The Society for engineering in agricultural, food, and biological systems

Paper Number:042128
An ASAE Meeting Presentation

Using Time Domain Reflectometry for Evaluating Near-Surface Soil-Crop Dynamics of an Animal Waste Amended Soil

Bryan L. Woodbury, Agricultural Engineer

USDA-ARS U.S. Meat Animal Research Center, P.O. Box 166, Clay Center, Nebraska, woodbury@email.marc.usda.gov

John A. Nienaber, Agricultural Engineer

USDA-ARS U.S. Meat Animal Research Center, P.O. Box 166, Clay Center, Nebraska, nienber@email.marc.usda.gov

Roger A. Eigenberg, Agricultural Engineer

USDA-ARS U.S. Meat Anial Research Center, P.O. Box 166, Clay Center, Nebraska eigenberg@email.marc.usda.gov

Written for presentation at the
2004 ASAE/CSAE Annual International Meeting
Sponsored by ASAE and CSAE
Ottawa, Ontario Canada
August 1-4, 2004

Abstract. *Electromagnetic induction (EMI) mapping techniques have been demonstrated to be useful in monitoring seasonal soil-crop dynamics. These dynamics can be affected by many confounding seasonal changes in the soil profile. Time domain reflectometry (TDR) has been used to measure localized bulk soil electrical conductivity of soil horizons. The objective of this study was to use time domain reflectometry for clarifying near-surface soil-crop dynamics of an animal waste amended soil. Seasonal soil-crop EC dynamics measured by EMI and TDR were significantly ($p < 0.05$) correlated for all treatments except commercial fertilizer without a cover crop (NCK-No-Cover) treatment. NCK-No-Cover response difference is believed to be due to placement of commercial fertilizer directly above the TDR probe. The impact of fertilizer was greater on the TDR system than EMI, primarily due to surface area and volume measurement differences used by the two methods. Significant correlations of the two systems indicate the majority of EC dynamics measured by EMI were dominated by activity in the upper 0.15 cm of soil surface. As a result, the TDR study validates EMI as a tool for evaluating soil-crop dynamics of animal wasted amended soils.*

Keywords. Electromagnetic induction, Time domain reflectometry, Soil crop dynamics, Animal waste

Introduction

The key to applying animal waste as a soil amendment without polluting the surrounding environment is to apply only the amount that can be utilized by the crop. This may be simple in concept, but is very difficult to put into practice. The inability to accurately estimate the amount of nutrients mineralized during the growing season, evenly applying the waste across the field, and inherit soil spatial variability complicates precise management. Research is under way to develop predictive relationships that quantify key soil factors affecting mineralization of nutrients in manure (Griffin et al., 2002a, Griffin et al., 2002b). However, these studies cannot evaluate short-term, soil-crop dynamics or sample large areas to assess the impact of inherent soil variability. Eigenberg et al., (2003) found in a three years study that changing patterns of nitrogen helped explain the observed dynamics in EC_{EMI}.

Techniques have been developed that use electromagnetic induction (EMI), geostatistics, and survey map differencing to evaluate soil-crop electrical conductivity (EC_{EMI}) dynamics of an 800 m X 800 m corn silage plot (Eigenberg et al., 2003; Eigenberg et al., 2002). These techniques have provided additional insight into seasonal soil-crop dynamics. However, this technique is limited by the inability of EMI to detail soil dynamics near the surface. Time domain reflectometry (TDR) has the ability to monitor near-surface soil-crop bulk electrical conductivity (EC_{TDR}) dynamics.

Time domain reflectometry has been established as a means for independent determination of volumetric water content (θv) and and EC_{TDR} (Dalton, F.N., 1992; Dalton et al., 1984). More recently, TDR has been adapted to indirectly measure soil solution EC, and researchers have attempted to develop predictive equations for estimating soil nitrate levels (Das et al., 1999; Nissen, et al., 1998).

The overall objective of this study was to use TDR to clarify changes in EC_{EMI} of a manure amended soil as measured by EMI. This information, in conjunction with other data, will be used to develop management practices that better utilize nutrients in manure without causing negative environmental impact.

MATERIAL AND METHODS

A field plot growing corn silage has received nine years of controlled organic and inorganic amendment treatments. The treatments include commercial fertilizer (NCK), manure (MN), and compost (CN) to meet the nitrogen requirement, and manure (MP) and compost (CP) to meet the required phosphorus. Each of these sub-treatments has a fall cover crop or no-cover treatment. This results in ten separate treatments, which are arranged in a randomized block design with four replications (figure 1).

TDR volumetric water content (θ_v) was determined using the Topp equation (Topp et al., 1980). EC_{TDR} was determined using the Giese and Tiemann theory for electromagnetic waves (1975). Probe rod length was determined experimentally by incrementally shortening and inserting probes into soil exhibiting the worst expected attenuating conditions until sufficient signal was reflected for consistent calculation of θ_v and EC_{TDR}. Cell constants for each probe configuration were determined using linear regression of known solution EC, with respect to TDR measured values.

Field plot EC_{TDR} and EC_{EMI} data were collected using both TDR and EMI, respectively, from approximately the middle of May until the first of November, 2002. TDR data were collected every 15 minutes with an average output every hour. TDR data were adjusted for temperature using a predetermined laboratory calibration for the probes. EC_{EMI} data were temperature compensated using an expression reported by McKenzie et al. (1989). EC_{EMI} values were determined on a weekly basis using a technique developed by Eigenberg et al. (2002). A block of geostatistically determined EC_{EMI} values surrounding the TDR probes were averaged to limit plot spatial variability. Care was taken to eliminate the EC_{EMI} that were affected by the buried TDR probes.

Probes were constructed with a three-rod design using 3.2 mm diameter stainless steel rods. A 30 mm spacing was used between rods, with the length of exposed rods being 12.5 cm. The TDR probes were inserted vertically in treatments 303, 304, 305, 306, 307, and 308 of a silage field plot (figure 1). Probes were placed in the field following seeding in the spring of 2002, with a horizontal orientation between corn rows (figure 2). Horizontal probes were placed at a depth of approximately 15 cm. Type T thermocouple wires were installed at a depth of 15 cm to record soil temperatures.

A Campbell Scientific TDR 100 pulse generator was used to generate a step pulse signal. Signal was transmitted to two levels of 8:1 multiplexers and then to coaxial cable. Cable runs greater than 15 m were transmitted using low impedance RG-8 cable, and connected to multiplexer level 1. Cable runs less than 15 m were transmitted using RG-58 cable, and connected to multiplexer level 2. All equipment, cables, and connectors were 50 ohm impedance.

Field plot beef cattle manure or compost were applied early in the spring using a field spreader. The winter cover crop was destroyed by herbicides, then plots were tilled with a double off-set tandem disk following application of treatments. Plots were planted on April 25 (Table 1). The NCK treatment had post-emergence anhydrous ammonia injected between the rows following crop emergence on June 15). Since the TDR probes and wires were installed and buried, the anhydrous ammonia injection equipment by-passed the area where the probes were located. To compensate, a 32% solution of urea ammonium nitrate (UAN) was applied in a narrow band between the rows at a rate equivalent to the anhydrous ammonia application on June 17 (Table 1). A more detailed listing of specific agronomic events for 2002 is included in Table 1.

Table 1. Calendar dates of specific agronomic events for 2002. Note the numbers in parentheses are Julian days for year 2002.

Year	Manure Compost Applied	Cover Crop Killed	Field Planted	*Anhydrous Ammonia Applied	Corn 30 cm Tall	Silk	Harvest	Cover Planted
	April 11 (101)	April 15 (105)	April 25 (115)	June 15 (166)	June 19 (170)	July 22 (203)	Aug. 30 (242)	Sept. 18 (261)

* Note that anhydrous ammonia was applied to NCK treatment only.

RESULTS

Correlation coefficients between EC_{TDR} and EC_{EMI} for EMI survey dates for each treatment are included in Table 2. Significant ($p<0.05$) positive correlations were measured for all treatment combinations except NCK-No-Cover treatment. The strongest positive correlations were for CN-Cover (0.831) and MN-Cover (0.829) (Table 2). Each of these treatments had p-values less than 0.0001. It is interesting to note that no-cover EC values as measured by TDR and EMI were greater than cover treatments throughout most of the growing season (figures 3 and 4).

The fall planted cover crop utilized nutrients that were mineralized after harvest. In the spring, this cover crop was incorporated prior to planting. Microorganisms removed nutrients from the soil solution to mineralize this incorporated cover crop, thereby lowering the solution EC.

There was a significant ($p<0.05$) positive correlation between EC_{TDR} and EC_{EMI} values for the NCK-Cover Crop treatment (Table 2). However, there was a negative correlation between the EC_{TDR} and EC_{EMI} values for the NCK-No-Cover Crop treatment (Table 2). Both EC_{TDR} and EC_{EMI} values for the NCK-Cover and No-Cover Crop treatments followed similar trends until the addition of nitrogen fertilizer. The effect of fertilizer addition was much more prominent for the No-Cover treatment than the Cover treatment. Following fertilizer addition, EC_{TDR} increased while EC_{EMI} continued to decrease (figure 5). This elevated EC_{TDR} continued for the remainder of the sampling period.

There was a similar increase in EC_{TDR} for the Cover treatment following fertilizer addition (figure 5). This elevated EC_{TDR} continued until after the cover crop emerged and began utilizing residual nitrogen in the fall. The effect of fertilizer addition on EC_{TDR} was probably the result of fertilizer addition proximate to the probe, and volume of soil measured. Fertilizer addition was a narrow band of a 32% UAN solution that was applied between corn rows directly above TDR probes. This addition had a measurable impact since surface area and volume of soil measured by TDR to calculate an EC_{TDR} value was relatively small compared to EC_{EMI}. On the other hand, the larger surface area used to calculate an EC_{EMI} value diluted effect of the narrow concentrated band. Though we have no soil test data to verify, persistence of elevated EC_{TDR} values could be a result of drought conditions and lower than expected yield. This low yield utilized less nitrogen than expected.

Table 2. Correlation coefficients of EC data as measured by TDR and EMI for CN, MN, and NCK treatments.

	Cover	No-Cover
CN	**0.831**	**0.714**
p-value	<0.0001	0.0013
MN	**0.829**	**0.536**
p-value	<0.0001	0.0264
NCK	**0.782**	**-0.482**
p-value	0.0350	0.0726

CONCLUSIONS

Seasonal soil-crop EC dynamics measured by EMI and TDR were significantly ($p <0.05$) correlated for all treatments except the NCK-No-Cover treatment. This indicates the majority of EC dynamics measured by EMI were dominated by activity in the upper 0.15 cm of soil surface. As a result, it can be concluded that EMI has great potential as a tool for evaluating soil-crop dynamics of manure amended soils.

The correlations were larger for the cover treatments than for the no-cover treatments. This was particularly dramatic for the NCK treatments. The incorporated cover crop mineralized during the growing season, and acted similar to the broadcast animal waste. Also, the NCK-No-Cover treatment had all applied fertilizer in a concentrated narrow band between rows directly above TDR probe placement. The larger surface area measured by EMI diluted influence of this concentrated band, while values measured by TDR were greatly influenced. As a result, correlations between EC values determined by TDR and EMI for the NCK-No-Cover treatment were negative.

REFERENCES

Dalton, F.N., W.N. Herkelrath, D.S. Rawlins, and J.D. Rhoades. 1984. Time domain reflectometry: Simultaneous measurement of soil water content and electrical conductivity with a single probe. Science 224:989-990.

Dalton, F.N. 1992. Development of TDR for measuring soil water content and bulk EC. ASA Monograph In: Advances in measurement of soil physical properties: Bringing theory into practice. SSSA Special Pub. No. 30:143-167.

Das, B.S., J.M. Wraith, and W.P. Inskeep. 1999. Nitrate concentration in the root zone estimated using time domain reflectometry. Soil Sci. Soc. Am. J. 63:1561-1570.

Eigenberg, R.A., J.A. Nienaber, B.L. Woodbury, and R.B. Ferguson. 2003. Crop and soil status as indicated by electrical conductivity surveys of a field with cover crop and manure amendments. ASAE Paper #032338. St. Joseph, MI.

Eigenberg, R.A., J.W. Doran, J.A. Nienaber, R.B. Ferguson, and B.L. Woodbury. 2002. Electrical conductivity monitoring of soil condition and available N with animal manure and a cover crop. Agriculture, Ecosystems and Environment 88:183-193.

Giese, K., and R. Tiemann. 1975. Determination of the complex permittivity from thin-sample time domain reflectometry, Improved analysis of the step response waveform. Adv. Molec. Relax. Processes 7:45049.

Griffin, T.S., C.W. Honeycutt, and Z. He. 2002a. Effects of temperature, soil water status, and soil type on swine slurry nitrogen transformations. Biology and Fertility of Soils 36:442-446.

Griffin, T.S., S.L. Albrecht, J.M. Powell, R.A. Eigenberg, R.K. Hubbard, S.L. McGowen, B.L. Woodbury, and H.A. Torbert III. 2002b. Nitrogen mineralization from animal manure: USDA-ARS nationally coordinated research. Second Int'l. N Conference, Potomac, MD.

McKenzie, R.C., Chomistek, W., and Clark, N.F. 1989. Coversion of electromagnetic induction reading to saturated paste extract values in soils for different temperature, texture and moisture conditions. Can. J. Soil Sci. 69:25-32.

Nissen, H.H., P. Moldrup, and K. Henriksen. 1998. Time domain reflectometry measurements of nitrate transport in manure-amended soil. Soil Sci. Soc. Am. J. 62:99-109.

Topp, G.C., J.L. Davis, and A.P Annan. 1980. Electromagnetic determination of soil water content: measurement in coaxial transmission lines. Water Resour. Res. 16:574-582.

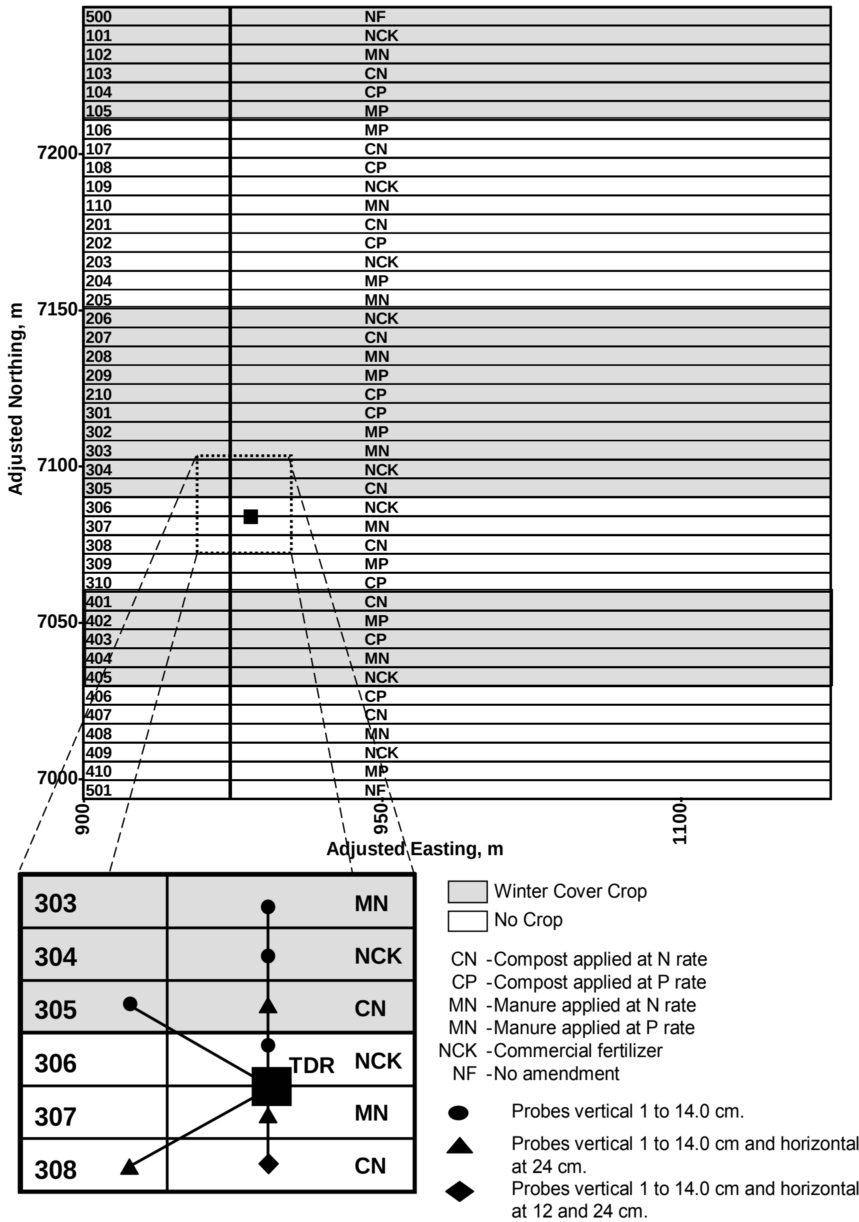

Figure 1. Diagram of the research silage field plot with treatments. Note the placement of the TDR probes. Note the shaded area perpendicular to the treatment rows is a no-crop treatment.

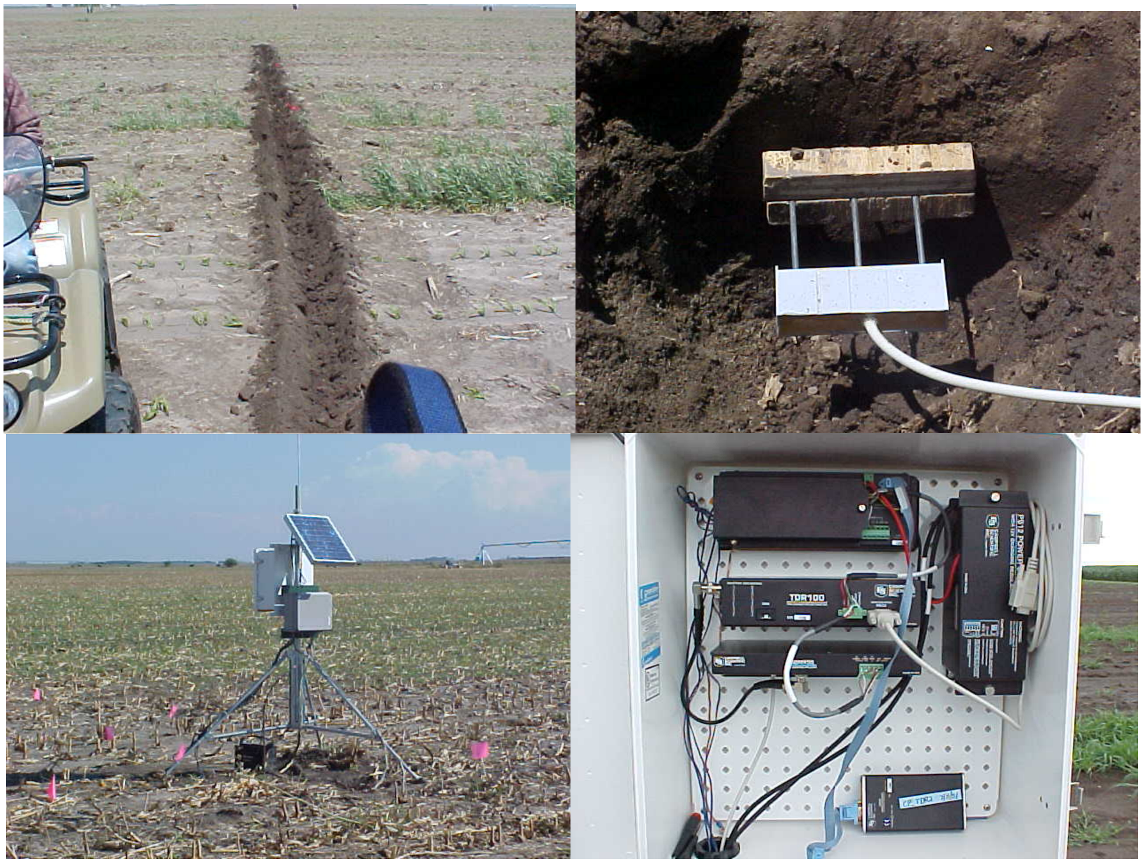

Figure 2. TDR probe field installation. Trench was cut perpendicular to the treatment rows. Cables were buried along the trench with TDR probes being inserted in the middle of each treatment at specified depth.

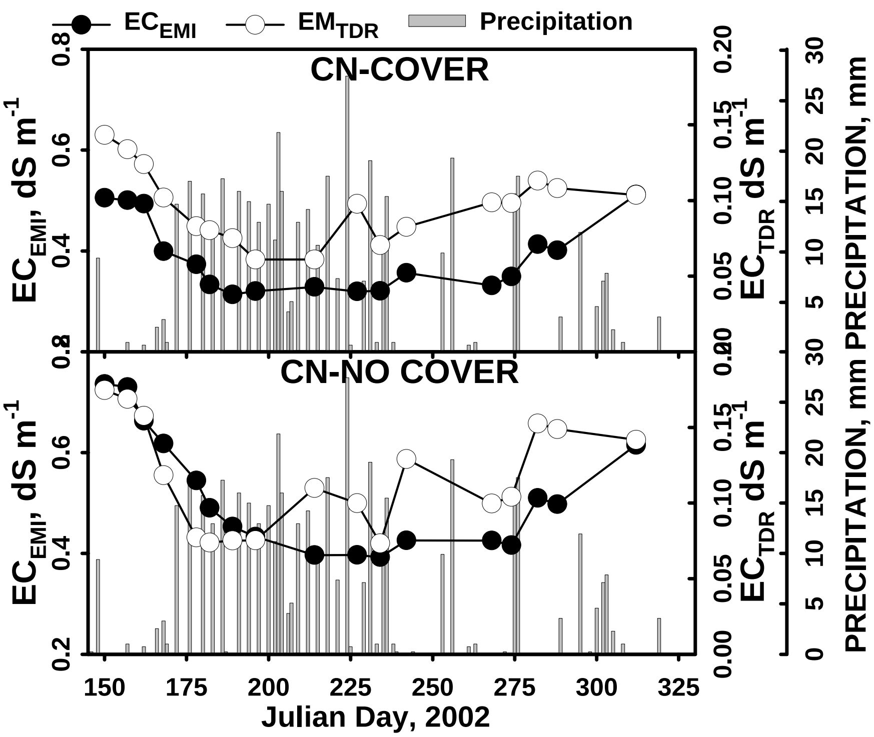

Figure 3. Apparent soil electrical conductivity (EC_{EMI}), bulk soil electrical conductivity (EC_{TDR}) and precipitation for compost at the nitrogen rate (CN), with cover-crop and no-cover- crop treatment for the 2002 growing season. EC_{TDR} values are shown only for EMI survey dates.

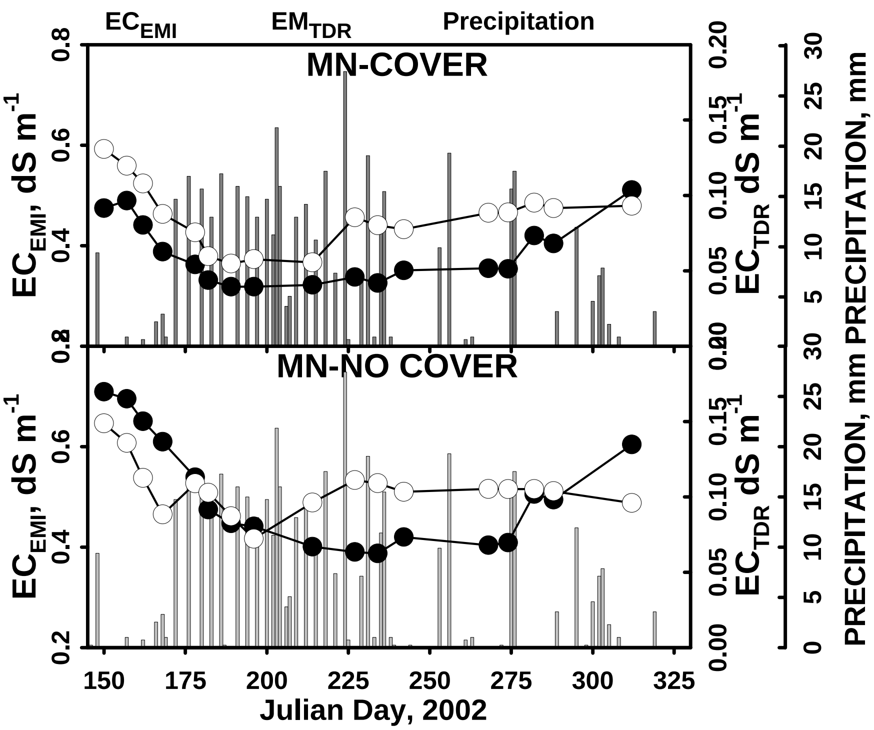

Figure 4. Apparent soil electrical conductivity (EC_{EMI}), bulk soil electrical conductivity (EC_{TDR}) and precipitation for manure at the nitrogen rate (MN), with cover crop and no cover crop treatment for the 2002 growing season. EC_{TDR} values are shown only for EMI survey dates.

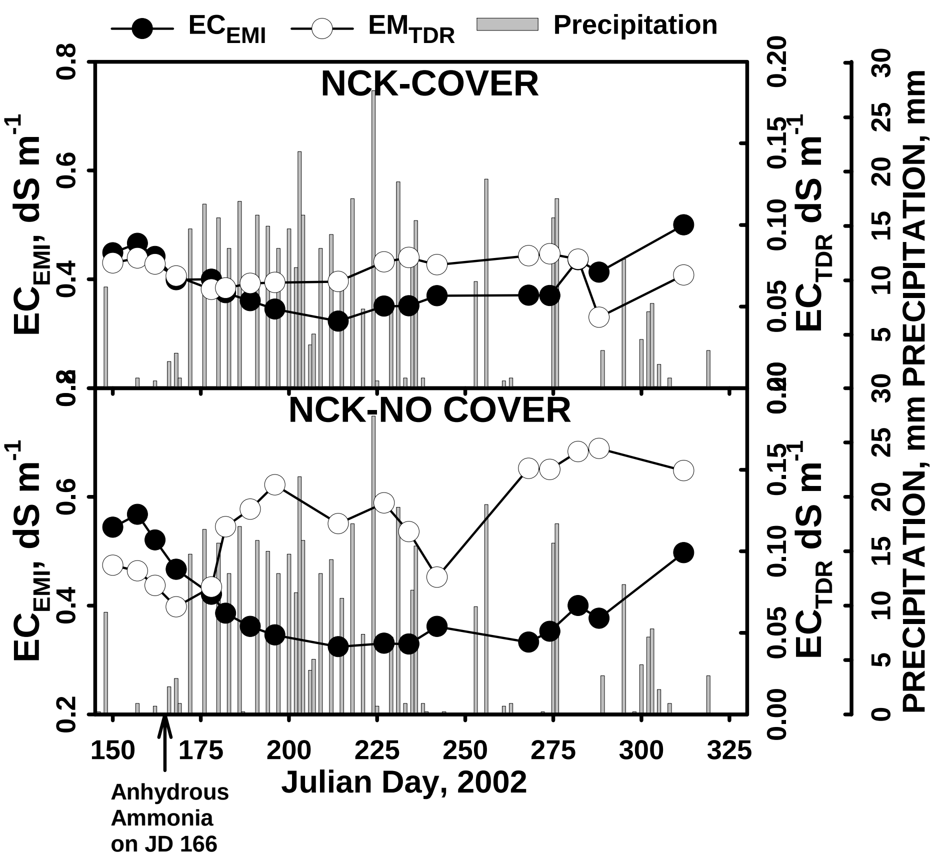

Figure 5. Apparent soil electrical conductivity (EC_{EMI}), bulk soil electrical conductivity (EC_{TDR}), and precipitation for commercial fertilizer at the nitrogen rate (NCK), with the cover crop and no-cover crop treatment for the 2002 growing season. EC_{TDR} values are shown only for EMI survey dates. Note date of post-emergence nitrogen fertilizer addition.