Arid Soil Research and Rehabilitation, Volume 7, pp. 29-38
Printed in the UK. All rights reserved.

0890-3069/93 $10.00 + .00
Copyright © 1993 Taylor & Francis

Coefficients for Estimating SAR from Soil pH and EC Data and Calculating pH from SAR and EC Values in Salinity Models

CHARLES W. ROBBINS

USDA-Agricultural Research Service
3793 North 3600 East
Kimberly, ID 83341, USA

Abstract *Data from highly weathered, low pH, sodic Australian soils have been used to develop a method for estimating soil exchangeable sodium percentage (ESP) or soil extract sodium adsorption ratio (SAR) from soil pH and electrical conductivity (EC) data. The method can also be used to calculate soil pH in soil salinity models using SAR and EC values. The pH was calculated as* $pH = A + (B \times SAR^{1/2})/(1 + C \times EC)$. *Rewriting the equations in terms of SAR (or ESP), gives SAR (or ESP)* $= [(pH - A)(1 + C \times EC)/B]^2$. *This study was conducted to determine whether these same methods could be used to predict the pH and SAR values for arid climate soils that are only slightly weathered and are often sodic under natural conditions. Existing pH, EC, and SAR data from Declo loam (coarse-loamy, mixed, mesic, Xerollic Calciorthids), Freedom silt loam (fine-silty, mixed, mesic, Xerollic Calciorthids), and Mazuma sandy loam (coarse-loamy, mixed (calcareous), mesic Typic Torriorthents) were used to calculate the* A, B, *and* C *coefficients for the three high sodium soils. Coefficients obtained for a particular soil site were then used to predict pH or SAR of soil samples at additional sites and the correlation between calculated and measured values were determined. The* A *values for the Idaho soils are about 0.8 greater than those for the Australian soils, which were not completely base saturated. The Australian soils* B *values were about twice that of the calcareous Idaho soils, and the* C *values were not significantly different for the Australian and Idaho soils. In both cases the* A *coefficient values were slightly smaller than or nearly equal to the smallest pH values in a particular data set. Using coefficients from one location of a particular sodic or saline-sodic soil to predict pH or SAR of the same soil, at a second location, was shown to be practical. Each soil type, however, requires its own set of coefficients. These relationships provide a rapid field method for estimating SAR or ESP from easily obtainable EC and pH data once the* A, B, *and* C *coefficients are determined for a particular soil. They also provide a method for pH calculation in soil salinity models that take into account soil EC and sodium effects on pH.*

Keywords sodic soils, saline soils, soil salinity, reclamation, amelioration

Introduction

Prudent management of irrigated arid and semiarid soils and land application of industrial and food processing wastes often requires frequent monitoring of soil salinity status changes. Such monitoring will often be done only where simple, rapid methods are available. Soil pH measurements are simple and rapid, and a number of rapid total

Received 4 June 1992; accepted 20 July 1992.

soluble soil salt measurement methods have recently been developed. The latter includes buried porous electrical conductivity (EC) sensors, four-probe electrode systems, electromagnetic induction sensors, and time-domain reflectometric electrode systems (Robbins and Wiegand 1990). In contrast, monitoring exchangeable sodium percentage (ESP) or sodium adsorption ratio (SAR) changes in soils is expensive and very time intensive. When sodic or saline–sodic soils are being reclaimed, or when high SAR waste or irrigation waters are being applied to productive soils, soil ESP or SAR status should be evaluated periodically. This, along with pH and EC monitoring, is advisable for selecting and adjusting water and waste and management practices.

Using data from highly weathered, sodic, Australian soils, a model was developed for estimating ESP or SAR from pH and EC data (Robbins and Meyer 1990). The model has the form

$$\text{SAR or ESP} = [(\text{pH} - A)(1 + C \times \text{EC})/B]^2 \tag{1}$$

When the coefficients A, B, and C are known for a particular soil, this method has the potential to economically and rapidly estimate ESP or SAR changes from more easily obtainable pH and EC data. For a particular soil, the coefficient values for estimating ESP are slightly different from those used for estimating SAR.

Salinity models currently in use for predicting chemical changes in soils do not consider the effects of exchangeable sodium or soluble salt concentration on soil pH (Robbins 1991; Suarez 1982; Tanji and Doneen 1966). In models that predict lime and gypsum precipitation and dissolution, pH is part of the necessary input data or is assumed to be constant throughout the calculation period. Those models also require the assumption that lime is present in the soil. Neither of the above assumptions are realistic for sodic or saline–sodic soil reclamation models or for modeling sodium degradation of non-salt-affected soils under many conditions. A useful pH calculation method was developed that includes ESP or SAR and EC change effects on soil pH in sodic and saline–sodic soil models (Robbins and Meyer 1990) and does not require the presence of lime. This was accomplished by rewriting Eq. 1 in terms of pH as

$$\text{pH} = A + (B \times \text{SAR}^{1/2})/(1 + C \times \text{EC}) \tag{2}$$

Equation 2 uses the same A, B, and C values as Eq. 1. The development of these equations is detailed by Robbins and Meyer (1990).

The original soils used to develop and test Eqs. 1 and 2 were sodic and saline–sodic soils from Australia. They were highly weathered and, for the most part, were not completely base saturated; in other words, the exchange capacity was partially neutralized with hydrogen and aluminum ions. Consequently, they were sodic in the sense that they contained more than 15% exchangeable sodium, but the pH was lower than that generally considered to be normal for a sodic or saline–sodic soil (Groenewegen 1961; Loveday 1974; Loveday et al. 1979).

The Australian study showed that the values for the coefficients A, B, and C differed for different soil types from the same area, but that similar soils from different areas had similar coefficient values. It also showed that the coefficient values differed with depth and that surface soil data had to be separated from subsoil data to get reasonable pH and SAR or ESP prediction precision (Robbins and Meyer 1990).

The purposes of this study were to determine the equation coefficients A, B, and C for three recently formed southern Idaho soils that contained sodic, saline–sodic, and

normal areas; to determine if coefficients from one area of a particular soil can be used to predict pH and SAR in another location for the same soil; to determine if the coefficients from the surface depths can be used for subsoil samples; and to compare the coefficients from these soils with those obtained from the Australian soils.

Materials and Methods

Existing pH, EC, and SAR data from several sites of three different sodic and saline-sodic soil series were used for this study. Four Declo loam (coarse-loamy, mixed, mesic, Xerollic Calciorthids) data sets were used. The first data set was taken from a 3-ha area that had not previously been irrigated and was partially leveled in April 1986. Prior to planting, four transects were established across the field, and soil samples were taken every 0.75 m for a total of 80 sample sites per transect. Each sample site was sampled from 0.00 to 0.25 m and from 0.25 to 0.50 m deep. Each soil sample was analyzed separately. The area was then planted to corn (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.) × sudan grass (*Sorghum sudanese* L.) hybrid plots and irrigated with low EC (<0.25 dS m^{-1}), low SAR (<0.3) water. No other treatments were applied to these soils. The following spring (1987) the second sample set was taken along the same four transects at the same space and depth increments. Transect A, which was 30 m from the up slope end of the field crossed an area that had from 0.0 to 0.3 m of soil removed during the field leveling. The other three transects were not significantly disturbed during the leveling process.

The third Declo loam data set was taken on eight different dates during the 1984 growing season and from five different crops. There were 91 samples taken over a distance of approximately 6 km. Samples were takes from 0.00 to 0.25 and from 0.25 to 0.50 cm. The sample sites had been irrigated at least intermittently, depending on water availability, for up to 100 years.

The fourth set of Declo loam samples was taken in 1984 from 35 nonirrigated sites adjacent to the 91 cropped sites discussed above. These sites were sampled to 1.25 m at 0.25-m increments to produce a total of 175 samples.

The Mazuma sandy loam (coarse-loamy, mixed, (calcareous), mesic, Typic Torriorthents) sample site consisted of a 4-ha field that had been irrigated for either 2 or 3 years over the 15-year period since it had been taken out of native vegetation. The field had not been cultivated during the remaining years. The field was divided into the west or upper and the east or lower portions and each half laid out on a 12 × 12 plot grid on 13-m centers. The center of each plot was sampled from the surface to 0.25 m and from 0.25 to 0.50 m. This provided 144 samples for each depth in each of the two parts of the field (Table 2). The 53 Freedom silt loam (fine-silty, mixed, mesic, Xerollic Calciorthids) samples were collected and analyzed during selection of a site to obtain surface soil (0.0 to 0.25 m) for a previous study (Tracy et al. 1984).

Saturation paste pH values were used throughout this study. Cation concentration data, used to calculate SAR, and solution EC data were obtained from extracts of the same saturation pastes used for pH measurements. Sodium was measured by flame emission spectrophotometry, and calcium and magnesium were measured by atomic absorption spectrophotometry.

Each sample data set was evaluated for consistency by determining the electrical charge balance between cations and anions, and calculating the EC from the cation and anion data, using the exponential method of McNeal et al. (1970). Since there was no way to check pH measurements directly, pH values were assumed to be correct unless

saturation extract carbonate and bicarbonate concentrations contradicted the pH values (Stumm and Morgan 1970). Individual samples that had a cation–anion imbalance, calculated vs. measured EC value differences greater than 10%, or questionable pH values were reanalyzed or rejected depending on sample availability.

The data were entered into a spreadsheet program by groups as shown in Tables 1 and 2. Using Eq. 1 to calculate SAR and Eq. 2 to calculate pH, the sum of squares difference between measured and calculated values was determined simultaneously for SAR and pH. Previous experience with this process suggested that the starting value for A is slightly less than the lowest measured pH value for a data set, that B usually varied between 0.1 and 1.0, and that C was usually less than 0.2 (Robbins and Meyer 1990). The values for A, B, and C were then individually adjusted in such a manner that the product of the two sums of square values was minimized. This process gives the best simultaneous prediction of pH and SAR using Eqs. 1 and 2.

To evaluate how accurately the pH and SAR could be predicted for one sample set of a particular soil series from the coefficients obtained from a second sample set, the average A, B, and C coefficient values from the 86B, 86C, and 86D, and all four of the 87 Declo loam transects were used to predict pH and SAR for the 91 surface sample sites. Likewise, the coefficients derived from the west 0.0- to 0.25-m Mazuma sandy loam plots were used to predict pH and SAR from the east plots and the predicted values were compared to the measured values.

Results

The coefficients A, B, and C for the Declo loam surface soil samples were very similar for the four transects over two years and for the samples taken from the 91 additional surface soil samples, except for transect A in 1986. The coefficient values for transect 86A and the 175 samples taken at five depths were quite different (Table 1). The sample sets with similar coefficient values had r^2 values of 0.70 or greater and standard deviations of 0.32 pH units or less when the predicted pH values were compared with the measured values. Likewise, the r^2 values were 0.79 or greater and the standard deviations were 8.3 SAR units or less when predicted and measured SAR values were compared. The failure of the two equations to predict pH and SAR for transect 86A, which had exposed subsoil areas, and the samples taken at five depths appears to reinforce previous results that these procedures cannot be used when subsoil and surface soil data are combined (Robbins and Meyer 1990).

When the coefficients calculated from the Declo transect surface soil data were used to predict pH and SAR values for the 91 Declo surface soil samples, the r^2 values were 0.70 and 0.81, respectively; and the standard deviations were 0.34 for pH and 43 for SAR. A comparison of measured pH and SAR values for the 91 surface soil samples, with values calculated from the means of the seven transect coefficient values, are shown in Figs. 1 and 2. Results from the transect 0.25- to 0.50-m depths are not shown here; however, the results confirmed the fact that low r^2 values and high standard deviations are produced from subsoil data.

The surface soil coefficients and the 0.25- to 0.50-m-depth soil coefficients for the Mazuma soil were similar to each other; but the subsoil r^2 values were considerably lower, and the standard deviation was greater in the subsoil increment than in the surface soil. Figures 3 and 4 show the results of using coefficients from the west Mazuma plot area to predict pH and SAR in the east set of plots. The Freedom silt loam data are from

Table 1
Declo Loam

Sample Set	A	B	C	pH r^2	pH SD	SAR r_2	SAR SD	Number of Samples	EC (dS m^{-1})	pH	SAR
Declo loam											
Transect 86 A	7.06	0.45	0.131	0.55	0.41	0.76	24.8	78	1.2–20.9	7.5–9.5	1.1–326
Transect 86 B	7.25	0.45	0.045	0.83	0.27	0.87	5.9	79	0.9–8.2	7.4–10.4	0.9–89
Transect 86 C	7.11	0.47	0.037	0.74	0.26	0.80	5.1	80	0.8–6.9	7.3–10.0	0.7–41
Transect 86 D	7.10	0.46	0.034	0.87	0.19	0.86	4.4	80	0.6–9.3	7.5–10.2	1.6–48
Transect 87 A	7.20	0.42	0.058	0.92	0.18	0.90	8.3	80	1.1–20.1	7.5–9.8	0.6–124
Transect 87 B	7.30	0.45	0.050	0.84	0.21	0.85	4.2	80	0.6–6.0	7.6–9.9	0.8–53
Transect 87 C	7.28	0.45	0.053	0.76	0.24	0.81	3.6	80	0.7–9.3	7.9–9.4	0.9–31
Transect 87 D	7.21	0.46	0.057	0.79	0.16	0.79	3.1	80	1.1–6.6	7.5–9.3	1.1–28
Surface samples from 91 sites	7.20	0.46	0.045	0.77	0.32	0.82	3.2	91	0.3–10.1	6.7–9.7	0.3–50
Five depth increments from 35 sites	7.41	0.27	0.094	0.55	0.40	0.62	83.4	175	0.5–40.2	7.1–9.9	1.0–570

Note. A, B, and C values for Eqs. 1 and 2 derived from ten data sets, and the estimation of pH and SAR from the coefficients derived from within the data sets and the EC, pH, and SAR ranges of each set. A, B, C values for Eq. 1: $\mathrm{SAR} = [(\mathrm{pH} - A)(1 + C \times \mathrm{EC})/B]^2$; and for Eq. 2: $\mathrm{pH} = A + (B \times \mathrm{SAR}^{1/2})/(1 + C \times \mathrm{EC})$.

Table 2
Mazuma Sandy Loam and Freedom Silt Loam

Sample Set	A	B	C	pH r^2	pH SD	SAR r_2	SAR SD	Number of Samples	EC (dS m^{-1})	pH	SAR
Mazuma sandy loam											
West plot 0–0.25 m	7.30	0.27	0.086	0.83	0.21	0.88	18.4	144	0.7–26.6	7.3–9.8	1.3–502
East plot 0–0.25 m	7.40	0.27	0.090	0.84	0.19	0.91	17.2	144	0.5–24.5	7.3–9.7	0.6–482
West plot 0.25–0.50 m	7.35	0.25	0.078	0.60	0.28	0.75	65.0	144	1.0–32.1	7.8–9.8	24–516
East plot 0.25–0.50 m	7.33	0.25	0.080	0.61	0.23	0.76	50.1	144	1.6–31	7.7–10.1	12.0–453
Freedom silt loam											
0–0.25 m	7.62	0.30	0.105	0.81	0.26	0.89	19.2	53	0.4–34	7.4–9.8	0.9–251

Note. A, B, and C values for Eqs. 1 and 2 derived from four data sets at two depths, and the estimation of pH and SAR from the coefficients derived from within the data sets and the EC, pH, and SAR ranges of each set. A, B, C values for Eq. 1: $\mathrm{SAR} = [(\mathrm{pH} - A)(1 + C \times \mathrm{EC})/B]^2$; and for Eq. 2: $\mathrm{pH} = A + (B \times \mathrm{SAR}^{1/2})/(1 + C \times \mathrm{EC})$.

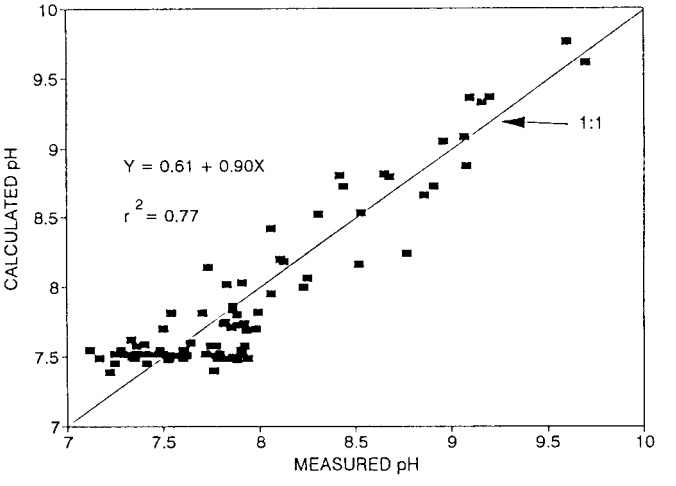

Figure 1. Measured vs. calculated pH values for 91 Declo loam surface soil samples using coefficients from seven transect sample sites over a 2-year period.

a more limited data set but are shown in Table 2 to reinforce the fact that each soil tends to have unique *A*, *B*, and *C* coefficient values.

Discussion

Total soluble salt concentration data can be measured very rapidly by a variety of methods, and saturated soil paste pH measurements are easily made in the field or laboratory. Exchangeable sodium measurements in soils, however, are very time and equipment-

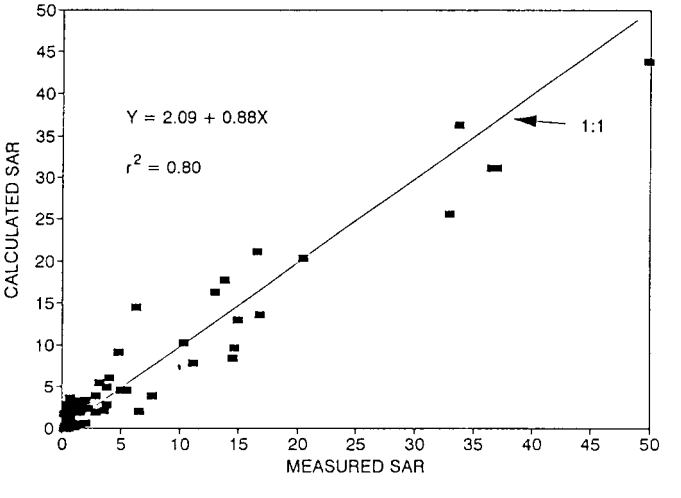

Figure 2. Measured vs. calculated SAR values for 91 Declo loam surface soil samples using coefficients from seven transect sample sites over a 2-year period.

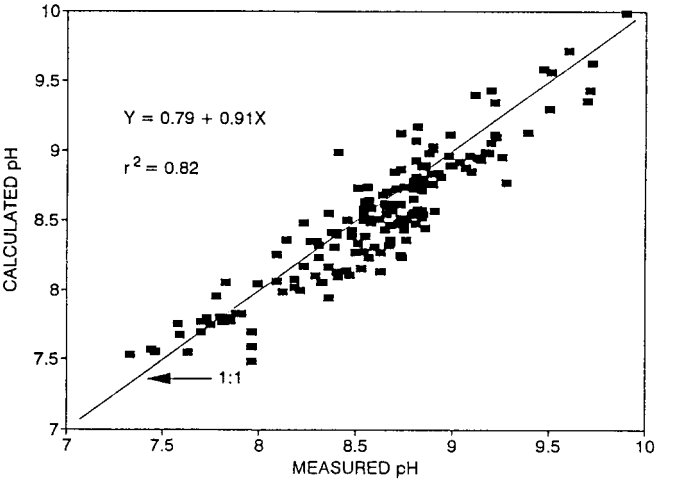

Figure 3. Measured vs. calculated pH values for the east 144 Mazuma sandy loam samples using coefficients from the west sample grid to predict pH.

intensive. As a partial solution to this problem, the SAR concept was originally developed as an alternative approximation of ESP when the SAR was calculated from saturated soil extract cations. Even with this simplification, SAR measurements are costly and require appreciable time and instrumentation input (Robbins and Wiegand 1990). For monitoring sodium status changes for a particular location, Eq. 1 with the necessary coefficient values and easily obtainable pH and EC data provides a useful tool to track reclamation or degradation changes with time where sodium is of concern.

Equation 2 provides a method for modeling the effect of SAR and EC changes on pH in soil chemistry models. Carbonate and bicarbonate chemistry in salt-affected soils is very closely associated with the soil pH, which is likewise influenced by solution SAR

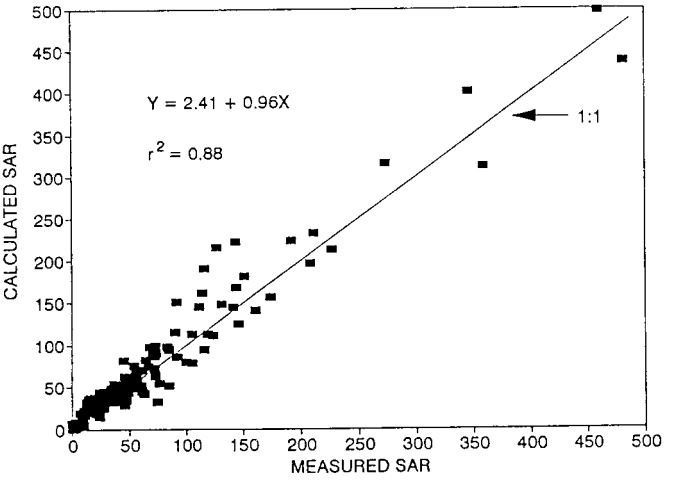

Figure 4. Measured vs. calculated SAR values for the east 144 Mazuma sandy loam samples using coefficients from the west sample grid to predict SAR.

and EC. In the past, these interactions have not been adequately addressed in soil salinity models.

Data from the four Idaho soils, as well as the Australian soil data (Robbins and Meyer 1990), show that the SAR standard deviation becomes large when SAR values exceed 100. From a practical standpoint, it really does not matter whether the SAR is 100 or 200, a high SAR value identifies an exchangeable sodium problem, and it will usually take only a very small increase in soluble Ca + Mg concentration to lower the SAR value an appreciable amount. At the very low soluble Ca + Mg concentrations in relation to Na concentrations found in sodic soils, a 0.5 m*M* error or change in Ca or Mg concentration value may make a 50% difference in the calculated SAR at SAR values greater than 100, and at the same time be meaningless in terms of its effect on soil physical and chemical properties.

The results of this study reinforce the conclusions of Robbins and Meyer (1990) that (1) calibrating the *A*, *B*, and *C* coefficients for sodic soil requires a pH range in excess of 2.0 pH units to obtain reasonable r^2 and standard deviations for the predicted versus measured values, (2) each sodic soil requires individual calibration coefficients for these models to be reasonably accurate, and (3) subsoil sample data should not be combined with surface soil data. The values for *A* for the Idaho soils are about 0.8 of a pH unit greater than those for the Australian soils, which were not completely base saturated. The Australian soils *B* values were about twice that of the calcareous Idaho soils and the *C* values were not significantly different for the Australian and Idaho soils. In both cases the *A* coefficient values were slightly smaller than or nearly equal to the smallest pH values in a particular data set. The factors that affect the coefficient values are discussed in detail by Robbins and Meyer (1990).

References

Groenewegen, H. 1961. Composition of the soluble and exchangeable ions of the salty soils of the Mirrool Irrigation Area (New South Wales). *Journal of Soil Science* 12:129–141.

Loveday, J. 1974. Data relating to site of field installation Project CF2: hydrology and salinity of a deep clay profile. *CSIRO Australia Division of Soils, Technical Memorandum 41/1974*. CSIRO, Canberra.

Loveday, J., H. J. Beatty, H. Morrow, and D. Thiedeman. 1979. Saturation extract data and salinity profile classes. *CSIRO Australia Division of Soils, Technical Memorandum 22/1979*. CSIRO, Canberra.

McNeal, B. L., J. D. Oster, and J. T. Hatcher. 1970. Calculation of electrical conductivity from solution composition data as an aid to in situ estimation of soil salinity. *Soil Science* 110:405–414.

Robbins, C. W. 1991. Solute transport and reactions in salt-affected soils, pp. 365–395, in John Hanks and J. T. Ritchie, eds., *Modeling Plant and Soil Systems*. American Society of Agronomy, Madison, Wisconsin.

Robbins, C. W., and W. S. Meyer. 1990. Calculating pH from EC and SAR values in salinity models and SAR from soil and bore water pH and EC data. *Australian Journal of Soil Research* 28:1001–1011.

Robbins, C. W., and C. L. Wiegand. 1990. Field and laboratory measurements, pp. 203–219, in K. K. Tanji, ed., *Agricultural Salinity Assessment and Management*. American Society of Civil Engineers, New York.

Stumm, W., and J. J. Morgan. 1970. *Aquatic Chemistry*. John Wiley, New York.

Suarez, D. L. 1982. Graphical calculation of ion concentration in calcium carbonate and/or gypsum soil solutions. *Journal of Environmental Quality* 11:302–308.

Tanji, K. K., and L. D. Doneen. 1966. A computer technique for prediction of $CaCO_3$ precipitation in HCO_3 salt solutions. *Soil Science Society of America Proceedings* 30:53–56.

Tracy, P. W., C. W. Robbins, and G. C. Lewis. 1984. Fluorite precipitation in a calcareous soil irrigated with high fluoride water. *Soil Science Society of American Proceedings* 48:1013–1016.