



Amending highly weathered soils with finely ground basalt rock

G.P. Gillman*, D.C. Burkett, R.J. Coventry

Tropical Plant Sciences, School of Tropical Biology, James Cook University, Queensland, Australia

Abstract

Surface (0–10 cm) samples of 7 soils from tropical coastal Queensland were incubated at room temperature and at field capacity with finely ground ($< 150 \mu$) basalt rock for 3 months. The amendment was applied at 0, 1, 5, 25 and 50 t/ha to cover situations of moderate application rates to that where the amendment might be banded to produce high local concentrations. Having an abrasion pH of about 9, the amendment was able to reduce both active acidity (as estimated by an increase in soil pH) and reserve acidity (reduction in % Al saturation of the CEC). Increases in soil pH resulted in increased CEC, depending on the variable charge nature of each soil, accompanied by increases in exchangeable Ca, Mg, and K supplied by the basalt. The amounts of basic cations converted to exchangeable form constituted only a fraction of the amounts applied. Thus the cations held in reserve ensure that the effect of cation enrichment will be prolonged. In some soils phosphate sorption was significantly reduced by crushed basalt application. Furthermore, 'available' P as measured by extraction with 0.005 M H_2SO_4 was increased. These effects appear to be due to the release of silicate from the basalt as well as modest amounts of phosphate in the rock. Three extractants commonly used for estimating Si availability in sugarcane production indicated that all 7 soils contained sub-optimal levels of the element. Application of crushed basalt rock increased extractable Si levels above what is considered sufficient for this crop. The incubated soils were placed in columns and leached with the equivalent of 2750-mm (average wet season) rainfall. Re-analysis showed that the favourable chemical soil properties imparted by the amendment were retained. These results add further support to the contention that the effects of amelioration will continue for some time. © 2002 Elsevier Science Ltd. All rights reserved.

1. Introduction

The use of basalt dust for soil amelioration is not new. In the 1930s researchers in Europe used dressings of basalt quarry wastes to good effect in the treatment of degraded lands and for the growing of forest trees (Albert, 1938; Hilf, 1938). Interest, however, in the efficacy of crushed basalt in soil amendment was revived by de Villiers (1961) who conducted a series of long term field trials in Mauritius using sugarcane as the test crop. Application rates were high (up to 180 t/ha), but the effects of increased yield of sugar continued throughout the length of the trial, indicating that a single large application could be amortized over many years. The

degree of fineness of the material used by de Villiers was not reported, but was actually described as 'dust'. De Villiers (1961) applied dressings of crushed basalt with normal applications of N, P, and K fertilizer, and in reviewing this work, Martin-Leake (1948) proposed a number of reasons why the amendment should be so successful, viz.

- Improved Si nutrition
- Enhanced trace element supply
- Alteration of soil physical properties
- Modification of mycorrhizal populations.

To examine the effects of crushed basalt application on the cation exchange properties of variable charge soils, Gillman (1980) applied crushed basalt scoria ground to three degrees of fineness, to a surface sample of an Oxisol. The amendment was applied at rates up to

* Corresponding author at: CSIRO Land and Water, PMB Aitkenvale, Queensland 4814, Australia.

E-mail address: gavin.gillman@csiro.au (G.P. Gillman).

Table 1
Some relevant information on the soils studied

Soil	Parent material	Clay mineralogy ^{a,b}	Organic matter (%)	Clay ^b (%)	Free ferric oxide ^b (%)
Tropeptic Haplorthox	Basalt rock	Ka > G = Ha	14.5	75	15
Tropeptic Haplorthox	Basalt fan	G > Go/Ha > Ka	8.2	40	15
Oxic Dystropept	Basalt alluvium	Ka > I = ChV	3.4	40	15
Orthoxic Tropudult	Granite fan	Ka > G > Go/Ha > = ChV	6.3	20	1
Oxic Dystropept	Granite alluvium	Ka > I > ChV	6.3	40	2
Tropeptic Haplorthox	Metamorphic rock	G > Ka > Go/Ha > I = ChV	3.9	20	1.5
Haplorthod	Beach ridge	n.d.	7.1	2	<0.1

^a Clay mineralogy: Ka = Kaolinite; G = Gibbsite; Ha = Haematite; Go = Goethite; I = Illite; ChV = Chloritized Vermiculite.

^b Estimates from previous studies.

200 t/ha, and the samples were incubated at 0.1 bar moisture tension for periods up to 12 months. With increasing rate of application, soil pH increased, thereby raising the CEC of this variable charge soil. Importantly, the increased CEC was occupied by exchangeable Ca, Mg, and K derived from the basalt. The effects were more pronounced as the basalt was more finely ground, reflecting an increased solubility of the scoria with fine grinding. Also, the observed effects increased with time of incubation.

Basalt rock dust, passing a 150 μ screen is now available in commercial quantities in north Queensland. The opportunity has therefore been taken to examine the soil chemical effects of applying finely ground hard basalt rock to a range of highly weathered soils representative of those occurring on the Queensland tropical coast. Surface (0–10 cm) samples of soil were incubated at field moisture capacity with increasing rates of basalt dust for a period of 3 months. The effects on soil pH, CEC, exchangeable basic and acidic cations, P sorption capacity, extractable P, and extractable Si were studied. In an attempt to predict the longevity of the effects observed, the incubated soils were then leached with an equivalent of 2750 mm of rainfall, and the soil properties re-determined.

2. Materials and methods

2.1. Soils

The 7 soils chosen for this study represent the major landforms and parent materials of tropical coastal Queensland. Some relevant characteristics are summarized in Table 1. Bulk samples from 0–10 cm depth were air dried and passed through a 2 mm sieve.

2.2. Crushed basalt amendment

Material passing a 150 μ sieve was supplied by Pacific Mineral Developments Pty. Ltd.

Table 2

Some relevant properties of the basalt material used for producing rock powder

<i>Chemical composition (ppm)</i>	
Si	216,000
Fe	105,000
Al	76,000
Ca	65,400
Mg	64,400
Na	20,300
Ti	15,200
K	12,500
P	3030
S	2150
<i>Particle size distribution</i>	
Passing 150 μ sieve	90%
62 μ	75%
30 μ	50%
15 μ	25%
<i>Primary rock forming minerals</i>	
Olivine	10%
Plagioclase	12%
Magnetite	10%
Augite	30%
Orthoclase	Minor
Apatite	0.5%
Altered glass	37%

Waste material passing the final screen (5 mm) at a rock crushing plant is used as stock for a ball-mill grinder. Concentrations of principal elements, and particle size typical of the commercially available product are presented in Table 2.

2.3. Incubation study

Crushed basalt rock was added to each sample at rates of 0, 1, 5, 25, and 50 t/ha. The lower rates are

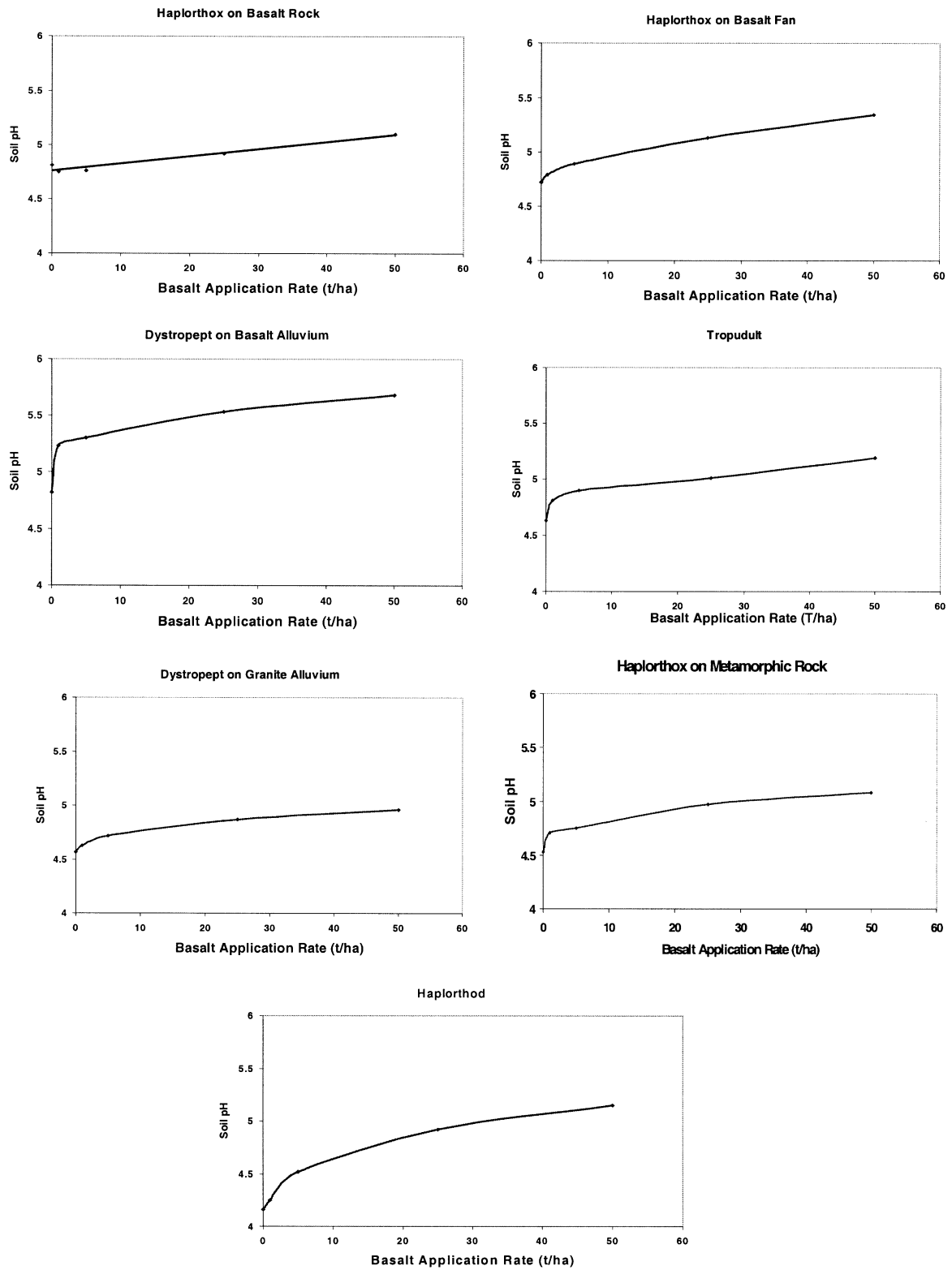


Fig. 1. Effect of crushed basalt rock amendment on pH of soils studied.

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 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.

2.4. Leaching study

Single replicates of the 0, 1, and 25 t/ha incubated soils were added to 15 cm diameter columns to a depth of 10 cm, and leached with daily additions of distilled

Table 3

The effect of crushed basalt amendment on the exchangeable basic cation content, cation exchange capacity, and exchangeable acidic cation content of the incubated soils. All units are cmol_c kg⁻¹. For each soil within a column, values with the same letter are not significantly different

Basalt (t/ha)	Ca	Mg	K	Na	CEC _{CE}	H + Al
<i>Haplorthox (basalt)</i>						
0	5.26a	3.4a	0.4a	0.11a	9.2a	0.33a
1	5.46a	3.1a	0.39a	0.1a	9.7a	0.36a
5	5.66a	3.2a	0.4a	0.15a	9.8a	0.37a
25	5.62a	4.5b	0.51b	0.23b	9.9a	0.26b
50	5.52a	5.9b	0.58c	0.32c	11.7b	0.16b
<i>Haplorthox (basalt fan)</i>						
0	0.95a	1a	0.11a	0.1a	3.1a	0.25a
1	1.11b	1.24b	0.12a	0.11a	3.1a	0.23ab
5	1.12b	1.4c	0.13a	0.12a	3.3a	0.21b
25	1.37c	2.28d	0.23b	0.24b	4.3b	0.10c
50	1.5d	2.88e	0.32c	0.35c	4.6b	0.10c
<i>Tropudult</i>						
0	0.82a	0.52a	0.15a	0.06a	2.3a	1.04a
1	0.89a	0.56a	0.16ab	0.06a	2.3a	0.72b
5	0.98a	0.8a	0.2b	0.1a	2.3a	0.54c
25	1.14b	1.64b	0.25c	0.22b	2.9b	0.35d
50	1.35c	2.04c	0.33d	0.31c	3.4c	0.18e
<i>Haplorthox (metamorphic rock)</i>						
0	0.26a	0.4a	0.06a	0.11a	2a	1.33a
1	0.26a	0.4a	0.05a	0.1a	1.9a	1.05b
5	0.32b	0.6b	0.07a	0.1a	2.1a	0.96c
25	0.49c	1.2c	0.15b	0.18b	2.6b	0.54d
50	0.73d	1.64d	0.24c	0.28c	2.8c	0.36e
<i>Dystropept (basalt alluvium)</i>						
0	1.78a	1.72a	0.39a	0.11a	5.5a	0.35a
1	1.76a	1.65a	0.41ab	0.13a	5.9b	0.27b
5	1.81a	1.60a	0.44b	0.10a	6.1b	0.2b
25	1.98ab	2.64b	0.49c	0.21b	6.6c	0.21b
50	2.14b	3.32c	0.60d	0.34c	7.2d	0.21b
<i>Dystropept (granite alluvium)</i>						
0	1.63a	1.2a	0.12a	0.04a	4.51a	1.99a
1	1.68a	1.2a	0.12a	0.04a	4.52a	1.84b
5	1.66a	1.6b	0.13a	0.04a	4.57a	1.59c
25	1.9b	2.8c	0.2b	0.06b	4.99b	1.03d
50	2.15c	3.52d	0.25c	0.18c	5.02b	0.62e
<i>Haplorthod</i>						
0	0.83a	0.56a	0.06a	0.07a	3a	1.10a
1	0.93a	0.72a	0.05a	0.08a	3.1a	0.90b
5	1.75b	1.16b	0.07b	0.1a	3.1a	0.50c
25	1.75b	2.44c	0.17c	0.19b	3.5b	0.16d
50	1.66b	2.6c	0.24d	0.28c	3.6b	0.08d

Table 4

Additional amounts of basic cations, expressed in kg/ha, supplied in exchangeable form by crushed basalt amendment, to the 7 soils of the study

Soil	MINPLUS (t/ha)	Exchange (kg/ha)		
		Ca	Mg	K
<i>Haplorthox on basalt rock</i>	1	40	-36	-4
	5	80	-24	0
	25	72	132	43
	50	52	300	70
<i>Haplorthox on basalt fan</i>	1	32	29	4
	5	34	48	8
	25	84	154	47
	50	110	226	82
<i>Tropudult</i>	1	14	5	4
	5	32	34	20
	25	64	134	39
	50	106	182	70
<i>Haplorthox on metamorphic rock</i>	1	0	0	-4
	5	12	0	4
	25	46	48	35
	50	94	48	70
<i>Dystropept on basalt alluvium</i>	1	-50	0	0
	5	110	5	0
	25	22	82	27
	50	52	125	55
<i>Dystropept on granite alluvium</i>	1	10	0	0
	5	6	48	4
	25	54	192	31
	50	104	278	51
<i>Haplorthod</i>	1	20	19	-4
	5	184	72	4
	25	184	226	43
	50	166	245	70
<i>Total amounts of cations applied in crushed basalt:</i>				
	1	65	64	13
	5	325	320	65
	25	1625	1600	325
	50	3250	3200	625

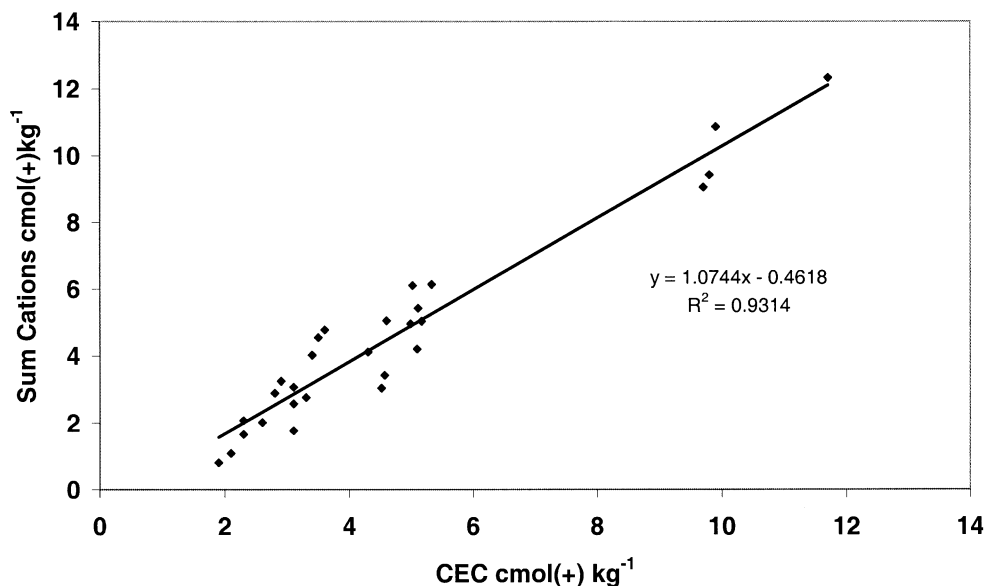


Fig. 2. Relationship between CEC_{CE} and sum of exchangeable basic cations for all soils over all basalt amendment treatments.

water for 5 days, followed by a 2-day rest period. Adding, in each of 6 successive weeks, the average monthly rainfall in that week simulated the 6 wettest months of the year. Thus a 6 month wet season was simulated in 6 weeks.

For each leaching column, sub-samples of daily leachate for each week were bulked to form a 'weekly leachate', which were similarly sub-sampled to form a 'final bulk leachate'. The chemical composition of this bulk leachate would be identical to that if all of the leachate from the column over the entire experiment had been collected. From knowledge of the total volume of leachate that passed through the column, and the chemical composition of the final bulk leachate, total amounts of elements leached from the column could be easily computed.

2.5. Analytical determinations

The compulsive exchange method (Gillman and Sumpter, 1986) was used to measure soil pH (pH_{BaCl_2}), exchangeable Ca, Mg, K, and Na, and cation exchange capacity (CEC_{CE}). Exchangeable acidic cations were extracted with 1 M KCl and titrated with 0.05 M NaOH to pH 8.5. Phosphate sorption isotherms were determined by the method of Fox and Kamprath (1970), but modified by using a 16-h equilibration period. 'Available P' was estimated by extraction with 0.005 M H_2SO_4 (Kerr and von Stieglitz, 1938). Three extractants were used to determine 'available Si'; 0.1 M $CaCl_2$ (Haysom and Chapman, 1975), phosphate/acetate buffer (Fox et

al., 1967), and 0.005 M H_2SO_4 (Kerr and von Stieglitz, 1938).

3. Results and discussion

3.1. Incubation study

3.1.1. Soil acidity

The basalt rock dust amendment has an abrasion pH of about pH 9, presumably due to the release of silicate ions upon contact with water, and their subsequent hydrolysis to poorly dissociated silicic acid. It would be expected, therefore, that application of the ameliorant to soil would have a liming effect.

The efficacy of addition of crushed basalt rock in the amelioration of soil active acidity, estimated by pH measurements, is summarized in Fig. 1. In some soils, a steady increase in soil pH across the range of basalt application rates was observed, while in others the initial dressing of 1 t/ha appeared to cause a sharp soil pH increase, followed by a more gradual rise. Application rates of about 25 t/ha were generally needed to raise soil pH above 5.

Perhaps of greater interest, particularly for the long term, was the effect of the amendment on soil reserve acidity, as measured by KCl extractable $H+Al$. The amendment caused an appreciable reduction in reserve acidity in 3 soils where it was proportionately high (Table 3). The three soils formed on basaltic parent materials do not have high levels of reserve acidity, and

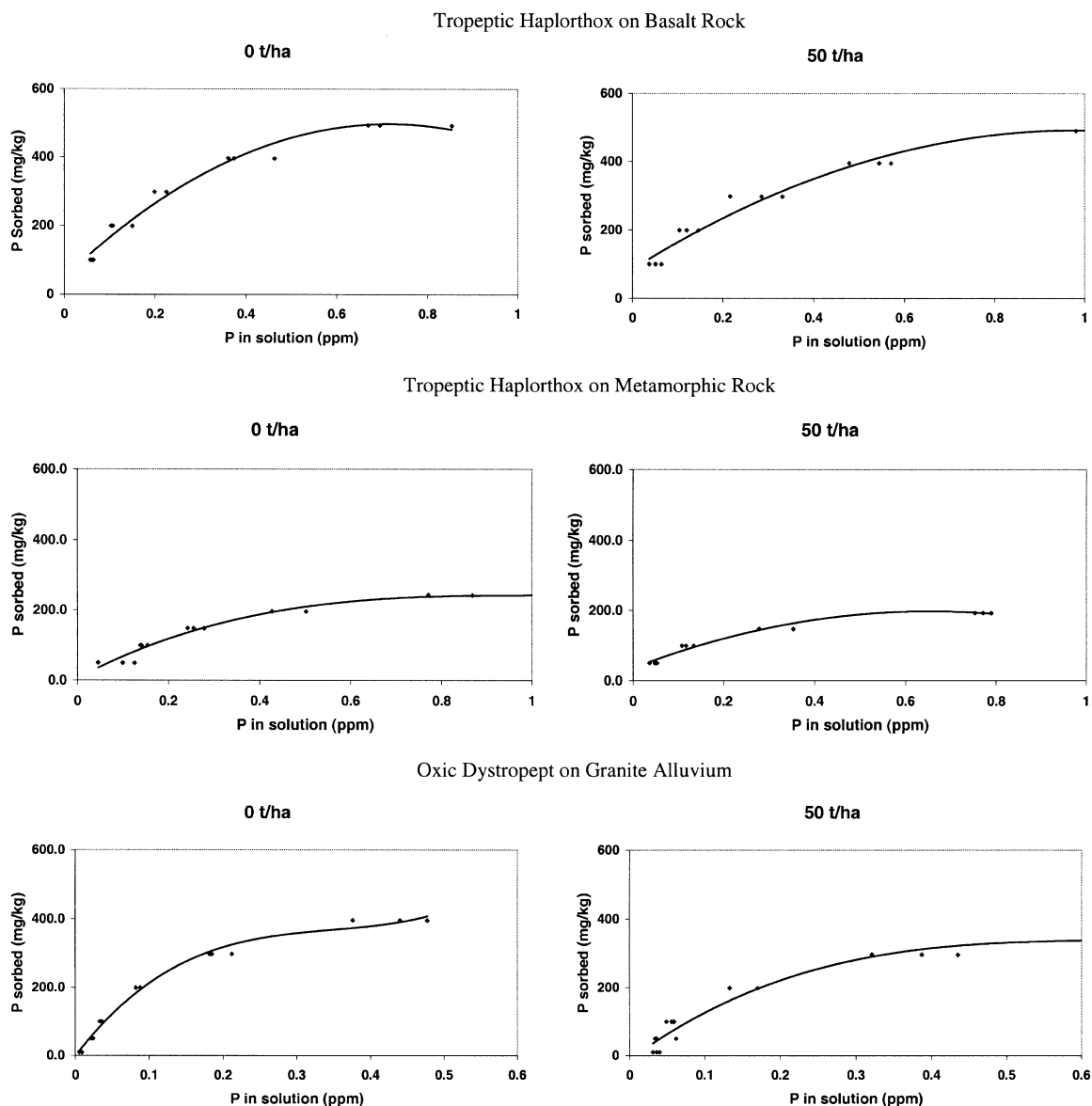


Fig. 3. Examples of phosphate sorption for incubated soil treated with zero and 50 t/ha crushed basalt amendment.

the effect of the amendment was not as pronounced as for the other 4 soils.

3.1.2. Cation exchange capacity and exchangeable basic cations

The compulsive exchange method used for the measurement of CEC in this study revealed the capacity of soils to retain exchangeable basic cations. It would appear from the CEC_{CE} values presented in Table 3 that the amendment had raised cation exchange capacity levels by relatively modest amounts. Closer inspection

of Table 3, however, shows that in their unamended state (0 t/ha) most of the soils were unsaturated with respect to basic cations. The release of Ca, Mg, K, and Na from the crushed basalt had resulted in the saturation with basic cations of previously existing and newly created CEC_{CE} . There was good agreement between the sum of basic cations, and CEC_{CE} across all soils (Fig. 2), indicating that the additional cations released were in fact associated with the exchange complex.

A better picture of the amounts of basic cations supplied by the ameliorant in exchangeable form is

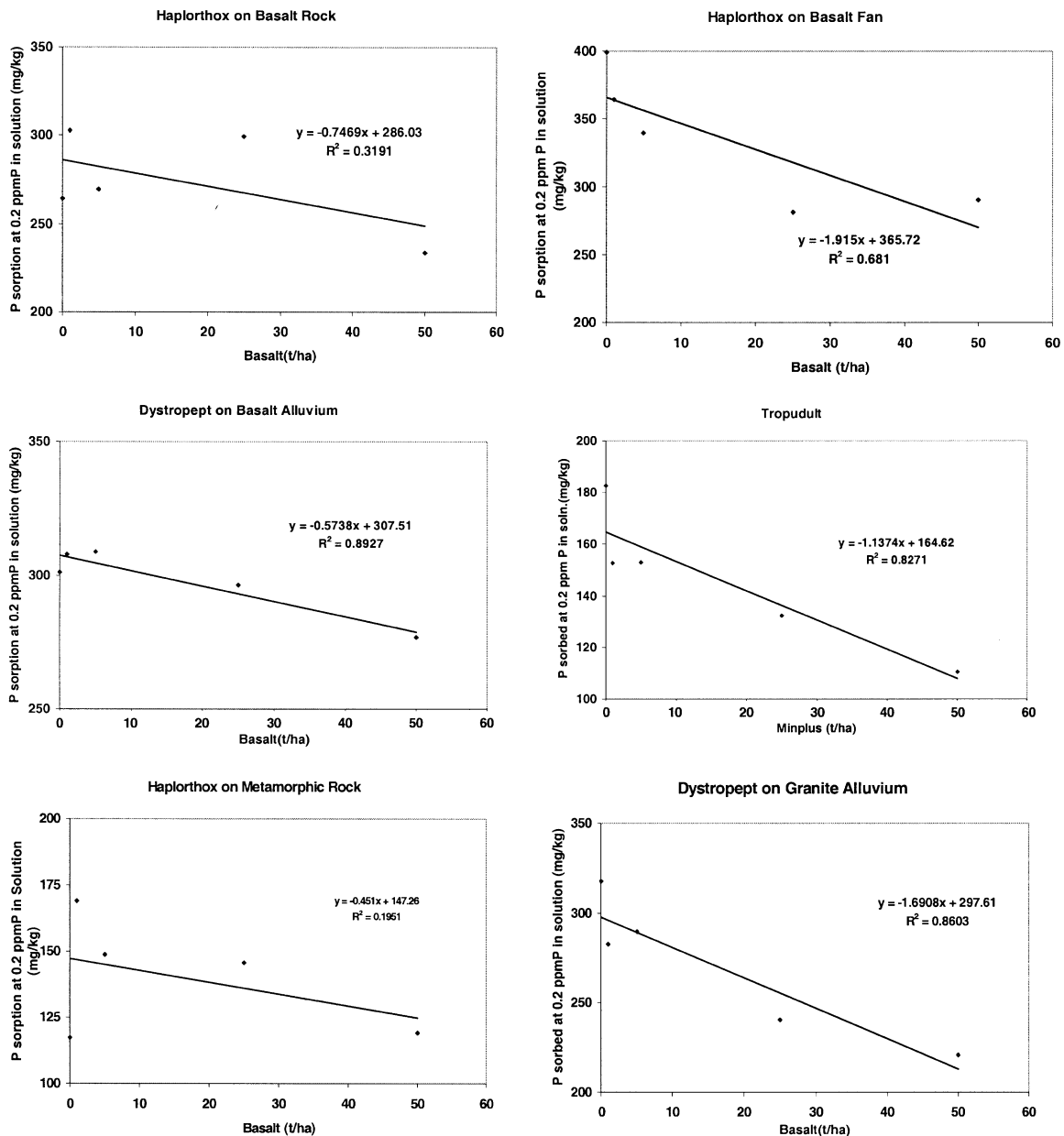


Fig. 4. Decrease in phosphate sorption with increasing rates of application of crushed basalt.

obtained by converting units for exchangeable cations to kg/ha, and subtracting the amounts that were present prior to amendment application (0 t/ha). The result of this treatment of the data is presented in Table 4. There were a number of anomalies resulting from the heavy factoring of small differences in some instances, but it is clear that the amendment was able to provide substantial amounts of Ca, Mg, and K to soils that obviously require it.

When the additional exchangeable basic cations are expressed as a percentage of what was actually applied (calculated from known concentrations in the amendment) it is seen that only a fraction of the total amount of cations applied had been released, particularly at the higher application rates (Table 4). If cations continue to be released to the exchange complex following plant uptake, cation supplementation should be effective for considerable periods of time.

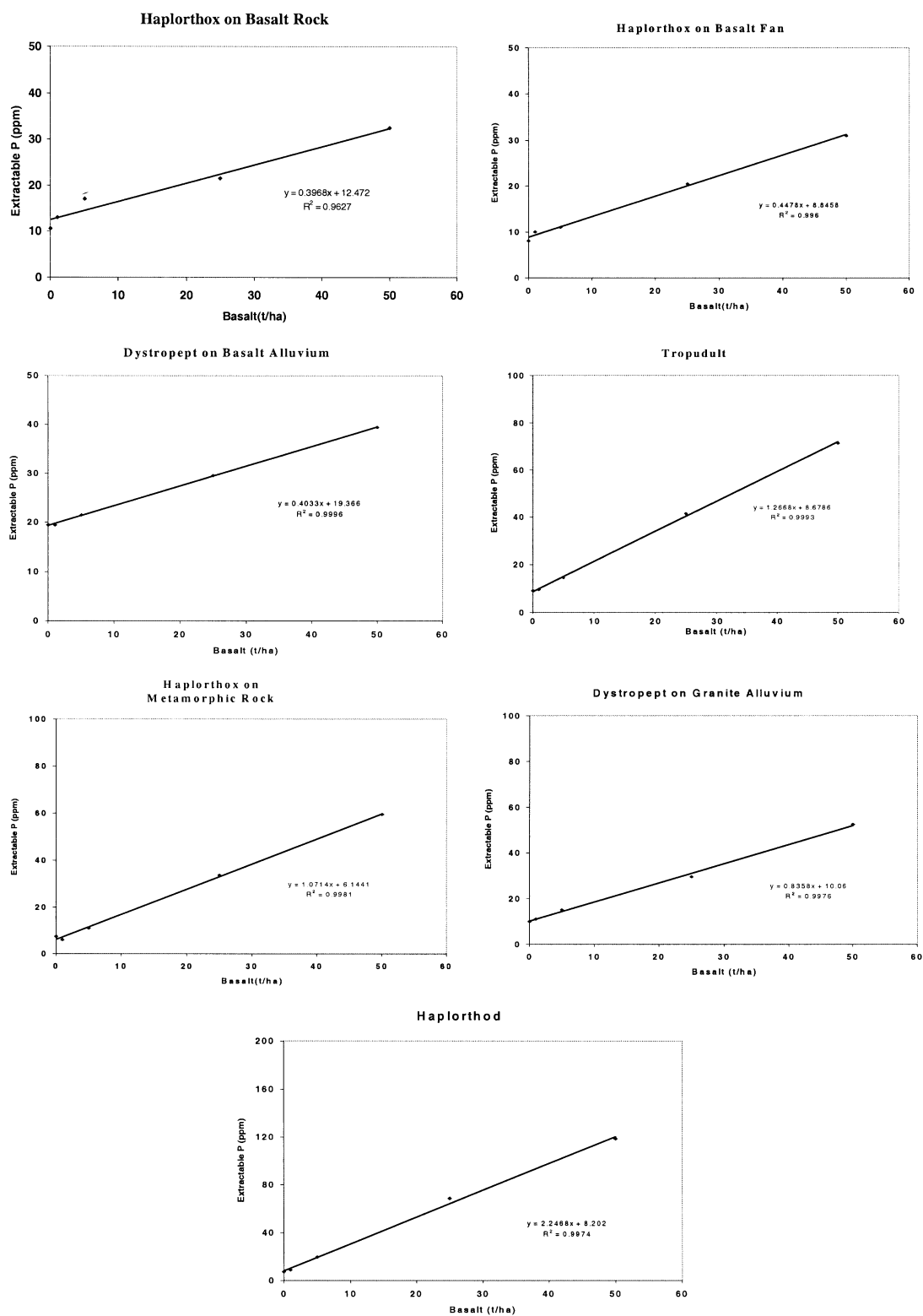


Fig. 5. Amounts of P extracted by 0.005 M H₂SO₄ with increasing rates of crushed basalt amendment.

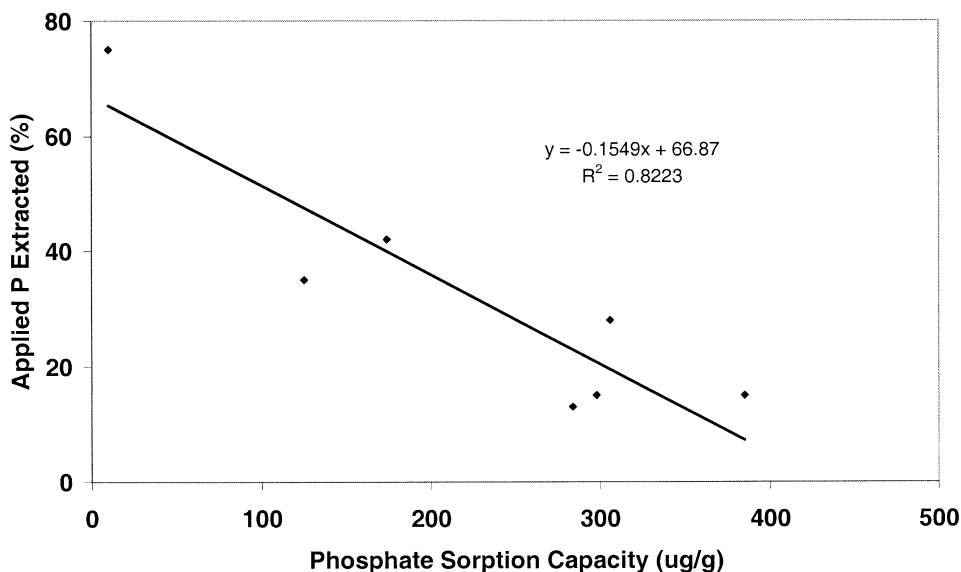


Fig. 6. Amounts of extractable P in soils treated with 50 t/ha crushed basalt (expressed as % of P applied in dust) versus the soil phosphate sorption capacity.

3.1.3. Phosphate sorption capacity and available phosphate

Examples of P sorption curves generated for incubated soils are presented in Fig. 3. From these curves, the amount of P sorbed at a standard solution P concentration of 0.2 µg P/ml can be obtained. These standardized P sorption capacities, expressed as µgP/g soil have been plotted against amendment application rate (Fig. 4). Phosphate sorption curves for the soil formed on the beach ridge were not pursued in view of the very low P sorption capacities of this soil.

There was a very poor correlation between P sorption and basalt application rate in 2 of the soils (Haplorthox on basalt rock and on metamorphic rock) but Fig. 4 depicts an overall trend of reduced P sorption capacity following amendment application. Taking the soil formed on granite alluvium for example, the slope constant of -1.69 shows that each t/ha of ameliorant reduces P sorption capacity by 1.69g P/tonne of soil. For an amendment rate of 10 t/ha, P application could be reduced by 17 kg/ha, equivalent to 170 kg/ha single superphosphate.

The method of Kerr and von Stieglitz (1938) is extensively used in the sugarcane production areas of Queensland to ascertain P sufficiency levels. A value greater than 20 µgP/g soil extracted by this method (0.005 M H₂SO₄) is indicative of soils that will not respond to P fertilization. Amounts of extractable P, expressed as µgP/g soil are plotted against crushed basalt application rate in Fig. 5.

An examination of Fig. 5 shows that all of the soils (with the possible exception of the Oxic Dystropept) would respond to P fertilization in their unamended states. Applications of crushed basalt rock raised the extractable P levels above the critical value of 20 µgP/g soil, but the amount needed to do this varies with soil type. It could be argued that the additional P resulted from displacement of adsorbed P by silicate released from the amendment. However, the greatest increase in extractable P was observed in the soil that has virtually no P sorption capacity, viz. the Haplorthod on the beach ridge. The amendment itself contains 0.3% P, which if completely brought into solution by the extractant would deliver 3 µgP/g soil for each t/ha of amendment applied. This is sufficient to account for the increased levels of extractable P found in the beach ridge soil.

Increases in extractable P in the other 6 soils were smaller, and tended to be inversely related to the soil P sorption capacity. This suggests that if P was released from the amendment in similar quantities for all soils, it was subsequently sorbed by the soil in amounts related to their P sorption capacities. The H₂SO₄ extractant then removed P in varying degrees from the 7 soils, depending on the actual mechanism by which it had been sorbed. (The term 'sorption' is meant to embrace a range of P removal pathways, including precipitation and chemical bonding to surface functional groups). The amounts of P extracted from each soil have been expressed as a percentage of the amount added as amendment, i.e. as a recovery factor, and plotted

against the soil P sorption capacity (Fig. 6). P sorption capacity was not measured for the Haplorthod, but it has been given a small, finite value. Though the relationship depicted in Fig. 6 is not strong, it supports the release/sorption mechanisms suggested above. In the extreme cases, P released to the Haplorthod was not sorbed and was easily extracted, whereas in the oxide-dominant soils formed on basaltic parent materials, the

Table 5

Amounts of Si extracted from the incubated soils by 3 extractants. For each soil within a column, values with the same letter are not significantly different

Soil	Basalt (t/ha)	Si extracted by		
		0.1 M CaCl ₂	Phosphate/ Acetate/ Buffer (ppm)	0.005 M H ₂ SO ₄
<i>Haplorthox on basalt rock</i>	0	16.4a	77.8a	155.5a
	1	17.1a	87.9a	183.6a
	5	21.3b	113.6b	260.0b
	25	32.4c	174.8c	765.4c
	50	37.9d	236.7d	1233.2d
<i>Haplorthox on basalt fan</i>	0	12.5a	38.5a	164.6a
	1	13.9b	43.4b	187.9b
	5	17.5c	54.1c	257.7c
	25	27.8d	104.3d	610.8d
	50	32.9e	156.1e	1220.4e
<i>Tropudult</i>	0	3.0a	18a	36.5a
	1	3.7b	25.7b	66.1b
	5	6.3c	39.3c	145.9c
	25	12.6d	70.3d	544.6d
	50	16.2e	116.6e	1029.4e
<i>Haplorthox on metamorphic rock</i>	0	2.9a	10.7a	30.9a
	1	3.4b	16.1b	58.0b
	5	8.1c	23.7c	131.9c
	25	19.9d	64.5d	534.0d
	50	24.6e	94.9e	988.7e
<i>Dystropept on basalt alluvium</i>	0	26.0a	90a	232.2a
	1	24.7a	97.5b	277.7b
	5	25.4a	112.7c	355.0c
	25	28.0a	150.5d	734.6d
	50	28.0a	201e	1195.1e
<i>Dystropept on granite alluvium</i>	0	8.1a	30.7a	133.8a
	1	7.8a	35.7b	157.0a
	5	8.9a	45.8c	227.6b
	25	14.3b	86.7d	597.7c
	50	17.5c	129.7e	1108.9d
<i>Haplorthod</i>	0	2.2a	12.2a	20.4a
	1	3.6b	16.2b	23.4a
	5	7.1c	18.2b	64.1b
	25	14.2d	26.7c	364.7c
	50	16.1e	39.1d	829.0d

P released was strongly sorbed, resulting in low extractable P values.

It is likely therefore, that the decrease in P sorption capacity resulting from application of crushed basalt rock was due to the release of P from the amendment,

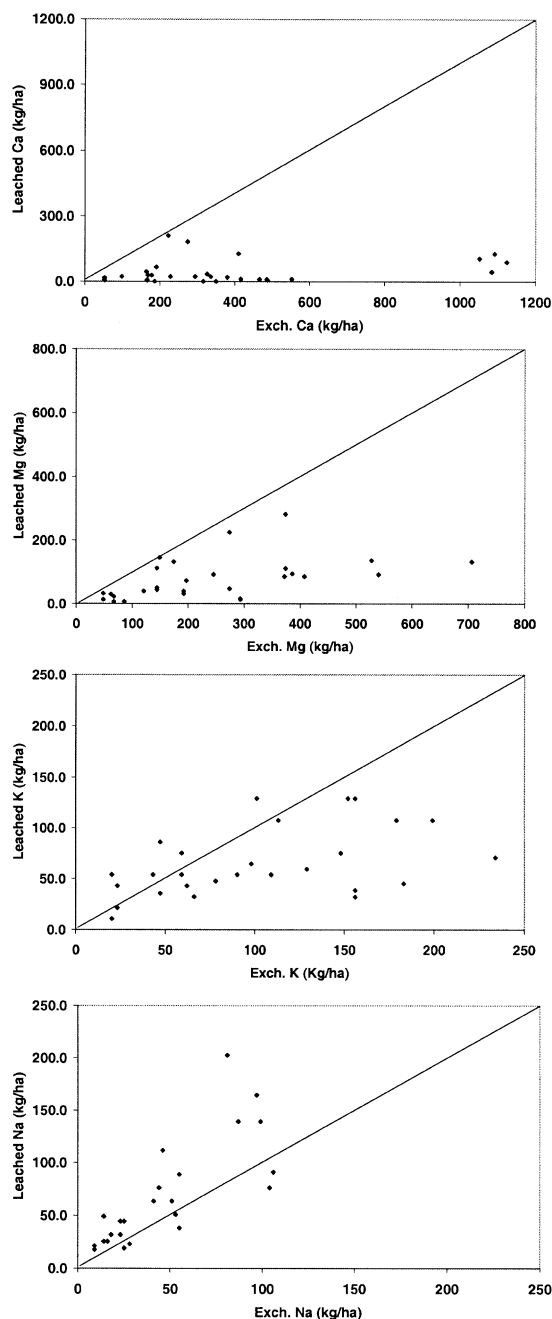


Fig. 7. Amounts of basic cations (kg/ha) lost during leaching versus exchangeable basic cation content (kg/ha) prior to leaching.

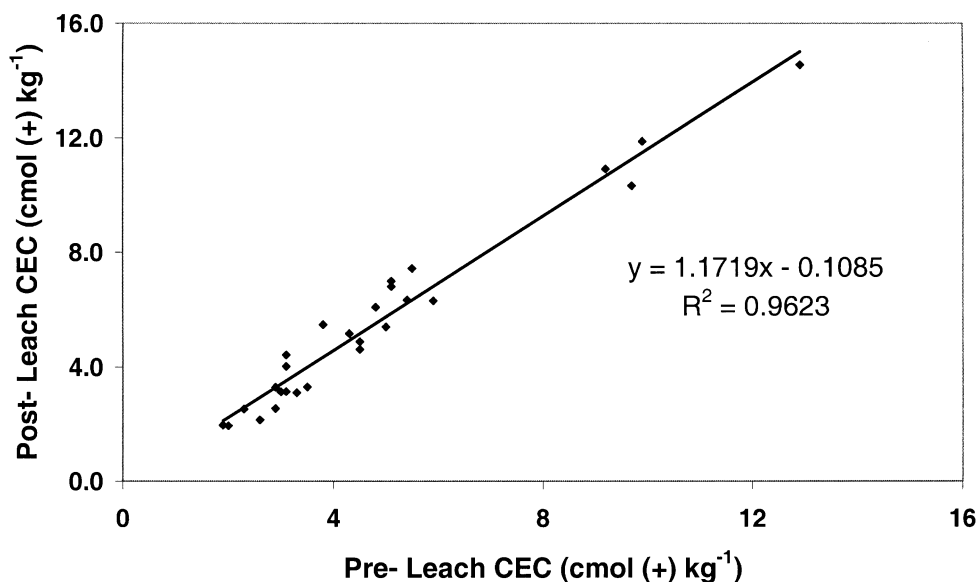


Fig. 8. Cation exchange capacity of incubated soils prior to and after leaching.

and its subsequent sorption. The extractable P values for the Haplorthod show that an application rate of 1 t/ha of amendment can raise soil P levels by 2.5 µgP/g soil which is greater than any of the reductions in P sorption capacity of the other 6 soils. The latter values are obtained from the slope constants in Fig. 4.

The increases in extractable P observed appear to be sufficient to provide enough available P for plant growth in the short term. Unlike Ca and Mg, the reserves of P in the amendment would be very limited (3 kgP/tonne) and it would not be reasonable to rely on the amendment as a long-term source of plant-available P.

3.1.4. Extractable silicon

Although it is rare to consider the element Si as an essential element in plant nutrition, it appears that crops such as sugarcane and rice do require it, and that certain levels of 'labile' Si must be present for optimum performance of these crops. A number of extractants have been used in attempts to identify the 'pools' of Si that are available to plants. In this study, Si was extracted from the incubated soils with 0.01 M CaCl₂ (Haysom and Chapman, 1975), a phosphate/acetate buffer at pH 3.5 (Fox et al., 1967), and with 0.005 M H₂SO₄ (Kerr and von Stieglitz, 1938). The effect of crushed basalt application on the amounts of Si extracted by these methods is summarized in Table 5.

The gross differences in Si extracted using the 3 solutions show that Si is removed from different 'pools', and that basalt application greatly increases the amounts

obtained. An attempt has been made to separate the Si that the extractants might simply dissolve from the amendment from the basalt-derived Si that has reacted with soil particle surfaces (labile Si). This may be done by considering the Haplorthod, which contains little of the components that would react with any Si released during incubation. The increased Si extraction resulting from ameliorant application to this sand may therefore be taken as the Si dissolved from crushed basalt during the extraction process. The data in Table 5 show that the increases in extractable Si with ameliorant application rate for the 6 other soils are greater than the increases recorded for the Haplorthod in most instances, indicating that the amendment has provided additional Si in labile form. The effect is particularly noticeable with the phosphate/acetate extractant.

There have been only limited studies that attempt to identify critical values for extractable Si, i.e. values above which a response would not be expected to field applications of Si. For the 0.01 M CaCl₂ extractant, Haysom and Chapman (1975) suggest a critical value of 20 ppm Si, while Fox et al. (1967) propose critical values of 150 ppm Si and 100 ppm Si for the phosphate/acetate and H₂SO₄ extractants respectively. Using these figures, it appears that all of the soils in this study would respond to Si application for optimum sugarcane production. Application of crushed basalt is able to raise the 'soil-related Si' above the critical levels, but field trials are necessary to more accurately assess the reliability of the criteria, and to relate the results of 3 months

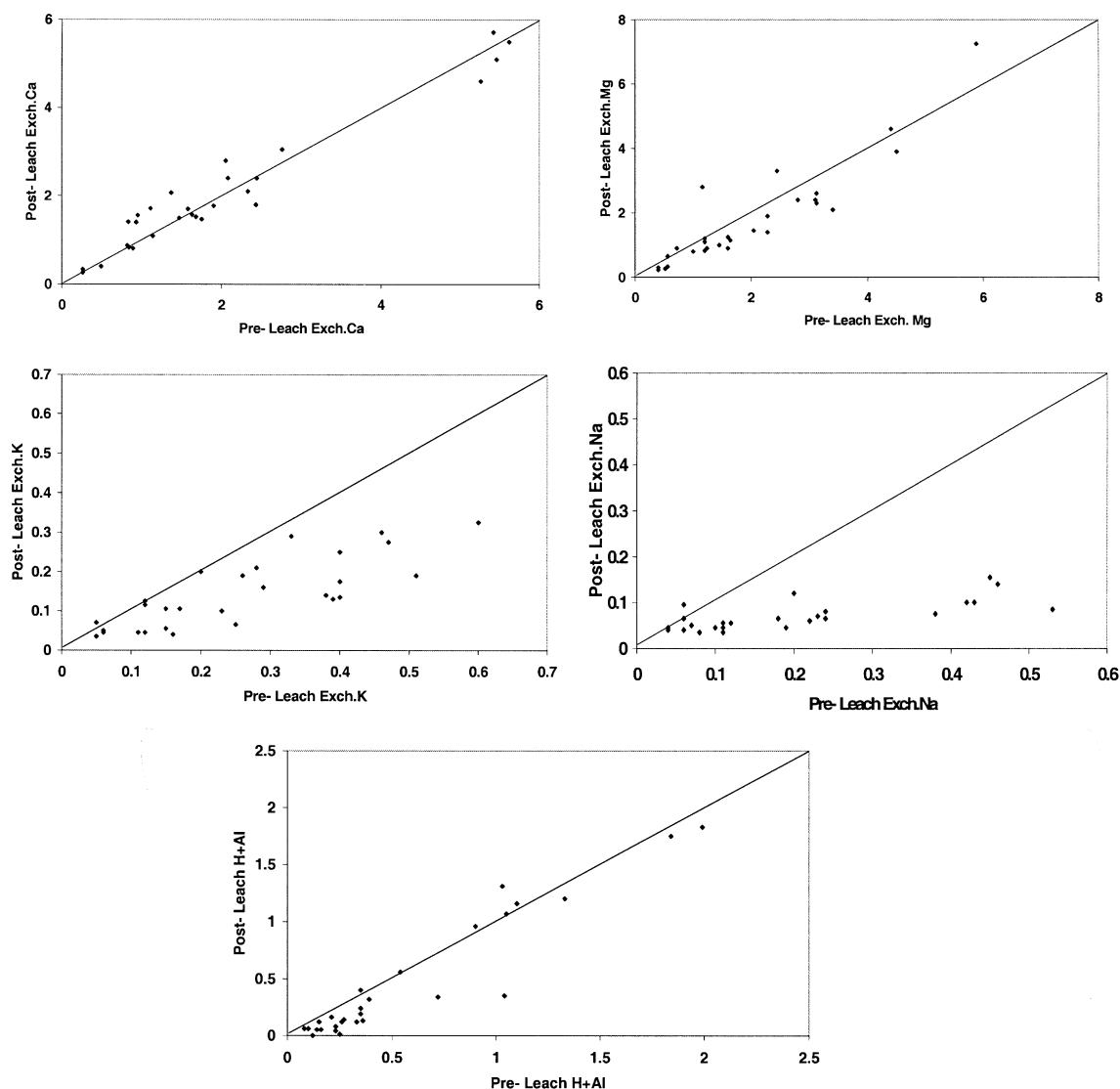


Fig. 9. Exchangeable basic cation contents of incubated soils prior to and after leaching.

laboratory incubation to the longer-term reactions which would continue in the field.

4. Leaching study

4.1. Leachate electrolytic conductivity (EC)

The EC of the leachate collected daily was measured to identify significant events such as pulses of salt movement from the column. The patterns of EC versus time (not presented) were similar for all soils, with the highest EC values being recorded in the first leachate

volume, followed by a rapid decrease to about 100 $\mu\text{S}/\text{cm}$ after between one and two 'rainfall months'.

4.2. Leachate pH

The pH of the leachate collected daily was also measured. As expected, leachate pH was higher in the columns containing crushed basalt rock dust, and increased in accordance with application rate. As the experiment progressed, there was a gradual increase in leachate pH across all samples, including the zero basalt application rates. This effect is attributed to a gradual increase in anoxic conditions in the columns as the soils

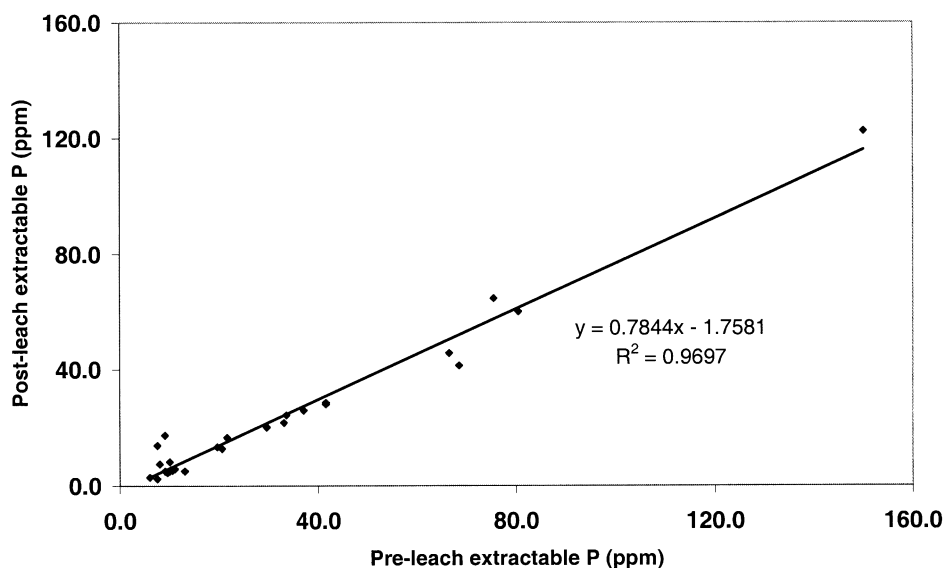


Fig. 10. Extractable phosphate contents of incubated soils prior to and after leaching.

became more compacted, and leaching rates slowed. There is a well-known relationship between soil pH and soil Eh (Bartlett, 1998).

4.3. Leachate cations

Cation concentrations in the leachate (bulk leachate) accumulated from each column at the end of the experiment were quite small. Knowledge of the total amount of water passed through each column, and the surface area of the column, allowed cation concentrations to be converted to kg/ha. These values can be compared to the exchangeable cation content prior to leaching, the latter also being expressed in kg/ha, to give some indication of the relative loss of cations from the system (Fig. 7).

Only minor amounts of Ca were removed, somewhat greater amounts of Mg and K, while the amounts of Na in the leachate exceeded the exchangeable Na values in most cases. The significance of these losses will be further evaluated when the exchangeable cation contents of the leached soils are discussed.

4.4. CEC and exchangeable cations

The cation exchange capacity of the leached soils was slightly higher following leaching (Fig. 8), consistent with the small increases in soil pH observed. This effect may be a laboratory artifact, but it may also indicate that during periods of continuously heavy rainfall, waterlogged conditions could cause a temporary increase in pH. The resulting increase in CEC in these

variable charge soils would retain cations at a time when they are most vulnerable to leaching.

Exchangeable cation contents of the leached soils are compared with pre-leach values in Fig. 9. There was little change in the amounts of exchangeable acidity, the highest values being related to the zero amendment rate samples. There was also little change to the contents of divalent exchangeable Ca and Mg. Since only minor amounts of Ca were removed during leaching, but greater amounts of Mg, it appears that additional Mg has been released from the amendment, for occupation of exchange sites. Contents of exchangeable K were reduced by about 50%, and losses of exchangeable Na were greater at about 75%.

4.5. Extractable P

The amounts of phosphate removed by the leaching program were small, and the soil 'available P' levels estimated by extraction with 0.005 M H₂SO₄ were maintained at about 80% of their pre-leaching levels (Fig. 10). It is likely, therefore, that the boost in labile P contents provided by the ameliorant will not be lost in leaching, and could satisfy crop requirements for a short time.

4.6. Extractable Si

Relatively small amounts of Si were found in the Bulk Leachate from each column, in the order of 10–50 µg Si/g soil. A comparison of Si extracted from the soils before and after leaching (Fig. 11) shows that in general, the amounts of Si that can be removed by each of the 3

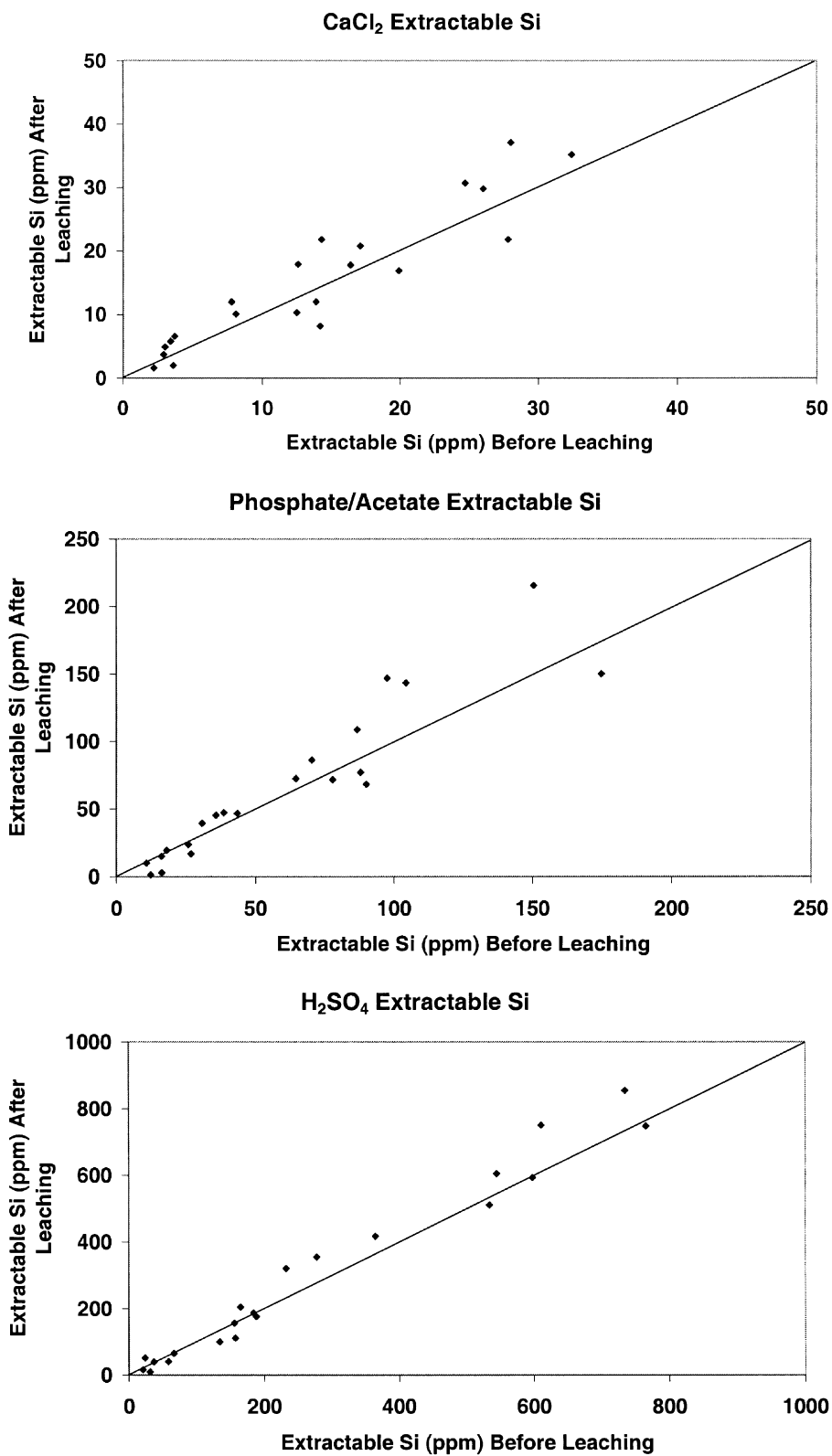


Fig. 11. Extractable Si contents of incubated soils (estimated by 3 methods) prior to and after leaching.

extractants were not affected by leaching. Either Si lost during the leaching process was replenished by the amendment, or the amounts leached were within the experimental error associated with the soil Si determinations before and after leaching.

5. Conclusion

The results of this short-term laboratory study have important implications with respect to soil management, that must of course be tested in the field. It appears, however, that the application of crushed basalt dust to acidic, cation deficient soils can effect changes enthusiastically described by de Villiers (1961) as soil rejuvenation.

Increases in soil pH are not as dramatic as is observed for lime applications at equivalent rates. Important reductions, however, in reserve acidity (exchangeable H + Al) are achieved, which should be long-lasting in view of the large amendment reserves of Ca and Mg that can be slowly released. The leaching experiment, and the strong 1:1 relationship between sum of basic cations and cation exchange capacity, show that the bulk of reserve divalent cations will only be released when cation exchange sites become available. Conversely, bioassessment studies might confirm that the lower amendment rates are quite sufficient to meet cation crop requirements via this slow release mechanism. Maintenance of base-saturated conditions for extended periods may also promote a soil microbe balance conducive to optimum plant growth.

Unfortunately, the dominance of Ca and Mg is to a degree at the expense of the monovalent cations. Losses of exchangeable K are of concern, and it is clear that the amendment will not be a long-term source of this element. There are no significant plant nutritional problems related to the relatively rapid loss of exchangeable Na, except that the equivalent amount of anions would leach with the cation. Under field conditions, this could result in the enhancement of NO₃⁻ leaching.

It is unlikely that sufficient quantities of silicate are released from the amendment to cause a reduction in phosphate sorption capacity, as has been postulated for soluble silicate amendments. Temporary reduction in phosphate sorption capacity, and increased availability of phosphate is achieved, however, by the release of phosphate from the rock, perhaps associated with easily weathered volcanic glass. The low total P content would not allow this situation to exist over an extended period.

There does, however, appear to be sufficient reaction between soil particle surfaces and released silicate to increase the level of labile Si to that sufficient for the needs of crops that actually require Si. Field studies will have to be undertaken to confirm this.

There are environmentally appealing reasons for using crushed basalt dust in soil amelioration. It allows the use of a waste material that is accumulating at rock crushing plants in large quantities, for the production of a material rich in nutrient cations and Si that are released at rates that avoid leaching and off-site pollution.

Acknowledgements

Funding for this research was totally provided by the Rural Industries Research and Development Corporation, whose support is gratefully acknowledged.

References

- Albert, R., 1938. On the use of fine debris from stone quarries for the improvement of poor forest soils. *Forstarchiv*. 14, 229–240.
- Bartlett, R.J., 1998. Characterizing soil redox behavior. In Sparks, D.L. (Ed.), *Soil Physical Chemistry*, Chapter 7, p. 371. CRC Press LLC.
- Fox, R.L., Silva, J.A., Younge, O.R., Plucknett, D.L., Sherman, G.D., 1967. Soil and plant silicon and silicate response by sugar cane. *Soil Sci. Soc. Am. Proc.* 31, 775–779.
- Fox, R.L., Kamprath, E.J., 1970. Phosphate sorption isotherms for evaluating the phosphate requirements of soil. *Soil Sci. Soc. Am. Proc.* 34, 902–907.
- Gillman, G.P., 1980. The effect of crushed basalt scoria on the cation exchange properties of a highly weathered soil. *Soil Sci. Soc. Am. J.* 44, 465–468.
- Gillman, G.P., Sumpter, E.A., 1986. Modification to the compulsive exchange method for measuring exchange characteristics of soils. *Aust. J. Soil Res.* 24, 61–66.
- Haysom, M.B.C., Chapman, L.S., 1975. Some aspects of the calcium silicate trial at Mackay. *Proc. Qd. Soc. Sugar Cane Technol.* 42, 117–122.
- Hilf, H.H., 1938. The manuring of poor soils with basalt grit. *Forstarchiv*. 14, 93–101.
- Kerr, W. H., von Steiglitz, C.M., 1938. The laboratory determination of soil fertility. Bureau of Sugar Exp. Sta. Tech. Comm. No. 9.
- Martin-Leake, H., 1948. Soil rejuvenation in Mauritius. *Int. Sugar J.* 50, 90–91.
- de Villiers, O.D'Hotman. 1961. Soil rejuvenation with crushed basalt in Mauritius. *Int. Sugar J.* 63, 363–364.