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Crushed rocks and mine tailings applied as K fertilizers on grassland

A.K. Bakken[1], H. Gautneb[2], T. Sveistrup[3] & K. Myhr[1]
[1]*The Norwegian Crop Research Institute, Kvithamar Research Centre, N-7500 Stjørdal, Norway;* [2]*Geological Survey of Norway, P.O. Box 3006, N-7002 Trondheim, Norway;* [3]*The Norwegian Crop Research Institute, Holt Research Centre, N-9005 Tromsø, Norway*

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Abstract

Crushed rocks and mine tailings containing biotite, K-feldspar and nepheline as K-bearing minerals were applied as K fertilizers in a series of 15 grassland field trials. A treatment with KCl as K-source outyielded treatments with rock based fertilizers in the first and the second experimental year. In the third and last year of the study when no K fertilizers were supplied, previously added carbonatite and biotite concentrate supported grass growth as much as previously added KCl did. Although it is concluded that a substantial part of the K bound in biotite and/or nepheline in crushed carbonatites, biotite concentrate and epidote schists is plant available, these rock/mineral products weathered too slowly to replenish the native pool of plant available K within a three year period with five harvests. The K bound in K-feldspar seemed to be nearly unavailable for the grass plants.

Introduction

In response to an increasing interest and demand for slow-releasing K fertilizers both in conventional and organic farming, the K-releasing capacity of a range of different crushed rocks and minerals has been investigated during the last decade (e.g. Bakken et al., 1997; Coroneos et al., 1996; Gautneb and Bakken, 1995; Hinsinger et al., 1996; Sanz Scovino and Rowell, 1988). From pot experiments with a wide range of Norwegian rocks and mine tailings simulating long term K-depletion by plants under field conditions (Bakken et al., 1997; Gautneb and Bakken, 1995) it was concluded that rocks containing biotite and/or nepheline as K-bearing minerals, and further considerable amounts of calcite, were promising sources for a fertilizer product. To further evaluate the potential of the crushed rocks and minerals as K fertilizers, a selection of them were applied in a series of grassland field trials in Northern and Central Norway. The results from these trials are presented here.

Materials and methods

Rocks, minerals and mine tailings

The rocks, minerals and mine tailings tested in the series of trials are listed in Table 1. The carbonatites are from the Lillebukt Alkaline Complex at Stjernøy in Norway (Mjelde, 1983; Strand, 1981). Deduster, FilterII and Lurgi are different types of tailings from the nepheline-syenite production (North Cape Minerals) also located at Stjernøy. The epidote schists is from a quarry at Inderøy in Norway, and the commercial product Adularia is from the fucoid beds near Ullapool in Scotland. The biotite is a mineral concentrate from the feldspar production of North Cape Minerals in Lillesand in Norway. For content of other elements than K, cf. Bakken et al. (1997) and Gautneb and Bakken (1995).

Whole rocks were crushed in a jaw crusher and a ball mill. The mineralogical and chemical composition (Table 1) was determined by microscopical examination of thin sections and by X-ray diffractometry (XRD) and X-ray fluorescence spectrometry (XRF) at The Geological Survey of Norway in Trondheim. At the same institute, the particle size distribution

Table 1. The content of potassium as analysed by X-ray fluorescence spectrometry and particle size distribution in different crushed rocks, minerals and mine tailings tested as K fertilizers in a series of field trials in grassland. The relative contribution from different minerals to total K is denoted

Rock/mineral type	K-content (%, w w^{-1})	Relative contribution from different minerals to total K (% of total)	Acid soluble K (% of total K)	Particle size distribution		
				10% < (μm)	50% < (μm)	90% < (μm)
Adularia	6.4	Ksp (80%), Bt (10%), Glt (10%)	10	2	152	662
Tailings Deduster	6.5	Ksp (77%), Ne (20%), Bt (3%)	28	2	18	38
Tailings FilterII	6.3	Ksp (77%), Ne (20%), Bt (3%)	25	1	5	18
Tailings Lurgi	4.6	Ksp (41%), Bt (40%), Ne (14%), Hbl (5%)	31	91	321	688
Biotite	6.6	Bt (100%)	52	227	565	974
Epidote schists	2.2	Bt (62%), Ms (32%), Hbl (4%), Pl (2%)	33	7	42	848
Carbonatite with Hbl	3.5	Ksp (60%), Ne (35%), Hbl (3%), Bt (1%)	92	11	120	962
Carbonatite Gammevann	3.2	Ksp (1%), Ne (18%), Bt (80%)	96	18	170	829

Mineral abbreviations are after Kretz (1983); Ksp – K-feldspar, Ms – muscovite, Pl – plagioclase, Bt – biotite, Glt – glauconite, Ne – nepheline. Hbl – hornblende. Acid soluble K represents K soluble in 7 *N* HNO_3.

was analysed by a Coulter particle analyser, and the content of acid soluble K by ICP-spectrometry after digestion in *7 N* HNO_3 for 30 min at 120 °C.

Field sites and experimental design

The altogether 15 trials constituting the series were located in Central and Northern Norway between latitudes 63 and 70°N covering a wide range of soil types and climatic conditions. The soils varied in initial K-content from 4 to 40 mg 100 g^{-1} (soluble in 1 *M* HNO_3), in loss on ignition from 3 to 91% and in pH from 4.8 to 7.2. The mean annual precipitation ranged from 400 to 1200 mm yr^{-1} between sites.

All trials were established in the spring the sowing year in fields which were mouldboard ploughed to 20–25 cm depth. Nitrogen (100 kg ha^{-1}), phosphorus (30 kg ha^{-1}), potassium (50 kg ha^{-1}), calcium (100 kg ha^{-1}), magnesium (20 kg ha^{-1}) and sulphur (50 kg ha^{-1}) were harrowed into the upper 5 cm layer of the top soil. Potassium was supplied from crushed rocks, minerals, tailings or KCl and the other nutrients from fertilizers free of K. The amount of rocks, minerals or tailings to be added was calculated on the basis of their total K-content as analysed by XRF (Table 1). A mixture (7:3 by seed weight) of timothy (*Phleum pratense* L.) and meadow fescue (*Festuca pratensis* L.) was sown into the different plots. In the trials located in Northern Norway meadow fescue was replaced by smooth meadow grass (*Poa pratensis* L.). The first year all fields and treatments were harvested once (in autumn), and the second and third year twice. Additional N (75 kg ha^{-1}) was applied after the first cut of the second and third year and additional K (50 kg ha^{-1}) after the first cut of the second year. Nitrogen (100 kg ha^{-1}), P (30 kg ha^{-1}), K (50 kg ha^{-1}, 2nd year only), Ca (100 kg ha^{-1}), Mg (20 kg ha^{-1}) and S (50 kg ha^{-1}) were also supplied at the onstart of spring regrowth the second and third year.

A total of 15 trials were laid out as randomized block experiments with three replicates. There were altogether 8 treatments (7 different K-sources + one treatment with no K-supply) per trial. Each plot was 3 m × 6 m. The treatments with epidote schists and biotite concentrate were included in 4 out of 15 trials and the treatments with mine tailings in the remaining 11. All other treatments were included in all trials.

Soil and herbage sampling and analyses

All soil samples were collected from the plough-layer (0–20 cm) and the plant samples from herbage cut 5 cm above soil surface. Soil and dried herbage were analysed at The Chemical Analytical Laboratory, Holt Research Centre, Tromsø, Norway. After dry ashing at 500 °C, the plant samples were digested in a mixture of concentrated HNO_3 and HCl (1:2) before analysis for K by a flame photometer. For the soil samples, the

Table 2. The total dry matter yield per year and the content of K in harvested plant material from the first cut in a series of grassland field trials with different rocks and minerals as K fertilizers. Least significant differences (LSD) between adjusted means for 15 trials are shown

Treatment	1st year		2nd year		3rd year	
	Dry yield (kg ha^{-1})	K-content (%, w w^{-1})	Dry yield (kg ha^{-1})	K-content (%, w w^{-1})	Dry yield (kg ha^{-1})	K-content (%, w w^{-1})
No K	1930	1.6	5750	1.4	5310	0.9
Adularia	2090	1.7	5770	1.5	5370	0.9
Tailings Deduster	2230	1.8	6140	1.4	5690	0.8
Tailings FilterII	2300	1.7	6280	1.4	5580	0.9
Tailings Lurgi	2420	1.8	6330	1.5	5880	0.9
Biotite	2090	1.9	6290	1.4	6360	1.0
Epidote schists	2210	1.8	6360	1.6	6000	1.0
Carbonatite with Hbl	2260	1.9	6670	1.5	6500	1.0
Carbonatite Gammevann	2340	1.8	6830	1.6	6760	1.0
KCl	2600	2.2	7970	2.1	6490	1.2
LSD (p <0.05)	210	0.2	500	0.1	410	0.1

content of K extractable in ammonium lactate (K_{AL}) and in 1 M HNO_3 was analysed according to Egnér et al. (1960) and Reitemeier et al. (1947), respectively. The soil pH was recorded in water extracts.

Statistical analyses

The data for dry yields and content of different elements in herbage and soil were analysed for all trials together by analysis of variance with means for trials as replicates. As some of the treatments were represented only in four trials and no significant interactions between trial and treatment appeared from the analyses of variance, Stevens' method for adjustment of treatment means was applied (Nissen and Mosleth, 1985). Least significant differences (LSD) between treatment means were calculated.

Table 3. The dry matter content and the content of Mg and Ca in the harvested herbage the second year of a series of grassland field trials with different crushed rocks, minerals and mine tailings as K fertilizers. Least significant differences (LSD) between adjusted means for 15 trials are shown

Treatment	Dry matter content of harvested herbage (%, w w^{-1})		Content of Mg and Ca in harvested herbage (%, w w^{-1})	
			Mg	Ca
	1st cut	2nd cut	1st cut	1st cut
No K	19.3	21.4	0.21	0.47
Adularia	19.3	21.4	0.23	0.50
Tailings Deduster	19.7	21.2	0.20	0.43
Tailings FilterII	19.3	20.1	0.20	0.43
Tailings Lurgi	19.7	21.4	0.20	0.44
Biotite	19.4	21.3	0.20	0.43
Epidote schists	19.1	20.9	0.20	0.46
Carbonatite with Hbl	19.7	20.7	0.18	0.43
Carbonatite Gammevann	19.5	20.4	0.19	0.43
KCl	18.0	18.5	0.17	0.42
LSD (p <0.05)	0.5	0.9	0.02	0.06

Results

The treatment with KCl as source for K outyielded all other treatments by more than 150 kg per ha and more than 1000 kg per ha for the first and second experimental year, respectively (Table 2). The third year, when no potassium was supplied, the dry yield was as least as high on plots that had previously been fertilized with the two carbonatites and the biotite concentrate as on plots fertilized with KCl (Table 2). The yield from these four treatments was about 1000 kg higher per ha than the yield from the plots without K fertilizer. The dry matter production on plots fertilized with Adularia or tailings Deduster and FilterII was nearly as low as the production on plots not supplied with K fertilizer for all the three years (Table 2).

The dry matter content of the harvested herbage was the second experimental year significantly lower on plots fertilized with KCl compared to all other treatments (Table 3). The herbage with the lowest dry

Table 4. The content of K soluble in 1 *M* HNO_3 (K soluble in ammonium lactate in brackets) in soil samples taken after the last cut in the second and third year of a series of grassland field trials with different crushed rocks, minerals and mine tailings as K fertilizers. The numbers shown are adjusted means for 9 trials

Treatment	K-content in soil (mg K $100g^{-1}$ dry soil)	
	End of 2nd year	End of 3rd year
No K	20.0 (4.9)	16.0 (4.5)
Adularia	19.3 (5.0)	15.9 (4.6)
Tailings Deduster	22.7 (6.2)	16.4 (5.4)
Tailings FilterII	21.3 (5.7)	15.9 (4.9)
Tailings Lurgi	27.0 (7.2)	18.5 (5.4)
Biotite	19.5 (4.7)	16.5 (5.0)
Epidote schists	17.3 (4.4)	14.9 (4.6)
Carbonatite with Hbl	25.9 (6.0)	18.5 (5.1)
Carbonatite Gammevann	22.8 (5.6)	17.4 (4.5)
KCl	22.6 (6.9)	17.3 (4.9)
LSD ($p < 0.05$)	3.4 (1.4)	3.6 (0.7)

matter content contained more K and less Mg on dry weight basis than the herbage from other treatments (Tables 2 and 3).

The acid soluble K in the soil in the plough layer was depleted during the experiment, irrespective of fertilizer treatment (Table 4). There was no clear relationship between the content of K in the soil in autumn of the second year and the dry yield the following year (Tables 2 and 4). The soil pH was not affected by fertilizer treatment (data not shown).

Discussion

In agreement with the findings in pot experiments with the same rock products (Bakken et al., 1997; Gautneb and Bakken, 1995) and with results from other field experiments (Sanz Scovino and Rowell, 1988) the K supplied as K-feldspar was nearly unavailable to the plants. This mineral, which was supplied from Adularia and the tailings FilterII and Deduster, did not support grass growth to any significant extent under the present field conditions and its weathering rate was obviously too low to cover the plant K-demand during three successive growth seasons.

The K in the crushed carbonatites and epidote schists was more plant available than the K bound in feldspar. As discussed by Bakken et al. (1997) and in agreement with the findings of Berthelin and Leyval (1982), the cause might be that these rocks contain nepheline and/or biotite as their main K-bearing minerals. At the temperatures, pH and moisture conditions normally occuring in cultivated soils, nepheline and biotite are known to disintegrate and thereby release K, at considerably higher rates than feldspars (Blum and Stillings, 1995; Lasaga, 1984; Nagy, 1995). Further comes that the carbonatites and the epidote schists contained more carbonate than the other rock-based fertilizers. Carbonates dissolve faster than silicates in most environments (Laronne, 1986), and other minerals in rock-particles with a high content of carbonate will consequently be more exposed to weathering and release K at a higher rate than minerals in rocks containing mainly silicates do. The weathering rate of the minerals is also influenced by the size or the specific surface of the mineral particles (Sparks and Huang, 1985). It is, however, unlikely that the differences in K availability between the feldspar and mica/nepheline products in the present study was related to differences in grain size. The crushed feldspar rocks were more finely ground than the other products (Table 1), and results from a previous experiment by Bakken et al. (1997) indicate that the size of the particles is of minor importance for the rate of K-release within the range of coarseness/fineness investigated here.

About 160 kg K per ha were removed by harvested plant material from plots with no external K-supply (estimated from results presented in Table 2). The K-yield for the same three-year period was 300 kg per ha for plots fertilized with KCl and 220 and 200 kg per ha for plots fertilized with the carbonatite Gammevann and epidote schists, respectively. In all K-treatments 200 kg K ha^{-1} was applied during the three-year period, and by subtracting the 160 kg «native» K (from the the soil) from the total K-yield in each treatment, it can be deduced that less than 30% of the K added as crushed rocks was taken up by plants during the trial. In comparison, about 70% of fertilizer K was taken up and later harvested in the KCl treatment. Although these numbers are only rough estimates of a nutrient balance, they indicate that even the most soluble rocks and minerals weather too slowly to replenish the native pool of plant available K within a short time scale. How long it takes before the unweathered rest of the K applied as rock and mineral products becomes plant available would be of interest to know. As energy and other resources are required when the rock based fertilizers are mined, crushed, transported and spread, they should contribute substantially to the soil fertility to be applied.

The content of K in plant tissues from the treatments other than KCl was as low as what is regarded as critical levels for both biophysical and biochemical functions in *Lolium multiflorum* (Barraclough and Leigh, 1993), and yield data confirm that the grass plants in the rock/mineral/tailings treatments have been grown at a suboptimal K-supply when rate of dry matter production is concerned. Herbage produced on soils low in soluble K might, however, be of good quality for ruminant animals because it normally contains higher levels of Mg and Ca (Jakobsen, 1993; Kemp and t'Hart, 1957). From that point of view the replacement of soluble K-salts with one of the products tested here might be beneficial in ley and silage production.

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References

Bakken AK, Gautneb H & Myhr K (1997) The potential of crushed rocks and mine tailings as slow-releasing K fertilizers assessed by intensive cropping with Italian ryegrass in different soil types. Nutr Cycl Agroecosys 47: 41–48

Barraclough PB & Leigh RA (1993) Critical plant K concentrations for growth and problems in the diagnosis of nutrient deficiencies by plant analysis. Plant and Soil 155/156: 219–222

Berthelin J & Leyval C (1982) Ability of symbiotic and non-symbiotic rhizospheric microflora of maize (*Zea mays*) to weather micas and to promote plant growth and plant nutrition. Plant and Soil 68: 369–377

Blum AE & Stillings LL (1995) Feldspar dissolution kinetics. In: White AF & Brantley SL (eds) Chemical Weathering Rates of Silicate Minerals, Reviews in Mineralogy 31: 291–351

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

Egnér H, Riehm H & Domingo WR (1960) Untersuchungen über die chemische Boden-Analyse als Grundlage für die Beurteilung des Nährstoffzustandes der Boden. Kungl Lantbrukshögskolans Annaler 26: 199–215

Gautneb H & Bakken AK (1995) Crushed rocks, minerals and mine tailings as sources of potassium in agriculture. NGU Bulletin 427: 119–122

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

Jakobsen ST (1993) Interaction between plant nutrients III. Antagonism between potassium, magnesium and calcium. Acta Agric Scand, Sect B, Soil and Plant Sci 43: 1–5

Kretz R (1983) Symbols for rock-forming minerals. Am Mineral 68: 277–279

Kemp A & t'Hart ML (1957) Grass tetany in grazing milking cows. Neth J Agric Sci 5: 4–17

Laronne JB (1986) Rate limitation and dissolution of highly soluble minerals. In: Coleman SM & Dethier DP (eds) Rate of Chemical Weathering of Rocks and Minerals, pp 83–91. Academic Press Inc, London

Lasaga AC (1984) Chemical kinetics of water-rock interactions. J Geophys Res 89: 4009–4025

Mjelde Ø (1983) Geologi og petrografi av nabberen nefelinsyenitt. Cand. real. thesis. University of Bergen, 315 pp. (In Norwegian)

Nagy KL (1995) Dissolution and precipitation kinetics of sheet silicates. In: White AF & Brantley SL (eds) Chemical Weathering Rates of Silicate Minerals, Reviews in Mineralogy 31: 173–233

Nissen Ø & Mosleth E (1985) Brukerveiledning for MSTAT statistikkprogram for mikrodatamaskiner. Landbruksbokhandelen ÅS-NLH. ISBN 82-557-0225-3 (In Norwegian)

Reitemeier RF, Holmes RS, Brown IC, Klipp LW & Parks RQ (1947) Release of nonexchangeable potassium by Greenhouse, Neubauer and laboratory methods. Soil Sci Soc Amer Proc 12: 138–162

Sanz Scovino JI & Rowell DL (1988) The use of feldspars as potassium fertilizers in the savannah of Colombia. Fert Res 17: 71–83

Sparks DL & Huang PM (1985) Release of soil potassium by weathering reactions. In: Munson RD (ed) Potassium in Agriculture, pp 202–276. American Society of Agronomy, Madison, WI

Strand T (1981) Lillebukt alkaline kompleks; karbonatittens mineralogi og petrokjemi. Cand. real. thesis, University of Bergen, 287 pp. (In Norwegian)