MONITORING WATER AND SALT MOVEMENT DURING A LEACHING IRRIGATION USING TIME DOMAIN REFLECTOMETRY

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ABSTRACT

Time domain reflectometry (TDR) has become an accepted method of measuring soil water content. Laboratory results have indicated that it may also be possible to measure soil electrical conductivity (EC) using TDR. The objectives of this experiment were to investigate the utility of TDR as a field measurement of EC and to illustrate a potential application of the technique. Field research was conducted at the Saskatchewan Irrigation Development Centre on a field which has been reclaimed from salinity over the past 10 years by the installation of tile drains and a fall leaching program. To test the accuracy of bulk soil EC measurements made by TDR (EC_T), EC was also measured on water samples from suction lysimeters which sampled at the same depths as the TDR waveguides and converted to a bulk soil basis (EC_S). Comparisons between EC_T and EC_S were made three times during the 1992 growing season (when the soil was relatively dry) and four times during the fall leaching period (when the soil was much wetter). EC_T was significantly correlated ($p<0.001$) to EC_S. However the measurement of EC_T was affected by soil moisture content and an empirical function had to be used to eliminate this source of variability. Good agreement ($R^2=0.93$) was obtained between EC_T and EC_S when this function was applied. During the leaching irrigation, water and salt movement was monitored by TDR. At most sites, a salt bulge could be clearly identified moving downward through the profile as the volume of water applied increased. With further investigation into the relationship between EC_T and water content, the rapid simultaneous measurement of water content and electrical conductivity made possible by TDR should prove useful in studies of salt movement.

INTRODUCTION

A method of making rapid simultaneous measurements of electrical conductivity (EC) and volumetric water content (Θ) in soil would have a wide range of applications in agricultural and environmental research. Time domain reflectometry (TDR) has become a well accepted method of measuring Θ (Topp et al. 1980; Heimovaara and Bouten, 1990). The method is rapid, suitable for remote data-logging and does not need to be calibrated for soil type. Laboratory investigations have shown that TDR can also be used to measure EC at a fixed water content. A number of researchers have derived equations which calculate EC from the attenuation of the of the TDR pulse in the waveguide and the reflection from the end of the waveguides (Dalton et al. 1984; Nadler et al. 1991; Topp et al. 1988). Field measurements of EC over a range of soil moisture contents may be more difficult because possible interactions between moisture and EC may affect TDR measurement. The objectives of this study were to investigate TDR as a measurement of EC in field conditions and to illustrate a potential application of TDR to monitor water and salt movement during a leaching irrigation.

THEORY

TDR operates by sending microwave pulses along coaxial cable to a waveguide which is installed in the medium to be tested. A waveguide consists of two or three parallel stainless steel rods which serve as transmission lines. In this study three rod waveguides were used to eliminate the need for an impedence balancing transformer in the line between the TDR unit and the waveguide (Zegelin et al., 1989). The speed at which the microwave pulse travels down the transmission lines depends on the dielectric constant of the material in contact with, and surrounding the waveguide. This gives a measurement of volumetric water content (Θ) since there is a unique relationship between the dielectric constant and Θ for most mineral soils (Topp et al. 1980; Soilmoisture 1990). The reduction of the microwave pulse as it passes along the waveguide (attenuation) is dependant on the electrical conductivity, dielectric constant and magnetic properties of the medium. In a non-magnetic medium, the attenuation of the pulse can therefore be used as a measure of EC.

A typical TDR trace is shown in Figure 1. The transit time (t) is the time the signal takes to pass along the waveguide. The start of the waveguide is marked by the sharp dip caused by a discontinuity purposely set in the transmission line at the start of the waveguide. In uniform soils the end of the waveguides can be identified as the point where the signal begins to rise again as it is reflected back. The transit time (in units of ns) is directly related to the dielectric constant (Ka):

$$Ka = \left(\frac{tc}{L}\right)^2$$

where c is the speed of light (cm ns^{-1}) and L is the waveguide length (cm).

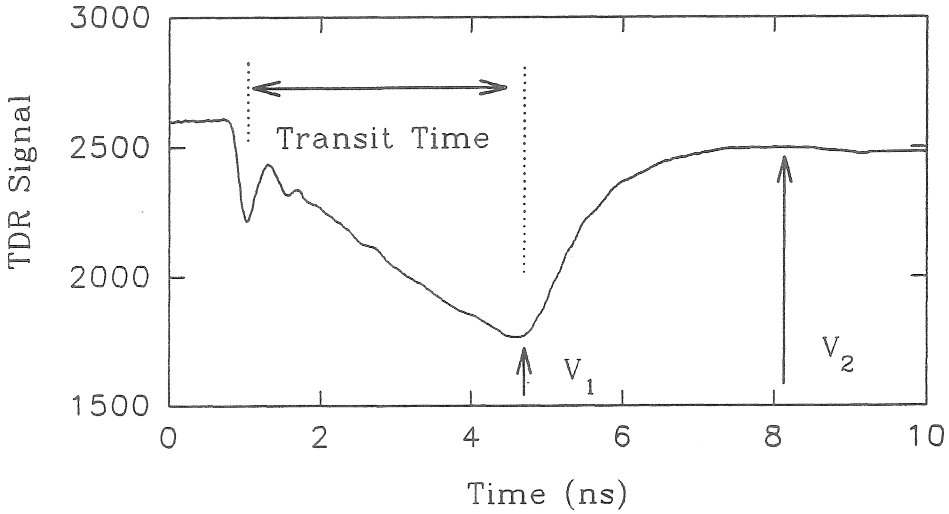

Figure 1. A typical TDR trace showing the transit time and the relative amplitudes used in the calculation of EC.

The volumetric water content can be calulated from Ka using the empirical relationship suggested by Topp et al. (1980):

$$Ka=3.03+9.3\theta+146\theta^{2}-76.7\theta^{3}$$

which is essentially independant of soil type, temperature, density and salinity and has been sucessfully applied by a number of researchers.

A number of different calculation procedures have been used to obtain bulk soil EC measurements from the attenuation of the TDR signal (Nadler et al. 1991). The simplest method was that proposed by Dalton et al. (1984) and since preliminary work indicated that all methods were equally effective, Dalton's method was used in this study:

$$EC_{T}=\frac{\sqrt{K_{a}}}{120\pi L}\ln\frac{V_{1}}{V_{2}-V_{1}}$$

where V_1 and V_2 are the signals at the start and end of the waveguides, respectively, as shown in Figure 1.

MATERIALS AND METHODS

The study was conducted at the Saskatchewan Irrigation Development Centre, near Outlook, Saskatchewan, in a field irrigated by linear sprinkler and tile drained at a depth of 2 m. The soil was mapped as a Bradwell loam with salinity ranging from moderate to non-saline by Strushnoff and Acton (1987). Over the last 10 years the field has been reclaimed from salinity using leaching irrigations. The 1992 fall leaching commenced on September 26 and continued to October 7. A total of 222 mm of irrigation water were applied in 6 passes ranging from 27 to 45 mm per pass. EC and moisture content were measured by TDR every second day between September 25 and October 14 and again on October 22.

TDR waveguides were paired with suction lysimeters which sampled at 30, 60, 90, 150 and 180 cm at four locations in the field. Measurements of EC made by TDR were compared to electrical conductivities measured on water samples taken from the lysimeters on 6 occasions during the summer and fall of 1992. In the summer soil conditions were comparitively dry and in the fall as leaching progressed the soils became increasingly wet. The TDR unit used in the study was a Trase Model 6050X1 (Soilmoisture Equipment Inc, Santa Barbara, California) which gives a digital readout of θ and has an option to store the graph of the TDR reading (eg Figure 1). Graphs were stored for each TDR reading made in this study.

The EC values measured on the water samples from the suction lysimeters were pore water EC values which were converted to a bulk soil basis using the method of Rhoades et al. (1976). This method takes into account the water content of the soil, the electrical conductivity of the solid phase and a function called soil water transmission coefficient which is water content dependant.

RESULTS AND DISCUSSION

The EC predicted using Dalton's method (EC_T) is plotted against EC_S in Figure 2. The two measurements of EC are significantly correlated ($p<0.001$) and the points follow the trend of the equivalence line but there is considerable scatter. Since the scatter of the points was thought to be due to interaction between EC and moisture content in the attenuation of the TDR signal, the TDR measured EC was corrected for moisture content using multiple regression analysis. The corrected EC_T is plotted against EC_S in Figure 3. The moisture content correction greatly improved the fit of the data points to the equivalence line. The correlation coefficient for the relationship between EC_T and EC_S was 0.93 (using log-transformed data). This relationship was considered strong enough to use TDR to monitor EC and Θ at the SIDC site where the calibration was obtained.

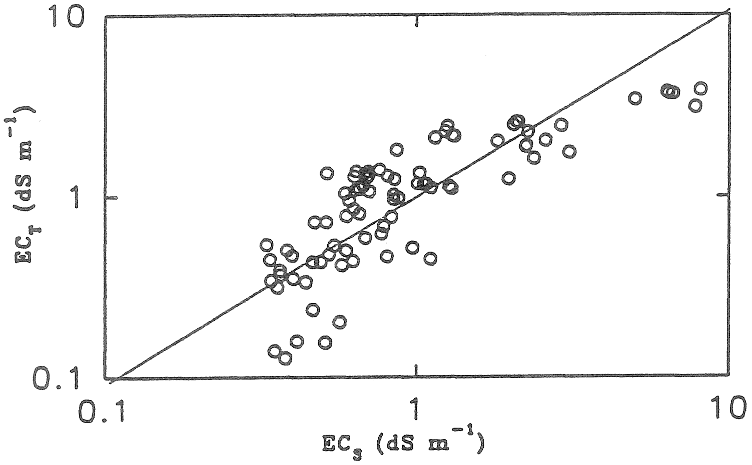

Figure 2. Relationship between EC measured by TDR and calculated by Dalton's method (EC_T) and EC_S.

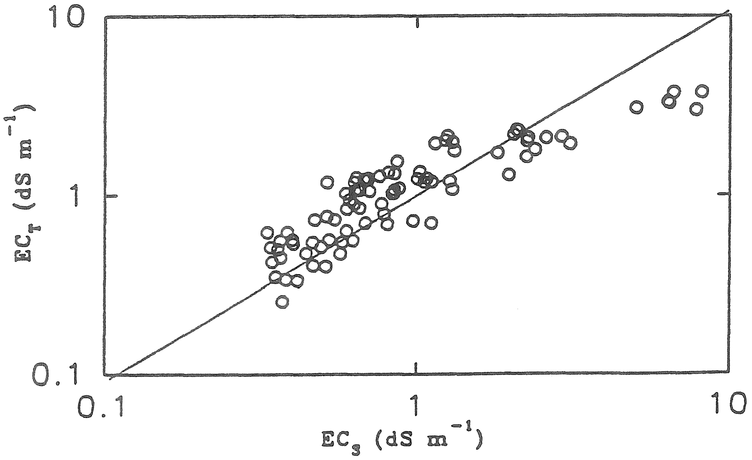

Figure 3. Relationship between EC measured by TDR after the moisture content correction has been applied and EC_S.

Typical Θ and EC profiles obtained during the leaching period are shown in Figure 4. September 25 was just before leaching began, 85 mm had been applied by September 30, 185 mm had been applied by October 7 and October 22 was two weeks after the end of the irrigation (222 mm).

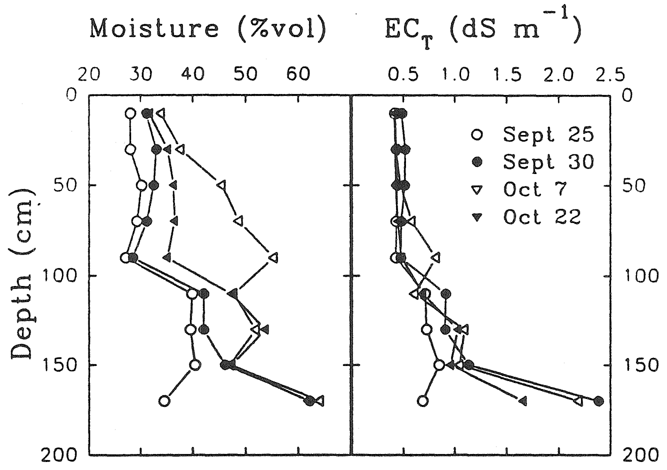

Figure 4. Moisture content and corrected EC measured by TDR with depth during the fall leaching irrigation.

Moisture content shows an increase from September 25 to September 30 throughout the profile and by October 7 a large water bulge had developed just above 100 cm depth. Moisture contents had decreased to around field capacity by October 22 at all but the deepest sampling point. Changes in EC were more subtle than those in water content but there was some evidence of salts being washed down the profile and, on October 7, EC values around 100-cm depth indicated that a salt bulge had developed. By October 22, EC had dropped to pre-leaching levels in the root zone (0-120 cm).

CONCLUSIONS

TDR was sucessfully used to estimate bulk soil electrical conductivity in field conditions and measurements provided useful data on changes in water content and electrical conductivity during fall leaching. There were some limitations to the utility of the method. Firstly, with present technology, TDR cannot be used to measure electrical conductivities greater than 6 dS m^{-1} because attenuation of the signal is so great that the reflected signal cannot be measured. Moisture content measurements are also difficult to obtain under these conditions. The second limitation is that electrical conductivity measured by TDR has to be calibrated for moisture content and it is not known if the same calibration will be applicable for all soils. Further research into the interaction between the water content of soil and electrical conductivity in the attenuation of the TDR signal in the waveguides is required.

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