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Field Mapping Soil Conductivity to Delineate Dryland Saline Seeps with Four-electrode Technique[1]

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ABSTRACT

Continuing incidence of saline-seep areas in the northern Great Plains dryland soils has created a need for detecting and delineating encroaching saline seeps before plant growth is affected. We evaluated the four-electrode conductivity technique for field mapping surface and subsurface soil salinity under dryland conditions.

Results indicated that the four-electrode conductivity technique can be used successfully to quickly field map surface and subsurface soil salinity boundaries of existing and potential saline-seep areas. This technique also depicted underground flow patterns of a shallow, saline ground water table.

Maps of apparent bulk soil conductivity values (EC_a) were used to locate the position of the recharge area in relation to the discharge (seep) area. While maps of discrete depth interval conductivity values (EC_x) provided more precise information, the time required may not warrant the additional required calculations unless a portable programable calculator is available. Mapping soil salinity with the four-electrode conductivity technique is easy, rapid, and relatively inexpensive. This technique provides information useful in making management decisions to prevent or alleviate a saline seep or other soil salinity problems.

Additional Index Words: **dryland salinity, four-electrode soil conductivity, shallow saline water tables.**

THERE IS a need for determining the extent of encroaching soil salinity conditions before salinity levels become high enough to affect plant growth and soil structure in dryland areas. New saline-seep areas in dry cropland areas of the northern Great Plains of the USA and Canada and similar areas in western Australia continue to develop yearly without warning. Therefore, early detection and delineation of the potential size of these salt-affected areas is important so that remedial measures can be initiated in time to prevent reduced crop production and further salinization of productive crop land (1, 3, 4, 5).

The four-electrode soil conductivity technique has been used to confirm suspected saline-seep areas and to measure soil salinity in the field without recourse to soil sampling (6, 7). Our objective was to evaluate the usefulness of the technique for delineating the surface and subsurface boundaries of encroaching and developed saline seeps. This technique should be especially appropriate for this purpose since four-electrode soil conductivity (EC_a) increases in proportion to both soil salinity and water content (6).

MATERIALS AND METHODS

Root zone soil electrical conductivity (0- to 120-cm soil depth) of a well-characterized saline-seep area (5) was mapped using four-electrode conductivity technique (Wenner configuration) described previously (6).

A 153 by 244 m area around the saline seep was gridded at 30.5-m intervals (Fig. 1). Surface topography and location of several observation wells are also shown in Fig. 1. Table 1 gives depth to the water table in several observation wells surrounding the seep for the spring 1972 (highest level) and at the time of this study (June 1974). The EC of the ground water in the seep area was about 7 mmhos/cm at the time of study. In June 1974, four-electrode soil resistance measurements were taken at each grid location with inter-electrode spacings, *a*, of 30, 60, 90, and 120 cm. Soil water content of the clay loam soil throughout most of the study area (excluding central part of seep) was near field capacity (Table 2). Within the central part of the saline-seep area (Fig. 1), water content in the 60- to 120-cm depth was at or near saturation. Apparent bulk soil conductivity (EC_a) values in mmhos/cm were calcalated as follows:

$$EC_a = 1000/2\pi aR \qquad [1]$$

where *a* is the inter-electrode spacing (cm) and *R* is the measured soil resistance (ohms).

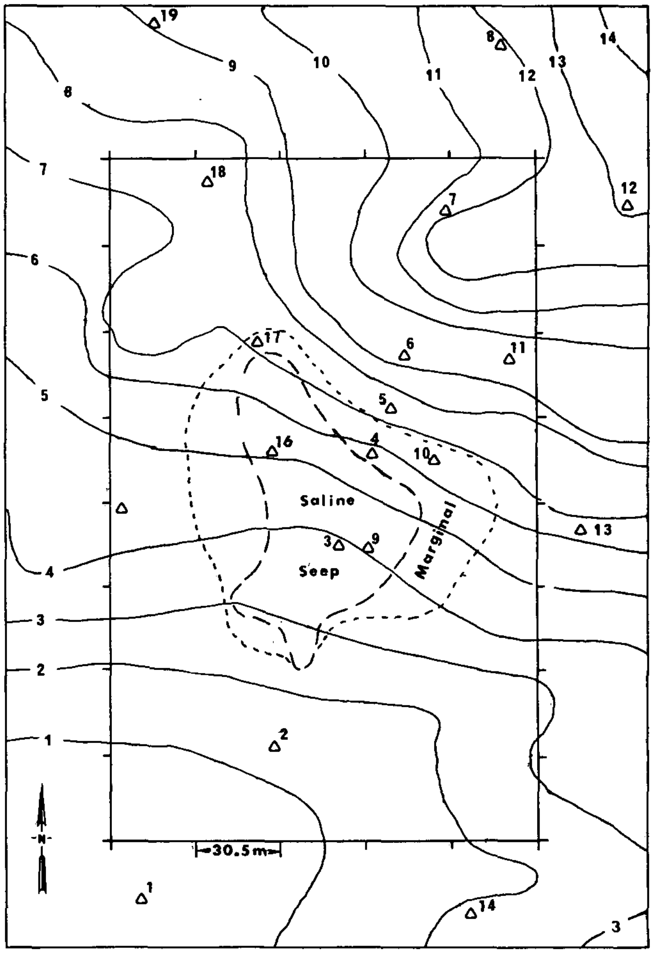

Fig. 1—A map showing relative surface topography in meters, the area around the saline seep that was gridded and surveyed, and the location of several observation wells (triangles with numbers).

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Table 1—Depth to top of water table at its highest elevation during the spring of 1972 and June 1974 in several observation wells located in and near the saline seep.

Well no.	Depth to water table, cm	
	Spring 1972	June 1974
1	146	238
2	58	174
3	0	67
4	37	113
5	82	158
6	162	253
7	250	356
8	210	274
9	3	65
10	58	119
11	146	234
12	329	408
13	73	155
14	146	238
15	79	189
16	3	91
17	58	131
18	152	234
19	274	384

Table 2—Summary of gravimetric soil water content and saturation percentage for four soil depth intervals (excluding central portion of saline-seep area).

Soil depth	Gravimetric field water content				Saturation			
	n†	$\bar{x}$	S_x	$S_{\bar{x}}$	n	$\bar{x}$	S_x	$S_{\bar{x}}$
cm				%				
0-30	24	17.0	5.1	1.0	24	46.5	4.7	1.0
30-60	24	18.5	3.7	0.7	24	46.5	4.7	1.0
60-90	24	19.1	3.4	0.7	24	48.9	4.4	0.9
90-120	23	18.8	2.0	0.4	23	50.6	3.3	0.7

† n = number of samples; $\bar{x}$ = mean value; S_x = standard deviation; and $S_{\bar{x}}$ = standard error of the mean.

Table 3—Correlation and simple linear regression analyses ($Y = mX + a$) between four-electrode soil conductivities (EC_a or EC_x) and saturation-extract conductivities (EC_e).

Soil depth, cm	n†	Y	X	m	a	r†	$SE_{y.x}$†	SE_a†	SE_m†
0-30	24	EC_e	EC_a	4.69	-0.07	0.974	1.06	0.28	0.23
0-60	24	EC_e	EC_a	4.69	0.16	0.949	1.35	0.41	0.33
0-90	24	EC_e	EC_a	4.84	0.18	0.938	1.35	0.47	0.38
0-120	24	EC_e	EC_a	5.12	-0.36	0.948	1.12	0.47	0.37
Above 4 depths combined	96	EC_e	EC_a	4.81	0.03	0.955	1.20	0.19	0.15
0-30	24	EC_e	EC_x	4.69	-0.07	0.974	1.06	0.28	0.23
30-60	24	EC_e	EC_x	4.75	0.34	0.887	2.12	0.71	0.53
60-90	24	EC_e	EC_x	5.30	-0.06	0.731	2.00	0.91	0.69
90-120	24	EC_e	EC_x	3.76	0.82	0.766	2.02	1.03	0.67
Above 4 depths combined	96	EC_e	EC_x	4.62	0.21	0.891	1.88	0.33	0.24

† n = number of samples; r = correlation coefficient; $SE_{y.x}$ = standard error of estimate of Y on X; SE_a = standard error of regression coefficient a; and SE_m = standard error of regression coefficient m.

Soil conductivity for discrete depth intervals (EC_x) within the bulk soil was calculated using the following equation reported by Halvorson and Rhoades (6):

$$EC_x = [(EC_{a_i} \cdot a_i) - (EC_{a_{i-1}} \cdot a_{i-1})]/(a_i - a_{i-1}) \qquad [2]$$

where a_i represents sampling depth, a_{i-1} represents the prior sampling depth, and $a_i - a_{i-1}$ represents the depth interval. EC_a and EC_x values were plotted at each grid location from which EC_a and EC_x isoline maps were constructed.

Soil samples were collected by 30-cm increments to a 120-cm depth at 24 of the grid locations. Gravimetric soil water content, saturation-extract electrical conductivity (EC_e), and saturation percentage (SP) were determined on each soil sample (8). Linear regression analysis was used to relate EC_a and EC_x to EC_e.

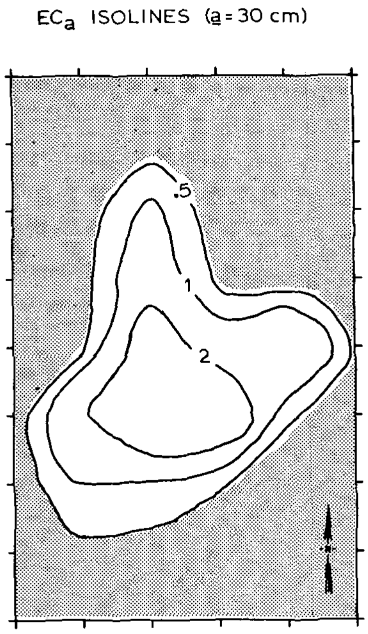

Fig. 2—Map of four-electrode EC_a or EC_x isolines when the electrode spacing *(a)* was 30 cm. Shaded area has four-electrode conductivity of <0.5 mmhos/cm.

RESULTS AND DISCUSSION

Figure 1 shows the visual location of the saline seep and marginally affected areas within the test area mapped. The area labeled "saline seep" had salts visible on the soil surface with only highly salt tolerant plants growing. Test wells no. 3, 9, and 16 show the close proximity of the water table (0 to 3 cm) to the soil surface within the saline-seep area during spring 1972 (Table 1), which explains why salts had accumulated on the soil surface ($EC_e \simeq 20$ mmhos/cm) within this area. Although salts were not visible on the soil surface in the area labeled "marginal," the alfalfa (*Medicago sativa*) stand was sparse and stunted. The water table in the marginal area (test wells no. 4, 10, and 17) had not approached the soil surface as closely as in the "saline-seep" area. Determined EC_e's (Table 3), for several grid locations within the marginal area, ranged from about 2 to 9 mmhos/cm. This level of salinity is excessive for optimum alfalfa production, indicating that salinity, though not visually identifiable, was limiting plant growth in the marginal area. The area outside the saline seep and marginally affected areas was characterized by low salinity ($EC_e < 1$ mmhos/cm) and deep water tables.

The EC_a isolines for the 0- to 30-cm soil depth (a = 30 cm) are shown in Fig. 2. Areas with EC_a values of < 0.5 mmhos/cm correspond to the area unaffected by the saline ground water table and having low salt content (EC_e < 2.4 mmhos/cm). Areas with EC_a values of 0.5–1.5 and > 1.5 roughly correspond to the marginally affected and saline-seep areas, respectively. The area with an EC_a level of >0.5 mmhos/cm is slightly larger than that mapped visually. These data show that the EC_a map, corresponding to

EC$_x$ ISOLINES (30-60cm depth)

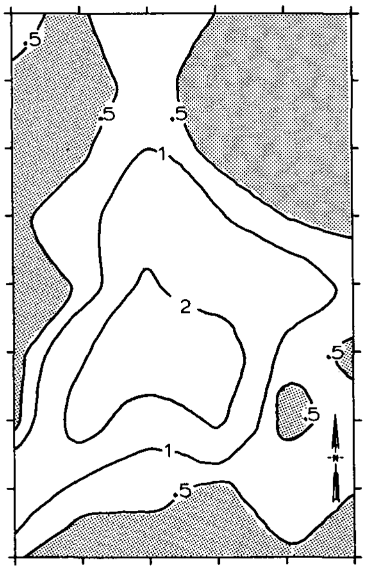

Fig. 3—Map of interval four-electrode salinity, EC$_x$, for the 30- to 60-cm soil depth interval. Shaded area represents area with <0.5 mmhos/cm four-electrode conductivity.

EC$_x$ ISOLINES (60-90cm depth)

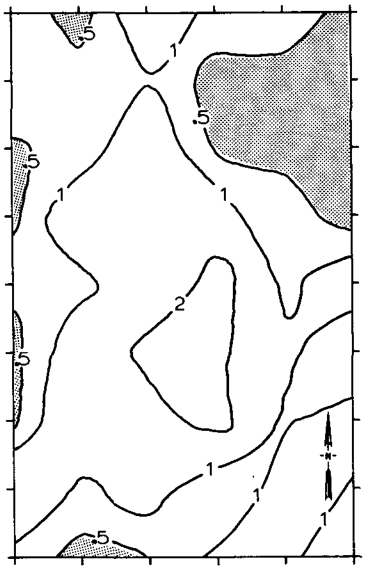

Fig. 4—Map of interval four-electrode salinity, EC$_x$, for the 60- to 90-cm soil depth interval. Shaded area represents area with <0.5 mmhos/cm four-electrode conductivity.

EC$_a$ ISOLINES (a = 60 cm)

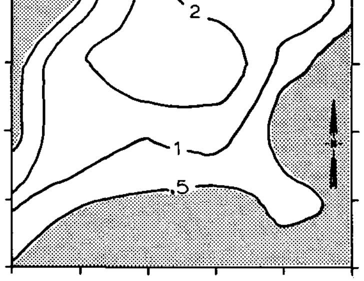

Fig. 5—Map of four-electrode EC$_a$ isolines when the electrode spacing (*a*) was 60 cm. Shaded area represents area with <0.5 mmhos/cm four-electrode conductivity.

the 0- to 30-cm soil depth, delineated areas unaffected and affected by degree by saline seeps.

The EC$_x$ isolines for the 30- to 60-cm soil depth are shown in Fig. 3. The area with an EC$_x$ value >0.5 mmhos/cm has increased when considering this subsurface interval. This resulted because of increased proximity of more area to the saline water body. Configuration of the saline water body and its probable entry and exit points to and from the seep area become discernable when comparing the surface topography (Fig. 1) with EC$_x$ isolines in Fig. 3. Based on surface topography, relative water table level observations, and previous work (5); entry points are assumed to be on the upslope (north and east) part of the seep and the exit point on the downslope (southwest) part of the seep. The underground pattern of the saline ground water table and its influence on subsurface soil salinity became even better defined and traceable as EC$_x$ values for the 60- to 90-cm depth were mapped (Fig. 4).

These EC$_x$ maps indicated that the saline water table which was at the >230-cm depth did not greatly affect root zone conductivity in the northeast section of the test area. Surface topography probably did not affect the EC$_x$ or EC$_a$ readings in the southcentral section of the area mapped, and the small areas of low conductivity are real. The EC$_x$ maps clearly indicate the subsurface location of the shallow saline water table.

Although EC$_a$ values do not give the detail of EC$_x$ values, mapping EC$_a$ conductivity isolines produced much of the same information as mapping EC$_x$ values. Figure 5 shows the EC$_a$ isolines for the 0- to 60-cm soil depth interval. The channel patterns for the water entering into and exiting from the seep area start to become discernable. For the 0- to 90- and 0- to 120-cm soil depths (Fig. 6 and 7), the EC$_a$ isolines show more of the area as affected by the saline water body and give information similar to Fig. 3 and 4. The influence of the shallow perched saline ground water table on subsurface soil conductivity becomes obvious at the wider electrode spacings. Since sufficient information for delineating the boundaries of saline-seep affected land is obtained from EC$_a$ maps, the additional calculations and time required to make EC$_x$ maps may not be warranted for this application.

The EC$_a$ and EC$_x$ data presented in Fig. 3 to 7 help to explain the reduced alfalfa stand and growth in the marginal or fringe area of the saline seep. As the alfalfa roots penetrated deeper into the soil profile, they encountered a more saline and wet environment which reduced the alfalfa stand,

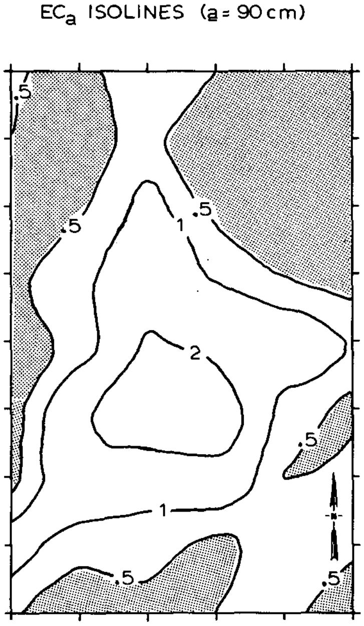

Fig. 6—Map of four-electrode EC_a isolines when the electrode spacing *(a)* was 90 cm. Shaded area represents area of <0.5 mmhos/cm four-electrode conductivity.

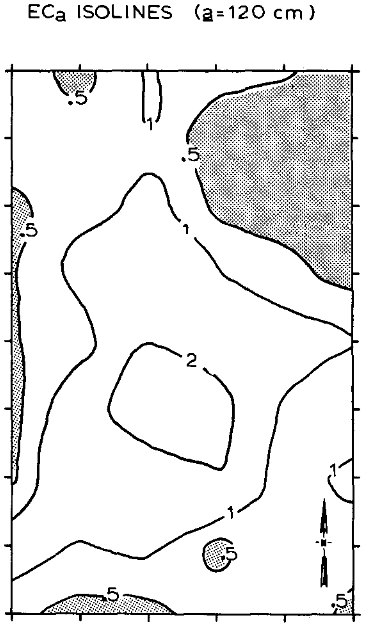

Fig. 7—Map of four-electrode EC_a isolines when the electrode spacing *(a)* was 120 cm. Shaded area represents area with <0.5 mmhos/cm four-electrode conductivity.

vigor, and growth. Calculated EC_e values, from EC_x data (Table 3), of $>$ 8 mmhos/cm were found in the soil profile of the marginal area. Bernstein (2) indicated that a salinity level of about 9 mmhos/cm will reduce alfalfa yields by 50%.

Gridding the 3.7-ha test area surveyed, making the EC_a readings at each grid location to a 120-cm soil depth at 30-cm increments, calculating the EC_x values, and drawing the maps required about 12 man hours. Based on the data presented, using a fixed inter-electrode spacing of 60 cm will yield substantial information on root zone conductivity and the proximity of a saline water table to the soil surface.

Traversing a field with a fixed inter-electrode spacing of 90 cm would be useful in detecting shallow perched ground water tables and potential root zone salinity problems. Experience and use of a single electrode spacing would considerably reduce the time required to make a salinity survey. After locating an area with a potential soil salinity problem, one could make a more detailed survey with more electrode spacings and grid locations to map the potential extent of the encroaching saline area. Potential saline-seep areas are those areas near the top, side, or base of a hill with the right geologic makeup to cause the shallow ground water to surface. In these areas, the water table is close enough to the soil surface to produce, with time, an excessively saline and wet soil profile that will prevent full yield production. Potential saline-seep areas can be located by having a knowledge of the local geology, watching for wetter than normal soil conditions, lush after harvest weed growth, delayed maturity, excessive or reduced crop growth, or a faint white cast to the soil surface at any of the geomorphic positions mentioned.

Because the soil water in the surveyed area was near field capacity and of similar soil type (Table 2) the EC_a measurements can also be used to map soil salinity of the area (6, 7). The saturation percentage (Table 2) and previous work (5) indicated that texture was fairly uniform, with a slight increase in clay content with increasing profile depth. Results of the linear regression analyses between EC_a or EC_x and EC_e are reported in Table 3. The EC_a values correlated significantly with EC_e values at all electrode spacings. Correlation coefficients *(r)* between EC_x and EC_e decreased with increasing depth of sampling (down to 90 cm). This was expected since the four-electrode conductivity value, EC_x, represents a larger soil volume than the EC_e values. The vertical and horizontal heterogeneity of salinity in the soil profile is probably the cause of the lower *r* values with depth. However, all correlation coefficients were significant at the $P = 0.01$ level.

The data presented demonstrate that the four-electrode technique can be used to quickly map the extent of saline-seep affected soil bodies in the field without soil sampling. With an established EC_a vs. EC_e calibration curve, approximate soil EC_e values can also be mapped in the field without recourse to soil sampling and laboratory analyses. An EC_a or EC_x map can give information concerning the direction or location of the saline-seep recharge area. This information can be very useful in planning remedial measures to control the growth of a saline-seep area. This is particularly true if the location of the recharge area is not visually obvious.

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