Electrical Conductivity in Soil Extracts: Chemical Factors and Their Intensity*1

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ABSTRACT

The electrical conductivity (EC) of 1:5 soil-water extract (EC1:5) was studied utilizing path coefficient analysis. The study focused on revealing the main chemical factors contributing to EC of soil extracts and their relative importance. Results showed that the most important factors influencing the EC1:5 of coastal salt-affected soils were the concentration of salt in 1:5 soil-water extract (Sc), Cl−, and the sodium adsorption ratio (SAR), while effects of pH, CO3−, HCO3−, soluble sodium percentage (SSP), and sodium dianion ratio (SDR) were very weak. Though the direct path coefficients between EC1:5 and SO42−, Ca2+, Mg2+, K+, or Na+ were not high, influence of other chemical factors caused the coefficients to increase, making the summation of their direct and indirect path coefficients relatively high. Evidences showed that multiple regression relations between EC1:5 and most of the primary factors (Sc, Cl−, and SAR) had sound reliability and very good accuracy.

Key Words: chemical properties, electrical conductivity, impact factor, soil salinization

Quantitative analysis of soluble salts in soils and/or groundwater is one of the key processes in studying soil salt dynamics and assessing soil salinity (Marshal and Holmes, 1979; Committee of Saline Soils of Soil Science Society of China, 1989; Wang, 1993; Mao et al., 1997; Mehdi et al., 2004; Chen et al., 2004). The total salt content and electrical conductivity (EC) of a soil extract are the most widely used parameters for describing soil salinity. Recent advances in soil science (Zhang et al., 2005) show that due to the variety in soil moisture under field conditions, soil salinity expressed by total salt content cannot reflect effective field salt content with sound reliability, especially when exploring the relation between plant growth and soil salinity (Yan et al., 2005; Bhatti et al., 2005).

EC1:5, which is the EC of a soil extract in a solution of 1 part soil diluted by 5 parts water, is a comprehensive parameter reflecting information on effective soil salinity under a certain soil water content and is convenient to obtain with sound comparability and repeatability (Rhoades et al., 1990, 1999; Sun, 2000). Today the EC of a 1:5 soil extract is used to describe soil salinity in almost all international periodicals (Tam and Wong, 1998; Ramsis et al., 1999; Hopkins and Richardson, 1999; Heydari et al., 2001; Zhang et al., 2003) and many Chinese researchers actively utilize it. However, due to the absence of an internationally recognized uniform sample preparation method, the time-consuming nature of the procedure (United States Salinity Laboratory Staff, 1954), the diversity of soil salinity properties, and the difference in the customary ratios of soil to water in weight, an international criteria of measuring EC of soil extract has, as yet, not been established, with many researchers still making use of soil total salt content in g kg−1 to characterize soil salinity (e.g., Xie, 1989; Zhang et al., 2003).

The soil extract EC analysis method, governed by the principle of the electrical effect of an electrolyte, is a succinct and valuable analytical method for a soil salinity assessment. Among the many approaches for obtaining soil solution samples, extraction is the most universal method. Although there are several soil-water ratios used in EC measurements of soil extract, such as 1:1, 1:2, 1:5, 1:10, and also

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saturation (Committee of Agricultural Chemistry of Soil Science Society of China, 1983; He and Niu, 1997; Zhang et al., 2003), in China 1:5 is the most popular.

However, extraction also has its limitations. For instance, a certain soil-water ratio used may not reflect the broad range of moisture found in nature, or EC values of soil water extracts may be dependent on the dilution factor and not easily compared with the EC of other soil-water ratio extracts having a different dilution factor (Institute of Soil Science, Chinese Academy of Sciences, 1978; Wu and Wang, 1997; Sun, 2000; Liu and Yang, 2001). When determining soil salinity using EC of a soil-water extract, many possible factors, such as soil-water ratio, soil salt composition, solution total salinity, electrophoretic mobility, solution temperature, and constant of the conductance cell (Cai et al., 1997; Soil Science Society of China, 1999), will affect soil salinity measurements to a certain extent.

Many studies have been carried out to explore the relations between EC of soil extracts and total salt content of soils, but very few of these have touched upon salinization in coastal areas. Soil samples used in this study were taken from the typical coastal land of China, and hence the relation between $EC_{1:5}$ and total salt content of such soils will have sound practical value. However, further exploration to determine which factors are dominant to EC, especially those based on soil chemical properties, still needs to be conducted. Therefore, this study focused on revealing the main chemical factors contributing to EC of soil extracts and their relative importance.

MATERIALS AND METHODS

Soils and preparation

Soil samples used (silt loam) in this study were collected from Dongchuan farm situated on typical coastal lands of China, about 50 km northeast to Dongtai City. Layers of 0–10, 10–20, 20–40, 40–60, 60–80, 80–120, 120–150, and 150–200 cm were sampled in each of the 15 soil profiles (due to shallow groundwater table, 117 soil samples were collected). The soil samples were air-dried (the gravimetric water content after air-drying was about 0.06 g g$^{-1}$), ground, and sieved through a 20-mesh screen, Following which for each soil sample the 1:5 soil-water extract was prepared and its EC, pH, and salt composition were measured by standard methods (Soil Science Society of China, 1999).

Analysis

First, stochastic measurements on the original data of three typical soil profiles (i.e. 24 soil samples) with respect to different salt content and profile salt distribution were selected as verification data resources to test the regression relations and coefficients obtained with the other original 12 soil profiles (i.e. 93 soil samples).

Then, the relation between $EC_{1:5}$ and total salt content of soils was established using a regression analysis. Next, aggregating 93 soil samples, a correlation analysis was conducted with the dependent variable $EC_{1:5}$ at 25 °C, and independent variables including concentration of salt in 1:5 soil-water extract ($S_c$, g L$^{-1}$), ion concentration (mmol L$^{-1}$), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), sodium dianion ratio (SDR), and pH. Using the results of this correlation analysis direct and indirect path coefficients for the same variables were obtained. The correlations between $EC_{1:5}$ and the chemical properties of soil extract were then analyzed. For the three most important factors in determining $EC_{1:5}$, regression equations were developed and validated for accuracy and applicability utilizing an ANOVA test.

RESULTS AND DISCUSSION

The relation between $EC_{1:5}$ and total salt content of soils

The characteristic relation between the EC of soil extract and total salt content was

$$EC_{1:5} = 0.3658S_t - 0.0152 \quad (r^2 = 0.988, \ P < 0.01, \ n = 93) \quad (1)$$
where $EC_{1:5}$ is the EC of 1:5 soil-water extract in $dS \, m^{-1}$; and $S_i$ is the total salt content in $g \, kg^{-1}$.

**Path analysis method and its principle**

Swell Wright, in 1918–1921, originally brought forward the path analysis method as an advanced analysis method to research the consequences of genetics (Bhatt, 1973; Ming, 1990). Path analysis can not only be used to determine correlation between two variables, but also, by decomposing coefficients to direct and indirect coefficients, indicate the relative importance of each variable to the result in a comprehensive system.

Suppose that within one associated system a dependent variable $y$ is linear to independent variables $x_i$ ($i = 1, 2, 3, \ldots, n$), then the regression can be shown as:

$$y = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_n x_n$$

(2)

where $b_i$ ($i = 0, 1, 2, 3, \ldots, n$) are regression coefficients that are not known, but can be acquired by ordinary least-squares methods. Eq. 2 can be converted to a normal matrix equation of:

$$
\begin{bmatrix}
1 & r_{x_1,x_2} & \cdots & r_{x_1,x_n} \\
r_{x_2,x_1} & 1 & \cdots & r_{x_2,x_n} \\
\vdots & \vdots & \ddots & \vdots \\
r_{x_n,x_1} & r_{x_n,x_2} & \cdots & 1
\end{bmatrix}
\begin{bmatrix}
P_{yx_1} \\
P_{yx_2} \\
\vdots \\
P_{yx_n}
\end{bmatrix}
=
\begin{bmatrix}
r_{x_1,y} \\
r_{x_2,y} \\
\vdots \\
r_{x_n,y}
\end{bmatrix}
$$

(3)

where $r_{x_i,y}$ is the correlation between independent variables $x_i$ and $x_j$; the direct path coefficient $P_{yx_i}$ is the normal partial regression coefficient of $x_i$ to $y$, which reveals the relative importance of independent variables; and $r_{x_i,y}$ is the correlation between $x_i$ and $y$. $P_{yx_i}$ can be calculated from the normal matrix equation since:

$$P_{yx_i} = \alpha_i \delta_{x_i}/\delta_y \quad (i = 1, 2, \ldots, n)$$

(4)

where $\alpha_i$ is the partial regression coefficient between $y$ and $x_i$; and $\delta_{x_i}$ and $\delta_y$ are the standard deviations of $x_i$ and $y$, respectively.

$r_{x_i,x_j} P_{yx_j}$ is the indirect path coefficient between $x_i$ and $y$ via $x_j$. Thus, the path coefficient of all residuals is defined by:

$$P_{ye} = [1 - (r_{x_1,y} P_{yx_1} + r_{x_2,y} P_{yx_2} + \cdots + r_{x_n,y} P_{yx_n})]^{1/2}$$

(5)

A high value of $P_{ye}$ means the error is large or some other important factors have been excluded.

**Path coefficient for chemical properties in soil extracts**

The correlation coefficients between selected independent variables (i.e. chemical properties of soil extract) and the dependent variable ($EC_{1:5}$), as well as correlation coefficients between any two independent variables, are shown in Table I.

Results from Table I and Eq. 3 were utilized to obtain the direct and indirect path coefficients for the same variables (Table II). In Table II, data on the diagonal are direct path coefficients, while the rest are indirect path coefficients. The residual path coefficient from Eq. 5 was 0.061, and because of this small value, it could be concluded that the analytical error was negligible with no other important factors being excluded.

**Correlation between $EC_{1:5}$ and chemical properties of soil extract**

Table II shows the sequence of the direct path coefficients, as: $Cl^- > S_0 > SAR > Na^+ > K^+ > Mg^{2+} > SDR > CO_3^{2-} > SO_4^{2-} > HCO_3^- > pH > SSP > Ca^{2+}$. The direct path coefficient for $pH$,
TABLE I
Correlation coefficients between chemical properties of soil extract and \( EC_{1:5} \) and between any two chemical properties of soil extract \((P < 0.05)\)

<table>
<thead>
<tr>
<th>Chemical property of soil extract(^a)\</th>
<th>pH</th>
<th>( CO_{3}^{2-} )</th>
<th>HCO(_3)</th>
<th>Cl(^-)</th>
<th>( SO_{4}^{2-} )</th>
<th>Ca(^{2+})</th>
<th>Mg(^{2+})</th>
<th>K(^+)</th>
<th>Na(^+)</th>
<th>Sc</th>
<th>SAR</th>
<th>SSP</th>
<th>SDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( CO_{3}^{2-} )</td>
<td>0.511</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCO(_3)</td>
<td>0.460</td>
<td>0.203</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl(^-)</td>
<td>-0.305</td>
<td>-0.174</td>
<td>-0.415</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( SO_{4}^{2-} )</td>
<td>-0.318</td>
<td>-0.176</td>
<td>-0.417</td>
<td>0.839</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca(^{2+})</td>
<td>-0.325</td>
<td>-0.243</td>
<td>-0.095</td>
<td>0.818</td>
<td>0.710</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg(^{2+})</td>
<td>-0.294</td>
<td>-0.170</td>
<td>-0.297</td>
<td>0.951</td>
<td>0.852</td>
<td>0.817</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K(^+)</td>
<td>-0.241</td>
<td>-0.108</td>
<td>-0.413</td>
<td>0.894</td>
<td>0.782</td>
<td>0.684</td>
<td>0.868</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na(^+)</td>
<td>-0.271</td>
<td>-0.129</td>
<td>-0.399</td>
<td>0.997</td>
<td>0.853</td>
<td>0.807</td>
<td>0.940</td>
<td>0.889</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sc</td>
<td>-0.270</td>
<td>-0.138</td>
<td>-0.365</td>
<td>0.996</td>
<td>0.862</td>
<td>0.828</td>
<td>0.957</td>
<td>0.895</td>
<td>0.998</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAR</td>
<td>-0.143</td>
<td>0.022</td>
<td>-0.505</td>
<td>0.862</td>
<td>0.719</td>
<td>0.577</td>
<td>0.699</td>
<td>0.796</td>
<td>0.885</td>
<td>0.859</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSP</td>
<td>0.100</td>
<td>0.140</td>
<td>-0.449</td>
<td>0.316</td>
<td>0.244</td>
<td>-0.043</td>
<td>0.104</td>
<td>0.392</td>
<td>0.351</td>
<td>0.307</td>
<td>0.688</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>SDR</td>
<td>0.183</td>
<td>0.290</td>
<td>-0.365</td>
<td>0.218</td>
<td>0.140</td>
<td>-0.136</td>
<td>0.006</td>
<td>0.270</td>
<td>0.260</td>
<td>0.213</td>
<td>0.650</td>
<td>0.897</td>
<td>1</td>
</tr>
<tr>
<td>( EC_{1:5} )</td>
<td>-0.313</td>
<td>-0.182</td>
<td>-0.427</td>
<td>0.997</td>
<td>0.847</td>
<td>0.813</td>
<td>0.946</td>
<td>0.903</td>
<td>0.995</td>
<td>0.994</td>
<td>0.869</td>
<td>0.330</td>
<td>0.230</td>
</tr>
</tbody>
</table>

\(^a)\) All ion symbols, such as Cl\(^-\) or Mg\(^{2+}\), in this study mean concentration of anion/cation related, respectively, in mmol L\(^{-1}\); Sc is the concentration of salt in 1:5 soil-water extract; SAR is the sodium adsorption ratio, \( SAR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})^{1/2}} \); SSP is the soluble sodium percentage \((\%)\), \( SSP = 100Na^+/[2(Ca^{2+} + Mg^{2+}) + Na^+] \); and SDR is the sodium dianion ratio, \( SDR = \frac{Na^+}{[2(Ca^{2+} + Mg^{2+})]} \).

\( CO_{3}^{2-}, HCO_{3}, SSP, \) or SDR was minor, and so was the sum of the direct and indirect path coefficients for each of those five factors mentioned above. This indicated that the direct and indirect contribution of each of these five variables to \( EC_{1:5} \) was negligible and could be disregarded.

Also, the direct path coefficients for \( SO_{4}^{2-}, Ca^{2+}, Mg^{2+}, K^+, \) and Na\(^+\) were not high, whereas the sum of the direct and indirect path coefficients for each was relatively high. This could have been due to the influence of other chemical factors that enhanced their indirect contribution to \( EC_{1:5} \). Meanwhile, the direct path coefficients of Cl\(^-\), Sc, and SAR were all rather high, as was the sum of their direct and indirect path coefficients. This indicated that they not only contributed indirectly via other chemical factors, but also had a strong, direct contribution to \( EC_{1:5} \). These three related factors had a significant correlation \((P < 0.05)\) with \( EC_{1:5} \), and they were the uppermost three important factors in \( EC_{1:5} \). Moreover, the indirect path coefficients between any two of Cl\(^-\), Sc, and SAR were obviously high, which showed that the interactions of these three factors had an appreciable effect on \( EC_{1:5} \). This result was consistent with that of Rhoades et al. (1999) who pointed out that in soil solutions, ion composition and total salinity were the two most important factors for the EC of a 1:5 soil extract.

Since Cl\(^-\), Sc, and SAR were the most important factors in determining \( EC_{1:5} \), regression functions (Eqs. 6 to 9) of \( EC_{1:5} \) concerning Cl\(^-\), Sc and/or SAR were obtained and shown as:

\[
EC_{1:5} = 1.8288Sc - 0.0152 \quad (r^2 = 0.988)
\]

\[
EC_{1:5} = 0.1121Cl^- + 0.1693 \quad (r^2 = 0.9945)
\]

\[
EC_{1:5} = 0.1046Cl^- + 0.124Sc + 0.15633 \quad (r^2 = 0.9946)
\]

\[
EC_{1:5} = 0.1011Cl^- + 0.1254Sc + 0.0087SAR + 0.1141 \quad (r^2 = 0.9949)
\]

where \( EC_{1:5} \) is EC of 1:5 soil-water extract in dS m\(^{-1}\); Sc is the concentration of salt in 1:5 soil-water extract in g L\(^{-1}\); Cl\(^-\) is concentration of anion Cl\(^-\) in mmol L\(^{-1}\); and SAR is the sodium adsorption ratio.
TABLE II
Path coefficients between chemical properties of soil extract and $EC_{1.5}$ with data on the diagonal as direct path coefficients and the rest as indirect path coefficients, and the sum of the direct and indirect path coefficients for each chemical property of soil extract

<table>
<thead>
<tr>
<th>Chemical property of soil extract&lt;sup&gt;a&lt;/sup&gt;</th>
<th>pH</th>
<th>CO$_3^{2-}$</th>
<th>HCO$_3^-$</th>
<th>Cl$^-$</th>
<th>SO$_4^{2-}$</th>
<th>Ca$^{2+}$</th>
<th>Mg$^{2+}$</th>
<th>K$^+$</th>
<th>Na$^+$</th>
<th>Sc</th>
<th>SAR</th>
<th>SSP</th>
<th>SDR</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>-0.0110</td>
<td>-0.0134</td>
<td>-0.0089</td>
<td>-0.1496</td>
<td>0.0012</td>
<td>-0.0140</td>
<td>-0.0125</td>
<td>0.0144</td>
<td>-0.0958</td>
<td>-0.0217</td>
<td>-0.0008</td>
<td>-0.0073</td>
<td>-0.3132</td>
<td></td>
</tr>
<tr>
<td>CO$_3^{2-}$</td>
<td>-0.0058</td>
<td>-0.0262</td>
<td>-0.0039</td>
<td>-0.0851</td>
<td>0.0035</td>
<td>0.0009</td>
<td>-0.0081</td>
<td>-0.0056</td>
<td>0.0069</td>
<td>-0.0488</td>
<td>0.0033</td>
<td>-0.0011</td>
<td>-0.116</td>
<td>-0.1815</td>
</tr>
<tr>
<td>HCO$_3^-$</td>
<td>-0.0052</td>
<td>-0.0053</td>
<td>-0.0193</td>
<td>-0.2033</td>
<td>0.0083</td>
<td>0.0004</td>
<td>-0.0141</td>
<td>-0.0214</td>
<td>0.0212</td>
<td>-0.1292</td>
<td>-0.0766</td>
<td>0.0034</td>
<td>0.0146</td>
<td>-0.4266</td>
</tr>
<tr>
<td>Cl$^-$</td>
<td>0.0034</td>
<td>0.0045</td>
<td>0.0080</td>
<td>0.4899</td>
<td>-0.0168</td>
<td>-0.0030</td>
<td>0.0451</td>
<td>0.0464</td>
<td>-0.0530</td>
<td>0.3529</td>
<td>0.1309</td>
<td>-0.0024</td>
<td>-0.0087</td>
<td>0.9973</td>
</tr>
<tr>
<td>SO$_4^{2-}$</td>
<td>0.0036</td>
<td>0.0046</td>
<td>0.0080</td>
<td>0.4109</td>
<td>-0.0200</td>
<td>-0.0026</td>
<td>0.0404</td>
<td>0.0406</td>
<td>-0.0453</td>
<td>0.3055</td>
<td>0.1091</td>
<td>-0.0019</td>
<td>-0.0056</td>
<td>0.8474</td>
</tr>
<tr>
<td>Ca$^{2+}$</td>
<td>0.0037</td>
<td>0.0064</td>
<td>0.0018</td>
<td>0.4008</td>
<td>-0.0142</td>
<td>-0.0037</td>
<td>0.0388</td>
<td>0.0355</td>
<td>-0.0429</td>
<td>0.2935</td>
<td>0.0876</td>
<td>0.0003</td>
<td>0.0054</td>
<td>0.8130</td>
</tr>
<tr>
<td>Mg$^{2+}$</td>
<td>0.0033</td>
<td>0.0044</td>
<td>0.0057</td>
<td>0.4657</td>
<td>-0.0170</td>
<td>-0.0030</td>
<td>0.0475</td>
<td>0.0451</td>
<td>-0.0499</td>
<td>0.3391</td>
<td>0.1060</td>
<td>-0.0008</td>
<td>-0.0002</td>
<td>0.9458</td>
</tr>
<tr>
<td>K$^+$</td>
<td>0.0027</td>
<td>0.0028</td>
<td>0.0100</td>
<td>0.4379</td>
<td>-0.0156</td>
<td>-0.0025</td>
<td>0.0412</td>
<td>0.0519</td>
<td>-0.0472</td>
<td>0.3169</td>
<td>0.1208</td>
<td>-0.0030</td>
<td>-0.0108</td>
<td>0.9030</td>
</tr>
<tr>
<td>Na$^+$</td>
<td>0.0031</td>
<td>0.0034</td>
<td>0.0080</td>
<td>0.4882</td>
<td>-0.0170</td>
<td>-0.0030</td>
<td>0.0446</td>
<td>0.0462</td>
<td>-0.0532</td>
<td>0.3534</td>
<td>0.1344</td>
<td>-0.0027</td>
<td>-0.0104</td>
<td>0.9946</td>
</tr>
<tr>
<td>Sc</td>
<td>0.0030</td>
<td>0.0036</td>
<td>0.0070</td>
<td>0.4880</td>
<td>-0.0172</td>
<td>-0.0030</td>
<td>0.0454</td>
<td>0.0465</td>
<td>-0.0530</td>
<td>0.3543</td>
<td>0.1303</td>
<td>-0.0024</td>
<td>-0.0085</td>
<td>0.9940</td>
</tr>
<tr>
<td>SAR</td>
<td>0.0016</td>
<td>0.0006</td>
<td>0.0097</td>
<td>0.4224</td>
<td>-0.0144</td>
<td>-0.0020</td>
<td>0.0332</td>
<td>0.0413</td>
<td>-0.0470</td>
<td>0.3042</td>
<td>0.1518</td>
<td>-0.0053</td>
<td>-0.0259</td>
<td>0.8689</td>
</tr>
<tr>
<td>SSP</td>
<td>-0.0010</td>
<td>-0.0037</td>
<td>0.0087</td>
<td>0.1549</td>
<td>-0.0049</td>
<td>0.0002</td>
<td>0.0049</td>
<td>0.0204</td>
<td>-0.0187</td>
<td>0.1089</td>
<td>0.1045</td>
<td>-0.0077</td>
<td>-0.0358</td>
<td>0.3306</td>
</tr>
<tr>
<td>SDR</td>
<td>-0.0021</td>
<td>-0.0076</td>
<td>0.0070</td>
<td>0.1069</td>
<td>-0.0028</td>
<td>0.0005</td>
<td>0.0003</td>
<td>0.0140</td>
<td>-0.0138</td>
<td>0.0755</td>
<td>0.0987</td>
<td>-0.0069</td>
<td>-0.0399</td>
<td>0.2299</td>
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</tbody>
</table>

<sup>a</sup>All ion symbols, such as Cl$^-$ and Mg$^{2+}$, in this study mean concentration of anion/cation related, respectively, in mmol L$^{-1}$; $S_c$ is the concentration of salt in 1:5 soil-water extract; SAR is the sodium adsorption ratio; SSP is the soluble sodium percentage (%); and SDR is the sodium diion ratio.
As can be observed from the $r^2$ in Eqs. 6 to 9, if $\text{Cl}^-$, $S_c$, and/or $SAR$ have been given, $EC_{1:5}$ could be calculated with sound reliability. At the same time, according to the related function $\text{Cl}^-$, $S_c$, or $SAR$ could be obtained when necessary.

**Validation of regression equations**

Validation of the above four regression functions with ANOVA is shown in Table III, where $EC_{1:5}$ of the validating samples (i.e. 24 soil samples) ranged from 0.14 dS m$^{-1}$ to 8.01 dS m$^{-1}$. As illustrated in Table III, the differences between the measured $EC_{1:5}$ and calculated $EC_{1:5}$ according to all functions were not significant at the 0.01 level. This suggested that the calculated $EC_{1:5}$ could be substituted for the measured $EC_{1:5}$, that is, the calculated $EC_{1:5}$ could be used as an unbiased estimator of measured $EC_{1:5}$, and the four regression functions stated above could be employed to precisely predict EC of 1:5 soil-water extract.

**TABLE III**

<table>
<thead>
<tr>
<th>Equation</th>
<th>Source</th>
<th>df</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>$F$</th>
<th>$P$</th>
<th>RMSE$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Within groups</td>
<td>1</td>
<td>0.0553</td>
<td>0.0553</td>
<td>0.0099</td>
<td>0.9212</td>
<td>0.3272</td>
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<tr>
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<td>Between groups</td>
<td>46</td>
<td>257.2224</td>
<td>5.5918</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Within groups</td>
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<td>0.0243</td>
<td>0.0243</td>
<td>0.0044</td>
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<tr>
<td></td>
<td>Between groups</td>
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<td>254.2299</td>
<td>5.5267</td>
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<td></td>
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<tr>
<td>8</td>
<td>Within groups</td>
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<td>0.0268</td>
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<td>0.9448</td>
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<tr>
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<td>5.5338</td>
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<td></td>
</tr>
<tr>
<td>9</td>
<td>Within groups</td>
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<td>0.0063</td>
<td>0.0012</td>
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<td>251.0932</td>
<td>5.4585</td>
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</tr>
</tbody>
</table>

$^a$RMSE—root mean squared error.

The relation between concentration of salt in 1:5 soil-water extract ($S_c$ in g L$^{-1}$) and EC is generally linear within a certain range of $S_c$ (commonly no larger than 15 g L$^{-1}$), and the deviation will usually increase with an increase in $S_c$ or total soil salt content (Wu and Wang, 1997). When $S_c$ or total soil salt content becomes relatively high, the increment of EC will slow down, and then become curvilinear (He and Niu, 1997; Zhang et al., 2003). Soil salinities used in this study were of a long range, as a result concentrations of salt in the soil-water extract varied greatly. To further analyze precision and applicability of the four regression functions in Eqs. 6 to 9, the mean error (ME) and root mean squared error (RMSE) (Table III) of the four regression functions mentioned above were plotted (Fig. 1). Fig. 1 showed that the sequence of precision for all equations was Eq. 9 > Eq. 7 > Eq. 8 > Eq. 6 and that each equation had great practical utility.

![Fig. 1 Plot of root mean square error (RMSE) vs. mean error (ME) for the regression equations (Eqs. 6–9).](image-url)
CONCLUSIONS

For the coastal saline soil used in this research, EC of 1:5 soil-water extract ($EC_{1:5}$ in dS m$^{-1}$) and total soil salt content ($S_t$ in g kg$^{-1}$) showed a highly significant linear correlation ($P < 0.01$). It was also found that many chemical properties influenced EC of the soil-water extract to a different extent, with the predominant factors being concentration of the negative ion, $Cl^{-}$; salt concentration of soil-water extract, $S_c$; and the sodium adsorption ratio, SAR. Four regression functions were established between EC of the 1:5 soil-water extract and the predominant chemical properties all of which had high practical utility.

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REFERENCES


