



## Testing the ability of plants to access potassium from framework silicate minerals



David A.C. Manning<sup>a,\*</sup>, Joana Baptista<sup>a</sup>, Mallely Sanchez Limon<sup>b</sup>, Kirsten Brandt<sup>c</sup>

<sup>a</sup> School of Civil Engineering & Geosciences, Newcastle University, NE1 7RU, Newcastle upon Tyne, UK

<sup>b</sup> University Claude Bernard Lyon 1, 43 Boulevard du 11 Novembre 1918, 69100 Villeurbanne, France

<sup>c</sup> School of Agriculture, Food and Rural Development, Newcastle University, NE1 7RU, Newcastle upon Tyne, UK

### HIGHLIGHTS

- Plant growth in artificial soil has derived K from potassium feldspar as well as mica.
- Use of mica (phlogopite) as a source of K gives response similar to KCl control.
- The observed growth response in both cases increases with increasing mineral dose.
- K content in plant tissue increases with dose, and confirms a mineral source for K.
- The results highlight the potential of feldspar, in syenite rock, as a source of K for tropical soils.

### GRAPHICAL ABSTRACT



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### ABSTRACT

The availability of K, essential for plant growth, from syenite (a silicate rock in which potassium feldspar is the dominant mineral; >90 wt%), and phlogopite mica has been demonstrated using carefully designed plant growth pot experiments in which the only added source of K was the mineral of interest, with no loss of nutrients through drainage. Using pure quartz sand as a soil, both growth (increase in diameter) of leek plants and K-content of the plant material showed a dose-dependent positive response to the application (114–43000 mg K/pot) of milled syenite with increases in plant diameter of 0.5–0.7 mm/week, increasing with application rate. Phlogopite mica (114–6000 mg K/pot) supported the highest observed increase in diameter (approx. 1 mm/week) and plant K-content, both similar to that observed for a positive control (KCl). These experiments demonstrate that plants can obtain K for growth from milled syenite, in which feldspar is the dominant K-bearing mineral, and confirm previous observations that micas can be an effective source of K.

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### 1. Introduction

For healthy growth, all plants require a range of major and trace nutrients. With the exception of nitrogen, the ultimate source of all

\* Corresponding author.

E-mail address: [David.Manning@newcastle.ac.uk](mailto:David.Manning@newcastle.ac.uk) (D.A.C. Manning).

nutrients is the geological mineral assemblage that occurs within a soil. The function of soil minerals varies, with (for example) congruent dissolution of apatite providing P, and cation exchange on clay surfaces controlling K and N (as ammonium) within the soil solution.

This paper focuses on the availability of K for plant growth, and demonstrates for the first time that K is available for plant growth when potassium feldspar ( $\text{KAlSi}_3\text{O}_8$ ) is the dominant source of K in a soil. Potassium feldspar occurs widely in (especially temperate) soils, yet is regarded as inert on the timescale of crop production given its slow rate of dissolution as determined in the laboratory and low K yields in conventional laboratory tests of K availability (Harley and Gilkes, 2000; Manning, 2010a; White and Brantley, 1995). Other widely occurring potassium silicate minerals include micas, which have long been known to act as sources of K through cation exchange and weathering reactions (Sparks and Huang, 1985; Mohammed et al., 2014). Similarly, there is long-standing evidence that nepheline-bearing rocks (including nepheline syenites; nepheline is also an aluminosilicate mineral, a feldspathoid) may be effective as sources of K for plant growth (Ciceri et al., 2015). Conventionally, potassium fertilisers are based on soluble salts, derived from the natural mineral sylvite (KCl) or sulfates such as polyhalite ( $\text{K}_2\text{SO}_4 \cdot 2\text{CaSO}_4 \cdot \text{MgSO}_4 \cdot 2\text{H}_2\text{O}$ ) and carnallite ( $\text{MgCl}_2 \cdot \text{KCl} \cdot 6\text{H}_2\text{O}$ ).

Globally, inputs of K to soils from all sources (including crop residues) are much less than the amount removed through the harvesting of crops (Sheldrick et al., 2002). Nutrient balance studies show that if this deficit was an accurate representation of the need for K to support crop growth, then the requirement for supplementation with K would be far greater than the need for P or N, which more often are in balance (Sheldrick et al., 2002). Indeed, if all K removed annually by crops had to be replaced to fill the 'potash gap' (Manning, 2015), world mined production of potash would need to double. The ability of many soils to sustain reasonable yields without annual supply of K thus indicates that their content of plant available K may be replenished from sources already present in the soil (Mohammed et al. 2014).

At present, global production of K fertilisers is about 33.5 million tonnes  $\text{K}_2\text{O}$  equivalent annually (Jasinski, 2014), typically mined from deposits of natural K chloride and sulfate salts, some of which contain other nutrients. 99% of world potash is mined from just 12 countries, dominated by Canada (Rittenhouse, 1979), and whole continental regions have insignificant (e.g. Africa, Australasia), or low production (e.g. South America). The price of K fertilisers reached US\$1000/tonne in 2009 (Manning, 2010a), reducing to US\$350–400/tonne more recently. In addition to paying the commodity price and for value added during processing, farmers must pay high associated transport and distribution costs. Additionally, K from sources such as KCl is highly soluble and can be rapidly lost through leaching, so (depending on the soil) it may need to be replaced for every growing season.

To supply the K required for crop growth it is therefore important to consider novel inputs in addition to conventional sources, given constraints on price and availability. K silicate minerals including feldspar and mica contain up to 16 wt% and 11 wt%  $\text{K}_2\text{O}$  respectively, and have been used in a number of studies (Ciceri et al., 2015). In particular, Leonardos et al. (1987) present a convincing case for the use of silicate minerals as sources of K for deeply weathered tropical soils, where leaching of conventional salt-based fertilisers often removes nutrients even before they can be used by the growing plants. But although some trials have given positive results (e.g. Bakken et al., 1997, 2000; Sanz-Scovino and Rowell, 1988; Mohammed et al., 2014; Manning, 2010b), other trials have failed to do so (e.g. Bolland and Baker, 2000; Harley and Gilkes, 2000; Hinsinger et al., 1996), and the generally low price, historically, of conventional K fertilisers has reduced the need for alternatives.

A critical aspect of the use of novel sources of K is the unambiguous demonstration that K within a plant is derived from a known source. In this paper, we report the design and results of experiments in which we show that K can be derived from (a) milled syenite rock in which

potassium feldspar is present as the dominant K-bearing mineral, or (b) mica (the mineral phlogopite). We believe that this is the first time that K availability from a feldspathic rock to plants has been demonstrated experimentally, and our results support the future design and use of silicate minerals as fertilisers particularly in deeply-leached tropical soils in which oxide minerals predominate.

## 2. Materials and methods

Plant growth experiments were carried out using closed system pot trials in which there was no through drainage that would permit unknown loss of nutrients from the pot, and in which the dominant source of K was the silicate mineral of interest. An artificial soil was used, based on a high purity silica sand ('Sibelco RHT': >99% quartz and >99% 125–710  $\mu\text{m}$  grain size, [www.sibelco.eu](http://www.sibelco.eu)), which was mixed with 20% organic matter (Irish moss peat – fine, Recipe no 822, East Riding Horticulture, [www.eastridinghorticultureltd.co.uk](http://www.eastridinghorticultureltd.co.uk)) by volume, corresponding to approximately 3% by weight and adding potentially 4–8 mg K (based on supplier's specification) equally to each pot. The K sources were syenite (12.8%  $\text{K}_2\text{O}$ ) supplied by Terrativa SA (Belo Horizonte, Brazil) and phlogopite mica (10.19%  $\text{K}_2\text{O}$ ) supplied by LKAB minerals (product PD900; [www.lkabminerals.com](http://www.lkabminerals.com)). The syenite was supplied milled, and the phlogopite was supplied as flakes (approx. 5 mm or less) and was milled using a TEMA mill prior to use. Both were sieved to <0.150  $\mu\text{m}$ . The chemical compositions of the materials used (Table 1) were determined by X-ray fluorescence spectroscopy using a Panalytical PW2404 wavelength-dispersive sequential X-ray spectrometer (School of Geosciences, Edinburgh University). Major elements were determined on fused glass discs, 40 mm-diameter, prepared from approximately 0.9 g of sample powder mixed with 4.5 g lithium metaborate flux and fused in Pt-5%Au crucibles at 1100 °C. Mineralogically (based on petrography), the syenite is composed of >90% K-feldspar (microcline), with <10 wt% each of pyroxene, amphibole and accessory minerals, all of which are K-free, and biotite. X-ray diffraction (Supplementary material) did not detect biotite (or any other mica) in the syenite used in these experiments; this technique would normally detect the (001) reflection of micas at >1 wt%.

In addition, the particle size distribution of the materials used was determined using a Malvern Mastersizer 2000 (Malvern Instruments Ltd., Malvern, UK); the results show 90% of the milled syenite was <150  $\mu\text{m}$ , and 90% of the milled phlogopite was <60  $\mu\text{m}$  (Supplementary material; Fig. S2). Particle surfaces were observed using a Carl Zeiss SIGMA HD VP Field Emission scanning electron microscope combined with an Oxford AZtec ED X-ray analysis system to confirm mineral identification (School of Geosciences, Edinburgh University).

Characterised by ourselves, these commercial materials were chosen to ensure (as far as possible) use of tightly specified materials that are available from commercial sources for future experiments or commercial use.

**Table 1**

Chemical composition of mineral materials used in the experiments. The three syenite samples are replicates of the material used.

wt%	Phlogopite	Syenite 1	Syenite 2	Syenite 3	Sand
$\text{SiO}_2$	41.97	62.55	62.60	62.77	98.89
$\text{Al}_2\text{O}_3$	9.54	16.26	16.30	16.40	0.13
$\text{Fe}_2\text{O}_3$	9.05	2.81	2.81	2.80	0.26
MgO	24.16	0.69	0.70	0.72	0.23
CaO	0.62	2.11	2.16	2.15	0.03
$\text{Na}_2\text{O}$	0.02	1.50	1.52	1.52	n.d.
$\text{K}_2\text{O}$	10.2	12.78	12.79	12.70	0.019
$\text{TiO}_2$	0.18	0.31	0.31	0.33	0.031
MnO	0.04	0.07	0.07	0.07	n.d.
$\text{P}_2\text{O}_5$	0.12	0.19	0.20	0.20	0.012
LOI	3.82	0.50	0.35	0.33	0.13
Total	99.85	99.75	99.81	99.98	99.71

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