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L.A.Q.

Subject: Geophysical Investigations at the Beltsville Agricultural Research Center, Beltsville, Maryland; 10 - 13 April 1995

Date: 10 May 1995

Doolittle folder

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Purpose:
To characterize the sustainable agriculture field at the Beltsville Agricultural Research Center using ground-penetrating radar (GPR) and electromagnetic induction (EM) techniques.

Participants:
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Laura Lengnick, Soil Scientist, ARS, BARC, Beltsville, MD
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Activities:
On 10 April, GPR surveys were completed within the sustainable agriculture field. On 11 April, EM techniques were used to characterize the same field.

STUDY SITE
The sustainable agriculture field is located in the northwest portion of the Beltsville Agricultural Research Center, and to the north and northwest of Rosedale Park. Soil patterns within the field were complex. The field contains delineations of Christiana silt loam, 0 to 2 percent slopes; Christiana silt loam, 2 to 5 percent slopes, moderately eroded; Christiana silt loam, 5 to 10 percent slopes, moderately eroded; Elkton silt loam; Keyport silt loam, 0 to 2 percent slopes; and Keyport silt loam, 0 to 2 percent slopes, moderately eroded (Kirby et al., 1967). Christiana is a member of the clayey, kaolinitic, mesic Typic Paleudults family. Elkton is a member of the clayey, mixed, mesic Typic Ochraquults family. Keyport is a member of the clayey, mixed, mesic Aquic Hapludults family.

A more detailed soil survey of the sustainable agriculture field was recently completed. This survey resulted in the recognition of a larger number of soils and soil delineations. Generally, soils recognized in the eastern portion were finer textured than soils identified in the western portion of the field. Soils recognized in the eastern portion of the study site included members of the Christiana, Elkton, Keyport, and

Othello series. Othello is a member of the fine-silty, mixed, mesic Typic Ochraquults family. Soils mapped in the western portion of the study site included members of the Downer, Matapeake, and Mattapex series. These soils are member of the coarse-loamy, siliceous, mesic Typic Hapludults; fine-loamy, mixed, mesic Typic Hapludults; and fine-loamy, mixed, mesic Aquic Hapludults families, respectively.

MATERIALS AND METHODS

Ground-penetrating radar:

Background:

Ground-penetrating radar is an impulse radar system designed for shallow, subsurface investigations. Short pulses of electromagnetic energy in the VHF and UHF frequency range are transmitted into the ground from an antenna which is moved along the surface. The pulses form a wavefront which moves downward until it contacts an interface separating layers of differing dielectrics properties. There a portion of the pulse's energy is reflected back to the receiving antenna. The receiving unit samples and amplifies the reflected energy and converts it into a similarly shaped waveform in a lower frequency range. The processed reflected waveforms are displayed on either a video screen, thermal plotter, or graphic recorder, or are recorded on magnetic tape for future playback or processing. The graphic recorder and thermal plotter use a variable gray scale to display the reflected waveforms.

Because it does not perform equally in all soils, ground-penetrating radar is an imperfect tool. Many soils, because of their high electrical conductivity, are essentially radar opaque (Cook, 1973). These soils limit observation depths and diminish the likelihood of resolving subsurface features. While, in some instances, the depth of observation can be extended by using multiple arrays, closely spaced borehole antennas, or relying on signal processing methods, these techniques are more expensive and time consuming than surface approaches.

In some soils, the use of GPR is inappropriate. In these soil and for some types of shallow investigations, other geophysical techniques are available which can provide more reliable and less ambiguous data. Knowledge of the chemical, physical, and mineralogical properties of soils and their distribution can facilitate the assessment of sites for GPR applications.

When assessing the appropriateness of using GPR, a major consideration is signal attenuation at the desired antenna operating frequency (Daniels et al., 1988). The maximum depth of observation decreases rapidly with increasing antenna frequency. High frequency antennas (>500 mHz) can provide well resolved images of shallow features in soils having low conductivity. However, levels of signal attenuation are often prohibitive to GPR systems in soil having high conductivity (Daniels et al., 1988). In these soils, low frequency antenna can be used to improve the depth of observation. However, as lower frequency antennas are used in an attempt to achieve the desired depth of observation, the resolution of subsurface features is reduced.

The maximum depth of observation is, to a large degree, determined by the conductivity of the soil. Soils having high conductivities rapidly dissipate the radar's energy and restrict observation depths. The principal factors influencing the conductivity of soils to electromagnetic radiation are: (i) degree of water saturation, (ii) amount and type of salts in solution, and (iii) the amount and type of clay.

Equipment:
The radar units used in this study were the Subsurface Interface Radar (SIR) System-2 and System-8. Both systems are manufactured by Geophysical Survey Systems, Inc. (GSSI). The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. Components of the SIR System-8 used in this study were the model 4800 control unit, ADTEK SR 8004H graphic recorder, power distribution unit, and transmission cable (30 m). Both systems were powered by a 12-volt vehicular battery. The model 3105 (300 mHz) and 3110 (120 mHz) antennas were used in this investigation.

GPR Calibration and Interpretations:
Calibration trials were conducted with both radar systems. A scanning time of 70 nanoseconds (ns) was established on the radar control units. As part of the calibration trials, a reflector was buried at a depth of 40 cm (16 inches). Based on the scaled depth to this reflector, the calculated dielectric constant of the surficial silt deposits was 12. The velocity of propagation was 0.087 m/ns (0.286 ft/ns). With scanning time of 70 ns, the maximum observation depth was about 3 m (10 ft).

Figure 1 is an example of a radar profile. The horizontal scale represent units of distance traveled along a survey line. This scale is dependent upon the speed of antenna advance across the soil surface, paper advance through the recorder, and editing techniques used during any post-processing of the data. The vertical scale is a time scale or depth scale which is based on the velocity of signal propagation through the mediums. The dashed vertical lines are event markers. These lines have been inserted on the radar profile to indicate known observation points along the traverse. The evenly spaced horizontal lines are scale lines. Scale lines provide reference planes for relative depth assessments.

Most radar profile consist of four basic components: start of scan pulse (A), inherent antenna noise (B), surface image (C), and subsurface images. With the exception of the start of scan image, and unless limited by high rates of signal attenuation or proximity of two or more closely spaced interface reflections, these components appear as a group of multiple bands. These bands, which are produced by oscillation in the reflected signals, limit the ability of GPR to resolve shallow or closely spaced interfaces. The dark bands occur at both positive and negative signal amplitudes. The narrow white bands represent the neutral or zero crossing between positive and negative signal amplitudes.

The start of scan pulse (A) is the result of the direct coupling of the transmit and receive antennas. Though a source of unwanted clutter, the start of scan pulse is often used as a time reference line. Reflections inherent in and unique to each antenna are the first series of multiple bands (B). Generally the width of these bands increases with decreasing antenna frequency and signal filtration. These reflections are also a source of unwanted noise on radar profiles. The surface reflection (C) represents the first major interface signal. Below the surface reflection are reflections from subsurface interfaces (D). Interfaces can be categorized as plane reflectors or point reflectors. Most soil horizons and geologic layers will appear as continuous, parallel, multiple bands similar to those appearing in the left-hand portion of Figure 1. Small objects, such as buried artifacts, roots, or rock fragments, will appear as point reflectors and will produce hyperbolic patterns similar to the one appearing in the right-hand portion of Figure 1.

GPR Survey Procedures:
The control and recording units were mounted in a 4WD vehicle. An antenna was placed in a sled and towed behind the vehicle. Separate surveys were completed using the SIR System-2 with a 300 mHz antenna, and the SIR System-8 with a 120 mHz antenna.

Each survey was conducted by towing an antenna along 13 parallel grid lines. Traverses were completed along grid lines having essentially an east - west orientation. Surveys were conducted in only one, and not orthogonal directions. The lines varied in length from 150 to 625 m. Along each line, survey flags had been inserted in the ground at intervals of 25 m. As the radar antenna passed each flag, the radar operator impressed a segmented line, or distance mark, on the radar profile. Though the radar provides a continuous record of subsurface conditions, interpretations were restricted to these observation points.

Electromagnetic Induction:
Background:
Electromagnetic induction is a non-invasive geophysical technique which uses electromagnetic energy to measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted average measurement for a column of earthen materials to a specified observation depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are produced by changes in the electrical conductivity of soils and other earthen materials. The electrical conductivity of soils is influenced by the (i) volumetric water content, (ii) type and concentration of ions in solution, (iii) temperature and phase of the soil water, and (iv) amount and type of clays in the soil matrix, (McNeill, 1980). The apparent conductivity of soils increases with increases in the exchange capacity and the water, soluble salt, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

Though seldom diagnostic in themselves, lateral and vertical variations in apparent conductivity have been used to infer changes in soils and soil properties. As EM measurements integrate the bulk physical and chemical properties for a defined observation depth into a single value, responses can be associated with changes in soils and soil map units (Hoekstra et al., 1992; Jaynes et al., 1993). For each soil, the inherent variability in physical and chemical properties, as well as temporal variations in soil water and temperature, will establish a unique and characteristic range of observable apparent conductivity values. This range can be influenced by differences in use or management practices (Sudduth and Kitchen, 1993).

Electromagnetic induction is not suitable for use in all soil investigations. Generally, the use of EM techniques has been most successful in areas where subsurface properties are reasonably homogeneous, the effects of one property (e.g. clay, water, or salt content) dominates over the other properties, and variations in EM response can be related to changes in the dominant property (Cook et al., 1992). Some soil properties and soil types can be inferred or predicted with EM techniques provided one is cognizant of changes in parent materials, topography, drainage, and vegetation.

Equipment:
The electromagnetic induction meters were the EM38 and EM31, manufactured by GEONICS Limited. The observation depth of an EM meter is dependent upon intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. The EM38 meter has a fixed intercoil spacing of 1.0 m. It operates at a frequency of 13.2 kHz. The EM38 meter has effective observation depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). The EM31 meter has a fixed intercoil spacing of 3.66 m. It operates at a frequency of 9.8 kHz. The EM31 meter has effective observation depths of about 3 and 6 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1979). Measurements of conductivity are expressed as milliSiemens per meter (mS/m).

Two-dimensional plots of the survey area were prepared using the software program SURFER for Windows developed by Golden Software, Inc. Data used to construct these simulations were kriged and the resulting matrices smoothed using cubic spline techniques.

Survey Procedures:
An irregularly-shaped grid had been established across the sustainable agriculture field (about 40 acres) at the Beltsville Research Center. The grid was marked by 296 survey flags which had been inserted in the ground at a 25 m interval. At each of the 296 grid intersections, measurements were taken with an EM38 and an EM31 meter. Measurements were taken with each meter placed on the ground surface in both the horizontal and vertical dipole orientations.

RESULTS

Radar survey:

With both systems and antennas, high rates of signal attenuation within the medium-textured surface layers and the moderately-fine to fine textured argillic horizons limited the depth of observation. In most areas, high rates of signal attenuation limited the depth of observation to the argillic horizon. Generally, within the sustainable agriculture field, depths to the argillic horizon were shallow (less than 50 cm). In some areas the depth of penetration was not limited by this layer. In these areas, it was presumed that the clay content of the argillic horizon and the soil were less. Areas having lower clay contents are less attenuating to the radar signals. However, even in these areas, radar profiles continued to be plagued by high level of unwanted signal noise, and weak or intermittent subsurface reflections. Soils having lower clay contents occurred principally in the western portion of the field.

Within the sustainable agriculture field, the potential for successful GPR soil or hydrogeologic interpretations is low. Most radar profiles were exceedingly depth restricted and difficult to interpret. In areas where GPR was able to profiled to greater depths, profiles consisted of numerous, short, segmented interfaces which varied laterally in expression. In many of these areas, GPR profiles were highly complex and often consisted of multiple superimposed or segmented subsurface interfaces. The absences of a sharply defined and continuous subsurface reflector limited the interpretation of radar profiles. Without a prohibitive number of auger observations, it would be difficult to adequately interpret the radar profiles.

EM Survey:
Interpretations of the EM data are based on the identification of spatial patterns within the data set. Figures 2 and 3 are two-dimensional plots of the EM data collected with the EM38 meter in the horizontal and vertical dipole orientations, respectively. Figures 4 and 5 are two-dimensional plots of the EM data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. For Figure 2, 3, 4, and 5, the intervals are 5, 10, 25, and 20 mS/m, respectively. Variations in isoline intervals reflect the range in EM responses measured with each meter and orientation.

In Figures 2, 3, 4, and 5, EM responses were strongly influenced by the presence of "cultural features." Within the study site, the influence of overhead power lines (southern and western portion of site) and metallic fences (northeast corner of study site) were recognized during the course of the survey. The presence of additional cultural features was suggested by either anomalously low (< 1 mS/m) or high (>30 mS/m) EM responses, and by artificial (linear) patterns appearing on the simulated plots.

In the horizontal dipole orientation (Figures 2 and 4), both meters detected a linear feature extending across the central portion of the site. This feature appears to be about 50 m wide and extends, in an east to west direction, about 500 m across the site. The pattern suggests a former roadway and/or buried utility line. At the western end of the linear feature is a 175 m subsection, which is conspicuous because of its exceptionally high EM responses. This anomalously high subsection appears in all plots (Figures 2, 3, 4, and 5). It was inferred that the linear feature detectable only in the horizontal dipole orientation (Figures 2 and 4) represents a relatively shallow features, perhaps a former road bed. As the anomalously high, 175 m subsection was detectable with both meters and orientations, it was presumed to represents a larger, deeper feature, possibly a former structure.

Within the sustainable agriculture field, cultural features so strongly influenced the EM responses that soil and hydrogeologic patterns were obscured. To reduce the influence of cultural features, responses less than 1 mS/m or greater than 30 mS/m were deleted from the data set. Two-dimensional plots were developed (Figures 6, 7, 8, 9) from the revised data set (248 observations). The basic statistics for each meter are displayed in Table 1.

For the field, EM responses generally increased slightly with increasing observation depth (responses of the EM38 meter were less those of the EM31 meter, and, for the EM31 meter, responses in the horizontal dipole orientation were typically less than those in vertical dipole orientation). This pattern probably reflects increased soil moisture and/or clay contents with increasing soil depths.

Table 1
Electromagnetic Induction Survey
of the
Sustainable Agriculture Field
(all values are in mS/m)

Meter	Orientation	Minimum	Maximum	Quartiles 1st	Median	3rd	Average
EM38	Horizontal	5	27	10	12	14	12.4
EM38	Vertical	5	23	10	12	15	12.2
EM31	Horizontal	8	31	13	16	19	16.4
EM31	Vertical	9	31	14	17	19	16.8

Electromagnetic induction methods focuses on the rate and magnitude of change in responses from place to place. Variations in each meters response can be related to differences in soil type, landscape position, and depth to contrasting materials. Two-dimensional maps prepared from EM data provide a graphic description of variations in soils and/or soil properties within the survey site.

Figures 6 and 7 represent two-dimensional maps prepared from data collected with the EM38 meter in the horizontal and the vertical dipole orientations, respectively. At most observation points, values of apparent conductivity measured with the EM38 meter remained the same or decreased slightly with increasing depth (horizontal dipole measurements > vertical dipole orientation). This relationship was believed to reflect decreasing clay and volumetric water content with increasing soil depth (0 to 150 cm).

Figures 8 and 9 represent two-dimensional maps prepared from data collected with the EM31 meter in the horizontal and the vertical dipole orientations, respectively. With the exception of the western portion of the site, values of apparent conductivity remained the same or increased slightly with increasing depth (horizontal dipole measurements < vertical dipole orientation). This relationship was believed to reflect increasing clay and volumetric water content with increasing soil depth (0 to 6 m).

The two-dimensional maps can be used to show not only the spatial distribution of apparent conductivity values, but to quantify the magnitude and rate of change in soils and soil properties. Comparing figures 6, 7, 8, and 9, values of apparent conductivity were highest in the eastern portion of the study site. Soils recognized in the eastern portion of the study site included members of the Christiana, Elkton, Keyport, and Othello series. These soils have fine and moderately fine textured argillic horizons. Values of apparent conductivity were lowest in the western portion of the site where the clay and volumetric water contents were assumed to be lower. Soils mapped in the western portion of the study site included members of the Downer, Matapeake, and Mattapex series. These soils have medium and moderately-fine textured argillic horizons.

In general, soils in the eastern portion of the study site had higher clay contents within their control section than soils in the western portion of the study site. Differences in soils and clay contents could explain the observed differences in EM responses. These figures provide a continuous description of the rate and magnitude of change in apparent conductivity and inferred soil properties.

RESULTS:

1. Within the sustainable agriculture field, because of relatively high rates of signal attenuation, GPR techniques are inappropriate for deep investigations. Because of the discontinuous nature of many soil features and, in the lack of adequate "ground-truthed" information, GPR techniques were too interpretative for shallow investigations over this relatively extensive area (40 acres).

2. Radar profiles collected with the 120 mHz antenna have been returned to Dr. Lengnick under a separate cover letter. Radar profiles collected with the 300 mHz have been stored on tape. These profiles will be stored for future processing or retrieval.

3. Electromagnetic induction techniques disclosed the location of several "cultural features" within the study site (see Figures 2, 3, 4, and 5). These features have the appearance of a road leading to a buried structure. Knowledge of the presence and location of these features should be of assistance to researchers tasked with assessing the effects of crop rotation, cover crops and low-till cultivation, or the application of chemical and biologic controls within the sustainable agriculture field.

4. Two-dimensional plots can provide a continuous description of the rate and magnitude of change in apparent conductivity and inferred soils or soil properties. These plots can be used to evaluate the adequacy of sampling schemes.

5. With adequate soil probe measurements, either GPR or EM techniques can be used to assess the depth to shallow, finer-textured argillic horizons.

It has been my pleasure to work with you and Tim and to be a part of your project. If I can be of any further assistance, please do not hesitate to call or write.

With kind regards

Jim Doolittle

James A. Doolittle
Research Soil Scientist

cc:
J. Culver, Assistant Director, Soil Survey Division, NSSC, NRCS, Lincoln, NE
S. Holzhey, Assistant Director, Soil Survey Division, NSSC, NRCS, Lincoln, NE

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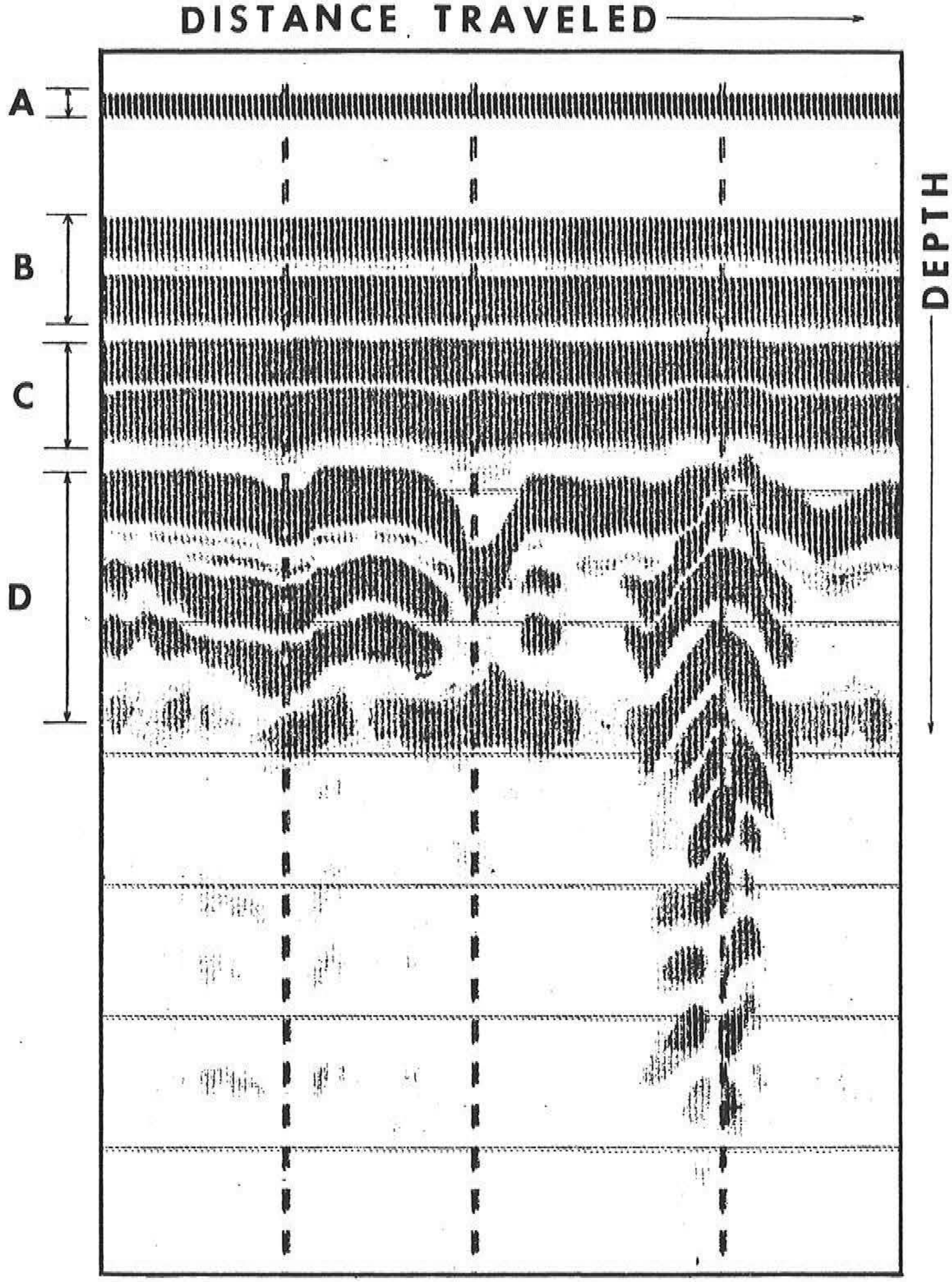
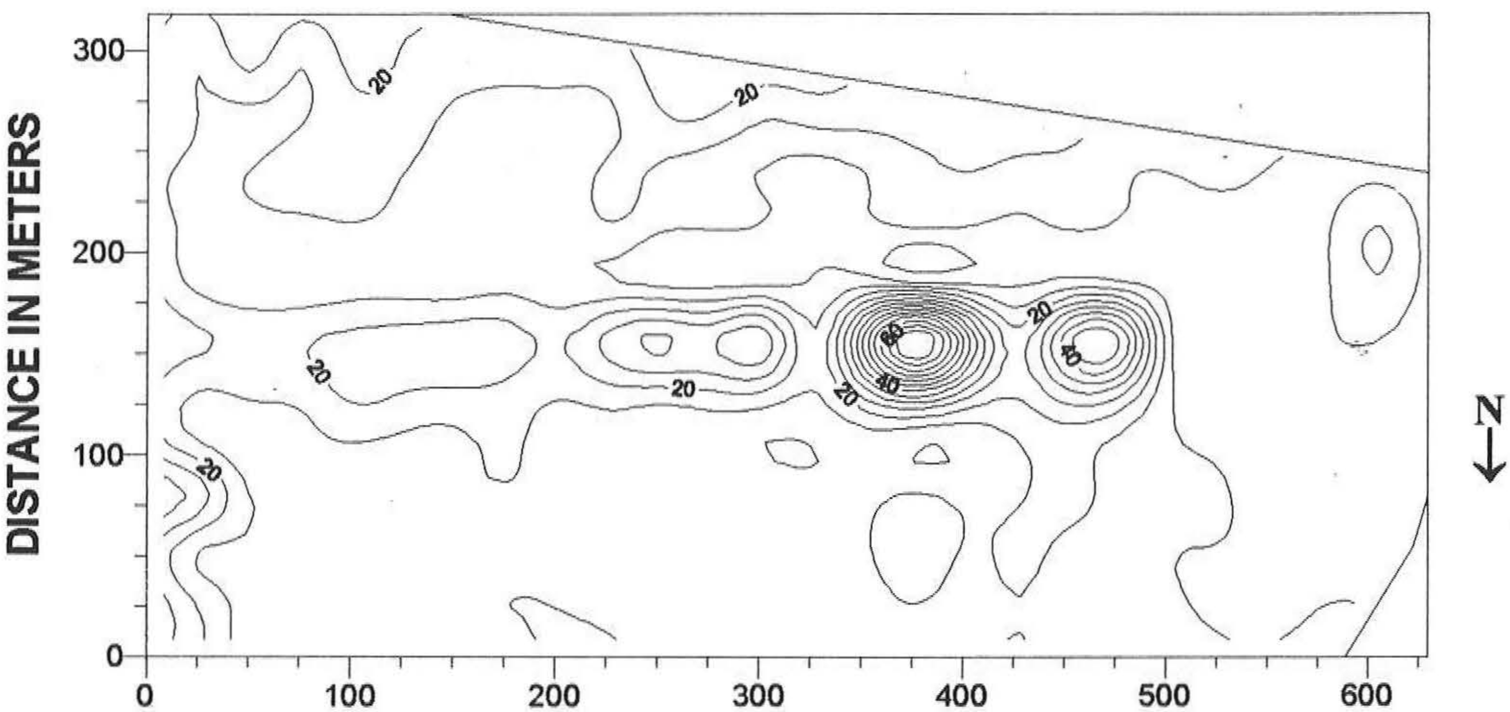


FIG. 1

A GRAPHIC PROFILE

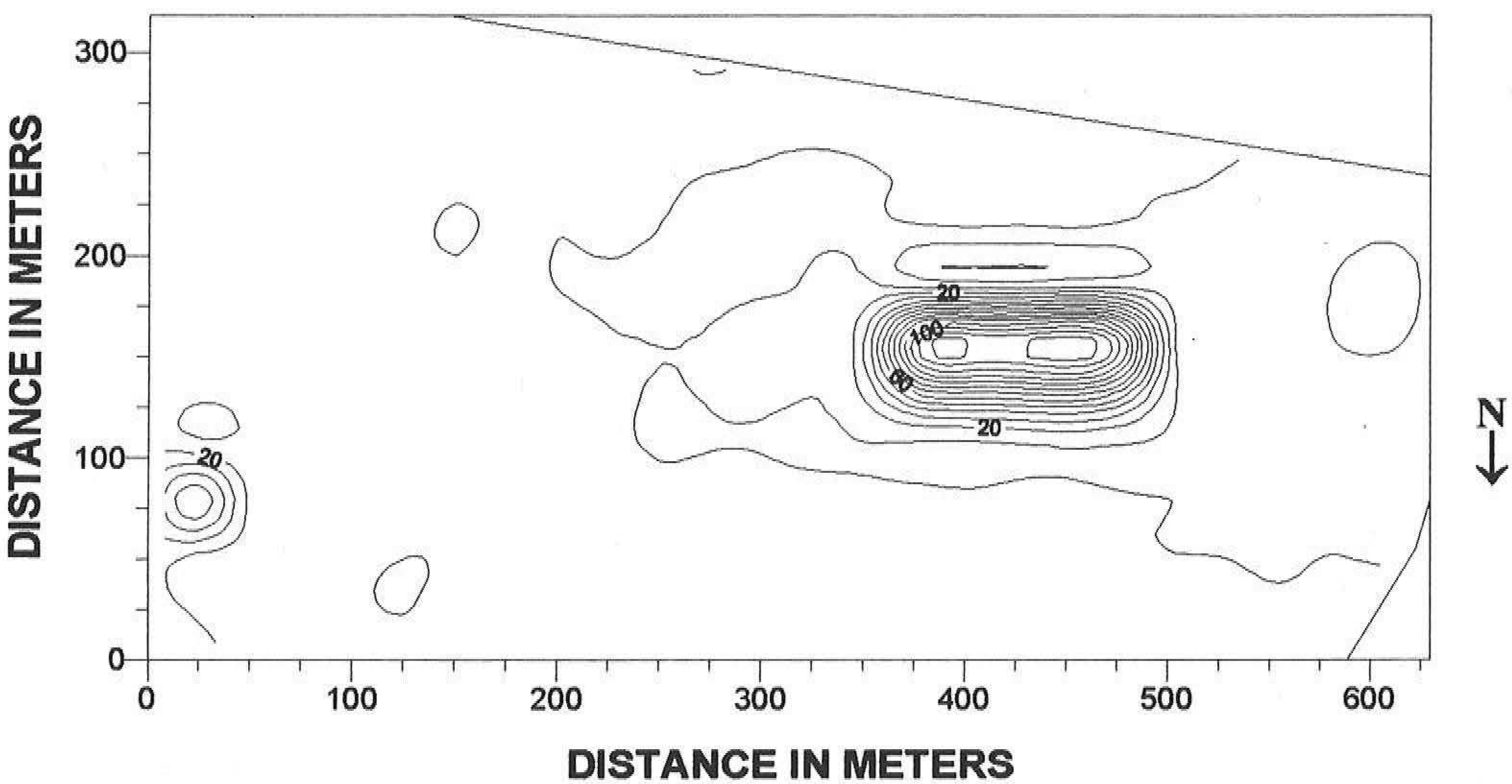
SUSTAINABLE AGRICULTURE PROJECT FIELD

EM38 METER
HORIZONTAL DIPOLE ORIENTATION
INTERVAL = 5 mS/m



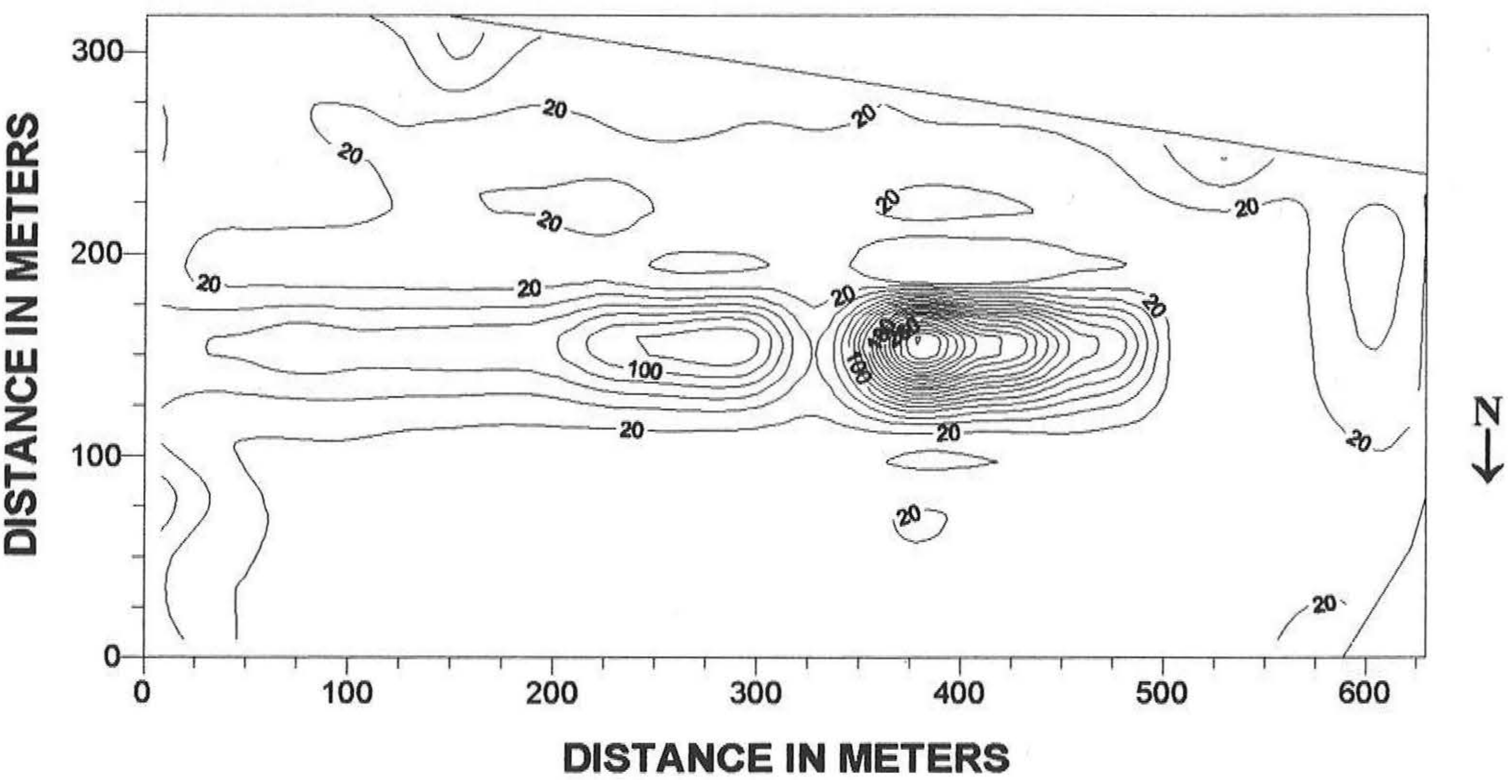
SUSTAINABLE AGRICULTURE PROJECT FIELD

EM38 METER
VERTICAL DIPOLE ORIENTATION
INTERVAL = 10 mS/m



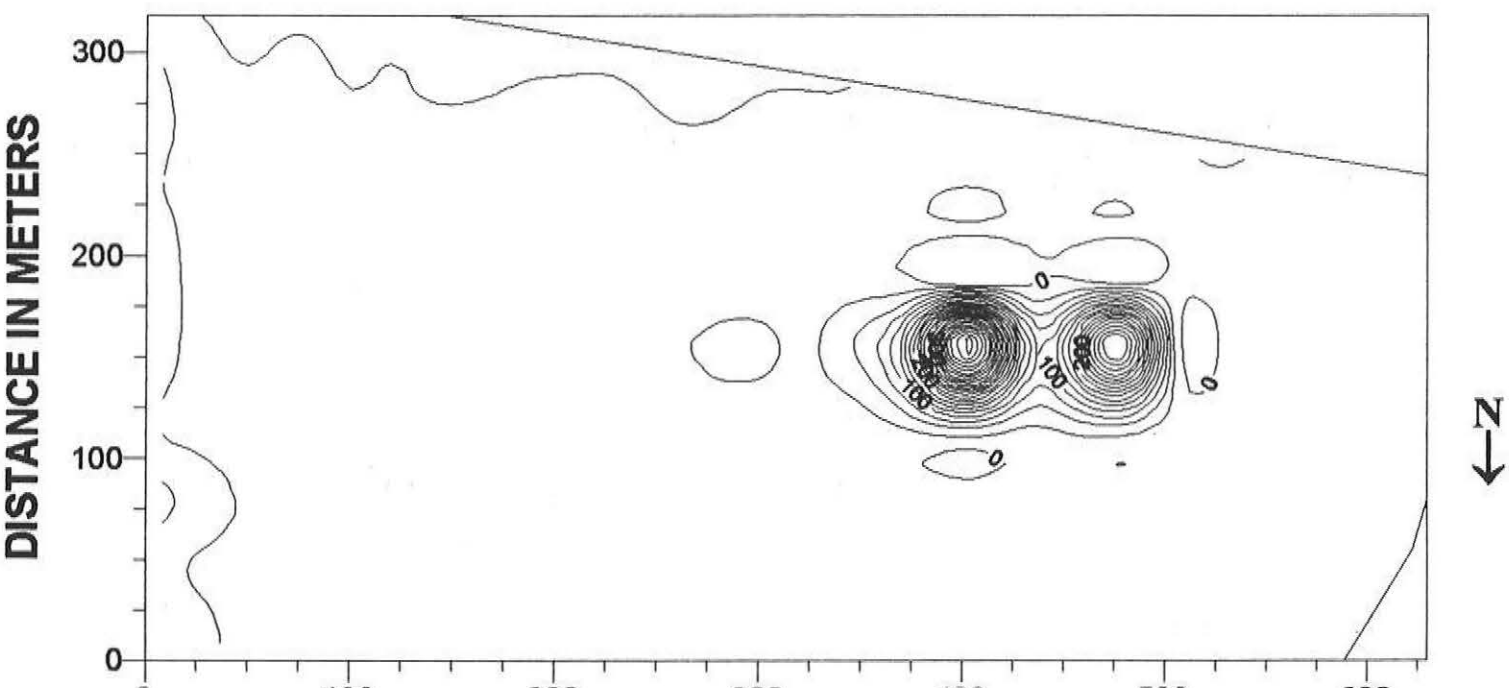
SUSTAINABLE AGRICULTURE PROJECT FIELD

EM31 METER
HORIZONTAL DIPOLE ORIENTATION
INTERVAL = 20 mS/m



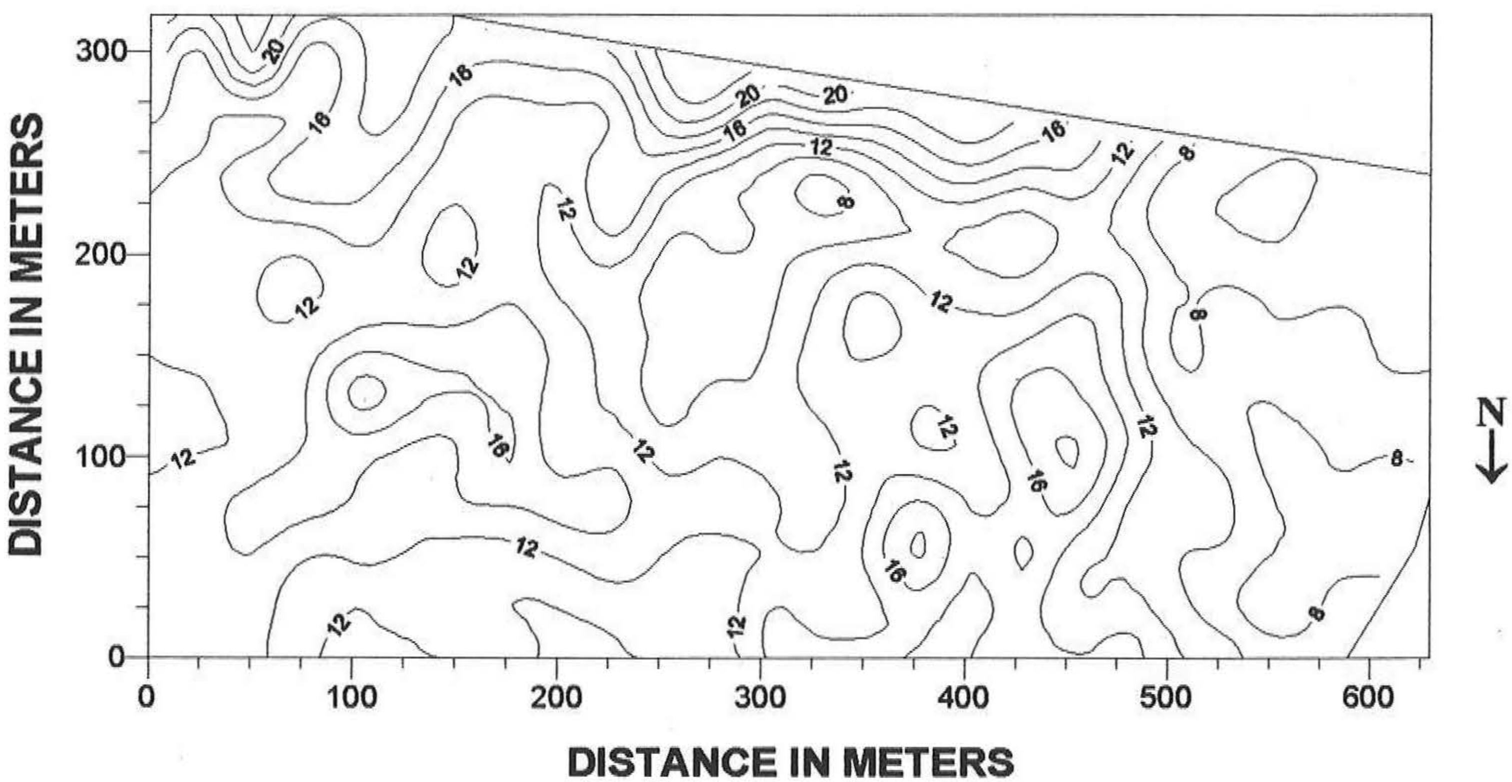
SUSTAINABLE AGRICULTURE PROJECT FIELD

EM31 METER
VERTICAL DIPOLE ORIENTATION
INTERVAL = 25 mS/m



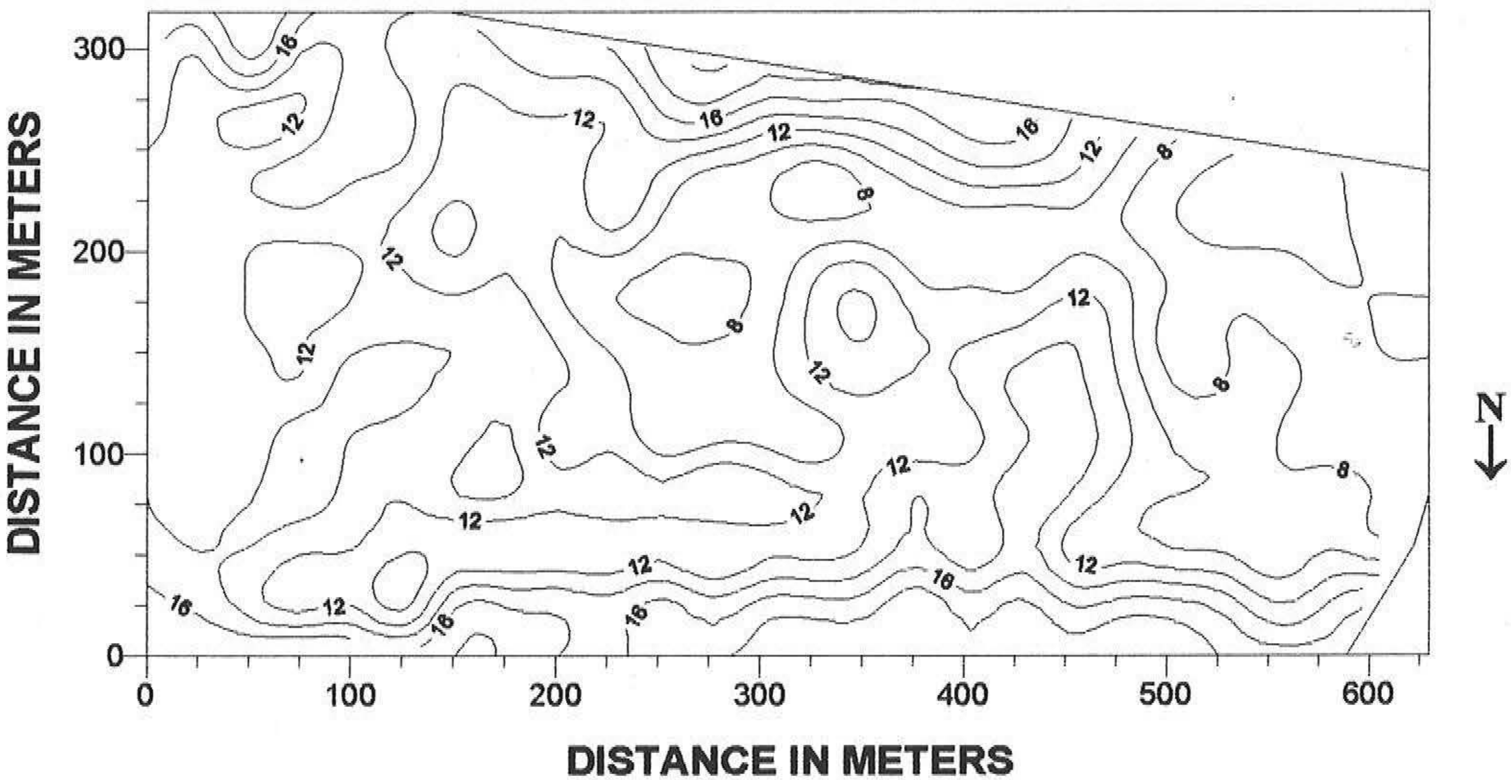
SUSTAINABLE AGRICULTURE PROJECT FIELD

EM38 METER
HORIZONTAL DIPOLE ORIENTATION



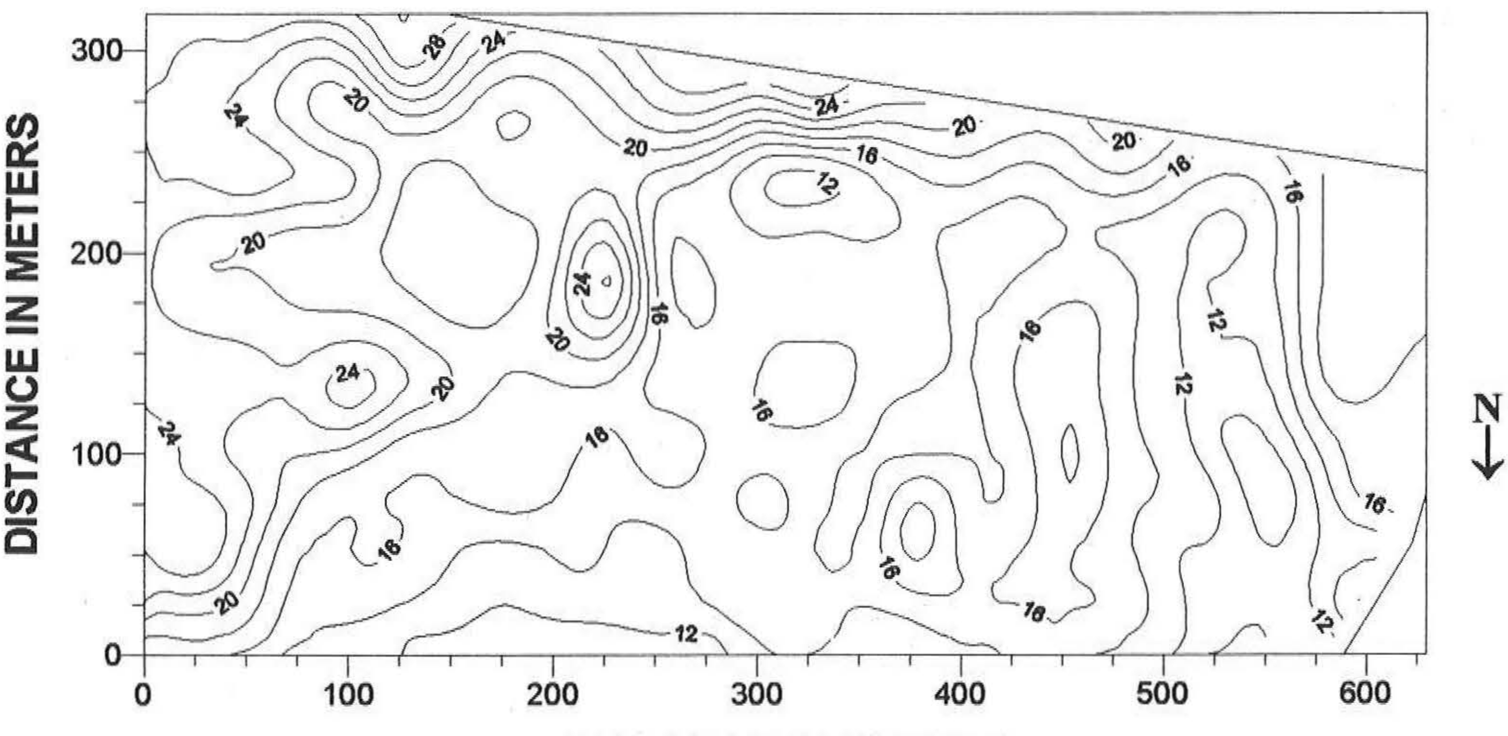
SUSTAINABLE AGRICULTURE PROJECT FIELD

EM38 METER
VERTICAL DIPOLE ORIENTATION



SUSTAINABLE AGRICULTURE PROJECT FIELD

EM31 METER
HORIZONTAL DIPOLE ORIENTATION



SUSTAINABLE AGRICULTURE PROJECT FIELD

EM31 METER
VERTICAL DIPOLE ORIENTATION