Evaluating Soil Compaction with a Portable Electronic Cone Penetrometer

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SUMMARY. During Summer 1997, soil compaction in agricultural fields was evaluated using a portable electronic cone penetrometer. Rather than requiring the operator to read from an analog scale, this penetrometer stores data in a digital form, which are downloaded to a personal computer for analysis. Soil strength, measured in 1-inch (2.5-cm) increments, can be stored for up to 100 25-inch (64-cm) deep soil profiles. This instrument can be operated by a single person and facilitates collecting large data sets required to characterize highly variable soil environments. Because the penetrometer was designed to measure and formulate predictions about the trafficability of wet soils, it is often incapable of measuring the higher soil resistance occurring in drier agricultural fields. If used soon after rainfall or irrigation, it is useful in detecting hardpans associated with tillage or traffic patterns.

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Numerous studies describe the deleterious effect of compact soil horizons on crop root growth (Barber, 1971; Unger and Kaspar, 1994; Vepraskas, 1994). Observations suggest that root systems of several vegetable crops can be limited by compact soil layers (Lorenz and Maynard, 1988; Portas, 1973). The numerous tillage and residue management options in use today have complex effects on soil properties. Tillage implements, vehicular traffic, and residue cover all affect soil strength. Research tools are needed to evaluate how management schemes affect soil properties and crop performance.

Soil compaction can be inferred from measurements of bulk density, porosity, or penetrometer resistance (Chen and Tessire, 1997; Vepraskas, 1994). An advantage of using a penetrometer is that no soil removal is required. Because penetrometer resistance changes with soil wetness, soil moisture measurements are often necessary for data interpretation.

A variety of portable analog and digital soil penetrometers are available. The U.S. Army Corps of Engineers recently developed a penetrometer with features overcoming limitations of other models used in agricultural systems. Goodman and Rowse (1984) described a model with operating depth limited to 6 inches (15 cm), Reeves et al. (1992) used a benchtop rather than a portable model, Christensen et al. (1998) described a model which requires two operators, and Hendrick (1969) described a model with an analog paper chart recorder. Anderson et al. (1980) described three models, one providing spurious results due to the spring mechanism, one vehicle-mounted unit with limited portability, and one similar to the model described here but requiring data to be transcribed from a calculator to a computer file. The penetrometer used in this study is designed for use by a single operator and stores data in a digital format. The objective of this research was to evaluate the usefulness of this portable electronic penetrometer for characterization of compaction in agricultural soils.

Materials and methods

This study utilized a portable electronic penetrometer developed by the U.S. Army Corps of Engineers. Penetrometer resistance, up to 750 lb/inch^2 (5.2 MPa) is measured by a load

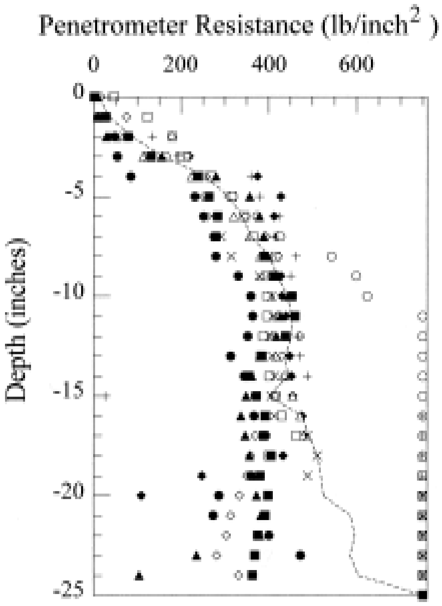

Fig. 1. Penetrometer resistance profiles from a wheel track within a single experimental plot at the Tidewater Research Station. Symbols represent individual data points for each of 10 profiles. The line indicates mean values for each 1-inch (2.5-cm) depth increment (145 lb/inch^2 = 1.0 MPa).

cell (model #SSM-AJ-500, Interface, Scottsdale, Ariz.) connected to a tapered (30° angle) probe with 0.2-inch^2 (130-mm^2) cross-sectional area. A 0.5-inch^2 (320-mm^2) probe tip with a 30° angle is also available. An electronic eye senses the vertical distance above the soil surface, and load cell distortion is used to calculate penetrometer resistance at each inch. A single operator pushes the penetrometer into the soil by leaning on a metal handle. The device stores data for up to 100 25-inch (63-cm) deep soil profiles. Individual data points and averages for selected profiles are downloaded to a DOS-based personal computer. Data are averaged for each 1-inch (2.5-cm) increment, for eight overlapping 4-inch (10-cm) increments (0 to 4, 3 to 7, 6 to 10, 9 to 13, 12 to 16, 15 to 19, 18 to 22, and 21 to 25 inches), and for four overlapping 7-inch (18-cm) increments (0 to 7, 6 to 13, 12 to 19, and 18 to 25 inches). Data reported here include both 1-inch and 4-inch increments. With a portable computer, profile data can be viewed in the field. The penetrometer and portable battery pack weigh 12.6 lb (5.7 kg) can be operated by a single person at a rate of about one profile per minute. A single operator weighing approximately 150 lb (68 kg) collected all data reported here.

During the summer of 1997, we measured soil penetrometer resistance at the Tidewater Research Station in Washington County, and at commercial farms in Beaufort and Perquimans Counties, North Carolina. At the Tidewater Research Station, penetrometer resistance was measured on a long-term tillage study planted in soybean [*Glycine max* (L.) Merr.]. This study had been established 15 years earlier on a Portsmouth fine sandy loam (fine-loamy over sandy or sandy-skeletal, mixed, thermic Typic Umbraquults). The experimental layout was a randomized complete block design with four replicates, and 25×50-ft (7.6×15-m) plots. For each comparison (dry vs. wet, crop row vs. tractor tire track, conventional till vs. notill), we probed five to ten subsamples per plot.

At the Beaufort County site, we sampled a soybean field on a Tomotley fine sandy loam (fine-loamy, mixed, thermic Typic Ochraquults). Six months before our measurements, a 24-inch (61-cm) deep subsoil shank had been drawn through two areas of the field, each with four subsoil slits spaced 10 ft (3 m) apart. Subsoil slit positions were evident from surface residue disturbance since there was no other tillage at this site. Twenty four subsamples were probed from each of the following situations: subsoil slits, halfway between slits, and in surrounding areas at least 10 ft from the nearest slit.

At the Perquimans County site, adjacent conventional till and notill soybean fields on a Scuppernong muck (loamy, mixed, dysic thermic Terric Medisaprists) were sampled to assess compaction in vehicular turning zones. Surface drainage systems in this region result in long [5000 ft (1520 m)], narrow [300 ft (91 m)] fields with restricted vehicle traffic patterns. Eight subsamples were probed at locations 10, 50, 100, 200, and 300 ft (3, 15, 30, 61, and 91 m) from the field edge. Most turning occurs within 30 ft (9 m) of the field edge.

Statistical comparisons, where appropriate, were based on Fisher's protected LSD.

Results and discussion

The variable nature of soil penetrometer resistance requires large sample sizes for statistical inferences to be made (Fig. 1). This penetrometer is well-suited to collect such large data sets, and its digital format avoids the need for operators to read data from analog scales or to transcribe data (Anderson et al., 1980; Hendrick, 1969). It is smaller and easier to move throughout a crop field than are electronic penetrometers used by Reeves et al. (1992) and Christensen et al. (1998). Variability in resistance associated with operators and probe speeds can be minimized by using a single, attentive operator. Such variability is not necessarily a problem or limitation, it may merely require larger sample sizes for conclusive results. Calculations based on the variability presented in Fig. 1 suggest that this penetrometer is most appropriate for field studies in which treatments of interest have penetrometer resistances which differ by at least 25% to 50% at the depth of interest (Table 1). At the inter-

Table 1. Estimates of the number of replicate penetrometer resistance profiles (N) required to detect significant differences between treatments for different soil depths. Calculations are based on data presented in Fig. 1 (1 inch = 2.5 cm; 145 lb/inch^2 = 1.0 MPa).

			N required for different confidence intervals (CI)					
Depth	Mean	SD	CI = 10% of mean		CI = 25% of mean		CI = 50% of mean	
(inches)	(lb/inch^2)	(lb/inch^2)	$p < 0.05$	$p < 0.10$	$p < 0.05$	$p < 0.10$	$p < 0.05$	$p < 0.10$
3	156	52	225	147	36	24	9	6
6	341	59	62	41	10	7	2	1
9	421	70	58	38	9	6	2	1
12	454	110	121	79	20	13	5	3
18	512	170	225	147	36	24	9	6

^{z}N = [t^2(SD)^2] / d^2 , where t = student's t (9 df) and d = half of desired confidence interval width [i.e., mean × (% of mean / 100) × 0.5] (Steel and Torrie, 1980).

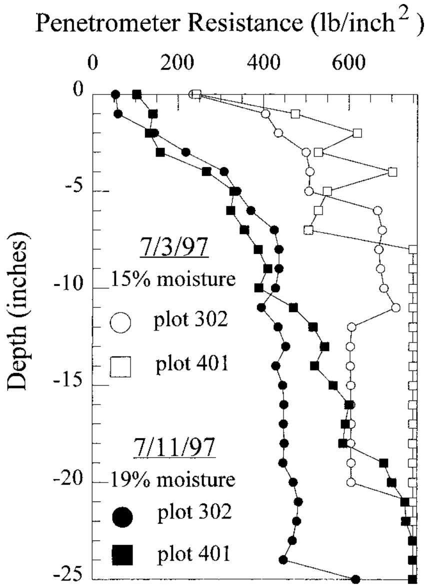

Fig. 2. Penetrometer resistance profiles from two experimental plots collected before (3 July 1997), and following (11 July 1997), irrigation and rainfall. Soil moisture was determined in the 0- to 6-inch (15-cm) depth increment (145 lb/inch^2 = 1.0 MPa).

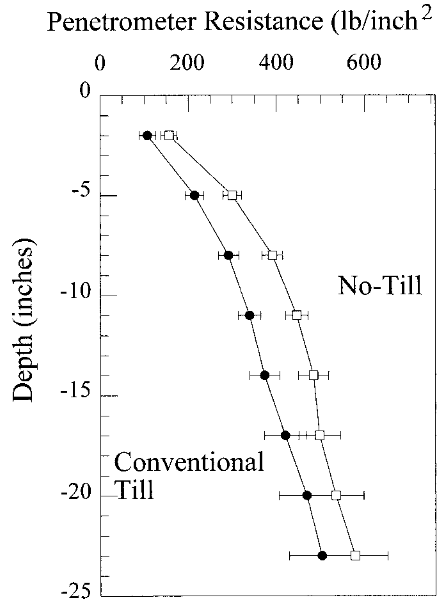

Fig. 4. Penetrometer resistance profiles from notill and conventionally managed soybean research plots. Values plotted are means for 4-inch increments. Error bars indicate standard deviation, differences were not significant at any depth (145 lb/inch^2 = 1.0 MPa).

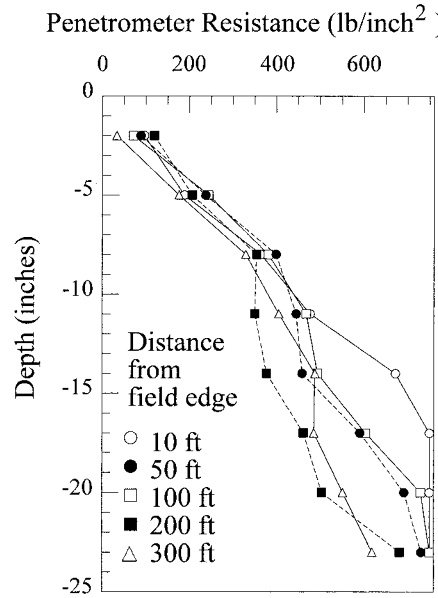

Fig. 6. Penetrometer resistance profiles from different locations in a notill soybean field indicating increased subsoil compaction near the more heavily trafficked edge. Values plotted are means for 4-inch (10-cm) increments (145 lb/inch^2 = 1.0 MPa).

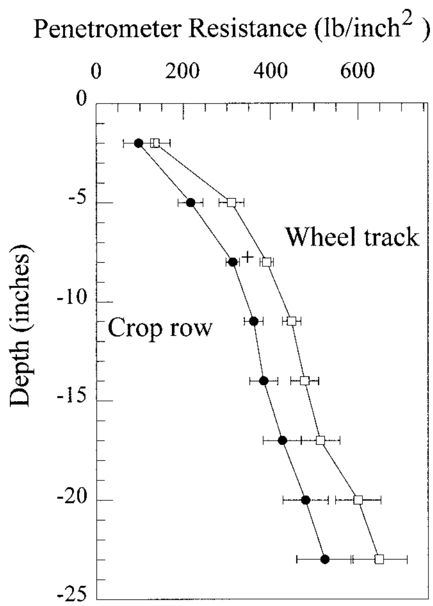

Fig. 3. Penetrometer resistance profiles from within wheel tracks and crop rows of conventionally tilled soybean research plots. Values plotted are means for 4-inch (10-cm) increments. Error bars indicate standard deviation, differences were significant (*p* < 0.1) at the 6- to 10-inch (15- to 25-cm) depth increment (145 lb/inch^2 = 1.0 MPa).

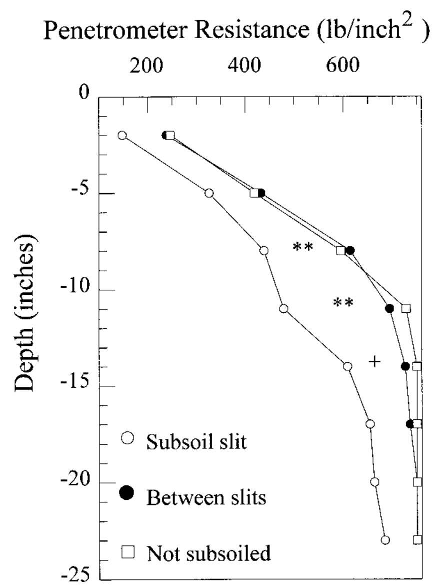

Fig. 5. Penetrometer resistance profiles from subsoil slits, areas located at the 5 ft (1.5 m) midpoint between slits (between slits), and areas located at least 10 ft (3 m) from the nearest subsoil slit (not subsoiled). Values plotted are means for 4-inch (10-cm) increments. Penetrometer resistance was significantly lower in the subsoil slits at the 6- to 10-inch (*p* < 0.01), 9- to 13-inch (*p* < 0.01), and 12- to 16-inch (*p* < 0.1) depth increments (145 lb/inch^2 = 1.0 MPa).

mediate soil depths where compaction is likely to occur (6 to 12 inches, 15 to 30 cm), required sample sizes are smaller than for either surface or deeper layers.

At the Tidewater Research Station, penetrometer resistance was lower on 11 July, as a result of increased soil moisture due to irrigation and rainfall [1-inch (2.5 cm)] following the 3 July sampling date (Fig. 2). Penetrometer resistance was higher in tractor tire tracks than in crop rows, although differences were not significant except at the 6- to 10-inch (15- to 25-cm) depth increment (*p* < 0.1, Fig. 3). Penetrometer resistance was higher in the crop rows of long-term notill than in conventional till soybeans, although differences were not significant (Fig. 4).

At the Beaufort and Perquimans county sites, penetrometer resistance was lower in subsoil slits (Fig. 5), and higher in subsoils [12 to 19 inches (30 to 48 cm)] near the heavily trafficked edges of a notill field (Fig. 6). Field-edge compaction was not detected in an adjacent conventionally tilled field (data not shown).

Although convenient to operate, this penetrometer has some limitations for agricultural field use. It was designed to make predictions about the trafficability of wet soils, and is often incapable of measuring the higher soil resistance occurring in drained agricultural fields. The maximum resistance measured is 750 lb / inch^2 (5.2 MPa), which was frequently exceeded for some soils (Figs. 1, 2, 5, 6). This limitation complicates data analysis, and may erroneously indicate treatment convergence at the upper limit. To minimize this problem, the penetrometer should be used when soils are near *in situ* field capacity.

In summary, if sufficient samples are obtained to account for soil variability, and if soils are near field capacity, this instrument allows a single operator to quantify soil penetrometer resistance profiles in agricultural fields.

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