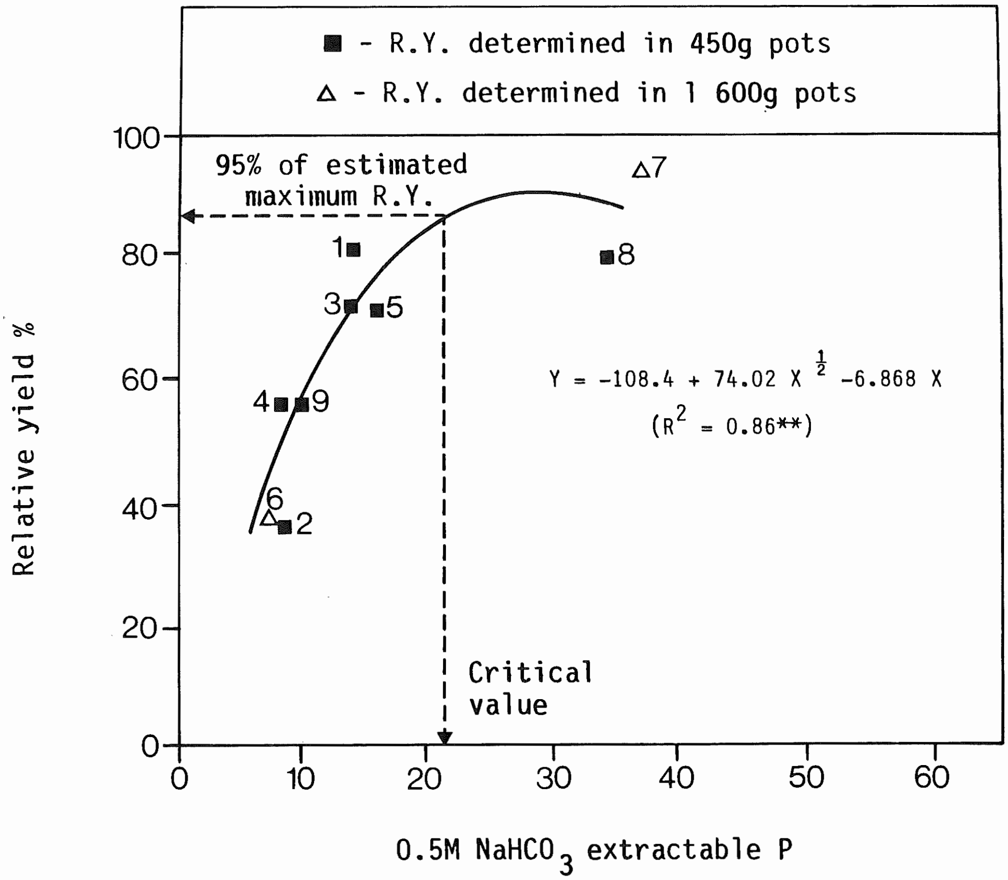

Figure 2. Relationship between relative yield and 0.5 M $NaHCO_3$ extractable soil phosphorus on nine soils.

Even though absolute growth of lucerne in the 450 g pots is much less than in the 1600 g pots, all phosphorus treatments are similarly affected. The use of relative yield (R.Y. = P_0/P_{max}) as the measure of soil phosphorus status largely negates absolute growth rate differences between plants grown in different sized pots.

Using data from all nine soils, R.Y. was significantly correlated with both 0.5 M $NaHCO_3$ extractable phosphorus (R^2 = 0.86**) and 0.005 M H_2SO_4 extractable phosphorus (R^2 = 0.84**). These regressions, illustrated in Figures 2 and 3, show that Soils 6 and 7 (tested in 1600 g pots) fall within the same general relationships as the other seven soils. Critical soil phosphorus values based on 95% of the estimated maximum R.Y. were 21 µg g^{-1} for the 0.5 M $NaHCO_3$ extraction and 33 µg g^{-1} for the 0.005 M H_2SO_4 extraction.

Factorial experiments

Significant yield ratios for main effects (verified for only three elements) are shown in Table 4.

Significant two factor interactions based on dry matter yields are shown in Table 5.

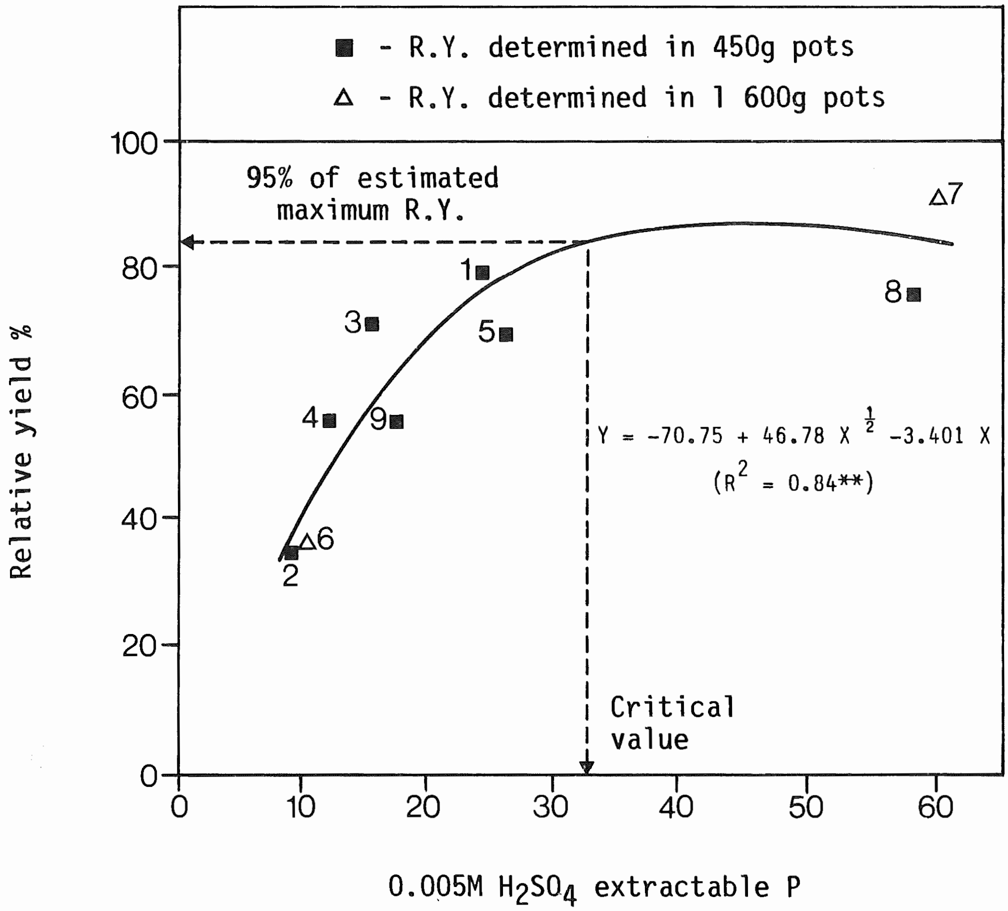

Figure 3. Relationship between relative yield and 0.005 M H_2SO_4 extractable soil phosphorus on nine soils.

Table 4. **Significant yield ratios† for main effects found in data for dry weight of tops**

Effect	Soil number								
	1	2	3	4	5	6	7	8	9
Lime		1.25**			1.10*	2.28**	1.56**		1.23**
S	2.01**	3.11**	1.61**	1.81**	1.14**	1.87**	1.13**		1.78**
Mo			1.08*				0.91*		1.12**
Mean yield (g per pot)	2.31	1.91	1.65	2.13	3.09	1.18	1.25	1.20	1.89
CV %	8.1	11.3	8.5	4.3	11.2	18.4	11.3	20.1	8.4

† Yield ratio = $\left(\frac{\text{Yield of treated plants}}{\text{Yield of untreated plants}}\right)$.

* Mean yield of treated plants significantly different to that for untreated plants at $P < 0.05$.
** Mean yield of treated plants significantly different to that for untreated plants at $P < 0.01$.
CV Coefficient of variation.

Table 5. **Significant two factor interactions found in data for dry weight of tops**

Effect	Soil number								
	1	2	3	4	5	6	7	8	9
Lime × Mo		*							
Lime × CuB				*					*
Lime × Zn							*		
Lime × S			**			*			
S × K		**		**					**
S × Mo			**	*			**		*
S × CuB	*								
K × Mo							*		

* Mean yield of treated plants significantly different to that for untreated plants at $P < 0.05$.
** Mean yield of treated plants significantly different to that for untreated plants at $P < 0.01$.

Sulphur. Sulphur was found to be deficient on all soils except Soil 8. Mean plant sulphur concentrations for nil sulphur treatments on sulphur deficient soils ranged from 0.10 to 0.20%. The suggested critical concentration is 0.20% (Andrew 1977). Mean sulphur concentrations for sulphur treated plants ranged from 0.28 to 0.43%. After correcting for possible effects of lime and molybdenum on plant nitrogen concentrations by selecting treatments that had both nutrients added, plant sulphur concentrations were found to be significantly correlated with plant nitrogen concentrations (r = 0.67, P<0.01) over all soils.

Total soil sulphur is not a good indicator of plant yield and would not have enabled pre-selection of the one non-responsive soil (8) in this study. Sulphur deficiency was so marked in some soils that responses to other nutrients occurred only after the addition of sulphur. The interactions are discussed in the relevant sections.

These results indicate a widespread deficiency of sulphur in the surface horizons of solodic soils. However, they must be viewed in conjunction with full soil profile analysis since it has been shown that sulphur responses in the field can be masked by relatively low levels of sulphur in the subsoil. Jones (1970) concluded that subsoil sulphate accounted for lack of response by lucerne to sulphur applications on black earths on the Darling Downs. The non-responsive field site used by this author had sulphate values up to 40 ppm (1:1 soil water extract). Sulphate values (1:1 soil water extract) for the solodic soils varied widely, but 16 of 37 sites analysed by Webb *et al.* (1982) had sulphate values greater than 40 ppm. Of the sites used in the pot experiments only Sites 1, 2, 5 and 6 had subsoil sulphate analyses carried out. These data are given in Table 6. Sites 1 and 2 had low sulphate values whereas 5 and 6 had relatively high values. It is possible then that at certain sites, such as Site 2, responses to sulphur may occur for a perennial pasture, particularly if it is not deep rooted.

Table 6. Sulphate concentration as $SO_4^=$ ppm air dry soil (1:1 soil water extract) for four solodic soils used in pot experiments

Soil depth (cm)	Soil number			
	1	2	5	6
0 to 10	12.49	0.0	106	76.85
20 to 30	13.93	13.93	115	475.50
50 to 60	33.00	16.33	48.03	110.47
80 to 90	29.77	13.92	38.90	96.06

Molybdenum and its interactions. After correction of sulphur deficiency three soils (3, 4, 9) showed positive responses to molybdenum addition. Taking into account the possible effects of sulphur and lime, mean plant nitrogen concentrations increased from 3.95 to 4.20% on molybdenum addition. Since total nitrogen levels are fairly high in these soils, nitrogen mineralisation with resultant plant uptake may mask any field molybdenum response.

In Soil 2, lime increased yields in the absence of molybdenum; were reflected in a plant nitrogen increase from 4.0 to 4.4%. However, in the presence of molybdenum there was no yield increase, corresponding plant nitrogen levels being 4.4. and 4.3%. This lime × molybdenum interaction is similar to that found by Anderson and Moye (1952) and Jones and Crack (1970).

The effects of molybdenum in Soil 7 are difficult to explain. The interactions indicate that sulphur and potassium alleviated a growth depression due to molybdenum addition. The plants in this soil were pale green and a second harvest was taken after the addition of 0.104 g NH_4NO_3 (in solution) to each pot. The addition of nitrogen alleviated the depressive effect of molybdenum.

Lime. Positive yield responses were recorded to lime addition on Soils 2, 5, 6, 7 and 9. In Soil 3 lime increased yield in the absence of sulphur while in Soil 6 there was an additive response to both lime and sulphur. The most important effects of lime are those associated with pH and availability of calcium, manganese, aluminium and molybdenum (Munns and Fox 1977).

Soil pH values on lime responsive soils ranged from 6.2 to 7.0. At these levels the yield response to lime is not thought to be due to an effect of pH on host–rhizobium symbiosis (Andrew 1976). It is also unlikely that manganese or aluminium would be affecting growth at these pH levels. The effect of molybdenum was accounted for in the experimental design. Munns and Fox (1977) reported growth responses to lime above pH 6.0 for a number of species (including *M. sativa*). These authors suggested that the response may be due to an increase in calcium activity on liming. This may be the case in this experiment. However, it is not reflected in plant calcium concentrations (range 1.23 to 2.17% for nil calcium treatments) which are considered adequate compared with the results of Andrew and Johnson (1976). Calcium may have affected host–rhizobium symbiosis in Soil 6 where plant nitrogen concentration increased by 38 and 20% following lime addition in the absence and presence of sulphur, respectively. This was not the case for the remaining lime responsive soils which exhibited no overall trend of nitrogen increase on lime addition.

Potassium and other nutrients. The sulphur × potassium interaction on Soils 2 and 9 indicated the possibility of a potassium deficiency in these soils. However, this could not have been diagnosed accurately from plant analysis as potassium concentrations for nil potassium treatments ranged from 1.26 to 2.88% potassium, which are above the suggested critical value of 1.2% (Andrew and Robins 1969b). In Soil 4 sulphur overcame a yield depression on addition of potassium. This is thought to be due to an alleviation of chloride toxicity by dilution (resulting from the yield increase on sulphur addition). Potassium was added as KCl (Table 1) and a number of workers have reported damage to legumes with high rates of KCl (Andrew and Robins 1969c; Hall 1971; Smith 1971; Rominger, Smith and Peterson 1976; and Webb *et al.* 1977).

Soil analysis indicated that copper levels were adequate, whereas for zinc, Soils 2, 4 and 6 would be considered deficient (Viets and Lindsay 1973). After correction of sulphur deficiency, mean plant copper concentrations ranged from 6.5 to 7.1 ppm in Soils 2, 4, 6 and indicate a potential deficiency of copper when compared with the suggested critical value of 7 ppm (Melsted, Motto and Peck 1969). All other soils had plant copper concentrations above the suggested critical level. The response to the copper-boron treatment in the presence of sulphur in Soil 1 cannot be explained from plant copper concentrations.

The response to zinc addition in the presence of lime in Soil 7 is thought to be pH induced. Mean plant zinc level was 33 ppm before liming and 15 ppm after liming. This indicates sufficiency and marginal conditions, respectively, when compared with the suggested critical value of 15 ppm (Melsted *et al.* 1969). Reduction in plant zinc concentration on liming has been reported by Pauli, Roscoe Ellis and Moser (1968) and Webb *et al.* (1977). Plant zinc concentrations in Soil 4 ranged from 10 to 14 ppm which, coupled with the low soil zinc levels, indicate the likelihood of a zinc deficiency in this soil. All other soils had plant zinc levels considered adequate for growth. However, the low soil zinc levels of some of the soils should be kept in mind when assessing the fertility status of these soils.

4. GENERAL DISCUSSION

The differences in chemical properties of the solodic soils used were not related to thickness of A horizon and, consequently, it is understandable that this property is not related to the nutrient response in pots of the surface 10 cm of these soils. Lucerne yield responses to phosphorus in pots were most marked on the solodic soils from Brigalow Research Station near Theodore (Webb *et al.* 1977), and responses to lime and zinc and the various interactions were similar to those achieved in this study with soils from a wider range of sites.

It is recognised that fertility status of the solodic soils is best studied under field conditions where climatic and genotypic influences can be accounted for. However, results from glasshouse experiments provide useful information on likely nutrient responses. Indications from the data presented here are that phosphorus, sulphur, potassium, lime, molybdenum and zinc would be limiting to plant growth at some sites in solodic soils.

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