FACTORS INFLUENCING AVAILABILITY OF POTASSIUM TO SUGARCANE IN SOUTH AFRICA

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ABSTRACT
During the past four decades there has been considerable research into the K requirement of sugarcane in South Africa. Correlations established between soil and leaf analysis and crop responses to K fertilizer are reviewed. Although fertilizer recommendations based on soil and leaf analysis have provided a useful guide to determining the K requirements of sugarcane they are continually being modified in the light of current research, which has revealed that various soil and climatic factors can markedly influence the availability of K to sugarcane.

Key words: Sugarcane, soil and leaf analysis, fertilizer, non-exchangeable potassium, potassium fixation.

INTRODUCTION
Due to marked differences in climate and geological parent materials the South African sugar industry contains a wide range of soils. Thirty-three soil forms have been described (Anon1) and these have been divided into various categories based on similarity of chemical and physical properties (Moberly and Meyer2). In particular soil type has greatly influenced the availability of potassium to cane. During the past four decades the K requirements of cane have been the subject of extensive research in the field, laboratory and glasshouse by the South African Sugar Association Experiment Station, which has developed soil and leaf analysis as a basis for fertilizer advice. The various factors that influence the availability of K to sugarcane and which therefore affect the reliability with which K recommendations can be made, are reviewed.

RESPONSE OF SUGARCANE TO K FERTILIZER
The most important phase that added substantially to knowledge of sugarcane nutrition under local conditions was the establishment by the Experiment Station in 1950 of thirty-one 3x3x3 NPK exploratory trials. In 1956 these trials were superseded by a more comprehensive series of fifty-three 4x2x3 NPK regional fertilizer
Generally, the results reported by du Toit showed economic responses to N and K fertilizers at levels far higher than those in use at the time and assisted greatly in the development of rational fertilizer programs. By correlating soil and analytical data with the yield responses obtained from these trials it was possible to provide minimum or threshold values of nutrients required for optimum cane growth. This formed the basis for the Fertilizer Advisory Service (FAS), which operates today from the Experiment Station (Wood).

The mean responses of sugarcane to applied K in the NPK exploratory and RFT trials were reviewed by Stewart and Wood. Results of a 1970 industry-wide nutrient survey (Meyer et al.) revealed that 44% of the 487 leaf samples analyzed were K deficient, as were 40% of the 487 soil samples. In a more recent survey (Meyer et al.), K was also the most limiting nutrient, based on both soil and leaf analysis, with the incidence of K deficiency being particularly high in the irrigated cane areas. Consequently more than 70 further K fertilizer trials have been conducted in which significant responses in some instances to as much as 300 kg K/ha were obtained.

SOIL ANALYSIS AND CROP RESPONSE TO K

Based on the 1N ammonium acetate extraction procedure the threshold value used for K by the FAS was 112 ppm for all soils until 1982, when it was modified to accommodate soil texture following results from glasshouse trials (Wood and Harrows) and a re-assessment of early and of the more recent K fertilizer trials (Meyer and Wood). The average responses to applied K from more than 100 trials were classified according to three soil textural categories and arranged in decreasing order of exchangeable K as shown in Table 1. On light to medium textured soils most responses to applied K were significant and coincided with pre-treatment soil K levels below 112 ppm K. Responses on heavier textured soils, however, were variable and not well correlated with pre-treatment soil K levels, many significant responses being associated with soil values of exchangeable K ranging from 112 to 549 ppm. An interim threshold value of 150 ppm K was therefore introduced for soils with a clay content of more than 30%. However, results mainly from irrigated N/K fertilizer trials in Swaziland, Pongola and more recently the Eastern Transvaal (Donaldson et al.), confirmed that 150 ppm K was not adequate for base saturated soils with more than 40% clay, and with melanic and red orthic A horizons in which 2:1 lattice clays predominate. These soils are often K-fixing and contain a high proportion of K selective clay minerals (Wood). A threshold value of 225 ppm K was therefore introduced to cater for this category of soils in the northern irrigated cane areas (Anon).
LEAF ANALYSIS AND K REQUIREMENT

Foliar diagnosis based on the analysis of the central portion of the top visible dewlap (TVD) leaf has been useful in evaluating the K status of the crop. An assessment of the exploratory and RFT trial data indicated that a response of at least 13 tons cane per hectare could be expected when the value of K in the TVD leaf fell below 1.0% (Du Toit®). Between the values of 1.0 and 1.25% K responses were variable, and above 1.25% responses to K were unlikely. The critical value now used for leaf K by FAS in 1.05% K.

TABLE 1. Summary of experimental responses to applied K in relation to soil textural class and soil exchangeable K intervals.

<table>
<thead>
<tr>
<th>Soil K intervals (ppm)</th>
<th>Sand to loamy sands (less than 15% clay)</th>
<th>Sandy loams to sandy clay loams (15-30% clay)</th>
<th>Clays (more than 30% clay)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of responses</td>
<td>Average responses</td>
<td>No. of responses</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>No. significant</td>
<td>Total</td>
</tr>
<tr>
<td>Less than 45</td>
<td>11</td>
<td>10</td>
<td>23.8</td>
</tr>
<tr>
<td>46 to 67</td>
<td>13</td>
<td>9</td>
<td>13.7</td>
</tr>
<tr>
<td>68 to 112</td>
<td>12</td>
<td>8</td>
<td>10.0</td>
</tr>
<tr>
<td>113 to 157</td>
<td>3</td>
<td>1</td>
<td>7.8</td>
</tr>
<tr>
<td>158 to 222</td>
<td>3</td>
<td>3</td>
<td>2.6</td>
</tr>
<tr>
<td>223 to 290</td>
<td>1</td>
<td>1</td>
<td>2.6</td>
</tr>
<tr>
<td>More than 290</td>
<td>1</td>
<td>1</td>
<td>2.6</td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td>28</td>
<td>45</td>
</tr>
</tbody>
</table>

FACTORS AFFECTING K AVAILABILITY

Results of field trials have indicated that problems still exist in predicting correctly the K requirement of sugarcane. Although soil and leaf analysis have been used fairly successfully, low leaf K/high soil K anomalies have been reported from several areas within the South African sugar industry. Wood and Meyer²⁸ noted various soil and climatic factors that can influence the availability of K to cane, so affecting the reliability with which K recommendations can be made. Recent studies at the Experiment Station have emphasized the importance of several of these factors.
Apparent suppression of K uptake

Numerous leaf analyses had indicated that K uptake by winter harvested cane growing on Ca and Mg saturated clays of the northern irrigated cane areas was often severely depressed despite apparently adequate amounts of exchangeable soil K, whereas leaf Ca and Mg values were excessive. Four trials were conducted to determine whether winter cut cane would respond to early (August) or late (October) applications of K fertilizer. In three trials a significantly greater response to sucrose yield was obtained to K applied early at 300 kg K/ha than when application was delayed to October. This indicated that the supply or rate of release of K from the soil was inadequate during spring and early summer and necessitated an increase in the threshold value to 225 ppm K for these soils. However, apart from the soil effect per se, K uptake was affected also by the following factors:

Season: Although yield response to 300 kg K/ha was optimal (average of 3.5 metric tons sucrose/ha), the associated leaf K values during much of the spring/early summer growth period, where this and other K fertilizer treatments were applied, would have been interpreted as highly deficient (Table 2). Based on a leaf weight threshold value of 1.05% K, the K fertilizer requirement was apparently being overestimated under these conditions.

| TABLE 2. Third leaf K, Ca and Mg values (DM%) at various ages in trial 1. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Age (months)    | 2.5 m           | 4 m             | 6 m             | 9 m             |
| Treatment kg K/ha | 24/7/87         | 14/9/87         | 13/11/87        | 10/2/87         |
| Early           | Late            | C                 | Ca              | Mg              |
|                 |                 | 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  |
| 0               | 0.35 1.19 0.63  | 0.51 1.01 1.01   | 0.73 0.61 0.36  | 1.09 0.34 0.27  | 1.12 0.32 0.28  |
| 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  | 1.15 0.34 0.28  |
| 600             | 0.38 1.09 0.61  | 0.59 0.97 0.97   | 0.91 0.58 0.58  | 1.15 0.34 0.28  | 1.10 0.34 0.27  |
|                 | 0.30 1.15 0.64  | 0.33 1.16 1.16   | 0.53 0.78 0.78  | 1.10 0.34 0.27  | 1.10 0.34 0.27  |
|                 | 0.30 1.14 0.62  | 0.28 1.20 1.16   | 0.54 0.76 0.69  | 1.10 0.31 0.25  | 1.10 0.31 0.25  |

with 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 ratio of (Ca + Mg) to (K + K), the larger was the period that leaf K uptake was depressed due to enhanced uptake of Ca and Mg. These results support those of Humbert who reported 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.

**Soil temperature and moisture:** Interaction between soil temperature and moisture content is also important in uptake of K by cane. Figure 1 shows how closely changes in afternoon temperatures in one K trial were mirrored by the pattern of leaf K uptake, irrespective of K fertilizer treatment. From September to November 1987 soil temperature rose slowly under prevailing wet soil conditions, so reducing the temperature dependent mobility of the K ions (Ching and Barber4). From December onwards, due to increased evaporative demand, soil moisture conditions and temperature normalized and there was a corresponding increase in K uptake with an accompanying decrease in Ca and Mg as reported by Mederski and Stackhouse15. With a range in soil temperature of about 15°C between June and January not uncommon in the semi-arid irrigated cane areas of the industry this may affect K uptake. In Hawaii, K deficiency symptoms were reported in cane growing in heavy clay soils well supplied with K but poor in structure, compacted and with a high Ca saturation (Humbert12). The difficulty experienced by the crop in obtaining adequate K could be exacerbated by a low soil temperature and a high soil moisture status through over-irrigation. In the light of these effects on K uptake a seasonal correction factor has been introduced for the leaf K threshold value for cane harvested on a winter cycle in the northern irrigated cane areas as shown below.

<table>
<thead>
<tr>
<th>Crop age</th>
<th>Month of sampling</th>
<th>Acceptable leaf K %</th>
</tr>
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<tbody>
<tr>
<td>3 to 5 months</td>
<td>mid Oct-Nov</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Dec-Jan</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>Feb-April</td>
<td>1.05</td>
</tr>
</tbody>
</table>

**Potassium fixation**

In the above K trials the residual effects of the early applications of K (300 kg K/ha) on extractable K values measured five months after application are shown in Figure 2. The increase in soil K varied between sites, a more rapid increase occurring in experiment 2 when compared with experiments 1 and 4. The rate of increase was inversely related to the soil K sorption capacity (Aarafin et al.), as measured by the K desorption index (KDI) values (Wood and Meyer29). On average an application of 300 kg K/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 in experiment 1, which had the highest K sorption capacity (KDI 0.59). In N/K fertilizer trials on Swaziland soils substantial applications of
Increases have been relatively small. This is probably because many of the soils are strongly K-fixing and contain a high proportion of K-selective clay minerals. Some of the largest responses to applied K have been obtained on vertisols with an exchangeable K content of about 350 ppm. A higher threshold value of at least 300 ppm K is therefore indicated on these soils, and further K trials are being conducted to determine the effects of K fixation on optimum rate of applied K.

**Subsoil K**

A factor which has received insufficient attention when K fertilizer recommendations are made for cane is the contribution which the subsoil makes to the available K requirement of the crop. Routine soil testing is usually restricted to the topsoil (0-200 mm) though cane roots can also take up nutrients from much greater depths (Wood and Wood). Grimme et al. found that as moisture content of a loess topsoil decreased together with nutrient uptake rates, up to 50% of the daily K requirement of the crop could be supplied by the subsoil. Work at the Experiment Station has shown that amounts of exchangeable K in subsoils of the sugar industry vary with soil type and clay mineralogy. Subsoil K was extracted from a range of sugar
lattice clays predominated had smaller amounts of exchangeable K and IK reserves were much lower.

stated that exchangeable K in itself was a poor index of K availability for long duration crops like sugarcane or in a continuous cropping system. Soil K measured by 1N ammonium acetate, electro-ultrafiltration (EUF, Németh29) and 1N nitric acid extraction (Haysom30) was compared with K availability during exhaustive cropping of a wide range of sugar industry soils. Wood5 reported on the relative efficiency of the various extraction procedures in predicting the K supplying power of 44 soils.

Exchangeable K as index of K availability

At a given level of exchangeable K some soils exhibit a greater response to applied K fertilizer than others, even under similar climatic conditions. Hunsigi and Srivastava19 stated that exchangeable K in itself was a poor index of K availability for long duration crops like sugarcane or in a continuous cropping system. Soil K measured by 1N ammonium acetate, electro-ultrafiltration (EUF, Németh29) and 1N nitric acid extraction (Haysom30) was compared with K availability during exhaustive cropping of a wide range of sugar industry soils. Wood5 reported on the relative efficiency of the various extraction procedures in predicting the K supplying power of 44 soils.
FIGURE 2. Relationship between applied K treatment and residual soil exchangeable K values.

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Release of non-exchangeable K reserves

Soils of the South African sugar industry differ greatly in their K release potential depending on clay content, clay mineralogy and extent of weathering. Although their non-exchangeable K reserves have been assessed by EUF and other methods (Wood18), it has proved difficult to determine the rate at which these reserves are released to the exchangeable and solution forms, which are readily available for plant uptake. They are, according to Martin and Sparks14, the most important aspect of non-exchangeable K.

The release of interlayer or non-exchangeable K was therefore measured by Wood and Schroeder28 on a range of sugar industry soils using the method of Grooterhorst and Grimme29, which is based on the miscible displacement technique of Sparks et al21. The soils were leached with 0.1M BaCl₂ at a rate of 1.5 ml/min per 100 minutes and the leachate was collected at five minute intervals. For each soil, two potassium fractions with different release rates were identified: a fast desorbing fraction equivalent to exchangeable K and a second fraction equivalent to non-exchangeable K.

![Figure 3: Release of non-exchangeable potassium with time from a range of sugar industry soils.](image-url)
K. Sustained release of non-exchangeable K reserves was apparent in many soils containing a high proportion of 2:1 lattice clays, whereas the opposite was observed in soils in which 1:1 lattice clays predominated (Figure 3). The BaCl₂ extraction method has enabled the classification of South African sugar industry soils into four categories according to their ability to release non-exchangeable K, and will assist in predicting the rate at which non-exchangeable K reserves are able to replenish potassium in the soil solution. This system of classification is expected to improve K fertilizer recommendations but first it has to be calibrated against results obtained from the large number of K trials that have been conducted on sugar industry soils.

CONCLUSIONS

Although soil and leaf analysis have been used quite successfully to determine the correct amounts of K fertilizer required, it is apparent that various soil and climatic factors can influence the availability of K to cane, which will affect the reliability of K recommendations. For example, results from recent N/K fertilizer trials in the northern irrigated cane areas confirmed that 150 ppm K was not adequate for base saturated soils with more than 40% clay content, and this resulted in an increase in the K threshold value to 225 ppm K for this category of soils. Also the effects of soil moisture and temperature on leaf K uptake have resulted in the introduction of a seasonal correction factor for the leaf K threshold value for irrigated cane cut on a winter cycle.

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LES FACTEURS QUI INFLUENT SUR LA DISPONIBILITE DE LA POTASSE À LA CANNE À SUCRE AU SUD-AFRIQUE

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RESUME

Durant les quatrées dernières décadas, il y eut une recherche assez marquée sur les besoins en potasse de la canne à sucre au Sud-Afrique. Les corrélatons établies entre la teneur en potasse du sol et de la feuille et la réponse de la canne sont rapportées. Malgré que les recommandations de fertilisant basées sur les analyses du sol et de la feuille ont été utile pour guider les besoins en potasse de la canne, elles sont continuellement revisées à la lumière des résultats qui précéentement ont démontre que plusieurs facteurs pédologique et climatique peuvent influencer sur la disponibilité de la potasse.

Mots clef: Canne à sucre, analyse de sol et feuille, fertilisant, potasse non-changeable, fixation de la potasse.
RESUMEN

Durante los últimos 40 años se ha investigado cuidadosamente, en África del Sur, los requisitos de K en caña de azúcar. Se hizo una revisión de las correlaciones entre los análisis de suelos y foliáceos, y la reacción de la cosecha a fertilizantes potásicos. Aunque las recomendaciones de fertilizantes, basadas en los análisis de suelos y foliáceos, han sido útiles para las determinaciones de los requisitos de K, constantemente se han modificado de acuerdo a las técnicas modernas que indican que ciertos suelos y factores climáticos pueden influir significativamente en la disponibilidad de K por la caña de azúcar.