PENETRATION RESISTANCE ISOPLETHS FOR ASSESSMENT OF SOIL STRENGTH UNDER VARYING MANAGEMENT REGIMES

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ABSTRACT

Diagnostic techniques to evaluate cultural practice effectiveness for managing soil strengths are needed. A recording penetrometer used on a uniform grid of penetrations produced analog records (on 3 x 5 cards) of soil strength vs depth. These were used to develop profile contour plots of soil strength. Digitization was done using a flatbed plotter, programmed to aid in placement of the digitizing eyepiece. Contour depth, shape, and frequency of strength observations were used to compare tillage treatments. Methods of strength correction for soil water differences and other applications are discussed.

INTRODUCTION

High soil strengths (cone index or penetration resistance) resulting from tillage, traffic, or genetic pans inhibit root growth (Voorhees, 1987, Trouse, 1983) and limit root exploration for water and nutrients (Taylor et al., 1966; Gerard et al., 1982; Barley et al., 1965). Various management techniques prevent or eliminate high strength zones and maintain root pathways (Busscher et al., 1988, Campbell and Phene, 1977; Elkins and Hendrick, 1983; and Voorhees et al., 1978). Suitable diagnostic techniques are needed for evaluating cultural practice effectiveness. Cone tip penetrometers are commonly used to assess soil strength. The earliest penetrometers involved a simple proving ring that recorded only the maximum soil strength encountered for the depth of penetration. A new technique involves the recording penetrometer (Carter, 1967; Morrison and Bartek, 1987; Terry and Wilson, 1952). There are three types: handheld, manual, analogue; tractor-mounted, hydraulically driven, digitizing; and handheld, manual, digitizing.

Cost, portability, and field ruggedness make handheld types attractive. Tractor-mounted hydraulic types have the advantages of constant insertion rate and direct computer interface, enhancing precision and data reduction, but are costly, have limited field accessibility (e.g., in corn), and impose additional traffic. Strengths recorded using constant insertion rate probes and manual probes were compared by Morrison and Bartek (1987) who concluded their agreement was good. If care is taken to maintain reasonably uniform insertion rates, readings from manual units discriminate even subtle strength pattern differences (Busscher and Sojka, 1987; Busscher et al., 1986a). In non-agricultural studies, handheld types may be the only penetrometers portable to remote sites (Adams et al., 1982). Finally, the cost advantage of analogue over digitizing handheld types remains a factor, since analogue plots can be rapidly digitized with computer equipment already on hand at most research stations and have the potential for automated image analysis. The authors have developed a system of profile strength assessment with a commercial manual probe (Carter, 1967). This paper outlines and demonstrates the method using a comparison of fall vs spring-bedding.

METHODS AND THEORY

Irrigated Russet Burbank potatoes (Solanum tuberosum L.) were grown on a Greenleaf silt loam (fine-silty, mixed, mesic Xerollic Haplargids) which had been fall-bedded (FB) or bedded before spring planting (SB). Following planting, traffic was limited to a mid-season herbicide application. Soil strength was compared by determining profile strength contours shortly before harvest at two field locations (replications) for each treatment.

Strength assessment involved analogue recording of a grid of soil strengths by making penetrations at 11.4 cm intervals perpendicular to known sources of strength variation (e.g., planted rows, wheel ruts, etc.). Probing depths were to 60 cm (20 cm below the tillage) to reduce spurious reading effects three replicate probings spaced 10-12 cm apart, parallel to the strength variation for each position of measurement, were recorded on an index card as strength vs depth. No attempt to order the replicated probings was made. Each card was placed on a flatbed plotter, used as both a digitizer and an eyepiece controller, and digitized at 5 cm depth increments via a semi-automated process (Busscher et al., 1986b). The method is similar to those used with freely moving digitizers, but here the computer positions the eyepiece on the baseline, greatly accelerating digitization. A single operator can process up to 300 cards (12,000 digitized entries) per day, including automatically averaging the three separate tracings at each depth and recording the data electronically. After the last depth of each card was digitized, the baseline was redigitized. If the slope of the baseline was not zero when all points were entered, they were corrected for the change in strength due to the slope (tilting of the card). Cone indices were thus known for each intersection of a grid with intervals 5 cm deep by 11.4 cm wide. Isopleths were drawn from the matrix giving a penetration resistance contour map.

Log transformed cone indices (Cassel and Nelson, 1979) were statistically tested using both the general linear models procedure (GLM) and the regression procedure (REG) of SAS (SAS Institute, 1985). The GLM design used was Tillage, Rep., Tillage x Rep., Depth, Position, Depth x Tillage, and Position x Tillage, with depth and position considered covariants with the tillage variable. Since strength does not vary linearly with position, position squared was used in the GLM procedure.

A regression equation modeled strength vs soil depth and lateral position using the first four orders of the depth and position and the first and second order interaction terms. Regressions were performed for each treatment and for selected combinations of treatments that were compared. Significance among treatments was determined by calculating an F statistic from the respective error mean squares of the selected combinations and the appropriate individual treatments, using a 10% level of significance with the Bonferroni adjustment for multiple comparison procedures (Draper and Smith, 1966). The Bonferroni adjustment divides the significance by the number of comparisons. The $P < 0.10$ level of significance for 100 samples uses a 0.001 F table. Individual comparisons were not made if the treatments were not statistically different in the GLM table. The regression procedure simulates strength as a function of position and depth and compares the simulation of fit. If the simulations significantly describe the data, a simple F-statistic can be calculated from the error mean squares and degrees of freedom. The GLM and REG procedures used in this manner rejected the null hypothesis if either strengths were dissimilar or were distributed differently.

Gravimetric soil water contents (W) from regular depth intervals for all treatments and probing dates were statistically tested by analysis of variance at the 5% level using GLM. Correcting strengths for significant differences in W between probings permits examination of soil strength aspects other than those caused by W (Busscher, 1987). Perumpral (1987) examined various soil-water correction methods, and Bennie (1986) showed that cone index could be predicted as a function of moisture content and bulk density by:

$$\mathrm{Log}\ (C) = a^{*}\ \mathrm{LOG}\ (B) + b^{*}\ \mathrm{LOG}\ (W) + \mathrm{Log}\ (c) \qquad [1]$$

where C is cone index, B is bulk density, W is gravimetric water content and a, b, and c are soil dependent parameters. To correct cone indices of one treatment for differences in W between it and another treatment, the model takes the form:

$$C_1/C_2 = (W_1/W_2)^b \qquad [2]$$

RESULTS AND DISCUSSION

Researchers disagree about the precise limits of penetration resistance to root growth, which varies with species and soil properties (Taylor et al., 1966; Camp and Lund, 1968; Campbell et al., 1974, and Gerard et al., 1982). Most literature indicates that 2.0 MPa as measured by a 5-mm flat-tipped penetrometer is a limit. This corresponded to 2.5 to 3.0 MPa for a 13-mm diameter 30 degree cone-tipped recording penetrometer (Busscher et al. 1986a). Once the critical penetration resistance is established, relative profile soil strengths can be evaluated. Figure 1 shows the soil strength contours of SB and FB treatments at field water contents (a and b, respectively) and FB corrected to the SB field water content (CB) in Figure 1c. It is apparent that the uncorrected strengths of the FB treatment (Fig. 1b) result in part from a drier profile, because upon correction, contours change depth and shape (Fig. 1c). Mean strengths for SB, FB, and CB were 3.82, 2.18 and 2.34 MPa, respectively. Spring Bedding (SB) was significantly different from FB and CB. Depth to the 1 MPa strength contour in Figure 1a is well above 0.2m but in 1c is well below 0.2m. Similarly the 3.0 and 4.0 MPa isopleths are deeper in Figure 1c. Since there is no intervening shallower high strength zone this indicates a more favorable rooting volume for FB as profile W varies. A zone of traffic-related compaction is identifiable in SB as the lobes of 2.0 MPa and 3.0MPa strength centered under the trafficked inter-row in Figure 1a. The frequency distribution of strength (Figure 2) verifies that FB should favor rooting since low strengths occur more frequently in the FB and CB treatments observed.

There are various approaches to correction for W. Asady, Hook, and Threadgill (1987) considered the water effects separately as a covariate. Busscher (1987) compared equations that corrected C in flat-tipped penetrometers for differences in W among treatments. One of the better equations solved a boundary value problem to obtain a sigmoid relationship between C and W. Here C was a function of Secant($\pi/2*(W/SAT-1)-1$) where SAT is the porosity of the soil. Recently Busscher and Sojka (1988) scaled profile cone indices from 0 to 1 to provide patterns of relative strength. This permitted comparison of cone indices with W differences without correction.

Other strength evaluation approaches (not shown) include determining mean depth to critical penetration resistance, taking the simple mean of profile strength readings, or finding the mean profile cross-sectional areas between given strength limits. Since water and nutrient availability depend on the volume of rootable soil it is useful to compare the cross-sectional areas of soil below a given penetration resistance, provided shallow high-strength layers do not overlie non-limiting layers which, though inaccessible by roots, would increase calculated rootable volume. Each approach has validity and can be used with crop data to determine strength-dependent relationships via regression analysis. An example of this approach would be the regression of yield on the area of profile below the critical soil strength.

CONCLUSION

Determination of soil penetration resistance isopleths provides an effective means of evaluating effectiveness of cultural practices for managing soil strength.

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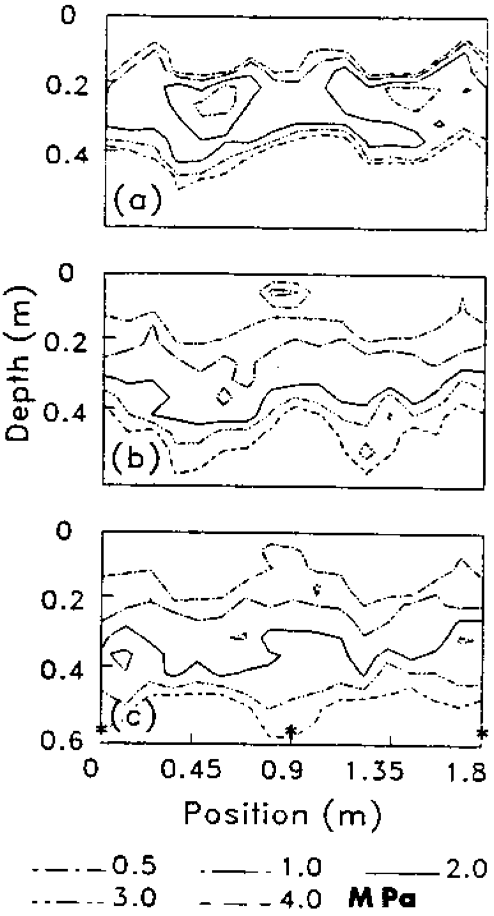

Figure 1.--Soil isostrength contours of (a) spring bedded, SB, at field water content (b) fall bedded, FB, at field water content and (c) fall bedded corrected to the water content distribution of the spring bedded treatment, CB. Contour lines are in MPa. Asterisks are row locations.

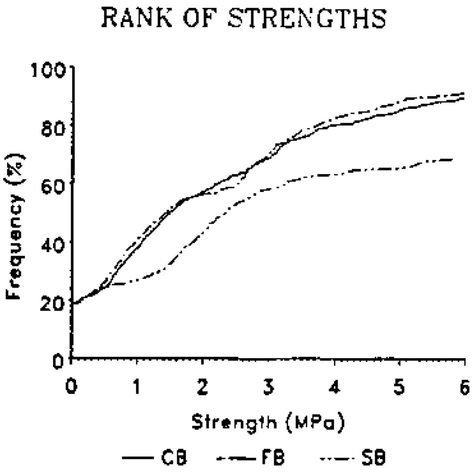

Figure 2.--Distribution of strength values for fall bedded, and spring bedded data at field water contents and for fall bedded data corrected to the water content distribution of the spring bedded treatment.

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