RELEASE OF NON-EXCHANGEABLE POTASSIUM RESERVES FROM A RANGE OF SUGAR INDUSTRY SOILS

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Abstract

An improved method for extracting exchangeable and non-exchangeable potassium (K) in soils using $BaCl_2$ was compared with several other methods of extraction. Non-exchangeable K comes mainly from interlayer sites of clay minerals in soils. Rate of exchange of interlayer K is a function of time and depends on its location in the interlayers. An attempt was made to characterise interlayer K by measuring its release from a range of South African sugar industry soils. For each soil two K fractions with different desorption rates were identified: a fast desorbing K fraction equivalent to exchangeable K, and a second fraction released more slowly from the clay interlayers and equivalent to non-exchangeable K. Sustained release of non-exchangeable K reserves was apparent in many soils containing a high proportion of K-selective clay minerals (2:1 lattice clays), whereas the opposite was observed in soils in which 1:1 lattice clays predominated. It should now be possible to predict more accurately the rate at which non-exchangeable K reserves are able to replenish K equilibrium in the soil solution. This is important as it will influence crop response to applied K fertilizer.

Introduction

Non-exchangeable potassium (K) renews the supply of K to the soil and is in equilibrium with exchangeable K. It is also important in supplying K to plant roots. In a review on the behaviour of non-exchangeable K in soils, Martin and Sparks (1985), stated that the most important aspect of non-exchangeable soil K is the rate at which it is released to the exchangeable and solution forms which are readily available for plant uptake. The rate and magnitude of release are primarily dependent on two factors: a) the level of K in the soil solution, and b) the type and amount of clay minerals present.

Table 1

Properties of the soils used

No.	Soil series	Soil form	pH (water)	Clay %	CEC meq/100g		*Clay minerals	Parent material
					soil	clay		
				Swaziland soils				
1	Betusile	Dundee	6,5	6	6,6	100,0	Vm, kt	Alluvium
2	Canterbury	Bonheim	6,9	56	23,8	42,5	St, Kt, vm, mi	Dolerite/basalt
3	Kwezi	Arcadia	8,2	58	58,8	101,3	St, kt, mi	Dolerite/basalt
4	Rondspring(1)	Shortlands	5,1	44	16,9	38,4	Kt, mi, is	Dolerite/basalt
5	Rondspring(2)	Shortlands	7,7	25	18,1	72,4	Kt, mi, is	Dolerite/basalt
6	Somerling	Mayo	6,8	45	17,5	38,9	Kt, Is, mi	Granite
7	Tambankulu	Tambankulu	6,5	38	23,2	61,1	St, kt	Dolerite/basalt
8	Vimy	Bonheim	7,4	41	25,0	61,0	St, Kt, Vm, is	Dolerite/basalt
9	Zwide	Estcourt	6,8	30	11,7	39,0	Mi, St, kt, vm	Middle Ecca sediments
				Coast lowlands soils				
10	Arcadia	Arcadia	7,5	58	57,9	99,8	St, mi, is	Dolerite/basalt
11	Glenrosa	Glenrosa	5,2	8	3,8	47,5	Kt, st	Granite
12	Mayo	Mayo	5,9	25	13,5	54,0	Kt, mi, vm	Granite
13	Mispah	Mispah	8,0	18	15,8	77,8	mi, kt, fs	Cave sandstone
14	Phoenix	Rensburg	6,2	44	27,2	61,8	St, Kt, mi	Alluvium
15	Shortlands(1)	Shortlands	7,9	50	31,0	62,0	Kt, mi, is	Dolerite
16	Shortlands(2)	Shortlands	7,8	42	31,7	75,5	Kt, mi, is	Dolerite
				Midlands top and subsoils				
17	Balgowan	Clovelly	4,4	55	12,4	22,5	Kt, Mi, st	Lower Ecca shale
18	Balmoral(2)	Hutton	5,2	51	7,0	13,7	Kt, gb, ch	Dolerite
19	Balmoral(3)	Hutton	5,7	32	14,9	46,6	Kt, gb, ch	Dolerite
20	Griffin	Griffin	4,2	21	4,9	23,3	Kt, Ch, gb	Dwyka tillite
21	Inanda(2)	Inanda	4,9	48	5,8	12,1	Kt, gb	Table Mountain Sandstone
22	Inanda(3)	Inanda	5,4	31	9,7	31,3	Kt, gb	Table Mountain Sandstone
23	Inanda(4)	Inanda	5,5	45	13,3	29,6	Kt, gb	Table Mountain Sandstone
24	Sprinz(2)	Inanda	5,8	53	20,0	37,7	Kt, gb	Dolerite
25	Nomanci(s)	Nomanci	4,8	17	7,5	44,1	Kt, gb	Table Mountain Sandstone
26	Sprinz(1)(s)	Inanda	5,6	53	7,0	13,2	Kt, gb	Dolerite
27	Vimy(s)	Hutton	6,5	45	14,6	32,4	Kt, gb, ch	Dolerite

* Capitals indicate dominant and small letters accessory minerals (s) denotes subsoil Kt = kaolinite St = smectite Mi = mica Vm = vermiculite Ch = chlorite Fs = feldspar Gb = gibbsite Is = interstratified clay minerals

According to Grimme (1985), it depends on the extent of reduction of K concentration in the soil solution whether exchangeable K only or also non-exchangeable K will be involved in the replenishment/release process. This implies that non-exchangeable K release from inter-lattice sites of clay minerals will probably be greatest in the soil nearest to the root surface (Claassen and Jungk, 1982). Grimme (1985) states that release of K from inter-lattice sites is a slow process compared with K mobility in solution. Soils of the South African and Swaziland sugar industry differ greatly in their K release potential depending on clay content, clay mineralogy and degree of weathering. Their non-exchangeable K reserves have been assessed by electro-ultrafiltration (EUF) as well as by other methods (Wood, 1985). However, it has not yet been possible to determine satisfactorily the rate at which K reserves can replenish K in equilibrium with the soil solution. Using an improved method for extracting exchangeable and non-exchangeable K in soils, and comparing it with other extraction procedures an attempt was made to characterise interlayer K by measuring its release rate from a range of sugar industry soils.

Procedure

Laboratory

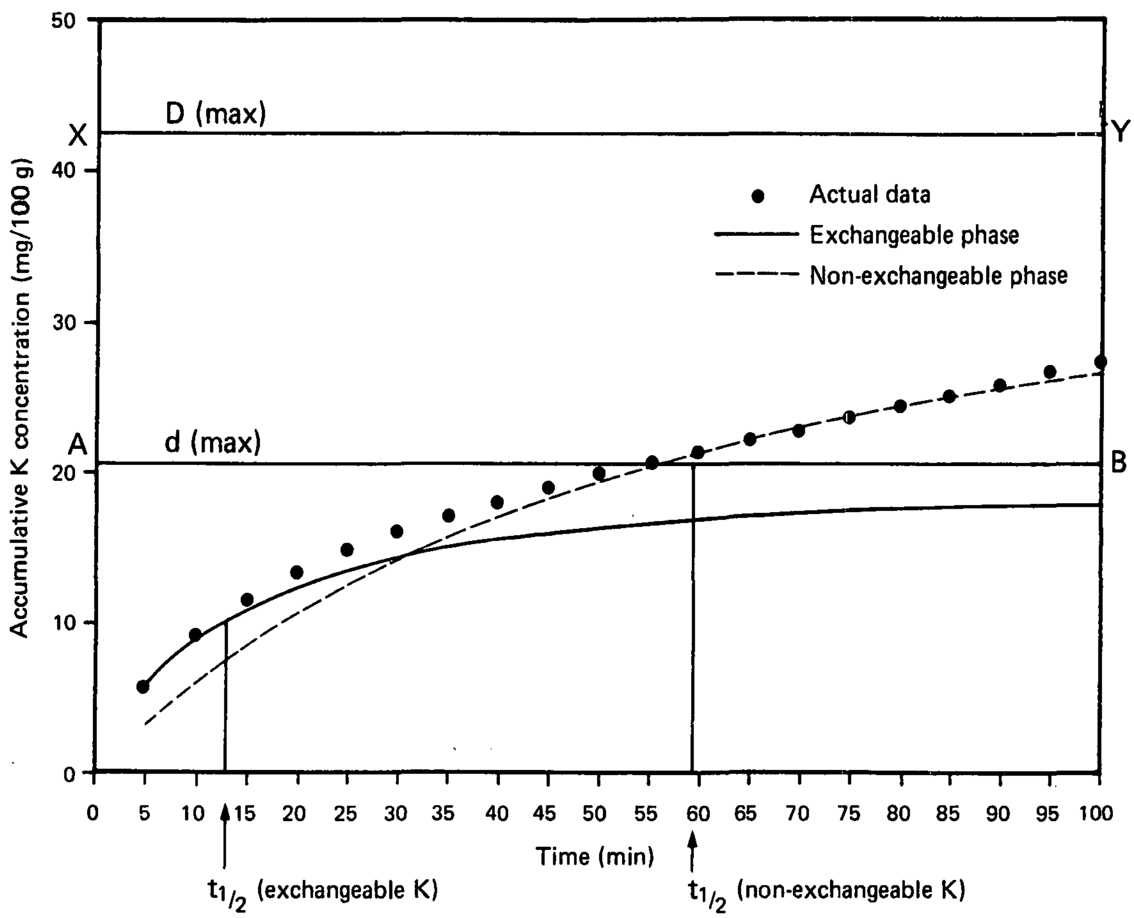
Twenty-four topsoils (0-200 mm) and three subsoils (200-400 mm) were selected having widely differing properties with regard to parent material, texture and clay mineralogy (Beater, 1970; Le Roux, 1972, 1974; WF Kirsten and MV Fey, personal communication). A summary of some of the relevant properties of the soils is given in Table 1.

The method used to measure the release of interlayer or non-exchangeable K was that of Grooterhorst and Grimme (1989) based on the miscible displacement technique of Sparks *et al.*, (1980). Duplicate 2 g soil samples, 1 mm sieved, were leached with 0,1M $BaCl_2$ at a rate of 1,5 ml/min for 100 minutes. The leachate was collected at 5 min intervals using a Gilson 203 fraction collector.

K concentration in the leachate was determined by atomic absorption and cumulative desorbed K values were calculated for each soil and plotted as a function of time.

Other methods used to determine potassium were as follows:

- Exchangeable K: 10 g soil shaken with 100 ml 1N ammonium acetate for 20 min.
- HNO_3-K: Reflux 2,5g soil with 100 ml 1N nitric acid for 30 min (based on Haysom's method, 1971)
- EUF-K: In this method, which uses an electric field to extract K ions from an aqueous soil suspension, two EUF-K fractions were determined using a Vogel 724 EUF apparatus as described by Németh (1979, 1982). The quantities of K desorbed by EUF at 5 min intervals up to 60 min were totalled. K desorption was then plotted as a function of time.



Exchangeable K potential = 20,5 mg/100 g
Non-exchangeable K potential = 42,5 – 20,5 = 22,0 mg/100 g

FIGURE 1 Cumulative desorbed K values for a Mayo form soil as a function of time, and theoretical curves fitted to the data representing the exchangeable and non-exchangeable fractions.

EUF-K 0-30: This fraction refers to a 30 min extraction of 5 g oven-dry soil at 200 V and 20°C.

EUF-K 30-60: This fraction refers to extraction for a further period of 30 min during which the voltage is raised from 200 to 400 and the temperature from 20 to 80°C.

Glasshouse

To obtain correlations between the soil analysis data and K uptake by plants, a glasshouse pot experiment was conducted. The technique used has been described in detail by Wood and Burrows (1980). The 27 soils were cropped with sorghum (babala) until the supply of K to the crop was exhausted. The K measured by different extraction procedures was compared with cumulative K uptake (mg/100g soil) by sorghum after six cuts and after cropping to exhaustion those treatments where no K fertilizer had been added (K_0).

Results and Discussion

Soil characteristics

The widely differing characteristics of the soils selected which are related to their origin from different parent materials are shown in Table 1. The table shows that pH values varied between 4,2 and 8,2 and CEC between 4 and 59 meq/100 g soil. Whereas in the Swaziland lowveld, soils in which K selective 2:1 lattice clay minerals such as smectite predominate, in the more highly weathered soils of the Natal midlands 1:1 lattice clays such as kaolinite predominate, which adsorb relatively little potassium.

$BaCl_2$ desorption curves

As indicated by Grooterhorst and Grimme (1989) it was found that K desorption for each soil could be described by two second order equations:

$$d = D.t/(t + t_{1/2}) \quad (1)$$

$$\text{with } t_{1/2} = 1/(kD) \quad (2)$$

where D = total desorbable K

t = time

$t_{1/2}$ = halftime (period in which half the original K concentration has been leached from the soil)

For each soil two K fractions with different desorption rates could be identified:

i) a fast desorbing fraction comparable to exchangeable K

ii) a second fraction released more slowly from the interlattice sites of clay minerals (non-exchangeable K).

By means of equations (1) and (2), parameters were derived which characterised the maximum desorbable quantity of each K fraction and its respective release rate. For example in Fig 1, representing a Mayo form soil, d(max) is the estimated maximum exchangeable K and represented by the asymptote AB, while D(max) is the estimated maximum total desorbable K (exchangeable + non-exchangeable K) and shown as asymptote (XY).

The theoretical curves which represent non-exchangeable soil K were used as a comparison of sustained release of K for a range of soils (Fig 2a). The K desorption rates as a function of time were then calculated for each of these soils (Fig 3a).

EUF desorption curves

In a manner similar to that described for the $BaCl_2$ data, theoretical curves were fitted to the EUF data for the same range of soils. Second order equations were used to calculate the estimated maximum desorbable exchangeable K (d(max)EUF) based on the EUF-K 0-30 fraction, and non-exchangeable K (D(max)EUF) based on the EUF-K 30-60 fraction. The maximum desorbable K in this case was given by d(max)EUF+D(max)EUF. Fig 2b shows the theoretical curves for non-exchangeable K based on EUF, while the K desorption rates for the different soils are shown in Fig 3b.

Soil K status and cumulative K uptake by sorghum

The K values obtained with the different extractants for the 27 soils used in the glasshouse experiments are shown in Table 2, with the mean cumulative K uptake data from the K_0 treatments after six cuts and after the soils were cropped to exhaustion.

Correlation between the different extraction procedures

Table 3 shows that the methods of K determination (NH_4OAc, $BaCl_2$, EUF-K 0-30 min, EUF-K 0-60 min and HNO_3) were well correlated with the estimates of exchangeable K and maximum desorbable K. However, the $BaCl_2$ method was better correlated with D(max) than were the other methods (r = 0,82, 0,92, 0,66, 0,78 and 0,64 respectively). In all cases the HNO_3-K was less well correlated with the estimates of exchangeable and maximum desorbable K than any of the other methods.

Correlations between soil K release and cumulative K uptake

The correlation coefficients between soil K release by the various extraction procedures and cumulative K uptake by sorghum after six cuts and after cropping to exhaustion were calculated for the soils (Table 4). The 27 soils were split into two groups, namely those rich in 2:1 clays and those which had a preponderance of 1:1 clays. Cumulative K uptake after six cuts from soils which contained few K selective clay minerals was generally better correlated with the estimates of exchangeable K release (d(max) and d(max)EUF) than cumulative K uptake after six cuts on soils containing predominantly 2:1 clays. This indicates that the soils with mainly 1:1 clays had few K reserves and cane growing on these soils must rely largely on the exchangeable K for its K requirement. Total K uptake after cropping to exhaustion, although generally less well correlated with K release indices than the respective K uptake values after six cuts, was well correlated with D(max), d(max)EUF+D(max)EUF and HNO_3-K. This indicates that the use of the second order equations to predict the release of non-exchangeable K was superior to those estimates which did not take this into account.

Categorising soils in terms of K release

The theoretical curves of accumulated non-exchangeable K as a function of time based on $BaCl_2$ and EUF extraction (Fig 2a and b) allow for the classification of soils into groups according to their K supplying power. However, the ability of a soil to show sustained release of non-exchangeable K was better estimated from the rate of K desorption curves (Fig 3a and b). Compared with the EUF release curves the $BaCl_2$ curves were better able to reflect the ability of some soils, particularly those with a predominance of 2:1 lattice clays, to maintain sustained release of K.

Based on the parameters obtained from the second order equations for $BaCl_2$ data, availability of non-exchangeable soil K was classified into four categories (Table 5), according to:

i) the release rates (which were related to the shape of the desorption curves and the values of $t_{1/2}$)

ii) the potential non-exchangeable K or 'K reserve'.

Using this approach it should now be possible to classify all sugar industry soils into these four categories.

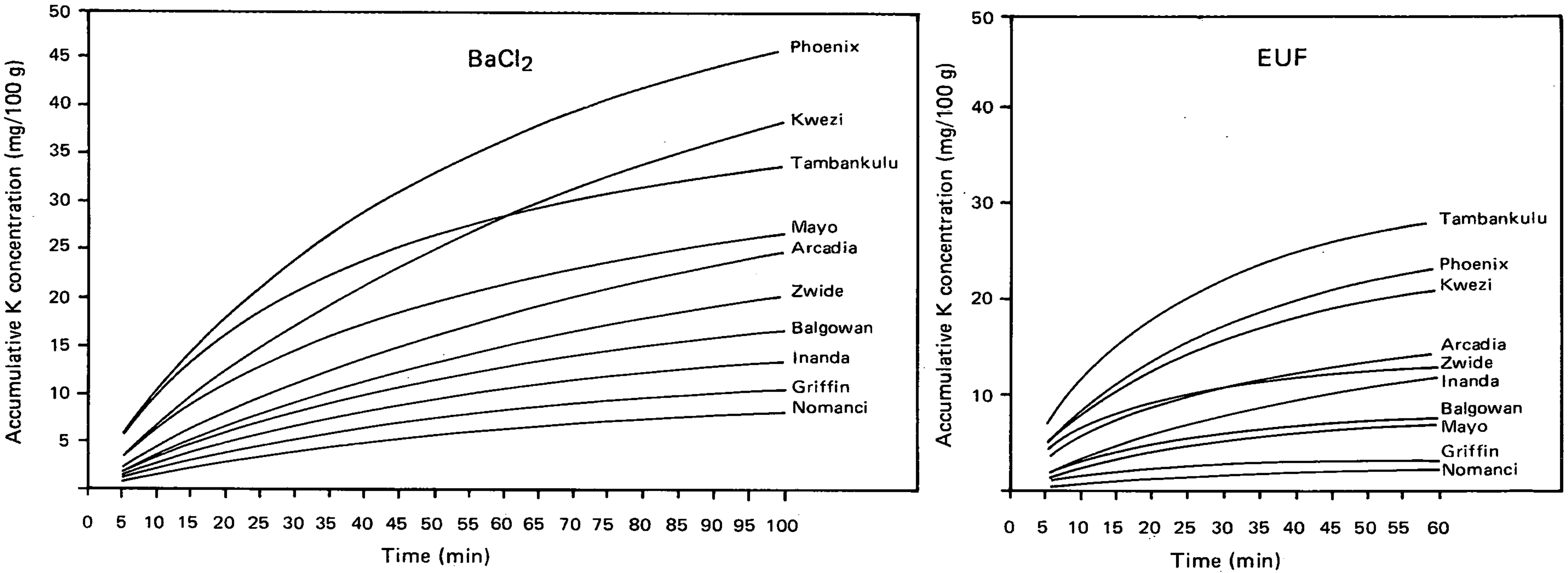


FIGURE 2 (a & b) Theoretical curves fitted to non-exchangeable K desorption data.

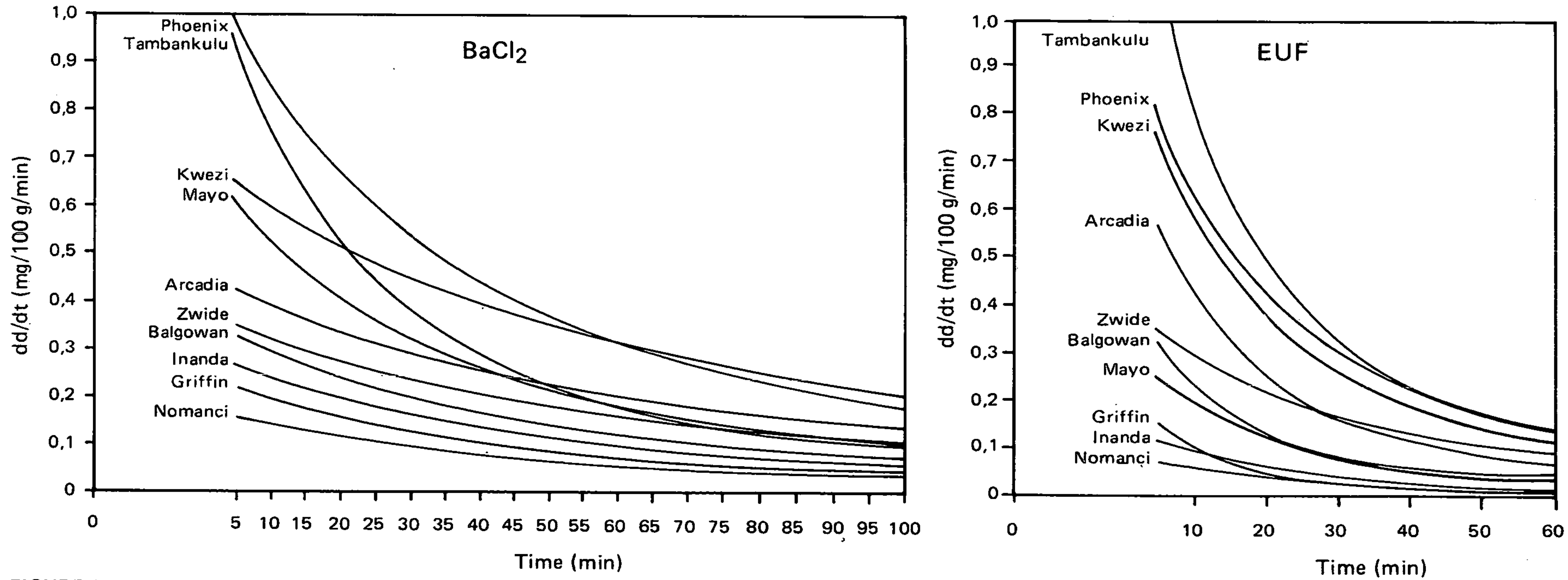


FIGURE 3 (a & b) Desorption rates of non-exchangeable K as a function of time.

Table 2

Analytical data and balance sheet from potassium pot trials after continuous cropping

No.	Soil series	No. of cuts	K uptake mg/100g Ko (total)	K uptake mg/100g Ko (6 cuts)	$BaCl_2$-K mg/100g	NH_4OAc-K mg/100g (Ex-K)	HNO_3-K mg/100g	EUF 0–30 200V 20 C mg/100g	EUF 30–60 400 V 80 C mg/100g	EUF 0–60 mg/100g
					Swaziland soils					
1	Betusile	10	20,1	16,1	18,5	10,6	69,6	4,6	3,8	8,4
2	Canterbury	22	77,0	49,4	34,5	25,4	106,0	4,5	14,0	18,5
3	Kwezi	17	53,4	24,4	38,0	28,4	87,0	6,6	15,4	22,0
4	Rondspring(1)	35	111,1	35,5	20,8	19,1	133,1	9,2	7,6	16,8
5	Rondspring(2)	22	171,6	98,1	90,4	72,7	180,0	51,4	42,1	93,5
6	Somerling	23	109,4	66,3	24,5	28,8	178,0	7,6	13,5	21,1
7	Tambankulu	19	56,6	43,4	33,3	38,0	100,9	11,7	21,5	33,2
8	Vimy	24	62,3	48,2	28,3	22,1	67,9	8,5	14,8	23,3
9	Zwide	19	48,5	28,3	20,5	15,2	107,0	4,9	7,9	12,8
					Coast lowlands soils					
10	Arcadia	35	47,5	22,3	25,6	18,2	56,9	7,1	11,0	18,1
11	Glenrosa	7	12,1	11,4	19,4	8,6	75,3	7,8	3,4	11,2
12	Mayo	17	27,3	17,8	27,8	12,7	35,2	6,7	5,2	11,9
13	Mispah	9	11,0	9,6	7,6	6,1	23,2	2,5	3,7	6,2
14	Phoenix	54	243,3	49,9	45,9	29,1	158,1	14,1	17,8	31,1
15	Shortlands(1)	42	100,7	35,2	14,0	15,4	117,8	4,5	11,9	16,4
16	Shortlands(2)	18	43,1	34,6	20,2	10,3	35,2	4,5	7,3	11,8
					Midlands top and subsoils					
17	Balgowan	9	23,0	20,7	16,8	19,4	35,9	13,1	6,2	19,3
18	Balmoral(2)	9	22,6	21,0	28,8	21,8	25,7	10,0	7,1	17,1
19	Balmoral(3)	10	9,6	7,1	14,9	6,1	18,0	3,7	2,9	6,6
20	Griffin	9	7,9	7,1	10,7	7,6	22,5	4,3	2,7	7,0
21	Inanda(2)	9	49,0	47,5	42,5	39,6	54,7	31,2	10,6	41,8
22	Inanda(3)	7	8,8	8,0	13,7	7,6	18,8	5,5	2,5	8,0
23	Inanda(4)	10	28,1	25,9	35,4	23,0	31,8	19,9	8,1	28,0
24	Sprinz(2)	13	24,4	19,0	15,2	20,9	29,1	15,3	6,5	21,8
25	Nomanci(s)	8	4,5	3,5	8,6	5,0	25,3	2,1	1,4	3,5
26	Sprinz(1)(s)	13	26,2	21,8	21,0	19,9	28,5	12,0	5,9	17,9
27	Vimy(s)	13	15,0	9,5	11,2	8,2	31,5	3,0	3,9	6,9

(s) = subsoil

Table 3

Correlation coefficient of linear regression (r) between the methods of K determination and the estimates of exchangeable and maximum desorbable K

Methods of K determination	$BaCl_2$ d(max)	$BaCl_2$ D(max)
NH_4OAc	0.95 ***	0.82 ***
$BaCl_2$	0.98 ***	0.92 ***
EUF 0–30	0.86 ***	0.66 ***
EUF 0–60	0.94 ***	0.78 ***
HNO_3	0.64 ***	0.64 ***

*** significant at P < 0.001

Conclusions

The $BaCl_2$ extraction procedure has led to an improved estimation of maximum desorbable K and K desorption rates for sugar industry soils. This enables them to be classified into four categories according to their ability to release non-exchangeable K. The $BaCl_2$ procedure also appears to be better able to predict the rate at which non-exchangeable K reserves are able to replenish K in equilibrium with the soil solution. The pot trial results indicated that exchangeable K is not a very reliable measure of K availability as the K use of a crop growing on soils with similar exchangeable K values was not necessarily the same. This is largely due to the considerable difference in their non-exchangeable K reserves (see soils 8 and 18 in Table 2). Before using the system of classification based on non-exchangeable K release to improve K fertilizer recommendations for cane, it will be necessary to calibrate the system against results obtained from the large number of K trials that have been conducted on sugar industry soils.

Table 4

Correlation coefficients of linear regression (r) between estimates of K release and cumulative K uptake

Estimates of K release	K uptake (6 cuts) (predominantly 1:1 clays)	K uptake (6 cuts) (predominantly 2:1 clays)	K uptake (total) (all soils)
NH_4OAc-K	0.85 ***	0.87 ***	0.65 ***
$BaCl_2$-K	0.84 ***	0.77 ***	0.68 ***
d(max)	0.91 ***	0.71 **	0.69 ***
D(max)	0.76 ***	0.60 **	0.71 ***
D(max)-d(max)	0.38 (ns)	0.03 (ns)	0.40 *
EUF 0–30	0.80 ***	0.80 ***	0.46 *
EUF 0–60	0.81 ***	0.84 ***	0.63 ***
d(max)EUF	0.89 ***	0.76 **	0.57 **
d(max)EUF+D(max) EUF	0.93 ***	0.81 ***	0.70 ***
HNO_3-K	-	-	0.83 ***

* significant at P < 0.05
** significant at P < 0.01
*** significant at P < 0.001
(ns) not significant

Table 5

Categorisation of various soil series according to non-exchangeable K availability

	Non-exchangeable soil potassium availability			
K release rate	Rapid ← Slower			
K reserves	Low → High			
Soil series	Mispah Sprinz(1) Sprinz(2)	Balgowan Balmoral(2) Glenrosa Griffin Inanda(3) Nomanci Shortlands(1) Vimy(sub)	Balmoral(3) Betusile Inanda(2) Inanda(4) Mayo Rondspring(1) Rondspring(2) Shortlands(2) Somerling Tambankulu Vimy	Arcadia Canterbury Kwezi Phoenix Zwide

However, it must be recognised that growth of plants can often be impaired if a substantial part of their K requirement has to be drawn from non-exchangeable K. Release rates from clay minerals are often not sufficient to supply the major part of the K demand of a high yielding crop (Grimme, 1974). Nonetheless, compared to many crops, sugarcane needs a somewhat lower K supply rate owing to its relatively long growing season, and for this reason can rely to a greater extent on non-exchangeable soil K reserves where these are substantial.

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