Subject: -- Ground-Penetrating Radar Assistance --

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Purpose:
The purpose of this investigation was to evaluate the potentials of using ground-penetrating radar (GPR) as a tool for golf green management.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Sam Indorante, MLRA Project Leader, USDA-NRCS, Carbondale, IL
She-Kong Chong, Hydrologist-Soil Physicist, Dept. Plant, Soils, and General Agriculture, Southern Illinois University, Carbondale, IL
Kathy Renfro, Golf Course Superintendent, Hickory Ridge Golf Course, Carbondale, IL

Activities:
All field activities were completed on 22 October 1999. The Hickory Ridge Golf Course is a public golf course that is owned and operated by the Carbondale Park District.

Equipment:
The radar unit used in this study was the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc.¹ The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. The model 5103 (400 mHz) antenna was used in this study.

The radar profile shown in this report was processed through the WINRAD software package.¹ Processing was limited to signal stacking, horizontal scaling, color transforms and table customizing. Color transformation and table customization were used to reduce signal amplitudes and background noise.

Background:
Ground-penetrating radar is an impulse radar system designed for shallow, subsurface investigations. This noninvasive geophysical tool provides a continuous profile of subsurface features. Ground-penetrating radar has attributes similar to seismic reflection methods. Short pulses of electromagnetic energy in the VHF and UHF frequency range are transmitted into the ground from an antenna that is moved along the surface. The pulses form a wavefront that moves downward until it contacts an interface separating layers of differing electrical properties. At each interface, a portion of the pulse's energy is reflected back to the receiving antenna. In general, the more abrupt and contrasting the electromagnetic properties across an interface, the greater the amplitude of the reflected signal and the more intense the resulting image on a radar profile. The GPR receiving unit samples and amplifies the

¹ Trade names have been used in this report to provide specific information. Their use does not constitute endorsement.
reflected energy and converts it into a similarly shaped waveform in a lower frequency range. The processed reflected waveforms can be displayed on a video screen, thermal plotter, or recorded on an internal hard drive for future playback or processing.

Ground-penetrating radar is an effective tool for imaging near-surface features. This technique has been used to locate buried drains, irrigation pipes, and utility cables (Annan et al., 1984; Asmussen et al., 1986; Chow and Rees, 1989). In addition, GPR has been used to monitor the movements of wetting fronts through surface layers (Vellidis et al., 1990), detect perched water tables (Freeland et al., 1998), and chart subsurface soil horizons and layers (Collins and Doolittle, 1987; Mokma et al., 1990: Raper et al., 1990). In these studies, GPR has proven to be a fast, noninvasive tool for the detection and accurate depth measurement of subsurface features. No documented study is known that discusses the use of GPR as a tool for golf green management. The purpose of this investigation was to evaluate the feasibility of using GPR as a tool for golf green management.

**Calibration:**
The model 5103 (400 mHz) antenna was used in this study. The maximum depth of observation decreases rapidly with increasing antenna frequency. High frequency antennas (>400 mHz) provide well-resolved images of shallow features in soils that have low electrical conductivity. In golf green management surveys, the depth of interest is generally less than 20 inches and concerns are principally confined to the sandy root zone mixture. For these surveys, the 400 mHz antenna provides adequate observation depths and resolution of subsurface features. Though not available for this study, the use of a 900 mHz antenna would improve the resolution of subsurface features discussed in this report.

Ground-penetrating radar is a time scaled system. This system measures the time it takes electromagnetic energy to travel from an antenna to an interface (i.e., soil horizon, stratigraphic layer, buried artifact) and back. To convert travel time into a depth scale, the velocity of pulse propagation must be known. Several methods are available to determine the velocity of propagation. A direct and accurate method is to measure the two-way travel time to a known reflector on a radar profile. The velocity of propagation can then be determined using the equation (after Morey, 1974):

\[ V = \frac{2D}{T} \quad [1] \]

Equation [1] describes the relationship of the average propagation velocity (V) to the depth (D) and two-way pulse travel time (T) to a reflector. In this study of a golf green, the two-way radar pulse travel time through the sandy root zone mixture was compared to the measured depth to the underlying, finer-textured soil material at several observation points. Based on the round-trip travel time to this interface, the averaged velocity of propagation through the upper part of the soil profile was estimated to be 0.1049 meters per nanoseconds (m/ns). Based on this velocity, a scanning time of 20 ns provided a maximum observation depth of about 1.05 m.

**Interpretation:**
Figure 1 is a representative radar profile from a golf green. The horizontal scale represents units of distance traveled along an antenna traverse. The length of the radar traverse depicted in Figure 1 is about 19 m (62.5 ft). Survey flags had been inserted in the ground at intervals of 1.52 m (5 ft). As the antenna was pulled past each flag, the operator impressed a vertical mark on the radar profile. In Figure 1, these vertical marks, which appear in the upper part of the radar profile, have been numbered sequentially (1 to 12).

The vertical scale is a time scale that can be converted into a depth scale if the average velocity of signal propagation through each layer is known. The numbers that appear along the left-hand border of this figure represent units of time (in nanoseconds). Because of differences in soil water content, the velocity of signal propagation is faster through the sandy root zone mixture than the underlying loamy soil materials. To correctly depth scale the radar profile, two depth scales are needed: one for the sandy root zone mixture and one for the underlying loamy subsurface layers. The average velocity of propagation through the sandy surface layers was 0.1049 m/ns. At this velocity, scanning times of 5 and 10 nanoseconds provides observation depths of about 25 and 50 cm (about 10 and 20 in).
Each interface appearing on the radar profile is generally displayed as a group of dark bands. The dark bands (red and blue in Figure 1) occur at both positive and negative signal amplitudes. The narrow white band(s) separating the darker bands represent the neutral or zero crossing between positive and negative signal amplitudes.

In Figure 1, the upper-most interface represents reflections from the soil surface. This interface appears as a series of continuous, parallel bands. Near observation points 3 and 4, this interface appears to rise on the radar profile. However, the surface is smooth and nearly level across the entire green. The apparent rise in the soil surface near these two observation points (3 and 4) is attributed to a localized acceleration in the velocity of propagation through the sandy root zone mixture. Golfers typically exit the green near observation points 3 and 4. Because of the steady and focused traffic, the soil has been compacted. Differences in soil compaction (due to traffic) affects not only the soil’s bulk density and moisture content, but also the propagation velocity of the radar signals.

The major subsurface reflection seen in this radar profile is the contact of the sandy root zone mixture with the underlying loamy soil materials. This interface is laterally continuous but variable in expression. The bands become slightly wider near observation point 1, and between observation points 8 and 11. These areas have known subsurface drainage problems. In these areas, lateral changes in pulse widths are associated with changes in the dominant frequency caused of variations in soil moisture contents. Increased soil water content within the sandy root zone mixture results in a broadening or dispersion of the radar pulse. As a consequence, localized areas of subsurface wetness and poor drainage can be inferred from radar profiles.

Small objects such as rocks, roots, or buried cultural features can produce hyperbolic patterns. Features that produce these reflections are referred to as "point reflectors." In Figure 1, four point reflectors have been identified and labeled (see “A”). These reflectors represent buried, 4-in, perforated, plastic drainage pipes. These pipes are partially embedded in the underlying loamy soil materials. Ground-penetrating radar can be used to quickly and nondestructively locate and map buried drainage and irrigation systems beneath golf greens.

**Results:**
The sandy, electrically resistive root zone mixture found beneath golf greens is ideally suited to GPR. Ground-penetrating radar provides a rapid, noninvasive method for subsurface investigations. With GPR, multiple traverses of golf greens can be readily completed and detailed cross sections showing the thickness of the sandy root zone mixture prepared. In addition, areas of subsurface wetness and poor drainage can be identified and the locations of buried drainage and irrigation systems can be mapped.

It was my pleasure to work again in Illinois and with Sam Indorante.

With kind regards,

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References


