Comparison of cone and prismatic tips for measuring soil mechanical resistance by a horizontal sensor

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Abstract: Soil mechanical resistance induced by compaction of agricultural soils is one of the main concerns as it restricts crop yield. In this study two cone and prismatic tips were compared to measure soil mechanical resistance by a multi-tips horizontal sensor. The horizontal sensor equipped with S-shaped load cells was mounted on the backside of each tip. A factorial experiment was designed with two types of tip and three levels of soil compaction. Experiments conducted in the soil bin laboratory. Comparison results between the two cone and prismatic tips of horizontal sensor showed that soil mechanical resistance measured by the sensor had significant differences with each other and also with vertical cone penetrometer data. Cone tip had greater values than prismatic tip at all levels of soil compaction. It can be concluded that the horizontal sensor can be used for measuring soil mechanical resistance with both tips. However, the results of prismatic tip had better linear correlation with vertical penetrometer data.

Keywords: cone tip, cone penetrometer, horizontal sensor, prismatic tip, soil mechanical resistance

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1 Introduction

Compaction of agricultural soils is one of the main concerns as it restricts the growth of plant root and crop yield because of heavy tractor traffic. Soil compaction still gets researchers' attention to overcome this unsolved issue. On-the-go soil mechanical resistance sensors have been studied by several researchers in precision farming over the past two decades (Adamchuk et al., 2001; Adamchuk et al., 2001; Andrade et al., 2001; Chukwu and Bowers, 2005; Chung et al., 2003; Hemmat et al., 2009; Sharifi, 2004; Sharifi et al., 2007; Sharifi et al., 2011; Sharifi and Mohsenimanesh, 2012; Sirjacobs et al., 2002; Sudduth et al., 2008; Sun et al., 2005). The most popular compaction sensors are on-the-go soil strength sensors measuring either the cutting or penetration resistance of a mechanical tool as a parameter that can be related to the state of soil compactness (Naderi et al., 2014). However, horizontal penetrometer resistance is also affected by some soil physical properties added to soil bulk density like vertical penetrometer resistance. It is important to find out the presence of compacted layers, depth and thickness and spatial location without need of digging holes in the field (Sharifi et al., 2011).

Cone penetrometer readings need a "stop-and-go" procedure with data collected at discrete locations. Because of this limit, it would be laborious and time-consuming to collect enough data with a cone penetrometer to map compaction variations accurately within a field (Chung et al., 2004). A multi-prismatic tips horizontal sensor with apex angles of 60 and base areas comparable to the ASAE Standards were tested to measure soil strength continuously (Chung et al., 2003). A flap faced tine horizontal sensor was developed to measure soil compaction at different depths of soil profiles (Sharifi, 2004). Sun et al. (2005) designed a combined horizontal penetrometer for the on-the-go and simultaneous measurement of soil water content and mechanical resistance. Chukwu and Bowers (2005) developed a three-depth soil mechanical impedance sensor and tested within a laboratory soil bin. Hemmat et al. (2009) developed a single-prismatic tip horizontal soil mechanical resistance sensor to see the failure in front of

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it while penetrating soil at three different depths. They found that average horizontal soil mechanical resistance values at the depths of 20 and 25 cm were similar due to the brittle failure in both cases. However, when the tip worked below the critical depth of the sensor, the value of horizontal resistance index at 30 cm depth increased three times in comparison with that at the depth of 20 or 25 cm. This was due to change in failure from brittle to compressive below the critical depth. There was a significant relationship ($R^2 = 0.75$) between horizontal resistance index and cone index for the 30 cm depth, whereas for shallower depths the relation was not significant. Chung et al. (2003 and 2004) built a soil strength profile sensor to measure soil mechanical strength using a load cell arrangement in front of a tine. They studied the effect of spacing and extension of the prismatic tips at two speeds and two depths. They chose spacing and extension of the tips of 102 and 51 mm respectively and linearly related the cone penetrometer data to prismatic soil strength index. Sharifi and Mohsenimanesh (2012) developed a multi-cone tips horizontal sensor on a tine face by shafts to measure soil mechanical resistance. On the base of literature reviewed, there are still improvements to be made for higher accuracy and reliability of sensing devices. Therefore, the objective of this study was to compare the two types of cone and prismatic tips of the multi-tips horizontal sensors to measure soil mechanical resistance.

2 Material and methods

2.1 Soil bin description

To compare the two cone and prismatic tips of the developed horizontal sensors, tests were conducted in the soil bin laboratory of the Agricultural Engineering Research Institute (AERI) located in Karaj, Iran. A soil bin facility provides better homogeneous soil conditions than in typical field conditions. The soil bin is equipped with a soil processor unit. Different levels of soil compaction can be achieved by adjusting the pressure of a compaction roller and the number of rolling passes on the soil layers. The soil bin is 24 m long, 1.5 m wide and 1 m deep. The effective length of the soil bin used in the experiments is 10 m. The soil texture is clay loam according to Natural Resource Conservation Service, US Department of Agriculture. Table 1 and Figure 1 give the texture of experimental soil.

Table 1 Texture of experimental soil

Textural composition %			**Texture**
Sand	Silt	Clay	Clay loam
38	33	29	

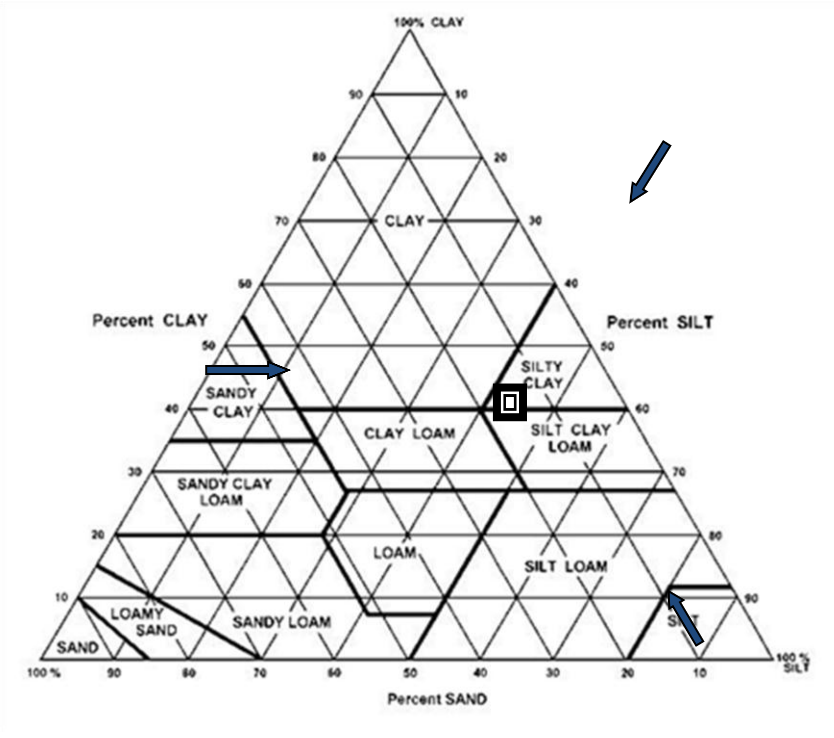
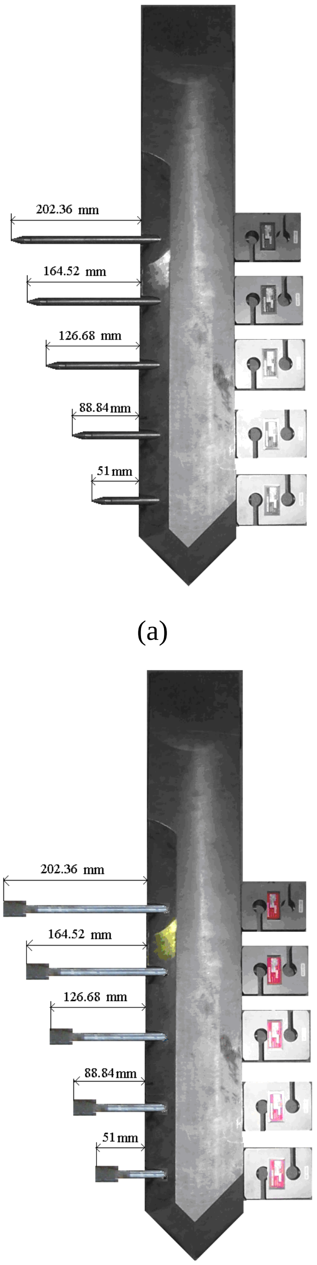


Figure 1 Soil texture triangle marking the experimental soil texture

2.1 Sensor development and calibration

For conducting this experimental work, a tine with a multi-tips horizontal sensor using replaceable cone and prismatic tips, was developed to measure the mechanical resistance of soil at multiple depths. The width of tine was 2.5 cm. The apex angle of both tips was 30 ° with the same base area of 323 mm^2 (ASAE Standard, 2005). The tips were mounted horizontally on the tine face. The sensing shafts were mounted horizontally on the tines, and their length reduced from the shallower positions to the deepest one. The 20000-N S- shaped strain gauged Bongshin load cells (Model DBBP, Bongshin Load Cell Co., Ltd. m Korea) then mounted on the backside of each shaft as a sensing unit (Figure 2). Each sensing unit of the instrumented tine was calibrated in the laboratory by applying known forces and measuring loading cells output voltages. The vertical sensing interval was 102 mm (Chung et al., 2003), thus allowing to get accurate strength measurement data from tips on that spacing. Soil mechanical resistance acts applying pressures on each sensing units, therefore, the load cell inside the sensing unit deforms and measures soil mechanical resistance at the specified depth. The sensors were evaluated in the controlled soil bin laboratory conditions working at depths of 400 mm on a clay loam soil and constant soil moisture content (Figure 3). A data logging system (Campbell CR23X) was used to record measurements with sampling rate of 25 Hz. The upper tip kept above the soil surface during the experiment and the other four tips used in the tests worked at the desired depths.

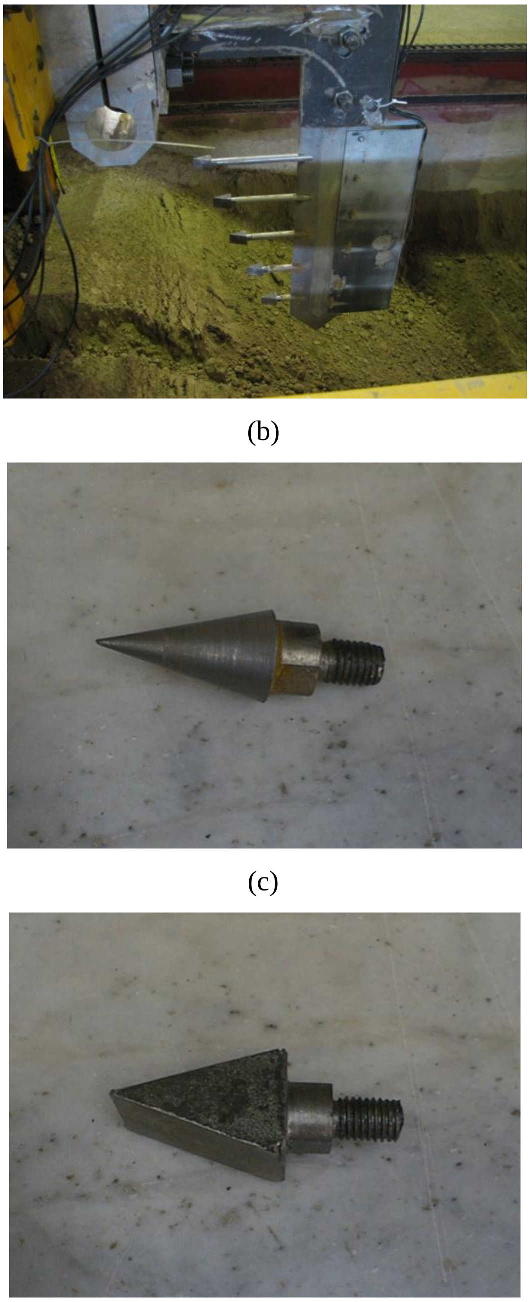


(a)

(b)

Figure 2 Multi-tips horizontal sensor with (a) cone tips and (b) prismatic tips

(a)



(b)

(c)

(d)

Figure 3 Sensor for measuring mechanical impedance of soil with (a) cone tips and (b) prismatic tips at multiple depths in a soil bin test and closer images of (c) cone and (d) prismatic tips

2.2 Soil preparation and experimental design

A factorial experiment in completely randomized block design (CRBD) was chosen with four replications for analyzing experimental data. The experiment was designed with two levels of tips (cone and prismatic) at three levels of uniform soil compaction (2 roll passes, 4 roll passes, 6 roll passes). The uniform soil compaction was reached by passing different numbers of rolls from bottom upwards the soil profile. At each level of soil compaction, the soil was added in 5 cm depth increments and after passing roller on the surface (with a combination of passing a flat roller to compact the soil and a spike roller to lock the layer together), water was sprayed on the surface to achieve the needed water content. The layer was left to reach the average moisture content of 13% to allow the water to drain down and then next layer was added until reaching the top (Naderi et al., 2012). Moisture content and bulk density values with related standard deviations under different numbers of roll passes are presented in Table 2.

Table 2 Moisture content and bulk density values under different numbers of roll passes at depth used in this experiment

Level of soil compaction	Depth cm	Bulk density g/cm^3		Moisture content %	
		Mean	Sd	Mean	Sd
2 roll passes	0-40	1.26	0.03	13.43	1.9
4 roll passes	0-40	1.30	0.08	12.75	1.4
6 roll passes	0-40	1.41	0.01	13.24	0.99

Vertical soil mechanical resistance (Cone Index) was measured at working depth of 0 to 40 cm at 10 points along the soil bin by an Eijkelkamp hand pushed penetrometer (Eijkelkamp, The Netherlands; cone base area of 1 cm^2, cone apex angle of 60°) (Anonymous, 2016).

3 Results and discussion

3.1 Calibration

Calibration graphs showed that there were good linear correlations between each load cell and applied forces. Table 3 depicts the coefficients of calibration of load cells. Load cell 1 was used above the soil surface in the experiments.

Table 3 Calibration of load cells

Load cell	Coefficient of calibration	Calibration equation	Standard deviation
1	0.9932	$y = 0.0007x + 0.0165$	0.4291
2	0.9443	$y = 0.0006x + 0.0244$	0.4016
3	0.9966	$y = 0.0006x + 0.0323$	0.4019
4	0.9991	$y = 0.0006x + 0.0198$	0.4202
5	0.9948	$y = 0.0006x + 0.0262$	0.4031

3.2 Comparison of two tips

The means of soil mechanical resistance of several groups were statistically tested by analysis of variance to see if they were all equal in comparison of the two tips data using Duncan's multiple range test. Results showed that tip had significant effect on data measured by horizontal sensor. There were also significant differences between the data of the cone and prismatic tips at level of 5% (Table 4). As expected the difference was because of different soil failure in front of each type of tips. This failure has influence on the soil mechanical resistance value. The values of horizontal soil mechanical resistance measured by cone tip are greater than that of prismatic tip at all depths and soil compaction levels. Those values also increased with increasing of depth. Increase in mean values of soil mechanical resistance of cone tips could be explained by greater contact area of cone tips with soil. The obtained results are in agreement with the similar studies that measured horizontal soil mechanical resistance (Chung et al., 2004; Sharifi, 2004)

Table 4 Results of comparing the effect of soil mechanical resistance means (MPa) for tips and levels of soil compactions at different depths of soil

	Depth cm							
	5		15		25		35	
	Cone	Prismatic	Cone	Prismatic	Cone	Prismatic	Cone	Prismatic
2 Roll Passages	1.82	0.71	2.41	0.98	3.82	1.11	4.43	1.48
4 Roll passages	2.34	1.18	3.30	1.65	3.92	2.14	4.59	2.59
6 Roll passages	2.37	1.20	4.17	2.28	5.76	2.95	7.54	3.13

The graphs of soil mechanical resistance obtained from multi-tips horizontal sensor were shown in Figures 4 & 5. The data from a section (4 m distance) of an example data collection in the presented in the Figures for compaction level of 2 roll passes at different depths of soil. Lower values of soil mechanical resistance were observed from prismatic tips due to smaller contact area of tip with soil.

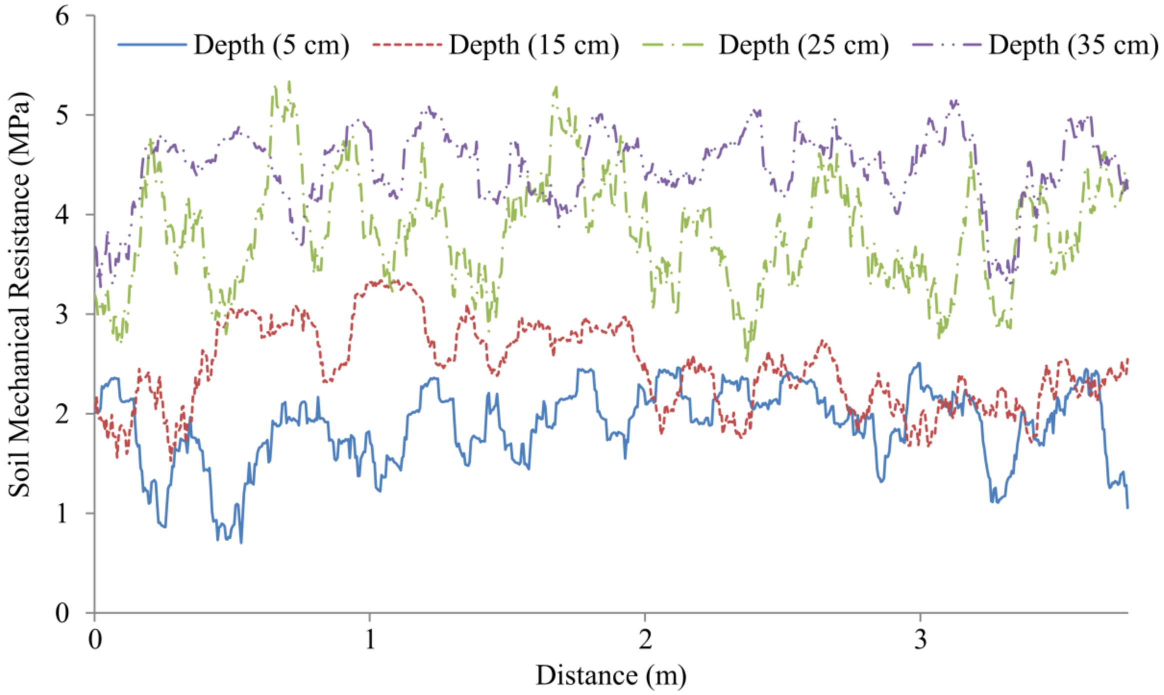


Figure 4 Soil mechanical resistance measured by multi-cone tips horizontal sensor (an example data collection for compaction level of 2 roll passes, BD= 1.26 g/cm^3 and MC=13.43 %)

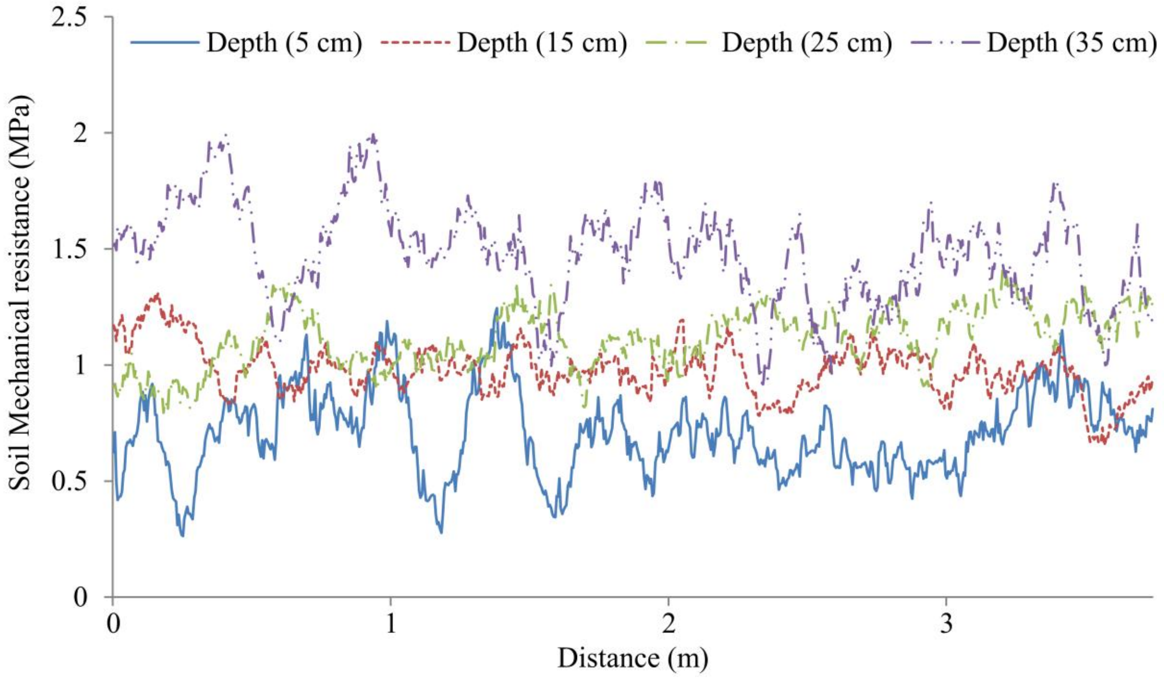


Figure 5 Soil mechanical resistance measured by multi-prismatic tips horizontal sensor (an example data collection for compaction level of 2 roll passes BD= 1.26 g/cm^3 and MC=13.43%)

3.3 Comparison of soil mechanical measured by horizontal sensor and vertical penetrometer

Results showed that the measured soil mechanical resistance using both tips was significantly different compared to data from vertical penetrometer. The correlation between the two tips and cone index data was investigated using linear correlation. The results are shown in Table 5.

Table 5 Coefficient of correlation between the two tips of horizontal sensor and vertical penetrometer (CI) at depths of 0 to 40 cm

CI	Horizontal sensor	
	Cone tip	Prismatic tip
0-40 cm	0-40 cm	0-40 cm
	0.8614	0.8846

There is good correlation between the two tips of horizontal sensor and vertical cone penetrometer from 0 to 40 cm depths. The coefficients of correlation at a shallower depth of 0-10 cm were 0.4447 and 0.3693 for prismatic tip and cone tip, respectively. However, the coefficient of prismatic tip was higher than that of the cone tip. This result could be related to the effect of failure mode by prismatic tip on soil mechanical resistance measurement compared with the measurement by cone tip. Prismatic tip has the same soil failure pattern as vertical cone penetrometer and low disturbance of soil. Hemmat et al. (2009) also found that soil mechanical resistance increased by as soil depth increased for prismatic tips. This was due to change in failure mode from brittle to compressive type. In this case the tip was working below the critical depth for the tine in that soil condition. Godwin and Spoor (1977) stated that when a tine works horizontally in the soil, a crescent failure occurs above critical depth and below this depth, only lateral failure would occur. Chung and Sudduth (2006) reported that the soil failure by a vertical cone penetrometer would be similar at all depths below the depth where the soil failure will be formed.

4 Conclusions

Comparison results between the two cone and prismatic tips of horizontal sensor showed that soil mechanical resistance measured by the sensor had significant differences with each other and also with vertical cone penetrometer data. Cone tips had greater values than prismatic tips at all levels of soil compaction.

The results of prismatic tips had better linear correlation with vertical penetrometer data at depths of 0 to 40 cm than that of cone tips because both induce the same soil failure pattern. It can be concluded that the multi-tips horizontal sensor can be used for measuring soil mechanical resistance with both tips.

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References

Adamchuk, V.I., M.T. Morgan, and H. Sumali. 2001. Application of a strain gauge array to estimate soil mechanical impedance on-the-go. *Trans ASABE,* 44 (6): 1377-1383.

Alihamsiyah, T., E.G. Humphires, and C.G. Bowers. 1990. A technique for horizontal measurement of soil mechanical impedance. *Trans ASABE,* 33 (1): 73-77.

Andrade, P., U. Rosa, S.K. Upadhyaya, B.M. Jenkins, J. Aguera-vega, and M. Josah. 2001. Soil profile force measurement using an instrumented tine. *Paper No. 01-1060, ASAE, St. Joesph, MI.*

Andrade, P., S.K. Upadhyaya, B.M. Jenkins, and A.G.S. Filho. 2002. Evaluating of the UC Davis compaction profile sensor. *Paper No. 02-1185, ASAE, St. Joseph, MI.*

Anonymous. 2016. https://en.eijkelkamp.com/products/field-measurement-equipment/tech-specs-hand-penetrometer-eijkelkamp-set-a.html. Accessed on 27/04/2016.ASAE Standard, S313.3. 2005. Soil cone penetrometer. *St. Joseph. MI. ASAE.*

Chukwu, E.C., and G. Bowers. 2005. Instantaneous multiple depth soil mechanical impedance sensing from a moving vehicle. *Trans ASABE,* 48 (3): 885-894.

Chung, S.O., K.A. Sudduth, and J.W. Hummel. 2003. On-the-go soil strength profile sensor using a load cell array. *Paper No. 03-1071, ASAE, St. Joseph, MI.*

Chung, S.O., K.A. Sudduth, C. Pluffie, and N.R. Kitchen. 2004. Evaluation of an on-the-go soil strength profile sensor using soil bin and field data. *Paper No. 04-1039, ASAE, St. Joseph, MI.*

Chung, S.O., and K.A. Sudduth, 2006. Soil failure models for vertically operating and horizontally operating strength sensors. *Trans. ASABE,* 49 (4): 851–863.

Godwin, R.J., and G. Spoor. 1977. Soil failure with narrow tines. *Journal of Agricultural Engineering Research,* 22 (4): 213–228.

Hemmat, A., A. Khorsandi, A. Masoumi, and V.I. Adamchuk. 2009. Influence of failure mode induced by a horizontally operated single tip penetrometer on measured soil resistance. *Soil & Tillage Research,* 105 (1): 49-54.

Sharifi, A. 2004. Development of a soil compaction profile sensor. PhD Thesis. *Cranfield University at Silsoe, UK.*

Sharifi, A., R.J. Godwin, M.J. O'Dogherty, and M.L. Dresser. 2007. Evaluating the performance of a soil compaction sensor. *Soil Use and Management,* 23(2): 171–177.

Sharifi, A., A. Mohsenimanesh, and B. Jamshidi. 2011. A modified arrangement of multi-prismatic tips on a horizontal sensor for on-the-go measurement of soil mechanical resistance. *Journal of Food, Agriculture and Environment,* 9 (3 & 4): 775-778.

Sharifi, A. and A. Mohsenimanesh. 2012. Soil mechanical resistance measurement by an unique multi-cone tips horizontal sensor. *International Agrophysics,* 26(1): 61-64.

Sirjacobs, D., B. Hanquet, F. Lebeau, and M.F. Destain. 2002. On-line soil mechanical resistance mapping and correlation with soil physical properties for precision agriculture. *Soil & Tillage Research,* 64 (3&4): 231-242.

Sudduth, K.A., S.O. Chung, P. Anderade, and S.K. Upadhyaya. 2008. Field comparison of two prototype soil strength profile sensor. *Computer and Electronics in Agriculture,* 61(1): 20-31.

Sun, Y., D. Maa, P. Schulze Lammers, O. Schmittmann, and M. Rosa. 2006. On-the-go measurement of soil water content and mechanical resistance by a combined horizontal penetrometer. *Soil & Tillage Research,* 86(2): 209-217.

Naderi-Boldaji, M., R. Alimardani, A. Hemmat, A. Sharifi, A.R. Keyhani, M.Z. Tekeste, and T. Keller. 2014. 3D finite element simulation of a single-tip horizontal penetrometer–soil interaction. Part II: Soil bin verification of the model in a clay-loam soil. *Soil & Tillage Research,* 144: 211-219.

Naderi-Boldaji, M., A. Sharifi, A. Hemmat, R. Alimardani, and T. Keller. 2014. Feasibility study on the potential of electrical conductivity sensor Veris® 3100 for field mapping of topsoil strength. *Biosystems Engineering,* 126: 1-11.