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Comparison of Log Transformed and Scaled Cone Indices

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ABSTRACT

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Changes in soil properties with time and position make it difficult to analyze cone index data taken throughout a growing season. It was hypothesized that scaling would aid in interpretation. Cone indices were measured at 10 different dates over two growing seasons in conventional- and conservation-tillage plots in Florence, SC. They were measured at 0.05-m depth intervals to a depth of 0.55 m at spacings of 0.1 m across two 0.76-m wide rows of soybean or maize. Cone indices were scaled by subtracting each value by the mean and dividing by the range of cone indices for each date of measurement. This yielded an equal mean (zero) for each date with a unique distribution. Unscaled values were transformed by taking their logarithm to normalize the data. Log transformed data varied significantly with date of measurement but not between treatments. Scaled values did not vary with date of measurement but did vary between tillage treatments. Both unscaled and scaled cone indices varied significantly with water content. Scaling has the potential to improve the analysis of cone index data by reducing or eliminating some of the confounding treatment effects.

INTRODUCTION

The exploration of the soil by roots for water and nutrients is necessary for proper plant growth. However, it can be reduced by compaction (Taylor and Bruce, 1965; Blanchar et al., 1978). As soil cone index increases, root growth decreases, and eventually stops. The amount of root growth reduction for a given cone index will vary among plant species and varieties as well as among soil types (Gerard et al., 1982). Flat-tipped penetrometer readings of 1 and 2 MPa have been used as root reducing and restricting limits, respectively (Taylor et al., 1966; Blanchar et al., 1978). It is common for the E horizon (A_2) of many sandy southeastern Coastal Plain soils to have such strengths (Campbell et al., 1974).

Deep in-row tillage is recommended to disrupt the E horizon and permit deep root growth. However, because of reconsolidation, this tillage must often be performed annually (Busscher et al., 1985). It is difficult to quantify the soil strength build-up or the differences between treatments because cone indices fluctuate throughout the growing season, changing with water content or location of the destructive measurement by the penetrometer (Taylor et al., 1966; Camp and Lund, 1968; Mirreh and Ketcheson, 1972; Gupta and Larson, 1979; Ayers and Perumpral, 1982; Gerard et al., 1982; Spivey et al., 1986).

It was hypothesized that scaling the cone indices for different times within the growing season would aid in the interpretation of data taken over a growing season. Scaling factors, such as the mean cone index or range of cone indices, vary with time themselves. However, they would reduce the variation with time of the scaled cone indices by normalizing them to the same mean and range. Comparisons would then be among the distributions throughout the profile of different tillage treatments.

METHODS AND MATERIALS

This study was conducted on a Norfolk loamy sand (fine, loamy, siliceous, thermic, Typic Paleudult) at the Coastal Plains Research Center in Florence, SC. The E horizon is loamy sand; it is approximately 0.2–0.4 m deep. The B_t horizon is a sandy clay; it begins at approximately 0.4 m.

Field plots, 14 m by 40 m, were planted to soybean in 1983, to maize in 1984, and to soybean in 1985 with a row width of 0.76 m. Two tillage treatments had been maintained for 2 years previous to, as well as during, the study. The treatments with four replications were in a randomized complete block design. In Treatment 1, the conventional-tillage treatment, the soil was disked in the fall after harvest to a depth of approximately 0.15 m to bury the stubble, and periodically disked to keep the surface clear of weeds. In Treatment 2, the conservation-tillage treatment, stover remained throughout the winter. Weed growth was controlled with glyphosate or paraquat as needed and at the time of planting. Both treatments included in-row subsoiling to a depth of about 0.45 m at the time of planting with the Brown–Harden Superseeder[1]. The Superseeder has forward-angled, straight shanks, 50 mm wide with 63.5 mm wide shoes. Fluted coulters acting as strip tillers were located 75 mm from both sides of the shanks.

Cone indices were measured on 26, 27 June, 9 July, 6, 15, 29 August 1984 and 25 March, 10 April, 14 May and 13 August 1985. Measurements were taken with a hand-operated, analogue, recording penetrometer with a 13 mm diam-

[1]Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

eter, 30° cone tip (Carter, 1967). Cone indices were recorded each 0.05 m to a depth of 0.55 m across two rows at 0.1-m horizontal intervals. Three measurements were made at each interval across the rows, entered into the computer, and averaged using the method of Busscher et al. (1985). The data consisted of cone indices for the 11 depths at each of 17 positions across two rows for both treatments, and for all four replications on all of the above dates. The sets of cone indices for the two rows were taken as duplicate samples and averaged for comparison across a single row.

The statistical design was a split plot with replications and tillage treatments as main plots, split on dates of measurement. Soil depth and position across the row were treated as covariates. Since cone index data is not normal, it was transformed by taking the logarithm of the cone index (Cassel and Nelson, 1979) before analysis. In-row and mid-row gravimetric soil water contents were taken in each treatment of each replicate at 0.1-m intervals to 0.6 m depth at the same time as the cone indices. Cone indices were analyzed with water content as a covariate as recommended by Asady et al. (1987) using the general linear models procedure of SAS (1985) with the statistical design of Table 1.

Cone index was not found to vary linearly with position; this can also be seen in the non-linear isostrength lines of Figs. 1 and 2. Therefore, position squared was used in the design shown in Table 1. It showed a significant difference similar to Busscher et al. (1988). Since no statistical difference was noted between the water-content samples taken in-row or mid-row, these were averaged and assumed to be the same across the row.

TABLE 1

Statistical design and level of significance for analysis of cone indices that have been log transformed and scaled

Source	df	Level of significance	
		Log	Scaled
Tillage (T)	1	0.30	0.08
Replicate (R)	3	0.08	0.10
T×R (Error 1[1])	3	–	–
Date (D)	9	*	0.48
R(T×D) (Error 2)	63	–	–
Depth	1	*	*
Water content	1	*	*
$Position^2$	1	*	*
Error 3	4310		

[1]Three error terms in the statistical design are used for the variables listed above them and below the previous error term.

*Significant at least at the 0.01 level.

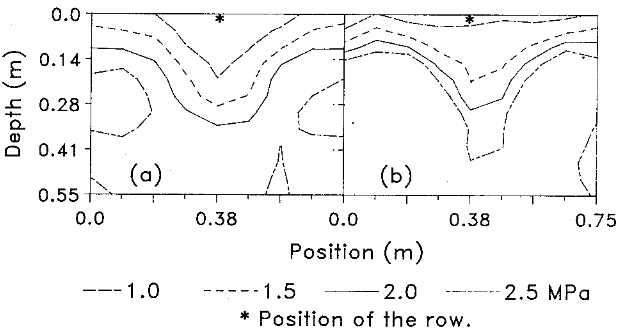

Fig. 1. Contour plots of log transformed cone indices of the conservation-tillage (a) and the conventional-tillage treatments (b) as a function of profile depth and lateral position across a row for 15 August 1984.

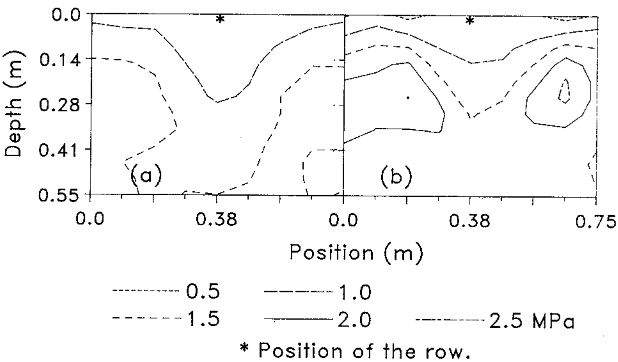

Fig. 2. Contour plots of scaled cone indices of the conservation-tillage (a) and the conventional-tillage treatments (b) as a function of profile depth and lateral position across a row for 15 August 1984. Units for the contours are dimensionless.

The analysis of cone indices was repeated as above, except that it was scaled by

$$CI_s = (CI - CI_a)/(CI_m - CI_o)$$

where: CI is the measured cone index and CI_s, CI_a, CI_m, and CI_o are the scaled, average, maximum, and minimum cone indices for each tillage treatment for each date. The maxima and minima used for all cases were obtained after averaging over replications which eliminated extreme variations. The minimum value ranged from 0.001 to 1.15 MPa and the maximum from 2.51 to 6.50 MPa.

RESULTS AND DISCUSSION

Both the log transformed and the scaled cone indices were normally distributed at the 1% level of confidence using the Kolomogorov D statistic.

For the log transformed data, the overall mean cone index for the conventional-tillage treatment (1.92 MPa) was slightly higher than for the minimum-tillage treatment (1.87 MPa). Though the difference was not significant, it can be at least partially explained by the disking to keep the surface weed free. This could have contributed to a lower surface yet higher subsoil cone index for the conventional-tillage treatment. In fact, above 0.15 m, the zone loosened by the disk, cone indices were significantly lower for the conventional-tillage treatment (1.33 MPa) than for the conservation-tillage treatment (1.46 MPa). Yet, in the subsoil, the conventional-tillage treatment had the higher cone indices (2.89 vs. 2.33 MPa for the conservation treatment). It is in the subsoil where many of the strength problems exist in Coastal Plain soils (Campbell et al., 1974).

Log transformed cone indices differed with date, soil water content, soil depth, and position across the row (Table 1). Although cone indices differed by date, there was no build-up of strength, no significant or even consistent increase of cone index with time over growing seasons (Table 2). Cone index values were confounded by non-consistent variability of water content throughout the growing season. Some researchers (Ibrahim and Miller, 1988) have dealt with this problem by irrigating the profile before taking the strength readings. However, drops in cone index for southeastern Coastal Plain soils caused by even

TABLE 2

Inverse transformations[1] of the log transformed and scaled mean cone indices and gravimetric water contents for both tillage treatments on each date

Date	Cone index (MPa)				Water content (kg kg^{-1})	
	Log mean		Scaled mean		1	2
	1[2]	2	1	2		
26 6 1984	2.16	2.44	3.24	2.47	0.126	0.151
27 6 1984	1.52	1.34	2.38	1.67	0.115	0.151
09 7 1984	1.61	1.50	1.99	1.65	0.133	0.156
06 8 1984	1.61	1.53	1.69	1.56	0.151	0.159
15 8 1984	2.37	1.94	2.51	2.01	0.121	0.151
29 8 1984	3.48	3.09	3.90	3.15	0.109	0.133
25 3 1985	1.67	2.20	1.93	2.30	0.153	0.134
10 4 1985	1.68	1.88	2.07	2.35	0.135	0.130
14 5 1985	1.54	1.44	1.96	1.85	0.129	0.136
13 8 1985	1.63	1.34	1.86	1.51	0.146	0.156

[1]The inverse transformation changes the mean back to its original form in MPa. Because of the nature of its transformation the inverse transformed scaled mean is equal to the mean of the original data.

[2]Treatments: 1 = conventional tillage; 2 = conservation tillage.

small amounts of wetting are often significant (Camp and Lund, 1968; Campbell et al., 1974). These changes can easily mask treatment differences.

The variation of log transformed index with water content can be seen in each of the dates of measurement. The tillage treatment with the lower mean water content, whether conservation- or conventional-tillage treatment, had the higher mean log cone index (except for one of the dates of tillage 26 June 1984, see Table 2). This was also true for the scaled values, even on 26 June. No significant, consistent trend of water content and cone index change can be traced throughout the growing season. However, cone index differences are related to water content as seen in Table 1 and it is reasonable to believe that at least some of the differences between treatments and within the profile were the result of differences in water content.

Another cause of the cone index difference with date could be the destructive nature of the sampling of the cone penetrometer. This forces the researcher to sample near to but not at the previous measurement positions. Sampling started at one end of the plots and moved inward by at least 0.2 m on each successive sampling. Spatial differences within the field can be another source of variation.

Difference of cone index with depth is expected even in uniform soil by increasing overburden pressure owing to soil weight. In this soil, which has a genetic subsurface hard layer, cone index does generally increase with depth but it also has a zone of high strength. This can be seen at depths of 0.2–0.4 m in Figs. 1 and 2 for both the log transformed and scaled cone index values. Difference with position across the row was a result of the deep tillage which is seen in Figs. 1 and 2 by the drop in strength or scaled strength beneath the row.

After scaling, significance with date was eliminated (Table 1). In fact, with a 48% level of probability, treatments varied randomly with date. Despite the elimination of variability of significance with date by scaling, scaled cone index was still significantly different with water content.

The scaled cone indices differed significantly with tillage treatment which implies that once the difference with date can be eliminated, a difference in treatment can be noticed. To confirm this, the data were not corrected for changes in depth, water content, or position squared in a separate analysis (using a Type I mean square for the error term SAS (1985)). In this case, the scaled cone indices were not significantly different, which suggests that the other variables can mask treatment differences.

The scaling factors of the mean and range of values for both treatments for each date were also analyzed. Since there were fewer degrees of freedom (nine) than for the transformed or the scaled data, they were analyzed only as a function of water content. Both mean and range varied significantly with water content.

CONCLUSION

The elimination of significance with date for the scaled values (Table 1) showed that the cone indices for the profile could be scaled to eliminate variation over time and/or position of measurement. This could provide a simple means of improving the evaluation and interpretation of cone index measurements taken over a growing season. Since the correction used parameters which varied over water content, it is reasonable to assume that the correction was at least partly for water content.

Scaling helped to distinguish the significance between treatments for cone index data taken throughout the growing season. Unscaled cone indices (log transformed cone indices) differed with date but not treatment. Scaled cone indices differed with treatment but not with date of measurement. Scaling factors of mean profile cone index and range of cone indices varied with water content.

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