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# Development of an Electro-Mechanical System to Identify & Map Adverse Soil Compaction Using GIS&GPS

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# Development of an Electro-Mechanical System to Identify & Map Adverse Soil Compaction Using GIS&GPS


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**Abstract.** *A stand-alone electro-mechanical system with a 32-inch disc coulter was developed and tested to identify soil compaction in a 1-acre field located at the University of Kentucky Animal Research Center (UKARC). The system was evaluated by making four passes in the square grid cell. With the aid of hydraulic actuation, the coulter oscillated between depths of 100mm (4-in) and 330mm (13-in) as it moved forward and recorded the vertical impedance force given by the soil continuously. Forty standard soil cone penetrometer measurements along the diagonals to a depth of 400mm (16-in) were taken and the average cone indices (MPa) at different depths for the entire grid cell were compared to the average coulter indices (CuI(N/mm), defined as the penetration force divided by the perimeter of the coulter disc in contact with soil) at corresponding depths. Ten soil bulk density measurements were taken at depths of (100,150,200,250,300mm) per each grid cell and averaged. Pearson correlation coefficient (r) and coefficient of determination ($r^2$) were found to be 0.716 and 0.51between CuI and CI respectively. The depth and spatial locations of maximum vertical impedance force and maximum CuI were determined.*



**Keywords.** Soil Compaction, Cone index, Coulter index, Impedance, GPS


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# Development of an Electro-Mechanical System to Identify & Map Adverse Soil Compaction Using GIS&GPS

**By**

**S.K.Pitla[1] and L.G.Wells[2]**

## Introduction

The presence of root restrictive compacted layers in a field hinders plant growth and causes yield loss. In most cases machine traffic can be attributed to the formation of soil hard pans. Determining the depth of these root impeding layers is important to mitigate soil compaction by applying site specific tillage. The fact that the compacted layers can occur at a deeper or shallower depth (Raper et al 2000a) in a field makes the determination of the depth of this layer more challenging and demands the use of precise instruments which can accurately measure soil compaction at different depths. Site specific variable depth tillage controls compaction and conserves energy required for tillage (Morgan and Ess,1997).Energy savings of as much as 42.8% and fuel savings of 28.4% was indicated by Gorocu et al.,(2001)when variable depth tillage was applied .Hence, identifying the depth of compacted layers is vital in carrying out efficient field practices.

A traditional way of determining the depth of these hardpans is to use a standard soil cone penetrometer (ASAE 1999a, ASAE 1999b) which determines the cone indices (CI) at different depths and estimates the soil compaction. A major drawback in using a single shaft soil cone penetrometer is that the data obtained is discrete which makes it inefficient to identify the compaction levels of a massive field. Collecting enormous data with a soil cone penetrometer is tedious and time consuming. To overcome this glitch and speed up the process automated hydraulically driven multi-probe soil cone penetrometers have been developed (Perumpral 1987; Sudduth et al., 1989; L.G.Wells et al., 2000; Raper et al., 1999). Contemporary site specific field management practices demanded superior instruments which can estimate soil compaction by collecting impedance data on-the-go, unlike automated multi-probe soil cone penetrometer which is a stop-and-go device.

Mapping of spatial and depth variation of soil resistance is important for employing site specific variable depth tillage, To serve this purpose numerous prototypes were developed by researchers which can measure the impedance given by the soil on-the-go (Andrade et al., 2001; Adamchuck et al., 2001; Chung et al., 2003).An instrumented subsoiler to map the soil hardpans was designed by Manor and Clark (2001).An instrumented blade system to map soil

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[1] The investigation reported in this paper (00-00-000) is part of a project of the Kentucky Agricultural Experiment Station and is published with the approval of the director. Mention of trade names is for informational purposes only and does not necessarily imply endorsement by the Kentucky Agricultural Experiment Station.

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resistance was developed by Adamchuck et al.,(2004).Glancey et al.,(1989) developed an instrumented chisel with strain gauge array to measure the impedance given by the soil. A horizontally operating prismatic tool was developed by Sudduth et al., (2003) to measure the impedance forces on-the-go. A multiple blade soil mechanical resistance mapping system was developed by Adamchuk et al., (2005) to measure impedance at three depths. A tine mounted with eight independent load cells was designed by Andrade et al., (2001) to measure mechanical resistance over a depth of 60cm.The present research focuses on using a very common tillage tool (coulter disc) to develop an easy to use continuous impedance measuring unit on-the-go.

## Objectives

The objectives of this research were

- To develop and test a stand-alone electro-mechanical system(Coulter Penetrometer) which has the capability of cycling up and down in a field continuously between 0 and 13 inches depth and measure penetration resistance given by the soil at all depths.
- To determine the efficacy of the system by correlating a new parameter developed known as Coulter Index (CuI) to Cone Index (CI) and develop empirical equations which can predict cone indices from coulter indices.
- To identify depth and spatial locations of soil hardpan with the aid of cone index, coulter index and GPS data

## Materials and Methods

### *Coulter Penetrometer development*

In the past, researchers used vertical blades with strain gauges as their chief impedance measuring tools. In this research a 81cm (32-inch) coulter disc was used to come up with a continuous impedance measuring device on-the-go called “coulter penetrometer”. The coulter penetrometer developed can be seen in Figure1 which is mounted on a three-point hitch. Center link (8) and mast (1) were designed and fabricated to mount the entire setup on the three point hitch of a tractor. The center link was sized to lift the coulter penetrometer completely above the ground when not in use. A double acting 30.5cm (12-inch) stroke cylinder (cylinder in red) with 5.1cm (2-inch) bore was positioned between the foot of the mast and the center link to adjust the setup so that the coulter is vertical to the ground at all times during its operation. Another double acting cylinder with 35.6cm (14-inch) stroke (5) and 2-inch in diameter was mounted vertical to the ground on the mast to cycle the coulter up and down. Two track rollers (2) (model number CRSB-96) were used to facilitate the rolling of the binocular shaped block in the guide way (7) to which the coulter disc is attached. The coulter disc was free to rotate in lateral direction which avoided the building up of sideward forces on the disc.

### *Hydraulics and Instrumentation*

The tractor’s hydraulic power was used to extend and retract the 35.6 cm (14-inch) vertical cylinder which allowed the oscillation of the coulter disc. A DS105 series directional control valve (6) was used to control the direction of the fluid flow. The directional control valve used had two solenoids and with both solenoids de-energized, the spool is held in its neutral position by spring force. The solenoids were powered alternatively by switching the 12V input with a PMD-1208LS data acquisition device and an RT series (DC coil miniature relay).The data acquisition module had 4 differential analog input channels with 12 bit A/D conversion capability and 16 digital I/O channels. A CLWG series linear depth transducer (4) was mounted between the top of the mast and the binocular shaped block to record the real time depth of the coulter disc at all times. A PX 176 series Omega pressure sensor (3) with a load rating of 34.5MPa (5000 psi) was fitted into a port at one end of the cylinder to measure the vertical resistance pressure given by the soil when the coulter is pushed down into the soil. A Garmin GPS with an accuracy of approximately 4.9m (16 ft) was used to determine the global position of the coulter penetrometer. A multi-functional control program was developed using Visual Basic 6.0 to record the data from all sensors in real-time and control the cycling of the coulter disc. The program worked in two modes namely, automatic and manual mode. In Manual mode we can raise and lower the coulter using push buttons on the V.B interface and in automatic mode, once the program is started the coulter disc oscillates continuously between 10.2 and 33.0 cm (4 and 13) inches during its operation and records the data.

### *Data Collection and Field Testing*

The testing of the coulter penetrometer was done at the University of Kentucky Animal Research Center (UKARC) in the summer of 2006.The field under test was a (0.4ha) 1-acre square cell. The coulter penetrometer was run at a horizontal speed of 4km/hr and with a vertical penetration speed of 3.76m/min (148 inch/min). Testing of the coulter penetrometer during test can be seen in figure2. The fluid flow rate was set to approximately7.6 l/min (2 GPM) to be able to achieve 5 cycles for each pass in a single 0.4ha (1 acre) square grid cell. Each cycle constituted the downward and upward

motion of the coulter disc between 10.2 and 33.0cm ( 4 and 13 inches). Four passes were made with the coulter penetrometer and the vertical penetration pressure data and depth data were recorded at a sampling frequency of 10Hz.GPS location was updated every one second. A similar procedure was repeated to collect the data from the second 1-acre square grid cell.

A multi probe soil cone penetrometer was used to collect the cone index (CI) data. Forty standard cone index measurements were taken along the diagonals of the square grid cell between depths of 10.2 and 33.0 cm (4 and 13inches) in the increments 6.4mm (0.25 inches). The multiprobe soil cone penetrometer can be seen in figure3.Ten soil bulk density measurements were taken using a nuclear moisture density testing machine. The density and moisture content measurements were taken at depths of 100, 150, 200, 250 and 300 mm. The nuclear moisture density testing machine can be seen in figure 3.

### *Determination of Coulter Index (CuI)*

The Coulter index is defined as the penetration force (N) divided by the perimeter (mm) of the coulter disc in contact with the soil. The analytic expression used to evaluate the perimeter of the coulter in contact with the soil at different depths is given by equation (1)

$$\ell = 2\,r\ Cos^{-1}\left(1-\frac{d}{r}\right) \tag{1}$$

$\ell$ = perimeter of the coulter disc in contact with the soil (mm)

$r$ = radius of the coulter disc (mm)

$d$ = depth at which the coulter is moving in the soil (mm)

The penetration resistance pressure given by the soil is measured by the pressure sensor embedded at one end of the vertical cylinder. This measured resistance pressure is then multiplied by the area of cross-section of the bore of the cylinder to obtain the force with which the coulter is being propelled into the soil. The vertical impedance force given by the soil is computed using equation (2)

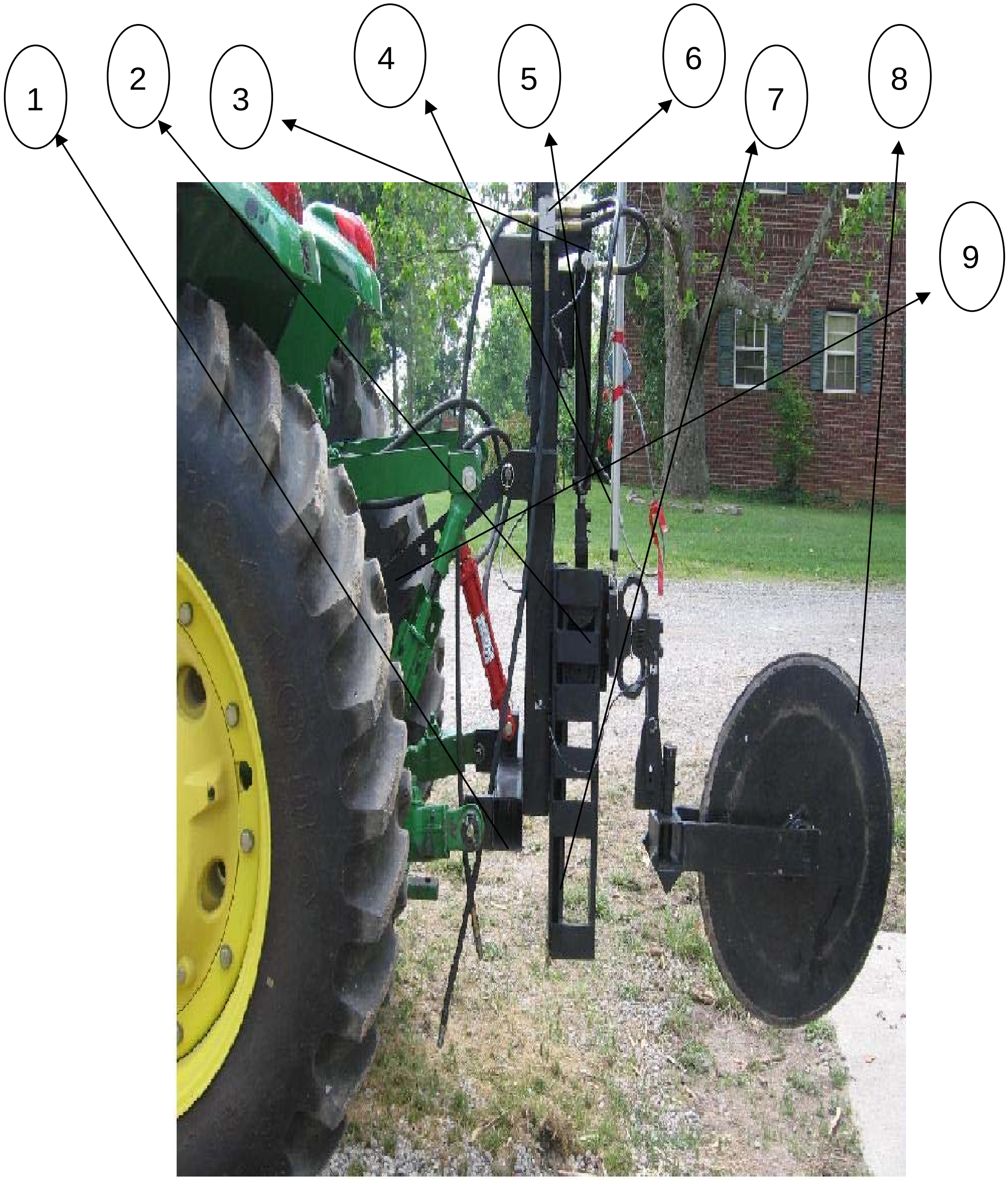


Figure1. Coulter penetrometer mounted on the three-point hitch of a tractor

$$f = AP \quad (2)$$

where,

$f$ = vertical impedance force given by the soil (N)

$A$= Area of cross-section of the bore of the cylinder ($mm^2$)

$P$= Penetration resistance pressure measured by the pressure transducer ($N/mm^2$)

Thus, the coulter index (CuI) is given by equation (3)

$$\text{CuI} = \left(\frac{f}{l}\right) \text{ N/mm} \tag{3}$$

Figure2. Coulter penetrometer during the field test at UKARC

Figure3. Multi-probe soil cone penetrometer (left) and digital nuclear moisture density testing machine (right)

## Results and Discussion

### *CI,CuI and dry soil bulk density variation with depth*

Considerable variation in the average cone indices and average coulter indices with respect to depth was found. Figures 4 and 5 give the average CI and average CuI profiles respectively for the 0.4ha (1-acre) square grid cell. The maximum average CI was found to be 3.86 MPa which occurred at a depth of 152.4mm (6in), while the maximum average CuI was found to be 23.91 N/mm which occurred at a depth of 101.6mm (4in).Therefore, a compacted layer or soil hard pan between10.2 and 15.2(4 and 6 inches) can be expected where tillage needs to be applied. Figure6 gives the average vertical impedance force profile and the maximum was found to be 16.18 KN at a depth of 234.95mm (9.25in).The dry soil bulk density variation with respect to depth can be seen in figure7.The maximum average dry soil bulk density was found to be 1.537 $Mg/m^3$ at a depth of 150mm (6in).The maximum vertical impedance force obtained in 0.4ha(one-acre) grid cell was 29.9KN.This maximum force occurred at a spatial location of 38.0857 latitude, -84.7412 longitude,266.1 altitude and at a depth of 18.4cm(7.25in).The maximum CuI obtained for the grid cell was 53.97 N/mm and the corresponding spatial location and depth was 38.08642 latitude, -84.7411 longitude,268.4 altitude and10.8cm(4.25in) in respectively. The maximum CI obtained for the whole grid cell was 5.42 MPa at a depth of 22.2cm (8.75 in). Thus, this impedance information can be mapped using GIS to locate the soil hardpan.

### *Relationship between CI and CuI*

The Pearson correlation coefficient (r) calculated between CuI and CI was 0.716.The high value of correlation coefficient (r) indicated that a significant linear relationship exists between the two variables. Figure8 illustrates the fitted regression line between CI and CuI with a coefficient of determination $r^2$ = 0.512 for depths between 10.2 and 33.0cm( 4 and 13 inches) .Hence, CI can be expressed in terms of CuI with an acceptable linear relationship.

## Conclusions

In this research a novel, versatile, on-the-go, continuous soil impedance measuring device known as “coulter penetrometer” was successfully developed and tested. The device upon testing showed acceptable accuracy in measuring the impedance forces given by the soil. The device was stand-alone in its functioning and was effective in identifying the soil hardpans. Analysis of the data revealed that CI can be estimated from coulter index (CuI) using a linear fitted regression line. The spatial and depth locations of maximum CuI and maximum vertical impedance force in the 0.4ha (one-acre) square grid cell were determined.

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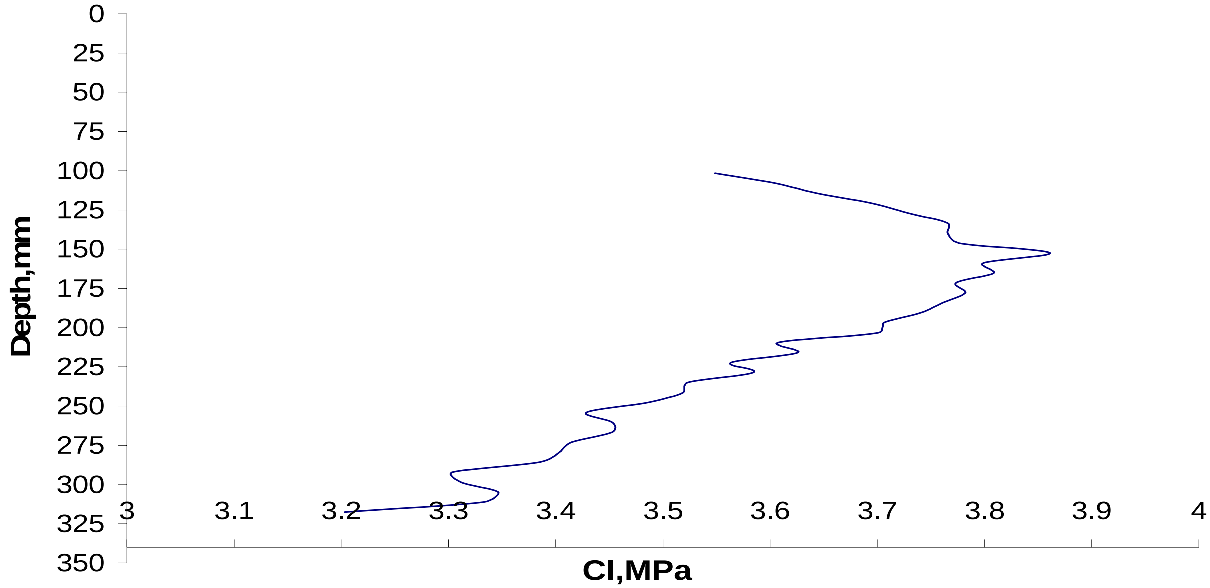


Figure4.  Depth Vs average CI for 0.4ha (one-acre) square grid cell

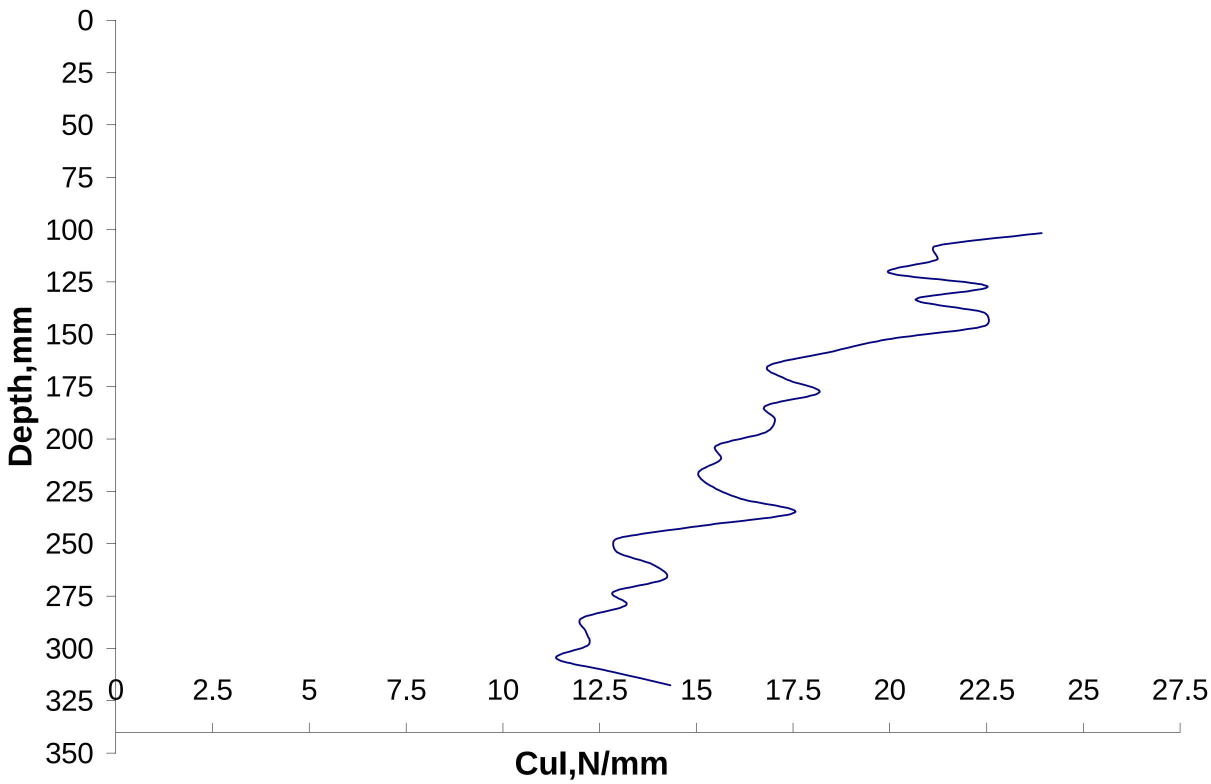


Figure5. Depth Vs average CuI for 0.4ha (one-acre) square grid cell

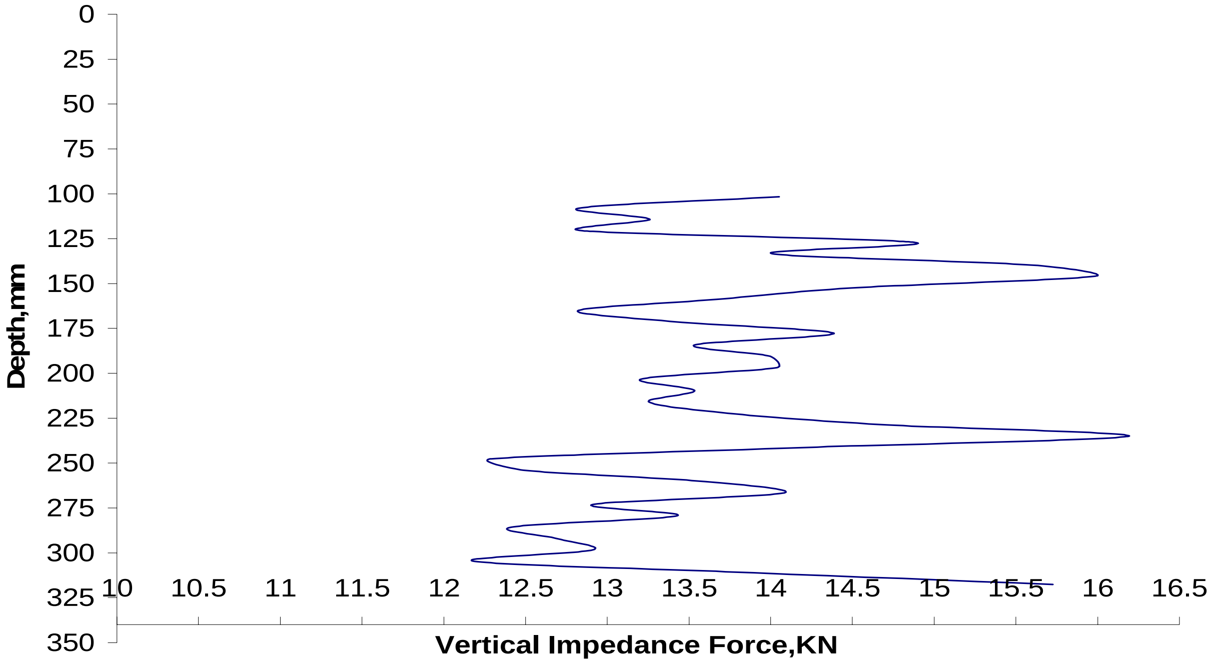


Figure6. Depth Vs average vertical impedance force for 0.4ha (one-acre) square grid cell

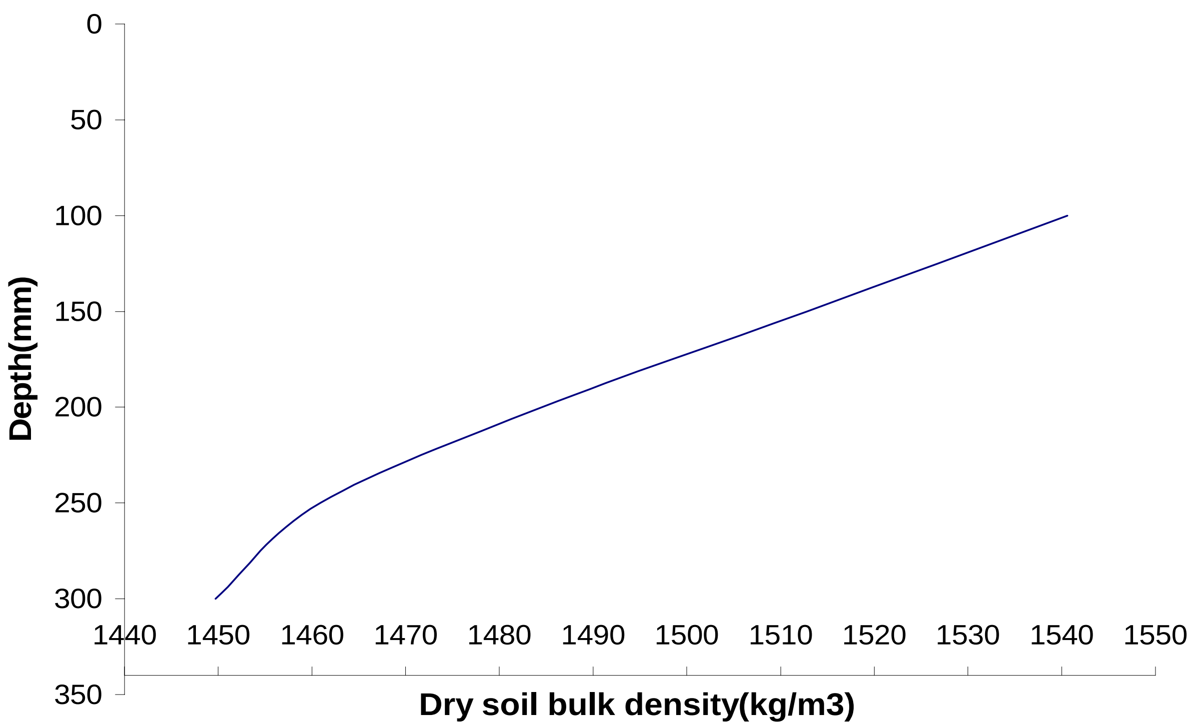


Figure7. Depth Vs average dry soil bulk density for0.4ha (one-acre) square grid cell

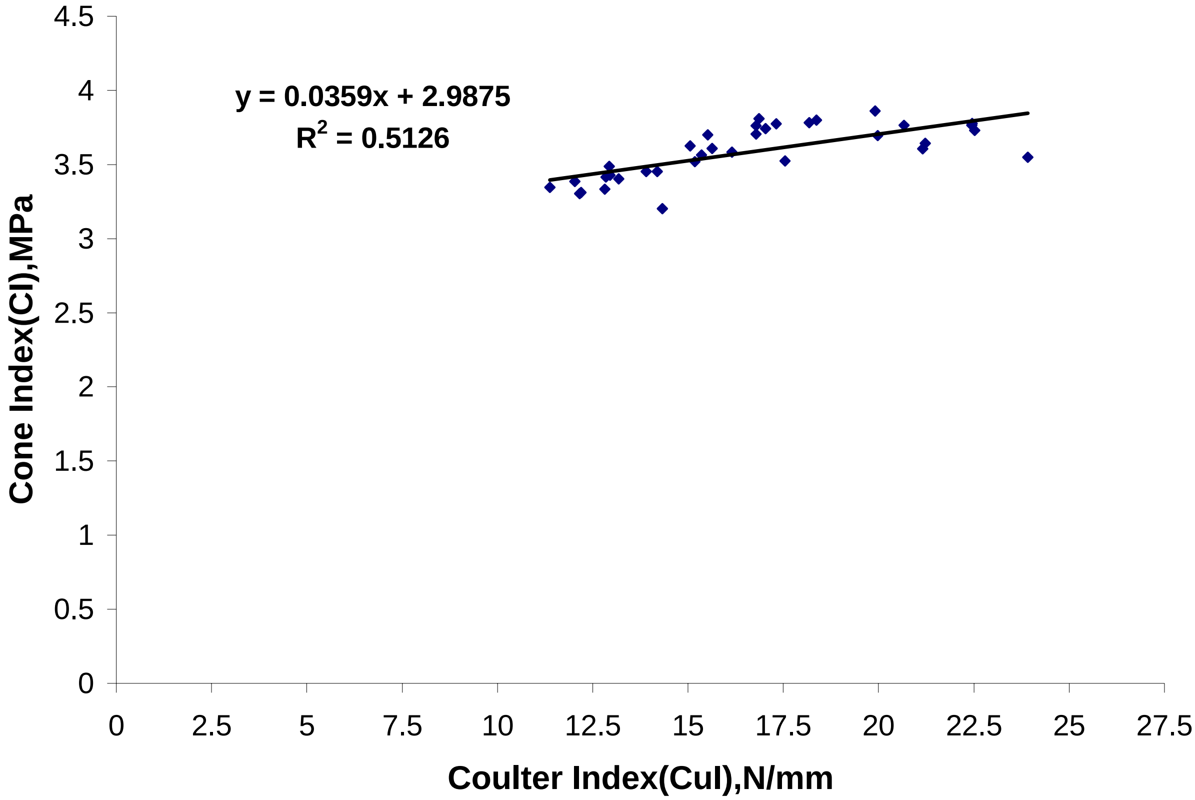


Figure8. Regression analysis between CuI & CI