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Subject: Investigation of tree roots with ground-penetrating radar (GPR) **Date:** 18 January 2001

To: John Butnor
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Purpose: The purpose of this investigation was to evaluate the suitability of using ground-penetrating radar to locate tree roots and buried woody coarse debris within representative Coastal Plain soils.

Participants:
John Butnor, Biological Scientist, USDA-FS, Southern Research Station, Research Triangle Park, NC
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
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Tom Stokes, Graduate Research Assistant, School of Forestry, Auburn University, Auburn, AL

Activities:
All activities were completed during the period of 11 to 13 December 2000.

Equipment:
The radar unit used in this study was the Subsurface Interface Radar (SIR) System-2000, manufactured by Geophysical Survey Systems, Inc. (GSSI).[1] The SIR System-2000 consists of a digital control unit (DC-2000) with keypad, LCD VGA video screen, and connector panel. A 12-volt battery powered the system. This system is backpack portable and, with an antenna, typically requires two people to operate. A model 5100 (1.5 GHz)) antenna was used in this study.

The radar profiles included in this report have been processed through the WINRAD software package developed by GSSI.[1]

Study Site:
The study site is located in Decatur County, Georgia, about nine miles southwest of Bainbridge. The study site consists of stands of loblolly pines that are managed by International Paper Company. These stands are referred to as the "Field of Dreams." The study site is located in an area of Troup and Lucy soils. The deep, somewhat excessively drained Troup soil and the very deep, well drained Lucy soil formed in sandy and loamy marine and fluvial sediments of the Southern Coastal Plain. Troup is a member of the loamy, kaolinitic, thermic Grossarenic Kandiudults Family. Lucy soil is a member of the loamy, kaolinitic, thermic Arenic Kandiudults family.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the antenna to an interface (e.g., root, soil horizon, stratigraphic layer) and back. To convert the travel time into a depth scale,

[1] Trade names have been used in this report to provide specific information. Their use does not constitute endorsement.

either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (D), two-way, pulse travel time (T), and propagation velocity (V) are described in the following equation (after Morey, 1974):

$$D = V*T/2$$

Velocity is expressed in meter per nanosecond. The amount and physical state (temperature dependent) of water have the greatest effect on the velocity of propagation.

The radar was calibration prior to fieldwork. A velocity of propagation for the upper part of the soil profile was estimated by burying a metallic object at a depth of 14 inches. Based on the round-trip travel time to the buried reflector, the averaged velocity of propagation was estimated to be 0.1355 m/ns. Based on an average velocity of propagation of 0.1355 m/ns, a scanning time of 10 ns provided a maximum penetration depth of about 0.68m (about 27 inches).

Field Procedures:
Twelve trees were selected in different treatment plots for detailed grid mapping with GPR. Prior to the GPR survey, each tree was felled. The stumps were cut even with the ground surface. Debris and litter were removed from the area immediately surrounding the stump. The detailed GPR survey was completed at each tree using a 1.5 GHz antenna, survey wheel and survey mat (equipment kindly loaned to this research project by Geophysical Survey Systems, Inc.). The mat was marked with a 24 by 24 inch grid. Grid lines are spaced at 2-inch intervals in orthogonal directions (13 in each direction). Pulling the 1.5 GHz antenna and survey wheel along the two sets of thirteen parallel grid lines completed a survey. Four surveys were completed at each tree by relocating the mat. The mat was relocated and aligned four times at each tree: one for the northwest, northeast, southeast, and southwest corners of the stump.

As data from the detailed grid surveys at each of the thirteen trees would be later processed and developed into three-dimensional block diagrams by Geophysical Survey Systems, Inc., the manufacturer prescribed the settings on the control unit. These settings are listed as "Setting 1" in Table 1. With these settings, no gain or filtration was applied to the radar data.

Table 1

Control Settings used on SIR-2000 Unit

	Setting 1	Setting 2
Sample/scan	256	256
Bits/sample	16	16
Scans/second	64	46
Stacking	0	0
Units	N	N
Scan Unit	200	200
Unit Mark	0	0
Dielectric Constant	4.9	4.9
Position	187.9	187.9
Range	10 ns	10 ns
GAIN	1	0 16 30 40
Low Pass Filter	0	4016
High Pass Filter	0	251
Horizontal Smoothing	3	3

In addition to the detail grid surveys, GPR traverses were completed along three, 3.6-m transect lines located near each of the twelve trees. Along each line, seven flags were inserted in the ground at intervals of 60 cm and served as observation points. At each observation point, soil cores were later obtained. "Setting 2" (see Table 1) was used for these surveys. This setting provided more appropriate gain and filtration to the radar data.

An additional twenty four trees were selected in three blocks (1, 2, 3) and four treatments (1, 3, 5, 7). Four diagonal 10-m traverse lines were established at each tree (with the tree as the center of a "X"). These lines were orientated in either an assumed northwest–southeast or a northeast-southwest direction. For each orientation, two parallel traverse lines were established to cross on each side of the tree and spanned the area between the adjoining rows of trees. Along each line, flags were inserted in the ground at intervals of 1 m and served as observation points. "Setting 2" (see Table 1) was used for these surveys.

Table 2 is a record of the radar survey and files completed with the study site.

Table 2

Record of GPR File, Identity of Tree, Location of Grid or GPR Traverse, and Observation Flag or Core Number.

File	Tree	Location	Flags
2	A	NW1/4	
3	A	NE1/4	
4	A	SE1/4	
5	A	SW1/4	
6	A	EAST LINE	1 TO 7
7	A	RIGHT LINE	7 TO 1
8	A	CROSS LINES	1 TO 7
9	B	EAST LINE	8 TO 14
10	B	RIGHT LINE	14 TO 8
11	B	CROSS LINES	8 TO 14
12	B	NW1/4	
13	B	NE1/4	
14	B	SE1/4	
15	B	SW1/4	
16	C	NW1/4	
17	C	NE1/4	
18	C	SE1/4	
19	C	SW1/4	
21	C	EAST LINE	15 TO 21
22	C	RIGHT LINE	21 TO 15
23	C	CROSS LINES	15 TO 21
24	D	EAST LINE	22 TO 28
25	D	RIGHT LINE	28 TO 22
26	D	CROSS LINES	22 TO 28
27	D	NW1/4	
28	D	NE1/4	
29	D	SE1/4	
30	D	SW1/4	
31	E	NW1/4	
32	E	NE1/4	
33	E	SE1/4	
34	E	SW1/4	
35	E	EAST LINE	29 TO 35
36	E	RIGHT LINE	35 TO 29
37	E	CROSS LINES	29 TO 35
38	F	EAST LINE	36 TO 42
39	F	RIGHT LINE	42 TO 36
40	F	CROSS LINES	36 TO 42
41	F	NW1/4	
42	F	NE1/4	
43	F	SE1/4	
44	F	SW1/4	

File	Tree	Location	Flags
45	G	NW1/4	
46	G	NE1/4	
47	G	SE1/4	
48	G	SW1/4	
49	G	EAST LINE	43 TO 49
50	G	RIGHT LINE	49 TO 43
51	G	CROSS LINES	43 TO 49
52	H	EAST LINE	50 TO 56
53	H	RIGHT LINE	56 TO 50
54	H	CROSS LINES	50 TO 56
55	H	NW1/4	
56	H	NE1/4	
57	H	SE1/4	
58	H	SW1/4	
59	I	NW1/4	
60	I	NE1/4	
61	I	SE1/4	
62	I	SW1/4	
63	I	EAST LINE	57 TO 63
64	I	RIGHT LINE	63 T0 57
65	I	CROSS LINES	57 TO 63
66	J	EAST LINE	64 TO 70
67	J	RIGHT LINE	70 TO 64
68	J	CROSS LINES	64 TO 70
69	J	NW1/4	
70	J	NE1/4	
71	J	SE1/4	
72	J	SW1/4	
73	K	NW1/4	
74	K	NE1/4	
75	K	SE1/4	
76	K	SW1/4	
77	K	EAST LINE	71 TO 77
78	K	RIGHT LINE	77 T0 71
79	K	CROSS LINES	71 TO 77
80	L	NW1/4	
81	L	NE1/4	
82	L	SE1/4	
83	L	SW1/4	
84	L	EAST LINE	78 TO 84
85	L	RIGHT LINE	84 TO 78
86	L	CROSS LINES	78 TO 84

Table 2 (continued)

Record of GPR File, Identity of Tree, Location of Grid or GPR Traverse, and Observation Flag or Core Number.

File	Block	Treatment	Tree	Direction
87	1	3	A	SW - NE
88	1	3	A	NE - SW
89	1	3	A	SE - NW
90	1	3	A	NW - SE
91	1	3	B	SW - NE
92	1	3	B	NE - SW
93	1	3	B	SE - NW
94	1	3	B	NW - SE
95	1	7	A	SW - NE
96	1	7	A	NE - SW
97	1	7	A	SE - NW
98	1	7	A	NW - SE
99	1	7	B	SW - NE
100	1	7	B	NE - SW
101	1	7	B	SE - NW
102	1	7	B	NW - SE
103	1	5	A	SW - NE
104	1	5	A	NE - SW
105	1	5	A	SE - NW
106	1	5	A	NW - SE
107	1	5	B	SW - NE
108	1	5	B	NE - SW
109	1	5	B	SE - NW
110	1	5	B	NW - SE
111	1	1	A	SW - NE
112	1	1	A	NE - SW
113	1	1	A	SE - NW
114	1	1	A	NW - SE
115	1	1	B	SW - NE
116	1	1	B	NE - SW
117	1	1	B	SE - NW
118	1	1	B	NW - SE
119	3	3	A	SW - NE
120	3	3	A	NE - SW
121	3	3	A	SE - NW
122	3	3	A	NW - SE
123	3	3	B	SW - NE
124	3	3	B	NE - SW
125	3	3	B	SE - NW
126	3	3	B	NW - SE
127	3	1	A	SW - NE
128	3	1	A	NE - SW
129	3	1	A	SE - NW
130	3	1	A	NW - SE
131	3	1	B	SW - NE
132	3	1	B	NE - SW
133	3	1	B	SE - NW
134	3	1	B	NW - SE

File	Block	Treatment	Tree	Direction
135	3	7	A	SW - NE
136	3	7	A	NE - SW
137	3	7	A	SE - NW
138	3	7	A	NW - SE
139	3	7	B	SW - NE
140	3	7	B	NE - SW
141	3	7	B	SE - NW
142	3	7	B	NW - SE
143	3	5	A	SW - NE
144	3	5	A	NE - SW
145	3	5	A	SE - NW
146	3	5	A	NW - SE
147	3	5	B	SW - NE
148	3	5	B	NE - SW
149	3	5	B	SE - NW
150	3	5	B	NW - SE
151	2	7	A	SW - NE
152	2	7	A	NE - SW
153	2	7	A	SE - NW
154	2	7	A	NW - SE
155	2	7	B	SW - NE
156	2	7	B	NE - SW
157	2	7	B	SE - NW
158	2	7	B	NW - SE
159	2	1	A	SW - NE
160	2	1	A	NE - SW
161	2	1	A	SE - NW
162	2	1	A	NW - SE
163	2	1	B	SW - NE
164	2	1	B	NE - SW
165	2	1	B	SE - NW
166	2	1	B	NW - SE
167	2	5	A	SW - NE
168	2	5	A	NE - SW
169	2	5	A	SE - NW
170	2	5	A	NW - SE
171	2	5	B	SW - NE
172	2	5	B	NE - SW
173	2	5	B	SE - NW
174	2	5	B	NW - SE
175	2	3	A	SW - NE
176	2	3	A	NE - SW
177	2	3	A	SE - NW
178	2	3	A	NW - SE
179	2	3	B	SW - NE
180	2	3	B	NE - SW
181	2	3	B	SE - NW
182	2	3	B	NW - SE

interface provides an undesired subsurface reflection. It is noise. For image analysis, it would be beneficial if these sources of noise were removed.

Disposition of GPR data:
All data have been saved to disk. All radar files have been processed through WINRAD and a copy of these files both in .dzt and .bmp formats has been forwarded to John Butnor. These files are in three folders on the CD: "GA-PAD-GRIDS, GA-X-DETAIL, and GA-LINES." The folder "GA-PAD-GRIDS" contains the detail grid files from the twelve trees that were felled and latter excavated. The folder "GA-X-DETAIL" contains the files of the 6-m line surveys that were completed at each of the twelve trees. The folder "GA-LINES" contains the files of the line surveys that were completed at the additional twenty-four trees located in different treatment blocks.

A copy of the detail grid files from the twelve trees that were felled and latter excavated has been forwarded to Dan Delea, Geophysical Surveys Systems, Inc. He will prepare three-dimensional diagrams showing of the rooting patterns. The participants of this survey are indebted to the cordial assistance and services rendered by Geophysical Survey Systems, Inc.

It was my pleasure to assist and work with you again.

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:
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Reference

Morey, R. M. 1974. Continuous subsurface profiling by impulse radar. p. 212-232. *IN:* Proceedings, ASCE Engineering Foundation Conference on Subsurface Exploration for Underground Excavations and Heavy Construction, held at Henniker, New Hampshire. Aug. 11-16, 1974.

Post Processing of the GPR Data:
The following procedures were used to process the data. Files were reviewed and all double reference marks were removed. The double reference marks had been used to indicate the location of trees along survey lines. In addition, missing reference marks were inserted on radar profiles. All reference marks were converted into distance marks and the distance between the marks were normalized. Distance normalization parameters for the twelve trees that were selected for the detail survey were: 200 scans/meter and 1 meter/mark for each radar file collected on the mat, and 140 scans/meter and 1 meter mark for each radar file collected along the lines that adjoining the detailed grid area. For the additional 96 radar lines (radar files 87 to 182), distance normalization parameters were 100 scans/meter and 1 meter per mark.

For the files from the detailed grid survey collected on the radar mats, the range gain prescribed by GSSI was exceedingly low and required amplification in order for the reflectors to be apparent. Range gain was interactively added to the data using a linear gain at three gain nodes. The gain functions were increased to 2, 4, and 8 at gain nodes 1,2,and 3, respectively. Range gain was also applied to the data collected along the traverse lines. Once again range gain was interactively added to the data using a linear gain at three gain nodes. The gain functions were 1, 3, and 1 at gain nodes 1,2,and 3, respectively.

Interpretations:
Figure 1 is a representative radar profile from this study. This radar profile has been processed through the WINRAD software package. Processing was limited to range gain, distance normalization, color transforms and table customizing. Gain was increased to increase signal amplitudes.

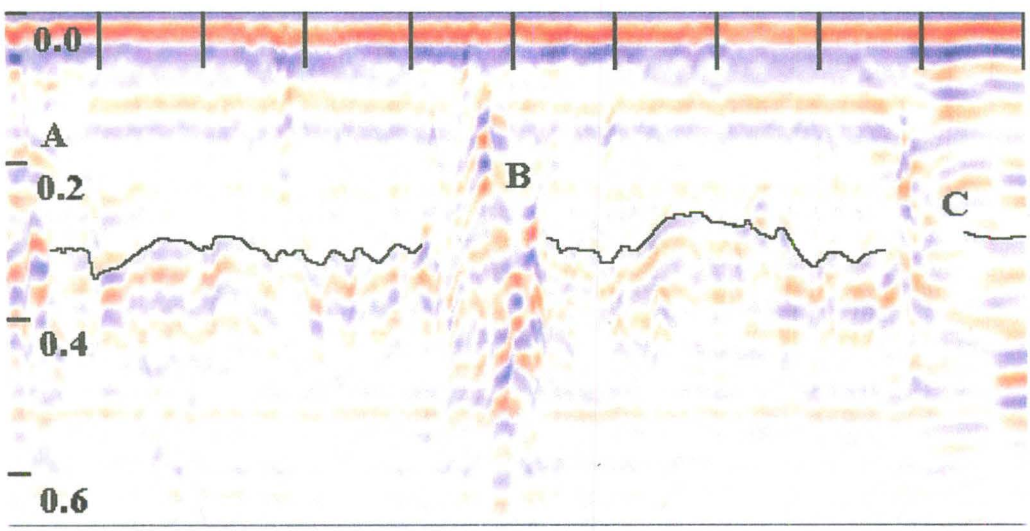

Figure 1. Representative radar profile from the GPR survey that was conducted in the "Field of Dreams," Bainbridge, Georgia.

In Figure 1, the parallel, multiple reflections at the top of the radar profile represent the soil surface. The horizontal scale represents units of distance traveled along the traverse line. The ten black vertical lines at the top of the radar profile represent equally spaced observation points. These points are spaced at an interval of about 1 m. The vertical scale along the left-hand border is a depth scale and is expressed in m.

In Figure 1, clusters of roots (see A, B, and C in Figure 1) occur along the tree rows. These clusters occur adjacent to tree. Tree roots produce high amplitude reflections. Areas between the trees are relatively free of point reflectors.

Two sources of system and background noise are apparent in Figure 1. Noise is an undesired reflection or signal. Each reflection consists of a positive and negative polarity signal and their multiples. Tree roots produce multiple reflections or "ringing" of the reflected signal. For each tree root two to five multiple reflections are produced. In Figure 1, the interface separating the very dark grayish brown, loamy sand surface and subsurface layers from the underlying yellowish red, fine sandy loam subsoil has been highlighted with a dark line. While the depth to the subsoil may be beneficial for some studies, in the analysis of tree roots, this