USE OF IN-FIELD MEASUREMENTS TO REFINE SALINITY—TOLERANCE THRESHOLDS FOR CULTIVARS OF SUGARCANE

By

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Abstract

CONSIDERATION that sugarcane has only moderate yield sensitivity to the impact of soil salinity was established largely from field experiments in the USA in the early 1960s with cultivars NC0293 and NC0310. Yield declined by 5.9% per dS/in increase in electrical conductivity of saturation extracts (ECe). These data were used in Australia for the past 33 years to interpret soil analysis and for provision of advice to canegrowers. However, accumulated field experience suggested that this approach was underestimating the impact on ratoon crops of sugarcane. We used an EM38 electromagnetic earth conductivity meter to quantify the range in soil salinity at two sites, prior to selecting 6–9 stations at each site for formal measurement of salinity in the soil profile and for determination of cane yield and juice quality. One cultivar was examined as plant cane, while three were examined as ratoon crops. Relevance of the USA standard was confirmed for a plant crop of the less salt-sensitive cultivar Q136, with a yield decline of 7.5% per dS/m ECe. However, yield of ratoon cane declined at 11.8, 12.1 and 16.9% per dS/m in ECe for the cultivars CP51-21, Q136 and CP44-101, respectively. Commercial Cane Sugar (CCS) also declined with increasing soil salinity, by 0.27–0.92 CCS units per dS/m ECe. Electrical conductivity of juice increased with increasing salinity as a reflection of increasing ash levels in juice. The higher ratio of ratoon to plant crops in commercial fields indicates that the more sensitive standard for ratoon cane should be adopted for interpretation of salinity hazards in soil. These data also suggest that cultivars should be classified as moderately sensitive to sensitive to salinity damage. Salinity, therefore, has an important and negative effect on the yield of sugarcane and quality of the extracted juice and these effects can be readily quantified from in-situ measurements of salinity and field-grown sugarcane.

Introduction

Soil salinity restricts yield on many crops, including sugarcane (Fogliata and Aso, 1965; Kobe and Sund, 1965; Bernstein et al., 1966a; Anon., 1970; FAO, 1973; Nelson and Ham, 2000) through water stress imposed by osmotic pressure of the soil water solution (Maas and Hoffman, 1977). Sugarcane grown under saline conditions takes up more potassium than sodium ions (Bernstein et al., 1996b; Kingston, 1982a) while attempting to achieve sufficient osmotic pressure for uptake of water (Janes, 1966). These ions cause an elevation of ash levels in juice inhibiting sugar recovery in the factory (Irvine, 1979). Salinity also reduces the quality of juice by depressing brix and pol (Bernstein et al., 1966b; Mehrad, 1968; Thomas et al. 1981), but effects on juice purity are variable.

The impact of salinity on sugarcane was quantified in pot studies (Syed and el-Swaify, 1972), large lysimeters (Young-Kong and McLean, 1969) and field plots (Bernstein et al., 1966a), where a range of salinity treatments was achieved by irrigation, usually with mixed salt solutions of appropriate concentrations. Another field-based approach was used by Nelson and Ham (2000) who exploited variation in salinity and sodicity within cane fields.

Criteria derived from artificial salt treatments in controlled conditions have potential to be more precise, yet more severe than those using inherent variation in the field, due to greater uniformity of the temporal and spatial concentrations in the root zone within managed treatments. Assessments obtained from commercial fields may also suffer from disadvantages of interaction with rainfall, sodicity for medium to heavy textured soils (Nelson and Ham, 2000), and the impact of water table elevation if soil salts emanate from shallow groundwater.
Because commercial crop yield is the only agronomically significant criterion for establishing salt tolerance (Maas and Hoffman, 1977), we need to consider the relevance of salinity response data obtained in managed environments to the more variable field situation. There is a sound theoretical basis for weighting the distribution of root zone salinity in proportion to distribution of roots, when interpreting yield response (Bingham and Garber, 1970). It is quite difficult to apply this weighting to commercial situations where the detail of root distributions generally is not known, and there is uncertainty about applicability of generalised root distribution models to different soil salinity profiles. For ease and commercial efficiency of providing advice to land managers we favour use of criteria based on an arithmetic average of the salinity in the soil depth containing most of the root system. Data for Australian conditions (Kingston, 1975; Nelson and Ham, 2000) show the 0–0.5 m interval contains 83–90% of roots in the surface 1.2 m of soil. This zone is also convenient for sampling the soil.

Criteria used for interpretation of soil salinity impacts on sugarcane in Australia (Calcino, 1994) were derived in the early 1970s from data of Bernstein et al. (1966a) and were generally only interpreted in relation to 0–0.25 m zone. Bernstein’s data showed that ECs values of <2, 2–4, 4–6 and >6 dS/m resulted in 0, 0–10, 10–20 and >20% loss of cane yield, respectively. These values were converted to equivalent EC15 values for a range of soil textures. However, we have observed a more severe impact of salinity in southern Queensland than was suggested from these criteria. Therefore, we reassessed the criteria in situ.

Materials and methods

Data in this paper were collected at two farms in southern Queensland, Australia, where salinity restricted yield of sugarcane. The Isis District site (25° 14’ S, 152° 17’ E) was on an irrigated cane farm, while the site in the Nambour District (26° 34’ S, 152° 57’ E) was on an un-irrigated site. The Isis data were acquired from a first ratoon of cultivar CP44-101 in 1985 and Nambour data from first ratoon of CP51-21 in 1998 and for plant and first-ratoon crops of Q136 in 2000 and 2001, respectively.

Fields were surveyed with an EM38 electromagnetic induction instrument (McNeil, 1986) to quantify the apparent electrical conductivity (ECa) to approximately 0.5, 1.0 and 1.5 m to index the distribution of salinity across the field. Six to nine stations (plots) that spanned the range of observed ECa values were then selected for subsequent measurement of cane yield and quality and soil salinity. Centroids of plots selected at the Q136 plant cane at Nambour in 2000 were located by differential global positioning system coordinates to allow use of the same sites for assessment in the first-ratoon crop.

Cane yield was determined in plots of 15 m² (two rows x 5 m) by the sampling method of Hogarth and Skinner (1967) when cane was 12 months of age. Soil samples were taken in 0.25 m increments to a depth of 1.0 m. Profile features (mottles and pale colours) and observation during soil sampling showed that the water table at both sites was most frequently located between 0.75 and 1.0 m depth and should not have a major impact on cane yield. Soils were assayed for pH in water and electrical conductivity in a 1:5 soil water extract (EC1:5). EC1:5 values were converted to electrical conductivity of the saturation extract (ECe) by multiplication of a water conversion factor (Shaw et al., 1987) based on clay content of the soil.

Six stems of cane from each plot were crushed in a laboratory mill to provide juice for analysis of brix and pol for calculation of Commercial Cane Sugar (CCS) content and electrical conductivity (ECj). ECj is strongly correlated with the ash content of juice (Kingston, 1982b). Yield was expressed as relative yield within each site and year. Impact of salinity on yield and cane quality parameters was determined from regression analysis using soil salinity averaged over the 0–0.5 m zone, as this is the zone of major root activity for sugarcane.

Results and discussion

Impact of salinity on cane yield and quality

There was a strong association between readings of the EM38 instrument (ECa) and values of ECe in the 0–0.5 m zone that was stable for plant and ratoon crops of Q136 (Figure 1a) and between ECa and relative cane yield (Figure 1b) where p<0.05. ECa from the EM38 in the horizontal dipole mode when held at 0.5 m above the soil surface was chosen as the index reading, rather than with the instrument in the same mode but operated at the soil surface, because of a superior correlation of the former position with ECe of the 0–0.5 m (r² = 0.80 as opposed to 0.65).

Comparison of regressions between ECa and ECa +0.5 m (Figure 1a) showed that variance and slopes of the plant and ratoon data sets were not significantly different (p<0.05).

However, the vertical separation or the intercepts of the first ratoon regression for relative cane yield was significantly less than for plant cane, but slopes were similar (Figure 1b). Salinity of the 0–0.5 m depth in soil had a moderate to strong negative association with cane yield, where r² ranged from 0.64 to
0.8 for \(p<0.05\) (Figure 2 a, b), with slope of the relationship ranging from \(-7.5\%\) to \(-16.9\%\) of relative cane yield per dS/m of \(EC_o\).

Increasing salinity of the 0–0.5 m zone was strongly correlated with increasing electrical conductivity (a measure of ash levels) in cane juice at the Nambour site (Figure 3); this also occurred at the Isis site where \(r^2 = 0.96\). Increasing salinity had a significant \((p<0.05)\) and negative effect on CCS of cane at all sites, with \(r^2 = 0.95, 0.88, 0.88\) and 0.48, respectively, for CP44-101, CP51-21, Q136 plant and Q136 ratoon, respectively. Further analysis of the data for Q136 showed that there was a significant \((p<0.05)\) and negative effect of salinity on juice purity \((r^2 = 0.87\) and 0.52). Salinity depressed purity because its effect on pol was 1.3 to 1.4 times greater than on brix (Figure 4a, b).

**Fig. 1 (a, b)**—Relationship between readings of apparent electrical conductivity of earth (mS/m) with an EM38 instrument in the horizontal dipole mode, when held 0.5 m above the earth \((ECa_{EM38h+0.5m})\) and (a) \(ECa\) of the 0–0.5 m depth zone and (b) relative cane yield of plant and first ratoon Q136 at the Nambour site, where \(** = p<0.05\).

**Fig. 2(a, b)**—Impact of soil salinity \((ECa)\) in 0–0.5 m depth of soil on relative cane yield of three cultivars, (a) first ratoons of CP44-101 and CP52-21 and (b) plant and first ratoon crops of Q136, where \(*** = p<0.05\).

**Fig. 3**—Association between salinity of 0–0.5 m soil depth \((ECa)\) and electrical conductivity of juice for CP51-21 and Q136 at the Nambour site, where \(*** = p<0.05\).
Conclusions

The strong correlation of ECₙ from the EM38 instrument with soil salinity (ECₙ) and cane yield confirms the utility of the instrument for rapid and non-destructive assessment of the impact of salinity on cane yield. Rapid calibration of the instrument for practical in-field use can be achieved by noting the correspondence of instrument readings with qualitative assessment of cane yield in adjoining fields. This allows surveys to be conducted in nearby fallow fields or areas not yet planted to sugarcane.

We have re-interpreted the data of Bernstein et al. (1966a) to produce quantitative relationships from their tabular data, showing that cane lost yield at the rate of 5.9 and 13.5% per dS/m of ECₙ for plant and first-ratoon crops, respectively. It appears that only the plant-cane data were used to derive the criteria used previously in Australia. The first ratoon data may have been disregarded, because Bernstein et al. (1966a) did caution that the ratoon data set was incomplete because some of the high salinity treatments failed to ratoon; effects on ratoon cane were, however, more severe than on plant cane. This was supported by our Q136 data where yield of plant and first ratoon crops declined at 7.5 and 12.1% per dS/m of ECₙ respectively, and yield of ratoon crops of CP51-21 and CP44-101 declined at 11.8 and 16.9% per dS/m of ECₙ respectively. Q136 is regarded as one of the more salt-tolerant varieties in Australia and its response as plant and ratoon cane is quite similar to that of the NCo cultivars used by Bernstein et al. (1966a). Nelson and Ham (2000) reported an average yield impact of 14% per dS/m of ECₙ for ratoon crops of five cultivars subjected to similar in-situ assessment in the Burdekin region of Australia. Thus, there is consistent reporting of more severe effects on ratoon than for the plant crops. This supported our field observations.

Our data in Figure 1b from the EM38 supported a significantly lower relative yield for first ratoon than plant crops of Q136, but the slopes of the functions were virtually identical, whereas there is a larger difference in the slopes of comparable yield functions based on ECₙ in Figure 2b. We offer no quantitative explanation of this situation, other than to advise that the EM38 should be used for broad definition of salinity hazards and that depth of penetration of readings from the chosen mode of operation is not confined to the 0–0.5 m zone, even though salinity in this zone was strongly correlated with EM38 response.

The significance of this revision of salinity thresholds can be assessed by comparison of the contemporary response functions with those based on plant crop data from Bernstein et al. (1966b) in Figure 5, in accordance with the framework provided by Mass and Hoffman (1977). Bernstein’s plant cane data and Mass and Hoffman (1977) classified sugarcane as a ‘moderately tolerant’ species, whereas our data suggest that the crop is moderately sensitive to sensitive to soil salinity. Use of equation (1) of Mass and Hoffman (1977) to calculate ECₙ for various yield impacts above the threshold value of ECₙ resulted in the proposed summary criteria (Table 1), where the cultivars in the moderately sensitive category include Q136 and CP51-21 and CP44-101 is classified as sensitive.

Our criteria are based on response of ratoon cane, because in most sugar industries the area of ratoons exceeds plant crops by more than three to one. Therefore, it seems logical to base the criteria on the most extensive and most sensitive crop class. This classification improves the agreement between the new Australian criteria and international reports (Table 2), even though the depth interval for classification is often not specified in the literature.

Data on the impact of soil salinity on quality of juice for both inorganic- and sucrose-related parameters (Figures 3 and 4) highlights the often un-recognised impact of soil or water salinity on productivity related parameters that affect sugar recovery. While a more saline environment has a positive

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**Fig. 4(a, b)**—Association between soil salinity of the 0–0.5 m soil depth and cane quality parameters in crops of Q136 plant and first ratoon cane. (a) brix and (b) pol, where \( p < 0.05 \).
impact on brix through elevating electrolytes in juice, these effects can be placed in perspective to show
that salinity has a much greater effect on brix through accumulation of soluble carbohydrates than on
inorganic ions, eg. juices with an EC of 3 and 5 dS/m will have total cation loadings of approximately 30
and 50 cmol(+)L, respectively. This will comprise a suite of cations, balanced by anions, but if we use
potassium as the dominant cation and an equal presence of chloride and sulfate ions, the inorganic
concentration will be approximately 2400 and 4000 mgL, respectively. If these juices have brix of 19.3%
and 18.1%, respectively (Figure 3), the increased electrolyte contributes only 0.16% to increased brix,
whereas brix actually declines by 1.2% units due to the reduced content of sugars.

Fig. 5—Results of in-field derivation of salinity response functions for Australian cultivars
compared with criteria developed by Bernstein et al. (1966a) according to the framework
proposed by Maas and Hoffmann (1977).

Table 1—Proposed criteria for interpretation of soil salinity data (EC, 0–0.5 m depth) for
impact on yield of sugarcane.

<table>
<thead>
<tr>
<th>Yield loss class</th>
<th>None</th>
<th>Slight</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield loss (%)</td>
<td>0</td>
<td>0–10</td>
<td>10–20</td>
<td>&gt;20</td>
</tr>
<tr>
<td>Moderately sensitive–sensitive cultivars</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EC₆(dS/m)</td>
<td>0–1.0</td>
<td>1.0–2.0</td>
<td>2.0–3.0</td>
<td>&gt;3.0</td>
</tr>
<tr>
<td>Sensitive cultivars</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EC₆(dS/m)</td>
<td>0–0.5</td>
<td>0.5–1.0</td>
<td>1.0–1.5</td>
<td>&gt;1.5</td>
</tr>
</tbody>
</table>

Table 2—Impact of salinity (EC₆) on cane yield from published data.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Reduction in cane yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>EC₆(dS/m)</td>
<td></td>
</tr>
<tr>
<td>Fogliata and Aso (1965)</td>
<td>1.5</td>
</tr>
<tr>
<td>Kobe and Sund (1965)</td>
<td>2.0</td>
</tr>
<tr>
<td>Bernstein et al. (1966a) (plant)</td>
<td>4.0</td>
</tr>
<tr>
<td>Bernstein et al. (1966a) (ratoon)</td>
<td>2.0</td>
</tr>
<tr>
<td>Anon. (1970)</td>
<td>2.0</td>
</tr>
<tr>
<td>FAO (1973)</td>
<td>4.0</td>
</tr>
</tbody>
</table>
We, therefore, propose that field-based assessments can be used to derive agronomically relevant salinity response criteria for sugarcane, as opposed to the more expensive and intensive approaches based on managed environments. Criteria should be based on response of ratoon crops, rather than on plant crops, because of the greater sensitivity and more extensive plantings of the latter crop class.

REFERENCES


UTILISATION DES RELEVÉS AUX CHAMPS POUR RAFFINER LES SEUILS DE TOLERANCE A LA SALINITE-DE LA CANNE A SUCRE

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MOTS-CLÉS: La Salinité, Rendement, La Qualité de Jus, EM38.

Résumé
LA CROYANCE que la canne à sucre n’est que modérément sensible à l’effet de la salinité du sol avait été établie principalement par des essais aux champs aux Etats-Unis au début des années 60 avec les variétés NCo293 et NCo310. Le rendement diminue de 5.9% pour chaque unité d’augmentation (dS/m) de la conductivité électrique des extraits de saturation (ECe). Ces données ont été utilisées en Australie pendant les 33 dernières années pour interpréter l’analyse du sol et pour prodiguer de conseil aux agriculteurs. Cependant, l’expérience acquise au fil des années suggère que cette approche sous-estime l’impact de la salinité sur les repousses de la canne. Nous avons utilisé un capteur de conductivité électromagnétique EM38 pour quantifier la gamme de salinité du sol à deux sites, avant de choisir 6-9 stations à chaque site pour quantifier formellement la salinité dans le profil du sol et mesurer le rendement de canne et la qualité du jus. Un cultivar a été examiné en canne vierge, alors que trois autres étaient des repousses. La pertinence de la norme établie aux Etats-Unis a été confirmée pour la canne vierge du cultivar Q136 moins sensible au sol, avec un déclin de rendement de 7.5% par dS/m ECe. Cependant, le rendement des repousses a diminué de 11.8, 12.1 et 16.9% par dS/m ECe pour les cultivars CP51-21, Q136 et CP44-101, respectivement. Le sucre commercial de canne (CCS) a également diminué avec l’augmentation de la salinité du sol, de 0.27-0.92 unité de CCS par dS/m ECe. La conductivité électrique du jus a augmenté avec l’augmentation de la salinité comme pour refléter les niveaux croissants de cendres dans le jus. La proportion plus élevée des repousses par rapport à la canne vierge dans les champs commerciaux indique qu’un seuil plus sensible devrait être adopté pour les repousses dans l’interprétation des risques de salinité dans le sol. Ces données suggèrent également que des cultivars doivent être classifiés comme modérément sensibles à sensibles aux effets néfastes de la salinité. La salinité a, donc, un important effet négatif sur le rendement de la canne à sucre et la qualité du jus extrait. Ces effets peuvent être aisément quantifiés par des mesures in-situ de salinité et de la croissance de la canne au champ.

USO DE MEDIDAS EN EL CAMPO PARA REFINAR LOS LÍMITES DE TOLERANCIA DE SALINIDAD, PARA VARIDADES DE CAÑA DE AZÚCAR

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PALABRAS CLAVES: Salinidad, Producción, Calidad de Jugo, EM38, Tallo de Caña de Azúcar.

Resumen
LA CONSIDERACIÓN de que la caña de azúcar tiene únicamente sensibilidad de producción moderada, al impacto de salinidad del suelo, se estableció ampliamente que los experimentos de campo en los EE.UU. a principios de los años 1960 con variedades NCo293 y NCo310. El rendimiento declinó de 5.9% por aumento de dS/m en la conductibilidad eléctrica de extractos de saturación (ECe). Estos datos se usaron en Australia durante los últimos 33 años para interpretar el análisis de suelo y para la provisión de consejo a productores de caña. Sin embargo, la experiencia de campo acumulada sugirió que, este abordaje estaba infravalorando el impacto sobre la producción de caña semilla de caña de azúcar. Usamos un medidor de conductibilidad electro-magnética de suelo EM38, para cuantificar el nivel de salinidad del suelo en dos sitios, antes de seleccionar 6-9 estaciones en cada sitio, para la medida formal de salinidad en el perfil del suelo y para la determinación de rendimiento de caña y calidad de jugo. Una variedad se examinó como cultivar de caña, mientras se examinaron tres como las cosechas de caña La relevancia de la norma de EE.UU. se confirmó, para una plantación de caña de la variedad Q136, menos sensible al sal, con una baja de rendimiento de 7.5% dS/m por ECe. Sin embargo, la producción de caña de semilla declinó de 11.8, 12.1 y 16.9% por dS/m en ECe para las variedades CP51-21, Q136 y CP44-101, respectivamente. Caña de Azúcar Comercial (C.A.C) también bajó con la salinidad del suelo aumentada, de 0.27-0.92 unidades de C.A.C por dS/m ECe. La conductibilidad eléctrica de jugo aumentó con la salinidad creciente como una reflexión de niveles de ceniza crecientes en el suelo. La proporción más alta de producción de plantas en los campos comerciales, indica que la norma más sensible para el tallo de caña debe adoptarse para la interpretación de riesgos de salinidad en el suelo. Estos datos también sugieren que las variedades deben ser clasificadas como ligeramente sensibles a sensibles, al daño de salinidad. Por consiguiente, la salinidad tiene un efecto importante y negativo en la producción de caña de azúcar y calidad de jugo extraído y estos efectos pueden cuantificarse fácilmente de las medidas in-situ de salinidad y de caña de azúcar crecido en el campo.