ABSTRACT

This study was undertaken to ascertain if soil sodicity significantly influences soil electrical conductivity ($\sigma_e$) - salinity calibrations. Laboratory columns of Fallbrook (Typic Haploxeralfs) and Yolo (Typic Xerorthents) soils were adjusted to various levels of salinity and sodicity by leaching them with solutions varying in electrical conductivity ($\sigma_w$) and sodium adsorption ratio (SAR); then $\sigma_e$ was measured using four-electrode techniques. Calibrations obtained between $\sigma_e$ and $\sigma_w$ over the $\sigma_w$ range 2 to 20 were compared at different levels of SAR ranging between 0 to 80 or 400. The calibrations between $\sigma_e$ and $\sigma_w$ were found to be insignificantly influenced by variations in SAR over the range studied. Normal variations in the exchangeable Na contents of typical saline, arid-land soils should not cause any serious misdiagnosis of soil salinity based on measurements of bulk $\sigma_e$ and use of $\sigma_e$-$\sigma_w$ calibrations.

Additional Index Words: soil sodicity, earth resistivity, sodium adsorption ratio.


MATERIALS AND METHODS

The electrical conductivities of two California soils, Fallbrook-B (USSSL soil no. 3677; fine-loamy, mixed thermic Typic Haploxeralfs) and Yolo (USSSL soil no. 3416; fine-silty, mixed, nonacid, thermic Typic Xerorthents) were studied as a function of exchangeable sodium percentage (ESP) on $\sigma_e$-$\sigma_w$ relations yielded inconsistent, inconclusive results. In a subsequent attempt (Shainberg et al., 1980), some hint of an ESP effect was evidenced but the variability of the data limited its conclusiveness. This study was undertaken using improved techniques and more critical methods of statistical analysis in an attempt to gain more conclusive data and to establish the influence, if any, of ESP on $\sigma_e$-$\sigma_w$ calibrations and the conditions under which ESP might produce a misdiagnosis of salinity level from $\sigma_e$ measurements.

REFERENCES


2 Visiting Research Scientist and Research Leader, Soil and Water Chemistry, U.S. Salinity Laboratory, Riverside, CA. This research was supported in part by a grant from the French Ministère des Affaires Etrangères.
mm air-dried soil into plastic cylinders (5.1-cm diam by 8-cm length) at average bulk densities (± 0.5%), of 1.35 kg m⁻³ (Yolo) or 1.31 kg m⁻³ (Fallbrook). For both the Fallbrook and Yolo soils, a set of seven columns were prepared in which the soil was constrained to prevent expansion through swelling (see Fig. 1). In addition, another set of seven columns was prepared for the Yolo soil in which the soil was unconstrained, but was kept fully saturated during the experiment. This was facilitated by placing a stopper in the top of the column through which a tube was inserted to permit water flow. Eight electrodes were inserted through the cylinder walls at intervals of about 1.8-cm around the middle perimeter of the soil column. Groups of any four neighboring electrodes were used as a four-electrode array; the outer two were used as current electrodes and the inner two as potential electrodes. By rotating the connections, five independent measurements of σw were made for any treatment using a Bison Model 2350A Earth Resistivity Meter. The appropriate cell constants were obtained by calibration using solutions of known σw-SAR values covering the ranges used in the experiment. These solutions included the following concentrations, in mmol L⁻¹: 200, 160, 120, 80, 60, 40, 20 and SAR values: 0, 10, 20, 30, 40, 80 and infinity (i.e., pure NaCl solution). The solutions were prepared from sodium and calcium-chloride salts.

The objective of the study was to compare σw calibration at various levels of ESP(SAR) to see if ESP affected the calibrations of the two soils. To accomplish this objective, an attempt was made to keep water content as constant as possible. The following procedure was carried out with the above objective in mind. The air in the soil columns was replaced with CO₂ to prevent air entrapment during saturation of the soils, since removal of air during leaching can cause errors in the measurement of σw (Frenkel et al., 1983). The soils were then saturated with the highest concentration solution of the appropriate SAR treatment. This leaching was continued using the same solution until the σw of the effluent no longer changed and was essentially that of the influent solution. At this time, five measurements of σw were made and a sample of the final effluent was analyzed for Na⁺, Ca²⁺, Mg²⁺ concentrations, and σw. Also, the weight of each “constrained” column, which had been previously tared, was measured so that the value of θ could be determined and checked for constancy. The height of each “unconstrained” column was measured to determine how much expansion had occurred through swelling. Subsequently, leaching was reinitiated using a solution of the same SAR, but of the next lower concentration. A series of such successive equilibrations were carried out until the permeability of the soil column became limiting.

**RESULTS AND DISCUSSION**

The experimental results are shown in Fig. 2 and 3 for the Fallbrook and Yolo constrained soils, respectively. Since there were no significant differences in the results obtained for the Yolo soil in the unconstrained and constrained columns (swelling occurring in the unconstrained soil columns was in the order of 5 to 10% in magnitude), only the constrained data are given. Changes in θ in the constrained columns, as determined from the weight measurements, were < 1%. There is no obvious or marked effect of ESP(SAR) on σw for these soils, within the limits of the accuracy of measurements and experimental conditions. The fact that separate columns were used for each SAR
treatment is one cause of the observed variation. It would have been preferable to use one column for each value of \( \sigma_a \) and to successively vary SAR, but this was impractical because of the very long time required to achieve ESP-SAR equilibration. Furthermore, the differential leaching that would be required at the different levels of concentration to achieve such equilibration would likely also create differences between columns and errors at least as great as those observed in this experiment. Part of the observed variation was related to errors in determining the actual values of ESP(SAR) existing in the middle of the soil column at the time \( \sigma_w \) was measured. This results from release of low amounts of \( \text{Ca}^{2+} \) and \( \text{Mg}^{2+} \) by mineral dissolution (which is ongoing in the columns during the leaching-equilibration process) which reduces the SAR values from those of the applied waters. The magnitude of error associated with this phenomenon is greatest where SAR is high and \( \sigma_a \) is low in the influent because, under these conditions, an increase of a few mmol (+) L\(^{-1}\) of \( \text{Ca}^{2+} + \text{Mg}^{2+} \) substantially alters the SAR of the influent solution. On the other hand, \( \sigma_w \) is not so markedly affected because the total amount of electrolyte added to the solution is small. Since the SAR value of the effluent did not attain that of the influent even after extensive leaching, the average of the influent and effluent solutions was used to represent SAR of the pore solution, except for the SAR infinity treatment (pure sodium chloride solution). In this case, the SAR of the effluent was used.

The experimental data are plotted in Fig. 4 and 5 in terms of \( \sigma_a = f(\text{SAR}) \) to further aid in the evaluation of the influence of ESP on \( \sigma_a \) and \( \sigma_w = f(\sigma_w) \) relations. The data over the SAR range of 0 to 40 are shown in Fig. 4a as linear plots; the wider SAR range of 10 to 400 are shown in Fig. 4b as semilog plots. These data show that there is no structure or trend in the \( \sigma_a \) values relative to SAR(ESP). The isolines of \( \sigma_a \) are essentially parallel to the SAR axis at any fixed value of \( \sigma_w \), except for Yolo soil at SAR 30. This discrepancy is likely an artifact of column preparation, since the “effect” diminished with increased leaching and did not occur at other levels of SAR. These figures show that \( \sigma_a \) is clearly dominated by \( \sigma_w \).

Two statistical approaches were undertaken in an attempt to more precisely evaluate the relative influences of \( \sigma_a \) and SAR on \( \sigma_a \). Because of the uncertainty regarding the accuracy of SAR, these analyses were made twice—once for the range of SAR <45 and again using all SAR values. For one analysis, the structural model given in Kendall and Stuart (1973) was fol-

Fig. 4. Relations between Fallbrook soil electrical conductivity \( (\sigma_a) \) and the electrical conductivity \( (\sigma_w) \) and sodium adsorption ratio (SAR) of the soil water for the ranges of SAR of 0 to 40 (a) and 10 to 400 (b).

Fig. 5. Relations between Yolo soil electrical conductivity \( (\sigma_a) \) and the electrical conductivity \( (\sigma_w) \) and sodium adsorption ratio (SAR) of the soil water for the ranges of SAR 0 to 40 (a) and 10 to 80 (b).
Table 2. Statistical parameters obtained in multilinear statistical analyses.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Regression values†</th>
<th>Standard errors‡</th>
<th>Test values§</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$X_i(\sigma_{av})$</td>
<td>$X_i$(SAR)</td>
<td>Int.</td>
</tr>
<tr>
<td>Fallbrook (all SAR data)</td>
<td>0.281</td>
<td>0.00009</td>
<td>0.408</td>
</tr>
<tr>
<td>Yolo (closed cell, SAR &lt; 45)</td>
<td>0.236</td>
<td>0.0013</td>
<td>0.602</td>
</tr>
<tr>
<td>Yolo (open cell, SAR &lt; 45)</td>
<td>0.261</td>
<td>-0.0017</td>
<td>0.577</td>
</tr>
</tbody>
</table>

† Magnitudes of the multilinear regression coefficients for $\sigma_{av}$ and SAR and the intercept values.
‡ Standard errors of the multilinear regression coefficients of $\sigma_{av}$ and SAR and the intercept values.
§ The test statistic is approximately distributed as $F(1, df)$.
¶ Degrees of freedom for the test statistic.

Table 3. Least squares linear regression analyses.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Function</th>
<th>Linear regression</th>
<th>Coefficient of correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Slope</td>
<td>Intercept</td>
</tr>
<tr>
<td>Fallbrook (all SAR data)</td>
<td>$\sigma_{av} = a\sigma_w + b$</td>
<td>0.280</td>
<td>0.422</td>
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<tr>
<td></td>
<td>$\sigma_w = a\sigma_{av} + b$</td>
<td>3.494</td>
<td>-1.266</td>
</tr>
<tr>
<td>Yolo (all SAR data)</td>
<td>$\sigma_{av} = a\sigma_w + b$</td>
<td>0.235</td>
<td>0.687</td>
</tr>
<tr>
<td></td>
<td>$\sigma_w = a\sigma_{av} + b$</td>
<td>3.909</td>
<td>-1.854</td>
</tr>
</tbody>
</table>

Results of simple (least squares) linear regression analyses of $\sigma_{av}$ and $\sigma_w$ for the Fallbrook and Yolo soils using data covering all SAR values are given in Table 3. These results show that $\sigma_{av}$ and $\sigma_w$ are highly correlated, irrespective of SAR.

The results of the multilinear regression statistical analyses are given in Table 2 in terms of the coefficients of $X(\sigma_{av})$ and $Y$(SAR), the regression intercepts ($I$), the standard errors of the coefficients and intercepts, the test values for the hypothesis that the coefficient of SAR is zero, and the df for the various data sets. The values of the SAR coefficients are very low (hence, they should have very little effect on $\sigma_{av}$ and are not statistically significant at the 5% level).

Results of simple (least squares) linear regression analyses of $\sigma_{av}$ and $\sigma_w$ for the Fallbrook and Yolo soils using data covering all SAR values are given in Table 3. These results show that $\sigma_{av}$ and $\sigma_w$ are highly correlated, irrespective of SAR.

Errors involved in measurements of $\sigma_{av}$, $\sigma_w$, and SAR under laboratory-controlled conditions exceed, and preclude, the detection of any influence of SAR on $\sigma_{av}$-$\sigma_w$ relations. It is concluded that variations in the exchangeable sodium contents of typical saline, arid land soils should not cause any serious misdiagnosis of soil salinity based upon measurements of soil $\sigma_{av}$ and use of $\sigma_{av}$ or $\sigma_{av}$-$\sigma_w$ field calibrations.

REFERENCES


