# ASH AND SUGARS IN CANE JUICE AT NCHALO SUGAR ESTATE, MALAWI: RELATIONSHIP WITH INORGANIC CONSTITUENTS IN SOIL

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## Abstract

Nchalo Sugar Estate in Malawi has consistently higher molasses purities and usually higher ash in final molasses than other mills in southern Africa. An investigation was conducted over two seasons to determine the main constituents of the ash and what relationship existed between the ions in juice, juice quality and the soil cations and salinity parameters. The influence of time of harvest was also considered.

Juice potassium, sulphate and chloride ions were the main components of ash. Soil potassium in the upper 60 cm of the soil profile correlated with the ash and potassium content of the juice extracts. Calcium and magnesium in the soil were positively associated with sucrose. Calcium and sodium in the soil were significantly and positively correlated with their respective cations in juice. The influence of time of harvest on soil constituents sampled within the 0-30 cm soil layer was non-significant except for electrical conductivity.

*Keywords*: sugarcane, Malawi, ash, cane quality, soil, potassium, salinity

## Introduction

Nchalo Sugar Estate is situated in the Shire river valley in Malawi, on soils of alluvial and colluvial origin. The topsoil contains high levels of calcium (3500 ppm), magnesium (800 ppm) and potassium (250 ppm), and has an average pH value of 7.6 ($H_2O$). Soil sodium values average 240 ppm. Long term mean annual rainfall is 700 mm and evaporation is 2000 mm. The estate is irrigated throughout the year, even through the rainy season, which usually extends from mid-December to mid-April.

The Nchalo factory is known to have low recoveries and high molasses purities relative to the other factories in the southern African sub-region. Several investigations have been conducted into this problem at Nchalo, and have indicated a problem associated with high ash levels in mixed juice (Lionnet, 1996, 2002).

Potassium is the dominant cation in cane juice (Irvine, 1978; Kingston, 1982), and has been reported by several authors to impact negatively on the recovery of sugar (Irvine, 1978; Clark, 1981; Meyer and Wood, 2001). Kingston (1982) undertook a study to examine the factors affecting the inorganic composition of first expressed juice at the Rocky Point factory in the Australian sugar industry, which was also experiencing high ash in the sugar produced.

The results showed that ash levels in first expressed juice were significantly affected by soil potassium, magnesium, sodium, chlorine and electrical conductivity (EC), but not by soil calcium. The ions of potassium, calcium, sodium and chlorine were significantly associated with their corresponding ion in cane juice, but not for magnesium.

From the results obtained by Kingston in 1982, it was suspected that similar conditions might exist at Nchalo. An in-depth investigation was carried out to more accurately determine the reasons for the high ash content of cane juice and to what extent the chemistry of the soil affected juice quality and the composition of ash in cane juice.

## Procedure

During the 2001 season, 411 fields harvested were sampled at a predetermined position (30 rows from the field's north-eastern corner and 50 m in from the field edge). All the millable cane from a one metre length of cane row was harvested, wrapped in a plastic tube and taken to the laboratory. A unique sample number was given to the cane sample. Soil samples were taken at two points along the metre length of row, at three depths (0-30, 30-60 and 60-90 cm), and composite samples were sent for analysis. A record was made of the field number, date, depth of soil sample, cane variety and growth conditions. Where relevant, comments pertaining to lodging, soil type, and salts on the soil surface were made. Soil samples were also given unique sample numbers. At the factory laboratory, the cane samples were weighed, stripped of trash and shredded for direct analysis of cane by the factory laboratory. About 500 ml of juice extract was frozen at -40ºC and sent in special cold boxes to the Sugar Milling Research Institute (SMRI) at the University of KwaZulu-Natal in Durban. The SMRI analysed the juice extract for pol, brix, glucose, fructose, sucrose, conductivity ash, potassium, calcium, magnesium, sodium and chloride. Phosphate and sulphate were additionally determined on juice extracts from fields harvested in 2002.

The soil samples were dried, sub-sampled and sent to the South African Sugar Association Experiment Station (SASEX) Fertiliser Advisory Service (FAS) for the analysis of exchangeable cations (1N ammonium acetate), as well electrical conductivity and pH in saturated extracts. The data obtained enabled an assessment of the salinity/sodicity status of the soil profiles that were sampled. Several samples were damaged in transit to South Africa. In 2001, complete data sets were available for 357 fields. In 2002, due to laboratory capacity and cost constraints, approximately every fourth field's juice extracts were sent to the SMRI. Complete data sets for 160 fields were obtained in 2002.

## Results and discussion

*Constituents of ash in juice*

Potassium in the juice extracts was the dominant cation in both seasons (Table 1).

Chloride was the dominant anion in 2001. In 2002, phosphates and sulphates were also analysed and this time sulphate was the dominant anion. It is likely that sulphate would also have been the dominant anion had this analysis been included in 2001.

**Table 1. Mean and ranges of ionic constituents of juice extracts for 2001 and 2002.**

| Ionic constituent (ppm) | 2001 | | | 2002 | | |
|---|---|---|---|---|---|---|
| | Min | Mean | Max | Min | Mean | Max |
| Calcium | 5 | 60 | 104 | 35 | 68 | 130 |
| Magnesium | 7 | 64 | 136 | 35 | 68 | 110 |
| Potassium | 42 | 810 | 1565 | 185 | 659 | 1100 |
| Sodium | 3 | 18 | 111 | 3 | 14 | 74 |
| Chloride | 57 | 342 | 949 | 75 | 365 | 1065 |
| Phosphate | ~ | ~ | ~ | 115 | 290 | 835 |
| Sulphate | ~ | ~ | ~ | 230 | 496 | 1195 |

*Soil constituents*

The mean and range in chemical composition of the saturated paste extracts is shown in Table 2.

**Table 2. Mean and ranges of soil cation concentrations, electrical conductivity (EC) and pH at three soil depths for 2001 and 2002.**

| Soil parameter (me%) | Season | 0-30 cm | | | 30-60 cm | | | 60-90 cm | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max |
| Calcium | 2001 | 2.80 | 16.91 | 46.18 | 2.63 | 16.37 | 43.98 | 2.79 | 15.41 | 46.21 |
| | 2002 | 5.23 | 19.37 | 45.20 | 4.82 | 18.82 | 43.40 | 0.80 | 17.45 | 49.40 |
| Magnesium | 2001 | 0.42 | 6.50 | 20.97 | 0.99 | 6.85 | 22.94 | 1.08 | 6.78 | 23.68 |
| | 2002 | 1.51 | 7.03 | 20.15 | 1.61 | 7.32 | 22.04 | 1.07 | 7.17 | 23.93 |
| Potassium | 2001 | 0.16 | 0.64 | 2.09 | 0.04 | 0.60 | 1.66 | 0.15 | 0.54 | 1.49 |
| | 2002 | 0.14 | 0.66 | 1.35 | 0.17 | 0.62 | 1.25 | 0.15 | 0.59 | 1.55 |
| Sodium | 2001 | 0.09 | 1.02 | 7.52 | 0.10 | 1.35 | 8.04 | 0.13 | 1.61 | 9.48 |
| | 2002 | 0.12 | 1.03 | 4.97 | 0.17 | 138 | 12.13 | 0.13 | 1.54 | 8.78 |
| EC (mS/m) | 2001 | 9.5 | 49.8 | 222 | 3 | 51.2 | 289 | 9 | 55.9 | 512 |
| | 2002 | 3.10 | 53.2 | 344 | 16 | 53.5 | 376 | 15 | 55.8 | 271 |
| pH ($H_2O$) | 2001 | 5.89 | 7.63 | 9.44 | 6.04 | 7.72 | 9.18 | 5.96 | 7.81 | 9.29 |
| | 2002 | 6.21 | 7.69 | 8.65 | 6.54 | 7.86 | 8.79 | 6.20 | 7.94 | 9.20 |

Overall, calcium was the dominant cation, followed by magnesium, sodium and potassium. The concentration of calcium and potassium decreased with depth, whereas magnesium and in particular sodium, increased with depth. Soil pH and EC also tended to increase with depth. Over the two seasons, only four samples had an EC value of more than 200 mS/m in the 0-30 cm soil depth layer and six samples at the 30-60 cm level. Soil magnesium and sodium, as a proportion of the cation exchange capacity of the soil, increased with depth, while potassium remained constant.

*Relationship between soil parameters and juice quality*

The correlation coefficients that were obtained between the various soil parameters and juice quality are shown in Table 3.

Soil potassium at all three depths was significantly and positively correlated with ash in juice in both seasons. However the level of significance decreased from 1 to 5% below 60 cm soil depth. Electrical conductivity in the 2001 season was highly significant and positively associated with juice ash content, but was non-significant in the 2002 season. Sucrose was positively and significantly associated in either one or both seasons for all soil parameters except for EC. Soil calcium and magnesium had the best correlations with sucrose.

The correlations between fructose and soil parameters were almost all negative. Soil sodium was the most strongly correlated with reducing sugars in 2001, and potassium was the strongest in 2002. Soil magnesium and sodium levels were positively related with juice purity. Significant correlations that might exist between soil cations with juice quality parameters do not necessarily imply that the respective juice cation correlated significantly with the particular juice quality parameter. For example, soil magnesium and sodium were significantly and positively correlated with juice purity, whereas juice magnesium and sodium were not.

**Table 3. Correlation coefficients between soil cations and electrical conductivity sampled at three soil depths, and juice quality parameters in 2001 and 2002.**

| Soil parameter | Soil depth (cm) | Juice quality parameter | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Ash % | | Sucrose % | | Fructose % | | Purity | |
| | | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 |
| Ca | 0-30 | 0.01 ns | -0.02 ns | 0.18 ** | 0.26 ** | -0.02 ns | -0.06 ns | 0.06 ns | 0.13 Ns |
| | 30-60 | -0.01 ns | 0.04 ns | 0.17 ** | 0.25 ** | -0.04 ns | -0.06 ns | 0.07 ns | 0.11 ns |
| | 60-90 | -0.01 ns | 0.03 ns | 0.12 * | 0.26 ** | 0.01 ns | -0.09 ns | 0.02 ns | 0.16 * |
| Mg | 0-30 | 0.05 ns | -0.03 ns | 0.20 ** | 0.27 ** | -0.11 * | -0.11 ns | 0.14 ** | 0.16 * |
| | 30-60 | 0.04 ns | -0.01 ns | 0.21 ** | 0-25 ** | -0.15 ** | -0.09 ns | 0.17 ** | 0.13 ns |
| | 60-90 | 0.02 ns | -0.03 ns | 0.16 ** | 0.27 ** | -0.06 ns | -0.12 ns | 0.10 * | 0.17 * |
| K | 0-30 | 0.23 ** | 0.26 ** | -0.03 ns | 0.16 * | 0.00 ns | -0.16 * | -0.10 * | 0.11 ns |
| | 30-60 | 0.17 ** | 0.28 ** | 0.05 ns | 0.16 * | -0.07 ns | -0.21 ** | -0.00 ns | 0.11 ns |
| | 60-90 | 0.11 * | 0.19 * | 0.05 ns | 0.24 ** | -0.05 ns | -0.20 ** | 0.02 ns | 0.17 * |
| Na | 0-30 | 0.10 ns | 0.02 ns | 0.16 ** | 0.19 * | -0.19 ** | -0.20 * | 0.16 ** | 0.21 ** |
| | 30-60 | 0.13 * | 0.00 ns | 0.21 ** | 0.14 ns | -0.20 ** | -0.08 ns | 0.19 ** | 0.11 ns |
| | 60-90 | 0.06 ns | -0.03 ns | 0.16 ** | 0.19 * | -0.16 ** | -0.11 ns | 0.18 ** | 0.17 * |

**Table 3. (continued)**

| Soil parameter | Soil depth (cm) | Juice quality parameter | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Ash % | | Sucrose % | | Fructose % | | Purity | |
| | | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 |
| EC | 0-30 | 0.25 ** | 0.11 ns | 0.05 ns | 0.03 ns | -0.13 * | -0.02 ns | 0.08 ns | 0.00 ns |
| | 30-60 | 0.25 ** | 0.11 ns | 0.05 ns | 0.03 ns | -0.13 * | -0.02 ns | 0.11 * | 0.01 ns |
| | 60-90 | 0.16 ** | 0.10 ns | 0.10 ns | 0.07 ns | -0.10 ns | -0.00 ns | 0.10 ns | 0.02 ns |

ns = non significant * = significant at $p<0.05$ ** = significant at $p<0.01$

*Relationship between soil parameters and inorganic composition of cane juice*

With the exception of magnesium, the soil cations up to a depth of 60 cm were significantly and positively correlated with their respective cation constituents in the juice extracts (Table 4).

Potassium and sodium were the only two cations in the juice that were related with the concentration of their respective ions below a depth of 90 cm. In general, soil magnesium showed no relationship with any of the ions in juice. Soil potassium was negatively correlated with juice magnesium during the 2001 season. The association was not significant for soil depths greater than 30 cm during the 2002 season. Sodium was significantly correlated with juice chloride at all depths in 2001, but only at the 0-30 cm depth layer in 2002.

Soil EC was significantly associated with juice sodium in both seasons, and with juice potassium and juice chloride during the 2001 season.

**Table 4. Correlation coefficients between soil cations and electrical conductivity sampled at three soil depths, and ionic constituents in juice extracts in 2001 and 2002.**

| Soil parameter | Soil depth (cm) | Ionic constituents in juice extracts | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Calcium | | Magnesium | | Potassium | | Sodium | | Chloride | |
| | | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 |
| Ca | 0-30 | 0.21 ** | 0.23 ** | -0.12 * | 0.03 ns | 0.01 ns | -0.04 ns | 0.02 ns | -0.06 ns | 0.01 ns | 0.03 ns |
| | 30-60 | 0.20 ** | 0.24 ** | -0.13 * | 0.01 ns | -0.01 ns | 0.01 ns | 0.05 ns | -0.07 ns | -0.13 * | 0.01 ns |
| | 60-90 | 0.15 ** | 0.21 ** | -0.14 ** | -0.03 ns | -0.01 ns | 0.01 ns | 0.03 ns | -0.11 ns | -0.17 ** | -0.20 ns |
| Mg | 0-30 | 0.07 ns | 0.11 ns | -0.01 ns | 0.02 ns | -0.01 ns | -0.01 ns | 0.09 ns | -0.01 ns | 0.03 ns | 0.08 ns |
| | 30-60 | 0.05 ns | 0.15 ns | 0.01 ns | 0.06 ns | -0.02 ns | -0.01 ns | 0.12 * | -0.00 ns | -0.04 ns | 0.06 ns |
| | 60-90 | 0.07 ns | 0.14 ns | 0.00 ns | 0.08 ns | -0.04 ns | -0.05 ns | 0.13 * | -0.03 ns | -0.05 ns | -0.08 ns |

**Table 4. (continued)**

| Soil parameter | Soil depth (cm) | Ionic constituents in juice extracts | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Calcium | | Magnesium | | Potassium | | Sodium | | Chloride | |
| | | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 |
| K | 0-30 | 0.02 ns | 0.04 ns | -0.26 ** | -0.20 * | 0.32 ** | 0.23 ** | 0.05 ns | -0.16 * | 0.09 ns | 0.06 ns |
| | 30-60 | -0.03 ns | 0.06 ns | -0.26 ** | -0.13 ns | 0.21 ** | 0.27 ** | 0.04 ns | -0.10 ns | 0.09 ns | 0.10 ns |
| | 60-90 | -0.04 ns | 0.16 * | -0.15 ** | -0.02 ns | 0.12 * | 0.10 ns | 0.10 ns | 0.03 ns | 0.01 ns | -0.05 ns |
| Na | 0-30 | -0.10 ns | 0.09 ns | 0.06 ns | 0.13 ns | -0.13 ns | -0.10 ns | 0.28 ** | 0.34 ** | 0.17 ** | 0.26 ** |
| | 30-60 | -0.06 ns | 0.06 ns | 0.06 ns | 0.16 * | 0.01 ns | -0.09 ns | 0.31 ** | 0.34 ** | 0.17 ** | -0.07 ns |
| | 60-90 | -0.14 ns | 0.16 ns | 0.03 ns | 0.10 ns | -0.02 ns | -0.10 ns | 0.27 ** | 0.15 ns | 0.16 ** | -0.14 ns |
| EC | 0-30 | -0.04 ns | 0.04 ns | 0.05 ns | 0.14 ns | 0.12 * | -0.06 ns | 0.21 ** | 0.30 ** | 0.37 ** | 0.18 ns |
| | 30-60 | -0.04 ns | 0.04 ns | 0.08 ns | 0.15 ns | 0.12 * | -0.06 ns | 0.21 ** | 0.30 ** | 0.37 ** | 0.02 ns |
| | 60-90 | -0.00 ns | 0.14 ns | 0.04 ns | 0.04 ns | 0.12 * | -0.03 ns | 0.20 ** | 0.18 * | 0.26 ** | 0.09 ns |

ns = non significant * = significant at $p<0.05$ ** = significant at $p<0.01$

*Fluctuations in soil constituents with time of harvest*

Soil cations within the 0-30 cm layer fluctuated with time of harvest, but these differences were not significant (Figures 1-5). The trend between the two seasons was more consistent for soil cations than for juice cations. The decline in soil potassium with time was similar to the decline in the potassium content of cane juice. Variations in electrical conductivity in soils sampled at the 0-30 cm depth over the harvest season were significant ($p<0.05$). Electrical conductivity increased steadily as the season progressed.

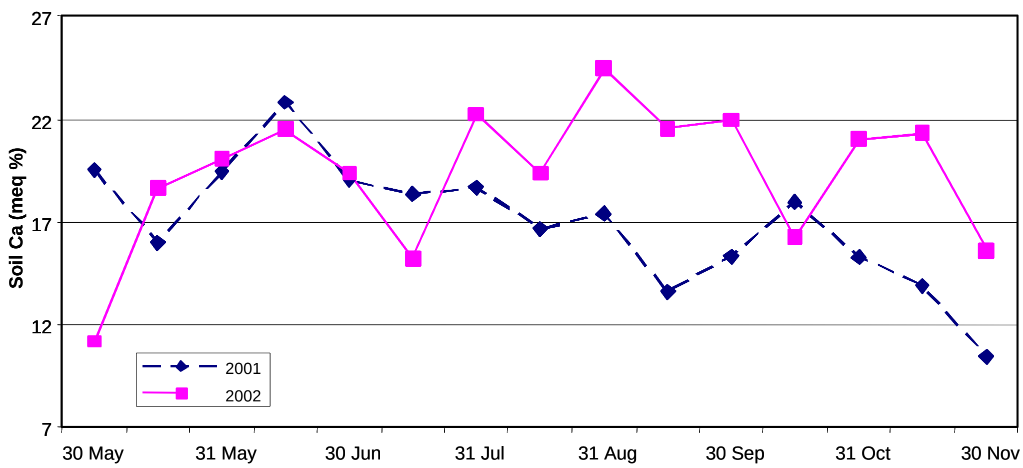


**Figure 1. Mean soil calcium sampled at 0-30 cm during the 2001 and 2002 harvest seasons.**

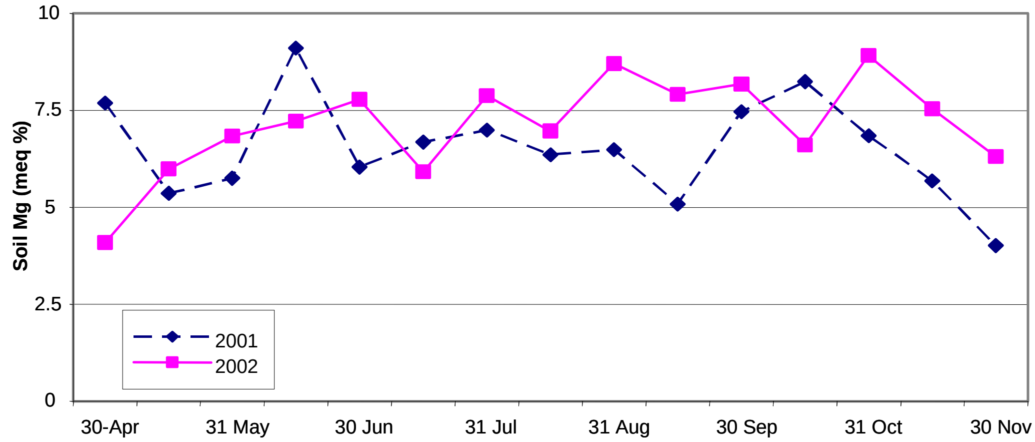


**Figure 2. Mean soil magnesium sampled at 0-30 cm during the 2001 and 2002 harvest seasons.**

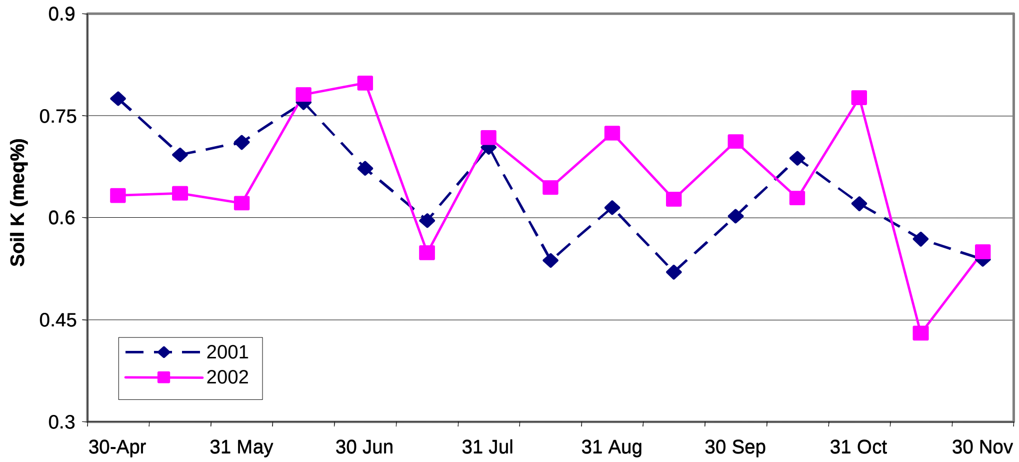


**Figure 3. Mean soil potassium sampled at 0-30 cm during the 2001 and 2002 harvest seasons.**

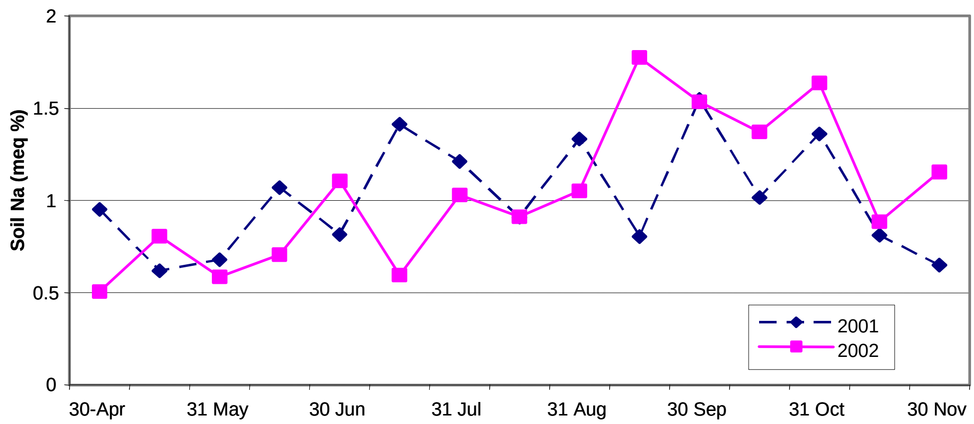


**Figure 4. Mean soil sodium sampled at 0-30 cm during the 2001 and 2002 harvest seasons.**

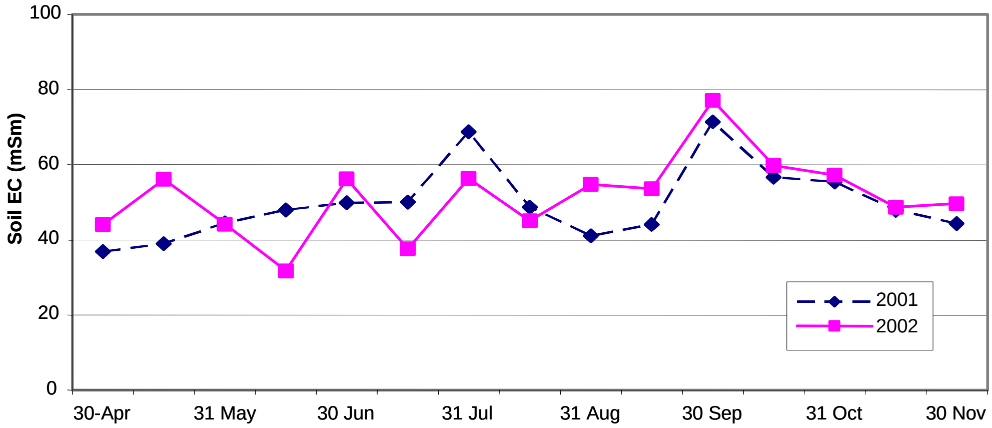


**Figure 5. Mean soil electrical conductivity sampled at 0-30 cm during the 2001 and 2002 harvest seasons.**

## Conclusions

Soil calcium, potassium and sodium were significantly and positively correlated with their respective cations in juice extracts. Soil magnesium, as at Rocky Point, was not significantly correlated with its juice cation. The negative correlation between soil potassium and magnesium observed in this study and also at Rocky Point was thought by Kingston (1982) to reflect an antagonistic effect by potassium. Soil potassium was the only cation to be significantly correlated with ash in juice in both seasons. EC was also significantly positively correlated with ash in juice in 2001. The cations did not differ significantly as the season progressed. However, EC increased significantly.

Unlike Rocky Point, EC values at Nchalo are low and unlikely to restrict cane growth. Sodium as a proportion of CEC, generally increased with depth. A reduction in soil salinity, however, through improved drainage and irrigation practices, would help to reduce ash in juice. Although it might be possible to reduce or restrict the uptake of certain cations through judicious fertilisation, this does not necessarily imply that the benefits would extend to the factory. This is because of the many non-significant associations between juice ions and juice quality that were observed during the course of this study. Despite this, balancing calcium and magnesium in the soil might improve the situation in the factory because of the negative correlations of these juice cations with ash and the positive associations they had with sucrose.

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