SOIL SCIENCE SOCIETY OF AMERICA
JOURNAL

VOL. 68 MARCH–APRIL 2004 No. 2

DIVISION S-1—SOIL PHYSICS

Minimizing Drift in Electrical Conductivity Measurements in High Temperature Environments using the EM-38

D. A. Robinson,* I. Lebron, S. M. Lesch, and P. Shouse

ABSTRACT

The EM-38 is a noninvasive instrument, commonly used for monitoring salinity, mapping bulk soil properties, and evaluating soil nutrient status. Users in the Southwest USA have observed as much as 20% "drift" in the measurement of bulk soil electrical conductivity (EC_a) with this instrument. This drift has usually been ignored or compensated for by statistical procedures. We performed laboratory and field experiments to determine if the drift is due to calibration instability of the instrument or to heating of the instrument by the sun. In laboratory experiments, after a warm-up period, the instrument provided constant readings in the range 25 to 40°C; above 40°C the response of the instrument was unpredictable. In field experiments, where we placed the EM-38 in a fixed location we observed an unexpected response at air temperatures below 40°C. Temperature sensors in different locations on the instrument demonstrated that temperature differences between the instrument's transmitting and receiving coils and the control panel (CP) were as great as 20°C. As the instrument is temperature compensated from this CP, erroneous compensation occurred when the instrument was placed in direct sunlight. In this study, we demonstrate that differential heating of the EM-38 is one cause of drift and erroneous bulk electrical conductivity measurement; shading the instrument substantially reduced this problem, effectively extending the reliable working temperature range by minimizing drift.

THE CONCEPT OF USING induced electromagnetic fields to measure ground conductivity has been applied in the geosciences for more than 50 yr (Belluigi, 1948; Wait 1954, 1955, 1982). Induction methods were used extensively for ore prospecting as metallic ore bodies can have substantial electrical conductivity (Keller and Frischknecht, 1966). They were also used for well logging in the petroleum exploration industry (Keller and Frischknecht, 1966). Noninvasive instruments were first considered for use in agriculture by De Jong et al. (1979). Since then the technique has been used to map a variety of physical quantities with which EC_a correlates (e.g., salinity, moisture, and clay content). Water content has been estimated from measurements of EC_a by Kachanoski et al. (1988) and Sheets and Hendrickx (1995), salinity by a number of authors (Corwin and Rhoades, 1982; Wollenhaupt et al., 1986; Hendrickx et al., 1992; Rhoades, 1993; Lesch et al., 1995a, 1995b; Rhoades et al., 1999), and inferring differences in mineralogy by Triantafilis et al. (2000). Increasingly, applications are being identified in precision agriculture for determining nutrient status and potential yield (Corwin and Lesch, 2003; Corwin et al., 2003).

The EM-38 has been adapted for general mapping in agriculture, an example is the Lower Colorado Region Salinity Assessment Program. This is a network of people and organizations that are committed to improving the assessment of soil salinity in agricultural fields in the Southern Colorado region to guide management decisions (http://www.ussl.ars.usda.gov/lcrsan/LCRhome.htm; verified 7 Oct. 2003). Soil mapping survey units consisting of converted spray rigs, mounted with dual dipole EM-38 units and GPS, have been used to map agricultural fields (Rhoades, 1993; Lesch et al., 1995a, 1995b; Triantafillis et al., 2002). Data has been analyzed using ESAP computer software to produce maps and statistical sampling plans (http://www.ussl.ars.usda.gov/MODELS/esap-95.htm; verified 7 Oct. 2003). As this network of users has developed, large amounts of data have been collected and some anomalous results have been observed.

The term drift has been used to describe disparate values in EM-38 data, collected at different times from the same location, that cannot be accounted for by changes in water content or soil temperature. The causes

D.A. Robinson, I. Lebron, S.M. Lesch, and P. Shouse, USDA-ARS, George E. Brown, Jr. Salinity Lab., 450 W. Big Springs Road, Riverside, CA 92507. Received 26 Feb. 2003. *Corresponding author (darearthscience@yahoo.com).

Published in Soil Sci. Soc. Am. J. 68:339–345 (2004).

677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: CP, control panel; EC_a, bulk soil electrical conductivity; H_i, induced magnetic field; H_p, primary magnetic field; Rx, receiving coil; Tx, transmitting coil.

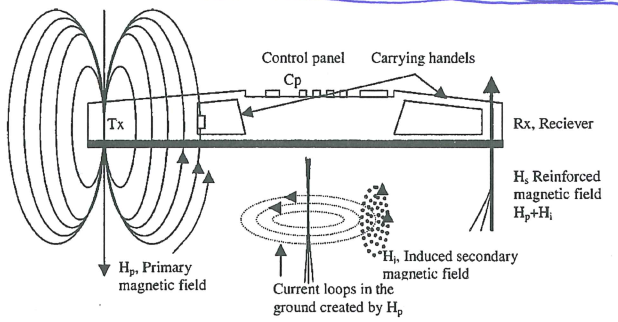

Fig. 2. Schematic diagram of the EM-38, which is 1 m in length. Tx is the transmitting coil and Rx is the receiving coil. Locations CP and Rx are where the temperature sensors were placed.

A standard single dipole EM-38 was used throughout the experiments. A second single dipole EM-38 was used to replicate both the indoor and outdoor experiments. The instruments were calibrated using the described standard method. The probe was placed 1.5 m above the ground on a wooden support; the vertical and horizontal readings were adjusted until the vertical read twice the value of the horizontal. The instruments were calibrated after a warm-up period of 2 h. The calibration was checked for consistency after each experimental run.

During the experiments we measured the temperature of the air, soil, and two parts of the instrument, the CP under which the instrument circuit is located, and at the receiving coil Rx (Fig. 2). Thermocouples, connected to a Campbell CR10x data logger (Campbell Scientific Inc., Logan, UT) were used to record the temperature every minute.

Controlled Experimental Setup Indoors

Indoor experiments were conducted with the EM-38 so that the temperature of the surroundings could be controlled. The first objective was to verify the reliability of EM-38 calibration. The EM-38 was calibrated and placed in a large room where temperature was maintained at 22 ± 1°C. The instrument was placed on a plastic drum, 1 m above the ground and kept in he vertical orientation for all experiments. By doing so the strument response to the ground, primarily the rebar (iron ls) in the concrete could be evaluated. EM-38 measure- ts were taken every minute and recorded on a Polycorder d several meters from the instrument.
second objective was to determine the reliability of the ents temperature compensation. This was performed ng the instrument with an electric blanket. Prelimi- were conducted to ensure that the blanket did not th the response of the EM-38. The response was thout the blanket, with the blanket wrapped ntral 50 cm of the instrument and with the pletely covered. No effect was observed, the were repeated, but this time with the blanket lly, the blanket was switched on and off this had any impact on the EM-38 response, observed.
experiments using the blanket to heat st determined the effect of differential the second determined the effect of ng. In the first of these experiments to the EM-38 circuit (CP, Fig. 2) instrument while maintaining the environment at constant temper- onductivity.
sed to determine the response of the instrument to uniform warming. This time the entire instrument was wrapped in the blanket and heated. In both experiments the temperature of the instrument was raised to a maximum of 55°C. This is a temperature commonly experienced during summer in the Southern USA.

Outdoor Experiments

Outdoor experiments at the U.S. Salinity Laboratory were conducted on bare soil (Arlington, sandy loam) that was irrigated once per day at 0600 h. Measurements were made on a series of warm sunny days in June and July of 2002 when the weather was similar to that commonly experienced during typical fieldwork. The EM-38 response was recorded continuously over a 10-h period beginning at 0900 h using a Polycorder located several meters from the instrument under shade. High temperatures did not affect the performance of the Polycorder. The experiments were run with the EM-38 in the vertical orientation. This allowed measurements of EC_a to be obtained from a depth where soil is least subject to changes in temperature or water content. The EM-38 was positioned on a 2.5-cm thick piece of wood placed on the ground to prevent heating from the soil and to ensure the same daily location. Soil temperature (10-cm depth) was also monitored at the beginning of each experiment. This was performed around mid-day and in the late afternoon, using a handheld temperature probe. The calibration of the instrument was checked periodically and found to be consistent. A final experiment on an asphalt surface was performed by placing the EM-38 in the vertical position on a 2.5-cm thick wood on top of asphalt. During the first 160 min the instrument was shaded, after that time the shade was removed and EC_a and temperatures at CP and Rx were recorded for 600 min.

RESULTS AND DISCUSSION

Controlled Experiments Indoors

Experiments were conducted indoors in a controlled environment to best define EM-38 response to constant temperatures, differential heating, and elevated temperatures. In the first experiment the instrument was switched on and run continuously at a constant air temperature of 22°C. The readings of the EM-38 were constant during a 12-h uninterrupted time period. This simple experiment was necessary to test the stability of the calibration of the EM-38. Since no jumps or sudden changes in EC_a were recorded and the readings remained constant this demonstrated that the cause of the drift was not unstable calibration.

In the next experiment the central section of the EM-38 containing the instrument circuit board was warmed using an electric blanket, while the transmitting and receiving coils were maintained at the ambient room temperature. The temperature of the receiving coil, floor, and air were monitored and remained constant at 22°C. The response, which was replicated by another single dipole EM-38 (data not shown), showed that as the instrument panel and circuitry warmed up, the instrument electrical conductivity response decreased (Fig. 3). This suggested that the instrument temperature compensation was located at, and controlled by, the instrument circuit board under the black CP (Fig. 2). This also suggests that the temperature compensation is provided for the coils and not the circuit. If the circuit were