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DIVISION S-2—SOIL CHEMISTRY

An Electrical Conductivity Probe for Determining Soil Salinity[1]

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ABSTRACT

An electrical conductivity probe for determining soil salinity is described with construction details. The probe's utility for measuring soil salinity within discrete soil depth intervals is illustrated with examples. Using the salinity probe, the Barnes method for estimating electrical conductivity profiles was shown to be accurate for soils that are reasonably homogeneous laterally.

Additional Index Words: **soil salinity probe.**

RHOADES AND INGVALSON (1971) demonstrated that soil salinity could be assessed in the field from bulk soil electrical conductivity (EC_a) without recourse to soil sampling and analysis. They used four equally spaced electrodes horizontally spanned over the soil area of interest and inserted a few centimeters into the soil (see Fig. 2, ibid) to determine EC_a. This technique (hereafter referred to as the Wenner array) measures the average salinity of a relatively large soil volume (see Fig. 6, ibid), about $5\pi a^3/6$, where "a" is the interelectrode distance. Expanding the interelectrode spacing increases the depth and volume of measurement.

Halvorson and Rhoades (1974) took advantage of this attribute and used the Wenner array technique to estimate salinity within discrete soil depth intervals by determining EC_a at a succession of interelectrode spacings (a). Assuming that the depth to which conductivity is measured is equal to "a", the volume of soil measured may be considered a layer (uniform laterally) to which successively deeper layers are added as "a" is expanded. Treating these layers as resistors in parallel, depth interval soil conductivity, designated by EC_x, is given by (Barnes, 1952)

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

where a_i is the sampling depth, and a_{i-1} is the prior sampling depth. The EC_x values calculated from Eq. [1] agreed reasonably well with EC_e values determined for each depth interval (Rhoades, 1975).

The assumptions that depth of measurement is "a" and that the soil layers can be accurately described by the "resistors in parallel" analogy, are not theoretically exact but are useful (Franklin and McLean, 1973). There are times when more accurate measurement of soil salinity distribution within the rootzone is desired, especially if the salinity is not uniform laterally; an alternative to the above method would be useful. This manuscript describes such a method using a single probe in which the four electrodes are mounted as annular rings, hereafter referred to as the salin-

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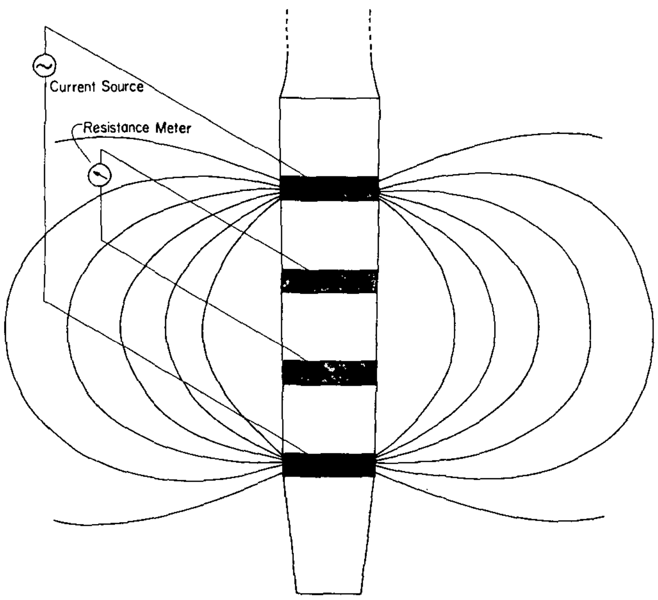

Fig. 1—Schematic illustrating the principle of the soil-salinity probe.

ity probe. Determinations of EC_a of the soil depth(s) of interest is made *after inserting the salinity probe into the soil to that depth(s)*.

CONSTRUCTION AND CALIBRATION OF SALINITY PROBE

Figure 1 illustrates the soil conductivity probe which in principle is similar to that of the surface-positioned Wenner array of electrodes. Four brass annular electrodes are juxtaposed between lucite insulators to form a probe. After the probe is inserted into the soil to the depth of interest, an electrical current (AC), I, is induced between the two outer electrodes, and the potential drop, E, is measured between the two inner electrodes. The ratio $R = E/I$ is recorded as a resistance, which can be converted to soil electrical conductivity with an appropriate "cell constant". The volume of measurement is an ellipitcal volume of soil encircling the probe (shown in Fig. 1).

Construction details and parts for the probe used in this study are illustrated in Fig. 2.[3] The spacing of 2.6 cm (center-to-center) between the pairs of electrodes was chosen so that soil salinity can be assessed within about 15-cm depth increments, while measuring EC_a in a soil volume of about 90 cm^3 ($5\pi a^3/3$). The probe is affixed to a thick-walled, anodized aluminum shaft so that it can be inserted to the desired depth in the soil via a hole made with a standard 2.3-cm OD Oakfield soil sampler. The leads from the electrodes exit from the handles for connection to an earth-resistance meter.[4] The probe is slightly tapered (1°) toward the tip so that all four electrodes firmly contact the soil upon insertion in the hole. Teflon gaskets are placed between the electrodes and lucite insulators, and the connection between the probe and shaft is sealed with epoxy to prevent water from entering and shorting out the electrodes.

The "cell constant" (k) for the probe was determined by submerging it in a large fiberglass barrel filled with solutions of known EC's. The cell constant was then calculated using

$$k = EC_{25} \cdot R_t \cdot \frac{1}{f_t} \qquad [2]$$

where EC_{25} is the electrical conductivity (mmho/cm) of the reference electrolyte solution at 25°C, R_t is the resistance (ohms) of the probe measured in the reference solution at its determined temperature, t, and f_t is the appropriate temperature correction factor (see

Table 1—Comparison of saturation extract electrical conductivity (EC_e) and soil electrical conductivity (EC_a) as measured with the salinity probe for salinity-adjusted Wellton-Mohawk soils, with corresponding saturation and field-water contents.

Soil type	Saturation percentage	Field water content	EC_e	EC_a	$EC_a = m(EC_e) + b$			
					m	b	r†	Sy.x‡
	% by wt	% by wt	mmho/cm					
1) Wellton ls	20	7	2.13	0.29	10.569	−0.810	0.991	0.860
	21	7	2.04	0.24				
	20	7	6.53	0.71				
	20	6	7.80	0.81				
	20	8	12.66	1.39				
	19	7	16.3	1.51				
2) Vint ls	34	9	1.67	0.27	9.533	−1.078	0.995	0.634
	36	11	1.97	0.25				
	35	9	4.83	0.69				
	34	9	8.72	1.04				
	36	12	8.90	1.11				
	36	14	17.4	1.88				
Wellton/Vint combined					9.931	−0.854	0.986	0.967
3) Gilman sl	33	12	2.05	0.49	8.086	−1.691	0.996	0.553
	33	16	2.76	0.48				
	33	12	6.84	1.11				
	32	15	10.8	1.59				
	31	14	14.7	1.97				
4) Dateland sl	26	13	2.62	0.30	7.892	-1.241	0.969	1.947
	28	13	8.99	1.26				
	25	12	21.5	2.59				
Gilman/Dateland combined					7.977	−1.453	0.978	1.344
5) Indio sil	43	21	2.68	0.76	4.469	−0.512	0.996	0.670
	49	21	3.19	0.94				
	54	25	9.64	2.17				
	43	22	11.6	2.70				
	56	25	14.2	3.09				
	44	21	19.8	4.70				
6) Glenbar sicl	54	24	2.48	0.80	4.273	−0.505	0.997	0.907
	46	22	10.7	2.45				
	54	25	19.7	4.80				
Indio/Glenbar combined					4.370	−0.437	0.996	0.685

† Coefficient of correlation.
‡ Standard error of estimate of EC_e on EC_a.

Table 15, U.S. Salinity Laboratory Staff, 1954). The cell constant was 19.5 cm^{-1} with only small differences observed between probes.

METHOD

Electrical conductivities (EC_a) measured with the salinity probe in the field were compared with soil sample salinities measured in the laboratory (EC_e) for the six most extensive soil types found in the Wellton-Mohawk Irrigation and Drainage District of southwestern Arizona. Soil EC_a was determined within small bodies of soil which had been adjusted in the field so they ranged in salinities from 2 to 20 mmho/cm by impounding saline waters (Na, Ca chloride mixtures) in 30-cm diameter by 45-cm long column sections driven about 5 cm into the soil. Two days after the impounded waters had infiltrated into the soils, when the soils had drained to about "field capacity," access holes were made to a 30-cm depth with an Oakfield soil sampler. The salinity probe was inserted and the soil resistance measured, from which the soil EC_a was calculated. After the probe was removed, soil was sampled (0 to 30 cm) immediately surrounding the hole with an 8-cm diameter barrel soil auger; the EC_e of this soil sample was determined in the laboratory. Linear regression analysis of the $EC_e - EC_a$ data was carried out using conventional methods.

RESULTS AND DISCUSSION

Water content, at saturation and in the field, saturation-extract electrical conductivities (EC_e), and soil electrical

[3]Manufactured by Micron Engineering and Manufacturing, Inc., Riverside, Calif., and now commerically available. Trade and company names are provided for the benefit of the reader and do not imply any endorsement by the U.S. Department of Agriculture.

[4]Several meters can be used for this purpose; the one used here was a Bison Model 2350.

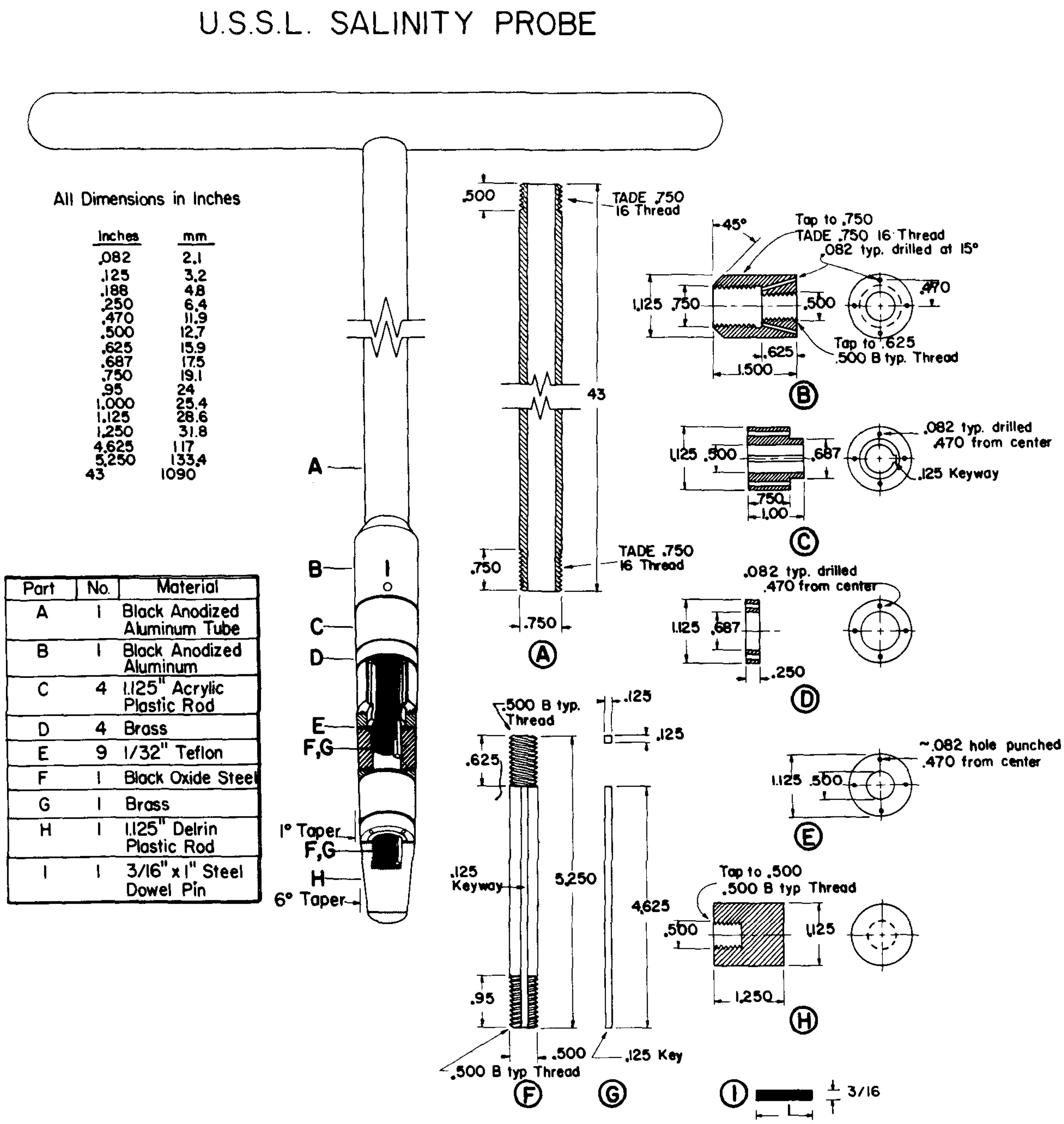

Fig. 2—Construction diagram of soil-salinity probe.

conductivities (EC_a) are given in Table 1 for the six soils. According to soil survey maps, these soils range in texture from loamy sands to silty clay loams. The water contents at field capacity range from 6 to 24% on a weight basis and the imposed EC_e from about 2 to 20 mmho/cm, giving a suitable range for calibration purposes.

Results of the regression analyses between EC_e and EC_a are given in Table 1. These data show a high degree of correlation ($r > 0.96$) and illustrate the salinity probe's applicability for its intended purpose, i.e., measuring soil salinity without recourse to soil sampling and laboratory analysis.

Because of the similarity of calibration relations for soils of similar "field capacity" water-holding capacity, it appears that soil salinity can be assessed for most of the soils of the Wellton-Mohawk Irrigation and Drainage District using only three calibration relations and knowledge of the soil-type. These calibrations are given in Table 1 and Fig. 3. Such similarity in $EC_e - EC_a$ relations for soils of similar water-holding capacity would be expected from the studies of Rhoades et al. (submitted) which showed that EC_a is related to the product of in situ water EC and volumetric water content. Probably $EC_e - EC_a$ calibrations may be estimated for other soils from their water-holding capacities or textures using currently available relations like those presented herein (unpublished data, this Laboratory).

Previously, soil-depth interval salinities had been estimated using measurements at increasing interelectrode

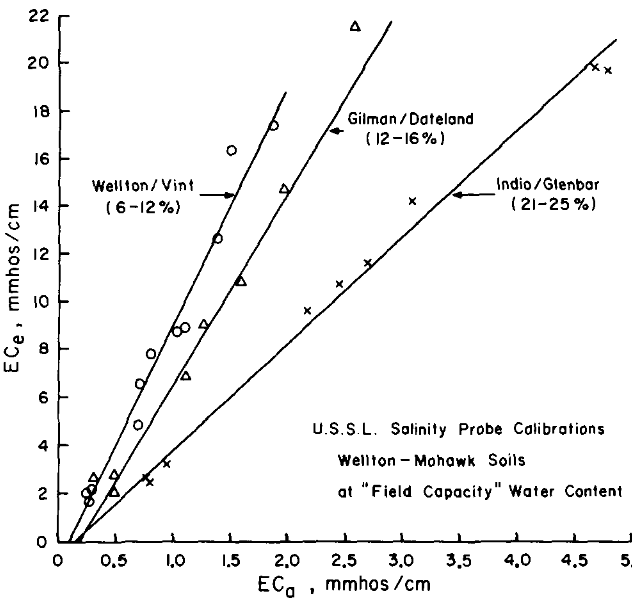

Fig. 3—EC_a – EC_e calibrations for Wellton-Mohawk soils as obtained with the soil-salinity probe.

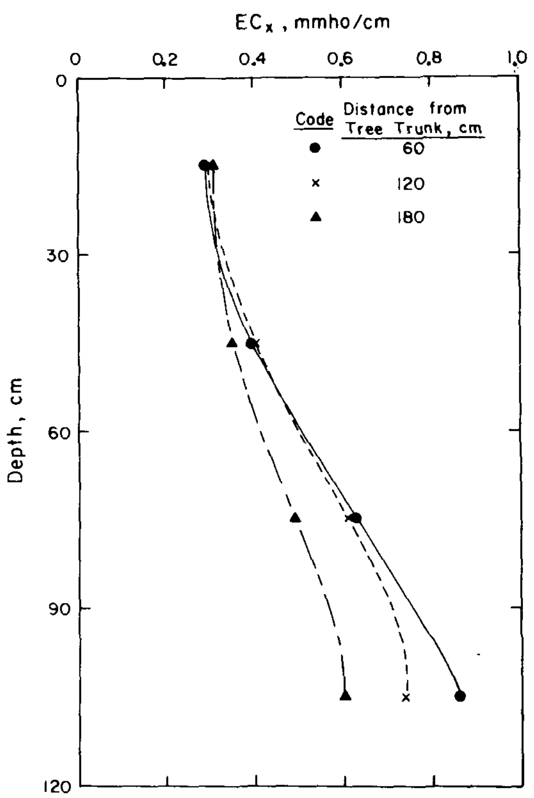

Fig. 4—Distribution of EC_x under a trickle-irrigated citrus tree with radial distance from the trunk and depth below the ground surface.

spacings in the Wenner array and Eq. [1]. The salinity probe was used to evaluate the accuracy of such estimated EC_x values. Electrical conductivity determinations were made at 15-, 45-, 75-, and 105-cm depths in the soil with the salinity probe and at interelectrode spacings of 30, 60, 90, and 120 cm using soil surface-positioned electrodes in the Wenner array in an alfalfa field of Indio silt loam soil. As shown in Table 2, the agreement between the EC_x values determined directly and those calculated using Eq. [1] is excellent. The Wenner array technique does not work as well when the soil is highly stratified or nonhomogeneous laterally (unpublished data). The salinity probe will not be so limited and hence should be more generally reliable in such cases.

Table 2—Comparison of soil interval electrical conductivities (EC_x) as determined with the salinity probe and as estimated from Eq. [1].

		Salinity probe		Wenner array		EC_x as determined by	
Depth interval	Soil temp.	Depth of probe insertion†	Resistance	Spacing	Resistance	Salinity probe	Wenner method
cm	°C	cm	ohms	cm	ohms	mmho/cm	
0- 30	28.1	15	34.85	30	9.99	0.52	0.49
30- 60	27.3	45	11.63	60	2.76	1.59	1.31
60- 90	25.9	75	9.33	90	1.31	2.04	2.05
90-120	24.8	105	10.23	120	0.89	1.90	1.88

† Depth of midpoint of the four electrodes.

Data of soil EC as determined with the salinity probe by depth within the rootzone of a trickle-irrigated citrus tree are given in Fig. 4. Here Eq. [1] and the Wenner configuration cannot be used because the soil (Dateland) salinity was not homogeneous laterally within discrete soil-depth intervals. Using the Dateland soil calibrations we see that soil salinity (EC_e) increased below this tree from about 1.1 mmho/cm in the 0- to 30-cm depth to from 3.5 to 5.5 mmho/cm in the 90- to 120-cm depth, depending on radial distance from the tree trunk.

CONCLUSIONS

The salinity probe can be used to more accurately determine soil salinity of a discrete depth interval in the soil profile than can the surface-positioned, four-electrode equipment. The probe does have some of the same limitations as soil samples and in situ salinity sensors (i.e., soil must be removed with a soil sampling tube, although no analyses are required), and it repsonds to a relatively small localized region within the soil. Thus, while this device can be used to diagnose soil salinity by taking a number of readings in the soil landscape to obtain a representative value, EC_a readings determined with the surface-positioned Wenner array are better suited to provide an index of *bulk* soil salinity. The salinity probe is particularly well adapted when more precise information of soil salinity by depth interval or within small localized soil regions (like furrow bed or location under trees) is desired and when textural stratification of the profile requires the use of different EC_e–EC_a calibrations for the different strata. The salinity probe is also very useful for establishing EC_e – EC_a calibrations. Thus, the two techniques complement each other.

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