United States Department of Agriculture
Soil Conservation Service **Chester, PA 19013**

Subject: Electromagnetic Induction (EM)- Puerto Rico; 26 to 28 January 1994 **Date:** 4 February 1994

To: Roy Vick
State Soil Scientist
USDA-Soil Conservation Service
Caribbean Area
P.O. Box 36468
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Purpose:
To provide field training to soil scientists on the use of the EM38 meter for soil survey investigation.

Participants:
Fred Beinroth, Professor of Soils, Univ. of PR, Mayaguez, PR
Milton Cortes, Resource Soil Scientist, SCS, Mayaguez, PR
John Davis, Assistant Staff Soil Scientist, SCS, St. Croix, V.I.
Jim Doolittle, Soil Specialist, SCS, Chester, PA
Carmen Santiago, Resource Soil Scientist, SCS, San Juan, PR
Miguel Valzquez, Graduate Student, Univ. of Puerto Rico, Mayaguez, PR
Roy Vick, State Soil Scientist, SCS, San Juan, PR

Activities:
On the morning of 27 January, the EM38 meter was tested in areas of Cotito (clayey, kaolinitic, isohyperthermic (shallow) Tropeptic Eutrorthox) and Coto (clayey, kaolinitic, isohyperthermic Tropeptic Haplorthox) at the Isabela Experiment Station. During the afternoon of 27 January, the EM meter was tested in areas of Bajura (fine, mixed, nonacid, isohyperthermic Vertic Tropaquept), Catano (carbonatic, isohyperthermic, Typic Tropopsamment), Coloso (fine, mixed, nonacid, isohyperthermic Aeric Tropic Fluvaquent), and Talante (coarse-loamy over sandy or sandy-skeletal, mixed, acid, isohyperthermic, Aeric Tropic Fluvaquent) soils near Cano La Puerte. On the morning of 28 January as detailed EM assessment of an area of Guanica (very-fine, montmorillonitic, isohyperthermic Udic Pellustert) soils was completed.

Equipment:
The electromagnetic induction meter was the EM38 manufactured by Geonics Limited+. The meter is portable and requires only one person to operate. The depth of penetration is dependent upon the intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. The EM38 meter integrates values of apparent conductivity over the upper 0.75 m in the horizontal dipole orientation, and over the upper 1.5 m in the vertical dipole orientation.

+ Trade names have been used to provide specific information. Their mention does not constitute endorsement.

Discussion:

Isabela Experiment Station.

The purpose of this study was to familiarize soil scientist with the EM38 meter and to use EM techniques to estimate the depth to bedrock in areas of karst. Results were erratic and no relationship was found between EM response and depth to bedrock. The study was curtailed when it became evident that interference was being received from a near-by U.S. Navy transmitting station. This site provided an excellent example of the effects of "cultural noise."

Flood-plain Soils near Cano La Puerte

Though similarities exist, changes in EM responses were found to correspond with changes in soil taxonomic types. This study helped to demonstrated that EM techniques can be used as a quality control tool in some areas to identify and chart variations in soils and soil properties.

Systematic Sampling of an Area of Guanica Soil

A 100 by 100 foot grid was established across an area Guanica soil. Survey flags were inserted in the ground at 20 foot intervals. At each of the 36 grid intersections, measurements were obtained with the EM38 meter in both the horizontal and vertical dipole orientations.

Variations in EM response were attributed to differences in the amount of salts within the soil profile. Values of apparent conductivity increased with depth at all observation sites (measurements obtained in the horizontal dipole orientation < measurements obtained in the vertical dipole orientation). An increase in EM response with depth suggests a normal salt profile with soluble salts being principally added to the soil profile from a water table (below) rather than from surface waters (above).

Electromagnetic induction methods focuses on the rate and magnitude of change in EM response from place to place. Isarithmic maps prepared from EM data can provide a graphic description of variations in soils and/or soil properties within a survey area. These maps can be used by soil scientist to locate representative sampling sites (based on apparent conductivity values) for soil characterization.

Figure 1 represents two-dimensional isarithmic maps prepared from data collected with the EM38 meter. These computer simulations chart apparent conductivity values collected in the horizontal and the vertical dipole orientations.

Soil boundaries separate areas of one kind soil from another. In the field, some soil boundaries are obvious, sharply defined, and conform to breaks in the landscape. Others soil boundaries are gradational and difficult to identify. With EM techniques, the rate of change in soils and soil properties can be inferred.

In Figure 1, patterns of apparent conductivity values are highly complex suggesting variability in soil properties over short distances. These patterns were attributed to variations in salt content. Sampling is needed to confirm interpretations and to develop predictive equations.

Results:

1. All participants received training in the operation and use of the EM38 meter.

2. Electromagnetic induction is an imperfect geophysical tool and is not equally suitable for use in all soil investigations. The success of an EM survey depends on the nature and variability of soil properties. Electromagnetic induction methods have been most effective in areas where subsurface soil properties are fairly homogeneous, the effects of one factor dominants over the others, and variations in the EM response can be related to changes in a single factor (e.g. soil moisture, soluble salt content, clay content, soil depth, or mineralogy). Ground-truth auger observations are required to verify interpretations.

3. EM techniques can be used in Puerto Rico to support transect data. Generally, changes in EM responses corresponded to changes in soil taxonomic types. In addition, EM techniques can be used to identify and chart variations in soils and soil properties across management units and to locate representative sampling sites (based on apparent conductivity values) for soil characterization.

4. An EM38 meter (serial number 8906008) was left in the custody of Roy Vick. The Soil Staff of Puerto Rico will evaluate the appropriateness of this tool for field investigations and site assessments in Puerto Rico. The multi-disciplinary use of this meter is encouraged. At the conclusion of a three month period (1 February to 1 May 1994), the equipment will be returned to Jim Doolittle (Soil Scientist, USDA-Soil Conservation Service, 160 East 7th Street, Chester, Pennsylvania 19013) by Federal Express.

5. Several articles on the use of EM techniques are forwarded to Roy Vick for a reference library.

Though my stay was short, it was my pleasure to work in Puerto Rico and to become acquainted with the members of your fine staff.

With kind regards

James A. Doolittle
Soil Specialist

cc:
C. S. Holzhey, Assistant Director, Soil Survey Division, NSSC, SCS, Lincoln, NE
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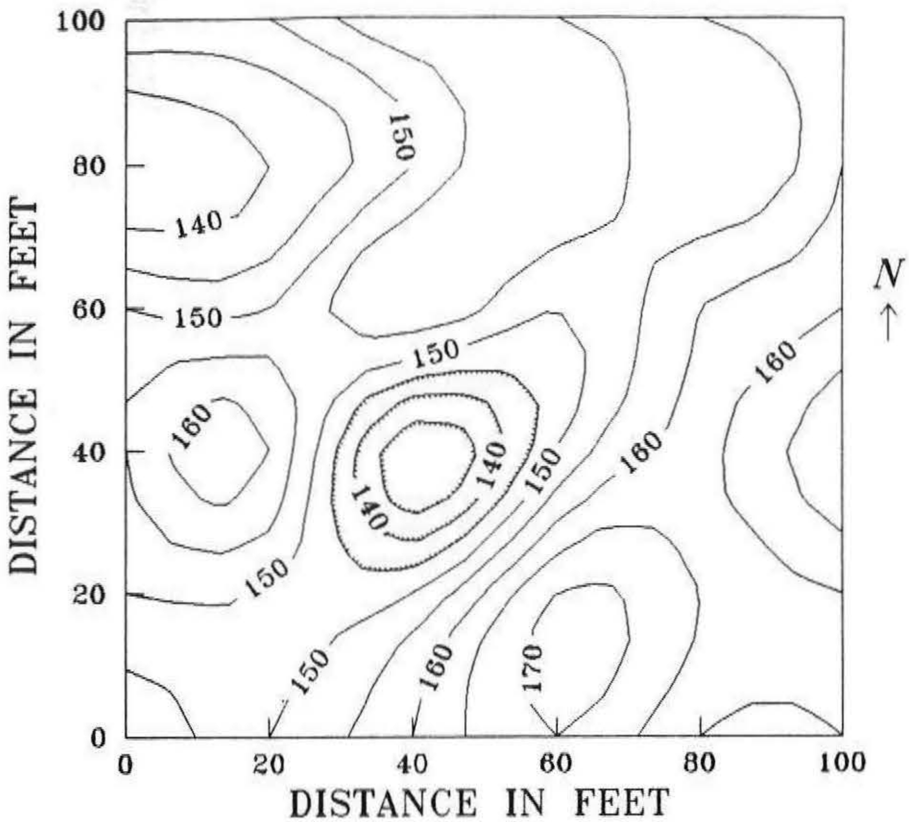
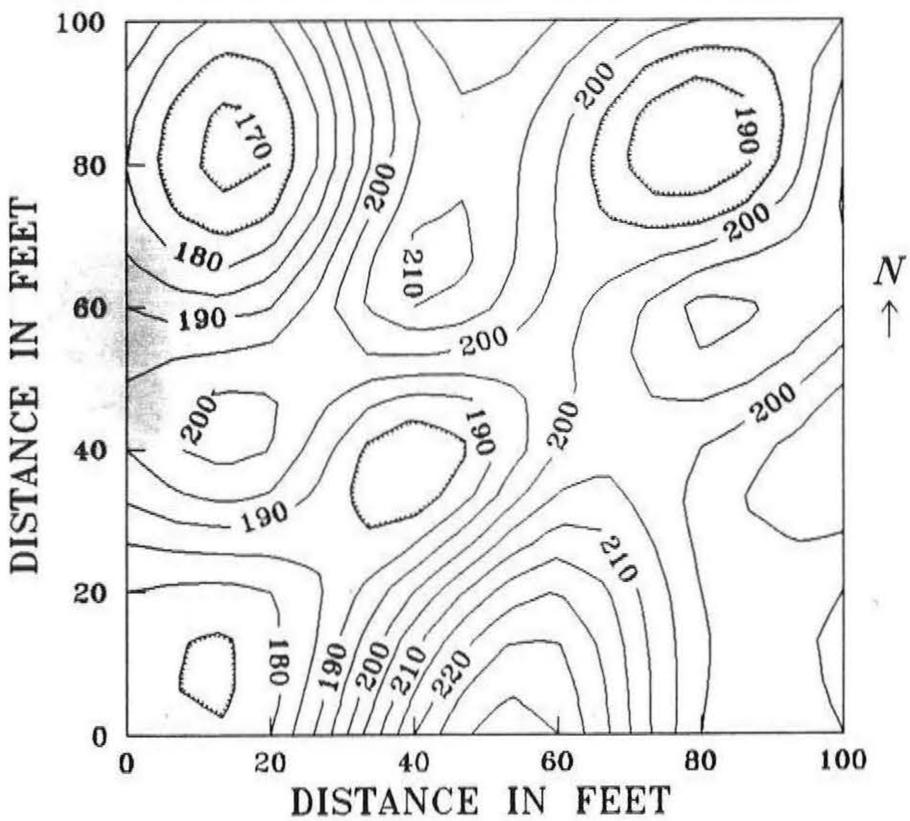
EM38 SURVEY OF AN AREA OF GUANICA SOIL

HORIZONTAL DIPOLE ORIENTATION



VERTICAL DIPOLE ORIENTATION



Review of Electromagnetic Induction Methods

Electromagnetic inductive (EM) is a surface-geophysical method in which electromagnetic energy is used to measure the terrain or apparent conductivity of earthen materials. This technique has been used extensively to monitor groundwater quality and potential seepage from waste sites (Brune and Doolittle, 1990; Byrnes and Stoner, 1988; De Rose, 1986; Greenhouse and Slaine, 1983; Greenhouse et al., 1987; and Siegrist and Hargett, 1989)

For surveying, the meter is placed on the ground surface or held above the surface at a specified distance. A power source within the meter generates an alternating current in the transmitter coil. The current flow produces a primary magnetic field and induces electrical currents in the soil. The induced current flow is proportional to the electrical conductivity of the intervening medium. The electrical currents create a secondary magnetic field in the soil. The secondary magnetic field is of the same frequency as the primary field but of different phase and direction. The primary and secondary fields are measured as a change in the potential induced in the receiver coil. At low transmission frequency, the ratio of the secondary to the primary magnetic field is directly proportional to the ground conductivity. Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

Electromagnetic methods measure the apparent conductivity of earthen materials. Apparent conductivity is the weighted average conductivity measurement for a column of earthen materials to a specified penetration depth (Greenhouse and Slaine; 1983). The averages are weighted according to the depth response function of the meter (Slavich and Petterson, 1990).

Variations in the meters response are produced by changes in the ionic concentration of earthen materials which reflects changes in sediment type, degree of saturation, nature of the ions in solution, and metallic objects. Factors influencing the conductivity of earthen materials include: (i) the volumetric water content, (ii) the amount and type of ions in the soil water, (iii) the amount and type of clays in the soil matrix, and (iv) the soil temperature. Williams and Baker (1982), and Williams (1983) observed that, in areas of salt affected soils, 65 to 70 percent of the variation in measurements could be explained by the concentration of soluble salts. However, as water provides the electrolytic solution through which the current must pass, a threshold level of moisture is required in order to obtain meaningful results (Van der Lelij, 1983).

The depth of penetration is dependent upon the intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. Table 3 list the anticipated depths of measurements for the EM31 and EM38 meters. The actual depth of measurement will depend on the conductivity of the earthen material(s) scanned.

Table 3

Depth of Measurement

Meter	Intercoil Spacing	Depth of Measurement Horizontal	Vertical
EM31	3.7 m	2.75 m	6.0 m
EM38	1.0 m	0.75 m	1.5 m

The conductivity meters provide limited vertical resolution and depth information. However, as discussed by Benson and others (1984), the absolute EM values are not necessarily diagnostic in themselves, but lateral and vertical variations in these measurements are significant. The seasonal variation in soil conductivity (produced by variations in soil moisture and temperature) can be added to the statement by Benson. Interpretations of the EM data are based on the identification of spatial patterns in the data set appearing on two-dimensional contour plots.

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