SOIL CONDUCTIVITY MAPS FOR MONITORING TEMPORAL CHANGES IN AN AGRONOMIC FIELD

R. A. Eigenberg, J. W. Doran, J. A. Nienaber, and B. L. Woodbury[1]

ABSTRACT

Temporal changes in soil composition are of interest in determining nutrient transport in the soil. This study was conducted to determine whether electromagnetic (EM) soil conductivity differences can be linked to feedlot manure application and then be used to trace these differences over a growing season. A series of soil conductivity maps of a research cornfield have been generated using GPS and EM induction methods. The site used in this study was treated over a six-year period with manure and compost applied at rates matching either the phosphorus or the nitrogen requirements of the corn. The plot was split with sub-treatments of a cover crop and no cover crop. Image processing techniques were used to establish treatment means for each of the growing season surveys. This method differentiated ($P<0.05$) the cover crop region and no-cover crop region with the exception of the period of rapid growth of the corn crop. This approach also distinguished ($P<0.05$) the nitrogen check treatment (commercial application rate) versus manure or compost treatment for both the cover crop and no-cover areas at strategic times in the growing season. The EM methods also provide insights into the dynamics of nutrient transformations and are supported with soil analysis. This paper will present the details of the methods used and the results of the study for one growing season.
Key words: electromagnetic induction, manure, nutrient, corn
Abbreviations: USMARC (U.S. Meat Animal Research Center), EM (Electromagnetic), GPS (Global Positioning System), EC (Electrical conductivity), EC_a (Profile weighted conductivity)

INTRODUCTION

Determination of nutrient buildup and the effect of nutrient transformations due to application of livestock waste to land is difficult to assess. Soil cores provide the most reliable measure but the methods are time consuming and costly. Monitoring of nutrient buildups at manure handling and application sites is necessary to determine effectiveness and risk potential. Traditional methods of monitoring and tracking nutrients use soil cores as the means of determining nutrient concentration at a given location with the location determined by conventional surveying methods. While this approach yields precision both in composition and position, it is expensive, time consuming and may not account for spatial variability of measured attributes at handling and application sites. Cheaper, quicker, but adequate methods are needed to evaluate the relative level of contaminants beneath waste management areas. Geophysical methods have the potential to fulfill that need, with electrical conductivity (EC) as one geophysical tool that shows promise for agricultural applications.

Instruments that measure soil conductivity without the use of soil probes are available commercially. These instruments use electromagnetic (EM) induction as a noninvasive method of measuring earth conductivities. For near surface EM exploration the instruments contain both a transmitter and receiver, with associated coils usually at a fixed (1 to 4 m) separation. The

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Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

signal sent out from the transmitter couples with the earth and causes a secondary EM field that is detected at the receiver. The ratio of the secondary EM field with respect to the primary field permits an estimate of the subsurface bulk conductivity. Profile weighted soil electrical conductivity (EC_a) can provide an indirect measure of important soil properties (Sudduth *et al*., 2000). The EM instrument is sensitive to factors that influence the soil conductivity which include: (1) soil moisture content, (2) amount and type of salts in solution, and (3) the amount and type of clays present (Brune and Doolittle, 1990).

Electromagnetic techniques are well suited for mapping soil conductivity to depths useful for the agriculturalist (McNeill, 1990). Electromagnetic terrain conductivity has been shown to be a very useful tool in locating seepage from animal waste lagoons (Ranjan *et al*., 1995). Sudduth and Kitchen (1993) used EM methods to estimate clay pan depth in soil. Electromagnetic methods have been used to map soil salinity hazards (Williams and Baker, 1982, Corwin and Rhoades, 1982). Electrical conductivity methods have been shown to be sensitive to areas of high nutrient levels (Eigenberg *et al*., 1996) and have been used to detect ionic concentrations on or near the soil surface resulting from field application of cattle feedlot manure. Electrical conductivity has generally been associated with determining soil salinity; however, EC also can serve as a measure of soluble nutrients (Smith and Doran, 1996) for both cations and anions. Doran *et al*. (1996) demonstrated the predictive capability of soil conductivity to estimate soil nitrate.

The purpose of this work was to generate a series of EC_a maps of a research cornfield with known application rates of compost, manure, commercial fertilizer, and cover crop history. This 'time lapse' sequence was planned to allow observation of temporal field dynamics as a result of treatment application and biological activity. Image processing methods were used to extract treatment soil conductivity values for the field. Statistical tests were performed to determine if temporal effects were significant for the manure, compost and cover crop treatments.

MATERIALS AND METHODS

Site

A cornfield located at the U. S. Meat Animal Research Center (USMARC) served as a comparison site for various manure and compost application rates for replacement of commercial fertilizer, with the same treatment assigned to field plots for six consecutive years. The soil at this site is of the taxonomic class of fine, montmorillonitic, mesic Pachic Argiustolls soil type and has 1% or less slope. Treatment plots include four replicates of treatments shown in Table 1. The field layout of treatments is represented in fig.1. Recommended rates were determined by anticipated crop needs and analysis of the compost and manure nutrient contents. Additionally, a comparison was made of a cover crop *versus* no cover crop superimposed over the above treatments. The work detailed in this paper was conducted between March and November of 1999.

Table 1. Treatment Plots in Cornfield.

Treatment	Description
CN	Compost applied at the recommended nitrogen rate
MN	Manure applied at the recommended nitrogen rate
CP	Compost applied at the recommended phosphorus rate
MP	Manure applied at the recommended phosphorus rate
NCK	Nitrogen check plot with commercial nitrogen applied at recommended rate

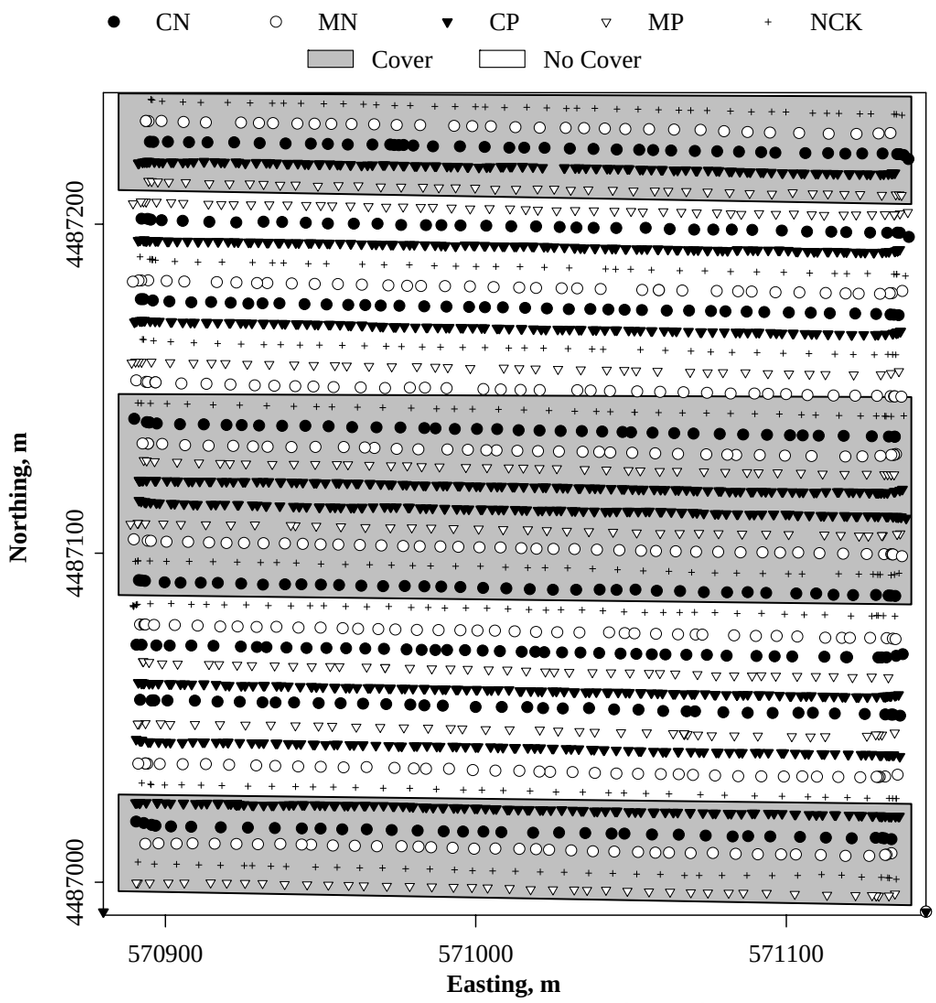

Figure 1. Treatment Layout of Cornfield Site.

Field Operations on the Research Cornfield

Field treatment nutrient application rates for each season were based on soil core analysis. Treatments MP and CP each had sufficient carry-over phosphorus in the 1999 season so that no manure or compost was applied to these treatment strips (6.1m wide). Treatments MN and CN were the only two treatments receiving manure/compost application on Julian Days (JD) 119 - 120. The field was disked on JD 121, worked with a spring-tooth on JD 133 and planted on JD 134. Commercial fertilizer was applied to NCK treatment on JD 164 as ammonia-N at a 84 kg/ha (75 lb/a) rate and urea-ammonium solution was side-dressed to MP, CP and NCK to supply 84 kg/ha (75lb/a) of available nitrogen on JD 201. The corn was harvested as silage on JD 251. The new cover crop of wheat was drilled on JD 263.

Equipment

A commercial magnetic dipole soil conductivity meter (EM-38 manufactured by Geonics Ltd., 1992) was used in this study. The EM-38 incorporates the transmitter and receiver coils fixed within the instrument with an inter-coil spacing of 1.0 meter. The EM-38 was operated in the coplanar horizontal mode measuring conductivity directly in milliSiemens per meter (mS/m), the international unit for conductivity is Siemens per meter. The units of mS/m may be divided by 100 to yield deciSiemens per meter (dS/m) or millimhos per centimeter (mmho/cm) which are commonly used soil EC units. This instrument/configuration has a response that varies with

depth in the soil yielding a profile weighted soil electrical conductivity, EC_a centered near 0.75 m (fig. 2).

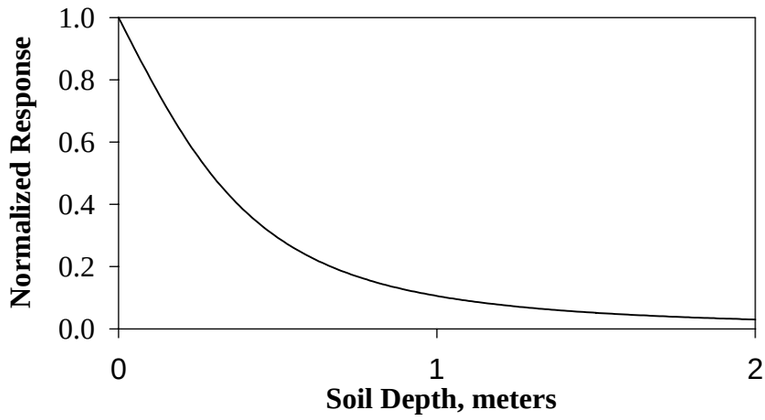

Figure 2. Normalized Soil Conductivity as a Function of Soil Depth for EM-38 Operated in Horizontal Mode (assuming homogeneity).

The EM-38 was transported through the field either mounted on a trailer that was pulled behind an ATV or pulled on a plastic sled by hand after the corn became too tall for the ATV system. The trailer was constructed of nonmetallic materials (fiberglass, plastic, wood and rubber), with the exception of metal in the axles of the wheels. The trailer elevated the EM-38 to 42 cm above the soil surface on smooth soil. A correction factor for the height above the soil was determined by making two passes through the cornfield: 1) the trailer was used to carry the EM-38 (42 cm above level ground), 2) the plastic sled was the carrier for the EM-38 (at ground level). Ratios of trailer to ground values were determined for each treatment of the field and are listed in Table 2. The mean value for correction of trailer height was 0.560 ± 0.007 and was used to adjust all trailer data to effective ground EC_a values. All reported EC_a measures in this paper have been corrected to the ground values.

Table 2. Comparison of EM-38 in Horizontal Mode Pulled Through Each Treatment Either Elevated to 42 Cm on a Trailer or Pulled on a Sled at Ground Elevation. Ratio of Trailer/Sled Determines Correction Factor for the Trailer.

	Sled	Trailer	Correction Factor
CN	73.95	41.69	0.564
MN	74.68	40.96	0.548
CP	67.92	38.32	0.564
MP	67.89	37.96	0.559
NCK	66.13	37.44	0.566
		Mean	0.560 ± 0.007

The reliability and repeatability of the EM-38 is important in discerning field driven events versus instrument artifacts. Methodology was used to reduce potential instrument impact such as zeroing the EM-38 at the same point in the field and traversing the field in an identical pattern each time. Additionally, basic tests were conducted on the EM-38 to establish the maximum uncertainty that the instrument may have contributed. Instrument drift is evident by the I/P zero correction made from a previous survey. The I/P reading is a measure of an internal signal of the EM-38 used to null the primary signal to allow higher receiver sensitivity (Geonics, 1992). The

usual I/P correction was in the 10 to 30 I/P unit range with an occasional correction range up to 50 I/P units. For the trailer mounted EM-38, the common adjustment of 10 to 30 I/P units results in offsets of 0.7 to 2.0 mS m^{-1} with the 50 I/P units, resulting in an approximate 3.4 mS m^{-1} offset corrected to ground level. The sled mounted instrument is less sensitive to I/P drift with 10 to 30 units corresponding to 0.2 to 0.5 mS m^{-1} and the 50 I/P units translating to an approximate 0.9 mS m^{-1} shift.

A test of thermal environment's impact on the EM-38 was done by comparing the mean ambient temperature during all surveys (High Plains Climate Center-Clay Center station, 5.6 km from research field) (http:\\hpccsun.unl.edu) and mean EC_a values. It was found that there was no significant (P=0.57) correlation of mean ambient temperature and mean EC_a values.

A Trimble PRO-XL GPS (global positioning system) unit was used to obtain positional data. The EM-38 was connected to the GPS unit (acting as the data collection device) through a small dedicated battery powered microcomputer (Onset Computer, Model IVa). The computer provided the necessary analog to digital conversion and data formatting to the serial interface NMEA (National Marine Electronics Association) interface standard. The serial data was sent to the GPS system to log positional and EC_a readings every second, a rate determined by ground speed and hardware acquisition capabilities. The treatment width was 6.1m; the design criterion was to maintain EC_a reading collection spacing at approximately the treatment width or less. The software/hardware collection rate was limited to one reading every second implicitly setting the upper limit on ground speed at approximately 6 m/s. Surveys were planned every week from the initial survey (JD 75) through the time that corn height restricted ATV travel through the field, with less frequent surveys thereafter. Rain and bad weather prevented surveys on the week of JD 123. Technical problems occurred on the week of JD 139 resulting in too few points being collected to produce a useful map. Otherwise, surveys were conducted each week while the corn was small enough to use the trailer. A sled system was used once the corn became too tall for the ATV and trailer. Sled surveys were conducted on JD 159, 165, 180, 193, 215, 236 and 250. After harvest, trailer surveys were conducted on JD 279, 313 and 334. This work summarizes the results of 20 maps generated over a 259-day period.

Soil cores were taken from randomly selected sites within each treatment and cover crop combination. The cores were taken within one day of the EC_a surveys. The soil cores were taken with a hand probe from depths of 0-23 cm and 23 - 46 cm. Two cores were taken at each site and blended. These samples were analyzed to determine concentrations of NO_3, NH_4 and soil moisture.

Data handling and processing

Map data was transferred to a PC after each survey with the stored files converted to ASCII format suitable for input into a contouring and 3-D mapping program (Surfer®,Golden Software, Inc., 809 14th Street, Golden, CO, 80401-1866). Maps were generated using an inverse distance interpolator. Kriging is a geostatistical interpolation method that gives more visually appealing plots than the inverse distance method. Krigging involves subjective inputs from the user in choice of model to be used and best fit of the chosen model to determine the needed model parameters. The inverse distance method is objective, is an exact interpolator (Keckler, 1995) and produces acceptable and repeatable results. The grid files were generated by Surfer® and established on a 200x200 grid; for the field under study (243m x 243m) the grid spacing produced a 1.22m grid resolution in the X and Y direction. This grid resolution was chosen to provide sufficient horizontal and vertical detail for image processing.

The processed images were scanned using the same path over each treatment location as the ATV had traversed in surveying the original field. This 'virtual' survey method allows image

processing methods such as image differencing to be employed to remove background fixed features and reduce variability. While not used for this work, subsequent reports will develop this method of reducing field variability. The scanned points of each treatment strip from the processed image were formatted to be compatible with statistical software (SAS, 1985) using a separate Basic program. Each scanned point contained identification for treatment, replicate, and cover. The multiple EC_a samples per treatment, 200 readings per treatment strip, were analyzed as repeated measures using the SAS (SAS, 1985) procedure PROC GLM. The comparisons were used to determine significance of mean differences between the EC_a readings for each treatment/cover/replicate.

RESULTS AND DISCUSSION

EC_a Maps

Figure 3 is an EC_a image of the cornfield that was produced at midpoint (JD 165) of the corn growing season. The treatment strips are apparent, indicating treatment separation. When viewed in sequence, the series of maps illustrates the field dynamics with overall EC_a values rising uniformly with time. The application of manure and compost produces clearly visible changes in map appearances. Subsequent darkening occurs in the later maps (JD 193 and beyond) as crop uptake and nutrient transport dominate the image. What is suggested in the images is more evident in the mean values reduced from the images shown in Tables 3 (no cover) and 4 (cover). The asterisks in the tables indicate significant differences ($P<0.05$) in treatments as compared to the commercial fertilizer check treatment (NCK). Table 3, EC_a mean values from the portion of the field without cover, demonstrates a difference of the CN treatment compared to NCK from the beginning of the season through harvest of the corn as silage. Manure at the nitrogen rate (MN) follows a similar pattern with significant differences on JD 75, 89, 119, 144, 154, 165 and 180. Table 4, EC_a values from the portion of the field with cover, shows significance only on JD 119, 144, 154, 165 and 180 for both CN and MN compared to NCK. It should be noted that the survey on JD 119 was conducted as manure and compost were being applied to the field and reflects treatments with and without manure and compost. The data for JD 119 is included for completeness but results from this survey date should not be considered conclusive. Plots generated from these tables are shown in the following section with corresponding discussion.

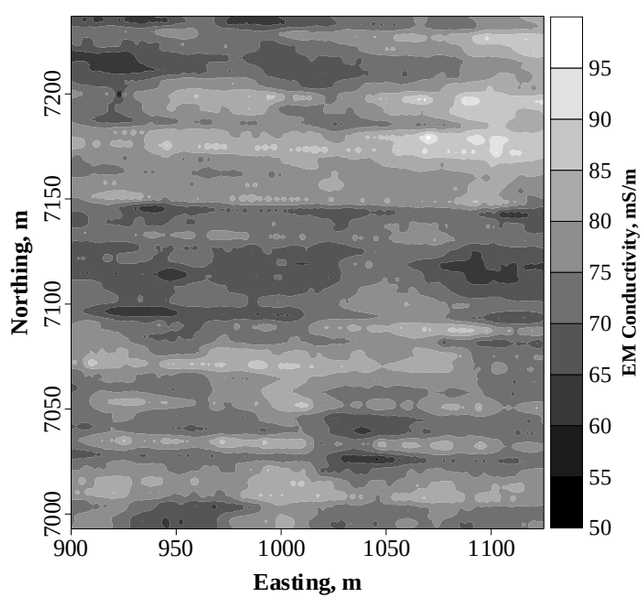

Figure 3. A Representative Image of the EC_a Map of the Cornfield Produced in the Middle of the Corn Growing Season (JD165). The Treatment Strips are Apparent, Indicating Conductivity Difference for the Treatments.

Table 3. Research Cornfield Mean EC_a Values by Treatment for Portion Without Cover Crop.

JD	Mode†	CN	CP	MN	MP	NCK
75	T	56.5 ± 2.5*	55.5 ± 2.4	55.8 ± 2.4*	55.0 ± 2.5	53.9 ± 2.7
82	T	60.6 ± 2.7*	58.9 ± 2.8	59.6 ± 2.1	58.2 ± 2.9	57.7 ± 2.5
89	T	62.0 ± 3.3*	60.5 ± 3.0	60.9 ± 2.8*	60.0 ± 3.0	59.5 ± 3.0
97	T	65.8 ± 3.4*	63.5 ± 3.1	64.6 ± 3.0	63.2 ± 3.4	62.4 ± 3.3
102	T	66.6 ± 3.6*	63.4 ± 3.1	64.8 ± 3.0	63.7 ± 3.5	63.1 ± 3.4
110	T	67.6 ± 2.7*	65.7 ± 2.8	66.4 ± 3.0	64.8 ± 3.3	63.9 ± 3.1
119	T	71.4 ± 3.0*	67.5 ± 2.5	69.7 ± 2.9*	67.1 ± 3.1	66.3 ± 2.8
133	T	66.6 ± 3.6*	62.4 ± 3.2	64.8 ± 3.7	61.8 ± 3.3	61.8 ± 3.1
144	T	76.9 ± 3.8*	73.5 ± 3.0	75.5 ± 3.4*	73.0 ± 3.4	73.1 ± 2.8
154	T	76.0 ± 4.1*	72.4 ± 3.5	74.2 ± 3.6*	71.2 ± 3.8	70.6 ± 3.2
159	S	76.9 ± 5.3*	73.8 ± 3.7	74.2 ± 5.1	71.7 ± 4.4	72.3 ± 3.7
165	S	81.6 ± 4.6*	77.1 ± 3.9	79.6 ± 4.2*	75.5 ± 4.0	75.2 ± 3.6
180	S	79.4 ± 4.7*	74.3 ± 3.8	76.6 ± 5.5*	72.5 ± 5.0	71.6 ± 4.6
193	S	62.0 ± 4.0	60.5 ± 3.3	62.1 ± 4.5	59.1 ± 4.2	60.7 ± 5.0
215	S	67.0 ± 5.7*	69.1 ± 5.3*	65.2 ± 5.3	66.5 ± 6.0	62.8 ± 5.2
236	S	55.9 ± 4.4*	58.7 ± 3.8*	56.5 ± 3.7	56.2 ± 4.9*	51.7 ± 3.5
250	S	55.5 ± 4.0	57.9 ± 3.2*	54.6 ± 3.8	54.9 ± 5.0	52.9 ± 4.0
279	T	57.2 ± 3.6	58.1 ± 3.0*	57.1 ± 3.1	56.1 ± 4.1	55.1 ± 3.0
313	T	58.2 ± 4.3	59.0 ± 3.8*	57.8 ± 4.0	57.2 ± 4.3	55.9 ± 3.8
334	T	52.7 ± 3.2	53.0 ± 2.8	52.3 ± 2.9	51.5 ± 3.6	50.9 ± 2.9

†T = surveyed using trailer, S = surveyed using sled
*Significantly different from NCK at P<0.05

Table 4. Research Cornfield EC_a Values by Treatment for Portion With Cover Crop.

JD	Mode†	CN	CP	MN	MP	NCK
75	T	49.6 ± 2.4	48.8 ± 3.0	49.8 ± 3.4	49.7 ± 3.3	49.8 ± 2.9
82	T	52.1 ± 3.3	52.1 ± 3.0	52.7 ± 3.7	52.7 ± 3.3	52.3 ± 3.6
89	T	52.4 ± 2.9	52.7 ± 3.0	52.6 ± 3.5	53.7 ± 3.7	53.8 ± 3.3
97	T	54.9 ± 3.1	54.9 ± 3.2	54.6 ± 3.8	55.7 ± 4.1	56.0 ± 4.2
102	T	55.0 ± 3.3	55.3 ± 3.0	54.2 ± 3.7	56.0 ± 4.0	56.2 ± 4.2
110	T	59.1 ± 3.7	57.3 ± 3.1	58.4 ± 3.9	58.5 ± 3.5	57.9 ± 3.4
119	T	63.9 ± 3.6*	60.8 ± 3.0	63.4 ± 3.5*	62.1 ± 3.1	61.2 ± 3.4
133	T	60.6 ± 4.8	57.2 ± 5.0	59.7 ± 5.5	57.4 ± 4.0	58.2 ± 4.6
144	T	72.6 ± 4.1*	68.7 ± 3.8	71.9 ± 4.1*	68.7 ± 3.5	69.2 ± 4.0
154	T	71.7 ± 4.4*	67.4 ± 4.0	71.0 ± 4.6*	67.8 ± 3.6	67.7 ± 4.0
159	S	69.9 ± 4.0	65.9 ± 5.4	69.2 ± 5.4	66.1 ± 4.2	66.6 ± 4.6
165	S	75.1 ± 4.1*	69.8 ± 3.7	75.2 ± 4.6*	70.8 ± 3.4	70.2 ± 4.0
180	S	74.1 ± 4.4*	70.0 ± 5.9	74.1 ± 5.3*	68.5 ± 4.1	68.1 ± 5.0
193	S	61.9 ± 4.3	60.6 ± 4.0	63.5 ± 6.1	60.9 ± 3.7	61.3 ± 4.6
215	S	66.5 ± 5.8	65.9 ± 5.6	65.5 ± 8.0	65.5 ± 5.2	64.3 ± 5.5
236	S	55.7 ± 4.5	57.1 ± 3.3	56.7 ± 4.8	56.6 ± 3.9	54.7 ± 4.1
250	S	56.3 ± 4.3	56.1 ± 3.4	56.7 ± 5.2	56.1 ± 2.8	56.7 ± 4.7
279	T	55.3 ± 4.8	54.3 ± 3.3	55.0 ± 5.5	54.9 ± 2.9	54.4 ± 4.9
313	T	51.8 ± 3.2	50.4 ± 2.5	50.9 ± 3.8	51.6 ± 2.8	51.5 ± 3.6
334	T	46.5 ± 3.0	46.0 ± 2.8	45.6 ± 2.8	46.7 ± 2.2	46.4 ± 3.4

† T = surveyed using trailer, S = surveyed using sled
*Significantly different from NCK at P<0.05

Soil electrical conductivity as an indicator of biophysical changes in plant available N

Seasonal changes in soil electrical conductivity as affected by manure, compost, and fertilizer N treatments for silage corn (*Zea mays* L.) with and without a rye (*Secale cereala* L.) cover crop for 1999 are shown in fig. 4 (a and b). In general, EC_a for all treatments increased from mid March (JD 75) through mid June (JD 165) when ammonium fertilizer N was applied to the N check plot and corn was almost 30 cm tall (4 to 6 leaf stage). Conductivity declined thereafter throughout the growing season, reaching values at or below the initial early spring values within 3 months after corn silage harvest of JD 251 (September 8).

The trends observed for EC_a during the growing season generally paralleled changes in soil temperature throughout the year (fig. 5). Soil microbial activity doubles with each 10º C increase in temperature between 10 and 35°C (Parkin *et al*., 1996). Thus the increases in EC_a with increasing temperature apparently followed a trend similar to that for microbial activity. The peaks in soil temperature throughout the year, however, were out of phase with those for conductivity which occurred 5 to 7 days earlier. If conductivity is a good indicator of the dynamics of soil available NO_3 levels, as suggested by Smith and Doran (1996), this may have resulted from the two step process of organic N mineralization. The formation of the first product NH_4 is brought about by many different microorganisms over a wide range of soil conditions. The second step, the oxidation of NH_4 to NO_3, is brought about by a select group of aerobic bacteria which are more sensitive to soil temperature, soil water content, and oxygen availability. Another explanation for the out of phase nature of temperature and EC_a is the fact that sudden declines in soil temperature are associated with rainfall events, especially during the early growing season. The delayed declines in EC_a are actually associated with the loss of NO_3 from soil due to leaching or denitrification which occur under wet soil conditions after rainfall (fig. 5).

The declines in EC_a (figs. 4a and 4b) which were observed between JD 121 to 134 and JD145 to 159 were apparently related to soil conditions which approached saturation during these periods as illustrated in fig. 6. Although fluctuations in soil water content were associated with oscillations in EC_a , it is obvious that water and nutrient uptake characteristics of growing corn was the major factor controlling soil electrical conductivity later in the growing season. This period in the growing season occurred between JD 165, when commercial fertilizer was applied to the N check and corn was about 30 cm tall, and when corn silage was harvested on JD 251 (fig. 7). It is interesting to note that the downward trend in soil EC_a was reversed between JD 193 and 215 at which time the corn was 2 to 3 m tall and in the silking stage. Researchers have noted that during silking of corn there is very little uptake of N, regardless of soil moisture condition and plant stress (James Schepers, 1999).

Soil electrical conductivity in an uncropped part of the field that was used for turning vehicles showed similar trends and oscillations to that observed for the cropped area, except EC_a values were poised at a higher level (data not shown). The variations in conductivity in the uncropped area were likely due to wetting and drying events which stimulated both loss of NO_3 due to leaching and denitrification and formation of NH_4 and NO_3 due to mineralization of soil organic matter.

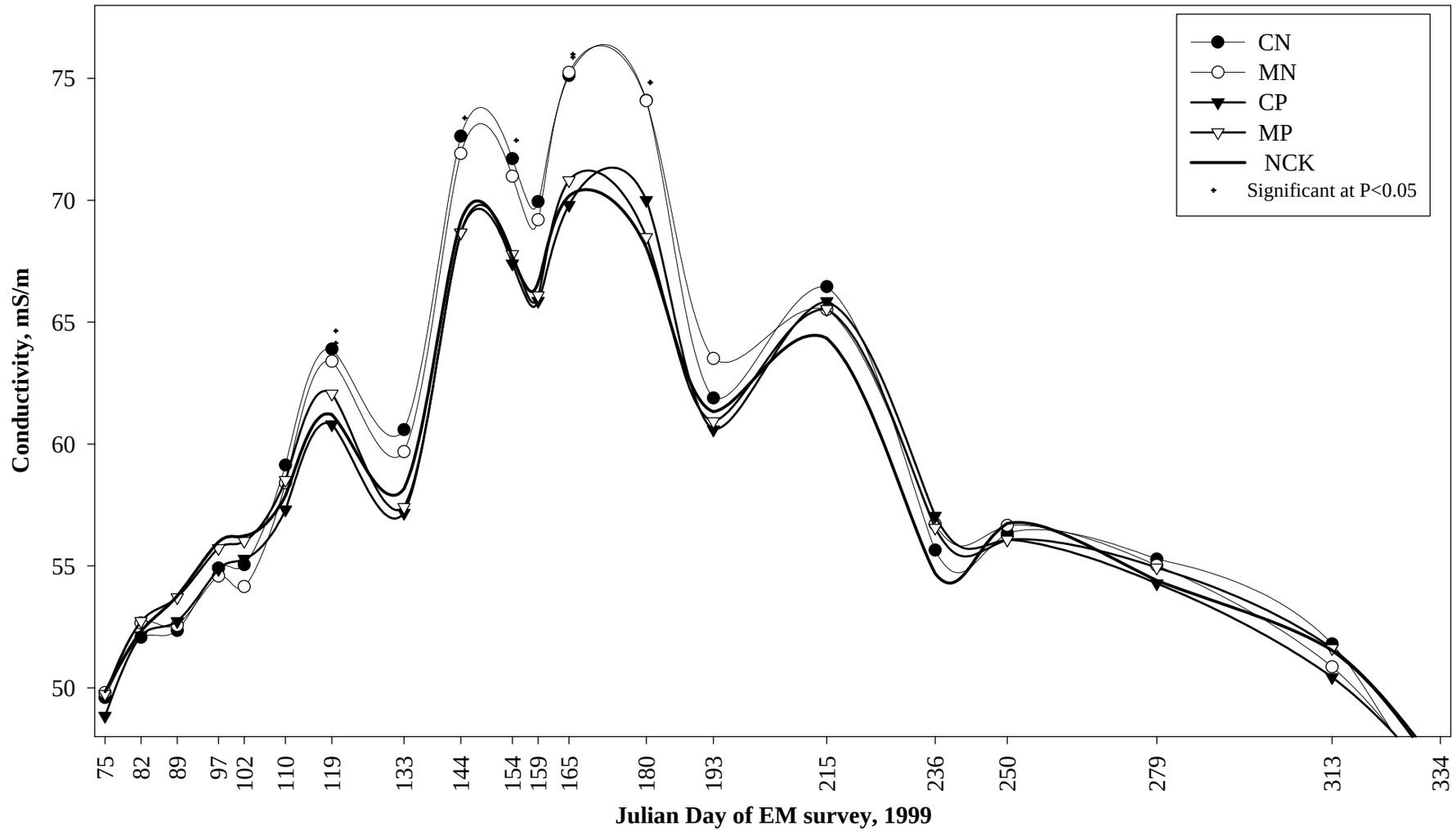

Figure 4a. Seasonal Changes in Soil EC_a as Affected by Manure, Compost and Fertilizer N Treatments for Silage Corn With a Rye Cover Crop.

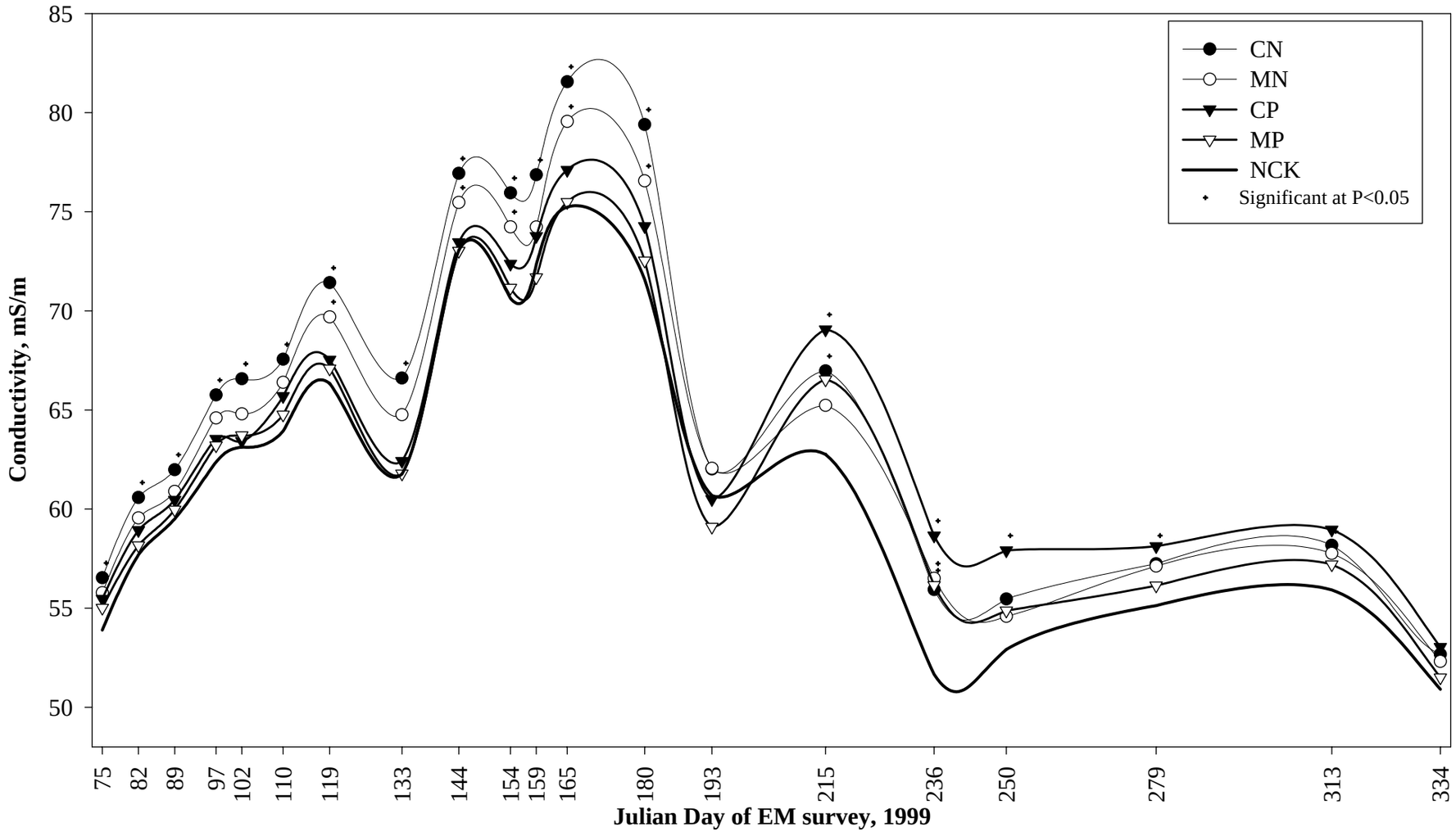

Figure 4b. Seasonal Changes in Soil EC_a as Affected by Manure, Compost and Fertilizer N Treatments for Silage Corn Without a Rye Cover Crop.

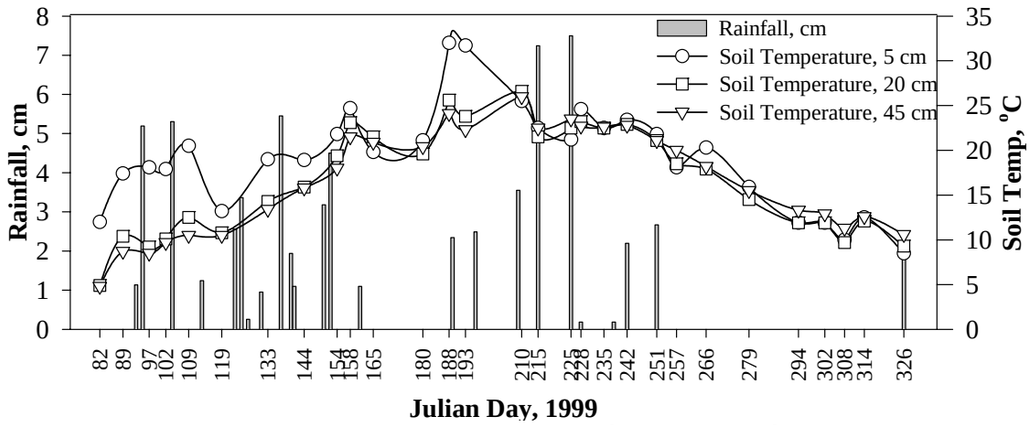

Figure 5. Soil Temperatures and Precipitation for 1999 (rainfall and irrigation).

The soil EC_a values observed in this study (fig. 7), 55 to 78 mS m^{-1} (.55 to .78 dS m^{-1}) were generally below the threshold of 0.8 to 1.0 dS m^{-1} (1:1 soil/water) above which the growth and activity of plants and microorganisms can be significantly altered (Smith and Doran, 1996). However, the results of this study suggest that soil electrical conductivity may serve as a useful indicator of available N in soil as suggested by Gajda *et al*. (2000) and Patriquin *et al*. (1993). Throughout periods of the year when corn was not in an active growth phase, the presence of rye as a growing cover crop resulted in significantly lower levels of EC_a (fig. 7). In general, the lower soil EC_a values with the growing cover crop were also associated with lower levels of NH_4 and NO_3 in soil (figs. 8 and 9). However, after disking and incorporation of the cover crop on (JD 121), soil NH_4 and NO_3 levels increased intermittently until JD 180 in cover crop plots, especially those receiving manure and compost (MN and CN). During this period two declines in conductivity after JD 121 and 145 were associated with brief rainfall periods which resulted in the soil approaching or exceeding saturation when soluble NO_3-N would be expected to be lost due to leaching or denitrification. Parkin *et al*. (1996) have demonstrated that considerable N can be lost from soil by denitrification when soil water content exceeds 80% relative saturation (80% water-filled pore space).

It appears from this study that the mineralization and loss of available N from soil can be reasonably estimated from soil electrical conductivity values. The average change in soil EC_a between JD 110, when compost and manure were added to soil, and JD 165 before corn started removing available N with and without cover crops averaged 0.15 and 0.13 dS m^{-1} (15 and 13 mS m^{-1}) which equates to 21 and 18.2 ppm available mineral N, respectively (Doran and Smith, 1996; EC (dS m^{-1}) X 140 ppm N dS^{-1} = $\mu g g^{-1}$ available N). Assuming an average soil bulk density of 1.35 g cm^{-3} and a soil depth of 60 cm (21 x 1.35 x 60/10 = 170 kg N ha^{-1}), 170 and 147 kg N ha^{-1} of gross N was mineralized over 55 days for the cover and no cover treatments, respectively. Declines in EC_a between JD 119 to 133 and 144 to 159 apparently associated with losses of N due to leaching and or denitrification, were 0.08 and 0.07 dS m^{-1} which represented NO_3-N losses of 91 and 79 kg N ha^{-1} for cover crop and no cover, respectively. Subtraction of N losses from the gross N mineralized during this 55 day period results in a net N available to corn plants of 79 and 68 kg N ha^{-1} on cover and no cover plots, respectively. This is equivalent to a plant available N formation rate of 1.2 to 1.4 kg N ha^{-1} da^{-1} which is similar to the range of 0.8 to 1.1 kg N ha^{-1} da^{-1} for soil from the same treatments that were incubated in the laboratory under ideal conditions of moisture and temperature (data not shown). Based on laboratory analyses for soil NO_3-N concentrations in the top 0-46 cm of soil between JD 110 and 165 (fig. 9), the average N mineralized from all treatments of the cover and no cover plots were 91 and 57 kg N ha^{-1}, respectively. This equates to an average mineralization rate of 1.65 and 1.03 kg N ha^{-1} da^{-1}. These average mineralization rates were higher than that estimated from conductivity values and

resulted mainly from higher mineralization rates for compost treatments which were 210 and 123 kg N ha^{-1} for cover and non-cover plots, respectively. However, all things considered, EC_a appeared to be a reliable indicator of soluble N gains and losses in soil. EC_a should serve as a reliable indicator of N sufficiency for corn early in the growing season and as an indicator of N surplus after harvest when N is prone to loss from leaching and/or denitrification.

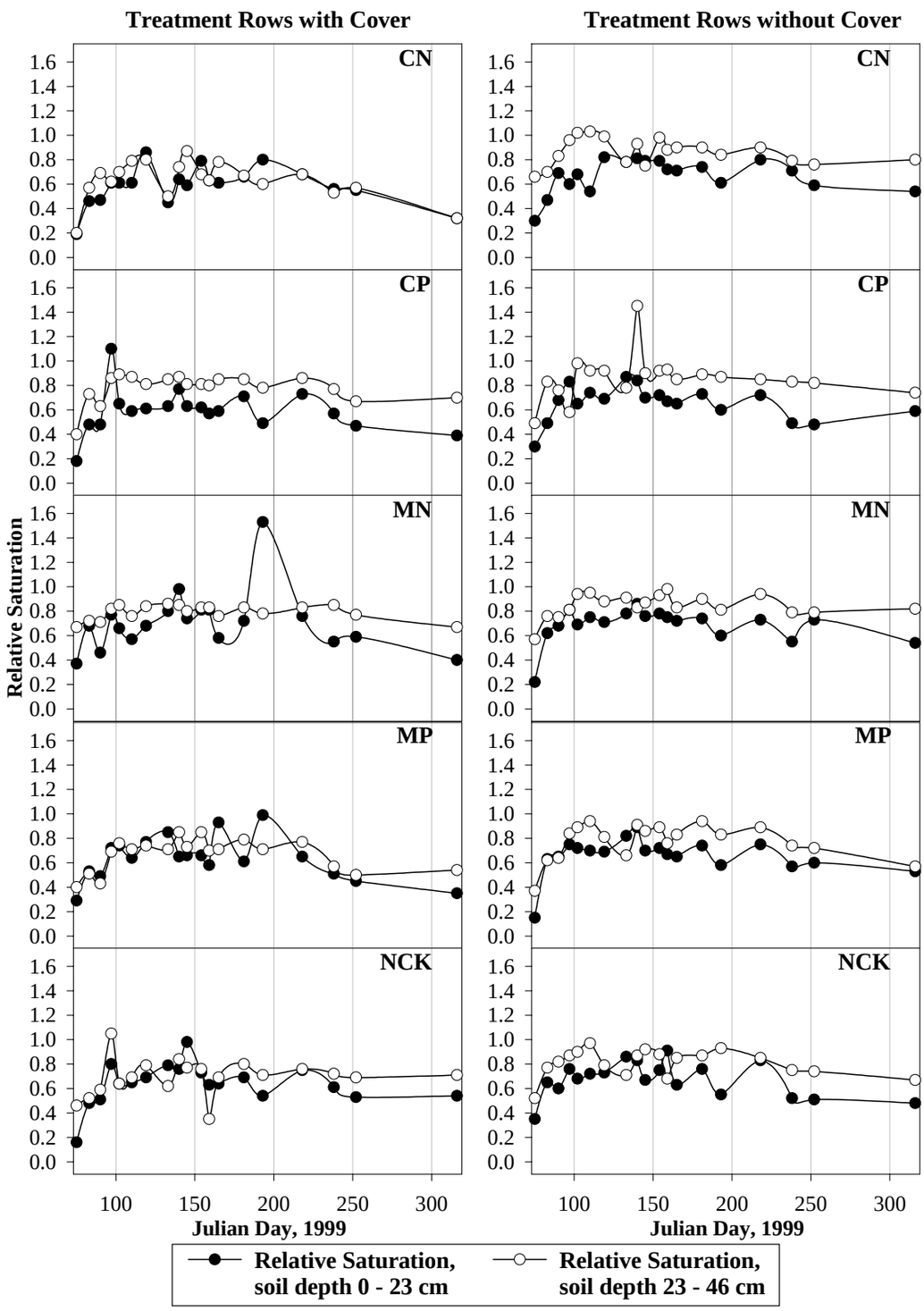

Figure 6. Relative Saturation Based on Assumed Bulk Density of 1.34 g cm^{-1} for the 0-23 cm Soil Depth and 1.39 g cm^{-1} for the 23-46 cm Soil Depth for Treatment With and Without Cover.

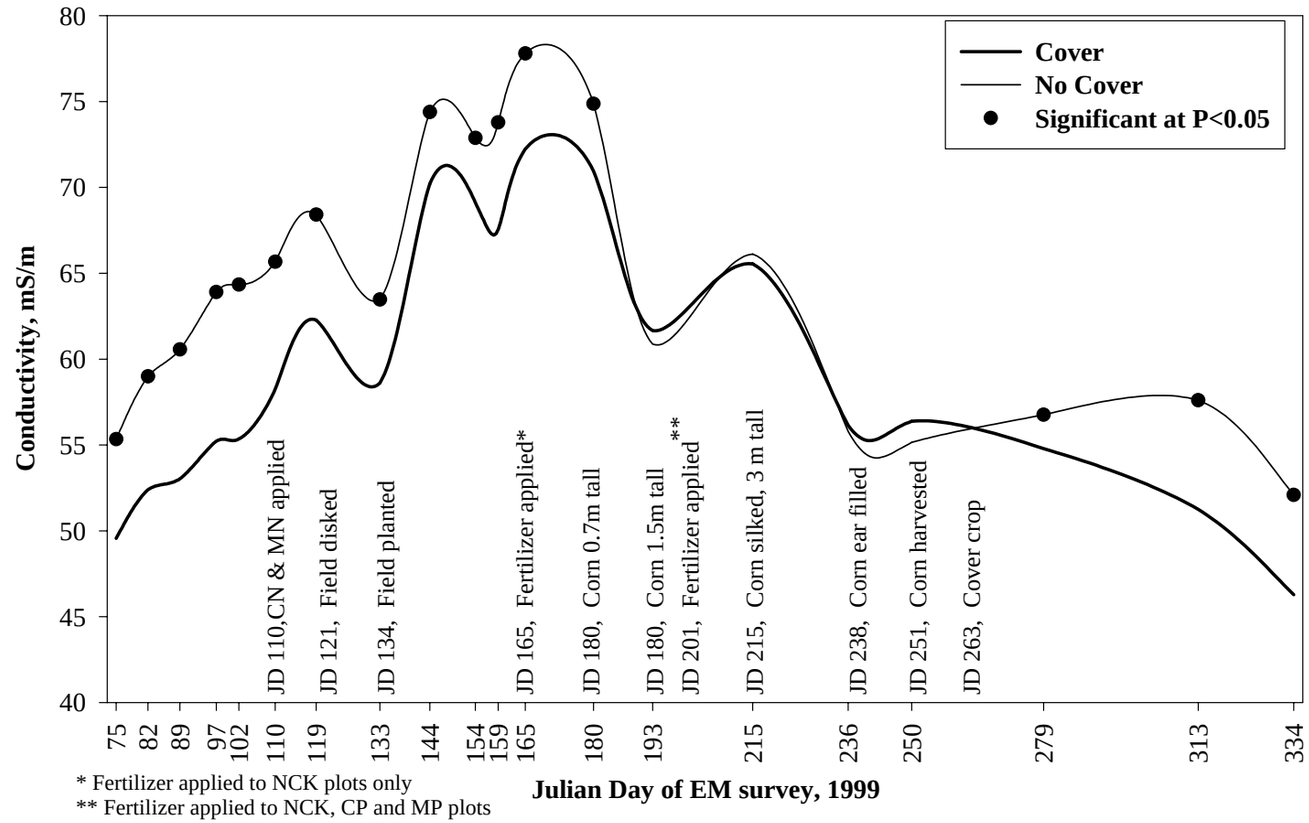

Figure 7. Comparison of the Rye Cover Crop Soil Conductivities and no Cover Crop. The Presence of Rye as a Growing Cover Crop Resulted in Significantly Lower Levels of Soil Electrical Conductivity Through Periods of the Year When Corn was not in an Active Growth Phase. Also Shown are Significant Events in the Crop Growing Season.

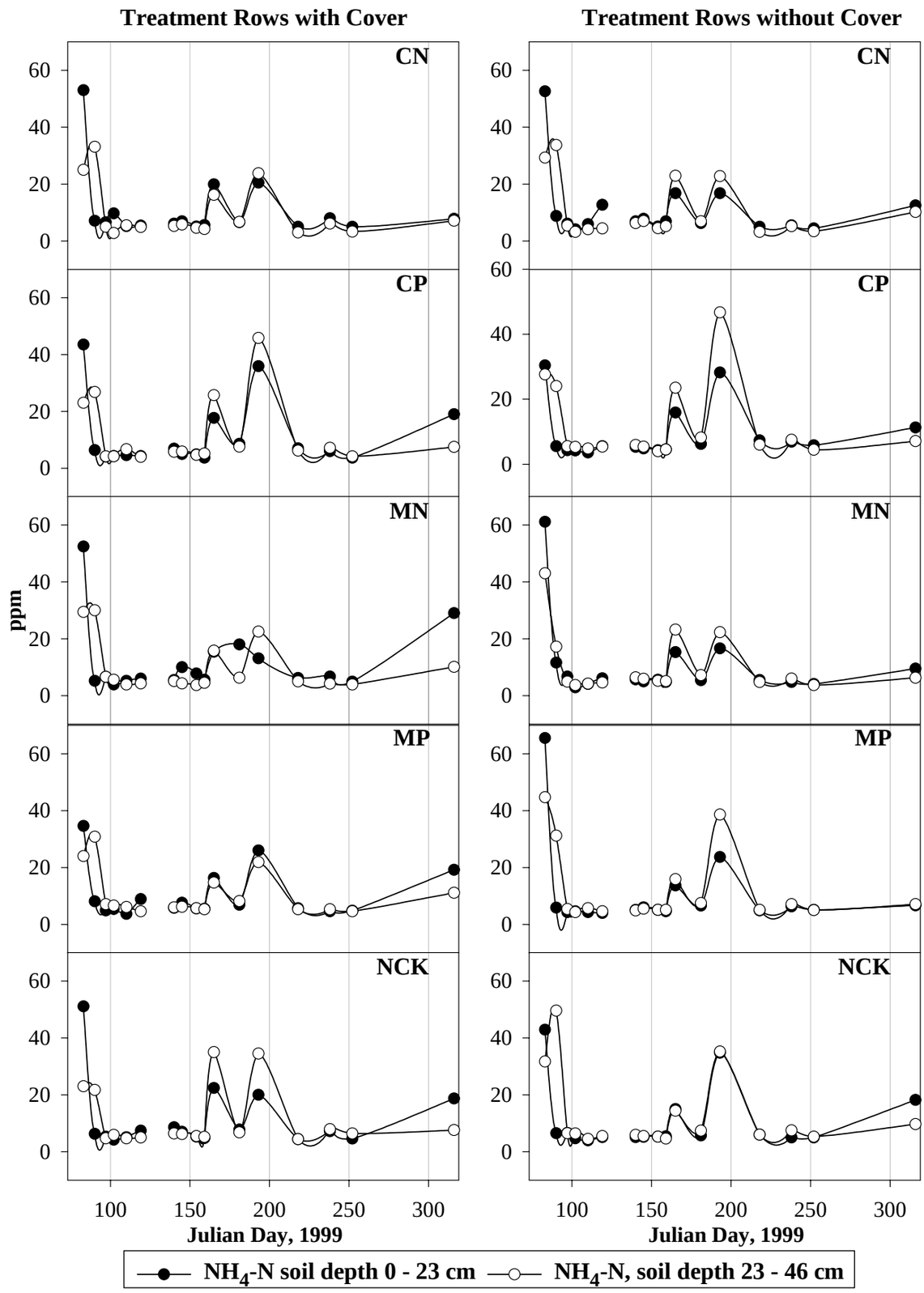

Figure 8. NH_4-N for the Corn Growing Season. (Ammonium values for day 133 contained errors and were not plotted.)

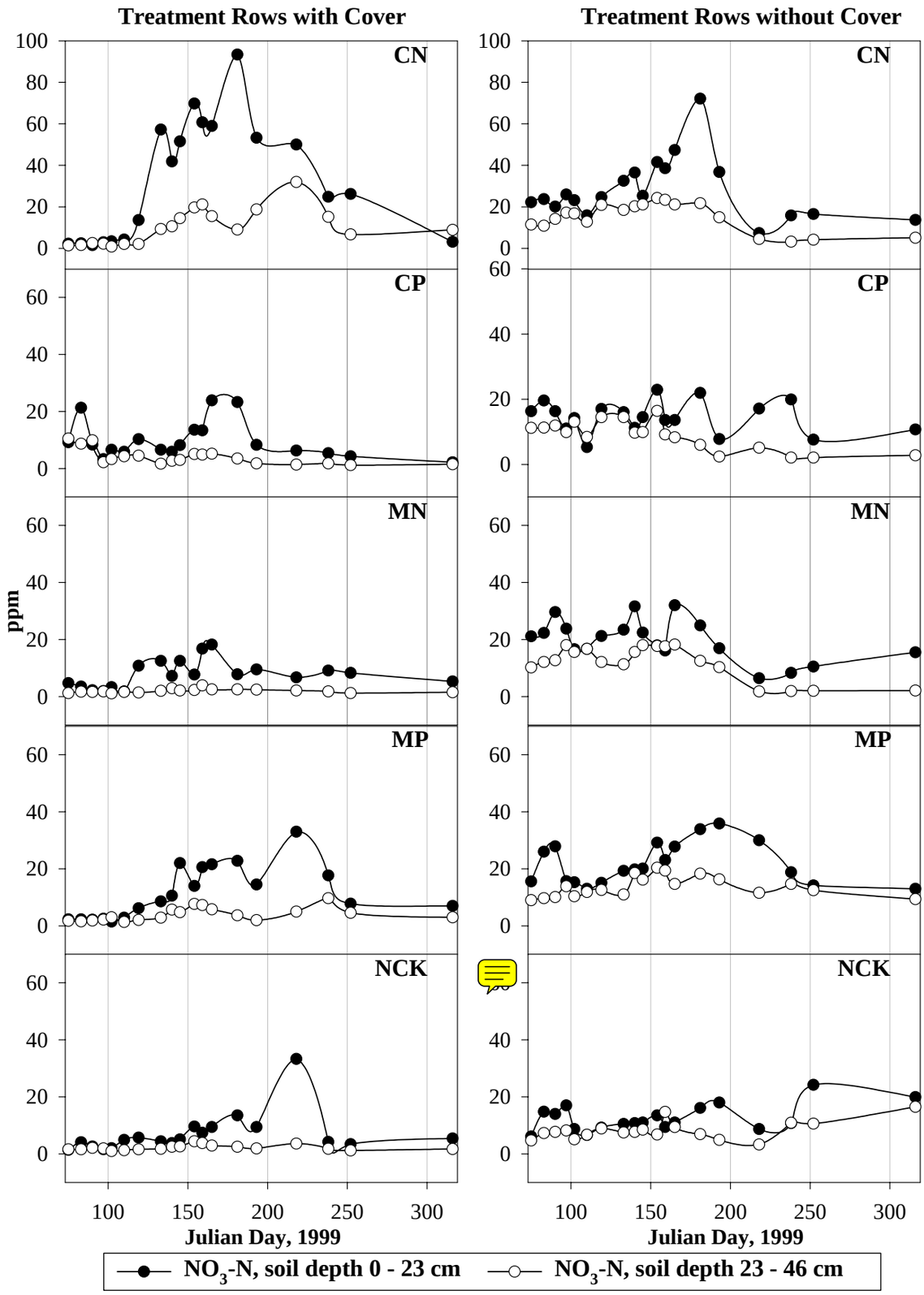

Figure 9. NO3-N Concentration for the 1999 Corn Growing Season for Treatments With and Without Cover.

Crop Yield

Ferguson and Nienaber (2000) reported that for the sevenyear study silage yield with application of organic residues was normally equal or greater than that from inorganic N fertilizer. The 1999 crop demonstrated the same trend with MN and CN having observably higher yield than MP and CP, with NCK showing the least yield.

Conclusion

Sequential EC_a maps of a research cornfield have demonstrated the dynamics of that cornfield. This method differentiated ($P<0.05$) the cover crop region and no-cover crop region with the exception of the period of rapid growth of the corn crop. This approach also distinguished ($P<0.05$) the nitrogen check treatment (commercial application rate) *versus* manure or compost treatment for both the cover crop and no-cover areas at strategic times in the growing season. Time sequence EC_a maps provided insights into temporal soil dynamics revealing identifiable differences in rates of change of soil conductivity among treatments. Soil conductivity appeared a reliable indicator of soluble N gains and losses in soil and may serve as a measure of N sufficiency for corn early in the growing season. Soil conductivity may also be used as an indicator of N surplus after harvest when N is prone to loss from leaching and/or denitrification.

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