Using Electromagnetic Induction (EMI) to Measure Soil Water.

George Truman1, Bill Manning1, Brooke Sauer2 and Derek Schneider3.

1. Senior Land Services Officer, North West Local Land Services
2. Precision Ag Development, McGregor Gourlay Agricultural Services
3. Senior Technical Officer, Precision Agriculture Research Group, University of New England

What is Electromagnetic induction Sensing

Electromagnetic induction sensing (EMI or more commonly referred to as simply EM) and other soil conduction devices (e.g. those that use resistivity) can be used to map apparent soil conductivity (ECa).

The most commonly used instruments for plant rooting depth measurement are the Geonics EM38-MK2 and the DUALEM-2 or the Geonics EM31 MK2 for looking deeper into the soil profile. The instruments can be handheld or mounted on a non-conductive sled or sling behind a vehicle and coupled to a GPS to allow mapping of large areas.

Electromagnetic induction measures the apparent electrical conductivity (ECa) of the soil profile. The instrument contains a transmitter and a receiver induction coil at opposite ends of the instrument. The length of the instrument, or the inter-coil spacing, dictates the depth of response in the soil for that instrument. Supplying current to the transmitter coil causes it to generate a magnetic field. This primary magnetic field interacts with the soil and soil solution and secondary 'eddy' currents are generated within the soil. The receiver coil detects the secondary currents generated within the soil. There are many physical and chemical soil attributes that are known to influence ECa including: percent of clay and texture, salinity, moisture content, CEC, mineralogy, porosity, organic matter, soil depth and temperature. However clay, moisture and salinity have the largest influence.

The EM38-MK2 can be likened to a bar magnet and as such the magnetic fields can operate in one of two dipole modes; vertical or horizontal. Physical rotation of the EM38 instrument by 90° changes the propagation of the magnetic field into the soil. Figure 1 shows the depth of soil that is having the most influence on the return signal. Think of it as a sensitivity chart, in vertical mode ~10% of the response is originating from the soil 0.4 m below the surface and the total response is normally distributed down to about 1.5 m. On the other hand the horizontal dipole response is highly skewed towards the surface with ~20% being generated in the top 0.1 m. Because of this horizontal measurements are generally avoided or treated with caution. A better way to measure shallower in the soil is to use an instrument with a shorter coil spacing, i.e. the EM38M-K2, which has coils spaced at both 0.5 m and 1 m.

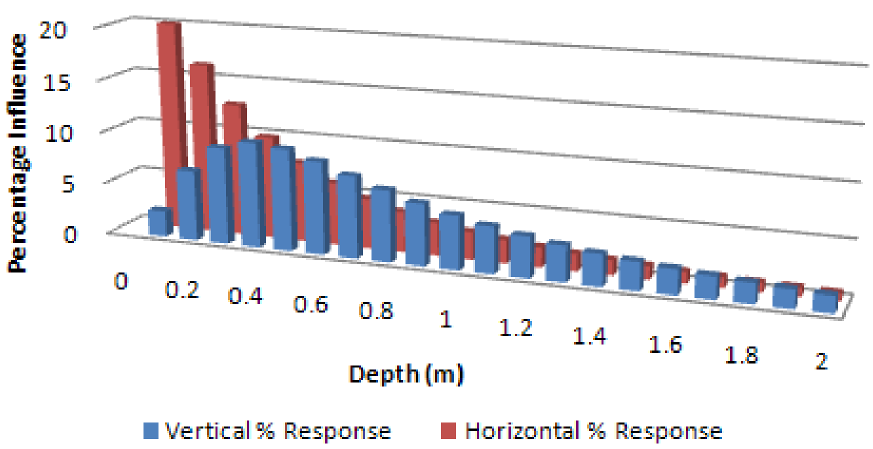

Figure 1: Depth of response or sensitivity graph for an EM38 (EMI sensor with 1m coil spacing)

Applications of EMI sensing

Apparent Electrical conductivity (ECa) has been used extensively to generate conductivity maps. Much work has been done to correlate these apparent conductivity maps to a soil attribute of interest, for example clay content or even individual nutrients with varying levels of success. This is done by undertaking ground truthing by taking cores or soil samples and conducting laboratory analysis. Maps of ECa are often compared to yield maps and in fields that contain areas of high salinity ECa maps can inversely correlate to yield maps, due to the significant yield reductions in saline areas from reduced plant available water capacity.

ECa is significantly influenced by soil moisture. In the absence of a shallow saline water table, out of the three soil attributes that have the largest influence on ECa soil water is the only one that changes significantly over a short period of time. The ability to measure soil water through non-invasive means is appealing from a crop risk management perspective.

However, careful calibration of ECa readings to soil water content needs to be performed. In non-uniform soils it may not be possible to generate a single soil moisture content to ECa calibration. Within highly uniform soils it may be possible to use a single calibration equation. A good calibration will involve measuring soil water by physically taking soil cores (for volumetric moisture content (VMC) measurements) and EM readings over changing soil water status. As we know that the correlation from ECa to soil VMC is linear we can interpolate or extrapolate to identify soil moisture levels for future ECa readings. Some calibrations which have been generated on vertosol soils in southern Queensland are shown in figure 2 below:

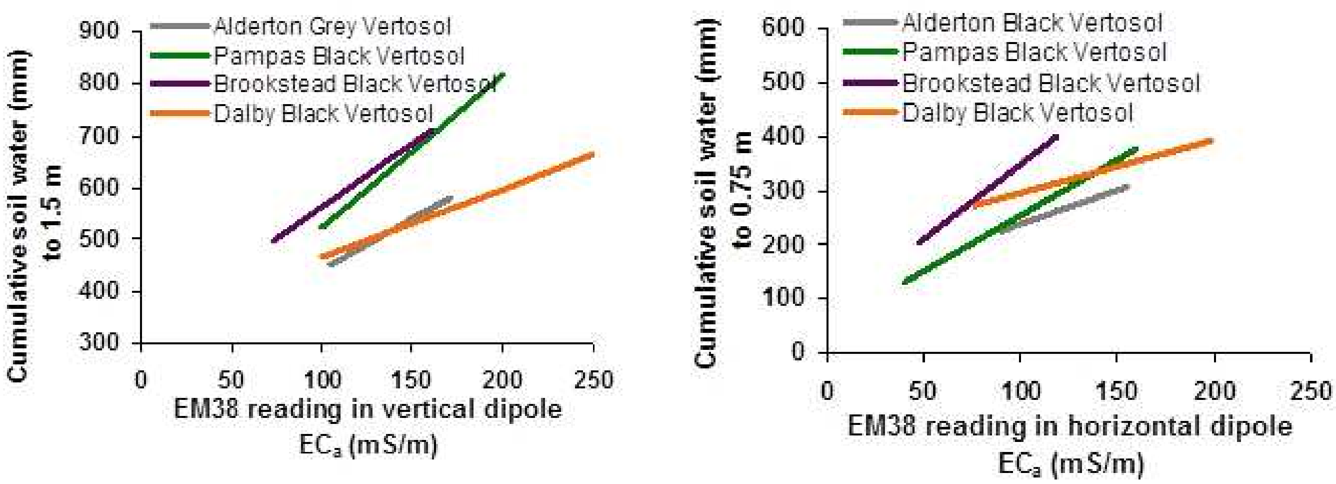

Figure 2: EM38 readings calibrated against soil water for southern QLD Vertosols - showing variation between sites and soil types for both vertical (1.5 m) and horizontal (0.75 m) dipoles (Foley J, 2013)

Using an EM38 to measure soil water

There is conjecture around the ideal methodology for using an EMI device to measure soil moisture. At any site the relationship between ECa and moisture level is linear in the absence of salinity. To accurately quantify the real change in ECa at a single site on two different days we have to be certain that the EMI device is behaving identically during both readings and proper calibration of the EMI device is essential. Changes in the instrument or the way it behaves between sample dates will lead to obvious errors in soil moisture prediction.

A specific methodology for collecting ECa data as a surrogate for soil water status has not been standardized. Research has shown that the greatest correlations between ECa and soil water occur with readings collected in the horizontal mode. However in the horizontal mode >40% of the response is generated in the top 10 cm beneath the instrument making it highly sensitive to small variations in elevation and soil surface water. At present it would be recommended to operate an EM38 in the vertical mode at a height of 10 cm above the soil surface.

Operation of the Geonics EM instruments

Handheld EM instruments are reasonably simple to use. However, refer to the manufacturer's instruction for correct instrument set-up procedures. Note that the instrument should be rested for approximately 15 minutes to warm up and stabilize before data collection.

The EM38 device displays the readings on a small digital screen which can be easily viewed and recorded manually. The EM38 can be connected to various data loggers using a RS232 cable for logging. To perform mapping the data logger will need to have a built-in GPS or be able to connect to, receive from and store a standard GPS feed along with simultaneous ECa measurements. Generally, both the feed from the EM38 and GPS are stored together with an identification number in a text or CSV file.

This is the most user friendly and compatible data format for processing at a later date and avoids issues around data access sometimes encountered when using proprietary devices.

Nulling

It is vital that the instrument is zeroed or nulled, using the procedure described in the operator's manual. This provides consistent readings over time. Wherever appropriate, nulling should be carried out in the same location under the same conditions. This ensures consistency and reduces error between multiple surveys over extended periods of time. Soil moisture will change under your nulling and zeroing site so keep this in mind when you are undertaking surveys over time.

Drift management

There are a number of factors that may cause minor instrument (and data) drift. These include battery voltage variation and temperature variation. Little can be done about temperature drift other than operating below 40°C. Above this point, the internal temperature regulation of an EM38 cuts out and you will receive unrepeatable measurements. Maintain a fresh battery in the device at all times, an EM38RT will do 8 hours with a good quality alkaline battery and poor quality batteries may induce drift earlier.

Servicing

The EM38 is a very robust, stable and precise electrical instrument, regular servicing and maintenance is not generally required. If you have concerns about the stability of the instrument it is recommended that you have the calibration of the instrument checked by a qualified technician.

When mapping on a broad scale some additional considerations include:

- The speed of travel should remain relatively constant.
- The instrument should remain at a relatively constant height.
- The resolution (number of data points per area) of the data can be reduced when travelling too quickly. When sampling at 10 samples per second (sps) a speed of ~25-30 km/hour is appropriate.
- Transect width is the biggest factor determining spatial resolution of ECa mapping. As a rule of thumb, do not exceed 50 m as the inherent variability in the soil may not be accurately identified. A transect width of 25 m is more appropriate for nearly all mapping scenarios.

Metallic Interference

It is important to be aware of the presence of factors that may interfere with the EM instrument. Metal objects strongly influence the EM signal. To eliminate or minimize interference:

- Avoid wearing steel capped boots.
- If mounting the EM38, use a non-conductive material.
- Consider the location of the cable and plugs, as the instrument is highly sensitive to metallic objects within 10cm of either coil. If a cable must be within this distance of a coil, ensure that it is unable to move.
- When towing behind a vehicle, tow the instrument 2-3 m behind the vehicle. Keep this distance constant.
- Avoid traversing near other conductive objects such as power poles, sheds and devices transmitting electromagnetic radiation, such as television transmitters.
- Even at large distances (>500m) electric fences can cause instability in the instrument, particularly an issue when you are nulling and calibrating an instrument.
  The instability caused by electric fences manifests itself as a rapid fluctuation up and down of the signal, usually of three or four mSm-1.

Picture 1: An EM38-MK2 mounted on a sled for survey work.

Local Land Services North West

Further Reading

Beecher H.G, (Ed), (2001). Electromagnetic techniques for agricultural resource management, Conference Proceedings, Australia Society of Soil Science Inc, Yanco Agricultural Institute, Yanco, NSW, July 2001.

Foley J, (2013). A 'how to' for getting soil water from your EM38 field measurements, Goondiwindi GRDC Grains Research Update, Goondiwindi ,QLD.

Foley J. L, Greve A, Huth N, Silburn D. M, (2012). Comparison of soil conductivity measured by ERT and EM38 geophysical methods along irrigated paddock transects on back vertosol soils. Yunusa I. (ed). Proceedings of 16th Agronomy Conference 2012. Armidale, NSW. 14-18 October 2012. Hossain M. B, Lamb D. W, Lockwood P. V, Frazier P, (2010). EM38 for volumetric soil water content estimation in the root-zone of deep vertosol soils. Computers and Electronics in Agriculture 74, 100- 109.

Mills T, (2008). Improved measurement of soil water under irrigated cotton. Summer scholarship, final report, Project number 5.10.03.17, Cotton Catchment Communities CRC.

Nagy V, Milics G, Smuk N, Kovacs A. J, Balla I, Jolankai M, Deakvari J, Szalay K. D, Fenyvesi L, Stekauerova V, Wilhelm Z, Rajkai K, Nemeth T, and Nemenyi M, (2013). Continuous field soil moisture content mapping by means of apparent electrical conductivity (ECa) measurement. Journal of Hydrology and Hydromechanics 61, 305-312.

Stanley J. N, Lamb D. W, Falzon G, Schneider D. A, (2014a). Apparent electrical conductivity (ECa) as a surrogate for neutron probe counts to measure soil moisture content in heavy clay soils (vertosols). Soil Research 52, 373-378.

Truman, G. Application of electromagnetic induction (EMI) in farm planning and management.
Contact the author George.truman@lls.nsw.gov.au

Stanley J. N, Lamb D. W, Irvine S. E, and Schneider, D. A, (2014b). Effect of aluminum neutron probe access tubes on the apparent electrical conductivity recorded by an electromagnetic soil survey sensor. Geoscience and Remote Sensing Letters 11, 333-336.

University of New England Precision Agriculture website https://www.une.edu.au/about-une/academic-schools/school-of-science-andtechnology/research/precision-agriculture/sensors/em38

une University of New England | Precision Agriculture Research Group

Local Land Services North West

Australian Government | National Landcare Programme