TECHNICAL NOTE:

COMPARISON OF THE VERIS PROFILER 3000 TO AN ASAE-STANDARD PENETROMETER

K. A. Sudduth, J. W. Hummel, S. T. Drummond

ABSTRACT. *Cone penetrometers, as standardized by ASAE, have been used for many years as the primary instrument for investigating and quantifying soil compaction. Recently, non−standard penetrometers have become commercially available. These instruments depart from the standard so they can simultaneously sense additional soil parameters [e.g., soil electrical conductivity (EC)] in addition to cone index (CI). In this research we compared CI data collected with the Veris Profiler 3000 EC−sensing penetrometer to CI data collected with ASAE−standard large cone and small cone penetrometers. The Profiler operated at a faster insertion speed and exhibited a non−standard cone geometry. Cone geometry had a significant effect when comparing this penetrometer to standard large and small cones. There was also a significant effect of cone size between the two standard cones. It was possible to develop CI−dependent equations relating data collected with one tip to data from another tip, but a large amount of scatter was present in the relationship. No significant effect of insertion speed was detected among the ASAE−standard insertion speed of 30 mm/s (1.2 in./s) and two higher speeds, 40 and 50 mm/s (1.6 and 2.0 in./s). The amount of scatter present in replicate CI data was inversely related to cone diameter, indicating that fewer measurements would be required to obtain a given level of precision with a larger cone.*

Keywords. *Cone penetrometer, Compaction, Cone index, Precision agriculture.*

The processes of soil formation over landscapes along with management−induced soil changes have created soil variations within fields that impact crop production. Soil compaction caused by wheel traffic or tillage operations is an important management−induced factor and can cause yield depression due to deleterious effects on root growth (Unger and Kaspar, 1994). Soil compaction has traditionally been measured with the cone penetrometer (Perumpral, 1987). Standard penetrometers exhibit variability due to clods and cracks, operating parameters, and soil wedge formation in front of the tip (Gill, 1968). Automated penetrometers have been developed to control operating parameters and speed collection of the amount of data required to characterize a field (Perumpral, 1987; Sudduth et al., 1989; Raper et al., 1999). Clark (1999) investigated the use of cone penetrometer data to develop soil strength maps at several different spatial scales. He reported that, due to the variability encountered, accurate mapping of soil strength would require collection of large amounts of data, even if data collection were confined to crop rows, thus collecting data only from untrafficked areas.

Precision agriculture technologies have increased interest among crop consultants and producers in collecting information to understand spatial variability. As a result, a number of manufacturers are now marketing instruments that can, when linked with a GPS receiver, provide spatially referenced soil property data. One such instrument is an automated cone penetrometer that can measure and record both soil strength and soil electrical conductivity (EC) data, available from Veris Technologies of Salina, Kansas (Drummond et al., 2000). The design of the Veris penetrometer is similar, but not identical, to ASAE Standard S313.3 (*ASAE Standards*, 2002a). The design differences were required to incorporate the elements for sensing soil EC, which is a parameter that is affected by a number of different soil properties including clay content, soil water content, varying depths of conductive soil layers, salinity, organic compounds, and metals. Many of these properties also influence soil water and plant growth in agricultural soils; therefore soil EC has been useful as an indicator of crop production variation within a field (Kitchen et al., 1999; 2003).

The purpose of this study was to evaluate several issues associated with use of Veris penetrometer CI measurements. Evaluation of EC measurements was not part of the study because the EC sensing system was revised by the manufacturer subsequent to these tests. Specific objectives of the study were to: compare the variability present in replicate penetrometer data; quantify the effects of the non−standard tip geometry of the Veris EC−sensing penetrometer; and evaluate the effects of insertion speed.

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Equipment and Procedures

Veris Profiler 3000 Penetrometer

The penetrometer used in this research was the Profiler 3000, manufactured by Veris Technologies (Salina, Kans.). It was a self−contained, trailer−mounted device, designed to be pulled through the field by an ATV, tractor, or other vehicle (Drummond et al., 2000). An onboard power unit and hydraulic cylinder were used to insert the penetrometer to a maximum depth of approximately 95 cm (37 in.). Actual insertion depth relative to the ground surface could vary several centimeters on uneven ground. Maximum insertion force was limited to approximately 1 kN (225 lb) or 5 MPa (725 psi) with the EC−sensing tip, to prevent overload of the mechanical components and sensing system. A second hydraulic cylinder pivoted the penetrometer mast through a transverse arc, allowing approximately 90 cm (35 in.) of side−to−side displacement for acquiring data across in−row and between−row locations.

Insertion depth was indicated by a proximity switch that sensed a slotted bar attached vertically to a floating foot, providing a reference to the actual ground surface. Data collection was triggered every 1.27 cm (0.5 in.) as the proximity switch, attached to the penetrometer shaft, moved past the slotted bar. Insertion force was measured by a pressure transducer between the penetrometer shaft and hydraulic cylinder. Soil EC was sensed immediately above the penetrometer tip. The penetrometer tip itself was electrically insulated from the penetrometer shaft with a thin dielectric ring. Electrical contact with the tip was by means of a small steel rod inside, and insulated from, the hollow shaft (fig. 1). Data were location−tagged by GPS and logged on the Veris instrument. Data recorded every 1.27 cm (0.5 in.) of insertion included CI, EC, and insertion speed.

The tip supplied with this penetrometer exhibited both similarities and differences as compared to ASAE Standard S313.3 (fig. 1). The included angle of the cone was the standard 30°; however, the size of the cone and shaft were intermediate between the ASAE−standard large cone and the standard small cone. The most obvious difference in geometry was the 13−mm (0.5−in.) long cylindrical shoulder immediately behind the cone (fig. 1). This cylindrical area facilitated EC measurement, but was considerably longer than the 1.5−mm (0.06−in.) shoulder allowed by the standard.

To allow collection of CI data conforming to ASAE S313.3, two additional shaft assemblies incorporating tips with the ASAE−standard large and small cone dimensions (fig. 1) were obtained. These assemblies could replace the EC−sensing tip on the Veris penetrometer, allowing collection of standard CI data. Tips for all three assemblies were machined from American Iron and Steel Institute (AISI) 4130 steel and heat treated. Although ASAE S313.3 recommends AISI 416 stainless steel to provide long−term corrosion resistance for penetrometer tips, the use of a non−stainless material should not have been an issue in these short−term tests.

Variability and Tip Geometry Comparison Tests

Tests were carried out at eight measurement sites. Two replicate sites were located on Mexico silty clay loam (Fine, smectitic, mesic Aeric Vertic Epiaqualfs) near Centralia in central Missouri. Mexico soils are very deep, somewhat poorly drained, very slowly permeable soils. The other six sites were located on Thorp silt loam (Fine−silty, mixed, superactive, mesic Argiaquic Argialbolls) at the University of Illinois Agricultural Engineering Farm, Urbana, Illinois. Thorp soils are very deep, poorly drained soils.

The Missouri sites (1 and 2) were managed in a long−term (since 1991) minimum−tillage corn−soybean rotation. Tillage operations in 2000 consisted of a tandem disk harrow, followed by two field cultivator passes prior to planting. Penetrometer data were collected on 25 May 2000, within a week after soybean planting. The Illinois sites were located

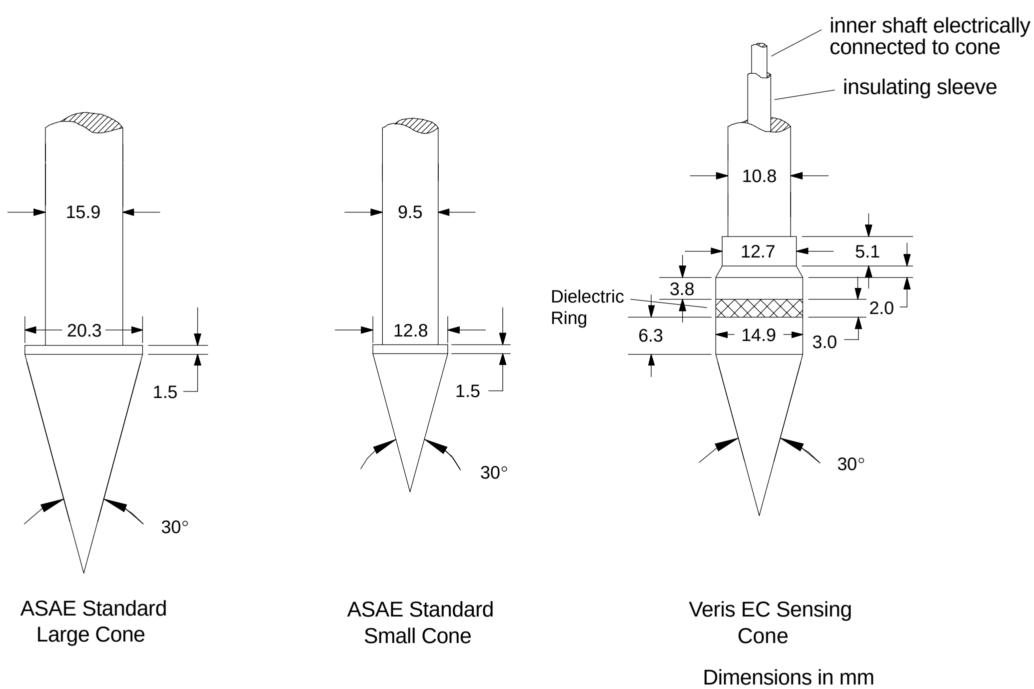

Figure 1. Tip geometry for ASAE−standard large cone, ASAE−standard small cone, and Veris EC−sensing cone (conversion: multiply mm by 0.03937 for in.).

on long−term (since 1992) compaction study plots used in earlier studies described by Ngunjiri and Siemens (1995). Three sites were on replicate uncompacted plots (Sites 3−5), while the other three were on replicate compacted plots (Sites 6−8), all in a corn−soybean rotation. All Illinois sites (3−8) were sweep plowed after harvest in the fall of 1999. Sites 6−8 were compacted in the spring of 2000 using a two−wheel−drive tractor weighted to approximately 10 Mg (22,000 lb), with 20% and 80% of the mass on the front and rear axles, respectively. The tractor was driven across the plots with the center−to−center distance between adjacent tire tracks approximately 0.38 m (15 in.), so that all the plot area received wheel traffic. All Illinois sites (3−8) then received two field cultivator passes prior to planting. Penetrometer data were collected on these plots on 8 and 9 May 2000, within 2 weeks after corn planting.

Data were collected with the EC tip at each of the following positions relative to the planting operation: trafficked row middle, trafficked shoulder, plant row, untrafficked shoulder, and untrafficked row middle (fig. 2). ASAE−standard large cone and small cone data were collected in the same pattern, with each set of data collected within 0.25 m (10 in.) of the previous set. Replications were located within 1 m along the same cropped row, thus all three replications of data at a single site were collected within a distance of 2.5 m (8 ft, fig. 2). The insertion speed used for these tests was 40 mm/s (1.6 in./s). At the time of penetrometer data collection, soil samples were obtained at each site to a depth of 90 cm (36 in.) on a 15−cm (6−in.) increment. Gravimetric soil moisture was determined from these samples by oven drying.

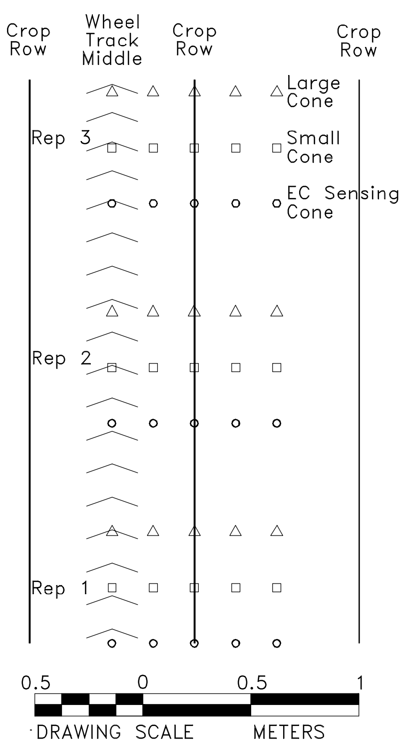

Figure 2. Layout of penetrometer tip comparison study (conversion: multiply m by 3.281 for ft).

Insertion Speed Tests

Recommended cone penetrometer insertion speed is 30 mm/s (1.2 in./s), although EP542 (*ASAE Standards*, 2002b) indicates that somewhat slower rates will not cause significant errors. As initially configured, the Veris penetrometer operated at an insertion speed of approximately 40 mm/s (1.6 in./s). To investigate the effect of insertion speed on CI readings, data were collected on a Mexico silty clay loam site within 400 m (1300 ft) of Sites 1 and 2 described above, on 11 May 2000. Three replications of data were collected both with the EC tip and the ASAE small tip. Data were collected in three positions relative to corn stubble rows: in the row, in the row middle, and at a point halfway between. By adjusting the oil flow rate to the hydraulic cylinder, three nominal insertion speeds were obtained: 30, 40, and 50 mm/s (1.2, 1.6, and 2.0 in./s). The 50 mm/s (2.0 in./s) insertion speed was the maximum achievable with the Veris hydraulic system.

Results and Discussion

CI Variability

A typical graph of CI as a function of depth is shown in figure 3. For visualization, data were averaged over replications and row positions for one uncompacted (fig. 3a) and one compacted (fig. 3b) Illinois site. As expected, the compacted site exhibited consistently higher CI near the soil surface, while the CI pattern deeper in the profile was similar between the two treatments. The highest CI readings were

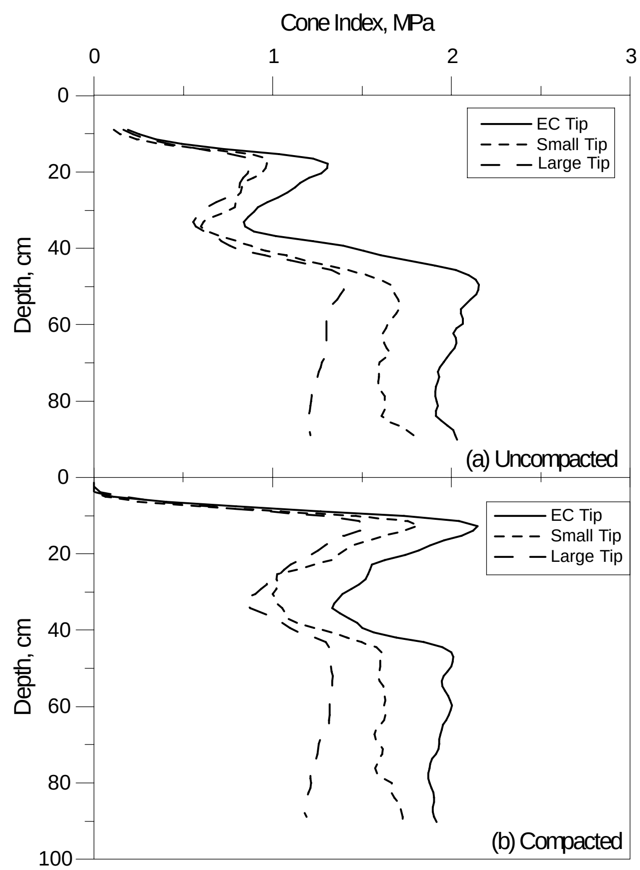

Figure 3. Typical plots of CI as a function of depth for (a) uncompacted and (b) compacted treatments (conversion: multiply MPa by 145.0 for psi, multiply cm by 0.3937 for in.).

obtained with the EC tip. The ASAE−standard large tip exhibited the lowest CI readings, while CI data from the small tip were intermediate to the others. This trend was especially apparent deeper in the soil profile.

Standard deviations of replication differences were calculated using all CI data from each tip (table 1). The deviation between replications decreased with increasing tip size. This result is consistent with Bradford (1980), who also found that the standard deviation of penetration force decreased with increasing penetrometer size. He theorized that the smaller probe would be more sensitive to the heterogeneity found in a structured soil with planes of weakness. Thus, a smaller probe might be preferred for assessing soil strength differences on a very fine spatial scale. A larger probe, since it would compress and shear a larger volume of soil, would not detect small cracks or voids and readings would vary less. Based on these results, the large cone would generally be preferred for characterizing compaction levels, as fewer replicate measurements would be required to obtain the same level of confidence in the data. However, the practical aspects of inserting the large cone, especially in dry soil, could make it unusable in some conditions.

Replication differences were compared as a function of depth (fig. 4). Shown in this figure are the differences between replications for each site−row position−depth combination, along with standard deviation bars. Standard deviations were generally highest in the 15− to 40−cm (6− to 16−in.) depth range. Here, below field cultivator operating depth, compaction variations due to traffic patterns in the current or previous years (i.e., variation between replications in relative placement of penetrometer measurement and tractor wheel track) may be more apparent than in the tilled surface [0 to 15 cm (0 to 6 in.)] layer. The deviation bands became narrower at greater depths in the profile, reflecting more spatially homogeneous soil characteristics with depth. The ASAE small tip, and to a lesser extent the EC−sensing tip, exhibited increases in replication differences at the deepest depths. We theorized that bending of the smaller penetrometer shaft and contact between the shaft and soil caused this increase in CI variability, a phenomenon that is noted in S313.3. These data show that if the ASAE small cone is used to collect CI data, readings from depths greater than about 60 cm (24 in.) should be scrutinized for increases in variability. Calculation of replication standard deviation as a function of depth is a convenient way to do this. The issue of data reliability with the small cone penetrometer is also addressed in S313.3, which suggests that the smaller cone (and shaft) should be used only over a limited depth range of 46 cm (18 in.).

TIP GEOMETRY COMPARISON

As a first step in understanding the effects of tip geometry, CI data were subjected to an analysis of variance. Tip, row position, and location/treatment (Missouri vs. Illinois uncompacted vs. Illinois compacted) all had a statistically significant effect on CI. Overall mean CI values for tip (table 1) were all significantly different, based on Duncan's multiple range test. Tip means calculated separately for each location/treatment and row position combination (i.e., means over depth and replication; table 2), were also all significantly different.

Table 1. Means, and standard deviations of replication differences, for CI readings obtained with each tip.

Tip	Mean MPa (psi)[a]	Std. Dev. MPa (psi)	CV (%)
EC−sensing	1.64 (238)	0.444 (64)	19
ASAE small cone	1.41 (205)	0.497 (72)	26
ASAE large cone	1.08 (157)	0.286 (41)	18

[a] Tip means are all significantly different based on Duncan's multiple range test ($\alpha = 0.05$).

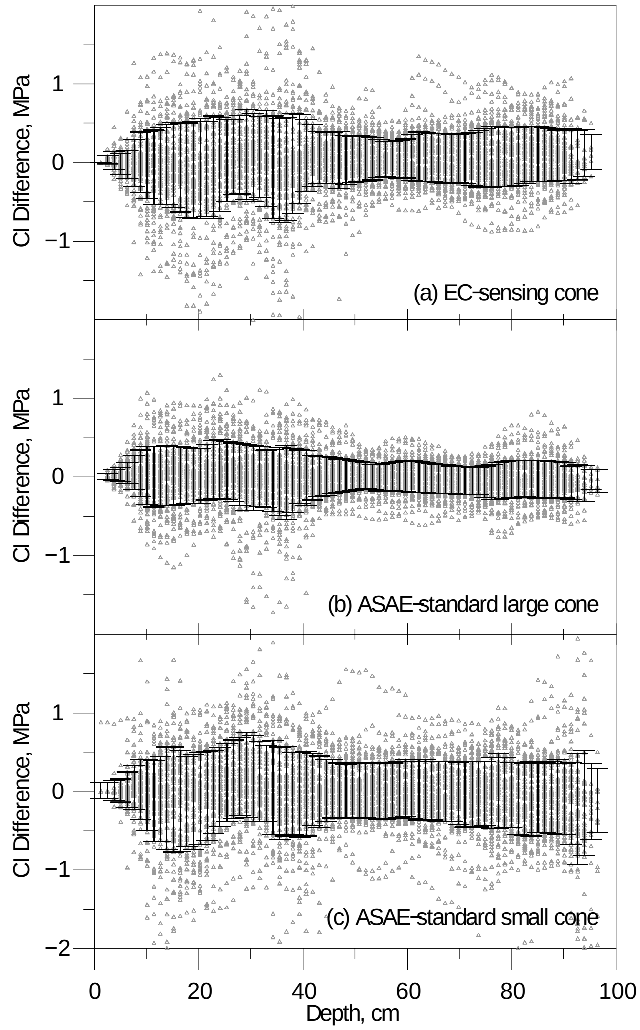

Figure 4. Difference between replications (with standard deviation bars) for CI data from (a) EC−sensing cone, (b) ASAE−standard large cone, and (c) ASAE−standard small cone, as a function of depth (conversion: multiply MPa by 145.0 for psi, multiply cm by 0.3937 for in.).

As shown in table 1, the mean CI for the ASAE−standard small cone was 30% higher than that for the large cone. In work by Freitag (1968), CI increased with decreasing cone size, for cones of the same shape. His laboratory tests in a wet, fine−grained soil showed an increase in CI of approximately 5% between the sizes of the ASAE−standard large and small cones. Although the increase noted by Freitag was less than that observed here, this ratio might be expected to change with soil texture and/or moisture conditions. In our work, the mean CI increase was approximately 23% in the Missouri tests on higher−clay, more fine−grained silty clay loam soil and 33% in the Illinois tests conducted on silt loam soil lower in clay content. Conditions at the time of data collections were not "wet" as in Freitag's test, since both sites had experienced a relatively dry spring prior to planting (table 3).

Table 2. Mean CI readings obtained for each tip at each location and row position.

Location/Treatment Row Position	Mean CI for each Tip, MPa (psi)[a] EC−Sensing	ASAE Small Cone	ASAE Large Cone
Missouri			
Mean of all row positions	1.79 (260)	1.40 (203)	1.14 (165)
Non−trafficked middle	1.79 (260)	1.32 (192)	1.10 (160)
Non−trafficked shoulder	1.80 (261)	1.43 (207)	1.18 (171)
Crop row	1.86 (270)	1.44 (209)	1.19 (172)
Wheel−track shoulder	1.72 (249)	1.43 (207)	1.09 (159)
Wheel−track middle	1.79 (260)	1.39 (202)	1.16 (168)
Illinois uncompacted			
Mean of all row positions	1.56 (226)	1.38 (200)	1.05 (152)
Non−trafficked middle	1.45 (211)	1.28 (186)	1.01 (146)
Non−trafficked shoulder	1.48 (215)	1.27 (184)	0.96 (140)
Crop row	1.61 (233)	1.38 (200)	1.08 (156)
Wheel−track shoulder	1.68 (243)	1.58 (230)	1.11 (161)
Wheel−track middle	1.60 (232)	1.41 (204)	1.07 (155)
Illinois compacted			
Mean of all row positions	1.63 (236)	1.42 (206)	1.07 (155)
Non−trafficked middle	1.62 (235)	1.33 (193)	1.08 (156)
Non−trafficked shoulder	1.52 (221)	1.39 (202)	1.01 (146)
Crop row	1.59 (231)	1.32 (192)	1.07 (155)
Wheel−track shoulder	1.70 (246)	1.54 (224)	1.05 (153)
Wheel−track middle	1.70 (246)	1.54 (224)	1.16 (168)

[a] Within a row, all means are significantly different based on Duncan's multiple range test ($\alpha = 0.05$).

Profile−average [0−90 cm (0−36 in.)] soil moisture was 28.2% at the Missouri sites and 24.4% at the Illinois sites at the time of data collection. Obviously, caution should be taken in comparing data collected using penetrometers with differing cone sizes (i.e., ASAE−standard large and small cones), even if the cone geometry is the same.

The EC−sensing tip exhibited the largest mean CI, 52% higher than that of the ASAE−standard large cone. This result could be expected as a result of sliding friction caused by the long cylindrical shoulder present on this tip (fig. 1). Freitag (1968) stated that adhesion of soil to the shaft could significantly affect the measured CI reading, particularly in sticky clays. His statement was based on having a standard relief between the cone base and the shaft, meaning that the shaft diameter was approximately 0.75 of the cone base diameter (*ASAE Standards*, 2002a). It is logical to assume this shaft adhesion would be more of an issue with the EC tip, since the cylindrical shoulder was the same diameter as the cone base. Armbruster et al. (1990) presented data showing that shaft friction and/or drag accounted for as much as 50% of the total CI measured at the upper end of the penetrometer shaft. We found that the increase in mean CI for the EC−sensing tip over the ASAE−standard small tip was approximately 13% for the Illinois site as compared to 28% for the Missouri site (18% increase over all data). When considering the compaction treatments at the Illinois site separately, the increase was 13% for the uncompacted treatment and 14% for the compacted treatment. The standard small tip was chosen for comparison as its base area [130 mm^2 (0.20 in.^{2})] was closest to the base area of the EC tip [174 mm^2 (0.27 in.^{2})]. The combination of clay and moisture content differences between the two sites may have caused the soil to exhibit more adhesive force along the penetrometer shoulder at the Missouri site. Compaction differences appeared to have little effect on the relationship between standard and non−standard CI data.

Table 3. Gravimetric soil moisture (%) at the time of penetrometer data collection.

Location/Treatment	Depth Increment, cm (in.) 0−15 (0−6)	15−30 (6−12)	30−45 (12−18)	45−60 (18−24)	60−75 (24−30)	75−90 (30−36)
Missouri	22.2	27.0	31.4	30.8	29.7	28.2
Illinois uncompacted	20.1	23.4	24.0	28.5	27.1	23.3
Illinois compacted	21.3	20.7	26.5	27.9	24.6	24.7

Regression equations were formulated to relate EC−tip CI readings to ASAE−standard tip readings, and also to relate readings from the two ASAE−standard tips. A stepwise procedure was used, incorporating location, and linear and squared terms of CI and depth. For each of the regression equations, all five parameters were significant, although the linear CI term always had the largest effect and entered the model first. Including all variables in the model reduced standard errors by 11% or less in all cases, with an average reduction of 9% compared to a simple linear regression on CI. Although the effect of location/soil (Missouri vs. Illinois sites) was significant, development of separate calibrations for each location reduced standard errors by a maximum of 5%, and only in some instances. Because of the relatively small improvements seen, and in the interest of parsimonious model development, only the CI term was included and overall regressions were developed including all locations. The data used in these regressions included all individual CI values for the particular tips being compared, with no averaging across row position, depth, or replication. Plots of these data (e.g., fig. 5) exhibited significant scatter in the relationship between CIs, but a linear trend with a slope different from one could be discerned.

The standard errors of these estimation equations (table 4) were similar in magnitude to the replication standard deviations shown in table 1. Estimation errors were also calculated as a function of depth. Figure 6 shows the standard errors obtained when relating CI data obtained with the EC−sensing tip to CI data obtained with the standard large tip.

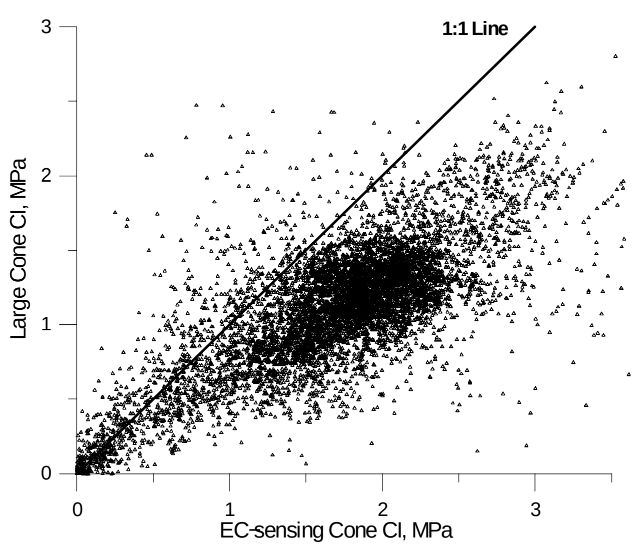

Figure 5. Comparison of large−cone data to EC−sensing cone data (conversion: multiply MPa by 145.0 for psi).

Table 4. Statistics for linear equations relating CI obtained with one tip to CI obtained with another tip.

Tips Related by Equation			
Dependent Variable	Independent Variable	R^2	Standard Error, MPa (psi)
Small tip	EC−sensing tip	0.57	0.413 (60)
Large tip	EC−sensing tip	0.60	0.294 (43)
Large tip	Small tip	0.59	0.296 (43)

The error bands (fig. 6) have the same general shape as the standard deviation bands of figure 4, and are intermediate in magnitude to those of the large tip and the EC−sensing tip. Depths in the soil profile where there was more variation between replications [i.e., shallower than 50 cm (20 in.), fig. 4] also exhibited higher estimation errors (fig. 6). In general, CI readings obtained with one tip could be related to CI data obtained with another tip with a precision approaching that of replicate data collected with a single tip within a 2.5 m (8 ft) distance (fig. 2).

In this study, we were able to develop reasonable relationships ($r^2 \approx 0.6$) for the soils and conditions present. However, the use of this approach under more widely varying conditions, such as coarse−textured versus fine−textured soils or variations in soil moisture, would require additional verification. It is possible that the differences in geometry between the EC−sensing tip and the ASAE−standard tips might lead to less predictable relationships under other conditions.

Insertion Speed Tests

Insertion speed test data were analyzed using an analysis of variance approach. Average insertion speed calculated over penetration depths of 10 to 86 cm (4 to 34 in.) was within 4% of target speed in all cases. Near−surface and end−of−stroke data were eliminated from this calculation due to increased noise in the speed data at these positions. The effect of speed on mean CI was not significant. Frietag (1968) reported a 10% increase in CI for a three− to four−fold increase in insertion speed. In this test, where insertion speed increased by less than 70%, the expected CI increase using Frietag's data would have been less than 2.5%. In our data, mean CI increased by 2% (not statistically significant) over the range of speeds. Soil heterogeneity (i.e., variation in CI between replicate penetrometer insertions) and the relatively narrow range of insertion speeds possible with the Veris penetrometer meant that differences were difficult to discern statistically. ASAE EP542 asserts that an insertion speed somewhat less than the standard 30 mm/s (1.2 in./s) is acceptable; this test suggests that speeds somewhat greater than the standard, at least up to 50 mm/s (2.0 in./s) will also produce acceptable results.

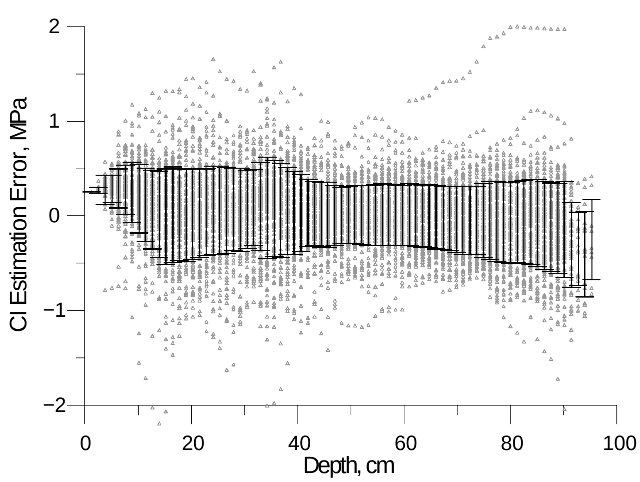

Figure 6. CI estimation error (with standard error bars) for conversion of EC−tip data to correspond with ASAE−standard large tip data (conversion: multiply MPa by 145.0 for psi, multiply cm by 0.3937 for in.).

Summary and Conclusions

An automated cone penetrometer, the Veris Profiler 3000, which measured soil electrical conductivity (EC) with depth in addition to cone index (CI) was evaluated. This penetrometer operated at a faster insertion speed and included cone geometry that did not conform to ASAE Standard S313.3. The effects of these non−standard parameters on CI were investigated by comparison to standard cone geometries and insertion speeds.

Pronounced differences in CI were observed among replicate measurements obtained using each penetrometer cone. These differences were a function of depth, with the greatest variation seen in the upper portions of the soil profile. The magnitudes of the differences were inversely related to cone size; therefore larger cones are preferable when collecting penetrometer data to measure soil compaction.

Cone geometry had a significant effect when comparing the non−standard penetrometer cone to ASAE−standard large and small cones. There was also a significant effect of cone size on CI between the two standard cones. Thus, it may be difficult to directly compare CI data obtained with different tip geometries or sizes. We developed CI−dependent equations relating data collected with one tip to data from another tip, but considerable scatter was present in the relationship. This scatter varied with depth and was of the same order of magnitude as that observed from multiple replications of data collected with the same tip. Although equations of this type might be used to relate Veris penetrometer data to ASAE−standard data under soil conditions similar to those encountered in this study, care should be taken in situations involving other soil types, soil conditions or moisture contents.

No significant effect of insertion speed was detected between the standard insertion speed of 30 mm/s (1.2 in./s) and the EC−sensing penetrometer speed of 40 mm/s (1.6 in./s). It appears that operation at 40 or 50 mm/s (1.6 or 2.0 in./s) would produce results comparable to those obtained at the standard speed.

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