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IMPROVING THE PREDICTION OF POTASSIUM REQUIREMENTS FOR IRRIGATED CANE ON BASE SATURATED LOWVELD SOILS

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Abstract

An investigation was conducted to determine whether current soil threshold values for predicting the K requirement of irrigated cane could be improved. Results from 26 K fertilizer trials in Swaziland and the Eastern Transvaal were summarised and yield responses to applied K correlated with various soil-K parameters. These included ammonium acetate exchangeable K, and the ratios K/clay, Ca + Mg/K and K/K + Ca + Mg. It was concluded that soil threshold values generally underestimated K requirement for irrigated cane grown on a winter cycle. K threshold values based on ammonium acetate exchangeable K were dependent on the sum of exchangeable Ca + Mg rather than clay content of the soil. The higher the value of the Ca + Mg/K ratio the greater was the probability of a response to applied K. For diagnostic purposes Ca + Mg/K ratios of 15 and 26 for winter and summer cut cane respectively provided a good separation between cane responding or not responding to additional K fertilizer. The results indicated that using the conventional soil K threshold value in conjunction with the Ca + Mg/K ratio would greatly improve the prediction of K requirement on base saturated lowveld soils. New soil-K threshold values are proposed and a method for predicting K fertilizer rates based on the use of a K desorption index is discussed.

Introduction

Potassium fertilizer recommendations for sugarcane growing in South Africa and Swaziland are based on the determination of soil exchangeable K by the 1N ammonium acetate procedure. For several years leaf analyses had indicated that K uptake by winter harvested irrigated cane growing on base saturated soils of the Eastern Transvaal and Swaziland was often severely depressed despite apparently adequate levels of exchangeable K. However, the results of a series of K trials conducted on Ca and Mg saturated clays of the Eastern Transvaal confirmed that winter cut cane responded significantly to early applications of K fertilizer (Donaldson *et al.*, 1990). This indicated that the supply of K from the soil was inadequate during the spring and early summer and resulted in an increase in soil K threshold values from 150 ppm to 225 ppm for soils with more than 40% clay.

Although the introduction of this new threshold value improved the probability of correctly predicting a response to K fertilizer in this soil category from 0,64 to 0,78, there was concern that a threshold value of 225 ppm K was too low for the more strongly K fixing heavy textured soils that occur in Swaziland (unpublished data).

Donaldson *et al.* (1990) suggested that K threshold values should be linked to a Ca + Mg soil ratio, and the potassium desorption index (KDI) or K fixing capacity of a soil could be used to determine the relative effectiveness of applied K. At the time there were insufficient data to confirm the diagnostic value of these soil K parameters. An investigation was subsequently undertaken, using data obtained from K fertilizer trials over the past decade on base saturated soils from both Swaziland and the Eastern Transvaal. The objective was twofold: firstly to validate the soil threshold value of 225 ppm K; and, secondly to determine whether the Ca + Mg ratio, or any other ratio related to soil K or the KDI value, would improve the prediction of K fertilizer requirement on base saturated soils.

Procedure

The evaluation was divided into four phases:

- Creating a K yield response soil data base.
- Testing the reliability of yield response data against current soil K threshold values.
- Developing new threshold values for K.
- Calibration of soil K desorption made in terms of K requirement.

Nature of data base: The K data set comprised cane and sucrose yields, and soil analytical data from 77 crop harvests obtained from 43 NK or K fertilizer trials, conducted between 1981 and 1991, in the irrigated areas of Swaziland and the Eastern Transvaal lowveld. All trials were superimposed on existing commercial fields of ratoon cane and comprised three K treatments, with application rates varying from zero to 600 kg K/ha. The cane variety most often used in Swaziland was NCo376, and both N14 and J59/3 were grown on the trials located in the Eastern Transvaal. For the purpose of minimising seasonal effects, trials harvested during winter (May to August) were separated from those harvested in summer (September to November). Data from selected winter harvested trials are summarised in Table 1.

Testing current soil K threshold values: The yield response to applied K was calculated by subtracting the sucrose yield obtained when no K fertilizer was applied from the yield obtained when the optimum amount of K was used. A minimum response of one ton sucrose/ha was considered to be acceptable because the monetary return based on the additional K was profitable. The responsive and non-responsive trials were classified in terms of the current K threshold values used by the Fertilizer Advisory Service at the Experiment Station and are shown for the winter and summer cycle trials in Table 2.

Developing new threshold values for K: To overcome the variation in sucrose yield that existed between experiment sites and different seasons, relative yield of sucrose (% Y) was used as the dependent variable in a regression analysis with various soil K parameters. Relative sucrose yield was computed by taking the yield of sucrose from the control treatment as a percentage of the highest yield obtained in each experiment. The soil K parameters in the regression study included ammonium acetate exchangeable K and the ratios $\frac{Ca + Mg}{K}$, $\frac{K \times 100}{K + Ca + Mg}$ and $\frac{K}{clay}$ (ppm).

The regression functions of best fit and the correlation coefficients obtained for winter and summer cut cane are summarised in Table 3.

Assessment of potassium fixation: Previous work has emphasised the importance of a knowledge of K fixation in assessing the availability of K in heavy clay soils containing mainly 2:1 lattice clay minerals (Meyer and Wood, 1985). K fixation capacity of soils from the various trial sites was assessed by interpolation from K adsorption isotherms using a method that was developed at the University of Georgia (Arifin *et al.*, 1973). K desorption isotherms were obtained by relating the amount of K that was added to the soil with that recovered by extraction with ammonium acetate. K desorption isotherms for a range of Swaziland soils are shown in Figure 1. The slope of the curve provides an indication of the fraction of added K that is exchangeable, and is referred to as the K desorption index (KDI). Laboratory KDI values (KDI 1) of the topsoils from most of the trial sites are shown in Table 1.

An estimate of field KDI values (KDI f) was also made by plotting for each trial residual levels of ammonium acetate exchangeable K in topsoil samples taken six months after K fertilizer treatment, against rates of additional K fertilizer (Figure 2). The slope of the line joining the two points determined the (KDI f) value.

Evaluation of response data in relation to soil K threshold value

Winter cycle cane: Generally the current soil K threshold values did not provide a good separation between K deficient and non-K deficient soils. Unexpected positive responses occurred in all categories of soil clay content (Table 2). Most of them occurred in the intermediate (30-40% clay) and heavy textured (>40% clay) soil categories. Positive responses to applied K were correctly predicted in only 10 out of 28 crops. This implies that K requirement would have been underestimated in the remaining 18 crops.

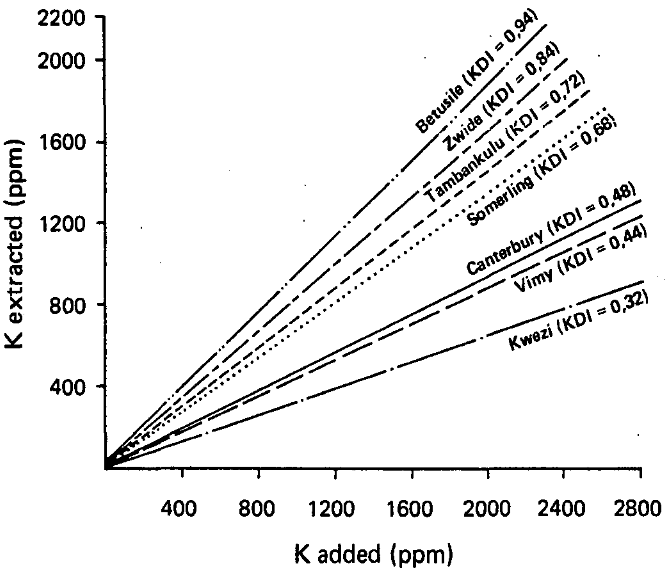

FIGURE 1 K desorption isotherms for seven Swaziland soils.

Table 1

Summary of results from K trials cut early season (winter cycle)

Trial	Variety	Soil set	Clay %	CEC meq %	KDI (1)	Control base status			Current K threshold ppm	$\frac{Ca + Mg}{K}$ ppm	$\frac{K}{K + Ca + Mg}$ meq %	t suc/ha			Stat sign	% Y
						K ppm	Ca ppm	Mg ppm				K_0	K_1	K_2		
K2/86	NCo376	'V'	59	53,7	0,79	514	8153	2150	225	20,4	2,20	14,6	15,9	14,8	NS	0,92
K3/89	NCo376	'T'	47	23,6	0,85	277	1989	950	225	10,6	3,82	19,6	21,7	21,6	S	0,90
K3/90	NCo376	'T'	47	23,6	0,85	198	2570	818	225	17,1	2,52	20,4	23,1	21,9	S	0,88
K3/91	NCo376	'T'	47	23,6	0,85	264	3145	848	225	14,9	2,88	17,5	20,1	19,2	S	0,87
K4/89	NCo376	'K'	59	57,1	0,67	290	9863	843	225	36,9	1,30	10,5	12,4	13,4	S	0,78
K6/91	NCo376	'R'	46	14,9	0,64	152	1357	752	225	12,9	2,90	13,9	15,2	15,6	S	0,89
K10/91	NCo376	'S'	44	25,5	0,63	261	2533	1065	225	13,8	3,01	22,2	22,2	22,6	NS	0,98
S10/91	NCo376	'Z'	35	13,9	0,59	187	1417	585	150	10,7	3,85	14,3	15,7	–	NS	0,91
Exp 1/90	N14	Sd	57	44,8	0,59	204	6748	1269	225	39,0	1,17	11,6	15,1	15,1	S	0,77
Exp 2/90	N14	Sd/Ar	63	38,5	0,82	175	2151	3283	225	31,0	1,16	10,3	14,2	14,0	S	0,72
Exp 3/90	J59/3	Sd	28	19,3	0,98	234	1848	1141	112	13,0	3,10	15,4	15,3	16,9	NS	0,91
Exp 4/90	N14	Sd	20	36,1	0,63	177	5882	749	112	37,0	1,26	13,5	16,7	15,3	S	0,81
NK1/82	NCo376	'Z'	30	11,7	0,84	116	1005	768	150	14,5	2,84	8,6	9,1	9,8	S	0,88
NK3/82	NCo376	'T'	41	21,4	0,72	145	1757	1470	225	22,6	1,97	15,1	16,0	16,3	NS	0,93
NK3/83	NCo376	'T'	41	21,4	0,72	136	1426	1670	225	23,3	1,87	14,0	15,2	15,0	NS	0,92
NK3/84	NCo376	'T'	41	21,4	0,72	121	1757	1477	225	26,3	1,68	16,0	18,3	18,9	S	0,85
NK4/82	NCo376	'K'	61	58,0	0,32	350	>1800	>220	225	24,5	(1,79)	18,8	19,5	19,8	NS	0,95
NK4/83	NCo376	'K'	61	58,0	0,32	337	>1800	>220	225	25,7	(1,72)	16,7	17,0	19,3	S	0,81
NK4/84	NCo376	'K'	61	58,0	0,32	327	>1800	>220	225	26,3	(1,68)	15,6	17,7	17,7	S	0,88
NK4/85	NCo376	'K'	61	58,0	0,32	271	>1800	>220	225	31,5	(1,41)	12,4	14,6	15,1	S	0,82
NK8/84	NCo376	'T'	46	17,9	0,72	119	>1800	>220	225	22,6	(1,92)	13,1	15,5	17,6	S	0,74
NK8/86	NCo376	'T'	46	17,9	0,72	96	>1800	>220	225	27,9	(1,60)	14,3	15,5	16,3	S	0,88
NK9/85	NCo376	'Z'	20	13,5	0,84	187	1332	63	112	10,3	3,88	15,4	14,9	15,5	NS	0,89
NK9/86	NCo376	'Z'	20	13,5	0,84	150	1336	489	112	12,2	3,45	16,8	16,3	16,9	NS	0,99
NK11/85	NCo376	'R'	59	17,1	0,82	271	1703	942	225	9,1	4,35	16,1	17,0	17,8	NS	0,90
NK11/86	NCo376	'R'	59	17,1	0,82	205	>1800	>220	225	12,0	(3,39)	19,0	18,5	19,2	NS	0,99
NK16/87	NCo376	'S'	34	21,7	0,82	190	2459	587	150	16,0	2,76	15,4	16,0	15,8	NS	0,96
NK16/88	NCo376	'S'	34	21,7	0,82	184	2459	587	150	16,6	2,67	15,8	16,8	15,8	NS	0,94
NK16/89	NCo376	'S'	34	21,7	0,82	185	2608	800	150	18,4	2,33	13,6	15,0	15,2	S	0,89
NK16/90	NCo376	'S'	34	21,7	0,82	164	2740	831	150	21,8	2,00	13,7	14,9	15,9	S	0,88
NK16/91	NCo376	'S'	34	21,7	0,82	154	2538	916	150	22,4	1,91	11,6	12,8	13,5	S	0,88

( )—estimated values

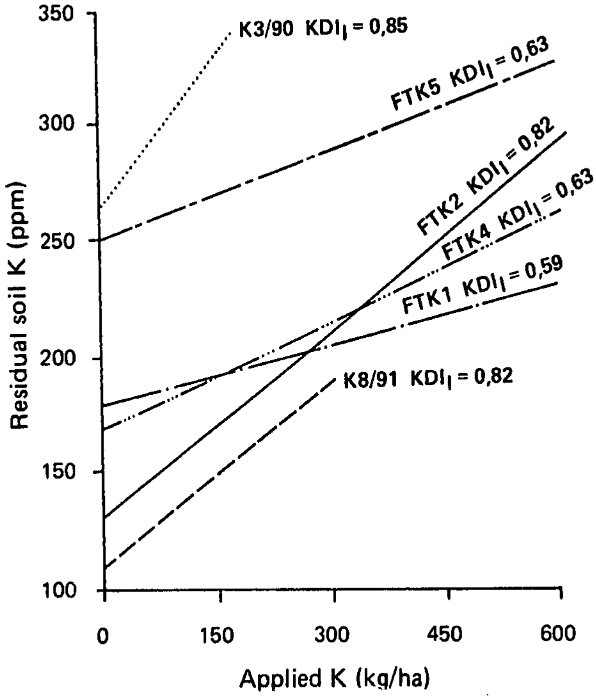

FIGURE 2 Relationship between applied K treatment and residual soil exchangeable K values.

Summer cycle cane: Although some unexpected responses to applied K occurred, these were minimal and generally the threshold values provided a good separation between K deficient and non-K deficient soils (Table 2). Positive responses to applied K were correctly predicted in eight out of 10 crops with pre-treatment K levels being below the respective threshold values. Neither of the two unexpected responses were statistically significant. Of the 18 crops that did not respond to applied K, four should have responded positively as the pre-treatment K levels were below the respective soil K threshold values.

Correlation between sucrose yield and soil K parameters

The regression study between sucrose yield and the various soil K parameters for both winter and summer cycle cane showed that ammonium acetate exchangeable K was poorly correlated with sucrose yield (Table 3). However the $\frac{Ca + Mg}{K}$ and $\frac{K \times 100}{K + Ca + Mg}$ soil ratios (meq %) were generally significant for both winter and summer cycle cane, and the $\frac{K\ ppm}{clay}$ ratio was significant only for the winter cycle cane.

The $\frac{Ca + Mg}{K}$ ratio proved to be superior as a diagnostic criterion and the greater the value of this ratio the greater was the probability of a response to applied K.

Table 2

Responses to applied K in relation to pre-plant soil K status and textural class (winter and summer harvested trials)

Harvest cycle	Soil K (ppm)	<30% clay		30–40% clay		>40% clay				Total	
						Non-vertic		Vertic			
		Resp.*	No resp.	Resp.*	No resp.	Resp.	No resp.	Resp.	No resp.	Resp.	No resp.
Winter	<112										
	112-150	1	1	1 (1)		5 (3)				7 (4)	1
	150-225	1 (1)	4	6 (3)	1	4 (4)	1			11 (8)	6
	>225	1	1		1	3 (2)	1	6 (4)	1	10 (6)	4
	Total	3 (1)	6	7 (4)	2	12 (9)	2	6 (4)	1	28 (18)	11
Summer	<112	2 (1)	2							2 (1)	2
	112-150		1					1 (1)		1 (1)	1
	150-225			1		3 (2)	2	2 (1)		6 (3)	2
	>225		9			1	4			1	13
	Total	2 (1)	12	1		4 (2)	6	3 (2)		10 (5)	18

* When response to K is at least 1 t suc/ha
( ) Significant at P = 0,05

Table 3

Regression functions of best fit between relative sucrose yield (% Y) and various soil-K parameters (x)

Soil-K parameters	Winter cut cane			Summer cut cane		
	Equation	r		Equation	r	
Exchangeable K	Non significant			Non significant		
Ca+Mg/K meq%	% Y = −0,00279x + 1,016	−0,742**	(4)	% Y = −0,00080x + 0,967	−0,658**	(7)
K.100/K+Ca+Mg meq%	% Y = 1 − 0,443 $10^{-0,268x}$	0,731**	(5)	% Y = 0,100 $10^{-0,0634x}$	0,628*	(8)
K_{ppm}/clay	% Y = 1 − 0,240 $10^{-0,0646x}$	0,407*	(6)	Non significant		

* significant at P = 0,05
** significant at P = 0,01

Extent of soil K fixation

Potassium fixation varied markedly, with KDI values ranging from 0,32 in strongly K fixing K set soils, to 0,94 for the more weakly K fixing Z and T set soils. KDI values associated with the R set soils ranged from 0,52 to 0,82. In a separate study of recently surveyed soils, it was established that soils from the Swaziland sugar industry were generally more strongly K fixing than those found in the South African sugar industry (unpublished data).

The affinity of the soils for K as measured by the slopes of the lines shown in Figure 1 declined in the order Kwezi > Vimy > Canterbury > Somerling > Tambankulu > Zwide. Comparison of the lines suggested that about four times more K is required to raise the concentration of the Kwezi soil solution to an equilibrium value of 200 ppm compared with the amount required for the Zwide soil. The lines indicated that the soils can be broadly grouped into three K fixation classes: those with KDI values below 0,55 (K, C and V sets), those where values range from 0,55 to 0,85 (R and T sets) and those with values above 0,85 (S, Z and W sets).

In practice, laboratory determined KDI values (KDI l) were lower than the KDI f values determined from the various curves shown in Figure 2. However, regression analysis using data from seven trials showed that these two parameters were satisfactorily correlated. The regression equation relating KDI l and KDI f was found to be: KDI f = 0,965 KDI l - 0,236 (r = 0,766*).

Discussion

Soil Ca and Mg content as factors influencing K uptake

The failure of the ammonium acetate exchangeable K values to correlate well with relative yield, whereas significant correlations were obtained when exchangeable K was used in conjunction with the exchangeable Ca and Mg status of the soil, demonstrates the strong dependence of K availability to cane on the Ca + Mg content of lowveld soils. It has been shown (Wood, 1985) that exchangeable K is a poor index for measuring K availability on base saturated soils in which 2:1 lattice clays predominate. Humbert (1971) stated that "high Ca and Mg saturation of many neutral to alkaline soils limits the quantities of K that can enter into sugarcane plants. Deficiency of K often exists with luxury consumption of Ca and Mg". The need to take cognisance of the level of Ca/Mg imbalance when interpreting soil data has been recognised for other crops (Cope and Rouse, 1973) and forms the basis of the 'basic cation saturation concept' in soil test interpretation as discussed by Beckett (1972) and McLean (1977).

Effect of K fixation

The difference in affinity between soils in fixing K may be ascribed to the differences in the surface areas of the clay minerals (Bühman *et al.*, 1985). It is known that the Kwezi soil has a high clay content with smectite as the dominant clay mineral, giving the soil its vertic character of a high shrink/swell potential. In general, K fixation showed no correlation with exchangeable K values. Soils with a similar exchangeable K content were associated with markedly different K concentrations in the saturation extract. These results agree with those of Grimme (1980) who reported that soils with a high exchangeable K content and a high K fixation capacity, may be more in need of K fertilizer than those with lower exchangeable K content, because of a lower K concentration in the soil solution. This could account for the response to applied K in the Kwezi soil, despite an initially high exchangeable K value of 350 ppm (see result from trial NK 4 in Table 1).

Improvements in predicting K requirement based on soil analysis

Base derived soil K threshold values

The results of the investigation showed that the prediction of K deficiency in base saturated clay soils of the irrigated lowveld can be substantially improved, by making K threshold values more dependent on the Ca + Mg content of the soil rather than on clay content. This implies that soils with a similar exchangeable K and clay content, but different Ca + Mg levels, would have a different K requirement. Regression analysis showed that for diagnostic purposes critical $\frac{\text{Ca + Mg}}{\text{K}}$ (ppm) ratios of 15 and 26 for winter and summer cycle cane respectively, provided the best separation between cane responding or not responding to additional K fertilizer. By rearranging these critical ratios, soil K availability was related to Ca and Mg in the following way:

$$\text{Winter cycle cane, K ppm} = \frac{\text{Ca + Mg}}{15}$$

$$\text{Summer cycle cane, K ppm} = \frac{\text{Ca + Mg}}{26}$$

These functions were used to compile the base derived soil K threshold values corresponding with different ranges of Ca + Mg content (ppm) shown in Table 4 for winter and summer cycle cane.

Table 4

Tentative K threshold values corresponding to different levels of Ca + Mg for winter and summer cycle cane

Exchangeable Ca + Mg content (ppm)	Soil K threshold (ppm)		Exchangeable Ca + Mg content (ppm)	Soil K threshold (ppm)	
	Winter	Summer		Winter	Summer
>7 000	450	270	4 000	265	155
6 500	430	250	3 500	235	135
6 000	400	230	3 000	200	110
5 500	365	210	2 500	165	110
5 000	330	190	2 000	135	110
4 500	300	175	<1 500	110	110

For a given level of soil Ca + Mg the exchangeable K threshold was greater for winter than summer cycle cane. This difference, not recognised before, could explain the depression in leaf K values of winter cut cane, as soil K status previously thought to be satisfactory may in fact have been deficient. The difference in threshold values between winter and summer can also be explained in terms of the temperature differential that exists between seasons, and its effect on the exchange and diffusion processes in the soil. During the cooler spring months the rate of K replenishment of the soil solution from the solid phase will be slower than that during the hot summer months (Donaldson *et al.*, 1990).

Calibration of the KDI procedure

KDI measurements have shown promise in this and previous studies, as the value provides an indication of the fraction of added K that is available. At present no cognisance is taken of the effect of K fixation in determining K requirement. The rate of increase in soil K to applied K, known as the K requirement factor (KRF), is inversely related to the KDI value. It has been established from the slopes of K desorption isotherms, that for strongly K fixing soils an application of 40 kg K/ha is required to raise the soil K level by 10 ppm; whereas about 25 kg K/ha is required in moderately K fixing soils, and 15 kg K/ha in weakly K fixing soils. The above relationships were used to compile a tentative set of K recommendations based on soil K deficit as illustrated in Figure 3. This shows that soils with the same K deficit but in different K fixation classes will have a different K requirement.

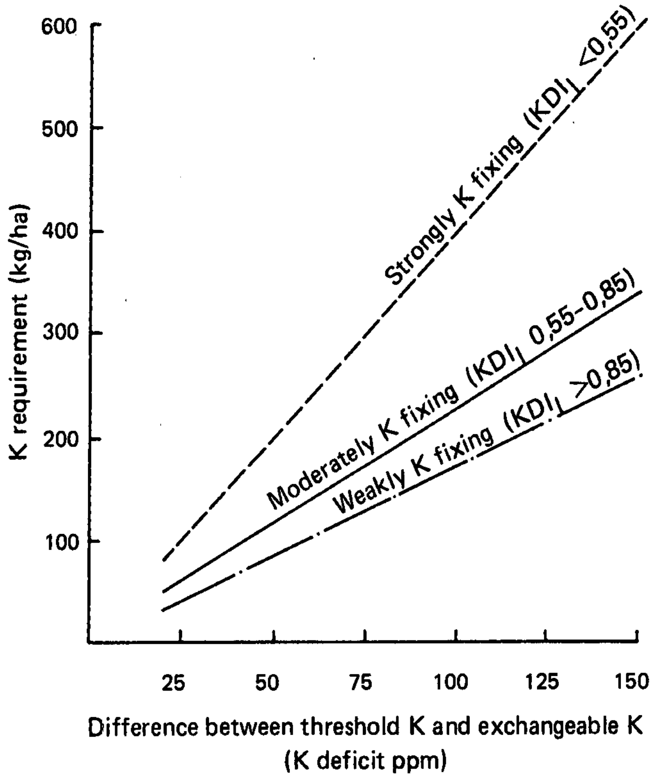

FIGURE 3 K requirement in relation to soil K deficit and KDI value for winter cycle irrigated cane.

Conclusions

The results of the investigation confirmed that current soil K threshold values of 150 ppm and 225 ppm for intermediate (30-40% clay) and heavy textured (>40% clay) soil categories, were inadequate for irrigated cane grown on a winter cycle in the lowveld, but appeared to be essentially correct for cane growing in a summer cycle.

Ammonium acetate exchangeable K is not a particularly good index for measuring K availability in base saturated soils in which 2:1 lattice clay minerals predominate, and there is a definite need to supplement the interpretation of K values by using the $\frac{Ca + Mg}{K}$ soil ratio.

It was apparent that soil K threshold values differed between winter and summer cycle cane. For diagnostic purposes, $\frac{Ca + Mg}{K}$ ratios of 15 and 26 for winter and summer cycle cane provided the best separation between cane responding or not responding to additional K fertilizer.

In drawing up K requirement tables, vertic soils should be separated from non-vertic soils in regard to selecting the appropriate threshold value.

In view of the KDI differential between South African and Swaziland sugar belt soils, provision should be made for the use of a KDI index to assist in the determination of K requirement of base saturated soils. However, further calibration against results from K field trials is first required.

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