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Thermodynamic Assessment of the Nutrient Status of Rubber-Growing Soils

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Plantation Crops Research Institute, P.O. Kudlu, Kasaragod

M. MOHINDER SINGH

Rubber Research Institute of Malaya, Kuala Lumpur, Malaysia

O. TALIBUDEEN

Rothamsted Experimental Station, Harpenden, Herts., U.K.

Schofield's thermodynamic concepts of intensity and quantity were used for measuring the potassium and phosphorus status of Malayan rubber-growing soils. It was shown that for acid soils in Malaya, intensity and quantity measurements need be done using aluminium as the reference ion instead of calcium used elsewhere. For phosphorus, intensities were measured in dilute ammonium chloride solutions instead of calcium chloride solutions used elsewhere and quantities were measured by isotopic exchange.

These thermodynamic indices and the conventional indices of acid-extractable and exchangeable values for potassium, and total and available indices for phosphate, which are in current routine use, were related to uptake by *Pueraria phaseoloides* in the glasshouse. This showed that for assessing the potassium status of Malayan soils, the buffer capacity value obtained from the slope of the quantity/intensity relationship curve was better than the conventional acid-extractable and exchangeable values currently used for determining the fertiliser requirements of rubber. For phosphorus, both conventional and thermodynamic quantity indices related directly to glasshouse cropping. More work is however necessary for a systematic correlation.

Large amounts of potassium and phosphorus fertilisers are applied on Malayan rubber-growing soils to obtain better growth of *Hevea brasiliensis* and greater yields of latex. Soil analysis plays a major role in the discriminatory application of these fertilisers. In Malaya soil testing for fertiliser advice is still based on conventional techniques. Boiling hydrochloric acid (6 N, 1 h) which extracts only a small fraction of the total soil cations and exchangeable cations (to $M \text{ NH}_4\text{OAc}$) are the methods used at present for estimating 'reserve' and 'available' soil potassium status respectively. For phosphorus, digestion with perchloric-sulphuric acid mixture, which extracts nearly all the phosphorus, gives the total reserve, and a 1-minute extraction of soil with an acidified ammonium fluoride reagent gives an estimate of the phosphorus 'available' to the crop. These conventional methods are able to distinguish between soils which are high and

low in nutrient content, but are not sufficiently sensitive to discriminate between soils with medium or low nutrient status. The need to improve the existing conventional methods was thus recognised. With the better knowledge of the physico-chemical reactions in soil that is now available, an attempt was made to rationalise soil testing using more fundamental concepts based on the hypotheses of SCHOFIELD (1947 and 1955), involving the soil solution for estimating the potassium and phosphorus status of the highly leached, acid, rubber-growing soils of Malaya.

For cations (only potassium is considered in this study), Schofield's Ratio Law states that 'when cations in solution are in equilibrium with a larger number of exchangeable ions, a change in the activity of the solution will not disturb the equilibrium if the activities of all monovalent cations are changed in one ratio, those of all the divalent ions in the square of

that ratio and those of all trivalent ions in the cube of that ratio.' This law will hold as long as the outside solution concentration is low enough for a diffuse double layer to form. K and Ca will therefore be in a fixed ratio on the soil for a given K/\sqrt{Ca} activity ratio in solution. This activity ratio is called the 'intensity' of the soil potassium and is a measure of the strength or potential with which an ion is attached to the electro-chemical system of the soil. The greater suitability of intensity measurements, expressed in terms of free energy or as activity ratios, over empirical methods for assessing the soil potassium availability has been indicated by correlation with the uptake of potassium by ryegrass (ARNOLD, 1962; MCCONAGHY AND SMILLIE, 1965; TALIBUDEEN AND DEY, 1968 a and b) and with the uptake by oats (ACQUAYE *et al.*, 1967) in the glasshouse. The soils used were however saturated mainly with calcium, and the potassium potential was measured with respect to calcium or calcium plus magnesium potential, activity ratios used being of the form K/\sqrt{Ca} or $K/\sqrt{(Ca + Mg)}$. TINKER (1964) stated that in very unsaturated soils account should also be taken of exchangeable alumi-

nium and proposed a modified procedure for acid soils. He found that the intensity index, $K/\{\sqrt{(Ca + Mg)} + P^3\sqrt{Al}\}$ related better to responses by oil palm to potassium manuring than $K/\sqrt{(Ca + Mg)}$. However in Malayan rubber-growing soils which are acidic with pH values being generally between 3.5 to 4.5, the calcium potential is low. Under such circumstances the potassium-calcium potential is not likely to represent the correct measure of potassium supply. Preliminary studies with rubber-growing soils confirmed this (MOHINDER SINGH *et al.*, 1968).

While intensity gives the strength with which the nutrient is held in the soil, a term 'quantity' is used to denote the amount of the ion present at a definite intensity or potential in the soil.

These quantity and intensity values obtained from the quantity/intensity relationship curves based on the potassium-calcium plus magnesium potential, gave poor relationships with the uptake of potassium by *Pueraria* in the glasshouse (MOHINDER SINGH *et al.*, 1968). It is considered that with the acid soils in Malaya potassium potential with respect to aluminium would be a better index than with respect to

TABLE 1. MECHANICAL AND CHEMICAL COMPOSITION OF TOP-SOILS (0-6") USED IN EXHAUSTIVE CROPPING FOR POTASSIUM BY *PUERARIA* IN GLASSHOUSE

Soil series	Mechanical analysis			pH (CaCl ₂)	Exchangeable cations (to M NH ₄ Cl) m-equiv./100 g soil					
	% oven dry soil				K ⁺	Ca ⁺⁺	Mg ⁺⁺	Al ⁺⁺⁺	Sum	% K in C.E.C.
	0.02-0.022 mm	< 0.002 mm	Surface area* m ² /g							
Rengam	8	41	111	4.0	0.14	0.78	0.09	1.92	2.93	4.8
Serdang	10	26	68	3.8	0.10	0.63	0.08	5.08	5.89	1.7
Selangor	43	40	188	3.6	0.37	1.39	1.80	12.40	15.96	2.3
Kuantan	33	46	248	4.3	0.10	1.23	0.40	0.90	2.63	3.8
Segamat	25	57	149	4.3	0.16	0.84	0.35	0.70	2.05	7.8
Batu Anam	34	51	66	3.8	0.12	1.20	0.33	3.10	4.75	2.5
Chemor	3	15	44	4.2	0.06	0.80	0.06	1.33	2.25	2.7
Ulu Tiram	7	20	62	4.2	0.06	0.78	0.07	1.60	2.51	2.4

*By ethylene glycol adsorption (courtesy of A.G. Rawson, Rothamsted Experimental Station)

calcium as these soils contain aluminium (Table 1) and not calcium as the predominant exchangeable cation. We have now examined quantity/intensity relationships using the intensity index $K/\sqrt[3]{Al}$, which represents the potassium-aluminium potential.

For phosphorus, the chemical potential of monocalcium phosphate, in the equilibrium soil solution, defined by $\frac{1}{2}pCa + p(H_2PO_4)$, was proposed (SCHOFIELD, 1955) as the function likely to give a numerical index of the condition in soil which mainly controls the availability of phosphate in Ca-dominant soils. Measurements were simplified by shaking soil with 0.01 M CaCl₂ in which the activity of Ca ions remains constant. The concentration of orthophosphate ion in 0.01 M CaCl₂ has further been used as a first approximation of the phosphorus potential or intensity. Acid soils are however aluminium-dominant and the aluminium phosphate potential, $\frac{1}{3}pAl + p(H_2PO_4)$, or as a first approximation, the concentration of phosphate ions in dilute AlCl₃ solution, is the obvious criterion. The extreme insolubility of aluminium phosphate make any measurements in dilute AlCl₃ solutions impractical. Others however have used solutions of potassium chloride for similar studies (ARAMBARRI AND TALIBUDEEN, 1959). But with our aluminium saturated soils, we have used 0.01 M NH₄Cl instead, since the NH₄ ion equilibrates with adsorbed Al ions more rapidly (e.g. SKEEN AND SUMNER, 1967).

EXPERIMENTAL

Materials

Surface soils (0-6") of eight major rubber-growing areas were sampled in the unmanured plots of, or adjacent to, current manurial trials, air-dried and sieved (< 2 mm). The mechanical and chemical composition of these soils is given in Table 1, which shows that all the soils, except the Selangor series soil, have rather small C.E.C. (cation exchange capacities) values (2.05 to 5.89 m-equiv./100 g soil) relative to their < 2 μ clay contents and specific surface areas. The Rengam and Segamat series soils have larger fractions of their C.E.C.s as potassium (4.8 and 7.8% respectively) than the other soils (2.5 \pm 0.7%).

Methods

Intensity and quantity measurements for potassium were made by a single equilibration method (after BECKETT, 1964a, but using 0.01 M AlCl₃ instead of 0.01 M CaCl₂ as follows:

Ten g soil samples were brought to a moisture content of 50% and left overnight; 25 ml of 0.012 M AlCl₃ solutions containing added amounts of potassium from 0 to 3 mM were added and shaken overnight. Preliminary studies in this laboratory showed that equilibrium was reached within this time and no appreciable fixation of potassium occurred. Potassium concentration in the equilibrium solutions was determined by emission flame spectrophotometry using a Unicam SP900A spectrophotometer and aluminium concentration was determined by the 'aluminon' method (CHENERY, 1948).

ΔK , the amount of potassium lost or gained by the soil (in m-equiv./100 g soil) relative to the initial state of the soil, was calculated from the difference of the initial and final concentrations of its solution. ΔK values were plotted against the intensity value $K/\sqrt[3]{Al}$ in the resulting equilibrium solutions calculated from their compositions. Linear quantity/intensity (Q/I) relationships, as shown in Figure 1, were obtained for Serdang, Selangor, Kuantan and Segamat series soils but for Rengam, Chemor,

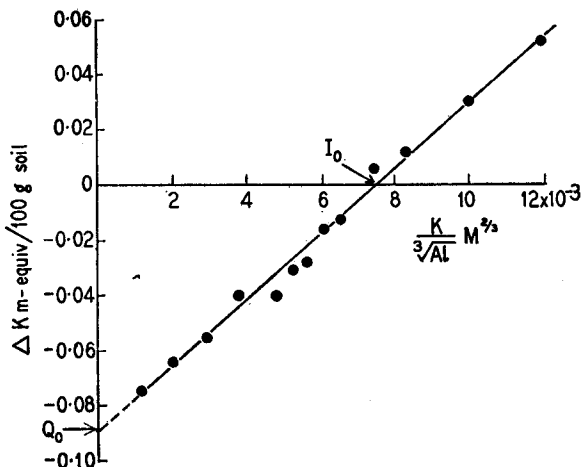


Figure 1. Q/I relationship of Kuantan series soil.

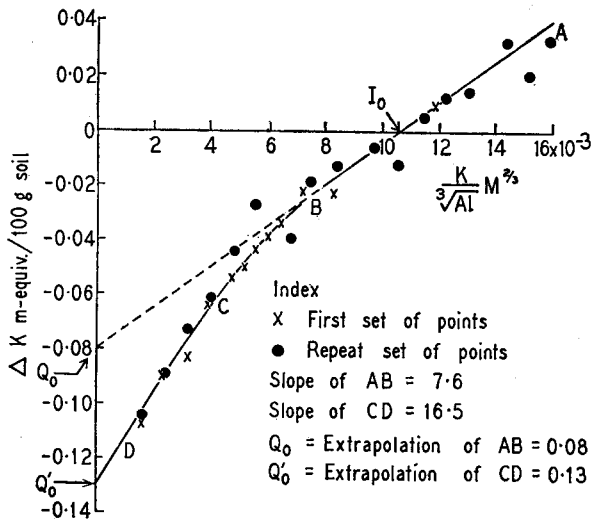


Figure 2. Q/I relationship of Batu Anam series soil.

Ulu Tiram and Batu Anam series soils, the Q/I curves were curvilinear for intensity values below $2.5, 3.5, 3.5$ and 7×10^{-3} respectively, which BECKETT (1964a) suggested is the general form of the Q/I curve (Figure 2). The 'true' intensity value (I_0) of the soil was read off from the 'no potassium exchange' position of the curve ($\Delta K = 0$); the quantity (Q_0) which maintains this intensity was obtained by extrapolating the lower linear portion of the Q/I curve for the Batu Anam series soil as an appreciable curvilinear part was obtained, and the fully linear relation for the others.

The potential buffering capacity ($B.C.$) of the soil to maintain a given potential against depletion is defined by $\delta Q/\delta I$ and is the rate of change of quantity with intensity. Three buffer capacity values were determined. $B.C.$ (laboratory) was taken as the slope of the linear portion of the Q/I curve. For $B.C.$ (cropping), δQ was taken as the potassium removed by *Pueraria* cropping in the glasshouse and δI was taken as $I_0 - 0.5 \times 10^{-3}$. I_0 , the initial soil intensity, was obtained from the Q/I curve. The potassium intensity of soils depleted by cropping was not measured here, so a value of 0.5×10^{-3} was used to calculate $B.C.$ (cropping), which was observed in the glasshouse cropping of soils with ryegrass

at Rothamsted (TALIBUDEEN AND DEY, 1968 a and b). For $B.C.$ (exchangeable), δQ was taken as the exchangeable value and δI the same as in $B.C.$ (cropping).

Intensity measurements for potassium were also made by a successive equilibration procedure developed at Rothamsted. Soil, wetted overnight, was shaken with $0.01 M AlCl_3$ solution for 2 hours and centrifuged. The supernatant solution was poured into a second centrifuge tube containing a fresh lot of pre-wetted soil and the procedure repeated until the $K/\sqrt[3]{AI}$ ratio did not change when equilibrated further with fresh lots of soil; five such equilibrations were necessary to attain equilibrium. This equilibrium value of $K/\sqrt[3]{AI}$ is a measure of the intensity.

Phosphorus intensity was measured by the successive equilibration procedure, described for potassium, using $0.01 M NH_4Cl$. The equilibrium P concentration was found to be very low, $1 \times 10^{-7} M$ and less, making accurate P measurements difficult and comparison of P intensities between soils insensitive.

An attempt to overcome the above difficulty was therefore made by adding small but differing amounts of citrate to the NH_4Cl equilibrating solutions and extrapolating the measured P concentrations to the values at zero citrate concentration to obtain the 'true' value. A single equilibration of 24 hours (instead of successive equilibrations) was used to save time and avoid microbial interference (see later). Table 2 shows the effect of citrate concentration on P intensity of a Batu Anam series soil (from Ladang Geddes Estate) which still shows residual effects on latex yield of earlier P manuring. The proportional change in phosphate concentration increases from $P_0 \rightarrow P_1 \rightarrow P_2$ as the citrate concentration decreases, except for the 'true' value of P_1 . These 'true' values cannot be taken as an absolute measure of phosphate intensity as the error on extrapolation is considerable (Table 2).

For routine purposes, the above extrapolation procedure is laborious. We therefore confined our measurements to an equilibrium value (24 h shaking) with $10^{-3} M$ citrate in $0.01 M NH_4Cl$.

TABLE 2. EFFECT OF CITRATE CONCENTRATION ON P INTENSITY OF A BATU ANAM SERIES SOIL

Soil treatment	Citrate concentration in 0.01M NH ₄ Cl solution			
	10 ⁻³ M	5 × 10 ⁻⁴ M	10 ⁻⁴ M	Zero citrate by extrapolation*
	Concentration of phosphorus in equilibrium solution × 10 ⁻⁷ M			
p ₀	13.1	5.2	0.59	(a) (b) 0.10 – 0.30
p ₁	17.5	11.8	1.32	0.15 – 0.70
p ₂	28.6	12.7	2.72	0.74 – 1.40

* From plot of:

(a) log phosphate concentration vs citrate conc.

(b) log phosphate concentration vs √citrate conc.

Quantity measurements of phosphate were made by isotopic exchange (ARAMBARRI AND TALIBUDEEN, 1959) of P³² as follows: 50 g of soil, pre-wetted to 50% moisture overnight, were equilibrated with 150 ml of 1.17 × 10⁻³ M citrate in 1.17 × 10⁻² M NH₄Cl; 60 ml of this equilibrium solution was then equilibrated with a fresh lot of 1 g of pre-wetted soil and labelled with P³². The rate of P³² exchange from the solution with the phosphorus in soil was measured over twelve days by following the change in radioactivity in the solution with time. 0.5 ml aliquots of the clear supernatant solution (obtained by centrifuging at 20 000 g) were dried on planchettes and assayed by solid Geiger-Muller counting. From each reaction tube a maximum of six samples (0.5 ml aliquot each) representing six different reaction times were drawn, thus keeping errors due to change in volume of the reaction solution below 5%. The rate of change of P³² radioactivity, corrected for decay, was then graphically analysed to calculate the 'rapid' and 'total' labile phosphate pools.

Fresh crystals of thymol were added daily to the reaction mixture to control immobilisation of inorganic P from solution by viable micro-organisms. The control was however erratic with some soils and reliable P measurements were generally possible for about five days

only. In such cases, only the rapid labile pool was measurable, the total labile pool value being inaccurate.

Glasshouse Cropping

Soils were repeatedly cropped in triplicate with *Pueraria phaseoloides* in the glasshouse; 400 g soils mixed with 200 g acid-washed quartz sand (72 mm) were packed in polythene pots of 3" diameter and 6" depth. Water was supplied by capillary rise through the perforated bottom of the pots. Twenty pre-germinated seedlings were established and were harvested every eight weeks. Cropping was terminated when dry matter produced fell below 0.2 g per pot. Of the eight soils used here, only three croppings were possible with Kuantan, Segamat, Chemor and Ulu Tiram series soils, while with Rengam, Serdang, Selangor and Batu Anam series, six croppings were obtained.

RESULTS AND DISCUSSION

Potassium

Intensity values for potassium by the single equilibration method (after Beckett) and the successive equilibration procedure developed at Rothamsted were similar. In the single-equilibration method, aluminium concentration in the equilibrium solutions was between 0.008 M and 0.010 M. The use of aluminium as a reference ion in the comparison of potassium intensities and quantities of soils was on the basis that the soils were found to have 50 to 90% aluminium in the exchange complex.

As can be noted from Table 3, quantity values obtained by interpolation of the quantity/intensity curve are lower than exchangeable values obtained by ammonium chloride leaching. This is in line with earlier findings by BECKETT (1964b). It has been explained earlier (MOHINDER SINGH *et al.*, 1968) that the exchangeable K may be considered as being composed of (a) an 'immediate' labile pool which equilibrates rapidly and is the one measured here as the quantity, and (b) a 'slow' or 'less readily' exchangeable pool which represents K held on 'specific' sites. This potassium held on 'specific' adsorption sites possibly accounts for the lower curvilinear part of the quantity/intensity curve (Figure 2).

TABLE 3. SOIL INDICES FOR POTASSIUM AND VALUES OF TOTAL UPTAKE BY *PUERARIA* IN GLASSHOUSE CROPPING FROM TOP-SOILS (0-6')

No.	Soil series	Exchangeable K, m-equiv./100g	Acid extractable K, m-equiv./100g	Q_0 , m-equiv./100g	$I_0 \times 10^{-3}$ M \ddagger	B.C. (laboratory)	Uptake by <i>Pueraria</i> , m-equiv./100g	B.C. (cropping)
1	Rengam	0.14	0.32	0.10	9.9	10.5	0.16	14
2	Serdang	0.10	2.95	0.08	5.1	15.7	0.42	72
3	Selangor	0.37	3.99	0.24	5.4	44.4	0.75	118
4	Kuantan	0.10	0.37	0.09	7.5	12.0	0.10	14
5	Segamat	0.16	0.42	0.12	9.2	13.1	0.10	11
6	Batu Anam	0.12	2.76	0.08(0.13) ^a	10.6	7.6(16.5) ^a	0.33	27
7	Chemor	0.06	0.26	0.03	7.0	4.3	0.06	9
8	Ulu Tiram	0.06	0.40	0.04	5.8	6.9	0.07	12

^a See Figure 2. Values represent extrapolation of upper and lower linear portions of Q/I curve.

Quantity/intensity relationships were determined on two soils (from an earlier sampling) to which potassium was added as KCl solution and aerobically incubated. Measurements after one week's incubation showed that quantities and intensities of potassium increased according to the amount of potassium added, but the buffering capacity remained unchanged from that of the untreated soil (Table 4). Measurements after eight weeks' incubation gave results similar to those after one week's incubation showing that the added potassium, which had

gone into the labile pool was still in this pool. In the two soils studied (Segamat and Selangor series) the added potassium had not been 'fixed' to some other form that is not in exchange equilibrium with the soil solution.

The thermodynamic indices of intensity, quantity and buffer capacity and the conventional indices of acid-extractable and exchangeable, for potassium, were examined against the uptake of potassium by *Pueraria* in the glasshouse. Linear correlation coefficients for these are given in Table 5.

TABLE 4. EFFECT OF POTASSIUM ADDITION ON THE POTASSIUM INTENSITY (I_0) QUANTITY (Q_0) AND BUFFER CAPACITY (B.C.) INDICES OF SOIL

Amount of K added, m-equiv./100g soil	Selangor series soil			Segamat series soil		
	Q_0 m-equiv./100g	$I_0 \times 10^{-3}$ M \ddagger	B.C.	Q_0 m-equiv./100g	$I_0 \times 10^{-3}$ M \ddagger	B.C.
0	0.28	7.5	38.0	0.10	13.0	7.7
0.15	0.42	11.2	37.5	0.28	36.0	7.8
0.375	0.67	18.0	37.0	0.55	71.4	7.7
0.75	1.02	27.7	37.0	1.00	126.6	7.9

TABLE 5. LINEAR CORRELATION COEFFICIENTS OF SOIL POTASSIUM INDICES WITH GLASSHOUSE CROPPING BY *PUERARIA*

Soil K Index	Correlation coefficient, r	
	All 8 soils	Excluding Selangor series soil
Acid-extractable	0.95***	0.96***
Exchangeable	0.83*	0.21 N.S.
Quantity (Q_0)	0.83*	0.42 N.S.
Intensity (I_0)	-0.36 N.S.	-0.02 N.S.
Buffer capacity (laboratory)	0.93***	0.79*
Buffer capacity (cropping)	0.95***	0.87*
Buffer capacity (exchangeable)	0.88**	0.56 N.S.

*** P < 0.001, ** P < 0.01, * P < 0.05, N.S.: not significant

Intensity values did not relate ($r = -0.36$) to uptake by *Pueraria* in the glasshouse. This is in contrast with the results obtained by growing ryegrass in the glasshouse from British soils (TALIBUDEEN AND DEY, 1968 a and b).

When the data of all the eight soils were considered, B.C.(laboratory), B.C.(cropping) and acid-extractable K gave highly significant correlations with the uptake by *Pueraria* (at the 0.1% level). For B.C. (exchangeable), the correlation was significant at the 1% level while for exchangeable and quantity (Q_0), the correlations were significant at the 5% level. When one extreme point, representing the data of Selangor series soil, was excluded from the correlation studies (Table 5), acid-extractable K maintained its significant correlation with cropping at the 0.1% level, while B.C. (laboratory) and B.C. (cropping) were still significantly correlated but only at the 5% level.

It is relevant to mention that when calcium chloride equilibrating solutions were used earlier instead of aluminium chloride, only B.C. (cropping) and acid-extractable K were

TABLE 6. SOIL INDICES FOR PHOSPHORUS OF A FORMERLY NPK-MANURED BATU ANAM SERIES SOIL^a

Treatment	Quantity indices in p.p.m.				Intensity $\times 10^{-2}M$	Dry rubber yield ^b
	Total P (n treatments)	'Available' P	Total labile pool (n ₂ treatment)	'Rapid' labile pool		
p_0	95	4.0	14.3	6.3	0.20	1.78
p_1	116	6.0	13.8	6.0	0.43	2.09
p_2	133	7.3	15.6	8.0	1.07	2.31
% increase from control (p_0)						
p_1	25	50	-3.5	-4.8	11.5	17
p_2	40	83	9.1	27	43.5	30

^aFrom Ladang Geddes Estate

^bMean yield per tapping per tree averaged over 6 monthly recordings (courtesy of B. J. Mainstone, Dunlop Research Centre)

significantly correlated to uptake by *Pueraria*. Unlike the aluminium chloride equilibrations B.C. (laboratory) showed poor correlation (MOHINDER SINGH *et al.*, 1968). The suitability of $AlCl_3$ for equilibrations for such very acid soils, as are used here, is therefore confirmed.

It is encouraging to note that when $AlCl_3$ equilibrations were used, B.C. (laboratory) and B.C. (cropping) gave correlations of similar significance. An examination of the relationship of soil indices to glasshouse cropping shown in Figure 3 indicates that although B.C. (laboratory), B.C. (cropping) and acid-extractable K all give good correlations, the acid-extractable index distinguishes between soils rich and poor in K status but does not discriminate between soils medium or low in K status. B.C. (laboratory), on the other hand, appears to give a

better spread of soil indices in relation to cropping. It therefore promises to be more useful for the discriminatory assessment of the potassium status of soils, especially those of very low status.

Phosphorus

Intensity and quantity measurements for phosphorus are given in Tables 6 to 8. Tables 6 and 7 contain results of soils taken from two manurial trials while Table 8 gives results of unmanured soils on which exhaustive cropping with *Pueraria* was done in the glasshouse (MOHINDER SINGH *et al.*, 1968). All the indices examined, conventional and thermodynamic, qualitatively relate to levels of phosphate manuring in the soils from the two manurial trials. Only the quantity indices of the three

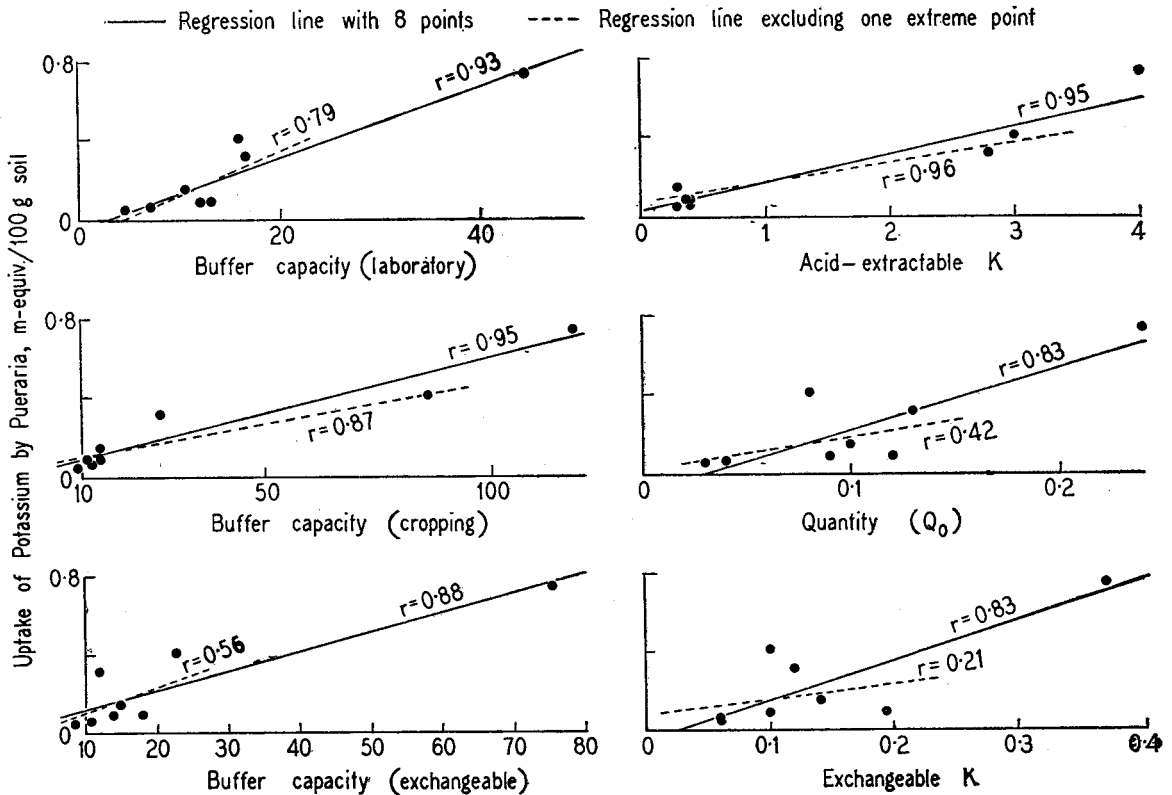


Figure 3. Relationship of soil indices with glasshouse cropping by *Pueraria*.

unmanured soils examined so far (Table 8) relate directly to glasshouse cropping.

CONCLUSIONS

Correlations of some soil indices with uptake by *Pueraria* in the glasshouse show that for assessing the potassium status of Malayan soils, the buffer capacity value obtained from quantity/intensity relationship using aluminium chloride equilibrating solutions was more useful than the acid-extractable and exchangeable values now being routinely used for determining fertiliser requirements of rubber. For phosphorus the limited work carried out showed that both conventional and thermodynamic quantity indices related directly to glasshouse cropping. More work is necessary for a systematic correlation.

TABLE 7. SOIL INDICES FOR PHOSPHORUS OF RENGAM SERIES SOIL (NPK MANURIAL EXPERIMENT)

Treatment	Quantity indices in p.p.m. ^a				'Intensity' ^b × 10 ⁻⁷ M
	Total P	'Available' P	'Total' labile pool	'Rapid' labile pool	
p ₀	153	4	20	5	2.7
p ₁	228	36	61	14	8.3
p ₂	307	86	65	20	9.9

^aMean of all N K₀ treatments.

^bEquilibrium concentration in 10⁻³M ammonium citrate plus 10⁻²M ammonium chloride

TABLE 8. SOIL INDICES FOR PHOSPHORUS OF THREE UNMANURED SOILS AND UPTAKE BY *PUERARIA* IN GLASSHOUSE

Soil series	Total P (p.p.m.)	'Available' P (p.p.m.)	'Rapid' labile pool (p.p.m.)	'Intensity' ^a × 10 ⁻⁷ M	Total uptake by <i>Pueraria</i> (p.p.m.)
Batu Anam	82	10	8	20.2	1.5
Rengam	155	14	12	10.4	2.5
Selangor	384	44	22	21.4	11.6

^aEquilibrium concentration in 10⁻³M ammonium citrate plus 10⁻²M ammonium chloride

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DISCUSSION

Chairman: Dr. S.K. Ng

Dr. K.T. Joseph commented on the use of ammonium citrate to detect measurable amounts of phosphorus and enquired if the intensity values were valid despite this empirical component. Mr. Mohinder Singh said that without the use of citrate the intensity values of phosphorus were too low to differentiate between soils. Initially the results for several concentrations of citrate were plotted and the phosphorus intensity was determined by extrapolating to zero-citrate. This was an inordinately time-consuming process for routine determinations. A small measure of empiricism had to be accepted in order to devise a laboratory method for large-scale application, in which the errors compared favourably with those tolerated in the older techniques using ammonium fluoride.

Dr. C.C. Webster discussed the extent to which the roots were able to exploit the soil. The Q/I relationship was affected only by the amount and nature of labile potassium in pot culture experiments where roots ramified throughout the entire soil available, whereas in the field the I value in the soil depleted by the roots could be maintained by movement of potassium from adjacent volumes of soil not in direct contact with the roots. Mr. Mohinder Singh replied that intensity was determined by the laboratory method, to provide a value of what the soil could support at any instant. He agreed this might be maintained in the field by movement of potassium. Dr. Webster added that during the life of a perennial tree crop such as *Hevea*, the supply of potassium might be maintained by the release of fixed potassium in the soil, which was not determined by these methods. Mr. Mohinder Singh agreed and added that methods to determine these were sought with a view to establishing polynomial relationships.

Mr. E. Bellis commented on the encouraging Q value relationships with the exhaustion cropping data and enquired how the thermodynamic assessments were affected when fertilisers had long contact with the soil. Mr. Mohinder Singh replied that on applying fertilisers both *quantity* and *intensity* would rise initially, but their ultimate values would depend on the amount taken up by plants and losses by leaching and might be the same as before manuring. Provided the buffer capacity was not altered, the shape of the Q/I curve would not be changed.