Nutrient Cycling in Agroecosystems **56:** 59–68, 2000.

Powdered granite is not an effective fertilizer for clover and wheat in sandy soils from Western Australia

M.D.A. Bolland[1] & M.J. Baker[2]
Agriculture Western Australia; [1]PO Box 1231, Bunbury, Western Australia 6231, Australia; [2]3 Baron-Hay Court, South Perth, Western Australia 6151, Australia

Received 13 January 1998; accepted in revised form 12 May 1998

Key words: bicarbonate-extractable potassium, muriate of potash, potassium, potassium chloride, relative effectiveness, silicate rock powder, *Triticum aestivum*, *Trifolium subterraneum*

Abstract

Granite (silicate) rock dust, a by-product of quarry operations, is being advocated and used as a fertilizer in the wheatbelt of south-western Australia (WA). The dust is insoluble and based on its nutrient element content (1.9% K and 0.3%P and negligible N) it is not expected to be a useful fertilizer. Previous laboratory studies and glasshouse experiments in WA suggest the dust is a slow release K fertilizer. This paper extends the previous studies to consider the dust as an NP or K fertilizer in the year of application in a field experiment on a soil deficient in N, P and K. In addition, the effectiveness of the dust as a K fertilizer was compared with the effectiveness of KCl (muriate of potash), the K fertilizer used in WA at present, in glasshouse experiments using K deficient soils. In the field experiment, compared with NP fertilizer or NPK fertilizer (urea, supplying N; superphosphate, providing P, S, Ca, Cu, Zn and Mo; KCl providing K), the dust had no effect on grain yield of wheat (*Triticum aestivum*); in fact dust applied at 20 t ha^{-1}, for unknown reasons, reduced yields by about 65% compared to the nil (no fertilizer, no dust) treatment. Relative to the nil treatment, applying NPK fertilizer increased yields about threefold, from 0.54 to 1.79 t ha. The glasshouse experiments showed that, relative to KCl, the dust was from about 0.02 to 14% as effective in K deficient grey sandy soils for producing dried tops of 30-day old wheat plants or 42-day old clover (*Trifolium subterraneum*) plants. In soils with adequate K (yellow sands, sandy loams or clays, loamy clays, clay loams and clays), neither KCl nor the dust affected yields of 30 to 42-day old wheat or clover plants grown in the glasshouse. In the glasshouse experiments, no yield depressions were measured for the dust applied up to 17 g dust per kg soil (equivalent to 17 t dust ha^{-1} mixed into the top 10 cm of soil in the field). It is concluded that the dust has no value as a fertilizer.

Introduction

In south-western Australia (WA), granite (silicate) rock is mined and crushed to provide material for making concrete, roads, and foundations for laying railway tracks. The by-product is a fine granite dust that has no use, and so is stockpiled. The dust is advocated, and is sold to a few farmers, as a fertilizer for soils in the wheatbelt of WA. However, the effectiveness of the dust as a fertilizer in soils of WA is not known. The dust is insoluble and contains 1.9% K, 0.3% P, negligible N, 0.08% Mg and 0.25% Ca. Applications of N, P and sometimes K fertilizer are required in WA soils for profitable crop and pasture production. There is no evidence for the need for applications of fertilizer Ca and Mg. Therefore, the dust would not be expected to be a profitable fertilizer for crops and pastures in WA. Experiments have been done in WA to show that this is so. Limited published laboratory and glasshouse studies done in WA (Hinsinger et al., 1996; Coroneos et al., 1996) suggest the dust provides K, but the dust is unlikely to be an economic alternative to potassium chloride (muriate of potash), the K fertilizer used in WA.

The results of the few experiments done elsewhere on various powdered silicate rocks as fertilizers or soil amendments have been summarized by Weerasuriya et al. (1993). Most of the studies have shown that the various powders are ineffective, and any small improvement in soil properties or plant yields were only achieved when very large, uneconomical amounts of the powders were applied (Gillman, 1980; Kahnt et al., 1986; Sanz Scovino and Rowell, 1987; Von Fragstein et al., 1988; Blum et al., 1989a, b; Baerug, 1991). A positive result obtained in one experiment may have been due to Ca, P and S also applied with the silicate powder (Von Mersi et al., 1992). Positive plant yield results have been achieved in some pot experiments by adding basalt, micaschist and migmatite (Leonardos et al., 1987).

This paper reports results of one field and four glasshouse experiment done in WA to assess granite dust as a fertilizer. The field experiment compared the dust with NP or NPK fertilizer for wheat grain production. One glasshouse experiment assessed whether the dust provided K, Ca or Mg for wheat, using soil samples collected from nearby the field experiment. Three glasshouse experiments compared the effectiveness of the dust and potassium chloride as K fertilizers.

Materials and methods

Granite dust

The rock dust was biotite-containing granite collected from Pioneer Quarries at Herne Hill, near Perth, Western Australia. It was the same sample of granite dust used in the glasshouse experiment of Hinsinger et al. (1996), and was used in all the experiments reported in this paper. The particle size distribution for the dust, on a percentage basis, was: < 2 μm, 2%; 2–10 μm, 7%; 20–75 μm, 7%; 75–106 μm, 3%; 106–150 μm, 3%; 150–180 μm, 2%; 180–300 μm, 7%; 300–600 μm, 14%; 600–100 μm, 13%; > 1000 μm, 42%. Chemical composition (g kg^{-1}) was as follows: SiO_2, 673; Al_2O_3, 135; TiO_2, 6.0; Fe_2O_3, 53.5; MnO, 0.7; CaO, 35.6; MgO, 13.8; K_2O, 22.9; Na_2O, 39.2; P_2O_5, 0.8; and SO_3, 0.3. Loss on ignition at 1200 ° C was 9.1 g kg^{-1}.

Soils

Some properties of the soils used for the one field and four glasshouse experiments are listed in Table 1. In WA, the Colwell (1963) bicarbonate procedure that is used to measure the current P status of soils is also used to measure the current K status of soils (Edwards, 1993). Unpublished data of W.J. Cox suggests that K deficiency is likely for Colwell soil test K values of $<$ 100 μg K g^{-1} soil for subterranean clover (*Trifolium subterraneum*), and for values $<$ 60 μg K g^{-1} for wheat (*Triticum aestivum*). Most pastures in WA are based on subterranean clover, and wheat is the most important crop.

Field experiment

The experiment was done in 1993 at Amery Acres, near the town of Dowerin, Western Australia. Average annual rainfall is 320 mm. The experiment compared fertilizer NPK only, rock dust only, when the dust was applied at 2 or 20 t ha^{-1}, and these same two levels of rock dust applied with either NP or NPK fertilizers (see Table 2). The 2 t ha^{-1} level of rock dust is closer to levels used on farms, which typically range from 0.5 to 4 t ha^{-1}. The 20 t ha^{-1} was added to see if this amount of dust supplied enough K to approach the maximum yield achieved by adding NPK fertilizer. There was also a nil treatment (no fertilizer and no rock dust). There were therefore 8 treatments, arranged in a completely randomised block, replicated 4 times. The P fertilizer was 400 kg ha^{-1} single superphosphate, containing 9.0% total P (80% water-soluble P), 19% Ca, 10.5% S, 0.60% Cu, 0.30% Zn and 0.06% Mo. The N fertilizer was 200 kg ha^{-1} urea, containing 46% N. The K fertilizer was 200 kg ha^{-1} potassium chloride, containing 50% K. The amounts of each of the nutrient elements applied were in excess of the amounts required to avoid deficiency. The size of each plot was 2 m by 20 m. The fertilizer and rock dust treatments were applied by hand to the soil surface, and all the plots were cultivated to 10 cm with a rotary hoe to incorporate the treatments into the soil. The plots were sown with wheat (cv. Aroona) at 60 kg seed ha^{-1}, in late May. Eight rows of seed, 180 mm apart, were sown at 5 cm depth down each plot with a tined seeder. When ripe, the grain was harvested at mid-December with a machine (a small plot combine harvester), excluding each outside row, and weighed.

Glasshouse experiments

There were four experiments. One was a nutrient omission experiment, using soil collected from nearby the field experiment, to determine whether the rock dust supplied K, Ca or Mg to wheat plants. The other three experiments measured the effectiveness of the rock dust as a K fertilizer relative to potassium chloride, using three different, representative, K deficient

Table 1. Some properties of the < 2 mm fraction of the top 10 cm of the soils used; names are locations of field sites and/or where soil samples were collected for the glasshouse experiments

	Dowerin	Kokeby	West Dale	Badgingarra
pH ($CaCl_2$)[a]	4.69	4.85	4.96	5.20
% clay[b]	1.1	1.4	1.6	1.3
Exchangeable K (c mole kg^{-1})[c]	0.03	0.04	0.06	0.04
Bicarbonate-extractable K (μg K g^{-1} soil)[d]	58	9	31	20
Organic carbon (%)[e]	0.42	0.68	1.21	0.84
Field capacity[f] (%)	11	11	12	10

[a] 1:5 soil:0.01 m $CaCl_2$ (w/v).
[b] Plummet method, as modified by Loveday (1974).
[c] Extracted by 0.01 m $SrCl_2$, and concentration of K in the extract measured by atomic absorption spectrophotometry.
[d] Extracted by Colwell (1963) procedure: 1 g of soil shaken with 100 mL 0.5 M $NaHCO_3$ on an end-over-end shaker (10 rpm) for 16 h at 23 °C. The K concentration in the extract solution was measured by flame atomic absorption spectrophotometry.
[e] Walkley and Black (1934).
[f] Gravimetric field capacity was measured by adding 500 mL of deionised water to the surface of 3 kg of dry soil in a pot and sealing the pot in a plastic bag. After 24 h, samples of soil were collected from about 10 cm below the surface and weighed. The samples were then dried in a 70 °C forced draught oven to constant weight, and the water content of the soil was calculated on a dry-weight basis.

sandy soils from WA. The experiments were done in a glasshouse with a mean temperature of 17 °C and range 12 to 25 °C.

Nutrient omission experiment

The experiment comprised a completely randomised block of the 12 treatments listed in Table 3. There were four replications. The 3 kg samples of Dowerin soil (see Table 1 for some properties) used per pot were weighed into plastic bags. Based on the results of preliminary experiments, the following basal nutrients were applied to all except the nil treatment to ensure N, P, S, Mn, Cu, Zn, B and Mo were non-limiting for production of wheat or clover (*Trifolium subterraneum*) in sandy soils from WA (g pot^{-1}): 0.65 NH_4NO_3 (0.23 g N pot^{-1}), 1.5 $NaH_2PO_4.2H_2O$ (0.3 g P pot^{-1}), 0.69 $(NH_4)_2$ SO_4 (0.15 g N pot^{-1}, 0.17 g S pot^{-1}), 0.35 $MnSO_4.H_20$ (0.11 g Mn pot^{-1}, 0.07 g S pot^{-1}), 0.03 $CuSO_4.5H_2O$ (0.01 g Cu pot^{-1}), 0.03 Zn $SO_{4.}7$ H_2O (0.01 g Zn pot^{-1}), 0.008 H_3BO_3(0.001 g B pot^{-1}), and 0.0008 Na_2MoO_4 (0.0004 g Mo pot^{-1}). Likewise, the following (g pot^{-1}) were added to provide adequate K, Ca and Mg: 0.6 KCl (0.3 g K pot^{-1}), 0.18 Mg $SO_4.7H_2O$ (0.018 g Mg pot^{-1}) and 0.13 $CaCl_2.2H_2O$ (0.047 g Ca pot^{-1}). All the salts were added to the soils as solutions. When the soils had dried after additions of the solutions, the rock dust treatments were applied, and the soils were thoroughly shaken in the bags to incorporate the nutrient elements and dust through the soils. The bags with the soil were placed in the pots, so the bags lined the pots, and the pots were not free draining. The pots were then watered to field capacity (Table 1) with deionized water. After 7 days equilibration, the pots were sown with wheat (cv. Aroona). Of the 10 plants sown per pot, 7 were kept and grown for 30 days. During this period the pots were regularly watered by weight to maintain the soil water content close to field capacity. The pots were re-randomised while watering. Extra nitrogen, using NH_4NO_3 and $(NH_4)_2$ SO_4 at the levels listed above, was added to the soil surface of all except the nil treatment at 10 and 20 days after sowing. The plant tops were harvested at ground level, oven-dried and weighed to measure yield of the dried tops.

Experiments comparing rock dust and KCl

All three experiments used 1.8 kg per pot of < 2 mm fraction of the top 10 cm of K deficient soil collected from farmer paddocks in different locations in Western Australia; see Table 1 from some soils properties.

Table 2. Grain yield of wheat measured in the field experiment in the year of applying fertilizer or rock dust (1993)

Treatment	Grain yield (kg/ha) + sd (n = 4)
Nil (no fertilizer or rock dust)	599±84
N, P and K fertilizer	1793±184
2 t ha^{-1} rock dust only	465±135
20 t ha^{-1} rock dust only	202±110
2 t ha^{-1} rock dust plus N and P fertilizer	1122±277
20 t ha^{-1} rock dust plus N and P fertilizer	766±102
2 t ha^{-1} rock dust plus N, P and K fertilizer	1460±104
20 t ha^{-1} rock dust plus N, P and K fertilizer	1610±71

Table 3. Yield of 30 day old dried wheat tops measured in the nutrient omission glasshouse experiment

Treatment[a]	Yield (g pot^{-1}) + sd (n = 4)
Nil (no rock dust, no fertilizer)	2.54±013
All nutrients, no rock dust	4.52±0.27
5 t ha^{-1} rock dust only	2.36±0.09
20 t ha^{-1} rock dust only	2.43±0.20
5 t ha^{-1} rock dust plus all nutrients	4.68±0.30
20 t ha^{-1} rock dust plus all nutrients	4.46±0.29
5 t ha^{-1} rock dust plus all nutrients except K	2.53±0.09
20 t ha^{-1} rock dust plus all nutrients except K	2.29±0.32
5 t ha^{-1} rock dust plus all nutrients except Ca	4.61±0.29
20 t ha^{-1} rock dust plus all nutrients except Ca	4.52±0.20
5 t ha^{-1} rock dust plus all nutrients except Mg	4.52±0.26
20 t ha^{-1} rock dust plus all nutrients except Mg	4.44±0.22

[a] Adding 15 or 60 g rock dust per pot, or 5 or 20 g rock dust per kg soil (3 kg of soil was used per pot) is equivalent to adding 5 or 20 t ha^{-1} rock dust in the field if the rock dust is mixed into the top 10 cm of soil in the field.

Wheat (cv. Aroona) was grown for 30 days in the soil from Badgingarra, and subterranean clover (cv. Dalkeith) was grown for 42 days in the other two experiments. Experimental procedures were the same as described for the nutrient omission experiment, except: half the amount of basal fertilizer was applied, because 1.8 kg of soil was used instead of 3 kg; no K was applied as a basal fertilizer; and fertilizer N basal was re-applied at 10, 20 and 30 days.

The experiment with the Badgingarra soil comprised a completely randomised block of a nil K treatment, 6 levels of K as KCl (mg K per pot: 15.4, 30.8, 46.2, 92.4, 138.6 and 231.0), and 7 levels of K as rock dust (15.4, 30.8, 46.2, 92.4, 138.6, 231.0, 462.0 mg K pot^{-1}). There were three replications.

The experiment with the West Dale soil comprised 20 levels of K as KCl (mg K per pot: 0, 1, 2, 4, 6, 8, 10, 15, 20, 30, 50, 60, 80, 150, 300, 600, 800, 1000, 1250, 1500) and 20 levels of K as rock dust (mg K pot^{-1}: 0, 5, 10, 20, 30, 40, 50, 60, 80, 100, 150, 250, 500, 1000, 2000, 3000, 4000, 5000, 7500 and 10000). There was no replication. The 20 levels of application of each fertilizer were used to adequately define the relationship between yield and the amount of K applied for both fertilizers enabling meaningfull calculations of the relative effectiveness of the fertilizers to be made (Barrow, 1985).

The experiment with the Kokeby soil comprised 25 levels of K as KCl (mg K per pot: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500 and 600) and 27 levels of K as rock dust (mg K pot^{-1}: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 2000, 3000, 4000, 8000, 10000, 20000 and 30000). There was no replication.

Soil samples to measure extractable K were collected from the experiments with the West Dale and Kokeby soils. The samples were collected just before sowing, 7 days after the fertilizers were added to the soils and the soils were first wetted up to field capacity. The samples were collected with a 1 cm diameter by 10 cm deep sampler that was pushed into the soil (the pots were 12 cm deep, and the soil in the pots was 11 cm deep; the diameter of the pots was 14 cm). One sample of soil was collected from each pot. The soil samples were air-dried, and bicarbonate-extractable K was measured by the method of Colwell (1963) developed to measure bicarbonate-extractable P: 1 g of soil was shaken with 100 mL of 0.5 m $NaHCO_3$ on an end-over-end shaker (10 rpm) for 16 h of 23 °C. The K concentration in the extract solution was measured by flame atomic absorption spectrophotometry. This K test is widely used in Western Australia to estimate the current K status of soils.

Calculating effectiveness of the K fertilizers

The effectiveness of KCl and rock dust as K fertilizer in the glasshouse experiments was calculated using yield of dried tops and bicarbonate-soluble K extracted from the soil.

Data for the relationship between yield of dried tops and the level of K applied were adequately described by a Mitscherlich equation:

$$y = a - b\exp.(-cx)$$

where y is the yield of dried tops (g pot^{-1}), x is the level of K applied (g K pot^{-1}), and a, b and c are coefficients. Coefficient a provides an estimate of the maximum yield plateau (asymptote), b the yield response (maximum yield minus the yield for the nil-K treatment, as determined from the fitted equation), and c describes the shape of the relationship between yield and the level of K applied, by estimating the rate at which the maximum yield plateau is approached as the level of K applied is increased. Data were fitted to the equation by non-linear regression using the Maximum Likelihood Program (Ross, 1980). Mean data were fitted for the experiment with Badgingarra soil.

The effectiveness of the rock dust was calculated relative to the effectiveness of KCl, to provide relative effectiveness (RE_{yield}) values. This was done by comparing the amount of K as rock dust and KCl required to produce the same yield. The RE_{yield} of rock dust is calculated by dividing the amount of K as KCl required to produce the target yield by the amount of K as rock dust required to the produce the same yield (Barrow and Campbell, 1972; Barrow, 1985). Provided both KCl and rock dust produce the same maximum yield plateau, RE_{yield} can be calculated by dividing the c coefficient for rock dust by the c coefficient for KCl. However, in the study reported here, rock dust did not always support the same maximum yield as KCl (Figure 1, Table 4). It is therefore not valid to use the value of the c coefficient of the Mitscherlich equation to compare the effectiveness of the fertilizers (Barrow and Campbell, 1972). Instead, the effectiveness of the fertilizers was compared using the initial slope of the relationship between yield and the level of K applied. For the Mitscherlich equation, as x tends to zero, dy/dx tends to bc, so that bc was used as an estimate of the initial slope. Therefore, RE_{yield} was calculated by dividing the initial slope for rock dust or KCl by the initial slope for KCl. Therefore, by definition, the RE_{yield} for KCl is 1.00. So if RE_{yield} of rock dust < 1.00, than K from rock dust is less effective than K from KCl, and vice-versa.

Data for the relationship between bicarbonate-soluble K extracted from the soil (soil test K) and the level of K applied were adequately described by a linear equation:

$$Y = A + BX$$

where Y is the soil test K (μg K g^{-1} soil), X is the level of K applied (g K pot^{-1}), and A and B are coefficients. The slope (B) coefficient provides a measure of the extractability of K from the soil by the Colwell procedure, and is therefore called extractability. The $RE_{soil\ test\ K}$ values were calculated by dividing the extractability of rock dust or KCl by the extractability of KCl, so the $RE_{soil\ test\ K}$ of KCl is, by definition, 1.00.

Results and discussion

Field experiment

Maximum grain yields were achieved by adding NPK fertilizer only (Table 2). The nil treatment (no fertilizer or rock dust) produced only about 30% of the maximum yield. Adding 2 t ha^{-1} rock dust only produced similar yields as the nil treatment. For unknown reasons, adding 20 t ha^{-1} rock dust only reduced yields, by about 65%, compared to the nil treatment (Table 2).

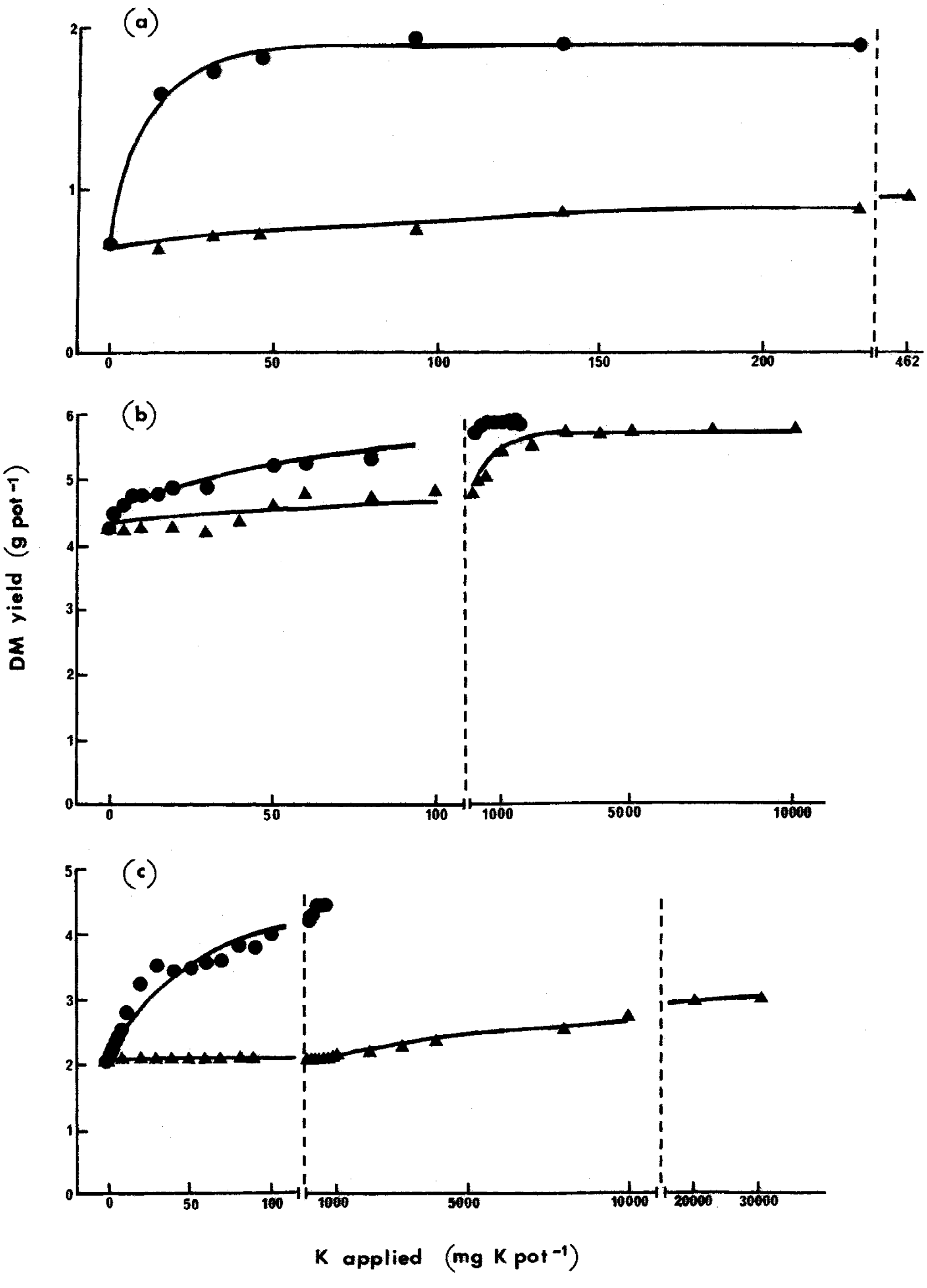

Figure 1. Relationship between yield of dried tops and the level of K applied as potassium chloride (muriate of potash) (●) or as rock dust (▲) for: (a) Badgingarra soil, and wheat grown for 30 days; (b) West Dale soil, and subterranean clover grown for 42 days; (c) Kokeby soil, and subterranean clover grown for 42 days. Lines are fits to the Mitscherlich equation, and the coefficients are listed in Table 4.

Table 4. Results for glasshouse experiments that compared the effectiveness of rock dust and KCl: value of coefficient of Mitscherlich equations fitted to the relationship between yield and the level of K applied, together with initial slope (*bc*), RE_{yield}, and K response

Fertilizer	Coefficients			R^2	*bc*	$RE_{yield}{}^{a}$	K response[b]
	a	*b*	*c*				
Badgingarra soil							
KCl	1.90	1.21	79.61	0.99	96.33	1.00	36%
Rock dust	1.00	0.36	5.44	0.95	1.96	0.02	
West Dale soil							
KCl	5.92	1.43	14.19	0.98	20.29	1.00	76%
Rock dust	5.75	1.36	2.09	0.91	2.84	0.14	
Kokeby soil							
KCl	4.35	2.29	21.38	0.96	48.96	1.00	47%
Rock dust	3.15	1.09	0.08	0.99	0.09	0.002	

[a] RE_{yield}, is calculated by dividing *bc* for each fertilizer by *bc* for KCl, so that the RE_{yield} for KCl is, by definition, always 1.00.
[b] K response, determined for KCl, is $[(a - b/a]$, expressed as a percentage.

Adding N and P fertilizer with the rock dust increased yields to about 63% of the maximum yield when 2 t ha^{-1} rock dust was applied, and to 43% of the maximum yield when 20 t ha^{-1} rock dust was applied (Table 2). In the experiment, it was not possible to determine whether this was due to N, or P, or both N and P. Adding K in addition to N and P fertilizer to the rock dust treatments increased yields to about 81% of the maximum yield for the 2 t ha^{-1} rock dust treatment, compared to about 90% of the maximum yield when 20 t ha^{-1} rock dust was applied (Table 2). Therefore, K limited grain yield of wheat production at the site, but yields were only improved by adding KCl fertilizer. Usually adding 200 kg ha^{-1} KCl (100 kg ha^{-1}K) is more than adequate to overcome K deficiency of wheat or clover in the WA wheatbelt (much unpublished data of W.J. Cox).

It is therefore concluded that, in the year of application of rock dust only (i.e. no fertilizer N, P or K), applying 2 t ha^{-1} rock dust had no effect on yields, and it reduced yields, by about 65%, when applied at 20 t ha^{-1}. Adding NPK fertilizer produced the best yields. Adding K, as KCl but not as rock dust, in addition to N and P, increased yields.

A previous glasshouse experiment, using soil collected from near the present field experiment, demonstrated that rock dust was a slow release K fertilizer (Hinsinger et al., 1996). The present field experiment suggests that the release of K from the granite dust was too slow to meet the demand for K by the wheat plants for producing grain. This was because in the field experiment when N and P fertilizers and rock dust were applied, adding fertilizer K increased grain yields of wheat by about 30% when 2 t ha^{-1} rock dust was applied, and by 110% when 20 t ha^{-1} rock dust was applied.

Table 5. Results of glasshouse experiments comparing rock dust with KCl: value of coefficients of linear equations fitted to the relationship between the amount of bicarbonate-soluble K (soil test K) extracted from the soil and the level of K applied, and $RE_{soil\ test\ K}$ values

Fertilizer	Coefficients		R^2	$RE_{soil\ test\ K}$
	A	*B*		
West Dale soil				
KCl	28	936	0.99	1.00
Rock dust	34	34	0.99	0.04
Kokeby soil				
KCl	13	99	0.98	1.00
Rock dust	11	0.3	0.85	0.003

The 20 t ha^{-1} rock dust treatment would be uneconomic to apply to farmer paddocks. The treatment was included to test whether rock dust could provide adequate K if enough was applied. As already stated, instead an unepected yield depression was obtained.

Nutrient omission glasshouse experiment

The maximum yield of 30-day old dried wheat tops was produced by adding all nutrient elements, regardless of the amount of rock dust applied (Table 3). The lowest yields were for when no fertilizer or rock dust were applied, or where only rock dust was applied at two levels. Adding all nutrient elements, except for either Ca or Mg, did not affect yields for both levels of rock dust applied (Table 3). Evidently there was enough Ca and Mg already present in the soil to avoid deficiency. However, adding all nutrients, but omitting K, for both the rock dust treatments, produced yields similar to the nil-treatment (no nutrient elements or rock dust applied) (Table 3). Previous studies (Hinsinger et al., 1996; Coroneos et al., 1996), showed that the rock dust provided K for plant growth. The lack of a yield response to applications of rock dust as a K fertilizer in this omission experiment is attributed to the insufficient dissolution of K from the rock dust to match the demand for K by the 30-day old wheat plants. That is, the rock dust, at the two levels applied, did not supply K at the rate required to meet the K requirements of the wheat plants.

Effectiveness of rock dust compared with potassium chloride

Yield

Compared with KCl, rock dust was poorly effective as a K fertilizer for producing yields of 30-day old wheat or 42-day old clover tops in all three soils (Figure 1). This was so for all levels of K applied.

The three soils used were K deficient so yield responses to applications of K as KCl or rock dust were obtained. As calculated from the KCl response curve, when the magnitude of the yield response was determined from ([maximum yield minus the yield for the nil K treatment] divided by the maximum yield, expressed as a percentage), responses to K varied from 76% for the West Dale soil, 47% for the Kokeby soil, and 36% for the Badgingarra soil (Table 4). It is concluded that the three soils were sufficiently responsive to applications of K fertilizer, as either KCl or rock dust, to enable a reasonable estimate of RE_{yield} to be obtained.

As calculated from the initial slope of the relationship between yield and the level of K applied, relative to KCl, rock dust was about: (i) 14% as effective for producing 42-day old dried clover tops in the West Dale soil; (ii) 2% as effective for producing 30-day old dried wheat tops in the Badgingarra soil; and (iii) only 0.2% as effective for producing 42-day old clover tops in the Kokeby soil (Table 4).

The results of three glasshouse experiments are reported here because the three sandy soils used were K deficient and so comparisons could be made between rock dust and KCl as K fertilizer. Many other pot experiments, similar to the three glasshouse experiments described here, were done with yellow sands, sandy loams, loam, clay loams and clayey soils collected from WA. The soils for these experiments had been collected from farmer paddocks to which no fertilizer K had been applied in previous years. However, no yield responses were obtained in these soils, presumably because these soils were not K deficient. That is, the soils contained sufficient indigenous K to meet plant requirements, so there were no yield responses to applications of fertilizer K, either as KCl or rock dust. Extractable K values for these soils ranged from 150 to 600 μg K g^{-1} soil. As previously stated, unpublished research of W.J. Cox in WA suggest that yield responses of subterranean clover to applications of fertilizer K occur in soils when extractable K values, measured using the same procedures used in the study reported here, were < 100 μg K g^{-1} soil for subterranean clover, and $< 60 \mu$g K g^{-1} soil for wheat.

There were no yield depressions when up to 30 g K as rock dust pot^{-1} (1.8 kg soil was used per pot) was applied to the three experiments reported here (Figure 1), or in the other glasshouse experiments with the various soils that showed no yield response to applications of fertilizer K. The highest levels of rock dust applied in these glasshouse experiments was equivalent to adding 17 t ha^{-1} rock dust in the field (17 g rock dust per kg soil), assuming the rock dust was mixed through the top 10 cm of the soil. The application of many levels of rock dust and KCl, and the inclusion of very large levels of both fertilizers, were done to adequately define the relationship between yield and the amount of fertilizer applied for both fertilizers. Only then is it possible to determine relative effectiveness values and how much rock dust is required instead of KCl to produce the same yield (Barrow, 1985). It would not be economic to apply the large amounts of either fertilizer in the field. Optimum KCl levels for wheat or pasture in WA are typically 50 to 100 kg KCl ha^{-1}.

Soil test K

Soil test K values were measured on soil samples collected 7 days after application of the K fertilizers and wetting up of the soil for the first time. Data are available for the West Dale and Kokeby soils. Much more K was extracted by the Colwell procedure from soil

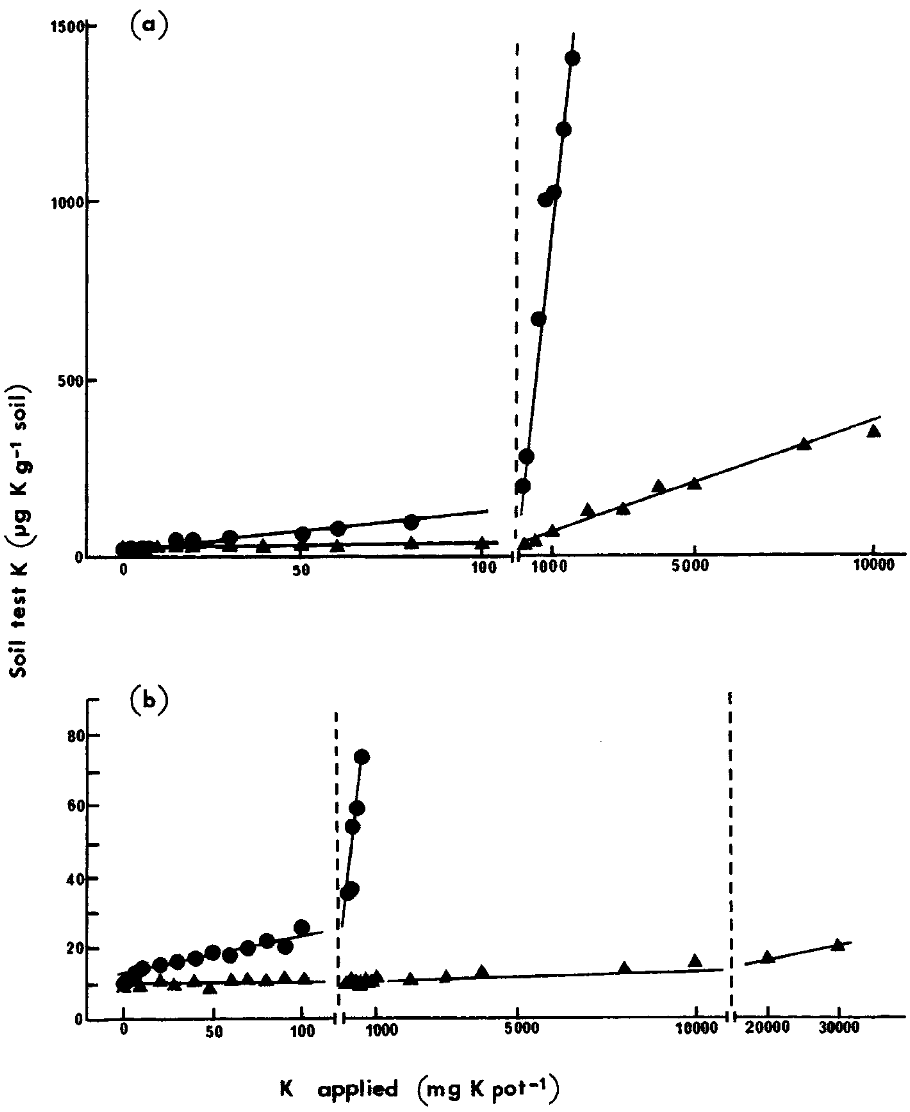

Figure 2. Relationship between bicarbonate-soluble K extracted from the soil (soil test K) and the level of K applied as potassium chloride (muriate of potash) (●) or as rock dust ((▲) for: (a) West Dale soil; (b) Kokeby soil. Lines are fits to a linear equation, and the coefficients are listed in Table 5.

treated with KCl than from soil treated with rock dust (Figure 2). Therefore, extractability of K by the Colwell procedure was much larger for soil treated with KCl (Table 5). The $RE_{\text{soil test K}}$ values indicated that rock dust was only about 4% as effective as KCl for the West Dale soil, and about 0.03% as effective as KCl for the Kokeby soil (Table 5). Therefore, fertilizer effectiveness values calculated using soil test K qualitatively parallel effectiveness values calculated using yield.

Conclusions

Based on its elemental composition alone, rock dust was never likely to be a useful fertilizer. This has been confirmed in the glasshouse and field studies reported here and elsewhere. Previous research in Western Australia has shown that the granite dust used in this study is a slow release K fertilizer (Hinsinger et al., 1996; Coroneos et al., 1996). The research reported in this paper extends these earlier studies to show that the dust is a very poor source of K compared with KCl for wheat production in the year of application in a field experiment, and for up to 30 days for wheat and 42 days for subterranean clover in glasshouse experiments. These experiments were done for educational and consumer protection purposes. The results of the experiments reported in this paper support previous studies listed in the Introduction that have mostly shown silicate rock powders to be poorly effective as fertilizers or as soil amendments. It is unlikely that rock dust would be an economic alternative to KCl in the short or long term for wheat and clover production in the wheatbelt of WA. At present it costs about $(Australian)150 per t to purchase and apply rock dust in the WA wheatbelt. Muriate of potash (KCl) cost about $310 per t to purchase and apply. Optimum applications of KCl (50% K) for subterranean clover and wheat in WA are between 100 to 200 kg ha^{-1}. The present paper suggests applications of up to 2 t ha^{-1} rock dust is not detrimental to yield. But because farmers get no yield benefits, they should not pay for the disposal of waste from quarry operations. The quarry operators should pay farmers for disposing of their waste.

It is therefore concluded that rock dust is unlikely to be a useful economic fertilizer for wheat and subterranean clover production in the wheatbelt of WA.

Acknowledgements

Barrie Oldfield, President of the Western Australian Branch of the Men of the Trees, helped with the field experiment, and provided enthusiastic support.

References

Baerug R (1991) Rock powder as a source of nutrients to different crops. 1. The magnesium effect of rock powder. Norsk Landbruksforkning 5: 183–188

Barrow NJ (1985) Comparing the effectiveness of fertilizers. Fert Res 8: 85–90

Barrow NJ & Campbell (1972) Methods of measuring the residual value of fertilizers. Aust J Exp Agric Anim Husb 12: 502–510

Blum WEH, Herbinger B, Mentler A, Ottner F, Pollak M, Unger E & Wenzel WW (1989a) Zur Verwendung von Gesteinsmehlen in der Landwirtschaft. I. Chemisch-mineralogische Zusammensetzung und Eignuns von Gesteinsmehlen als Bodenverbesserungsmittel. Z Pflanzenern Bodenk 152: 427–430

Blum WEH, Herbinger B, Mentler A, Ottner F, Pollak M, Unger E & Wenzel WW (1989b) Zur Verwendung von Gesteinsmehlen in der Landwirtschaft. II. Wirkung von Gesteinsmehlen als Dügemittel. Z Pflanzenern Bodenk 152: 421–425

Colwell JD (1963) The estimation of phosphorus fertilizer requirements of wheat in southern New South Wales by soil analysis. Aust J Exp Agric Anim Husb 3: 190–197

Coroneos C, Hinsinger P & Gilkes RJ (1996) Granite powder as a source of potassium for plants: a glasshouse bioassay comparing two pasture species. Fert Res 45: 143–152

Edwards NK (1993) Distribution of potassium in the soil profile of a sandplain soil under pasture species. In: Barrow NJ (ed) Plant Nutrition-from Genetic Engineering to Field Practice. Development in Plant and Soil Sciences, Vol 45. Kluwer Academic Publishers, Dordrecht, The Netherlands

Fragstein P von, Pertl W & Vogtmann H (1988) Verwitterungsverhalten silikatischer Gesteinsmehle unter Laborbedingungen. Z Pflanzeern Bodenk 151: 141–146

Gillman GP (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

Hinsinger P, Bolland MDA & Gilkes RJ (1996) Silicate rock powder: effect on selected chemical properties of a range of soils from Western Australia and on plant growth as assessed in a glasshouse experiment. Fert Res 45: 69–79

Kahnt G, Pfleiderer H and Hijazi LA (1986) Wirkungen meliorativer Gaben von Gesteinsmehlen und Gesteinssanden auf das Wachstum verschiedener Landwirtschaftlicher Kulturpflanzen sowie auf physukalische Kennwerte eines Sandbodens und eines Tonbodens. J Agronomy Crop Sci 157: 169–180

Leonardos OH, Fyfe WS & Kronberg BI (1987) The use of ground rocks in laterite systems: an improvement to the use of conventional soluble fertilizers? In: Ogura Y (ed) Proceedings of the International Seminar on Laterite, 14-17th October 1985, Tokyo, Japan Chem Geol 60: 361–370

Loveday J (1974) Methods for Analysis of Irrigated Soils. Commonwealth Bureau of Soil, Tech Commun No 54

Mersi W von, Kuhnert-Finkernagel R & Schinner F (1992) The influence of rock powders on microbiol activity of three forest soils. Z Pflanzenern Bodenk 155: 29–33

Ross GJS (1980) 'MLP Maximum Likelihood Program', Rothamsted Exp Stat: Harpenden, UK

Sanz Scovinoo JI & Rowell DL (1987) The use of feldspars as potassium fertilizers in the savannah of Colombia. Fert Res 17: 71–83

Weerasuriya TJ, Pushpakumara S & Cooray PI (1993) Acidulated pegmatitic mica: a promising new multi-nutrient mineral fertilizer. Fert Res 34: 67–77

Walkley A & Black IA (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic and titration method. Soil Sci 37: 29–38