EVALUATION OF POTASSIUM AVAILABILITY IN THREE MAJOR SOIL GROUPS IN THE SWAZILAND SUGARCANE AREAS

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Abstract

Exchangeable and non-exchangeable potassium extractable in ammonium acetate and nitric acid respectively were determined in soils of the duplex, plinthic ferrasol and oxisol groups in the Swaziland sugarcane growing areas. A greenhouse experiment showed that potassium, accumulated by six weeks old maize plants, was largely controlled by the initial level of exchangeable potassium. Although one unit of exchangeable potassium tended to be equally available in all soils, significant differences in distributions of non-exchangeable and exchangeable potassium percentage saturation levels between soils were found when sorted according to clay categories and clay mineralogy. Reserves of non-exchangeable potassium and percentage saturation levels were relatively low in the heavy soils. It was concluded that their ability to sustain the supply of potassium to plants on a long term basis may be more limited than in lighter soils. The implications of these results for making potassium fertiliser recommendations for sugarcane are discussed.

Introduction

The diagnostic and recommendation system for potassium nutrition of sugarcane used by growers in Swaziland is that developed by the Fertiliser Advisory Service (FAS) of the South African Sugar Association Experiment Station (SASEX). In this system the potassium status of the soil is determined using a 1N ammonium acetate extract (NH_4AOC). The results of an exhaustive greenhouse experiment conducted by Wood and Burrows (1980), showed that the threshold values separating potassium-deficient from non-deficient soils depend on clay content and increase from the light to the heavy clay soils.

Low leaf potassium content in sugarcane associated with apparently high levels of soil NH_4AOC-K, especially in winter cut cane, has become widespread in the Northern Irrigated Areas (NIA) over the past decade. This trend prompted closer scrutiny of the established NH_4AOC-K threshold values. An investigation conducted in the Eastern Transvaal recommended that the threshold value be increased from 150 to 225 ppm for soils containing more than 40% clay (Donaldson *et al.*, 1990). Another recent study, conducted in Swaziland, also established the need to increase the NH_4AOC-K threshold values (Henry *et al.*, 1992). This latter work also presented evidence that, in the base saturated lowveld soils, the NH_4AOC-K threshold values were sensitive to the sum of extractable Ca + Mg.

In these investigations attempts were made to solve the problem of the low leaf-K high soil-K anomaly by focusing on the NH_4AOC-K threshold values. NH_4AOC-K, however, is not the sole source of potassium available to plants. Non-exchangeable potassium (NExch-K), located within the structure of phylosilicates and tectosilicates, also contributes to the uptake of potassium by plants, especially in a situation of prolonged cropping as is the case with sugarcane. Wood and Schroeder (1991) showed that, in South African and Swaziland sugarcane belt soils, clay mineralogy had an important bearing on the content of NExch-K of the soils and its rate of release to the soil solution and uptake by plants. Data presented by these authors showed that the Swaziland soils were especially heterogenous in their clay mineralogy. The evidence suggests that the pattern of potassium supply to plants in the NIA is complex.

These considerations question the validity of using only NH_4AOC-K in making potassium fertiliser recommendations in the NIA as well as clay content without reference to mineralogy.

The objective of this paper is to gain a better understanding of the factors influencing potassium nutrition in the soils of the NIA and provide a basis for rationalising future work to improve the system of potassium fertiliser recommendation. The results of a study of the various forms of soil potassium in three major soil groups of the NIA, their relationships with plant potassium uptake and the effect of clay content on these relationships are reported.

Procedure

Soils

Soil samples were collected from commercial fields at Mhlume Sugar Company (MSCo), a 9 600 ha irrigated sugar estate in the north-eastern lowveld of Swaziland. The samples originated from the 0-0,15 m topsoil of the three major groups of soils occuring at MSCo. The groups of soils represented by the samples were the red freely draining oxisol (17 samples), the yellow-brown moderately draining plinthic ferrasol (21 samples) and the structureless grey saline/sodic poorly draining duplex soils (17 samples).

In terms of the Swaziland system of soil classification (Murdoch, 1972), soils in the oxisol group were classified as R and L sets, those in the plinthic ferrasol group as T and D sets and those in the duplex group are either H or Z sets. In terms of the South African binomial system of soil classification (Anon, 1991) the R and L set soils approximate to the Shortlands (R) and Hutton (L) forms, the T and D set soils to the Tambankulu (T) and Avalon (D) forms and the duplex soils are represented by the Katspruit (H) and Estcourt (Z) forms.

Extraction of soil potassium forms and mineralogy

Potassium in each soil was determined following extractions in water (1:1 saturated paste method), 1 N ammonium acetate (NH_4AOC) buffered to pH 7,5 and boiling 1 N nitric acid (HNO_3) solutions.

Potassium in the water extract (W-K) represents the fraction of the nutrient dissolved in the soil solution. NH_4AOC-K consists of both the potassium dissolved in the soil solution and that held in exchangeable form (Exch-K) on the clay particles. HNO_3-K is the sum of the water soluble, exchangeable and non-exchangeable forms of potassium.

NExch-K was estimated by subtracting from the level of HNO_3 the amount of NH_4AOC-K. An index of the Ca + Mg antagonism was also obtained by computing the percentage potassium (Exch-K form) of the CEC (K/CEC). Semi-quantitative X-ray diffraction analysis was conducted on 28 selected soil samples to determine the mineralogical composition of the clay fraction and feldspar content.

Greenhouse experiment

Duplicate pre-weighed pots were filled with soil to a volume of 2,5 *l* and arranged in a randomised design. Before potting, phosphorus as monocalcium phosphate $Ca(H_2PO_4)_2$ at rates specific to each soil was mixed with the soil to ensure that the phosphorus requirement would be met. No potassium was added and soil-K was the only source of potassium available to the plants during the experiment. Maize (cultivar TX 379) was used as the indicator crop and 12 seeds were planted per pot. Nitrogen as ammonium nitrate (NH_4NO_3) at a standard rate of 50 mg N/kg soil (120 kg N/ha) was top-dressed and the soils were brought to field capacity with distilled water and thereafter watered to field capacity as required. The leachate was returned to the soil after each irrigation event. One week after emergence the plants were thinned down to three per pot. Forty-two days after sowing, the vegetative parts of the plants were harvested, dried and weighed.

Total potassium uptake $(\text{Total-K})_{\text{plant}}$ was determined following digestion in concentrated selenised sulphuric acid. After harvest the soil contained in the pots was returned to the lab and NH_4AOC-K was determined. A balance sheet approach similar to that used by Conyers and McLean (1969) and Wood and Burrows (1980) was used to partition $(\text{Total-K})_{\text{plant}}$ between potassium supplied from exchangeable and non-exchangeable forms using the following relationships:

$$(\text{NH4AOC-K})_{\text{af}} = (\text{NH4AOC-K})_{\text{bf}} - (\text{Total-K})_{\text{plant}} + (\text{NExch-K})_{\text{released}} \qquad (1)$$

where:

$(\text{NH4AOC-K})_{\text{af}}$ is the Exch-K content of the soil after harvest
$(\text{NH4AOC-K})_{\text{bf}}$ is the Exch-K content prior to cropping
$(\text{NExch-K})_{\text{released}}$ is the amount of NExch-K which has been displaced to replenish the pool of Exch-K as it is being depleted by plant uptake.

The NExch-K released can effectively be regarded as having been taken up by the plant as, without its contribution, the content of $(\text{NH4AOC-K})_{\text{af}}$ would be lower than was actually measured. Hence:

$$(\text{Total-K})_{\text{plant}} = (\text{Exch-K})_{\text{plant}} + (\text{NExch-K})_{\text{released}} \qquad (2)$$

$(\text{Exch-K})_{\text{plant}}$ was determined by the difference between NH_4AOC before and after cropping, since by rearranging (1) and substituting $(\text{Total-K})_{\text{plant}}$ with (2) it can be shown that:

$$(\text{NH4AOC-K})_{\text{bf}} - (\text{NH4AOC-K})_{\text{af}} = (\text{Exch-K})_{\text{plant}} \qquad (3)$$

Using equation (2), $(\text{NExch-K})_{\text{released}}$, referred to hereafter as $(\text{NExch-K})_{\text{plant}}$, was determined by subtracting from $(\text{Total-K})_{\text{plant}}$ the content of $(\text{Exch-K})_{\text{plant}}$.

It must be noted that this method tends to overestimate the uptake of Exch-K and underestimate that of NExch-K. This is because the decrease in NH_4AOC-K was entirely attributed to the uptake of the vegetative part of the plant. Potassium uptake by the roots was not included in the balance sheet.

The greenhouse parameters were used to determine an index of the buffer power (BP) of the pool of soil NExch-K by computing the ratio $(\text{NExch-K/Exch-K})_{\text{plant}}$.

Results

General properties of the soils

The data reported in Table 1 show that, despite considerable overlap in the range of values associated with the physico-chemical properties of the different soil groups, significant differences in clay, carbon and CEC do occur.

The soils tended to be non-K fixing, as shown by the high values of the potassium desorption index (KDI). The values suggest that, on average, 3 kg K/ha is needed to raise the level of NH_4AOC-K by 1 ppm.

Mineralogical composition of the silicate clay fractions (Table 2) indicated that, while the duplex soils tended to be dominated by 2:1 lattice clays, the T&D and R&L groups consisted predominantly of 1:1 lattice clays. A further distinction between the duplex and other soil groups was the lower content of feldspars and larger amounts of mica.

Forms of soil potassium

The content of W-K was small compared to the amount of NH_4AOC-K (Table 3). For all practical purposes, NH_4AOC-K in the selected soils can be regarded as representing the exchangeable form of soil potassium and is approximately 40% of the total potassium extracted by HNO_3.

The effect of clay mineralogy on the distributions of soil potassium

Table 4 illustrates the importance of clay mineralogy on the distribution of soil potassium forms. The non-mica soils

Table 1

Some of the properties of the selected soils

Soil groups	n	Clay (%)		C (1) (%)		CEC (2) (meq/100gr soil)		KDI (3)	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
T & D	21	19-51	35	1,5-3,1	2,2	9,3-26,1	16,6	0,80-1,00	0,92
R & L	17	20-59	45	1,0-3,3	2,4	7,1-25,8	17,5	0,82-1,00	0,93
H & Z	17	14-39	30	1,2-2,1	1,5	5,2-23,9	14,1	0,70-1,00	0,88
Significance			**		**		NS		NS

Note: ** significant at P = (0,01)
NS non-significant

1. by the Walkley and Black procedure (1934)
2. in NH_4AOC buffered to pH 7
3. KDI: Potassium desorption index by the method of Arafin *et al.* (1973)

Table 2

Mineralogical composition of selected soils

Soil groups	2:1 Clay									1:1 Clay					
	Smectite			Mica			Inter-strat			Kaolinite			Feldspar		
	% Clay												% Soil		
	n (1)	Range	Mean	n	Range	Mean	n	Range	Mean	n	Range	Mean	n	Range	Mean
T & D n = 11	11	13-36	25	6	0-30	12	1	0-26	2	11	22-81	61	11	0,73-3,88	2,10
R & L n = 8	8	10-60	25	6	0-18	11	0	-	-	8	64-80	65	8	0,50-8,39	3,22
H & Z n = 9	8	0-45	32	7	0-49	29	2	0-24	4	7	0-59	35	7	0-3,81	1,55
Significance			NS			**			*			**			**

(1): number of samples containing the mineral

* NS non significant, * significant at P = (0,05), ** significant at P = (0,01)

Table 3

The distribution of soil-K forms prior to cropping in the three soils groups

Soil groups	W-K (mg/kg soil)		NH_4AOC-K (mg/kg soil)		NExch-K (mg/kg soil)		% of NH_4AOC-K of total (1)		K/CEC (%)	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
T & D n = 21	0,94-7,27	2,84	83-252	155	11-763	278	17-92	39	1,29-5,18	2,54
R & L n = 17	0,95-8,07	2,84	100-293	163	28-371	207	21-79	43	1,27-45	2,58
H & Z n = 17	1,02-7,31	2,45	71-271	163	67-714	278	13-58	34	1,54-6,38	3,07
Significance		NS		NS		*		NS		NS

W-K = water soluble potassium, NH_4AOC-K = amonium extractable potassium, NExch-K = non exchangeable potassium
(1) Total = NH_4AOC-K + NExch-K
NS non significant, * significant at P = (0,05), ** significant at P = (0,01)

Table 4

The effect of mica content on the distribution of the forms of soil potassium prior to cropping

Mineralogical category	Distribution of soils	Clay (%)		NH_4AOC-K (g/kg soil)		NExch-K (g/kg soil)		K/CEC (%)	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
Mica soils n=20	T=6, R=6, H=8	16-59	35	77-293	162	83-293	322	1,45-5,21	3,07
Non-mica soils n=8	T=5, R=2, H=1	29-49	41	77-155	125	77-155	145	1,52-2,38	1,83
Significance			NS		NS		*		**

NS non significant, * significant at P = (0,05), ** significant at P = (0,01)

were found to contain less potassium, especially NExch-K, and had lower K/CEC ratios (a sign of stronger Ca + Mg antagonism) than the micaceous soils.

The data also showed that the non-mica group tended to be dominated by the heavy soils, especially the T and R sets. It is clear, however, that although a degree of association exists between clay content and mineralogy, clay content was a poor predictor of mineralogy or NExch-K reserves. Some of the high clay soils contained mica, while some of the light soils contained no mica. The results suggest that a better predictor of clay mineralogy and NExch-K reserves is the ratio K/CEC for which statistically significant differences between the two mineralogical groups were found.

The effect of clay content on the distributions of soil potassium

Table 5 shows the distributions of soil-K forms according to the clay categories used by the FAS. None of the clay categories were dominated by a single soil type. However, duplex soils were absent where clay content exceeded 40%, whereas most R set soils fell into this category.

Significant differences in the distribution of soil-K forms were found between clay categories. The value of K/CEC decreased from the light to the heavy soils despite the fact that levels of NH_4AOC-K were lower in the light soils. This suggests that antagonism by Ca + Mg in potassium uptake could be more severe in the heavy soils. The increase in NExch-K was not linearly related to clay content. The largest

Table 5

Clay content versus the distribution of soil-K forms prior to cropping

Clay category (%)		Distribution of soil types	NH_4AOC-K (mg/kg soil)		NExch-K (mg/kg soil)		% of NH_4AOC-K of total (1)		K/CEC (%)	
			Range	Mean	Range	Mean	Range	Mean	Range	Mean
0-30	n = 17	T = 7, L = 2, H = 8	71-271	128	67-763	224	17-58	35	1,5-6,4	3,38
30-40	n = 17	T = 5, L = 1, R = 2, H = 9	102-265	192	11-714	354	13-92	35	1,4-4,0	2,80
> 40	n = 21	T = 9, R = 12	102-293	160	22-504	203	18-83	44	1,3-3,9	2,14
Significance				**		*		NS		**

(1) Total = NH_4AOC-K + NExch-K
NS non significant, * significant at P = (0,05), ** significant at P = (0,01)

Table 6

Partitioning of the potasssium uptake by the vegetative part of the plant

Clay category (%)		Total-K (mg/kg soil)		Exch-K (mg/kg soil)		NExch-K (mg/kg soil)		BP (1)	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
0-30	n = 17	69-199	117	24-157	72	14-84	45	0,14-2,37	0,93
30-40	n = 17	91-273	170	36-157	103	34-155	67	0,23-1,89	0,79
> 40	n = 21	44-354	169	42-217	96	2-137	73	0,05-1,70	0,82
Significance			**		NS		*		NS

(1)BP = Buffer power index $(NExch\text{-}K/Exch\text{-}K)_{plant}$
NS non significant, * significant at P = (0,05), ** significant at P = (0,01)

reserve of NExch-K was found in the intermediate 30-40% clay category, while both the light and heavy soils had similar contents of NExch-K. This again demonstrates that clay content alone is unreliable for predicting the NExch-K content of soils. The low content of NExch-K in the heavy soils tended to reflect their low content of potassium bearing minerals (mica). In contrast, in the light soils, the low content of NExch-K was more a reflection of their low clay content.

Plant uptake of potassium

Although the growth period was short and despite being underestimated, NExch-K accounted for about 40% of the total potassium taken up by the plants (Table 6). At the end of this short experiment, the pool of Exch-K had considerably depleted. The amount of exchangeable potassium removed by the plants over the six weeks growth period averaged more than 50% of the initial levels of NH_4AOC-K.

In spite of its larger NExch-K soil reserve, $(NExch\text{-}K)_{plant}$ in the intermediate clay category was not different from that of the heavy clay soils. In contrast, $(NExch\text{-}K)_{plant}$ in the low clay category was smaller than that of the heavy clay, despite similar contents of NExch-K soil reserves. This suggests that the soil content of NExch-K did not govern the uptake of potassium by plants in this experiment and that the pattern of replenishment of NH4AOC-K by the pool of NEXch-K was independent of clay. Additional evidence for this was the similarity in values of the buffer power index (BP) in all clay categories, as well as the non- significant correlations between NExch-K and plant potassium uptake (Table 8).

Regression analysis

The NH_4AOC procedure appeared to correlate best with potassium uptake by six weeks old maize (Table 7 for NH4AOC-K and Table 8 for NExch-K).

Table 7

Regression functions of best fit between $(Total\text{-}K)_{plant}$ (Y) and soil NH_4AOC-K (x) in three soil categories

Clay category (%)	Regression equation	R	Value of Y when x = 70	150	250
0-30 n = 17	Y = 0,62 x + 32	0,899	78	131	197
30-40 n = 17	Y = 0,73 x + 29	0,721	53	139	212
> 40 n = 21	Y = 0,84 x − 1	0,840	58	125	209

Table 8

Regression between soil NExch-K and $(Total\text{-}K)_{plant}$ and $(NExch\text{-}K)_{plant}$ - R values

Clay category (%)		Soil NExch-K vs	
		$(Total\text{-}K)_{plant}$	$(NExch\text{-}K)_{plant}$
0,30	n = 17	0,498*	0,107
30-40	n = 17	0,126	0,089
> 40	n = 21	0,321	0,105

* significant at P = (0,05)

The initial level of NH_4ACO-K was found to relate well to $(Exch\text{-}K)_{plant}$ (Figure 1). The relationship was not affected by clay content. The fact that a standard regression equation could adequately describe the relationship for all soils shows that NH_4AOC-K was equally available to plants in all soils.

The regression equations in Table 7 show that, at a given level of NH_4AOC-K, $(Total\text{-}K)_{plant}$ tended to be similar in the different clay categories. This suggests that, over the short term, uptake of potassium is controlled by the level of NH4AOC-K and is independent of clay content.

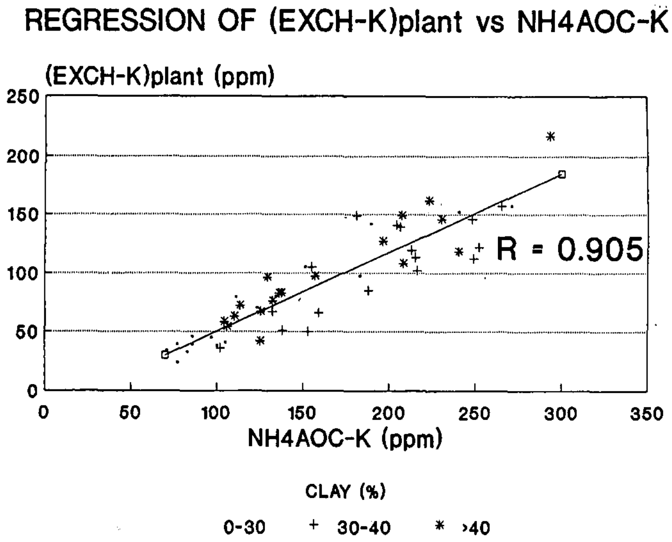

FIGURE 1

In general, the content of NH_4AOC-K related poorly to the soil content of NExch-K. The correlation coefficients (R) were 0,604, 0,436 and 0,536 for the 0-30, 30-40 and <40% clay categories respectively. Good correlations between these two parameters were obtained in soils of homogenous mineralogy, even when the clay type consisted of intergrades (Sharpley, 1989). The lack of correlation in the Swazi soils reflects the considerable heterogenity in clay mineralogy.

Discussion

The results of this experiment established the dominance of the exchangeable form of potassium in controlling the supply of soil potassium to plants over a short period of growth. No justification was found for adjusting the NH_4AOC-K threshold of short term crops according to clay content. The availability of NH_4AOC-K was shown not to be influenced by clay content. Although differences in NExch-K reserves existed between clay categories, the ability of the pool of NExch-K to buffer the depletion in Exch-K was found to be independent of clay content.

The situation could be different for long term crops feeding heavily on potassium, as in the case of a sugarcane cropping cycle. Despite the short duration of the experiment, the NH_4AOC-K content of the soils was found to deplete rapidly, while NExch-K was shown to supply a significant amount of the plant potassium. These trends suggest that, under prolonged cropping, plants are likely to rely increasingly upon the pool of NExch-K for their potassium requirement. NH_4AOC-K was found to relate poorly to NExch-K. It is therefore unlikely that NH_4AOC-K alone is sufficient to evaluate the potassium-supplying power of the soil over the long term. It would appear that, for long term crops, supplementing NH_4AOC-K with some measure of the NExch-K status of the soil would be useful.

Although clay content brought differences in the size of the NExch-K reserves, scrutiny of the relationships between clay mineralogy, NExch-K reserves and clay content showed that clay content was a poor index of NExch-K content.

Evidence presented in this work indicated that the size of the pool of NExch-K is not the most important factor in determining the amount of NExch-K released to plants. In considering the availability of NExch-K, Wood and Schroeder (1991) showed that the rate of release of the NExch-K pool matters more than the size of the reserve.

Kinetics consideration apart, the low content of NExch-K reserves in the heavy (>40%) clay soils, must be viewed with concern. The ability of these soils to supply potassium over the long term may be more limited than that of the soils of the intermediate clay category. Higher levels of NH_4AOC-K (higher threshold) for long term crops in the heavy soils could be justified in order to offset the lack of NExch-K reserves. In addition, antagonism between Ca, Mg and K has been shown to be more severe in the intermediate and high clay category soils than in the light soils. Higher levels of NH_4AOC-K may be justified in these categories in order to compensate for the stronger Ca + Mg antagonism.

Conclusion

The results of this experiment support previous findings that there is merit in determining the non-exchangeable reserves of potassium of Swaziland soils. If any justification exists to increase in the FAS system the NH4AOC-K threshold with increasing clay content, it did not lie in differences in the availability of the exchangeable potassium. It appeared rather to stem from differences in the distribution of either non-exchangeable potassium or potassium saturation levels, which tended to be less favourable in the heavy clay soils than the light ones. It is recommended that, in future calibration work on potassium extraction methods, a full characterisation of the aspects of non-exchangeable soil K be included to assist with the understanding of the complex processes which characterise the potassium supply to sugarcane in the heteregenous soils of the Swaziland sugarbelt. For advisory purposes the NH_4AOC procedure should be supplemented with a measure of the status of the NExch-K as is practised in the Australian sugar industry.

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