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# Soil mechanical resistance measurement by an unique multi-cone tips horizontal sensor

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A b s t r a c t. A multi-tips horizontal sensor was developed and mounted horizontally on a tine face by shafts. The length of shafts was reduced from top to down the tine. The developed system was evaluated in the controlled soil bin laboratory conditions with clay loam soil and uniform soil moisture content. The experiment was designed with soil compaction at three levels of uniform and non-uniform soil compaction in completely randomized block design with four replications. Vertical standard penetrometer was also used to compare with horizontal sensor data at whole working depth of 0 to 400 mm. The results indicated that there is a correlation with $R^2 = 0.86$ between soil cone penetrometer values and the horizontal soil mechanical resistance measurement system data. It can be concluded that the idea of reducing the length of the tips from top to down the tine face would give promising results.

K e y w o r d s: multi-tips horizontal sensor, soil mechanical resistance

## INTRODUCTION

Economic pressures in agriculture, have progressively favoured the use of more productive and therefore often heavier vehicle (Gysi *et al*., 2001). The ever-increasing mass of vehicle and often the necessity to work under unfavourable weather conditions increase the risk of soil compaction. Soil compaction caused by tractor traffic is another factor responsible for environmental degradation and leads to plant yields reduction (Głąb, 2007). It is therefore important to be able to determine the presence of compacted layers, their depth, thickness and spatial location without the necessity of digging a large number of holes in the field with either a spade or backhoe (Sharifi *et al*., 2007). An approach to quantify soil compaction is to measure soil mechanical strength with penetrometer (Rooney *et al*., 2001) and an economical hand-pushed digital penetrometer (Naderi *et a*l., 2009).

Cone penetrometer readings require a ‘stop-and-go’ procedure with data collected at discrete locations. Because of this limitation, it would be laborious and time consuming to collect enough data with a cone penetrometer to accurately map compaction variations within a field (Chung *et al*., 2004). A flap faced tine horizontal sensor was developed to measure soil compaction at different depths of soil profiles (Sharifi, 2004). He compared the performance of the sensing system with existing cone penetrometer method. The standard vertical cone penetrometer identifies changes in the soil properties down the soil profile with good resolution.

A combined horizontal penetrometer was designed for the on-the-go and simultaneous measurement of soil water content and mechanical resistance (Sun *et al*., 2005). There was a weak correlation with $R^2 = 0.51$, between the designed horizontal and ASAE standard vertical penetrometers. Chukwu *et al*. (2005) developed a three-depth soil mechanical impedance sensor and tested within a laboratory soil bin. Soil mechanical impedance measurements were made on a continuous basis at three simultaneous depths of 178, 279, and 381 mm from one end of the soil bin to the other using 3 prismatic tips and three Omega LCF500 load cells. A linear regression was fitted to the soil mechanical impedances measured by the three-depth sensor and the cone indexes measured with the Delmi penetrometer. The $R^2$ value was 0.76 and showed a strong linear correlation between the two measurements of soil mechanical impedance.

A horizontal measuring system with multiple instrumented shanks was designed and built to measure mechanical impedance of soil at different depths over the entire top 400 mm of the soil profile (Abbaspour-Gilandeh, 2009). The penetrometer data was averaged over 10 cm intervals and compared to the average force measurements from each instrumented shank of measurement system. There was a correlation with $R^2 = 0.77$ (the least correlation coefficient) at 0-100 mm depth and $R^2 = 0.83$ (the most correlation coefficient) at 300-400 mm depth between soil cone penetrometer data and

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instrumented measurement system values. However, due to thickness of shank and soil failures problem occurring in front of the shank, the existing system was not precise. There are still improvements to be made for higher accuracy and reliability of sensing devices.

Therefore, an experiment was developed with the following aims:

– to investigate the variations in soil strength continuously at four discrete depths simultaneously through the further development of sensing devices locations.
– to compare the performance of the sensing system with existing cone penetrometer method.

## MATERIALS AND METHODS

An experiment was conducted in the soil bin in Karaj (Iran), a facility of the Agricultural Engineering Research Institute (AERI), to investigate the effect of soil-instrumented tools interface under different soil compaction levels. For carrying out this experimental work, a tine with a multi-tips horizontal sensor using 30º cone tips with the same base area of 323 mm$^2$ was designed to dynamically measure mechanical impedance of soil at multiple depths. The cone tips were mounted horizontally on a tine face by shafts. The length of shafts was reduced about 37.84 mm in each layer from 202.36 mm at the top to 51 mm down the tine (Fig. 1b). The S-shaped load cells were then attached to the back of the shafts. The desired maximum vertical sensing interval was 102 mm contingent on being able to obtain accurate strength data from tips on that spacing. Soil mechanical resistance acts pressures on each sensing units, mounted on instrumented blade, hence, load cell inside the sensing unit deforms and measures soil mechanical resistance at specified depth. Load cells designed for the maximum soil strength of 8 MPa which obtained by examination of CI profile. Each sensing unit of instrumented blade was calibrated in the lab by applying known forces and measuring output voltages. The sensors were then evaluated in the controlled soil bin laboratory conditions with working depth of 400 mm on a clay loam soil and constant soil moisture content. A data logging system (Campbell CR23X) was used to record measurements with sampling rate of 25 Hz.

The experiment was designed with soil compaction at three levels of uniform soil compaction using 2 roll passes, 4 roll passes, 6 roll passes throughout the soil profile separately and three levels of non-uniform soil compaction (2-4-2 roll passes from top to down the soil profile, 2-6-2 roll passes, and 4-6-4 roll passes). The depth intervals were 100, 200 and 150 mm down the soil profile corresponding to 2-4-2 roll passes respectively. The same intervals were applied for 2-6-2 or 4-6-4 roll passes and the mass of the roll used in the experiment was approximately 450 kg.

For the analysis of experimental data, the SAS statistical program was used, and a factorial experimental in completely randomized block design was chosen with four replications. Moisture content and bulk density values under different number of roll passes at specific depths are presented (Table 1).

## RESULTS AND DISCUSSION

Figure 2 show the change in measurement results for both the horizontal resistance sensor with cone tips working at different depths and the vertically operated cone penetrometer. Soil resistance index values for the depth of 50 mm are presented in Fig. 2a. Average soil horizontal resistance index (HRI) values and soil vertical resistance

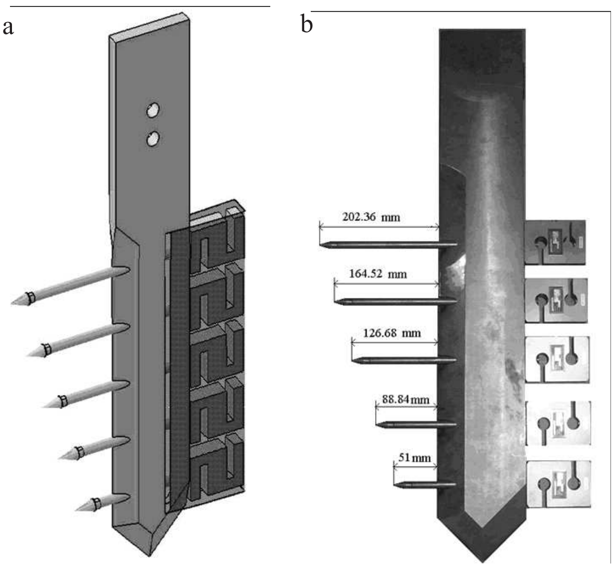


**Fig. 1.** Multiple-tips horizontal sensor: a – CAD model, b – structure of the soil mechanical resistance sensor showing sensing tip and load cell.

**Table 1.** Moisture content and bulk density values under different number of roll passes at specific depths used in this experiment

| Number of roll passes | Depth (mm) | Moisture content (%) | Bulk density (g cm$^{-3}$) |
|---|---|---|---|
| 2 | 0-150 | 12.31 | 1.24 |
| | 150-300 | 15.67 | 1.29 |
| | 300-450 | 12.31 | 1.25 |
| 4 | 0-150 | 11.72 | 1.33 |
| | 150-300 | 14.31 | 1.21 |
| | 300-450 | 12.21 | 1.35 |
| 6 | 0-150 | 12.15 | 1.41 |
| | 150-300 | 14.11 | 1.42 |
| | 300-450 | 13.45 | 1.40 |

index (VRI) were 1.77 and 1.60 MPa, respectively. The measurement results from the vertical penetrometer along the experiment demonstrated that the VRI was significantly smaller than HRI. Soil resistance index values for the depth of 150 mm are presented in Fig. 2b. Average soil HRI and VRI values were 2.26 and 1.69 MPa, respectively. The measurement results from the vertical penetrometer along the experiment demonstrated that the VRI was significantly smaller than HRI. A comparison of HRI and VRI at 50 and 150 mm depth treatment (Fig. 2a, b) shows that increases in depth result in increases in the maximum value of the resistance index. The average value of HRI and VRI (Fig. 2b) was increased by about 5.6 and 27%, respectively. Abbaspour-Gilandeh (2009) and Chukwu and Bowers (2005) also found that soil strength data increased by an increase in soil depth from both HRI and VRI values. This was due to the change in failure mode from brittle to compressive type. In this case, the tip was working below the critical depth of the sensor shank and below the depth of tillage. Soil resistance index values for the depth of 250 mm are presented in Fig. 2c. Average soil HRI and VRI values were 3.75 and 1.82 MPa, respectively. The measurement results from the vertical penetrometer along the experiment demonstrated that the VRI was significantly smaller than HRI. Soil resistance index values for the depth of 350 mm are presented in Fig. 2d. Average soil HRI and VRI values were 4.05 and 1.87 MPa, respectively. The measurement results from the vertical penetrometer along the experiment demonstrated that the VRI was significantly smaller than HRI. A comparison of HRI and VRI at 350 mm depth treatment (Fig. 2d) and the 250 mm treatment (Fig. 2c) shows that increases in depth result in increases in the maximum value of the resistance index. The average value of HRI and VR resistance index (Fig. 2d) was increased by about 2.7 and 7.5%, respectively. This was primarily due to the change in failure mode from brittle to compressive type. In this case, the tip was working below the critical depth of the sensor shank and below the depth of tillage.

Average soil HRI and soil VRI values for non-uniform soil compaction are presented in Table 2. Non-uniform soil compaction was reached by passing different number of rolls from top to down the soil profile. A comparison of HRI and VRI at different soil compaction layers shows that increases in the number of roll passes from top to down result in increases in the maximum value of the resistance index.

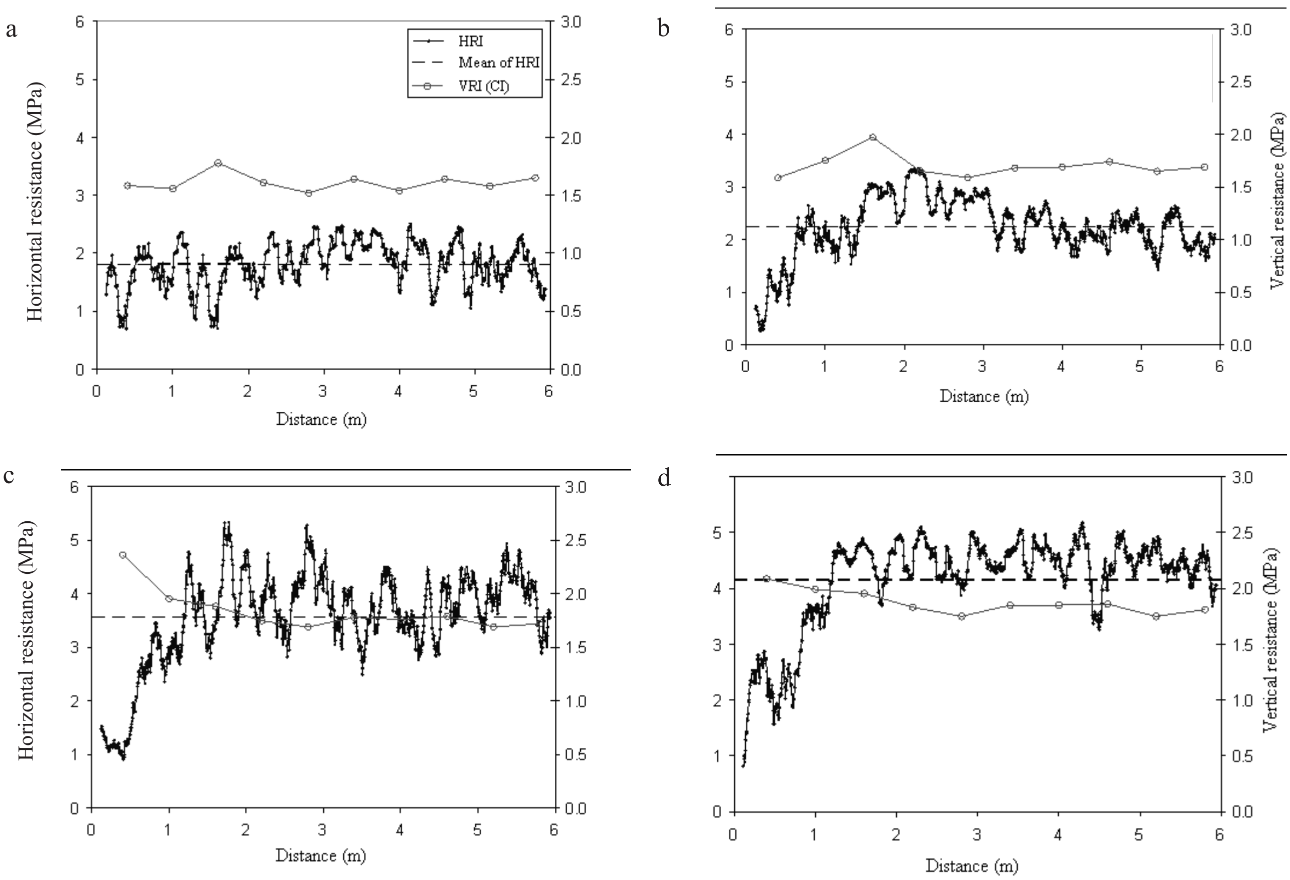


**Fig. 2.** Measurement results from the horizontal resistance sensor with cone tips and the vertical cone penetrometer working at different depths, average soil resistance index values for the depths of: a – 50, b – 150, c – 250, d – 350 mm. The distance is measured along the soil bin.

**T a b l e 2.** Average soil horizontal resistance index (HRI) values and soil vertical resistance index (VRI) with soil compaction at three levels of non-uniform soil compaction

| Depth (mm) | 2-6-2 roll passes | | 2-4-2 roll passes | | 4-6-4 roll passes | |
|---|---|---|---|---|---|---|
| | VRI (MPa) | HRI (MPa) | VRI (MPa) | HRI (MPa) | VRI (MPa) | HRI (MPa) |
| 50 | 1.40 | 1.88 | 1.38 | 2.00 | 1.89 | 2.20 |
| 150 | 2.06 | 3.55 | 2.37 | 3.64 | 2.39 | 5.00 |
| 250 | 3.50 | 4.97 | 4.10 | 6.25 | 4.15 | 4.60 |
| 350 | 3.14 | 4.26 | 3.32 | 6.21 | 4.03 | 3.68 |

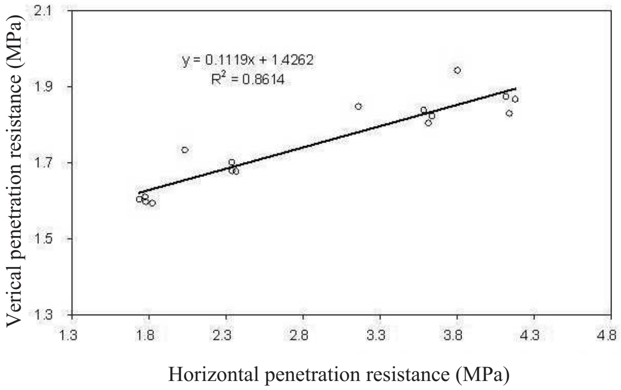


**Fig. 3.** Correlation between HRI and VRI with cone tips and cone index (CI) at working depth of 0-400 mm.

Moreover, the correlation between the measurement results from the VRI and HRI was investigated. As indicted in Fig. 3, there is a correlation with $R^2 = 0.86$ between soil HRI and VRI measurement system data at 0-400 mm soil depths.

## CONCLUSIONS

1. The system used is a unique system, and it proved suitable for measuring the horizontal resistance index (HRI) under different levels of uniform and non-uniform soil compaction with cone tips.

2. The idea of reducing the length of the tips from top to down the tine face would give promising results, $R^2 = 0.86$ between soil horizontal resistance index and vertical resistance index measurement system data at 0-400 mm soil depths.

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