The Effect of Crushed Basalt Scoria on the Cation Exchange Properties of a Highly Weathered Soil[1]

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ABSTRACT

Soil from the surface horizon of a highly weathered soil (Acrohumox) from tropical Queensland was mixed with crushed basaltic cinders and incubated in a moist condition for 12 months in the laboratory. The cation exchange capacity (CEC) increased from 9 to 14 meq/100 g in direct relationship to the rate of application and degree of fineness of the scoria, as well as to the duration of incubation. The increase in CEC was accompanied by an increase in exchangeable calcium, magnesium, and potassium. The results suggest that crushed basaltic scoria could be successfully used to prevent cation nutrient losses from highly weathered soils of the tropics.

Additional Index Words: specific surface, cation leaching.

ONE OF THE OBSTACLES to achieving full agricultural potential of highly weathered soils in tropical regions is their tendency to lose nutrient cations by leaching. The clay mineral components of these soils are principally kaolinite and hydrous oxides. Such soil components as well as organic matter derive much of their surface charge by the adsorption of the potential determining ions H^+ and OH^-. Thus variable charge is a function of the pH of the solution with which the surface is in contact. The surface charge also depends on the electrolyte concentration (η), the dielectric constant (ε), and the counterion valence (z) of the ambient solution. The relationship between surface charge density σ (esu per cm^2), and these parameters has been expressed mathematically as follows (Wann and Uehara, 1978):

$$\sigma = \left(\frac{2\eta\varepsilon kT}{\pi}\right)^{\frac{1}{2}} \sinh 1.15\, z\, (pH_0 - pH) \qquad [1]$$

where pH_0 is the pH when $\sigma = 0$, and kT have their usual meanings.

The relationship shows that the negative surface charge density can be changed by varying several parameters, viz. η, ε, T, z, or $(pH_0 - pH)$, but it is the last parameter, the difference between actual pH and

pH_0, which lends itself to practical manipulation in the field. Thus the more negative $(pH_0 - pH)$ is, the more negative is the surface charge density, and the greater is the CEC which is related to σ through a specific surface term (S) as,

$$CEC = S\sigma. \qquad [2]$$

The term $(pH_0 - pH)$ can be made more negative by increasing the soil pH or by decreasing pH_0. Soil pH can be increased by liming, and this is usually accomplished with calcium carbonate, although for highly weathered soils calcium silicate may be used. The pH_0 value apparently can be reduced by the introduction of a high valency anion, which will strongly bond to, and thereby impart its negative charge to, the surface. Hingston et al. (1972) have demonstrated this effect with phosphate, silicate, and selenite, on minerals usually encountered in highly weathered soils, i.e. gibbsite and goethite. It is therefore reasonable to assume that applications of silicate to oxidic soils would have the combined effect of raising pH and lowering pH_0, the result being increased negative surface charge density.

Earlier work in Mauritius showed that a single application of basalt dust to degraded sugarcane soils significantly increased sugar yields in the plant crop as well as in subsequent ratoon crops (D'Hotman de Villiers, 1961). The object of the present study was to examine the effect of large applications of a low cost silicate material, crushed basaltic scoria, on the CEC of a highly weathered soil from tropical north Queensland.

MATERIALS AND METHODS

Soil and Basalt Scoria

A surface (0–10 cm) sample of an Acrohumox under pasture was used. This soil is believed to have the same mineralogical composition as a soil from about 2 km away, in which the principal components were goethite, gibbsite, and kaolinite. Relevant chemical properties are summarized in Table 1.

The basalt scoria was obtained from a commercial partially weathered cinder deposit on Mt. Quincan, north Queensland. The actual sample obtained was that passing the finest ($\sim$ 3 mm) screen and was crushed in the laboratory to three degrees of fineness subsequently described as coarse, medium, and fine. Some relevant chemical properties are given in Table 1, while results of sieve analysis are presented in Table 2. Specific surface and CEC were high considering the relatively coarse particle size, indicating the presence of smectites or zeolites. An X-ray diffraction analysis (Fig. 1) of the fine material and the clay ($<2\mu m$) separated from this material, failed to identify either smectites or zeolites. In addition to the expected crystal-

Table 1—Selected chemical properties of the 0- to 10-cm
Acrohumox samples and basalt scoria
ground to three sizes.

Sample	pH†	E.C.†	CEC	Ca	Mg	K	Na	Specific surface
		siemens/cm			meq/100 g			m²/g
Acrohumox	5.4	3.15 × 10⁻⁴	6.4	4.11	1.69	0.27	0.02	–
Crushed basalt								
Coarse	7.8	1.90 × 10⁻⁵	9.5	9.32	4.87	0.40	0.33	84
Medium	8.2	2.50 × 10⁻⁵	12.3	10.47	5.34	0.44	0.40	78
Fine	8.5	2.70 × 10⁻⁵	16.3	11.31	6.29	0.47	0.57	77

† 1:5 soil/water.

Table 2—Sieve analysis of ground basalt scoris,
expressed as percent.

Degree of fineness	<63	63–125 μm	125–250 μm	250–500 μm	500–1,000 μm	1–2 mm	2–4 mm
				%			
Coarse	4.8	4.2	5.1	10.8	31.4	42.2	1.5
Medium	22.4	25.2	26.9	15.0	7.3	2.8	0.4
Fine	41.8	32.5	23.5	2.2	<0.1	0	0

line rock forming minerals, amorphous material is indicated by the broad band in Fig. 1B. This amorphous material obviously contributes to the high specific surface which in turn accounts for the high CEC values (Eq. [2]). Elemental analysis of a sample of basalt scoria taken from the same site are presented in Table 3 (P. J. Stephenson, James Cook University of North Queensland, personal communication. Analysts: P. Beasley and E. Kiss).

A bulk sample of the Acrohumox was passed through a 2-mm screen. Quantities sufficient to produce 10-cm columns (280 g) were mixed with 33, 66, and 99 g of each of the ground basalt materials (equivalent to 100, 200, and 300 ton/ha) and placed in 370-ml polyethylene-lined steel cans. Holes in the bottom of the cans allowed drainage. Demineralized water (150 ml) was added to each can, and after the excess had drained, the cans were placed in a large humidifier (100% RH) for periods of 3, 6, 9, and 12 months. Soil columns to which no basalt was added were used as controls.

The initial intent was to leach the soil with 250 ml of water each week, but drainage became impeded because of partial blocking of the holes, and leaching was discontinued after only 350 ml of water had passed through.

After the appropriate incubation time, the soil was dried, passed through a 2-mm sieve, and retained for analysis. The treatments were duplicated so that: 3 degrees of grinding × 4 incubation periods × 3 application rates × 2 replications + 8 controls = 80 samples.

Cation exchange capacity was estimated by a compulsive exchange method (Gillman, 1979). This method measures the capacity of a soil to retain cations at a pH and ionic strength equivalent to that of the soil solution (the moisture present at
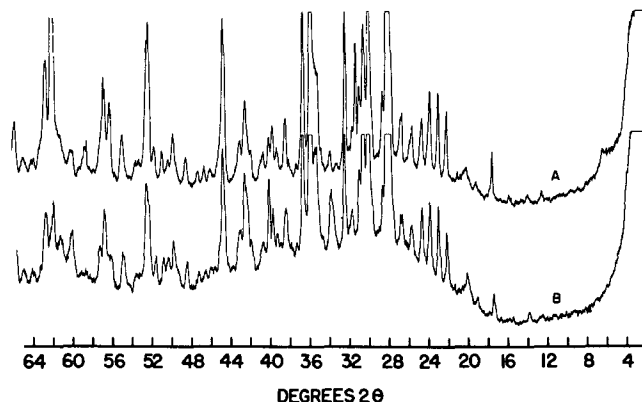

Fig. 1—X-ray diffractograms (Be filtered CuKα radiation) of: A, fine ground basaltic scoria; and B, clay separated from fine ground basaltic scoria.

0.1 bar matric tension). Unbuffered electrolytes are used to achieve the natural pH, and the appropriate ionic strength is obtained from the electrolytic conductivity of a soil/water suspension (Gillman and Bell, 1978). In this instance, the conductivity indicated that an ionic strength of 0.003 be used. The basic cations, Ca, Mg, K, and Na, were extracted with 0.1M BaCl₂ using a 1:10 soil/extractant ratio.

RESULTS AND DISCUSSION

The initial soil pH was 5.4 and CEC was 6.4 meq/100 g. However, Fig. 1 shows that simply incubating the soil at near saturation followed by drying raised the soil pH to about 6.1, and CEC to about 9.0 meq/100 g (Fig. 2). It is not known whether seasonal changes of this magnitude were actually encountered in the field.

The effect of the crushed basalt on soil pH, as related to degree of fineness, incubation time, and rate of application, is depicted in Fig. 2. This shows that pH rose with increasing amounts of basalt applied, and that fine grinding and time of reaction enhanced the effect. The pH increase was associated with an increase in the CEC of this variable charge soil (Fig. 3). At the highest application rate, the finely ground material raised the CEC from 9 to 14 meq/100 g after 9 to 12 months incubation. It was principally the very finely divided material which produced the effects, as there was a high correlation between CEC and amount of applied amendment passing the finer
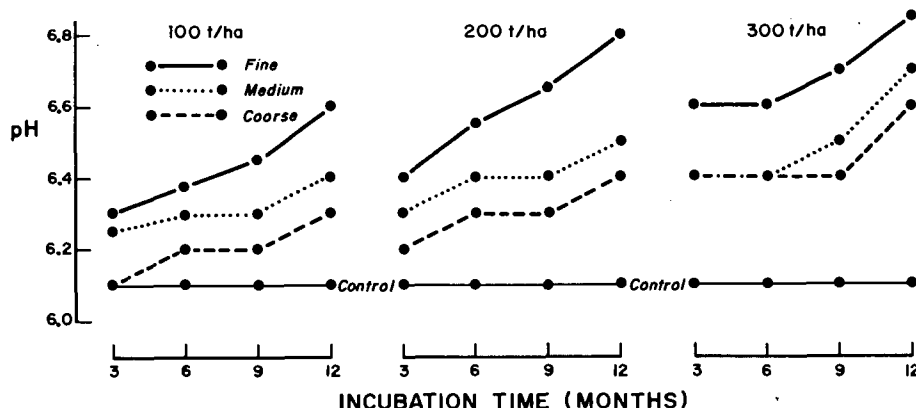

Fig. 2—The effect of degree of fineness, incubation time, and rate of application of crushed basalt on soil pH.
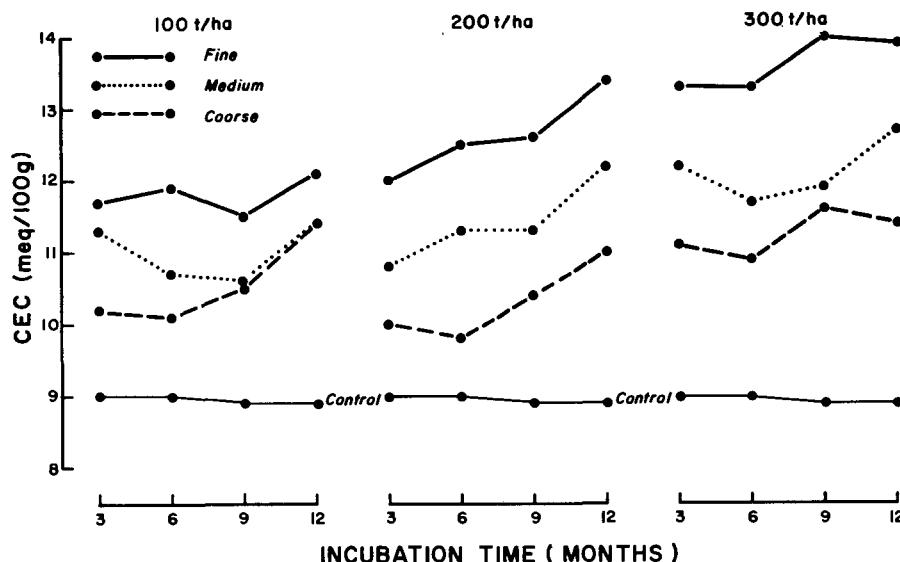
Fig. 3—The effect of degree of fineness, incubation time, and rate of application of crushed basalt on cation exchange capacity.

screens. The relationship between CEC and basalt amendment less than 125 μM size, after 12 months incubation, is illustrated in Fig. 4.

The measured increase in CEC was accompanied by an equivalent increase in the cations extracted with $0.1M$ $BaCl_2$, and these may be considered as exchangeable cations. The values obtained for Ca and Mg are summarized in Fig. 5. Extracted K increased from about 0.3 meq/100 g in the control to about 0.5 meq/100 g in the fine amendment at the highest application rate. The importance of this exchangeable cation increase is perhaps better understood when the results are expressed as kilogram/hectare. Calcium increased from 1,000 to 1,700 kg/ha and Mg from 240 to 500 kg/ha (Fig. 5). There was an increase from 120 to 200 kg/ha of exchangeable K. Considering the Ca, Mg, and K content of this material (Table 3), the highest rate of application represents 20 tons of Ca, 20 tons of Mg, and 3 tons of K per hectare. Apparently only a small fraction of this was mobilized during the this short term evaluation. Water extrac-

tion of representative incubated samples produced only about 0.01 meq per 100 g of Ca, and a similar amount of Mg, showing that the added cations are not susceptible to leaching.

An equivalent ratio for Ca/Mg was maintained at about 2:1 across all treatments, and the K/Ca ratio was constant at 0.06. This was in marked contrast to the (author's unpublished) results obtained when the same soil was incubated with Ca metasilicate or with portland cement at an application rate of 10 tons/ha, where even though the CEC rose sharply to over 20 meq/100 g, the exchange complex was almost completely dominated by Ca. Whereas cation imbalance caused by the application of monocation silicates would have to be corrected, it appears that crushed basalt supplies exchangeable cations in significant and balanced quantities.

The CEC of the coarse, medium, and fine ground materials was 9.5, 12.3, and 16.3 meq/100 g, respectively. This information, along with the CEC of the control was used to calculate the expected CEC if an additive effect only was operative. The calculated values were well below those actually measured, as demonstrated for the fine ground treatment in Fig. 6, showing that the increase in CEC was indeed the result of a chemical reaction between the soil and crushed basalt scoria.
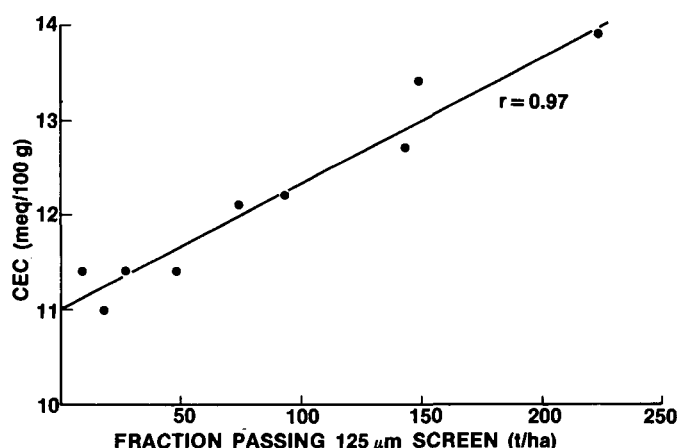

Fig. 4—Relationship between the amount of applied basalt passing the 125-μm screen and the cation exchange capacity (incubation time = 12 months).

Table 3—Elemental analysis of basalt scoria from Mt. Quincan (P. J. Stephenson, personal communication).

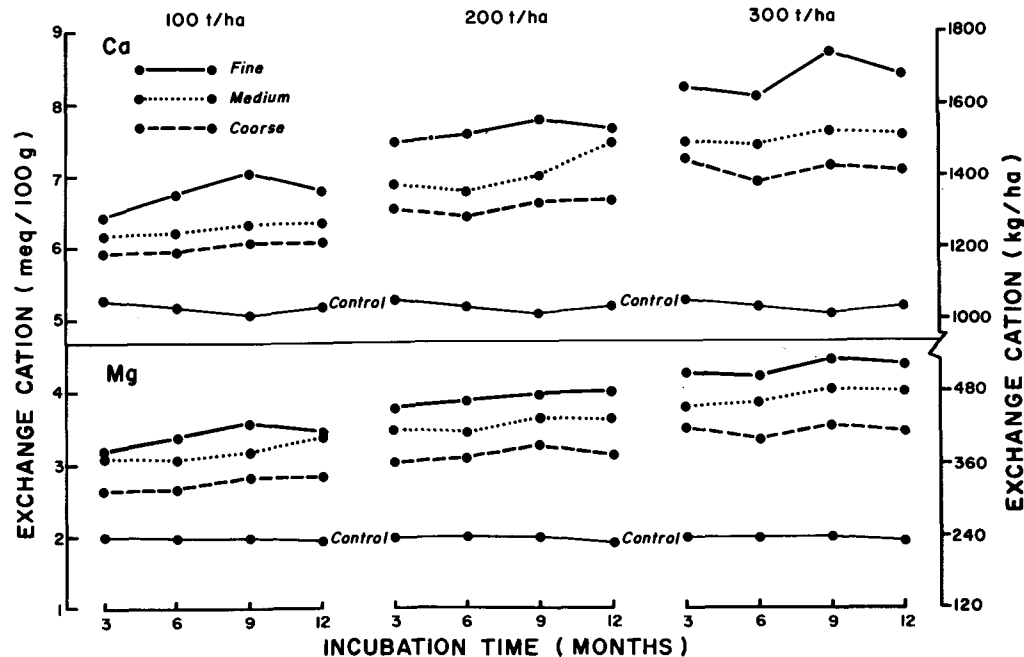| Compound	Percent
SiO_2	45.84
TiO_2	1.71
Al_2O_3	14.16
Fe_2O_3	3.64
FeO	6.78
MnO	0.17
MgO	11.12
CaO	9.98
Na_2O	2.74
K_2O	1.13
P_2O_5	0.53
Loss	2.19

Fig. 5—The effect of degree of fineness, incubation time, and rate of application of crushed basalt on exchangeable Ca and Mg.
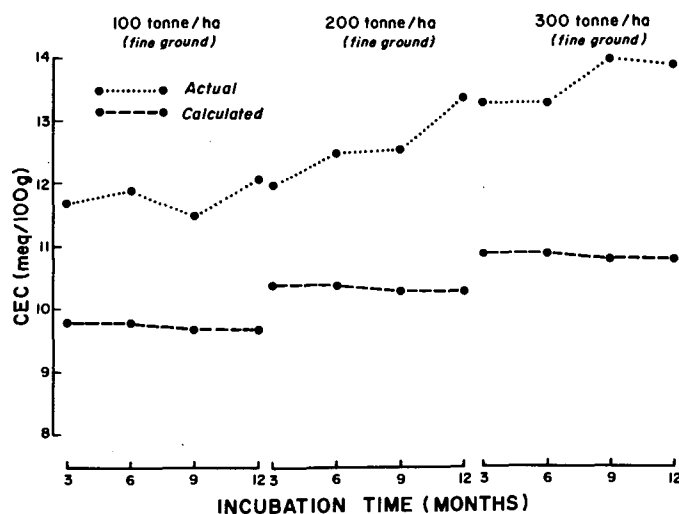

Fig. 6—Comparison between measured cation capacity and that calculated from values of soil and crushed scoria assuming an additive effect (fine ground material).

GENERAL DISCUSSION

At first consideration, the rates of application of the crushed basalt appear to be extraordinarily high. It is now relatively common in the sugar growing areas of north Queensland to apply portland cement to highly weathered soils at rates up to 10 tons/ha, and the increased yield apparently justifies the investment. Since the principal cost involved in producing crushed basalt is for the energy consumed in grinding, and because the energy required to crush basalt cinder is relatively modest, the large quantities of this material required could be produced at a competitive price. When it is further realized that a single large application of the basalt cinder may obviate the need to apply Ca and Mg for many years, as well as reduce

the leaching losses of applied NH_4 and K over a similarly long period, the initial cost appears more reasonable. Fortunately basaltic cinder cones are often associated with the soils which would benefit most from the amendment, viz. highly weathered soils low in silicate, so that transportation costs should be favorable.

This exploratory study was preliminary to pot and field trials to test the validity of the proposition that a relatively inexpensive silicate source would increase the CEC of highly weathered soils. The results show that crushed basaltic scoria does increase soil CEC, that reactivity is increased with increasing surface created by grinding, and that increased reaction should continue to produce added benefits with time. Pot trial studies should indicate whether any adverse effects, e.g. manganese toxicity, might be encountered. The experiment also demonstrates that a single large application should act as a convenient source of Ca, Mg, and K for a considerable period of time, and this in itself should be of great value for cation depleted soils of tropical regions.

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