RESPONSE TO POTASSIUM BY SUGARCANE GROWN ON BASE SATURATED CLAY SOILS IN THE EASTERN TRANSVAAL LOWVELD

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Abstract

Numerous leaf analyses had indicated that K uptake by winter cut cane (May to August) growing on Ca and Mg saturated clays of the Eastern Transvaal lowveld is often severely depressed, despite apparently adequate amounts of available soil K. Five trials were conducted to determine whether winter cut cane would respond to early (August) or late (October) applications of K fertilizer, and whether K recommendations for irrigated cane growing on these base saturated soils would require revision. Early application of K fertilizer gave greater sucrose yields than those obtained when K application was delayed until October. Responses to K fertilizer were related to foliar K levels and various soil properties. The results confirmed the need to increase the current K threshold value for this category of soils. The effects of soil K fixation, and seasonal changes in soil temperature and moisture content on K uptake were assessed and the results used to develop a seasonal correction factor for leaf K values during the early part of the growing season.

Introduction

Despite apparently adequate amounts of available soil K, numerous leaf analyses showed that in the highly calcium (Ca) and magnesium (Mg) saturated clay soils of the Eastern Transvaal and other areas of the lowveld, K uptake was depressed, particularly during the early stages of growth of winter harvested cane (May to August). From August to November before rapid summer growth commences, and the ratoon crop is two to five months old, leaf K values are often in the deficient to highly deficient range based on the current FAS threshold value of 1,05% K, while Ca and Mg values are above average to excessive (0,35 to 0,70%). Meyer *et al*[7] reported in a recent survey that between 1980 and 1988, 53% of all leaf samples analyzed from the Eastern Transvaal were K deficient. While it was recognized that there were various factors present which might restrict K uptake by cane in the Eastern Transvaal (Wood and Meyer[9]) it had not been established whether K deficiency during spring and early summer affected cane yield. A series of K trials was therefore conducted to determine whether the low leaf K values were indicative of potential yield loss. Data from the trials might indicate the need to increase the K threshold value further on these heavy clays, or to introduce a seasonal correction factor for the leaf K threshold value.

Experimental procedure

Description of sites: About 18% of sugarcane grown in the Eastern Transvaal is found on soils of the Shortlands form derived from basalt/diabase of the Komatipoort system (MacVicar and Perfect[5]). They are red-to-brown free-draining loams and clays of varying depths with stone inclusions. In many of the soils in the Malelane area, there is a predominance of 2:1 lattice clays which contain a high proportion of K selective clay minerals (Wood[8]), as well as large amounts of exchangeable Ca and Mg, and free lime is often found at depth.

Five fields, all of the Shortlands soil form, ranging in depth from 300 mm to over 1 000 mm and with a history of leaf K deficiency in spring, were selected as experimental sites on four different farms (see Table 1). Exchangeable bases in the soils were determined by extraction with 1N ammonium acetate while leaf samples were analyzed for K, Ca and Mg by X-ray spectrometry (Wood *et al*[10]). Chemically, the soils

Table 1

Selected characteristics of K trials sites

Expt. No.	Soil form	Variety	Crop cycle 1987/88	Soil depth range (mm)	Soil properties (0–200 mm): Physical: Clay %	Silt %	Sand %	Chemical: pH	P ppm	Ca ppm	Mg ppm	K ppm	NEAK** ppm	KDI	Ca + Mg / K ratio
1	Shortlands	N14	11/5–22/4	> 1 000	57	13	30	7,7	51	6 748	1 269	204	519	0,59	39
2	Shortlands/ Arcadia	N14	9/7–19/6	270–600	63	9	28	6,8	16	2 151	3 283	175	208	0,82	31
3	Shortlands	J59/3	25/8–13/6	560–920	28	17	55	6,8	23	1 848	1 141	234	1 208	0,98	13
4	Shortlands	N14	15/6–30/5	450–820	20	15	55	8,2	66	5 882	749	177	567	0,63	37
5	Shortlands	N14	*23/4–3/5	> 1 000	51	12	37	7,3	56	4 213	1 172	216	-	0,68	25

* 1988/89 ** non exchangeable available potassium

were neutral to alkaline in reaction and exchangeable K was above the 150 ppm K threshold value that was in use at the time.

Treatment design: The K fertilizer treatments and times of application for the five experiments are shown in Table 2. The trials were of a random block design and each treatment was replicated six times. Treatments 5 and 6 were intended to show whether fertilizer application in the second half of October would provide a better response than K application soon after harvesting. Two rates of K were tested, one as a split application. K fertilizer was always applied as potassium chloride banded by hand over the row.

Table 2
K treatments and times of application for the five K experiments

Treat. No.	kg K/ha applied	Experiment Number 1	2	3	4	*5
		Date of application				
First K application (early)						
1	0	-	-	-	-	-
2	300	17/6	23/9	16/9	9/9	13/5
3	300	17/6	23/9	16/9	9/9	13/5
4	600	17/6	23/9	16/9	9/9	13/5
5	0	-	-	-	-	-
6	0	-	-	-	-	-
Second K application (late)						
1	0	-	-	-	-	-
2	0	-	-	-	-	-
3	300	16/10	30/10	3/11	23/10	18/10
4	0	-	-	-	-	-
5	300	16/10	30/10	3/11	23/10	18/10
6	600	16/10	30/10	3/11	23/10	18/10

* K applied 1988 - remaining experiments K applied 1987

Management: The trials were superimposed on existing commercial fields of ratoon cane and normal farm husbandry was practised. N14 was the variety grown in all trials except experiment 3, where the variety was J59/3. In each experiment third leaf samples were taken at various intervals to monitor nutrient levels, and growth measurements were recorded to assess possible responses to treatments. No yields were recorded in experiment 5 as the trial was accidentally burnt.

Meteorological data were taken from the station at Kaalrug for experiment 2 and from the station at Mhlati for the remaining experiments. Monthly amounts of irrigation and rainfall and the estimated loss of moisture through evapotranspiration are shown in Table 3 for experiments 1 to 4. Estimates showed that excessive moisture was received in May, June and August 1987 in experiment 1, from September to December 1987 and February to April 1988 in experiment 2, and from July to September 1987 in experiment 4. Soil temperatures at 50 mm depth at both meteorological sites rose substantially only after October 1987. There were generally depressed evaporation rates from May to December during 1987 and 1988 relative to the long term average evaporation at Mhlati, and from September to December at Kaalrug during 1987.

Results

Cane growth: The effects of K treatments on stalk height or population, and cane and sucrose yields can be seen in Table 4 for experiments 1 to 4. In experiments 1, 2, 4 and 5 growth differences due to the early applied K treatments were soon apparent, while stalk heights were generally improved and responses were highly significant (P=0,01) in experiment 1. The number of millable stalks was also greater where additional potassium was applied reaching levels of significance in treatments 3 (P=0,01) and 5 (P=0,05) in experiment 4.

Yield and sugarcane quality: The growth responses resulted in statistically significant increases (P=0,01) in cane yield particularly in experiments 1 and 2. Generally the greatest responses were obtained where K fertilizer was applied soon after harvest. The early applications of K also produced higher sucrose yields than those obtained when K fertilizer application was delayed. The mean responses to treatment 2 (300 kgK/ha, early) and treatment 5 (300 kgK/ha, late) in experiments 1, 2 and 4 were 3,5 and 2,3 tons sucrose per hectare respectively. The substantial response in sucrose obtained in these three experiments to the early application of 300 kgK/ha was not improved by additional K fertilizer. Improvement in cane quality was generally apparent in all experiments following application of K fertilizer.

Table 3
Moisture and evapotranspiration data for experiments 1 to 4

	Measurement	1987 M	J	J	A	S	O	N	D	1988 J	F	M	A	M	J
Expt. 1	Total moisture mm/mth (irrig. + rainfall)	172	155	80	192										
	Estimated Et	40	61	92	118										
	Total moist. - Et	132	94	−12	74										
Expt. 2	Total moisture mm/mth (irrig. + rainfall)			63	134	256	244	237	250	219	447	286	256	12	24
	Estimated Et			42	106	106	140	127	161	215	177	156	127	103	103
	Total moist. - Et			21	28	150	104	110	89	4	270	130	129	−91	−79
Expt. 3	Total moisture mm/mth (irrig. + rainfall)				46	126	157	207	175	152	279	132	140	96	
	Estimated Et				10	74	134	142	176	204	138	109	86	71	
	Total moist. - Et				36	52	23	65	−1	−52	141	23	54	25	
Expt. 4	Total moisture mm/mth (irrig. + rainfall)		7	110	138	215	135	153	259	145	287	169	48	3	
	Estimated Et		17	59	83	105	158	143	176	204	183	145	114	95	
	Total moist. - Et		−10	51	55	110	−33	10	83	−59	104	24	−66	−92	

Table 4
Cane and sucrose yields and stalk heights, or population, for Experiments 1 to 4

Treatment kg K/ha Early	Late	Experiment 1 tc/ha	pol % cane	ts/ha	stalk Ht (mm)	Experiment 2 tc/ha	pol % cane	ts/ha	stalk ht (mm)	Experiment 3 tc/ha	pol % cane	ts/ha	stalk ht (mm)	Experiment 4 tc/ha	pol % cane	ts/ha	stalk popln. × 10^3
0	0	88	13,2	11,6	2 400	64	16,4	10,3	2 060	98	15,7	15,4	-	91	15,0	13,5	86
300	0	112**	13,5	15,1**	2 730**	84**	16,8	14,2**	2 130	96	16,0	15,3	-	109	15,5	16,7*	93
300	300	111**	13,6	15,0**	2 660**	85**	16,6	14,1**	2 060	99	15,8	15,6	-	111*	15,2	16,7*	108**
600	0	114**	13,3	15,1**	2 780**	82**	17,2	14,0**	2 170*	104	16,3	16,9	-	100	15,4	15,3	88
0	300	101	13,1	13,3	2 620**	76**	17,1	13,1**	2 010	102	15,6	15,9	-	103	15,4	15,9	104*
0	600	106*	14,2*	15,1*	2 550	77*	16,9	13,0**	2 130	108	16,0	17,4	-	102	15,5	15,8	89
Mean		105	13,5	14,2	2 620	78	16,9	13,1	2 090	101	15,9	16,1	-	103	15,3	15,6	95
CV%		13,4	5,4	14,5	5,4	9,0	5,3	10.0	4,0	13,2	6,5	14,1	-	16,5	4,1	14,7	12,5
SED		8,2	0,4	1,2	8,1	4,0	0,5	0,8	4,8	7,7	0,6	1,3	-	9,8	0,4	1,3	6,8
LSD (P=0,05)		16,9	0,9	2,5	168	8,3	1,1	1,6	99	15,9	1,2	2,7	-	20,1	0,7	2,7	14
(P=0,01)		22,9	1,2	3,3	228	11,3	1,4	2,1	133	21,5	1,7	3,7	-	27,2	1,0	3,7	19

Leaf analysis: Chlorotic leaves with necrotic tips and marginal firing were evident in all experiments, and weed competition became severe in untreated plots of experiments 1 and 5. Third leaf analyses showing K, Ca and Mg content at various dates of sampling for trials 1 and 2 are given in Table 5. In general the data confirmed the characteristic low leaf K, high Ca/Mg anomaly previously noted in the Eastern Transvaal and Swaziland (Wood and Meyer[9]) during the first five months of growth of winter harvested cane. K values showed a slight upward trend between August and October 1987, while from November onwards, K uptake increased markedly in all treatments, with a concomitant decline in Ca and Mg values. The decline in leaf Ca was almost a mirror image of the rise in K content in most experiments. In the four trials that showed a K response, K values in the untreated controls (no K fertilizer) were below the acceptable threshold value of 1,05% K. Initially however, the K values of the fertilized cane were also well below 1,05% K, and only from December onwards was leaf K status satisfactory. In experiment 3 where no response to K fertilizer was obtained, leaf K values from the untreated control plots were generally adequate throughout the sampling period (see Fig 1).

Table 5
Third leaf K, Ca and Mg values (DM%) at various ages in Experiments 1 and 2

Experiment 1

Age (months)		2,5 m			4 m			6 m			9 m		
Dates in 1987/88		24/7			14/9			13/11			10/2		
Treatment early	Treatment late	K	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K	Ca	Mg
0	0	0,25	1,20	0,68	0,33	1,15	0,48	0,39	0,90	0,46	0,72	0,46	0,33
300	0	0,35	1,19	0,63	0,51	1,01	1,01	0,75	0,61	0,36	1,09	0,34	0,27
300	300	0,32	1,19	0,64	0,50	1,03	1,03	0,78	0,57	0,26	1,12	0,32	0,28
600	0	0,38	1,09	0,61	0,59	0,97	0,97	0,91	0,58	0,58	1,15	0,34	0,28
0	300	0,30	1,15	0,64	0,33	1,16	1,16	0,53	0,78	0,78	1,10	0,34	0,27
0	600	0,30	1,14	0,62	0,28	1,20	1,16	0,54	0,76	0,69	1,10	0,31	0,25

Experiment 2

Age (months)		1,8 m			3 m			4,3 m			7 m		
Dates in 1987/88		2/9			8/10			16/11			9/2		
Treatment early	Treatment late	K	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K	Ca	Mg
0	0	0,38	0,36	0,74	0,43	0,42	0,63	0,59	0,31	0,58	1,02	0,20	0,30
300	0	0,34	0,33	0,70	0,45	0,38	0,60	0,80	0,30	0,54	1,05	0,19	0,33
300	300	0,37	0,31	0,71	0,52	0,48	0,69	0,79	0,28	0,52	1,05	0,21	0,33
600	0	0,42	0,31	0,67	0,52	0,42	0,59	0,94	0,26	0,40	1,15	0,19	0,31
0	300	0,38	0,28	0,61	0,48	0,45	0,69	0,73	0,23	0,46	0,94	0,23	0,34
0	600	0,37	0,30	0,70	0,43	0,42	0,67	0,69	0,21	0,43	1,05	0,19	0,30

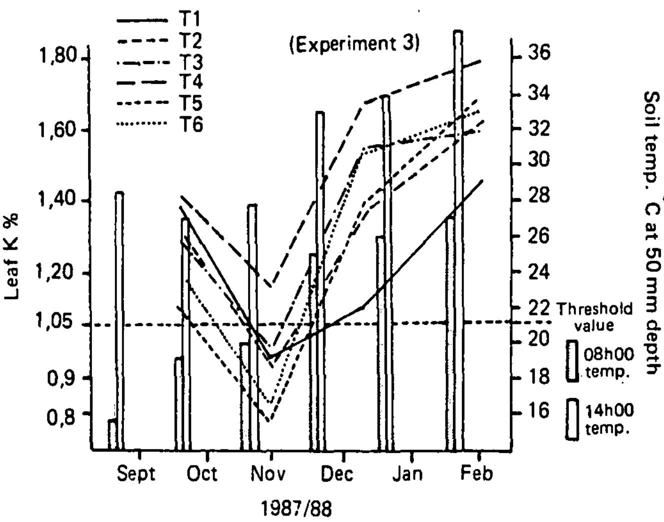

FIGURE 1 Changes in leaf K at various levels of applied K.

Soil analysis: Apart from moderate to marked increases in available soil K in the various treatments, levels of other nutrients were not affected. The residual effects of the early applications of K (300 kgK/ha) on extractable K values measured five months after application are shown in Fig 2. The increase in soil K varied between sites, a more rapid increase occurring in experiment 2 compared with experiments 1, 4 and 5. The rate of increase was inversely related to the soil K sorption capacity as measured by the K desorption index (KDI) value (Wood and Meyer[9]). On average, an application of 300 kgK/ha increased exchangeable K by 80 ppm in the soil in experiment 2 which had the lowest K sorption capacity (KDI 0,82), compared with an increase of only 30 ppm K in the soil at experiment 1 which had the highest K sorption capacity (KDI 0,59). The increase in exchangeable K also appeared to be inversely related to the degree of Ca saturation of the soil exchange complex. In

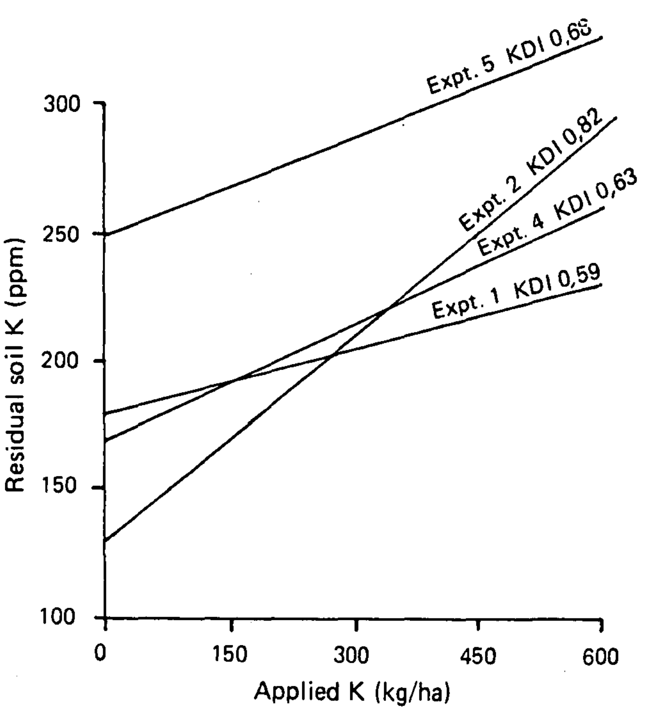

FIGURE 2 Relationship between applied K treatment and residual soil exchangeable K values.

trials 1 and 4 over 70% of the exchange complex was occupied by Ca ions whereas in trial 2 the situation was reversed, Mg being the dominant ion (70%) with Ca occupying only 27% of the exchange complex.

Discussion

Crop response relative to exchangeable K: Generally response to 300 kgK/ha applied early correlated well with the pre-treatment soil K content. The largest yield increase of 33% was obtained from the soil with the lowest exchangeable K value (experiment 2, 175 ppm K), while the smallest yield increase of 10% was obtained from the soil with the highest average exchangeable K value (experiment 3, 234 ppm K). Response to K fertilizer was also negatively correlated with the soil $\frac{Ca + Mg}{K}$ ratio, a significant response to applied K being generally associated with pre-treatment $\frac{Ca + Mg}{K}$ ratios of more than 20.

Crop response relative to leaf K content: Generally leaf K values, where K fertilizer treatments were applied, did not appear to provide a reliable indication of leaf K status relative to the current threshold value of 1,05% K, particularly during the early part of the growing season. In terms of yield response 300 kgK/ha applied early was found to be optimal; yet the associated leaf K values during much of the summer growth period would have been interpreted as highly deficient. Indications are that, based on a leaf threshold value of 1,05% K, the K fertilizer requirement is often being overestimated under these particular conditions, and that it will be necessary to adjust the threshold value during the spring and early summer to accommodate various seasonal effects.

Factors affecting K uptake

Wood and Meyer[9] considered various factors that could influence the rate of K release from soils. Three of these factors are now briefly reconsidered to help to explain the observed variations in leaf K uptake, and so provide an improved system for interpreting leaf and soil K values.

Ca and Mg antagonism: The increase in leaf K content with time in the untreated control treatments of the various trials was inversely correlated with leaf Ca and Mg content, which in turn was a function of the combined exchangeable Ca and Mg status of the soil. The higher the combined $\frac{Ca + Mg}{K}$ ratio, the greater was the time that leaf K uptake was apparently depressed due to enhanced uptake of Ca and Mg. These results support those of Humbert[4] who reported that "high Ca and Mg saturation of many neutral to alkaline soils unquestionably limits the quantities of K that can enter into sugarcane plants. Deficiency of K often exists with luxury consumption of Ca and Mg". This concurs with numerous observations made on young cane growing on the highly Ca/Mg saturated soils of Swaziland, the Eastern Transvaal and other lowveld areas indicating that the degree of Ca/Mg imbalance should be taken into account when interpreting soil and leaf K data from this region.

Soil moisture and temperature: In trials 1 to 4 moisture received by the crop during the winter months exceeded normal requirement. Thus over-irrigation probably occurred because crop water requirements were not adjusted with stage of growth and season. The unusually low evaporation rates experienced during spring and early summer in 1987 may have compounded the problem. As Ca and Mg are moved to the root surface mainly by mass-flow in the transpiration stream, at the expense of K ions which move to the root largely by diffusion (Barber[3]), excessive soil moisture would have tended to exacerbate the effects of Ca/Mg antagonism on the mobility of the ions. Thus to increase the amount of K ions delivered by diffusion, soil K concentration would need to be greatly increased. This could largely account for the responses obtained to K fertilizer where soil K values were thought to be adequate.

Interaction between soil temperature and moisture content is also important in uptake of K by cane. Fig 1 shows how closely changes in afternoon soil temperatures in experiment 3 were mirrored by the pattern of leaf K uptake irrespective of treatment. From September to November 1987 soil temperature rose slowly under the prevailing wet soil conditions, thus reducing the mobility of the temperature-dependent K ions. From December onwards, due to increased evaporative demand, soil moisture conditions and temperature normalized and there was a corresponding increase in K uptake. These observations are consistent with results from a trial on an Arcadia form soil in Swaziland (Meyer and Wood[6]) in which K uptake correlated with soil temperature. It was also shown that exchangeable K levels in 2:1 lattice clays such as the Arcadia form soil can be increased by more than 100% after air drying (Anon[1]).

Improved soil and leaf K threshold values: The trial results confirmed that the 150 ppm soil K threshold value was too low for heavy textured base saturated soils in which 2:1 lattice clay minerals predominate. From these results and those from a large number of N/K fertilizer trials in Swaziland and Pongola, it was decided to increase the threshold value to 225 ppm K for soils in the irrigated cane areas containing more than 40% clay, mainly with melanic and heavy orthic A horizons (Anon[2]).

Despite the low leaf K/high soil K anomaly noted on lowveld soils, leaf analysis generally remains a sensitive test for K nutrient status of cane. However, for base saturated soils particularly where the $\frac{Ca + Mg}{K}$ ratio is more than 20 it is recommended that leaf sampling of winter harvested cane commences only from mid-October onwards. Apart from the soil effect *per se*, the pattern of leaf K uptake is also affected by season and the prevailing soil moisture and temperature conditions. It is considered that a seasonal correction factor for the leaf K threshold value should be introduced and the recommendations below are suggested as an interim measure for cane varieties cut on a winter cycle.

Age of crop months	Month of sampling	Acceptable leaf K (DM%) All vars. except N14	N14
3-5	mid Oct - Nov	0,85	0,70
	Dec - Jan	0,95	0,80
	Feb - April	1,05	0,90

To derive the above values, data were used from the current variety trial programme, which show that on average the K content of variety N14 is 0,15% lower than that of most other varieties.

Conclusions

The main conclusions from this work are as follows:

* The significant response obtained to K applied early on base saturated clay soils indicates that the low leaf K/high soil K anomaly is due primarily to K limiting cane growth during spring and early summer.
* It is important to apply K fertilizer as soon as possible after harvesting cane in winter. Where natural ripening is practised, drying off of soils with mainly 2:1 lattice clays should considerably improve K availability, and timing of K application is likely to be less critical.
* Measures to improve irrigation control in the Eastern Transvaal and elsewhere could help indirectly to increase K availability, particularly on Ca/Mg-saturated soils by controlling soil moisture conditions in winter and early spring.
* Introduction of the 225 ppm K threshold value for irrigated soils with more than 40% clay content has improved the probability of correctly predicting a response to K fertilizer in this soil category from 0,64 to 0,78.
* Future selection of a threshold value may be linked to the $\frac{Ca + Mg}{K}$ ratio of a soil, while the KDI method has proved useful in predicting the fate of K applied to soils where K fixation occurs.
* Soil K availability is influenced by excessive soil moisture conditions, and the effect that drying prior to analysis has on K release from soils with vertic and melanic A horizons requires further investigation.

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