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STUDIES ON THE GILGAIED CLAY SOILS (Ug 5·2) OF THE HIGHWORTH LAND SYSTEM IN CENTRAL QUEENSLAND

2. GLASSHOUSE ASSESSMENT OF PLANT NUTRIENT STATUS

by A. A. WEBB, M.Agr.Sc.

SUMMARY

The plant nutrient status of 10 cracking clay soils of the Highworth Land System in east-central Queensland was studied in a glasshouse experiment. Lucerne *(Medicago sativa)* was the test legume and yield response data are presented for one harvest and for the sum of three harvests. All soils showed response to phosphorus in the first harvest and for the sum of three harvests but only the latter values showed significant correlation with soil test values. Response to sulphur for the sum of three harvests only, and the presence of sulphate-sulphur in the subsoil, suggests that this nutrient is unlikely to be limiting. Zinc may also be marginal at some sites. Potassium, boron, molybdenum, copper and manganese are unlikely to be deficient.

I. INTRODUCTION

Chemical properties of the gilgaied clay soils of the Highworth land system (Speck *et al.* 1968) were presented in part 1 of this series (Webb, Crack and Gill 1977).

Information on the nutrient status of these soils is extremely limited. Fergus (1962) included two gilgaied clay soils from sites in the Biloela and Kokotungo areas in his nutrient pot experiments. He reported plant growth responses to phosphorus.

This paper presents results of nutrient pot experiments conducted on gilgaied clays from 10 sites in the Dawson–Fitzroy area of east-central Queensland.

II. METHODS

Soil sampling and analysis

Ten sites were selected to provide soils with a range of chemical properties for nutrient studies in pots. Bulk samples were taken to a depth of 10 cm, sieved through a 10 mm mesh and weighed into 15 cm diameter polystrene pots lined with polyethylene bags. In all experiments 1 700 g air dry soil per pot were used; soil was poured into each pot with regular light tamping to achieve a similar bulk density.

Soils were analysed for pH, total nitrogen, organic carbon, extractable phosphorus, exchangeable cations, cation exchange capacity and chloride using the methods described in part 1 (Webb, Crack and Gill 1977).

Extractable sulphur was determined using the method of Johnson and Nishita (1952) after extraction with calcium phosphate for 1 hour (Barrow 1967). Total sulphur was determined by X-ray fluorescence spectroscopy, and copper and zinc and manganese were determined by atomic absorption spectrophotometry after extraction with DTPA (Follett and Lindsay 1971).

Nutrient experiments

Nutrient treatments consisted of the presence or absence of phosphorus, sulphur, molybdenum, zinc, potassium and boron combined; and copper, manganese and iron combined. A half replicate of a 2^6 factorial design was used. Details of chemical forms and rates used are given in table 1. Hunter river lucerne (*Medicago sativa*) was the test plant. All seeds were pregerminated and inoculated with *Rhizobium*. Eight to 10 plants were grown in each pot. Pots were watered regularly with de-ionised water to keep the soil above 60% of the available moisture.

TABLE 1

NUTRIENT COMPOUNDS USED AND THE APPROXIMATE RATE OF APPLICATION

Compound	kg ha^{-1}	Element	Kg ha^{-1}
P as $NaH_2PO_4 .2H_2O$	290	= P	58
S as Na_2SO_4 (anhydrous)	180	= S	41
Mo as $(NH_4)_6 Mo_7O_{24} .4H_2O$	0·45	= Mo	0·24
Zn as $ZnCl_2$	14	= Zn	7
K as $KHCO_3$	150	= K	59
B as $Na_2B_4O_7 .10H_2O$	3	= B	0·35
Cu as $CuCl_2 .2H_2O$	14	= Cu	5
Mn as $MnCl_2 .4H_2O$	14	= Mn	4
Fe as Iron chelate spray 0·2%	Leaves sprayed until run-off occurred.		

Plant tops were harvested 52 days from planting. They were allowed to regrow for 30 days, harvested, regrown for a further 32 days and harvested again. Plant material was dried at 70°C and weighed. Dried plant material from selected treatments was ground in a 'Glen Creston' stainless steel mill. Only plants treated with phosphorus were selected for chemical analysis. Plant nitrogen and phosphorus were determined on an Auto-analyser and potassium on a flame photometer following Kjeldahl digest. Sulphur, copper, zinc and manganese were determined by X-ray fluorescence spectroscopy. Boron was determined by the method of Hayes and Metcalfe (1962).

III. RESULTS AND DISCUSSION

Soil chemical properties

Analytical data for the 10 soils used in the experiments are shown in table 2. None of the soils had been fertilized previously.

Soil pH ranged from slightly acid (pH 6·2) to mildly alkaline (pH 7·6). Exchangeable potassium values were all well above 0·2 m equiv. per 100 g, a commonly accepted threshold value (Williams and Lipsett 1960). Extractable phosphorus levels ranged from low to moderately high. Acid extractable values were highly correlated with bicarbonate extractable values ($r = 0·85$, $P < 0·01$). Extractable sulphur (SO_4—S) was less than 12 p.p.m. for six of the 10 soils. Extractable copper levels were all high but seven of the extractable zinc values were low.

TABLE 2

ANALYTICAL DATA FOR SURFACE SOILS (0 TO 10 cm) USED IN POT EXPERIMENTS

Attribute	Site Number									
	2	4	6	15	52	67	81	82	89	96
pH	7·4	6·4	7·6	6·2	7·3	6·5	7·4	6·9	7·1	7·3
Total nitrogen (%)	0·134	0·140	0·101	0·107	0·166	0·184	0·157	0·149	0·152	0·137
Organic carbon (%)	1·3	1·5	0·7	1·0	1·8	1·9	1·5	1·4	1·2	1·0
Extractable phosphorus (p.p.m.)										
0·5M $NaHCO_3$ extract	32	38	16	20	45	28	40	25	23	28
0·01N H_2SO_4 extract	23	32	8	20	50	29	56	23	28	36
Cation exchange capacity (m. equiv. per 100 g.)	30	28	36	24	30	26	33	32	29	25
Exchangeable cations (m. equiv. per 100 g.)										
Calcium	26	10	27	12	6	18	22	28	21	20
Magnesium	9·4	15	16	9·6	23	8·4	11	8·4	10	7·6
Potassium	1·0	1·0	0·8	0·7	1·0	1·0	0·9	1·0	0·9	0·7
Sodium	1·0	1·8	1·0	2·0	2·3	1·1	2·8	0·9	1·5	1·8
Chloride (%)	0·016	0·024	0·003	0·009	0·011	0·022	0·022	0·023	0·019	0·015
Extractable sulphur (SO_4–S) (p.p.m.)	28	11	7	not determined	8	22	11	22	10	11
Total sulphur (p.p.m.)	400	340	270	310	410	510	390	390	320	300
DTPA extractable zinc (p.p.m.)	0·68	2·08	0·48	0·70	1·24	1·54	0·66	0·46	0·62	0·54
DTPA extractable copper (p.p.m.)	2·63	3·46	1·08	1·31	3·46	4·69	1·89	2·06	1·23	2·33
DTPA extractable manganese (p.p.m.)	348	900	404	832	1 172	120	1 200	1 240	780	872

Nutrient experiments

Plant yield ratios $\left(\frac{\text{yield of treated plants}}{\text{yield of untreated plants}}\right)$ for significant main effects for the first harvest and the total of three harvests are shown in tables 3 and 4 respectively. Responses were obtained to phosphorus, sulphur, zinc and potassium plus boron. Significant two factor interactions for the initial and the sum of three harvests are shown in table 5.

TABLE 3

SIGNIFICANT YIELD RATIOS FOR MAIN EFFECTS (FIRST HARVEST)

Effect	Site No.									
	2	4	6	15	52	67	81	82	89	96
P	1·43*	1·64*	1·44**	1·57**	1·25**	1·38**	1·41**	1·33**	1·56**	1·58**
S									0·87*	
Zn							1·12*			
K, B ..										1·22*
C.V. % ..	23	54	9	37	18	14	14	15	20	23

* 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.
C.V. Coefficient of variability.

TABLE 4

SIGNIFICANT YIELD RATIOS FOR MAIN EFFECTS (SUM OF THREE HARVESTS)

Effect	Site No.									
	2	4	6	15	52	67	81	82	89	96
P	1·27*	1·41**	1·76**	1·46**	1·16**	1·31**	1·21**	1·87**	1·45**	1·27**
S			1·24**	1·11*	1·30**		1·13**	0·91*	1·20*	1·29**
Zn						1·05**				1·13*
C.V. % ..	23	25	10	11	11	4	8	12	17	14

* 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.
C.V. Coefficient of variability.

TABLE 5

SIGNIFICANT TWO FACTOR INTERACTIONS FOR THE FIRST AND SUM OF THREE HARVESTS

—	Site No.					
	4	6	52	67	82	89
First Harvest		PxS** MoxK, B*			PxK, B*	
Sum of Three Harvests	ZnxCu, Mn, Fe*	PxS**	PxS*	SxMo* SxK, B* PxZn*		PxS*

* Mean yield of treated plants significantly different to that for untreated plants at $P < 0{\cdot}05$.
** Mean yield of treated plants significantly different to that for untreated plants at $P < 0{\cdot}01$.

Coefficients of variability (C.V.) for yield data for each site (table 3, table 4) differed. In the first harvest result, site 4 was particularly variable. At most sites C.V. in the sum of three harvest data was less than for first harvest data. For sites 67 and 81, it was particularly low and accounts for the low yield ratios reflecting highly significant responses.

PHOSPHORUS. Highly significant plant growth increases to phosphorus treatment were measured on all soils both in the initial and subsequent harvests. Yield ratios for the sum of three harvests were correlated significantly with extractable phosphorus levels in the soils.

However, yield ratios for the first harvest were not significantly correlated with extractable soil phosphorus. Logarithmic transformation of the data did not improve the relationships.

The lack of significant relationship between yield ratios for the first harvest and extractable soil phosphorus is difficult to explain. The implication from this is that other factors were influencing plant yield apart from applied phosphorus.

The significant regressions for extractable phosphorus and yield ratio are shown below.

Acid extract $y = 1{\cdot}78 - {\cdot}0119x$ ($r = -0{\cdot}72$, $P < {\cdot}05$)
Bicarbonate extract $y = 1{\cdot}94 - {\cdot}0176x$ ($r = -0{\cdot}72$, $P < {\cdot}05$)
Where y = yield ratio for sum of 3 harvests
x = extractable phosphorus (p.p.m.)

From the above regressions the critical extractable phosphorus level for the gilgaied clays is 65 p.p.m. for acid extract and 53 p.p.m. for bicarbonate extract. The acid extract value is in agreement with the sufficiency range of 60 to 80 p.p.m. proposed by Fergus (1962) for similar soils.

Limitations of the above data are similar to those outlined by Fergus (1962). These are—

1. the correlation was obtained using one species in the glasshouse and is therefore not directly applicable to other species or to field conditions.
2. the data apply to surface soil (0 to 10 cm) only and therefore do not account for subsoil nutrients.

Field responses to phosphorus fertilizer on the gilgaied clays have not been observed in this region.

SULPHUR. There were no responses to sulphur in the initial harvest but there were responses in six of the 10 soils in subsequent harvests.

Phosphorus x sulphur interactions occurred in three soils (6, 52, 89). In soil 6, sulphur reduced the phosphorus response in the first harvest. However, over the three harvests, sulphur greatly enhanced the yield in the presence of phosphorus; it had an additive effect to the phosphorus response. A similar effect occurred in the three harvests for soils 89 and 52.

On one soil (82), a plant yield depression (yield ratio 0·87, table 3) was recorded to sulphur application. The SO_4—S value for this soil was reasonably high and sulphur content of plants from selected treatments without sulphur was 0·3%. This is well above the suggested critical level of 0·22%S (Pumphrey and Moore 1965, Harward, Chao and Fang 1962). At the six sites where sulphur caused significant plant yield increases in subsequent harvests, plant sulphur contents of minus-sulphur plants in the initial harvest were less than 0·22% and initial soil SO_4 — S levels were $<$ 12 p.p.m. for the five responsive sites where analyses were done.

Beaton, Burns and Platon (1968) stated that where soil phosphorus is adequate the P/S ratio in the plant material should be a suitable indicator of the soil sulphur supply. In lucerne, this is usually about 1:1.

In this series of pot experiments the plants (P treated) which responded to sulphur had P/S ratios in the initial harvest of 1·8 : 1 to 2·0 : 1. Non-responsive plants had ratios of 1·1 : 1 to 1·4 : 1. This, together with the yield data, suggests that sulphur could become a limiting nutrient in some crop situations. However, sulphate–sulphur occurs at depth in a number of soil profiles examined and this current work does not take into account likely effects of this in field situations.

POTASSIUM. Significant plant responses were recorded in soil 96 to the potassium plus boron treatment in the first harvest, but not for the sum of three harvests. Exchangeable potassium values of all soils were above that at which a deficiency could be expected (Williams and Lipsett 1960). Plant potassium concentrations of potassium plus boron treatments also were above the critical value of 1·2% (Andrew and Robins 1969).

Potassium plus boron treatment caused a significant depression in yield in the presence of molybdenum in soil 6, and in the presence of sulphur in soil 67. It reduced the yield increase due to phosphorus in soil 82. The reasons for these depressions are obscure. Plant potassium concentrations in either the absence or presence of the potassium plus boron treatment for these soils were quite high but did not differ greatly (3·0 to 3·9% K).

Plant boron concentrations for the absence or presence of potassium plus boron treatment for soils 6, 82 and 96 were 78 and 83 p.p.m., 57 and 58 p.p.m., 41 and 45 p.p.m. respectively. It appears boron was not responsible for any of the plant response, and potassium effects also do not appear to have operated.

ZINC. A positive zinc response occurred in soil 81 (first harvest) and in soils 67 and 96 (sum of 3 harvests). In soil 67, zinc interacted with phosphorus to enhance the phosphorus response. In soil 4 in cumulative harvests, a significant zinc response occurred in the presence of the copper–manganese–iron treatment.

Mean plant zinc concentration for selected zinc treatments for soil 81 was 15 p.p.m. which is the suggested critical value (Melsted, Motto and Peck 1969). For soils 67 and 96 where a response was obtained only in cumulative harvests, plant zinc concentration of the zinc treatments in the first harvest were 27 and 18 p.p.m. respectively.

DTPA extractable zinc in the soils (table 2) indicates that seven of the 10 soils had zinc levels close to the suggested critical level in the soil of 0·5 p.p.m. (Brown, Quick and Eddings 1971). Soil zinc was poorly correlated with plant zinc.

OTHER NUTRIENTS. The copper–manganese–iron treatment did not have a significant effect on plant yield in any soil and featured only in the interaction mentioned above. No reason is suggested for this interaction. Mean plant copper concentration for selected copper treatments ranged from 7·4 to 15 p.p.m. copper. These values are higher than the critical value of 7 p.p.m. (Melsted, Motto and Peck 1969) and higher than the value of 5 p.p.m. suggested by Andrew and Thorne (1962) as marginal for legumes. DTPA extractable copper in all the soils was high. It was poorly correlated with plant copper.

Manganese analyses were carried out on plants and soils. All plant manganese contents (data not presented) were below the toxicity threshold of 380 p.p.m. (Andrew and Hegarty 1969). Soil manganese was highly correlated with plant manganese over all soils ($r = 0{\cdot}85$, $P < {\cdot}01$).

Molybdenum had no significant effect on plant yield or nitrogen content on its own, but did interact with the potassium plus boron treatment (soil 6), and sulphur (soil 67) to cause a significant yield depression.

IV. CONCLUSIONS

While results from glasshouse experiments need confirmation in the field, they are useful in providing information on likely nutrient responses. On this basis, the above experiments indicated that phosphorus deficiency is likely to be widespread on the gilgaied clays of the Highworth land system.

Zinc deficiency is not likely to be widespread, but at occasional sites could be marginal. Sulphur levels in the surface soil may be marginal at many sites. Since responses to sulphur were not present in the initial harvest and only occurred with successive harvests, serious deficiencies are unlikely, particularly where sulphate–sulphur occurs in the subsoil. Potassium, boron, molybdenum, copper and manganese deficiencies are unlikely.

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REFERENCES

ANDREW, C. S. and HEGARTY, M. P. (1969). Comparative responses to manganese excess of eight tropical and four temperate pasture legume species. *Aust. J. agric. Res.* 20:687.

ANDREW, C. S. and ROBINS, M. F. (1969b). The effect of potassium on the growth and chemical composition of some tropical and temperate pasture legumes. 1. Growth and critical percentages of potassium. *Aust. J. agric. Res.* 20:999.

ANDREW, C. S. and THORNE, PEGGY M. (1962). Comparative responses to copper of some tropical and temperate pasture legumes. *Aust. J. agric. Res.* 13:821.

BARROW, N. J. (1967). Studies on extraction and on availability to plants of absorbed plus soluble sulphate. *Soil Science* 104:242.

BEATON, J. D.; BURNS, G. R. and PLATON, J. (1968). Determination of sulphur in soils and plant material. Tech. Bull. No. 14. The Sulphur Institute, Washington, D.C.

BROWN, A. L.; QUICK, J. and EDDINGS, J. L. (1971). A comparison of analytical methods for soil zinc. *Soil Sci. Soc. Amer. Proc.* 35:105.

FERGUS, I. F. (1962). The nutrient status of some soils of the brigalow lands. *C.S.I.R.O., Aust. Div. Soils divl. Rep.* 1/62.

FOLLETT, R. H. and LINDSAY, W. L. (1971). Changes in D.T.P.A.—extractable zinc, iron, manganese and copper in soils following fertilization. *Soil Sci. Soc. Amer. Proc.* 35:600.

HARWARD, M. E., CHAO, T. T. and FANG, S. C. (1962). The sulphur status and sulphur supplying power of Oregon soils. *Agron. J.* 54:101

HAYES, M. R. and METCALFE, J. (1962). The Boron–Curcumen Complex in the determination of trace amount of boron. *Analyst* 87:956–69.

JOHNSON, C. M., and NISHITA, H. (1952). Microestimation of sulphur in plant materials, soils and irrigation waters. *Anal. Chem.* 24:736.

MELSTED, S. W., MOTTO, H. L. and PECK, T. R. (1969). Critical plant nutrient composition values useful in interpreting plant analysis data. *Agron. J.* 61:17.

PUMPHREY, F. V. and MOORE, D. P. (1965). Diagnosing sulphur deficiency in alfalfa from plant analysis. *Agron. J.* 57:364.

SPECK, N. H., WRIGHT, R. L., SWEENY, F. C., PERRY, R. A., FITZPATRICK, E. A., NIX, H. A., GUNN, R. H. and WILSON, I. B. (1968). Lands of the Dawson–Fitzroy Area, Queensland, *C.S.I.R.O. Aust. Land Res. Ser. No.* 21.

WEBB, A. A., CRACK, B. J. and GILL, J. Y. (1977). Studies on the gilgaied clay soils (Ug 5·2) of the Highworth Land System in east-central Queensland. 1. Chemical characteristics. *Qd. J. agric. Anim. Sci.* 34:53.

WILLIAMS, C. H. and LIPSETT, J. (1960). The build up of available potassium under subterranean clover pastures on a podzolic soil. *Aust. J. agric. Res.* 11:473.

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The author is an officer of Agricultural Chemistry Branch, Department of Primary Industries and is stationed at Biloela.