Electromagnetic Induction methods for monitoring soil water in irrigated cropping systems.

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Abstract

Effective monitoring of soil water is important in irrigated cropping systems if optimal yield is to be achieved whilst maintaining efficient use of water. Currently, farm managers use technologies such as neutron moisture meters to regularly estimate soil water in the field to assist in irrigation planning. However, these methods require a large time investment for installation, operation and calibration, and involve the logistical costs inherent with the use of a nuclear source. These issues often preclude the monitoring of all management units within an irrigation farm. Electromagnetic induction (EMI) techniques may provide an alternative that is rapid and simple and allows a greater number of measurements to be taken for the same time investment.

Application of EMI was undertaken within three irrigated fields to evaluate its effectiveness for informing irrigation decisions. Temperature correction and calibration was found to be straightforward for clay soils in the irrigation areas on the Darling Downs. EMI was able to accurately quantify the change in total soil water to 90cm throughout the season. Future work will investigate methods for rapid calibration and estimating the vertical distribution of soil water.

Key Words

EM38, Neutron moisture probe, irrigation management.

Introduction

Effective monitoring of soil water is important for informing management decisions in irrigated cropping systems if optimal yield is to be achieved whilst maintaining efficient use of water. Many different measurement approaches have been used depending on the type of soil and cropping system being employed. Currently, farm managers on the Darling Downs have used technologies such as neutron moisture meters (NMM) to regularly estimate soil water in the field to assist in irrigation planning. Whilst these have been employed with some success, limitations in employing them efficiently across both time and space have lead to restrictions in their use. NMM approaches can be labour intensive and so logistical constraints on the number and placement of monitoring sites is always a concern for farm managers. Electromagnetic Induction (EMI) has potential advantages over NMM methods for soil water monitoring including non-use of radioactivity, speed and ease of use, and its non-invasive nature. Use of the EM38 does not require wiring, electronic equipment or access tubes to be installed into the field. For these reasons, an EMI technique has been developed to enable managers to repeatedly monitor a large number of sites over an extended period in cropped fields.

EMI techniques are regularly used to assess soil spatial variability, especially in precision agriculture (Corwin and Plant 2005). They have been used to study variations in soil depth, soil type, salinity and the risk of deep drainage of water. An extensive list of the range of applications for EMI techniques in agricultural systems is included in Corwin and Lesch (2005). EMI provides a measure of the bulk electrical conductivity (EC_a) of the soil profile, and as this is affected by variation in soil moisture, the technique has also been employed to study the variability of soil moisture across fields (Kachanoski *et al.* 1988; Reedy and Scanlon 2003). Huth and Poulton (2007) showed that through careful selection of sites, and consistent reading of the same sites, the impacts of spatial variation of clay, salt and organic matter upon conductivity measures could avoided. Furthermore, they showed that when adjustments are made for the effects of seasonal fluctuations in soil temperatures, the remaining variation in EMI measurements correlated strongly with variation in soil moisture. This provides a rapid method for estimating soil moisture content at a large number of field locations. The following describes how such EMI techniques can be employed for soil water monitoring for informing irrigation management.

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Methods

Theory

The EM38 (Geonics Ltd, Canada) measures the apparent bulk soil electrical conductivity (EC_a) by inducing a small current within the soil via a primary electromagnetic field from a transmitting coil and measuring the resultant secondary field via a receiving coil. The EM38 allows two depth responses through simple changes in the orientation of the instrument (vertical, horizontal). The depth response for the vertical dipole (ϕ_v) is much deeper than for the horizontal dipole (ϕ_h) (Figure 1) which is heavily influenced by surface EC. Cook and Walker (1992) showed that linear combinations of vertical and horizontal readings can be used to create a density function that better matches the portion of the soil profile under study. For example, Huth and Poulton (2007) employed a combination of readings in both dipoles to provide a depth response more appropriate for measuring soil water over the surface 0.9m of the soil profile (ϕ_t). The simple weighting of the two values is as follows:

$$EC_t = \alpha_v \, EC_v + \alpha_h \, EC_h \qquad \text{Eqn 1.}$$

Where EC_t is the weighted total and EC_v and EC_h are the EC_a measurements in the vertical and horizontal dipoles respectively. Values for the weighting coefficients, α_v and α_h, are 0.77 and 0.23 for vertical and horizontal dipoles. The value of EC_t provides a good spatial average of EC_a which Huth and Poulton (2007) showed to correlate with soil moisture measurements on a grey vertosol. However, Huth and Poulton (2007) also showed the importance of correcting EC_a measurements for seasonal variation in soil temperatures. Therefore, equation 1 should be applied using temperature-corrected EC_a values. Correction factors for both dipoles were calculated using the approach of Huth and Poulton (2007) (Figure 2).

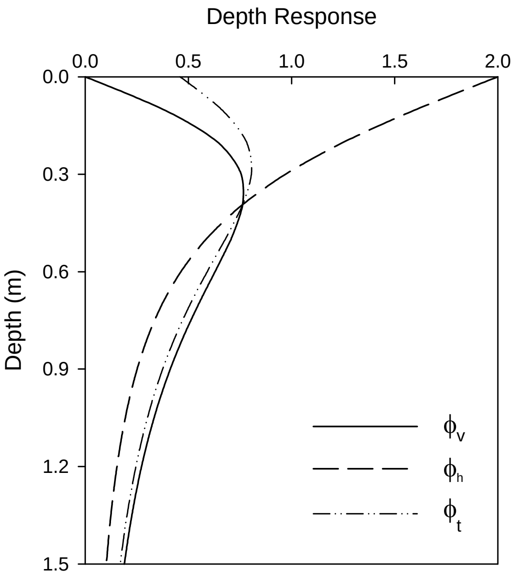

Figure 1. Depth response functions for EM38 used in either the vertical, $\phi_v(z)$, or horizontal dipole, $\phi_h(z)$. The linear combination, $\phi_t(z)$, of these (equation 1, α_v=0.77, α_h=0.23) from Huth and Poulton (2007) is shown for comparison.

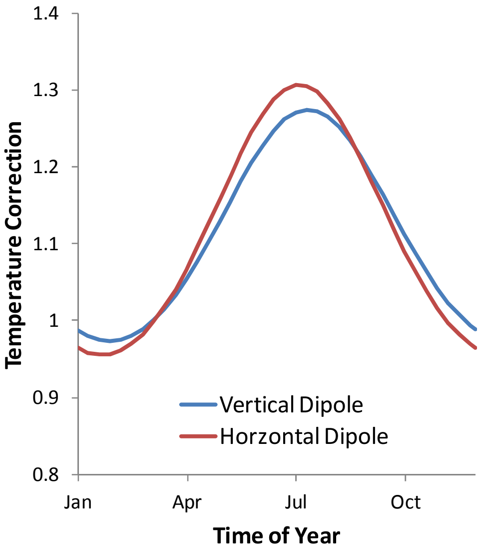

Figure 2. Temperature correction factor for EC_a measurements in the vertical or horizontal dipole used in this study. Calculated using the approach of Huth and Poulton (2007).

The approach to applying the EM38 for soil water monitoring used in this study was

1) Paired readings of EC_v and EC_h were taken on several dates at the same 8 locations surrounding each NMM monitoring tube (4 on the hill/row, 4 in the furrow) in each of the three case study fields. Consistent monitoring of the same sites minimises the impact of spatial variation in soil salts, clay and organic matter which can affect EC_a readings.
2) Each EC_v and EC_h reading was corrected for seasonal temperature variations using the approach of Huth and Poulton (2007). Individual corrections for vertical and horizontal dipole measurements were applied based upon the day of the year. (See Table 1 in Huth and Poulton (2007) for example values).
3) EC_t was calculated from the temperature corrected values of EC_v and EC_h using equation 1.

4) EC_t was regressed against measurements of total soil water using NMM to provide a field-specific calibration for the EMI soil water monitoring technique.

Field Study

A field study was undertaken to evaluate the effectiveness of the EM38 for soil water monitoring for irrigation management in cotton. Three sites near Brookstead on the Darling Downs were chosen to provide a range of clay soils (Table 1). At each site, a single irrigated cotton field undergoing regular monitoring using two NMM access tubes was chosen and regular measurements were made with the EM38 as described above on dates for which NMM readings were also being taken. For these sites, a single generic NMM calibration equation has been used for estimating soil water for irrigation management. This approach reflects the pragmatic approach managers must use when monitoring a large number of fields with variable soil properties. The influence of this on the results of this study is likely to be low because the linear calibrations often required for both NMM and EMI would result in consistent trends between the two instruments. Any error in calibration would affect the absolute values of the NMM soil water estimates, but not the amount of correlation between the NMM and EMI values. Regression of EMI against the NMM estimates of soil water was therefore used to create an EMI calibration for each site. The goodness of fit of this regression indicates the ability of the EMI approach, once calibrated, to provide similar estimates of soil water for irrigation management.

Table 1. Description of case study soils taken from APSoil soil plant available water capacity (PAWC) database (Dalgliesh and Foale 1998) including soil type, local name, APSoil database reference number and estimated total plant available water capacity (PAWC) to 1.8m depth.

Field	Soil Type	Local Name	APSoil Number	Cotton PAWC to 1.8m (mm)
BD10	Black Vertosol	Mywybilla	1	290
24	Black Vertosol	Anchorfield	6	273
2A	Grey Vertosol	Cecilvale	4	293

Results

Correlation between NMM estimates of total soil water to 90cm and EC_t were high (Figure 3). At all sites, the EM38 was able to explain over 90% of the temporal variation in soil water using NMM with over 97% of the variation captured at site 24. Linear regressions differed between sites reflecting the site differences in clay, organic matter and salts. There was some discrepancy between approaches for the driest soil conditions at site BD10 but the source of the variation is unclear and could lie with either method. Estimated time courses in total soil water were very similar as a result of the high level of correlation between measures (Figure 4). At each site, the response in soil water to rainfall or irrigation was captured closely.

Discussion

Whilst the results are sufficient to demonstrate the capacity of the EM38 to provide a similar level of accuracy to that provided by NMM, the same data has been used in calibration and evaluation. Comparison of estimates using an independent calibration is required and such data is currently being collated for this purpose. However, strong correlation between NMM and EMI measurements suggests that rapid monitoring using EM38 could potentially be used in place of NMM once a suitable calibration is obtained.

Conclusions

These case studies have shown that the EM38, when used correctly, can provide estimates of total stored soil moisture that are close to those generated using the NMM techniques commonly used by irrigation managers on clay soils. Measurement with the EM38 is faster, thus allowing for more measurements to be made. The EM38 also has an advantage in that it does not use a nuclear radiation source. NMM currently has an advantage in that it provides information on the vertical distribution of soil water. Work is currently underway to evaluate the use of the EM38 MkII which provides for shallower readings through the provision of a second coil spacing. Finally, research is also being undertaken into rapid methods for calibrating the EM38 for soil water estimates through the use of in-field calibration measurements and existing soils databases.

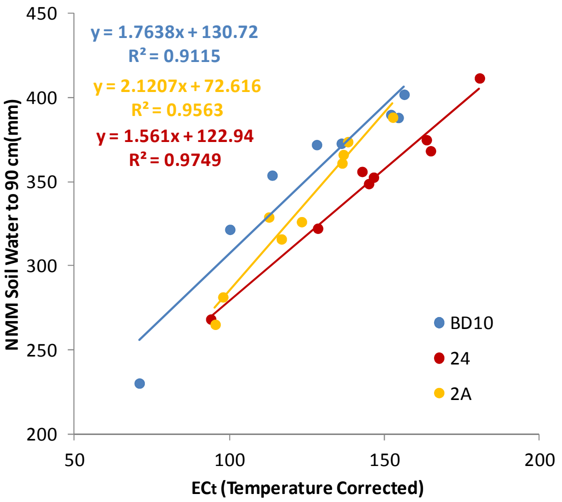

Figure 3. Comparison of NMM estimated total soil water to 90cm depth against temperature corrected bulk soil apparent conductivity measured with an EM38 and calculated using Equation 1.

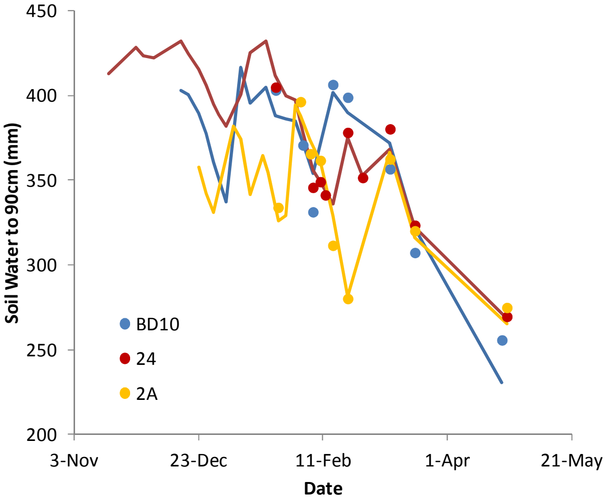

Figure 4. Time course of estimated total soil water to 90cm depth using NMM (lines) and EMI (symbols).

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