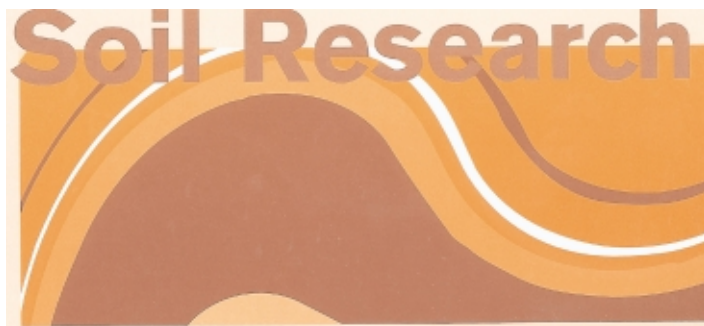


CSIRO Publishing

Australian *Journal* of Soil Research



VOLUME 39, 2001

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An international journal for the publication of
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Australian Journal of Soil Research

CSIRO Publishing

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A laboratory study of application of basalt dust to highly weathered soils: effect on soil cation chemistry

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Abstract

Surface (0–10 cm) samples from 7 highly weathered soils in tropical coastal Queensland were incubated for 3 months at room temperature and at field moisture capacity with basalt dust applied in 2 size fractions: <150 µm and 40 µm. The basalt application was mixed at 0, 1, 5, 25, and 50 t/ha to cover situations of moderate applications as well as where the amendment might be banded to achieve high local concentrations. Basalt dust application caused desirable increases in soil pH, reduced the content of exchangeable acidic cations, increased soil cation exchange capacity, and increased the content of base cations in all soils.

By determining fundamental surface charge characteristics of these variable charge soils, it was possible to show that the additional base cations released from the basalt dust were present as exchangeable cations, and that the amounts released were controlled by the number of negatively charged sites available, i.e. soil cation exchange capacity.

Selected treatments were then subjected to a strong leaching environment to assess the longevity of the effects obtained. Soil properties remained virtually unchanged by the leaching treatment, except that significant amounts of monovalent K and Na were removed.

At the higher rates of application, the amounts of base cations released from the basalt were small in comparison with the actual amounts applied, indicating that the amendment could be effective over a considerable period of time.

Additional keywords: charge fingerprint.

Introduction

Many soils throughout the world may be termed ‘highly weathered’, resulting from dissolution and leaching processes over extremely long periods, or when precipitation is high, from rapid breakdown of easily weathered parent materials over shorter time spans (van Wambeke 1992). Such soils have passed through the weathering stage where the predominance of 2 : 1 type clays imparts the capacity to retain base (Ca, Mg, K, Na) nutrient cations in exchangeable form, and consequently have clays largely composed of kaolinite and oxides of iron and aluminium. The latter clay minerals have low cation exchange capacities (CEC), complicated further by the fact that CEC is dependent upon the pH and ionic strength of the soil solution (van Raij and Peech 1972; Uehara and Gillman 1981). Highly weathered soils generally have low contents of exchangeable calcium, magnesium, and potassium even in pristine condition, and little capacity to retain those nutrients when applied in water-soluble form.

In a series of field experiments with sugarcane on the island of Mauritius, significant responses to applications of basalt dust to highly weathered soils have been reported (de Villiers 1961). Single applications of up to 180 t/ha of the amendment produced an average yield increase of about 20% sugar cane over 5 harvests, and there was no diminution of the effect when the trial was abandoned. Believing that these results may have been due to increased levels of soil exchangeable base cations provided by the basalt dust, Gillman (1980) applied rates of crushed basaltic scoria to a highly weathered Oxisol from North

Queensland, and incubated the samples in a moist state for periods up to 12 months. Significant increases in soil pH, CEC, and exchangeable base cation contents with increasing amendment rates were obtained. The effects were further enhanced with increasing degree of fineness of the crushed scoria, and with increasing time of contact between the soil and the amendment.

This paper reports changes in soil chemical properties of 7 highly weathered soils from coastal tropical Queensland brought about by amelioration with crushed basaltic rock. Soil properties measured included surface charge characteristics, to allow a more complete interpretation of changes effected in the commonly determined cation exchange properties.

Materials and methods

Soils

Bulk samples of surface (0–10 cm) soil were taken from sites on the North Queensland tropical coast, where annual rainfall approximates 3600 mm per annum. Soil from each of the following soil series (Murtha 1986) were selected for the study: Pin Gin, red gradational textured soil formed on basalt rock; Mundoo, red gradational textured soil formed on alluvial basaltic fan; Innisfail, brown or reddish brown soil formed on basalt-derived alluvium; Tyson, red massive gradational textured soil formed on alluvial granitic fan; Tully, bright yellowish soil formed on granite-derived alluvium; Galmara, red soil formed on metamorphic rock; Kurrimine, well developed podsol formed on a sandy beach ridge. Relevant information on these soils is summarised in Table 1.

Crushed basalt

Finely ground hard basalt rock was supplied in 2 size classes by Pacific Mineral Developments Pty Ltd: one passing a 150- μ m sieve, and the other passing a 40- μ m sieve. Typical chemical and mineralogical properties of the basalt rock used in crushing operations are presented in Table 2.

Incubation experiment

Crushed basalt rock was added to each sample at rates of 0, 1, 5, 25, and 50 t/ha. The lower rates are representative of the amounts that may be broadcast, while the higher rates were included to assess the effects of cumulative additions, or where the amendment might be applied in bands. After thorough mixing, the treated samples were wetted to field capacity with distilled water containing 0.004% Cu to prevent

Table 1. Some relevant information on the soils studied

Soil series	Classification ^A	Parent material	Clay mineralogy ^{BC}	Organic matter ^C (%)	Clay ^C (%)	Free Ferric Oxide ^C (%)
Pin Gin	Tropeptic Haplorthox	Basalt rock	Ka > G = Ha	14.5	75	15
Mundoo	Tropeptic Haplorthox	Basalt fan	G > Go/Ha > Ka	8.2	40	15
Innisfail	Oxic Dystropept	Basalt alluvium	Ka > I = ChV	3.4	40	15
Tyson	Orthoxic Tropudult	Granite fan	Ka > G > Go/Ha = ChV	6.3	20	1
Tully	Oxic Dystropept	Granite alluvium	Ka > I > ChV	6.3	40	2
Galmara	Tropeptic Haplorthox	Metamorphic rock	G > Ka > Go/Ha > I = ChV	3.9	20	1.5
Kurrimine	Haplorthod	Beach ridge	n.d.	7.1	2	<0.1

^ASoil Survey Staff (1975).

^BKa, kaolinite; G, gibbsite; Ha, haematite; Go, goethite; I, illite; ChV, chloritized vermicullite.

^CEstimates from previous studies (Murtha 1986).

Table 2. Some relevant properties of the basalt rock used for producing rock powder

Chemical composition ^A (mg/L)		Primary rock forming minerals ^B (%)	
Silicon	216	Olivine	10
Iron	105	Plagioclase	12
Aluminium	76	Magnetite	10
Calcium	65.4	Augite	30
Magnesium	64.4	Orthoclase	Minor
Sodium	20.3	Apatite	0.5
Titanium	15.2	Altered Glass	37
Potassium	12.5		
Phosphorus	3.03		
Sulfur	2.15		

^ASource: Pacific Mineral Development Pty Ltd.^BSource: McSkimming (1998).

biological activity, and sealed in plastic bags for 3 months at room temperature. There were 5 replicates for each treatment. The soils were then dried, and sieved to 2 mm for analysis.

Leaching experiment

Single replicates of soil that had been incubated without basalt amendment, with <150 µm basalt at 1 t/ha and 25 t/ha, and with <40 µm basalt at 50 t/ha were added to 15-cm-diameter columns to a depth of 10 cm, and leached with daily additions of distilled water for 5 days, followed by a 2-day rest period. The amount of water added in each of 6 successive weeks matched the average monthly rainfall in that week, and simulated the 6 wettest months of the year. Thus a 6-month wet season was simulated in 6 weeks.

Leachates collected from each daily addition to each column were bulked in such a way that the concentrations in the final bulk sample were the same as if all of the leachate from each column had been collected. Total amounts of elements leached from each column could therefore be easily computed.

Analytical determinations

Charge fingerprints, which are curves describing the total cation exchange capacity (CEC_T), base cation exchange capacity (CEC_B), and anion exchange capacity (AEC) across a range of pH values, at solution ionic strength approximating field conditions, were determined using methodology described by Gillman and Sumpter (1986a). Amounts of exchangeable base cations, cation exchange capacity at soil pH (CEC_{CE}), as well as 'soil pH' itself (defined as the pH of a 1 : 10 soil : 0.002 M BaCl₂ suspension), were estimated in the compulsive exchange method of Gillman and Sumpter (1986b). Exchangeable acidic cations were extracted with 1 M KCl and the extract titrated with 0.05 M NaOH (Soil Survey Staff 1972).

The charge fingerprint, when determined at appropriate ionic strength, clearly indicates for any pH value in the agronomic range of soil pH (e.g. 4–6) the maximum capacity for retention of exchangeable base and acidic cations, and the maximum retention of exchangeable anions. In this study, soil sampling was confined to organic matter enriched surface horizons, so that AEC was relatively low. The ionic strength (I) chosen for each soil was calculated from an equation relating I to the electrolytic conductivity of a 1 : 5 soil : water suspension (Gillman and Bell 1978). Note, however, that a single I value was used for all basalt dust rates within a soil type.

In addition to the above mentioned properties, the point of zero charge of soil variable charge components, pH₀, can be estimated during the charge fingerprinting procedure. This fundamental surface property is the pH at which the sum of negative and positive charges on soil variable charge components is zero. The difference between this value, and the actual soil pH, determines to what extent the variable charge components will contribute CEC and AEC to the whole soil.

We have examined the effect of adding basalt dust to the soil on the pH₀ value, and on the overall shape of the charge fingerprint, to determine whether amounts of silicate have been released in sufficient quantity to alter surface charge characteristics. This aspect of the study was initially confined to the 0 and 50 t/ha

basalt dust treatments (<150 μm), and results indicated that extension to intermediate basalt dust rates was not necessary.

Results and discussion

The charge fingerprints for the 7 soils, at 0 and 50 t/ha basalt dust amelioration are presented in Fig. 1, where the pH_0 values are also included. From single sample analysis it is not possible to show whether small but statistically significant differences were effected

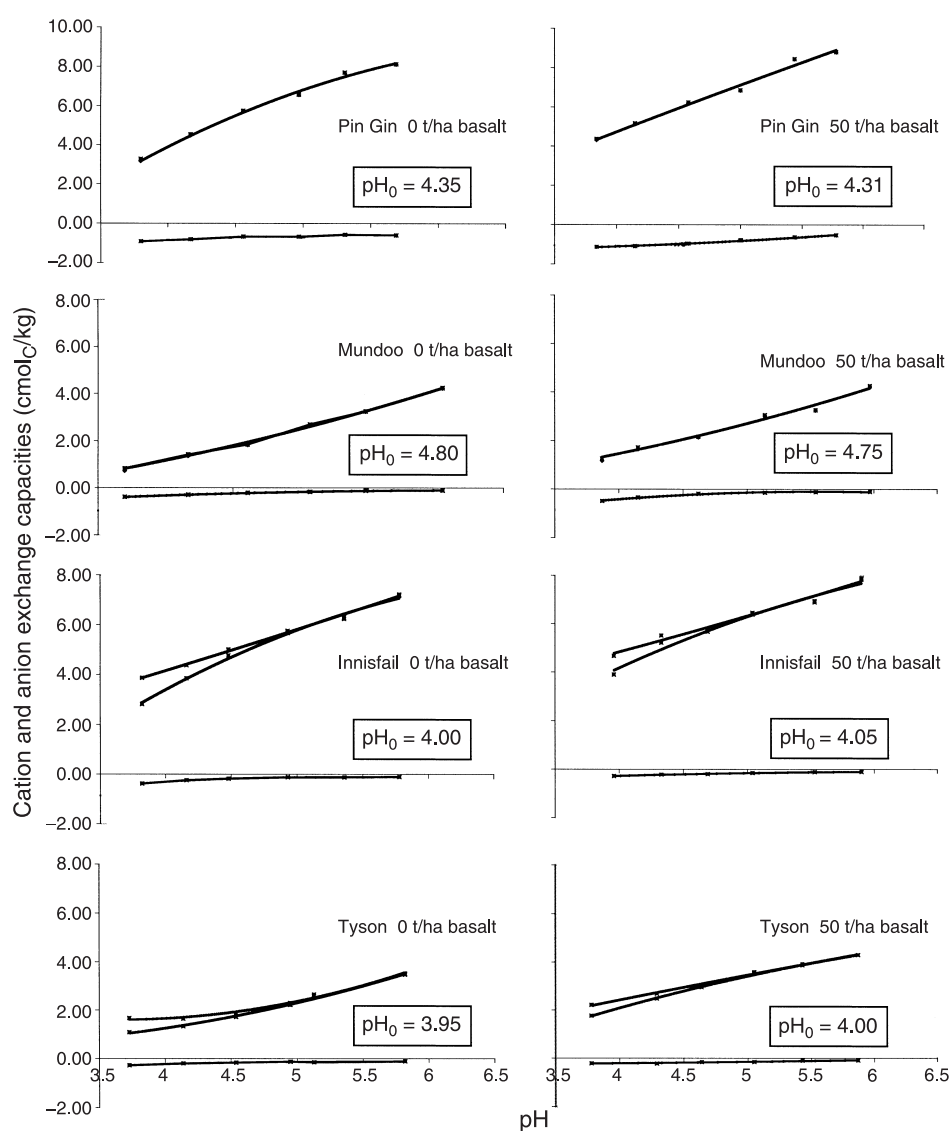


Fig. 1. Charge fingerprints of the seven study soils incubated with 0 t/ha and 50 t/ha basalt dust (<150 μm), and separately determined pH_0 values. Where CEC curves divide at low pH, the upper curve is CEC_T and the lower curve is CEC_B (see text); n.d. = not detected.

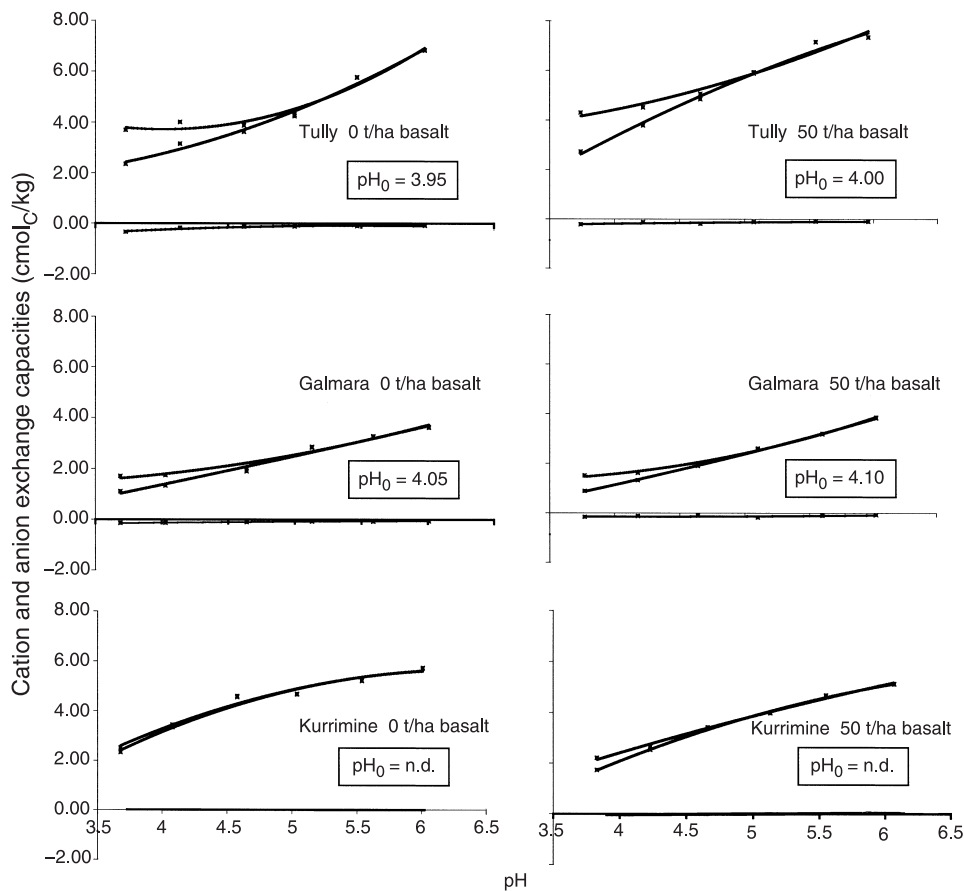


Fig. 1. (continued).

by the basalt treatment, but it is clear that differences that might have agronomic or environmental significance have not appeared. Therefore, the charge fingerprints of only the unamended soil samples were used to produce equations relating CEC to pH, to allow interpretation of the soil CEC and cation contents in the following discussion. These equations have been collated in Table 3, and will be used below to explain changes in soil cation exchange properties effected by the basalt ameliorant.

CEC_{CE} and extracted cations

Soil pH, CEC_{CE}, and amounts of base and acidic cations extracted from soil samples incubated with rates of basalt dust (<150 μm and <40 μm) are presented in Table 4. The immediate points of interest relating to effects produced by increasing rates of crushed basalt ameliorant can be summarised as:

- (1) an increase in soil pH,
- (2) a greater increase in soil pH with <40 μm dust than <150 μm dust,
- (3) an increase in CEC_{CE},
- (4) a decrease in extractable acidic cations, and
- (5) an increase in extractable base cations.

Table 3. Equations relating base cation exchange capacity (CEC_B) to soil pH for seven highly weathered soils in North Queensland

Units for CEC are cmol_c/kg

Soil series	Equation
Pin Gin	$\text{CEC}_B = -0.5624 (\text{pH})^2 + 7.9876 (\text{pH}) - 19.073$
Mundoo	$\text{CEC}_B = 0.1542 (\text{pH})^2 - 0.0408 (\text{pH}) - 1.1502$
Innisfail	$\text{CEC}_B = -0.4132 (\text{pH})^2 + 6.1054 (\text{pH}) - 14.418$
Tyson	$\text{CEC}_B = 0.2294 (\text{pH})^2 - 1.0139 (\text{pH}) + 1.6318$
Tully	$\text{CEC}_B = 0.3988 (\text{pH})^2 - 1.8935 (\text{pH}) + 3.9444$
Galmara	$\text{CEC}_B = 0.0290 (\text{pH})^2 + 0.8713 (\text{pH}) - 2.5861$
Kurrimine	$\text{CEC}_B = -0.4627 (\text{pH})^2 + 5.8513 (\text{pH}) - 2.5861$

Since the ameliorant has not appreciably altered fundamental surface charge properties, it may be concluded that the observed increases in CEC_{CE} are predominantly due to increases in soil pH. Therefore, CEC increases achieved should be predicted from the charge fingerprint. To test this, CEC_{CE} values were compared with predicted CEC_B values using the charge fingerprint equations (Table 3) and soil pH of the incubated samples. This comparison (Fig. 2) shows generally good agreement between the paired values, although the Mundoo soil tended to deviate from the relationship.

Acidic cations in the unamended soils (Table 4) were present only in minor proportions in the highly oxidic soils derived from basalt parent materials, but occupied greater percentages of the total CEC in the other soils. Applications of basalt dust reduced these values, as would be expected if soil pH were increased. This reduction in reserve acidity is of far greater importance than the modest decrease in active acidity (rise in pH) observed. Removal of Al from exchange sites could be effected by the release of silicate ions from the amendment, and their reaction with aluminium to form insoluble aluminosilicates, or the precipitation of hydroxy aluminium following hydroxyl ion liberation as silicate is hydrolysed to silicic acid.

The nature of the release of base cations from the crushed basalt was studied by comparing CEC with the sum of cations extracted. The results (average of 5 reps) illustrated in Fig. 3 show an almost 1:1 relationship between the 2 values across all soils and all basalt rates at 2 degrees of basalt fineness. Thus, sufficient cations were released to occupy newly created negatively charged sites, or sites vacated by exchangeable acidic cations.

Leaching experiment

The longevity, or otherwise, of the increase in CEC and exchangeable base cations was tested by leaching selected incubated samples in columns under a relatively harsh environment, where the equivalent of rainfall in the 6 wettest months of the year was applied over a 6-week period. In all, 2750 mm of 'rainfall' passed through the column. A comparison of soil pH, CEC_{CE}, and exchangeable base and acidic cations is presented in Table 5. As it was not possible to replicate the leaching columns used (28 in total), the differences between values before and after leaching cannot be statistically evaluated. It is possible, however, to discern some clear trends, summarised as:

- (1) a tendency for pH to rise,
- (2) a modest increases in CEC,

Table 4. The pH and exchange properties (cmol_e/kg) of two size fractions (<40 µm, <150 µm) of soils amended with basalt rock dustWithin size fractions values followed by the same letter are not significantly different at $P = 0.05$

Basalt (t/ha)	Soil pH		CEC _{CE}		Ca		Mg		K		Na		H+Al	
	<40	<150	<40	<150	<40	<150	<40	<150	<40	<150	<40	<150	<40	<150
<i>Pin Gin</i>														
0	4.8a	4.8a	9.2a	9.2a	5.3a	5.3a	3.4a	3.4a	0.40a	0.40a	0.11a	0.11a	0.33a	0.33a
1	4.8a	4.9a	9.7a	10.0a	5.5a	5.2a	3.1a	3.9a	0.39a	0.41a	0.10a	0.07b	0.40a	0.35a
5	4.8a	4.9a	9.8a	9.8a	5.7a	5.1a	3.2a	3.9a	0.40a	0.38b	0.15b	0.12c	0.37a	0.34a
25	4.9a	5.5b	9.9a	12.7b	5.6a	5.1a	5.6b	5.2b	0.51b	0.42c	0.23c	0.26d	0.26b	0.21b
50	5.1a	5.7b*	11.7b	12.9b	5.5a	5.4a	5.9b	5.9b	0.58c	0.46d	0.32d	0.45e	0.16b	0.23b
<i>Mundoo</i>														
0	4.7	4.7	3.1a	3.1a	1.0a	1.0a	1.0a	1.0a	0.11a	0.11a	0.10a	0.10a	0.25a	0.25a
1	4.8	4.9	3.1a	3.5b	1.1b	1.0a	1.2b	1.2b	0.12a	0.15b	0.11a	0.12b	0.23ab	0.21ab
5	4.9	5.0	3.3a	3.8b	1.1b	1.1b	1.4c	1.7c	0.13a	0.15b	0.12a	0.15b	0.21b	0.18b
25	5.1	5.4	4.3b	5.3c	1.4c	1.6c	2.3d	2.7d	0.23b	0.22c	0.24b	0.32c	0.10c	0.11c
50	5.3	5.6	4.6b	5.9c	1.5d	2.1d	2.9e	3.1e	0.32c	0.29d	0.34c	0.52d	0.10c	<0.05d
<i>Innisfail</i>														
0	4.8	4.8	5.5a	5.5a	1.8a	1.8a	1.7a	1.7a	0.39a	0.39a	0.11a	0.11a	0.35	0.35
1	5.2	5.5	5.9b	6.2b	1.8	1.7a	1.7a	1.8a	0.41ab	0.42ab	0.13a	0.14a	0.27	0
5	5.3	5.6	6.1b	6.6b	1.8a	1.9b	1.6a	2.5b	0.44b	0.44b	0.10a	0.18a	0.22	0
25	5.5	5.8	6.6c	7.2c	2.0ab	2.3c	2.6b	3.6c	0.49c	0.51c	0.21b	0.25b	0	0
50	5.7	6.0	7.2d	7.7d	2.1b	2.7d	3.3c	4.2d	0.60d	0.64d	0.34c	0.39c	0	0
<i>Tyson</i>														
0	4.6	4.6	2.3a	2.3a	0.8a	0.8a	0.5a	0.5a	0.15a	0.15a	0.06a	0.06a	1.04	1.04
1	4.8	4.9	2.3a	2.3a	0.9a	0.9a	0.6a	0.6a	0.16ab	0.14a	0.06a	0.07a	0.72	0.58
5	4.9	5.0	2.3a	2.5a	1.0a	0.9a	0.8a	1.1b	0.20b	0.17a	0.10b	0.11b	0.54	0.43
25	5.0	5.2	2.9b	3.1b	1.1b	1.2b	1.6b	2.0c	0.25c	0.26b	0.22c	0.26c	0.35	0.21
50	5.2	5.6	3.4c	3.8c	1.4c	1.5c	2.0c	2.0c	0.33d	0.38c	0.31d	0.38d	0.18	0.14
<i>Tully</i>														
0	4.6	4.6	4.5a	4.5a	1.6a	1.6a	1.2a	1.2a	0.12a	0.12a	0.04a	0.04a	1.99	1.99
1	4.6	4.8	4.3a	4.6a	1.7a	1.7b	1.2a	1.4a	0.12a	0.12a	0.04a	0.06a	1.84	1.82
5	4.7	4.8	4.6a	4.8a	1.7a	1.7b	1.6b	2.1b	0.13a	0.16b	0.04a	0.07a	1.59	1.46
25	4.9	5.0	5.0b	5.1b	1.9b	2.1c	2.9c	3.6c	0.20b	0.24c	0.06b	0.11b	1.03	0.69
50	5.0	5.1	5.0b	5.4b	2.2c	2.4d	3.5d	4.4d	0.25c	0.33d	0.18c	0.20c	0.62	0.39
<i>Galmara</i>														
0	4.5	4.5	2.0ab	2.0ab	0.3a	0.3a	0.4a	0.4a	0.06a	0.06a	0.11a	0.11a	1.33	1.33
1	4.7	4.8	1.9a	1.9a	0.3a	0.2a	0.4a	0.4a	0.05a	0.05a	0.10a	0.10a	1.05	0.96
5	4.8	4.9	2.1ab	2.1ab	0.3a	0.3a	0.6b	0.7b	0.07a	0.09a	0.10a	0.11a	0.96	0.72
25	5.0	5.1	2.6c	2.6c	0.5b	0.6b	1.2c	1.2c	0.15b	0.20b	0.18b	0.50b	0.54	0.44
50	5.1	5.3	2.8d	2.9d	0.7c	0.8c	1.6d	1.5c	0.24c	0.26c	0.28c	0.42b	0.36	0.35
<i>Kurrimine</i>														
0	4.2	4.2	3.0a	3.0a	0.8a	0.8a	0.6a	0.6a	0.06a	0.06a	0.07a	0.07a	1.10	1.1
1	4.3	4.4	3.1b	2.9b	0.9a	1.2b	0.7a	0.6a	0.05a	0.07a	0.08a	0.08a	0.90	0.8
5	4.5	4.7	3.2c	2.9c	1.8b	1.2b	1.2b	1.3b	0.07a	0.09b	0.10a	0.10a	0.50	0.44
25	4.9	5.3	3.5d	3.4d	1.8b	1.5c	2.4c	2.6c	0.17c	0.20c	0.19b	0.26c	0.16	0.09
50	5.2	5.4	3.6e	3.3d	1.7b	1.6c	2.6c	2.4c	0.24d	0.28d	0.28c	0.43d	0.08	0.08

(3) a good agreement between the sum of base cations before and after leaching, and

(4) a greater loss of monovalent cations compared with divalent cation losses.

We believe that the small increases in soil pH observed were due to the development of anoxic conditions in the columns when leaching rates gradually slowed over the course of the

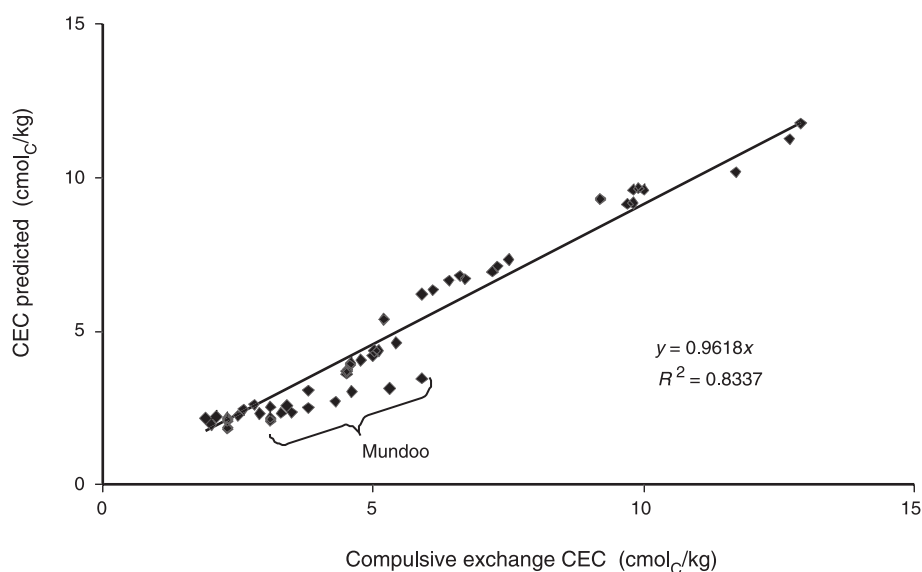


Fig. 2. Relationship between cation exchange capacity measured by compulsive exchange (CEC_{CE}) and CEC predicted from the charge fingerprint at soil pH.

experiment. In fact, leachate pH was recorded daily, and for most of the columns, a gradual rise in pH over each 5-day leaching period was observed, decreasing slightly during the subsequent 2-day leaching-free period. The small increases in cation exchange capacity measured at the end of the leaching experiment are attributed to the overall rise in soil pH.

The close relationship between the sums of base cations before and after leaching (Fig. 4) demonstrates the ability of the soils to maintain the favourable base status

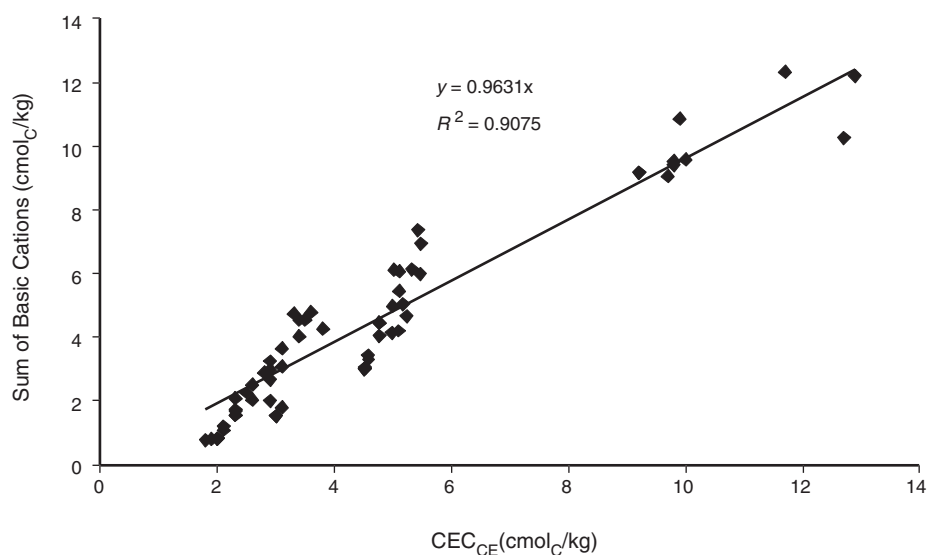


Fig. 3. Comparison of cation exchange capacity (CEC_{CE}) and sum of cations extracted with Ba/NH₄ chloride.

Table 5. The pH and exchange properties (cmol_c/kg) of soils before (B) and after (A) leaching with six months of simulated rainfall (2750 mm)

Treatment	pH		CEC		Ca		Mg		K		Na		H+Al		Sum bases	
	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A
<i>Pin Gin</i>																
0	4.8	4.9	9.2	10.9	5.3	4.6	3.4	2.1	0.40	0.14	0.11	0.06	0.33	0.12	9.2	6.9
1 t/ha <150 µm	4.8	4.9	9.7	10.3	5.5	5.1	3.1	2.4	0.39	0.13	0.10	0.05	0.36	0.13	9.1	7.7
25 t/ha <150 µm	4.9	5.1	9.9	11.9	5.6	5.5	4.5	3.9	0.51	0.19	0.23	0.07	0.26	0.12	10.8	9.7
50 t/ha <40 µm	5.7	5.5	12.9	14.5	5.4	5.7	5.9	7.3	0.46	0.30	0.45	0.16	0.23	0.08	12.2	13.4
<i>Mundoo</i>																
0	4.7	5.6	3.1	4.6	1	1.6	1	0.8	0.11	0.05	0.10	0.05	0.25	0.01	2.2	2.5
1 t/ha <150 µm	4.8	5.4	3.1	4.0	1.1	1.7	1.2	0.9	0.12	0.05	0.11	0.05	0.23	0.04	2.6	2.7
25 t/ha <150 µm	5.1	5.8	4.3	5.2	1.4	2.1	2.3	1.9	0.23	0.10	0.24	0.08	0.10	0.06	4.2	4.2
50 t/ha <40 µm	5.6	6.0	5.9	6.3	2.1	2.8	3.1	2.6	0.29	0.16	0.53	0.09	0.12	0	6.0	5.6
<i>Innisfail</i>																
0	4.8	5.1	4.8	6.4	2.3	2.1	1.6	0.9	0.40	0.18	0.11	0.04	0.35	0.24	4.4	3.2
1 t/ha <150 µm	5.2	5.3	5.1	6.5	2.1	2.4	1.6	1.3	0.40	0.25	0.12	0.06	0.27	0.14	4.2	4.0
25 t/ha <150 µm	5.5	5.3	5.1	6.7	2.4	2.4	2.3	1.4	0.47	0.28	0.24	0.07	0.21	0.16	5.4	4.1
50 t/ha <40 µm	6	5.3	5.5	6.9	2.8	3.05	3.1	2.3	0.60	0.33	0.46	0.14	0.15	0.12	7.0	5.8
<i>Tyson</i>																
0	4.6	4.9	2.3	2.5	0.8	0.9	0.5	0.26	0.15	0.06	0.06	0.07	1.04	0.35	1.5	1.3
1 t/ha <150 µm	4.8	5.0	2.3	2.5	0.9	0.8	0.6	0.33	0.16	0.04	0.06	0.04	0.72	0.34	1.7	1.2
25 t/ha <150 µm	5	5.1	2.9	3.3	1.1	1.1	1.6	1.15	0.25	0.07	0.22	0.06	0.35	0.19	3.2	2.4
50 t/ha <40 µm	5.6	5.4	3.8	5.5	1.5	1.5	2	1.45	0.38	0.14	0.38	0.08	0.14	0.05	4.3	3.2
<i>Tully</i>																
0	4.6	4.8	4.5	4.6	1.6	1.6	1.2	1.1	0.12	0.12	0.04	0.05	1.99	1.83	3.0	2.8
1 t/ha <150 µm	4.6	4.8	4.3	4.9	1.7	1.5	1.2	1.2	0.12	0.13	0.04	0.04	1.84	1.75	3.1	2.9
25 t/ha <150 µm	4.9	4.9	5	5.4	1.9	1.8	2.9	2.4	0.20	0.20	0.06	0.10	1.03	1.31	5.1	4.5
50 t/ha <40 µm	5.1	5.1	5.4	6.3	2.4	1.8	4.4	4.6	0.33	0.29	0.20	0.12	0.39	0.32	7.3	6.8
<i>Galamara</i>																
0	4.5	4.6	2	1.9	0.3	0.3	0.4	0.2	0.06	0.05	0.11	0.05	1.30	1.20	0.9	0.6
1 t/ha <150 µm	4.7	4.7	1.9	2.0	0.3	0.3	0.4	0.3	0.05	0.07	0.10	0.05	1.05	1.07	0.9	0.8
25 t/ha <150 µm	5	4.8	2.6	2.2	0.5	0.4	1.2	0.8	0.15	0.11	0.18	0.07	0.54	0.56	2.0	1.4
50 t/ha <40 µm	5.3	4.9	2.9	2.6	0.8	0.8	1.5	1.0	0.26	0.19	0.42	0.10	0.35	0.40	3.0	2.1
<i>Kurrimine</i>																
0	4.2	4.4	3	3.1	0.8	1.41	0.6	0.7	0.06	0.05	0.07	0.05	1.10	1.16	1.5	2.2
1 t/ha <150 µm	4.3	4.5	3.1	3.1	0.9	1.4	0.7	0.9	0.05	0.04	0.08	0.04	0.90	0.96	1.7	2.4
25 t/ha <150 µm	4.9	5.1	3.5	3.3	1.8	1.47	2.4	2.8	0.17	0.11	0.19	0.05	0.16	0.05	4.6	4.4
50 t/ha <40 µm	5.4	5.4	3.3	3.1	1.6	1.7	2.4	3.3	0.28	0.21	0.43	0.10	0.08	0.06	4.7	5.3

established by the ameliorant addition in a strong leaching environment. As stated above, however, some reorganisation of the base cation complement occurred, when proportionally more monovalent cations were leached than divalent cations. This is best illustrated by comparing the soil contents of the individual base cations before and after leaching (Fig. 5). As the absolute amounts of the monovalent cations are far lower than their divalent counterparts, the overall sum is not greatly altered.

The amounts of base cations removed from the columns during leaching, expressed as cmol_c/kg, are summarised in Table 6. Comparison between these values and those in Table 5 shows that in some cases, amounts of cations leached are of the same order of magnitude as the amounts present in exchangeable form, whereas in others only minor amounts of cations were leached. In most cases, the amounts of monovalent cations removed by leaching were greater than the amounts of cations initially present in

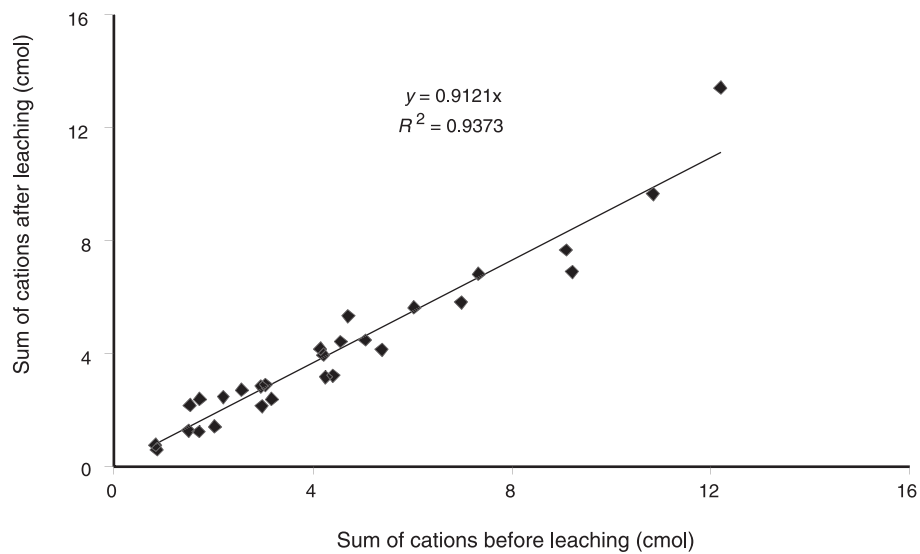


Fig. 4. Relationship between sum of base cations before and after leaching with 2750 mm water.

exchangeable form. To place these losses in perspective, calculated amounts of base cations added to the soil as basalt dust have been converted to cmol_c/kg and included in Table 6. Interpretation of the 1 t/ha results is difficult in these unreplicated trials, but it is quite clear that only a small fraction of the cations added at the high basalt dust rates has been leached.

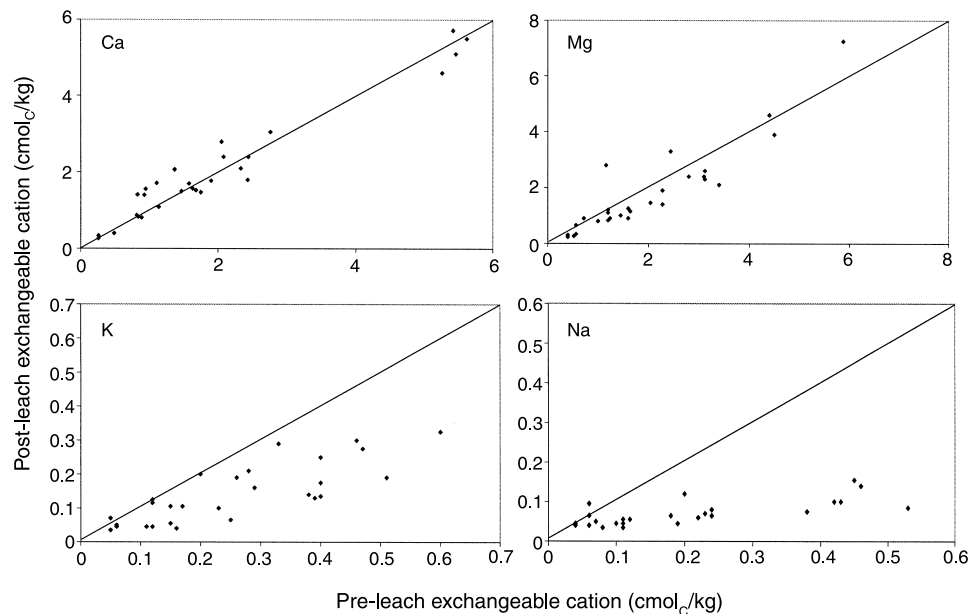


Fig. 5. Relationship between individual base cations before and after leaching with 2750 mm water.

Table 6. Amounts (cmol_c/kg) of cations removed from leaching columns by 2750 mm of simulated rainfall

Treatment	Calcium	Magnesium	Potassium	Sodium
<i>Pin Gin</i>				
0	0.5	0.7	0.33	0.19
1 t/ha <150 µm	0.6	0.7	0.33	0.19
25 t/ha <150 µm	0.4	0.8	0.28	0.22
50 t/ha <40 µm	0.2	1.1	0.28	0.33
<i>Mundoo</i>				
0	0.3	0.3	0.14	0.14
1 t/ha <150 µm	1.0	1.2	0.22	0.19
25 t/ha <150 µm	0.9	1.9	0.14	0.39
50 t/ha <40 µm	0.6	2.3	0.28	0.88
<i>Innisfail</i>				
0	<0.1	0.3	0.08	0.08
1 t/ha <150 µm	<0.1	0.3	0.10	0.10
25 t/ha <150 µm	<0.1	0.4	0.12	0.16
50 t/ha <40 µm	<0.1	0.9	0.18	0.40
<i>Tyson</i>				
0	0.2	0.2	0.14	0.11
1 t/ha <150 µm	0.1	0.2	0.11	0.11
25 t/ha <150 µm	0.1	0.6	0.17	0.28
50 t/ha <40 µm	0.1	0.8	0.19	0.61
<i>Tully</i>				
0	0.2	0.4	0.09	0.08
1 t/ha <150 µm	0.1	0.4	0.09	0.09
25 t/ha <150 µm	0.1	0.8	0.12	0.21
50 t/ha <40 µm	<0.1	1.1	0.15	0.49
<i>Galamara</i>				
0	<0.1	0.1	0.11	0.08
1 t/ha <150 µm	0.1	0.3	0.14	0.14
25 t/ha <150 µm	0.1	0.9	0.19	0.28
50 t/ha <40 µm	0.1	1.1	0.33	0.72
<i>Kurrimine</i>				
0	<0.1	0.1	0.06	0.11
1 t/ha <150 µm	<0.1	0.1	0.03	0.14
25 t/ha <150 µm	<0.1	0.1	0.08	0.33
50 t/ha <40 µm	<0.1	0.1	0.14	0.61
<i>Amounts added to columns as basalt dust</i>				
1 t/ha	0.3	0.5	0.03	0.09
25 t/ha	8.3	13.4	0.75	2.25
50 t/ha	16.5	26.8	1.5	4.5

General discussion

These incubation and leaching experiments have clearly demonstrated the potential for applications of basalt dust to favourably alter the exchangeable cation status of cation-deficient soils, and to maintain this ameliorative effect over sustained periods. In some situations, this may be preferable to the addition of calcitic or dolomitic limestone, which, although supplying Ca and Mg in far greater immediately available amounts, would be prone to greater leaching of these elements from the soil surface horizons. The possible deleterious effects, in the form of minor element (Cu, Zn) deficiency and loss of soil

structure, of raising soil pH of highly weathered soils too high should be recognised. In this respect, basalt application effects on soil pH appear to be mild and sustained.

The approach used in these studies has identified a mechanism by which cations are released from basalt dust into a plant-available form, by demonstrating the direct linkage between base soil charge characteristics and amounts of cations released. The overall concepts involved are summarised in Fig. 6.

The high abrasion pH (the pH of rock materials that have been finely crushed) of basalt dust produces a rise in pH of the soil solution, which in turn increases the cation exchange capacity of soil variable charge components as well as removing exchangeable Al from exchange sites. Small amounts of cations, limited by low solubilisation rates of basalt rock, are immediately attracted to available exchange sites, and this drives the release of more cations from the basalt. Thus, greater amounts of cations are solubilised than would be the case in the absence of the soil cation exchange complex.

Exchangeable cations maintain equilibrium with cations in the soil solution. The latter are subject to removal by leaching if excessive amounts of water are applied, or via plant uptake. In either case, soil solution cations continue to be replenished by the above mentioned mechanism. It would, therefore, appear that a single application of basalt would be effective in supplying cations to the soil solution over a considerable period of time.

Although it might not be economically viable to grind basalt dust to $<40\ \mu\text{m}$ for soil amendment purposes, the particular treatment was included to extend the ranges of pH and cation release obtained. The resulting uniformity of trends observed increase the reliability of the proposed mechanisms. It is worth noting, however, that the 180 000 tonnes of basalt fines waste resulting from the annual production of 'man sand' in Hawaii passes a 74- μm screen.

It would appear that the efficacy of the amendment lies in application rates that are high in relation to conventional rates of application of soil amendment such as lime or gypsum. Therefore, banding or other forms of strategic placement might be advisable. In broadcast mode, continued applications over a number of years would lead to an accumulation of amendment that should be amortised over an extended period.

The dominance of Ca and Mg on exchange sites in this study casts some doubt on whether all of the monovalent ions extracted with Ba/ NH_4 were in an exchangeable form. It is possible that the increases in K following incubation might not be sustained under field conditions. The effectiveness of the amendment in supplying sufficient K would depend on

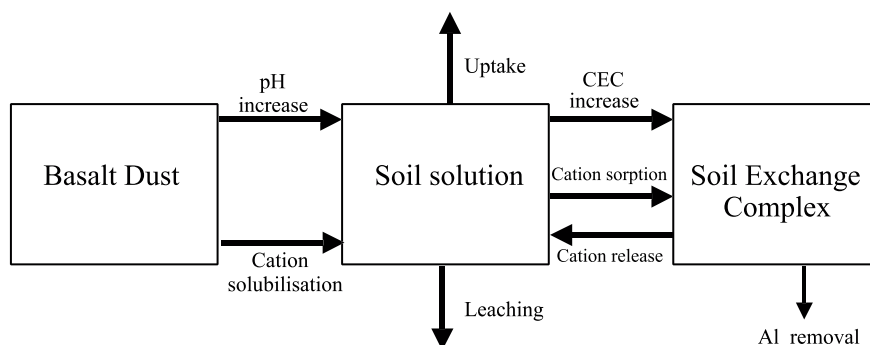


Fig. 6. A possible mechanism for cation release from basalt rock dust and its effects on soil properties.

the balance between plant growth/uptake and prevailing leaching conditions. De Villiers (1961) obtained his remarkable plant growth improvement results with basalt dust in Mauritius in conjunction with normal applications of NPK fertiliser.

Basalt fines, the <5-mm size fraction that remains as largely a waste product following rock crushing operations, are an ideal feedstock for the preparation of basalt dust. The concept of being able to use such waste material in soil amelioration is attractive, and it is hoped that field assessment, particularly trials conducted over a long-term, will validate the promising results obtained in this laboratory evaluation.

Acknowledgment

The authors gratefully acknowledge funding support for this project provided by the Rural Industries Research and Development Corporation of Australia.

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Manuscript received 7 September 2000, accepted 19 January 2001