Predicting Bulk Soil Electrical Conductivity versus Saturation Paste Extract Electrical Conductivity Calibrations from Soil Properties[1]

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ABSTRACT

Soil electrical conductivity was calibrated with salinity for 12 soil types, and the calibrations were related to soil properties. The calibration slope was found to be highly correlated with water-holding capacity and saturation percentage, whereas the intercept was highly correlated with clay content. These findings permit the prediction of calibrations for salinity diagnosis applications where direct calibrations are unavailable or unwarranted.

Additional Index Words: **salinity, electrical resistivity.**

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SOIL SALINITY is conventionally determined by measuring (generally in the laboratory) the electrical conductivity of the extract (EC_e) of a saturated soil paste. The paste is made using a sieved soil sample taken from the field. For a given soil type, EC_e and *bulk* soil electrical conductivity (EC_a) are highly correlated, and the latter can be directly measured in the field (without need for soil sampling and laboratory analysis) using four-electrode and electromagnetic induction methods (Rhoades and Ingvalson, 1971; Rhoades, 1976; Rhoades and van Schilfgaarde, 1976; Sriyotai and Gilmour, 1976; Halvorson et al., 1977; van Hoorn, 1980; Rhoades and Corwin, 1980). Until now, EC_e vs. EC_a calibrations for soils have been empirically determined using one of three techniques as described in Rhoades and Ingvalson (1971), Rhoades (1976), Rhoades et al. (1977), and Rhoades and Halvorson (1977).

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Rhoades and van Schilfgaarde (1976) concluded that calibrations between EC_a and EC_e, "salinity," were similar for soils of similar field capacity water-holding capacity and that the calibration parameters (slope and intercept of EC_e vs. EC_a linear plots) could be estimated from soil texture. Supportive evidence for this is apparent in the calibrations obtained for soils of the Northern Great Plains, which were found to be similar for soils of similar texture (Halvorson et al., 1977), and the work of Rhoades et al. (1976), which shows that

$$EC_a = [EC_w\theta]T + EC_s \qquad [1]$$

where θ is the volumetric water content, T is a transmission coefficient (linearly related to θ and to the tortuosity of the water film through which current flows in the liquid phase), EC_w is the electrical conductivity of the liquid phase in the soil matrix, and EC_s is the apparent electrical conductivity of the soil matrix, per se, that is, the so-called surface conductance. Thus, for a given level of soil water salt concentration (as represented by EC_w), EC_a will increase with θ. For routine field uses, EC_a vs. EC_e (essentially a dilution of EC_w) calibrations have been established for soils at near field capacity water content. That different soil types will have different calibration slopes is expected, since at field capacity, they will have different θT values because of their differences in texture and porosity.

The intercept parameter of linear EC_e vs. EC_a calibration lines is related to EC_s and hence to the amount and mobility of exchangeable cations as shown in Eq. [1] and as discussed in Rhoades (1978) and Shainberg et al. (1981). Thus, the calibration intercept is expected to be related to soil texture and clay content.

From the above, it is hypothesized that the slope and intercept values of the EC_e vs. EC_a calibration of any soil should be predictable from its properties, especially water-holding capacity and clay content. This study was undertaken to test this hypothesis and to obtain relations to estimate EC_e vs. EC_a calibrations for soils. The ability to predict such calibrations facilitates the use of four-probe and electromagnetic methods of measuring bulk soil electrical conductivity for diagnosing soil salinity in situations where EC_e vs. EC_a calibrations are unavailable or unwarranted.

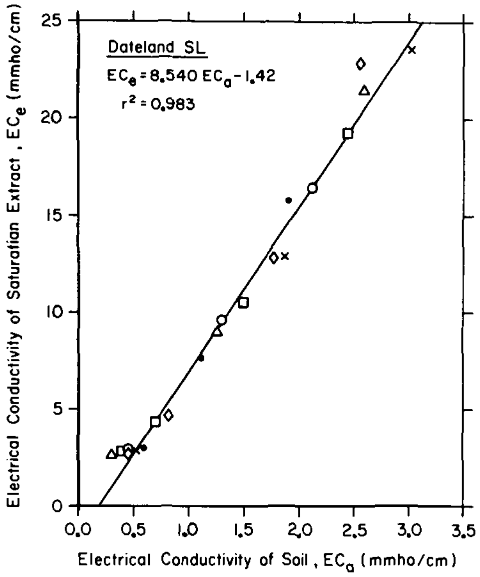

Fig. 1—Relation (calibration) between soil sample salinity (electrical conductivity of saturation extract, EC_e) and bulk soil electrical conductivity, (EC_a) determined for Dateland sandy loam. Calibrations made on six different occasions are represented by the six different symbols.

PROCEDURES

EC_e vs. EC_a calibrations were established for 12 Arizona (Wellton-Mohawk Irrigation and Drainage District) and California (Imperial Valley) soils using the field calibration method and the four-electrode salinity probe developed by Rhoades and van Schilfgaarde (1976). This method consists of measuring EC_a within a known soil volume and then measuring EC_e of soil samples representing that volume. The salinity probe was used to determine the EC_a values of small bodies of field soil that had been artificially salinized by leaching with a saline water (Na, Ca chloride mixtures) using a 30-cm diam by 45-cm long column section driven about 15 cm into the soil. An area of soil surrounding the cylinder was similarly leached with the aid of a berm of dirt formed around the cylinder and at a distance of 20 cm from it. At each soil-type site, at least four such leaching setups were installed; each was leached with a different salt concentration water so as to result in soil salinities (EC_e basis) in these discretely salinized soil bodies ranging from 2 to 20 mmho/cm. Two days after the impounded waters had infiltrated into the soils, when the soils had drained to about field capacity, the cylinders were removed, and access holes were made near the center of the cylinder area to a 24-cm depth using an Oakfield soil sampler. The "salinity probe" was then inserted down the access hole and centered at the 15-cm depth and the soil electrical conductivity measured. After the "salinity probe" was removed, soil at a depth of 9 to 24 cm and immediately surrounding the access hole was sampled with an 8-cm diam barrel soil auger; the EC_e of this soil sample was determined in the laboratory using conventional techniques (U.S. Salinity Laboratory Staff, 1954). Linear regression analysis of the EC_e vs. EC_a data was carried out using conventional least-squares techniques to establish the calibration slopes and intercepts for each soil type. Gravimetric (P_w) and volumetric (θ) field-capacity water contents were also obtained by collecting three samples of a known volume of leached and drained soil at the test site. Each sample was transferred to a tarred Al moisture can and weighed before and after oven-drying. Saturation percentage (SP), cation exchange capacity (CEC), and particle size analysis of the samples were determined using standard laboratory techniques (U.S. Salinity Laboratory Staff, 1954). The average value of the three replicates were used in the regression analysis.

RESULTS AND DISCUSSION

An example calibration for one of the soils (Dateland Sandy Loam—Typic Camborthids) is shown in Fig. 1. The calibration was carried out on six different occasions over a period of 2 years in the same general area of the field (individual sample sites were within about 25 m of one another) as represented by the different symbols. The calibration slope and intercept values determined are 8.54 and −1.42, respectively.

Table 1—Correlations between EC_e–EC_a calibration slope and various soil properties.

Soil property	m†	I†	Coefficient of correlation
Clay percentage	--	--	0.42
Clay plus silt percentage	−0.0719	+10.59	0.86
Gravimetric water content at field capacity (P_w), %	−0.3371	+12.23	0.96
Saturation percentage	−0.2206	+14.67	0.98

† Slope of calibration = m (soil property) + I, where m and I are slope and intercept, respectively, of linear regression equation.

Table 2—Correlations between soil matric conductivity (EC_s) and various soil properties.

Soil property	m†	I†	Coefficient of correlation
Clay percentage	0.0247	−0.0236	0.94
Saturation percentage	0.0147	−0.2275	0.37
Cation exchange capacity	0.0159	−0.070	0.67

† $EC_s = m$ (soil property) $+ I$, where m and I are slope and intercept, respectively, of linear regression equation.

The reproducibility and accuracy of the calibration are good, as indicated by the r^2 value of 0.983. Similar results were obtained for all soils, although slopes and intercept values differed.

Correlation between the calibration slopes of the soils and soil clay contents, clay plus silt contents, P_w's and SP's were made to see if the calibration slope could be predicted from some such easily measured and generally known soil property. Results are given in Table 1. As predicted, the calibration slopes are well correlated with soil properties. The best predictor of calibration slope is saturation percentage (see Fig. 2), although P_w and clay plus silt content would also suffice. Clay plus silt content of a soil is a good predicter, whereas in these soils, clay content alone was not, because the silt fraction contributes significantly to their water-holding capacities.

Correlations were determined between soil matrix electrical conductivity (EC_s), which is related to the EC_e vs. EC_a calibration intercept (I) values as $I = (EC_s)$ (EC_e vs. EC_a calibration slope), and soil clay content, CEC, and saturation percentage. Correlations were made with EC_s values rather than with the actual EC_e vs. EC_a calibration intercepts because the latter value is easily obtained from the former, as shown above, and because the former is a more basic parameter that can be used for other purposes (for example, see Shainberg et al., 1981). Correlation results are given in Table 2. Clay percentage was found to be the best soil property for use in predicting EC_s (and hence, the calibration intercept).

CONCLUSION

The calibration parameters (slope and intercept) needed to relate bulk soil EC and EC of the extract of the saturated soil paste, "soil salinity," were estimated from each of several soil properties. The slope was well predicted from soil SP or field capacity and from clay plus silt percentage. The intercept was best predicted from clay percentage. Because soil texture is related to all these soil properties, it is concluded that EC_e vs. EC_a calibrations can be approximated from texture classification. This permits estimates of an EC_e vs. EC_a calibration to be made in an uncalibrated field by the "feel" technique of identifying its soil texture.

These findings permit the prediction of EC_a vs. EC_e calibrations for salinity diagnosis purposes for soils where calibrations are unavailable or unwarranted. These calibrations developed for the four-electrode salinity probe will apply equally well when the measurement of EC_a is made using the inductive electromagnetic soil-conductivity meter (Rhoades and Corwin, 1980).

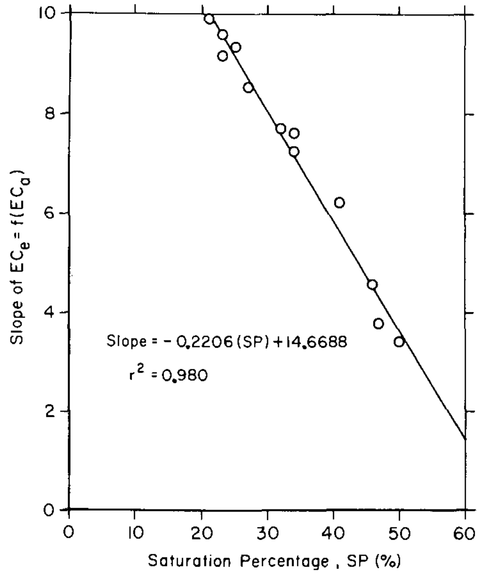

Fig. 2—Correlations between slopes of EC_e vs. EC_a calibrations for different soils and their saturation percentages.

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