Monitoring Soil Salinity

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SUITABLE inventories of soil salinity do not exist in the United States, nor are there monitoring programs to track the salinity status of soils. National or state programs to protect soils against salinity are likewise nonexistent.

Proper operation of a viable, permanent irrigated agriculture, which also uses water efficiently, requires periodic information on soil salinity. Only with this information can the effectiveness of irrigation project operation be assessed with respect to salt balance and water use efficiency.

The need for monitoring will likely increase. Less water will be available for leaching as the competition increases for water now used in irrigation. In addition, restrictions are expected to be placed on the discharge of salt from irrigation projects. With less leaching, there will be a corresponding increase in soil salinity.

Monitoring soil salinity is complicated by salinity's spatial variability. Numerous samples are needed to characterize an area. Monitoring is also complicated by salinity's dynamic nature, due to the influence of management practices, water table depth, soil permeability, consumptive water use, rainfall, and salinity of the perched groundwater. When the need for repeated measurements is multiplied by the extensive requirements of a single sampling period, the expenditures of time and effort with conventional soil sampling procedures increase proportionately. Furthermore, maps of current soil salinity will soon be out of date as management, weather, and water table conditions change.

Simple, practical methods for measuring field salinity are needed. Procedures for delineating representative areas within irrigation projects where periodic measurements can be made for monitoring are needed also, as are procedures for rapidly producing soil salinity maps. New instruments for measuring soil electrical conductivity, coupled with computer mapping techniques, have the potential for meeting salinity monitoring and mapping needs.

Measuring soil salinity

Soil salinity is most commonly determined by laboratory measurements of soil sample extracts (*27*). It can also be determined from soil water removed with vacuum extractors or in situ using salinity sensors. Another method involves bulk soil electrical conductivity, a measure of the overall conductivity of the solid, liquid, and air phases. Bulk conductivity can be determined with electrode probes or with electromagnetic induction devices. From bulk soil conductivity, soil solution conductivity— soil salinity—can be derived.

A recent evaluation of these methods of measuring soil salinity produced recommendations for the appropriate use of each method in different situations (*16, 17*).

Laboratory measurements. Although conventional laboratory measurements are still used repeatedly to assess soil salinity, the spatial variability of soil salinity, combined with its dynamic nature, makes characterization of a field an extremely labor-intensive task. In addition, soil water composition changes somewhat as soil is removed from its natural condition and dried, ground, sieved, diluted with water, and extracted. Only the composition under reference conditions, not actual conditions, can therefore be determined from soil samples.

Attempts can be made to minimize the required number of samples by resampling the same spot in the field (*9*). Relative

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changes can thus be ascertained more readily. But when the sampling location is moved even relatively short distances, soil variability differences often void simple comparisons of salinity changes. Also, the sampling process itself may alter some soil properties, such as infiltration rate, so the location is no longer representative of its prior condition. In cases where exchangeable cation compositions are needed, soil sampling is advantageous, if not requisite.

Use of vacuum extractors and sensors. Soil water samples can be collected with vacuum extractors and analyzed for soluble salts when the soil water suction is less than about 1 bar. Although the range in available soil moisture for crops extends to 15 bars suction, most water movement in soils takes place within the 0- to 1-bar range, when the water content is relatively high. The suction method is thus applicable for some monitoring needs but requires a relatively high water content. Various errors in sampling soil water can occur with the use of porous ceramic cup extractors, including sorption, leaching, diffusion, and sieving by the cup wall (*1, 8*). Soil water samples, being "point samples," may indicate relative changes in salt concentrations, but not quantitative changes, unless the frequency distribution of such measurements is established. For soil water samples collected with ceramic vacuum extractors to be representative of drainage below the sampling point, the distribution of the sample volume collected over time should be identical to the soil-water drainage rate curve (*2, 11, 28*). So even though vacuum extractors are versatile, easy to operate, in situ soil water sampling devices, they are not without limitations.

For many salinity monitoring and mapping needs, total salt concentration in soil water is sufficient data; specific solute concentrations are unnecessary. In such cases, neither soil nor water samples are required, and in situ devices that measure total salt concentration or a related parameter of soil water may be advantageous.

Salinity sensors have been used for continuously monitoring soil salinity in soil columns, lysimeters, and field experiments (*12, 13, 14, 15*). Many sensors are needed because of their small sampling volume and soil heterogeneity. In contrast to laboratory measurements of soil sample extracts, salinity sensors measure the electrical conductivity of soil water in situ.

Salinity sensors are not suited to measuring short-term changes in salinity because of their relatively long response time, up to several days (*29*). Also, soil disturbance during installation can cause errors associated with modified water infiltration over the sensor (*14*). Special precautions must be taken during installation. Furthermore, a salt sensor's calibration may change with time (*30*).

While not without limitations, salinity sensors can be used to continuously monitor the electrical conductivity of soil water at selected soil depths over relatively long periods of time.

Measuring salinity in bulk soil. Soil salinity also can be indirectly determined in situ from bulk soil electrical conductivity measurements. For any soil there is, at a given water content, a linear relation between electrical conductivity and salinity (*19, 22*). Once this relation (calibration) is established, salinity can be determined from field measurements of electrical conductivity at the reference water content. Calibrations between soil salinity and electrical conductivity have been successfully determined for many soils and used to diagnose salinity (*6, 7, 16, 20, 23*). Appropriate calibrations for different soil types can be predicted from soil properties (*19*).

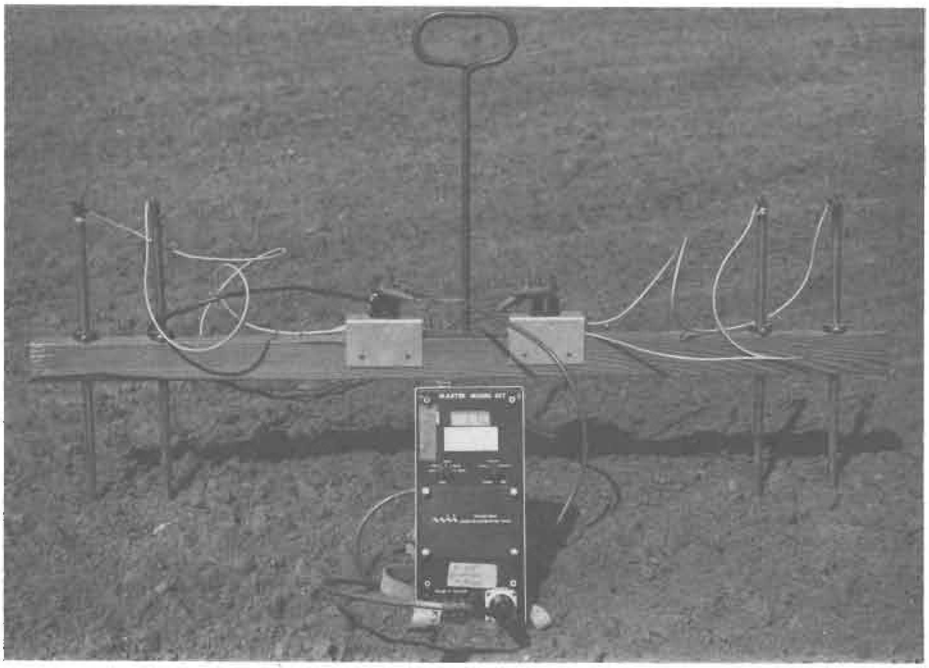
For irrigated soils, electrical conductivity measurements should be made after irrigation. Soil water content is then at field capacity. This water content is reproducible enough to establish the necessary calibrations.

Under dryland conditions, electrical conductivity should be measured in early spring, preferably in fallow land, to take advantage of relatively uniform soil water conditions when such soils are also near field capacity.

Although variation in water content influences electrical conductivity, the effect is not as marked as one might think. This is evident from the following consideration (*25*). After rapid drainage ceases following an irrigation and the soil is at "field capacity," further losses of soil water occur primarily by evapotranspiration. Almost all salts are excluded from the plant by the root membranes. No salt is removed by evaporation. Hence, the salt concentration (or electrical conductivity) of the remaining soil water increases as evapotranspiration reduces soil water.

Soil electrical conductivity can now be measured using commercially available equipment, either the four-electrode probe or the electromagnetic induction method. With the four-electrode probe, resistance to current flow within the soil is measured between a pair of electrodes while an electrical current is passed through the soil between another pair of electrodes. In the absence of appreciable layering, the depth of current penetration for such a configuration is roughly equal to one-third the outer-electrode spacing, and the average soil salinity to this depth is measured (*6, 20, 21*). By varying the interelectrode spacing, therefore, average soil salinity can be measured at different depths and within different volumes of soil.

This method's advantage is that a much larger volume of soil is measured than can be measured with soil samples, soil water extractors, or salinity sensors. Also, measuring soil salinity with this method is simple, fast, and particularly suited for



Horizontal arrangement of a four-electrode probe used to measure bulk soil electrical conductivity and a new generator/meter readout system.

routine salinity monitoring and mapping.

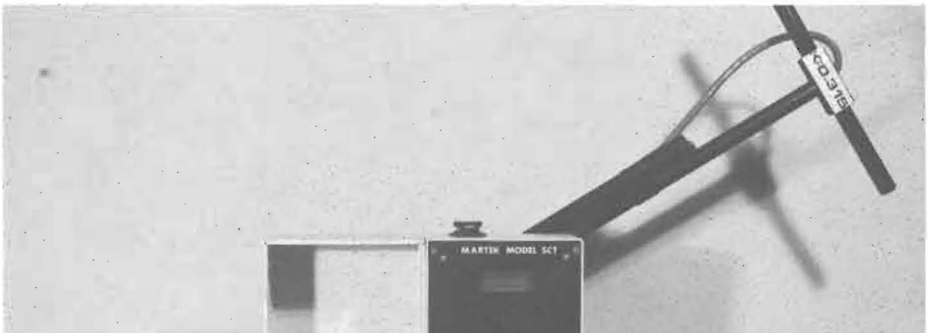
When information about salinity distribution with depth or within depth intervals is needed, the four-electrode salinity probe can be used. This probe has four annular rings molded into a plastic probe. The probe is slightly tapered so it can be inserted into the soil to the desired depth via a hole made with a soil-coring tube. In a portable version (*23*), the probe is attached to a shaft through which the electrical leads are passed and connected to a meter. In the burial unit (*18*), leads from the probe simply extend to the soil surface. The standard commercial unit measures a soil volume of about 143 cubic inches.

These devices permit more accurate determinations of soil salinity distribution than the surface-positioned four-electrode device. They require a core of soil to be removed with a soil sampling tube, but they respond to a relatively small volume of soil. Both the surface electrodes and salinity probe can be used together to great advantage. The burial-type probe can also be used as an in situ sensor for monitoring.

With the electromagnetic induction method, the imposition of a primary electromagnetic field within the soil induces current flow in the soil. The induced secondary electromagnetic field is directly proportion to electrical conductivity. Design of the EM-38 soil electromagnetic conductivity meter[1] permits a conductivity reading at the soil surface that is a cumulative reading of soil conductivities from the various strata above some depth in the soil. A series of equations is used to calculate actual conductivity within a given soil depth interval from electromagnetic apparent conductivity measurements taken both horizontally and vertically. Thus, the bulk soil electrical conductivities of various soil depth increments can be rapidly determined from two electromagnetic measurements made above ground.

This method is particularly suited for field salinity inventory or mapping applications. Data can be obtained nearly as rapidly as one can travel from one measurement site to another. To further expedite data accumulation, it is possible to log these readings in a hand-carried data logger and to process the data automatically. Because of the tremendous volume of data that can be obtained with this method, visual displays are the most useful means of presentation.

Commercial version of the soil salinity probe with generator/meter readout system.



Automated mapping of salinity

Improvements in computer hardware over the past decade, particularly in data storage and processing capability, have resulted in widespread application of automated mapping to a variety of natural resource disciplines. Automated mapping of geographically encoded data has been used to visually display tremendous amounts of positionally related data for cartographic, demographic, geologic, meteorologic, and planning purposes.

There are two common forms of mapping systems: grid cell systems and line segment (polygon) systems. A grid cell and its associated property attribute represent a spatial cell that is characterized by the dominant feature of that cell. The grid cell system is sufficient for mapping most soil properties because soil properties tend to change gradually over the landscape, making it difficult to establish a definitive boundary line for individual map units.

Grid cell maps are relatively easy to develop in comparison with polygonal mapping systems, hence their more widespread application. Cell systems, however, have been criticized for the fact that the grid cell size is the lower limit of spatial resolution. To increase spatial accuracy, if that is necessary, requires a reduction in grid cell size. But this, in turn, increases the quantity of data, which increases the burden on storage facilities and processing efficiency.

Spatial accuracy can be maximized by using a polygonal mapping system in which areal units are aggregate units of continuous data. Polygonal boundaries are defined by a series of connecting line segments. Unlike a grid cell system, associated attributes are assigned to point groups rather than to a single cell or point.

Generally speaking, the minimum requirements for an automated mapping system include a means of digitizing or associating a property attribute with a pair of x and y coordinates, a means of editing the database, and a means of graphically summarizing the data.

Association of position and property attribute is generally accomplished by manually digitizing line segment nodes (polygonal system) or digitizing and calculating the centroids (grid cell system), then relating the attribute to the corresponding point group (polygonal system) or centroid (grid cell system). Because digitizing can be a very labor-intensive task, database formation and maintenance for a dynamic soil property such as salinity can be extremely burdensome. Ideally, the association of property attribute and position is done at the time of property measurement.

Editing involves the correction of erroneous data entries. An editor should allow for insertion, deletion, and modification of map features. This is most quickly accomplished by an interactive system that permits immediate graphic display of an edited feature.

In addition to producing a graphic display of data, the plotting portion of an automated mapping system should provide curve smoothing for polygonal maps, shading, window selection, text entry, and scaling facilities. The combination of these capabilities renders a final hardcopy display of the positionally related data that can be easily interpreted.

Automated mapping has evolved from an electronic tool for creating maps to a

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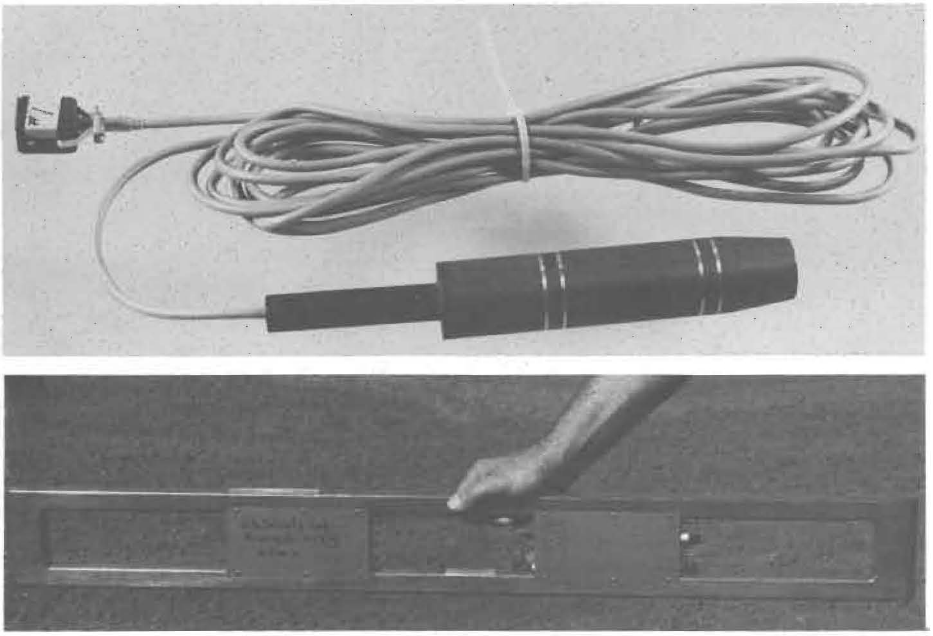
[1] Mention of products or companies is for readers' information and implies no endorsement by USDA.

sophisticated geographic information system that permits one to ask questions about the maps. This analytic capability has added a new dimension to automated mapping that can serve resource managers and others working with spatially related data. Addition of this analytic capability, however, requires more sophisticated data structures that contain attribute information associated with positional data in a compact, easily accessed format. A pilot study is underway that uses an efficient data structure to perform overlay analysis on interacting soil property, crop, and irrigation databases in an attempt to delineate areas of potential salination (5).

Overcoming the information gap

No extensive inventory exists of salinity on agricultural land in the arid West. Information of this nature is needed to formulate public policy and to devise management programs. From a single map, one can quickly gain an understanding of a complex, spatially associated database such as salinity. Visual displays of this type permit decisions to be made about irrigation water management, crop selection, location of salinity monitoring sites, intensity of salinity sampling, and salination trends. To create these visual displays, it is necessary to use current methods and devices for measuring soil electrical conductivity that lend themselves to establishment of an up-to-date, usable geographic information system for salinity.

A network of representative soil salinity monitoring stations should be established in irrigation projects, especially those projects undergoing changes in operation. A governmental agency ought to assume this responsibility. The fact that no agency is now monitoring soil salinity on irrigated land is a real concern from the standpoint of land and water degradation.



Burial-type salinity probe (top) partially removed from an installation tool. The probe is inserted into the soil via the access hole shown, then the installation tool is removed, leaving only the lead wires protruding from the soil. Geonics EM-38 prototype electromagnetic soil conductivity meter (bottom) placed on the ground in the vertical dipole position.

REFERENCES CITED

1. Alberts, E. E., R. E. Burwell, and G. E. Schuman. 1977. *Soil nitrate-nitrogen determined by coring and solution extraction techniques.* Soil Sci. Soc. Am. J. 41: 90-92.
2. Biggar, J. W., and D. R. Nielsen. 1976. *Spatial variability of the leaching characteristics of a field soil.* Water Resources Res. 12: 78-84.
3. Corwin, D. L., and J. D. Rhoades. 1982. *An improved technique for determining soil electrical conductivity—depth relations from above-ground electromagnetic measurements.* Soil Sci. Soc. Am. J. 46: 517.
4. Corwin, D. L., and J. D. Rhoades. 1983. *Measurement of inverted electrical conductivity profiles using electromagnetic induction.* Soil Sci. Soc. Am. J. (in press).
5. Corwin, D. L., and J. D. Rhoades. 1983. *The use of computer aided mapping techniques to delineate potential areas of salinity development: A conceptual introduction.* Geoderma (in press).
6. Halvorson, A. D., and J. D. Rhoades. 1974. *Assessing soil salinity and identifying potential saline—seep areas with field soil resistance measurements.* Soil Sci. Soc. Am. Proc. 38: 576-581.
7. Halvorson, A. D., J. D. Rhoades, and C. A. Reule. 1977. *Soil salinity—four-electrode conductivity relationships for soils of the Northern Great Plains.* Soil Sci. Soc. Am. J. 41: 966-971.
8. Hansen, E. A., and A. R. Harris. 1975. *Validity of soil-water samples collected with porous ceramic cups.* Soil Sci. Soc. Am. Proc. 39: 528-536.
9. Kelly, W. P., B. M. Lawerence, and H. D. Chapman. 1949. *Soil salinity in relation to irrigation.* Hilgardia 18: 635-665.
10. Kemper, W. D. 1959. *Estimation of osmotic stress in soil water from the electrical resistance of finely porous ceramic units.* Soil Sci. 87: 345-349.
11. Nielsen, D. R., J. W. Biggar, and K. T. Erh. 1973. *Spatial variability of field-measured soil-water properties.* Hilgardia 42: 215-259.
12. Oster, J. D., and R. D. Ingvalson. 1967. *In situ measurement of soil salinity with a sensor.* Soil Sci. Soc. Am. proc. 32: 572-574.
13. Oster, J. D., and L. S. Willardson. 1971. *Reliability of salinity sensors for the management of soil salinity.* Agron. J. 63: 695.
14. Oster, J. D., L. S. Willardson, and G. J. Hoffman. 1973. *Sprinkling and ponding techniques for reclaiming saline soils.* Trans., ASAE 16: 89-91.
15. Rhoades, J. D. 1972. *Quality of water for irrigation.* Soil Sci. 113: 277-284.
16. Rhoades, J. D. 1976. *Measuring, mapping, and monitoring field salinity and water table depths with soil resistance measurements.* FAO Soils Bull. 31: 159-186.
17. Rhoades, J. D. 1978. *Monitoring soil salinity: A review of methods.* In *Establishment of Water Quality Monitoring Programs.* Am. Water Resources Assoc., Minneapolis, Minn. pp. 150-165.
18. Rhoades, J. D. 1979. *Inexpensive four-electrode probe for monitoring soil salinity.* Soil Sci. Soc. Am. J. 43: 817-818.
19. Rhoades, J. D. 1981. *Predicting soil electrical conductivity-salinity calibrations from soil properties.* Soil Sci. Soc. Am. J. 45: 42-44.
20. Rhoades, J. D., and R. D. Ingvalson. 1971. *Determining salinity in field soils with soil resistance measurements.* Soil Sci. Soc. Am. Proc. 35: 54-60.
21. Rhoades, J. D., and A. D. Halvorson. 1977. *Electrical conductivity methods for detecting and delineating saline seeps and measuring salinity in Northern Great Plain's soils.* ARS-42. Agr. Res. Serv., U.S. Dept. Agr., Washington, D.C. 45 pp.
22. Rhoades, J. D., P.A.C. Raats, and R. J. Prather. 1976. *Effects of liquid-phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity.* Soil Sci. Soc. Am. J. 40: 651-655.
23. Rhoades, J. D., and J. van Schilfgaarde 1976. *An electrical conductivity probe for determining soil salinity* Soil Sci. Soc. Am. J. 40: 647-651.
24. Rhoades, J. D., and D. L. Corwin. 1981. *Determining soil electrical conductivity-depth relations using an inductive electromagnetic soil conductivity meter.* Soil Sci. Soc. Am. J. 45: 255-260.
25. Rhoades, J. D., D. L. Corwin, and G. J. Hoffman. 1981. *Scheduling and controlling irrigations from measurements of soil electrical conductivity.* In Proc., Irrigation Scheduling Conference. Am. Soc. Agr. Eng., St. Joseph, Mich. pp. 106-115.
26. Richards, L. A. 1966. *A soil salinity sensor of improved design.* Soil Sci. Soc. Am. Proc. 30: 333-337.
27. U.S. Salinity Laboratory. 1954. *Diagnosis and improvement of saline and alkali soils.* Agr. Handbk. No. 60. U.S. Dept. Agr., Washington, D.C. 100 pp.
28. van De Pol, R. M., P. J. Wierenga, and D. R. Nielsen. 1977. *Solute movement in a field.* Soil Sci. Soc. Am. J. 41: 10-13.
29. Wessling, J., and J. D. Oster. 1973. *Response of salinity sensors to rapidly changing salinity.* Soil Sci. Soc. Am. Proc. 37: 553-557.
30. Wood, J. D. 1978. *Calibration, stability, and response time for salinity sensors.* Soil Sci. Soc. Am. J. 42: 248-250. ☐