# CALIBRATION OF A MANUAL CONE PENETROMETER USING A DIGITAL PENETROLOGGER

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## ABSTRACT

Cone penetrometers standardized by American Standards for Agricultural Engineering (ASAE) have been major instruments for investigating and quantifying soil compaction. However, the continuous use of penetrometers often introduces errors to the Cone Index (CI) readings obtained from the instruments over time. An ASAE calibrated digital cone penetrometer and a manual penetrometer were tested on a sandy clay loamy soil at the National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria; using the ASAE small cone. The CI readings obtained for the two penetrometers were subjected to a statistical t-test. The results showed that the sensitivity of the manual cone penetrometer is comparable to that of the digital penetrologger at depths greater than 12cm as the mean difference showed no significant difference at this depth. However, at depths 0-11cm, there was significant difference in their mean difference; this shows the relative insensitivity of the manual cone penetrometer. The calibration results also showed that the continuous use of the manual cone penetrometer will require a multiplying factor of 1.165 to get a CI reading close to ideal. Improvement on the manual cone penetrometer will also assist in obtaining CI readings after tillage operations.


**Keywords:** cone penetrometer, soil compaction, ASAE small cone, calibration.

## INTRODUCTION

Soil compaction is the process by which the soil grains are re-arranged to decrease void space and bring them into closer contact with one another, thereby decreasing the bulk density (SSSA, 1996). The major contributor to forming soil compaction is various loads applied to the surface of unsaturated soils.

Soil compaction is one of the paramount information required for effective soil and crop management, and for terrain trafficability. It affects crop production by limiting potential yield and trafficability by limiting the potential traction. Regions of high mechanical resistance in the soil may result from natural soil features, heavy agricultural machinery traffic, or the formation


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of tillage implement pans. Thus soil quality must be determined and analyzed in order to increase crop productivity and trafficability (Boon et al., 2005).

Bradford (1986) in his work asserted that soil mechanical strength is an important soil parameter that affects root growth and water movement, and controls nutrient and contaminant transport below the rooting zone. The most common way to assess soil strength is by using a soil penetrometer, which characterizes the force needed to drive a cone of specific size into the soil

Moreover, quantitative assessment of soil compaction is necessary to determine its severity and to identify suitable mechanical, chemical or biological methods of intervention recommended for ameliorating or controlling soil compaction. Many studies have been conducted to understand the influence of bulk density (ρ) and water content (θ) on PR in the laboratory (Taylor and Gardner, 1963; Mirreh and Ketcheson, 1972; Ayers and Perumpal, 1982; Ayers and Bowen, 1987; Ohu et al. 1988) and field (Simmons and Cassel, 1989; Vasquez et al. 1991, Busscher et al. 1997, cited in Carlos, M.P.Z (2003), from which both empirical and theoretical relationships were obtained. Several indirect methods exist to measure soil compaction that rely on either increase in soil strength (i.e. mechanical impedance to penetrating objects) or reduction in interconnected pore spaces (Hemmat and Adamchuk, 2008, cited in Mojtaba et al, 2009).

Penetration resistance of soil can be measured with penetrometer. The penetrometer consists of a cone mounted on a rod that is pushed into the soil; penetration force is measured and recorded. For manual penetrometer, the metal rod pushed into the soil contains spring and an analogue readout that shows the corresponding resistance to motion in milliPaska (mPa). The rod is graduated with 0-7, 7-14 and 14-21 marks to indicate depth of penetration with corresponding resistance to motion of instrument. On the other hand, the digital penetrometer consists of the long rod pushed into the ground and a digital scale that displays both the penetration depth and the penetration force to give the Cone Index (CI) of the soil, which is calculated by dividing the force by the cross-sectional area of the cone. Penetration resistance is widely measured because it provides an easy and rapid method of assessing soil strength.

Calibration is a measurement process that assigns values to the property of an artifact or to the response of an instrument relative to reference standards or to a designated measurement process.

Instrument calibration is intended to eliminate or reduce bias in an instrument's reading over a range for all continuous values. A functional relationship is then established between the values of the standards and the corresponding measurement.

Two standard cone sizes have been recommended by ASAE (ASAE Standard S313.3, 2006) that the large size cone is often used in tractor-mounted penetrometers, and the small size in hand-pushed penetrometers. Amount of CI can be affected by the cone size and geometry. The problem of providing metrological centers with standards (standard specimens) of a prescribed class of accuracy is one of current interest. As was mentioned in Ermishin, Izmerit (2000), most of the equipment we use, both in the field and in the laboratory might be having some degree of errors over some long period of use without calibration. Therefore, calibration enables the determination of the degree of error in the instrument, i.e. Cone Penetrometer.

Therefore, the specific objectives of this research include (i) calibration of the manual cone penetrometer with the digital penetrologger, (ii) determination of the error, if any in the manual cone penetrometer and finding ways of improving the manual cone penetrometer.

## MATERIALS AND METHODS

**FIG. 1: Digital Cone penetrometer** **Manual Cone penetrometer in use**

A hand-pushed penetrometer with ASAE small cone and an Eijkelkamp (P1.52) digital penetrologger with the same cone type were used for this study. The two equipment were used on an untilled soil plot of length 50m and width 25m. Tillage practices were carried out on the plot of land in the direction of previous operation (ASAE Standard EP542). Other soil properties such as soil type, moisture content, bulk density were also determined under each condition. Soil type was determined using sieve method of soil classification, while the gravimetric method of soil moisture content determination was employed. The bulk density was determined using the core volume of the core sampler. In each of these processes, samples were collected in transparent nylon and duly labeled. Five points were randomly selected on the experimental plot, 5 insertions each was carried out for both untilled and tilled soil plot, respectively. An 85 Horsepower 2-wheel tractor was used to carry out ploughing and harrowing tillage operations, respectively and all soil properties earlier determined for the control was also carried out after the tillage operations. Penetration curves for the two penetrometers were plotted and standard statistical packages such as mean and standard deviation was used to determine the extend of deviation from actual reading of the penetrometer. Calibration of the manual penetrometer was done using the sensitive Eijkelkamp penetrologger; this will assist in ameliorating the defects of the penetrometer, if any.

**Bulk Density Determination**

Soil Bulk Density was calculated using the equation below:

$$Bulk\ Density\ (BD) = \frac{Mass\ of\ dry\ soil\ sample\ (g)}{Volume\ of\ soil\ sample\ (cm^3)} \quad (1)$$

**Soil Moisture Determination**

Moisture content of soil samples were determined gravimetrically using the equation below:

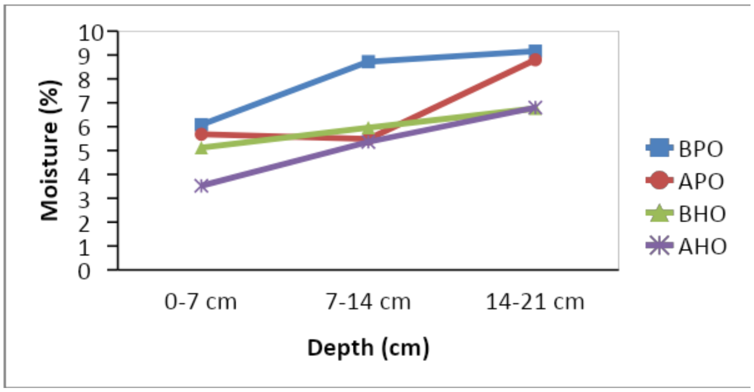
$$Moisture\ Content\ (\%) = \frac{Mass\ of\ moisture\ in\ sample}{Mass\ of\ dry\ soil}\ x\ 100 \quad (2)$$

## RESULTS AND DISCUSSION

**Table 1:** Soil Bulk density (g/cm3) with depth for both tilled and untilled soil.

| SOIL DEPTH | Before Ploughing operation | After Ploughing Operation | Before Harrowing Operation | After Harrowing Operation |
|---|---|---|---|---|
| 0-7 cm | 1.452 | 1.131 | 1.344 | 1.262 |
| 7-14 cm | 1.532 | 1.410 | 1.332 | 1.440 |
| 14-21 cm | 1.151 | 1.620 | 1.410 | 1.630 |

The soil type test revealed a sandy clay loam soil type for the plot used in this experiment. Bulk density of the soil was determined gravimetrically and the behavior of the soil bulk density with depth is as shown in Table 1. The figure indicated a slight increase in bulk density from 1.45g/cm$^3$ to 1.53 g/cm$^3$ and further decrease to 1.51g/cm$^{3.}$




KEY
BPO = Before ploughing operation
APO = After ploughing operation
BHO = Before Harrowing operation
AHO = After Harrowing operation

**Fig. 3:** Moisture percentage with depth for both tilled and untilled soil.

Moisture content was taken for soil depths, 0-20cm; five replications of this were taken. The variation of the soil moisture relative to depth is as shown in Figure 3. The figure indicated that the average moisture for the different depths was highest for untilled soil and increased with depth. The moisture content of the soil after ploughing operation initially decreased to a depth of 14cm and rose with depth to 21 cm depth. Moisture before harrowing operations was similar to that before ploughing operations as it increased with depth, though more steady and with relatively lower values, while after harrowing operation, moisture percentage rose steadily with depth, though relatively with much lower values.

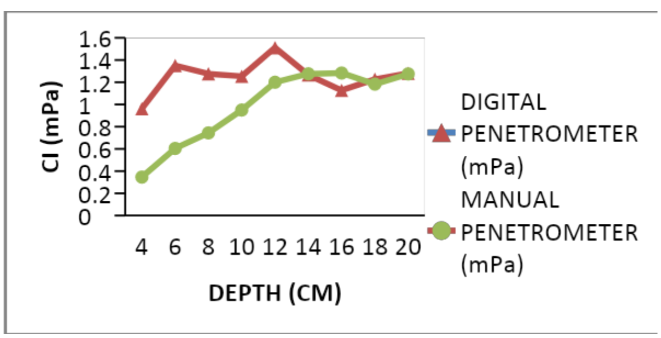



**Fig. 4:** Cone Index of penetrometers relative to depth before ploughing operation

Penetration (in mPa) recorded for the two penetrometers (Fig.4) shows that the digital penetrometer gives higher values for every depth of penetration taken. For most of the readings taken for the manual cone penetrometer, initial CI values usually for depths 0-3cm could not be obtained like that of the sensitive digital penetrologger. Fig. 4 also shows that the CI obtained for the digital penetrologger increased initially from 0.96 mPa at 4cm soil depth to 1.35 mPa at 6cm depth and started falling until it reached 1.25 mPa at 10cm depth. It increased sharply to 1.51 mPa at 12cm depth and later fell to 1.13 mPa at 16 cm depth. It later increased to 1.23 and later to 1.28 at depth 20 cm. This behavior may not be unconnected with the soil bulk density data earlier obtained for the soil depths; the bulk density increased from 1.45 to 1.53 g/cm$^3$, therefore required greater force for penetration for depths 0-14 cm (for untilled soil). The latter increase from about 16cm depth may not be unconnected with an increase in the moisture content at this depth (fig. 3).

**Table 2:** Descriptive Statistics of the two penetrometers before tillage operations

| Soil Depth | Device | N | Mean | Std. Error Mean |
|---|---|---|---|---|
| 0-4cm | Digital Reading | 5 | 0.9620 | 0.16865 |
| | Manual Reading | 5 | 0.3460 | 0.13534 |
| 5-6cm | Digital Reading | 5 | 1.3500 | 0.08820 |
| | Manual Reading | 5 | 0.6040 | 0.11232 |
| 7-8cm | Digital Reading | 5 | 1.2760 | 0.04366 |
| | Manual Reading | 5 | 0.7440 | 0.09130 |
| 9-10cm | Digital Reading | 5 | 1.2540 | 0.04739 |
| | Manual Reading | 5 | 0.9500 | 0.07071 |
| 11-12cm | Digital Reading | 5 | 1.5120 | 0.09505 |
| | Manual Reading | 5 | 1.2000 | 0.07583 |
| 13-14cm | Digital Reading | 5 | 1.2380 | 0.04705 |
| | Manual Reading | 5 | 1.2760 | 0.11369 |
| 15-16cm | Digital Reading | 3 | 1.1267 | 0.06360 |
| | Manual Reading | 3 | 1.2833 | 0.04410 |
| 17-18cm | Digital Reading | 3 | 1.2267 | 0.04631 |
| | Manual Reading | 3 | 1.1833 | 0.06009 |
| 19- 20cm | Digital Reading | 2 | 1.2800 | 0.04000 |
| | Manual Reading | 2 | 1.2750 | 0.12500 |

**Table 3:** Independent t test for the penetrometer

| soil depth | T | Df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | 95% C. I of mean difference Lower | Upper |
|---|---|---|---|---|---|---|---|
| 0-4cm | 2.849 | 8 | 0.022 | 0.61600 | 0.21624 | 0.11735 | 1.11465 |
| 5-6cm | 5.224 | 8 | 0.001 | 0.74600 | 0.14281 | 0.41667 | 1.07533 |
| 7-8cm | 5.257 | 8 | 0.001 | 0.53200 | 0.10120 | 0.29863 | 0.76537 |
| 9-10cm | 3.571 | 8 | 0.007 | 0.30400 | 0.08512 | 0.10770 | 0.50030 |
| 11-12cm | 2.566 | 8 | 0.033 | 0.31200 | 0.12159 | 0.03161 | 0.59239 |
| 13-14cm | -0.309 | 8 | 0.765 | -0.03800 | 0.12304 | -0.32174 | 0.24574 |
| 15-16cm | -2.024 | 4 | 0.113 | -0.15667 | 0.07739 | -0.37153 | 0.05820 |
| 17-18cm | 0.571 | 4 | 0.598 | 0.04333 | 0.07587 | -0.16730 | 0.25397 |
| 19 20cm | 0.038 | 2 | 0.973 | 0.00500 | 0.13124 | -0.55970 | 0.56970 |

Statistically, the t-test and descriptive statistics in Tables 2 and 3 show that there was significant differences between the CI means for the digital penetrologger and the manual penetrometer with respect to depths 0-12cm; but thereafter, there was no significant difference in their means. This indicates that the sensitivity of the manual penetrometer is comparable to that of the penetrologger at depths greater than 12cm.

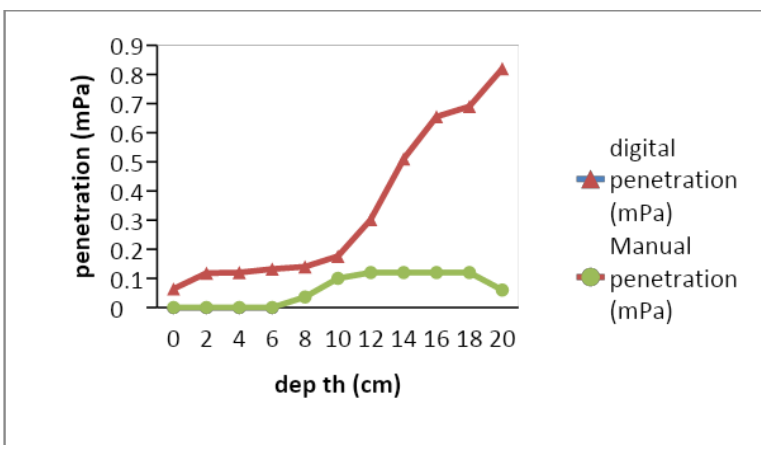



**Fig. 5:** Penetrometers' sensitivity after ploughing operation

CI values could not be obtained for most of the insertions after tillage operations for the manual cone penetrometer; this may not be unconnected to its relative insensitivity (see fig.5). On the other hand, the manual cone penetrometer reading showed no response initially, but had a continual increase in CI value of 0.35 mPa at depth 4cm to a CI value of 1.28 mPa at depth 16 cm. It later fell slightly to 1.18 mPa at depth 18cm and rose again to 1.28 mPa at depth 20 cm.

**Instrument Calibration**

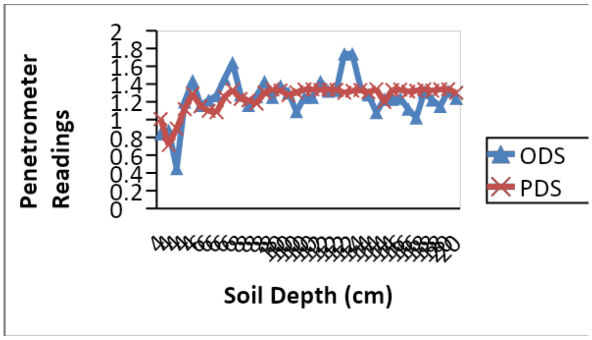



**Fig. 6:** Calibration curve

Due to the inconsistency in the CI obtained from the manual cone penetrometer after tillage operations; the CI obtained before tillage operations was utilized in the calibration exercise.

A quadratic fit to the CI data obtained for the penetrometer produces the calibration curve given as

$$DP = \underset{(0.12801)}{0.71358} + \underset{(0.31844)}{1.1249Mp} - \underset{(0.18520)}{0.050381Mp^2} \quad R = 60.8\%$$

where DP = Cone Index (CI) for digital penetrologger.

The correlation coefficient (R) shows a strong significant relationship between the calibrated curves. For a future measurement of CI using the manual cone penetrometer, for every Manual penetrometer reading as 1.15, the reference digital penetrologger will read 1.34, i.e.

for Mp = 1.15, Dp = 1.34 (see fig. 6)

## Conclusion

The results showed that the manual cone penetrometer has lost some degree of sensitivity and may need to be repaired. However, the t-test result indicates that the sensitivity of the manual penetrometer is comparable to that of the penetrologger at depths greater than 12cm.

The continuous use of the penetrometer will require a multiplying factor of 1.165 to get a reading close to ideal. Improvement on the manual cone penetrometer will also assist in obtaining CI reading after tillage operations.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