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The use of feldspars as potassium fertilizers in the savannah of Colombia

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Abstract. Finely ground sanidine feldspar from the Huila area of Colombia (< 100 mesh, largely sanidine, 7% K) and KCl were used as fertilizers in a pasture experiment at Carimagua on an oxisol containing lmg total K and 23 μg exchangeable K per g (0.6 μeq per g). The association of *Brachiaria dyctioneura* and *Pueraria phaseoloides* clearly responded to K taken up from the KCl with a small though non-significant response to the feldspar. During 14 months the crop took up between 25 and 68% of the KCl-K or about 10% of the feldspar-K. Much of the applied KCl became non-exchangeable, but was released as required by the crop: the soil contained an Al chlorite-vermiculite which held the native K and fixed and released K during the experiment. The feldspar may be valuable as a slow release fertilizer in low input agricultural systems particularly on leached soils of low ECEC.

Introduction

Tropical savannah produces a low output of dry matter which can be grazed by cattle. Improved productivity can result from high inputs to arable crops, or low inputs to improved pastures. There are 16 million hectares of savannah in Colombia and low input technology is being studied in the Tropical Pastures Programme of CIAT. Inputs can be through the use of (a) legumes to fix nitrogen, (b) rock phosphate as a slowly soluble source of phosphorus and calcium, and (c) lime to reduce the soluble aluminium and to supply calcium. If acid tolerant species are used, small amounts of rock phosphate may be the only input required [13]. Potassium availability is often low in these soil which normally have a variable charge, and a small effective cation exchange capacity at the low pH values produced by leaching. Application of KCl may be of limited use because being soluble, the potassium may initially be taken up in luxury amounts and is also readily leached. In Colombia, KCl has to be imported which causes a drain on foreign ex-

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change. Feldspar rocks, widespread in the Andes and in other parts of South America, may be useful as potassium fertilizers because of their slow-release characteristics.

The rate of release of K from feldspars has been explained by (a) a surface controlled reaction with constant rate of dissolution and (b) incongruent weathering with the formation of a protective residual coating and a parabolic rate of release of ions [6]. Holden and Berner [7] found no evidence of protective coatings: the parabolic release rate was explained by a surface controlled mechanism with very fine particles dissolving more quickly than larger ones [4]. Dissolution occurs with the etching of the surface by H^+ to produce pits [16]. However the reaction appears to be incongruent with the formation of an Al-rich silicate as a secondary mineral, and the interpretation of the kinetics is complex. The rate of release is pH dependent: increased solubility at low pH is also predicted from consideration of thermodynamic equilibrium between feldspar and solution [10] although theoretical K^+ concentrations are much higher than those found in practice. This implies that secondary reactions may be important in controlling rates of release [8] or that equilibrium is not reached.

There are early reports of the use of feldspars as K fertilizers [1] [3] but they have been little use subsequently. Interest has been renewed [9] [5, 1983] but we do not know whether K can became available in soils at rates significant for crop use. Apart from expecting that K would be more readily released into acid soils with low concentrations of K in soil solution it is not known if other soil chemical properties influence availability, although solubility considerations suggest that a low concentration of Al and Si in soil solution would also increase the rate of release.

A field experiment using cassava carried out by CIAT (unpublished) suggested that useful responses could be obtained with ground feldspar, and in 1984 a pasture experiment was established at the Carimagua Research Station in the eastern savannah of Colombia to study the availability of K under low input conditions. This paper gives the results: further information is available [5, 15].

Methods

The site for the field experiment was in the area La Reserva of the Carimagua Research Station, run jointly by Instituto Colombiano Agropecuario and Centro International de Agricultura Tropical. It is 4° 36′N and 71° 19′W at an elevation of 200 m. Mean daily temperature (1975–87) is between 26 and 28 °C throughout the year. In the four dry months (December to March) rainfall is 160 mm and potential evapotranspiration 860 mm. For the remainder of the year the amounts are 2040 and 1010 mm respectively.

Native savannah grasses were initially on this level site which had not been used for agricultural purposes before the experiment. The soil (ultic haplustox) is formed on reddish brown pleistocene clay; it is imperfectly to well drained with no ground water or stones in the upper 2 m and is a silty clay loam over clay loam. The upper 20 cm has a granular structure and an organic carbon content of 1.2%. Below this the structure is subangular blocky. Further properties of the soil are given later as part of Table 4. Extensive ant and termite activity occurs in these areas and soil was not uniform over the site, a factor which is considered further when the results are discussed.

The feldspar (Rio Tune) was obtained from a vein in the valley of the stream Abejones on the Las Mercedes farm in Teruel, Huila. It has 7% K and is a sanidine with quartz contamination and was ground (< 100 mesh) before application.

The site was ploughed to a depth of 20 cm. A basal fertilization was broadcast over the plots followed by harrowing. Huila rockphosphate supplied 20 kg P and 75 kg Ca ha^{-1} equivalent to 10 $\mu g\,g^{-1}$ and 1.9 $\mu eq\,g^{-1}$ in the top 20 cm, (2000 t) respectively, and MgO supplied 40 kg Mg ha^{-1} (1.6 $\mu eq\,g^{-1}$). These are recommended rates based on soil analysis for the establishment of forage grasses and legumes using low inputs [12]. The experiment was a split plot with three replications of each treatment in a factorial design. The treatments were 0, 20, 40 and 80 kg K ha^{-1} applied as either powdered feldspar or KCl (80 kg ha^{-1} = 40 $\mu g\,g^{-1}$ = 1.02 $\mu eq\,g^{-1}$). Each plot was 5 m × 3 m and measurements were made on a 3 m × 2 m area. The K was lightly cultivated into the surface soil. The grass *Brachiaria dyctioneura* and the legume *Pueraria phaseoloides* were sown with three alternate rows of each per plot. Both species are considered to be useful plants for these conditions, being part of the collection held by The Tropical Pastures Programme. The legume seeds were innoculated with *Rhyzobium*. After the second harvest, a further 25 kg Ca ha^{-1} (0.6 $\mu eq\,g^{-1}$) and 20 kg Mg ha^{-1} (0.8 $\mu eq\,g^{-1}$) were applied as $CaCl_2$ and $MgSO_4$.

Five harvests were taken during 14 months depending on plant growth as affected by rainfall. Fresh weight was determined, a subsample was oven dried (60 °C) and weighed and dry matter yield calculated. The dry matter was ground, N was determined by Kjeldahl distillation, and in an acid digest K, Ca and Mg were determined by atomic absorption and P colorimetrically.

Initially and after each harvest three soil subsamples (0–20 cm) were taken per plot, mixed, oven dried (60 °C) and crushed to pass a 2 mm sieve. The following analyses were made: pH, 1:1 in water; Ca, Mg and Al extracted with 1M KCl, Ca and Mg determined by atomic absorption, Al determined by titration with NaOH; P and K extracted with Bray 2 (0.1M HCl + 0.03M NH_4F) and determined colorimetrically and by atomic absorption respectively; total K extracted by 40% HF.

Results

Crop analysis

There was a small significant yield increase resulting from the KCl (Fig. 1), but the responses to feldspar are smaller than the least significant differences

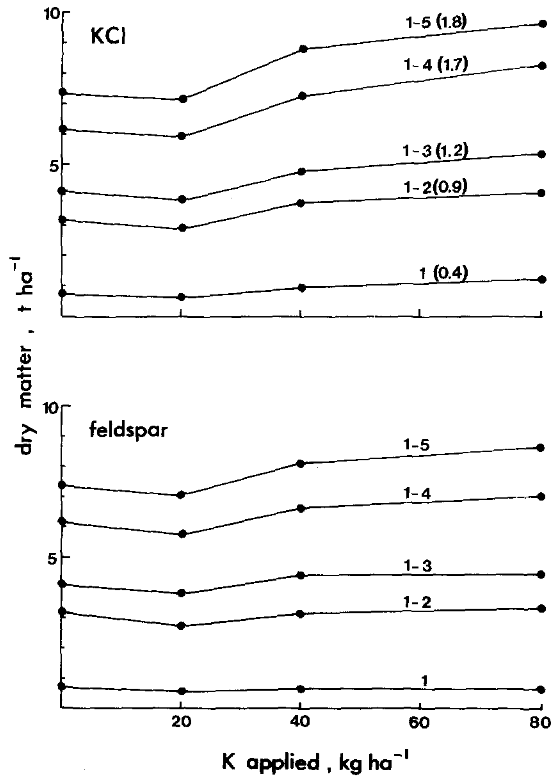

Fig. 1. Dry matter yield of *Brachiaria dyctioneura* + *Pueraria phaseoloides* in response to KCl and feldspar applications. The numbers against the lines are harvest numbers, and the lines give the cumulative yield for these harvests. The numbers in brackets are the least significant differences (5%) and apply to both fertilizers.

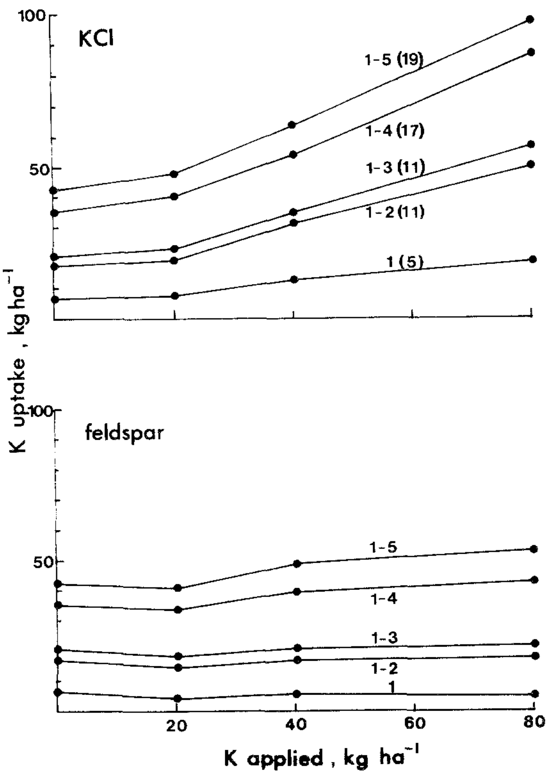

Fig. 2. Potassium uptake by *Brachiaria dyctioneura* + *Pueraria phaseoloides* in response to KCl and feldspar applications. Key as for Fig. 1

(5%). There appears to be an upward trend in yield however and this was tested through a linear regression analysis of the accumulative yield data for harvests 1 to 5. This gave the relationship yield (t ha^{-1}) = 7.16 + 0.018 K (kg ha^{-1}). The 95% confidence limits of the regression coefficient are 0.018 ± 0.033, and the 90% limits are 0.018 ± 0.023. A response to the feldspar has therefore not been proved and the apparent trend in yield would require more data to establish its significance. The lack of significant response may be related to the fact that a good yield was obtained in the zero treatment showing that K was not a serious limitation on this site. Very little rain fell between harvests 2 and 3, and the legume was seriously affected by the drought contributing little to yield in subsequent harvests. The grass was drought resistant and continued to grow well. There is a slight depression in growth in the 20 kg treatment. It is possible that this is the result of soil variability at the site.

Uptake of K is shown in Fig. 2. Much of the applied KCl is accumulated in the crop after 14 months. Increases in K uptake from the feldspar are

Table 1. Soil analysis (0–20 cm) initially and after each harvest.

Treatment		Harvest number					
		Initial	1	2	3	4	5
			Potassium, kg ha^{-1}				
Control	0	47*	39	31	36	60	39
KCL	20		47	31	31	70	39
	40		55	31	31	39	39
	80		55	31	39	47	55
Feldspar	20		39	31	31	47	39
	40		39	23	31	39	39
	80		39	31	31	86	55
Average for all treatments			Phosphorus, μg g^{-1}				
		2.4	4.7	2.7	2.4	1.6	2.0
			Calcium, μeq g^{-1}				
		1.3	2.3	2.1	2.2	2.3	2.3
			Magnesium, μeq g^{-1}				
		0.5	1.1	0.8	1.7	1.1	1.3

* 1 kg ha^{-1} = 0.013 μeq g^{-1} with 2000 t ha^{-1}

smaller than the least significant differences and the apparent trend in the data was again tested through a linear regression analysis for harvests 1 to 5. This gave the relationship K-uptake (kg ha^{-1}) = 40.9 + 0.15K (kg ha^{-1}) with 95% confidence limits being 0.15 $\pm$ 0.21 and 90% limits 0.15 $\pm$ 0.14. The trend was just significant therefore at 90%, but more data is needed. As for the yield data, the reserves of K on this site allowed 40 kg ha^{-1} to be taken up from the zero treatment which would tend to mask the effect of the feldspar. There is no depression in K uptake with 20 kg K applied, and so the yield depression for this treatment is not related to K supply. It is possible that because of ant and termite activity, organic matter levels happened to be lower on some of the 20 kg plots, so restricting the amounts of mineralized N.

Soil analysis

The soil initially had the following properties: pH 4.2; exchangeable Al = 27 μeq g^{-1}, Ca = 1.3, Mg = 0.5, ECEC = 28.8; % Al saturation = 80; total K = 1 mg g^{-1}; extractable P = 2.4 μg g^{-1}. Table 1 gives the soil analysis after each harvest. P, Ca and Mg levels are all low but are considered to be adequate for this low input system. The additions of these nutrients at seeding and after harvest 2 are detected in the analysis and about

Table 2. Rainfall and evapotranspiration (mm) at Carimagua.

Date		Rainfall	Potential evapo-transpiration	Actual evapo-transpiration
26.05.84 sowing		–	–	–
03.09.84 harvest	1	925	409	409
06.11.84	2	694	300	300
05.03.85	3	247	796	188
28.05.85	4	626	536	194
16.07.85	5	748	198	198

2 out of the 10 μg P added in the rock phosphate appears to be extractable after the first harvest.

Control plots

The initial soil K value of 47 kg ha^{-1} is an average for all plots before application of K. At the first harvest 6 kg K has been removed in the crop, and the soil now has 39 kg ha^{-1}. By the second harvest a further 10 kg has been taken up and soil K has decreased by a further 8 kg. At harvests 3 and 4 soil K increased despite further removals in the crop, and then decreased to 39 kg ha^{-1} again at harvest 5. Caution is needed in interpreting the soil data because (a) the amounts of soil K are small and the analysis only detects differences of about 8 kg ha^{-1} (0.1 μeq g^{-1}) and (b) soil variability led to considerable differences between replicate plots. Based on the initial extractions from 10 of the plots, the least significant difference (5%) for the soil K values is 15.9. This variability and the high K value of harvest 4 raised questions regarding the reliability of the Bray 2 method, for this was a 40 s shaking of soil and solution followed by filtering, and the short time of contact between soil and solution could give an inefficient extraction. Laboratory tests showed that the extraction was reproducible and gave similar values to 30 min Bray extractions and 30 min 1M NH_4NO_3 extractions. We therefore suspect that non-exchangeable K is released as a result of the dry period between harvests 2 and 3 and the rewetting between 3 and 4 (Table 2). Most of this released K is apparently fixed again by the final sampling date: only 5 kg was taken up by the crop at harvest 5. Associated pot and laboratory experiments have shown that this soil does give variable amounts of exchangeable K depending on pre-treatment. All soil samples were dried before extraction so it appears that release requires both a dry-wet cycle and time. For the whole cropping period 40 kg has been removed in the crop, but exchangeble K only decreased by 8 kg suggesting that the crop had taken up non-exchangeable K.

KCl plots

The addition of KCl to the plots does not raise the amount of exchangeable K by the amounts expected. After harvest 1 only 16 out of the 80 kg applied could be found barely significant response, with increased crop uptake due to the treatment being 11 kg. The amounts of K in the roots were not measured: we assume that this was released into the Bray extract after the soil was dried and ground. It appears therefore that applied K has been converted into a non-exchangeable form. Laboratory experiments showed that up to 200 μg K added per g moist soil (400 kg ha^{-1}) was completley extractable 30 min later by the standard Bray method (40 s) and also by both the 30 min Bray extraction and 1M NH_4NO_3, but after storage for 30 d the percentages extractable by the three solutions were 66, 75 and 94 respectively. Again, time appears to be an important factor in fixation. Bray solution is less efficient than NH_4NO_3, possibily because the cation concentration in the Bray solution is only 0.03 M NH_4^+ + 0.1M H^+. After harvests 2 and 3 none of the applied K could be extracted although after harvests 4 and 5 small amounts may have been. The crop however takes up much of the applied K during 14 months and Table 3 gives a balance sheet for soil and crop K. 68% of the 80 kg KCl treatment is eventually taken up, most of this by the fourth cut and so the K initially fixed must have been released again to be taken up by the crop. There can only be small amounts of the applied KCl held in fixed form at the end of the experiment or leached out of the soil. Leaching losses are possibily significant. Table 2 shows that during the experimental period about 2 m water passed through the soil. Drainage water concentrations are not known for this site, but the soil solution concentration in a 2:1 soil-water paste of the control soil was 2 mg l^{-1}. This would indicate that 37 kg ha^{-1} could have been lost from the 0–20 cm layer, with larger amounts possibly from the treated plots. Potassium concentrations between 0.3 and 3 mg l^{-1} have been measured in soil solution removed by tension cups from a Brazilian oxisol, but concentrations in the local rivers were undetectable [11]. Exchangeable K was measured down to 100 cm (20 cm layers) at the second and fifth harvests on all plots. Fertilizer K could not be detected within the profile at either harvest.

The distribution of K in relation to particle size and depth is shown in Table 4. The surface layers are more weathered than deeper horizons, but exchangeable K is higher at the surface, presumably the result of nutrient cycling by the vegetation [5, 1983]. The Al chlorite-Al vermiculite is probably the clay holding the reserves of K and able to fix and release added K. A more detailed description of the clay mineralogy of this soil is available [15]. There are similar reserves of K in hydrous mica-montmorillonite clays in soils from Brazil [2] which contained however only about a tenth of the total K measured in the Carimagua soil.

Table 3. A balance sheet for K the in soil and crop. (kg ha^{-1}) after five harvests.

Applied K		Exchangeable K	Crop uptake	Crop uptake of fertilizer K	Fertilizer K in fixed form or leached
	0	39*	43^{+}	0	
KCl	20	39	48	5	15
	40	39	64	21	19
	80	55	97	54	10
Feldspar	20	39	41	0	20
	40	39	48	5	35
	80	55	55	12	52

Least significant differences (5%): *16, $^{+}$19

Feldspar plots

After harvest 1, none of the applied K was extractable (Table 1). In laboratory experiments 300 μg K per g feldspar powder was extractable with Bray 2 (30 s). Thus for a field application of 80 kg K (1143 kg feldspar) the extractable K would only be 0.35 kg ha^{-1} which is not measurable by the techniques used here. For the same reason it is unlikely that any of the changes recorded after later harvests are due to the feldspar: this conclusion is reinforced by the fact that changes in the feldspar plots are similar to those of the KCl plots and probably reflect changes in the extractability of K due to changes in soil conditions. Fig. 2 suggests that K is taken up from the feldspar, and Table 3 summarizes the results. Large errors are involved but about 12 kg of the applied 80 kg K is apparently taken up in total by the crop. In laboratory experiments 9.6 mg K g^{-1} feldspar powder was extracted in five successive Bray extracts with a total extract time of 6d, equivalent to 11 kg ha^{-1} for the 80 kg field treatment. However 1M NH_4NO_3 extracted only 0.6 mg K g^{-1} (0.68 kg ha^{-1}) with about half of this coming out in the first extract. Even taking the slow rate of release into NH_4NO_3, there is an

Table 4. Potassium in the Carimagua Soil.

Soil horizon cm	K content (mg g^{-1}) in			Total K mg g^{-1} soil	Exchangeable K	
	Sand*	Silt	Clay		μg g^{-1}	kg ha^{-1}
0–20	0.17	0.91	2.66	1.00	23	46
20–40	0.08	0.66	2.32	1.08	16	32
40–60	0.08	0.50	2.57	1.25	12	24
60–80	0.08	0.58	3.73	1.83	8	16
80–100	0.08	0.66	3.90	1.91	8	16

* The surface hozizon has 6% sand (2 mm – 53 μm), 63% silt (53 – 2 μm) and 31% clay (< 2 μm). The remaining horizons have 6%, 58% and 36% respectively. Sand: predominantly quartz, trace of kaolinite; Silt: quartz, kaolinite, pyrophyllite, Al chlorite-vermiculite; Clay: kaolinite, Al chlorite-Al vermiculite, the vermiculite increases with depth.

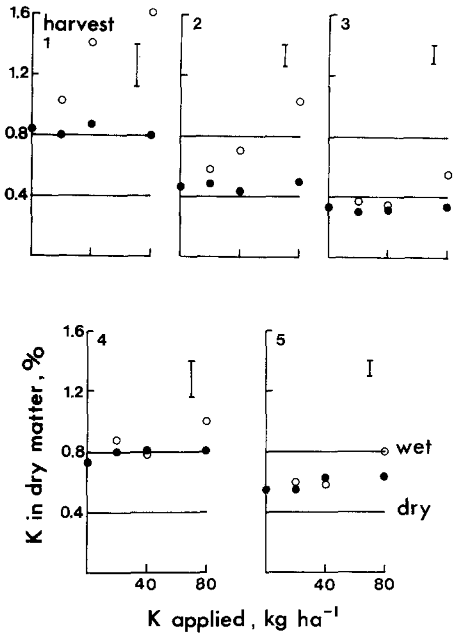

Fig. 3. Potassium concentrations in the dry matter of *Brachiaria dyctioneura* at the 5 harvests in response to KCl (open circles) and feldspar (closed circles) applications. The horizontal lines are the critical levels for wet and dry seasons. Vertical bars are the least significant differents (5%).

indication from laboratory experiments that K could be released in significant amounts over the long periods involved in field uptake. The feldspar results therefore suggest that this form of fertilizer released useful amounts of K under the conditions of the field experiment.

Plant composition

The K content of the grass is shown in Fig. 3. Critical levels are those given by CIAT [5, 1981] [12] for wet and dry conditions and are the levels at which the crop gives 80% of its maximum yield without lime in a low input system (see below). The control plots produce plants with K% close to the critical levels depending on rainfall except for harvest 2 which has a low percentage after a wet period. It would seem that the supply of native K is adequate for growth in agreement with the yield data in Fig. 1. Application of KCl increases the %K very significantly in early harvests, but has only small effects in later harvests by which time most of the K has been taken up. Feldspar applications have no effect in early harvests, but may show a small effect in harvests 4 and 5. By this time the control crop has taken up 43 kg ha^{-1} from soil initially holding 47 kg exchangeable K ha^{-1}: native K has therefore been reduced (although there was no measured decrease in exchangeable K) and the treated crops appear to be making use of the feldspar K (Table 3).

Conclusions

The soil used for this field experiment had unexpectedly high reserves of native K. It was not therefore ideal to test responses to slowly released feldspar K. However there were small responses in yield and about 10% of the feldspar K was taken up during 14 months, whereas 25–68% of the KCl–K was taken up over the same period depending on rate of application. The experiment was organised within the Tropical Pastures Programme of CIAT using low inputs of nutrients [14]: these are considered to be economically feasible for this area using species adapted to acid soils and a legume -*Rhizobium* association to supply nitrogen. From an academic view point an experiment to test the usefulness of a fertilizer source would normally involve the removal of all other growth contraints in order to see the maximum effect of the fertilizer being tested. The response and uptake of feldspar K was not tested under such conditions, because there was a need to use the feldspar in the savannah of Colombia where large inputs are not considered possible. The legume cannot have contributed much N to the grass because it was not drought resistant. The cultivation of the native vegetation into the soil probably led to appreciable amounts of mineralized N [17] and it is unlikely that there were growth constraints due to N shortage.

It is not possible to analyse the economics of feldspar use in detail. However the following costs apply at Carimagua. The price per tonne of ground feldspar is about \$30 with \$40 transport costs. If the feldspar contains 7% K then the cost of K is \$1000 per tonne. Spreading costs are not significant for the improvement of small areas of pasture likely to be attempted by local farmers. The equivalent figures for imported KCl are \$293 per tonne KCl which contains 50% K. Transport costs are again \$40 per tonne, giving a cost of \$666 per tonne K at Carimagua. Thus feldspar-K is more expensive than KCl-K. However there are disadvantages in using KCl: (i) imported KCl is a drain on foreign exchange (approximately \$40 million per year for all the Andean countries), (ii) it is more difficult to transport and store in marginal areas because of the risk of spoilage if it becomes damp, (iii) unlike feldspar, KCl cannot be mixed with seed and the two spread together because of salt damage, (iv) the exploitation of local feldspars is a source of employment and prices are not subject to fluctuation as in the case of imported KCl, and (v) all the KCl will be rapidly taken up by the crop or lost by leaching. The feldspar's slow release characteristics may give it a significant advantage if release continues over a number of years.

In the Carimagua experiment about 1.3 tonne dry matter per ha was the increase in yield from 80 kg K applied as feldspar. This will be converted into meat and CIAT have shown that about 65 kg animal weight is produced from this weight of grass, with a value of about $65 to the farmer. thus the outlay of $80 for the feldspar is recovered in about 18 months. Subsequent use of the remaining 90% would then be profitable. The economic value of the feldspar depends on the long term release of K which has not yet been tested although the experiments at Carimagua are still in progress.

The large reserves of K in this soil are significant in relation to the normally accepted properties of an Oxisol. Soil Taxonomy [18] describes an oxic horizon as having 'few or no primary minerals that can weather to release bases, iron or aluminium' but also comments that a '2:1 latice clay either is extremely resistant to weathering in a humid climate, perhaps more so than kaolin, or has formed from dust that accumulated slowly over the millenia. This is an Al- interlayered chlorite. . . . It is commonly present . . . in at least a moderate amount, but the amount decreases with depth'. The Carimagua soil shows these characteristics but there is an increase in the Al-vermiculite with depth. Although the clay holds its K and is resistant to weathering, the K appears to be available to crops. It seems that despite very low concentrations of K present in soil solution, plant roots create conditions which cause a significant release, so that uptake is primarily from initially non-exchangeable K with the amount of exchangeable K being relatively unchanged.

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