International Journal of Research in Agricultural Sciences
Volume 5, Issue 1, ISSN (Online): 2348 – 3997

Studies on Sensors for Measuring Soil Compaction for Effective Crop Production-A Review and Analysis

KAWALE NAGENDRA[1*], ASHOK SURVANSHI[2] and MARUTI[3]
[1*, 2 & 3] Assistant Professors, College of Horticulture, Bidar, UHS, Bagalkot (Karnataka State).
[*]Corresponding author email id: nagendrakawale@gmail.com

Date of publication (dd/mm/yyyy): 10/03/2018

Abstract – **The compaction of soil due to repeated field operation for many years makes the soils an impermeable layer called soil hardpan. The introduction of heavy machinery is also responsible for creating soil hard pan. A great amount of variability in the depth and thickness of hardpan layers of the different regions. However, farmers till the soil at constant depth leading to higher tillage costs. Optimum tillage depth may be shallower in some parts of the field. Variable depth tillage could be beneficial in optimizing the production costs. The aim of this study was to understand if the variable depth tillage is feasible. The energy savings of 56.4% and fuel savings of 33.8% could be achieved by adopting the variable-depth tillage system over the uniform and constant-depth (conventional) tillage. Therefore, VDT is recommended due to its advantages on energy and fuel savings.**

Keywords – **Sensors, Machinery, Soil Compaction, Tillage and Crop Production.**

I. INTRODUCTION

Soil information is required in precision agriculture for managing and understanding crop growth andterrain trafficability. Soil penetration resistance and shear stress are among the soil parameters that affectcrop production by limiting potential yield and affect machine mobility 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 of tillage implement pans.

It was observed from the reviews that almost 90% of the field area is pressurized by the tractor tyres at seedbed preparation, 35% at harvesting and finally, 60% at bailing respectively (munsuz, 1985). In general compaction of 80 kPa or more results in the blocking of root emergence of plants (Bowen and Goble, 1967). Subsoil becomes a compacted soil layer which prevents soil water infiltration through the depth which results up to 30% decrease in yield (Al-Adawi and Reeder, 1996). Thus, soil quality must be determined and analyzed in order to increase the crop productivity and machine traffic ability. The collection and analysis of soil information in an efficient and effective manner in a site specific scale at the field is therefore a scientific and technical challenge. Besides soil compaction, many factors such as soil water content, soil texture and penetration velocity, bulk density may also have impact on cone index during measurement (Arvidsson and Hakansson, 2014).

Soil penetration resistance is related to the pressure required to form a spherical cavity into the soil, large enough to accommodate the cone of the penetrometer, allowing for the friction resistance between the cones and its surrounding soil (Vaz*et al.,* 2001). In situ measurement of soil penetration resistance is carried out with special equipment known as a soil conepenetrometer in accordance with the procedure standardized in ASAE Standard.

The Missoula Technology and Development Center (MTDC) evaluated three hand-held electronic cone penetrometers. Until recently, similar penetrometers were comprised of a dial indicator with a stress ring connected to a round rod with scaled depth markings. The rod has a cone-shaped tip at one end and a handle for pushing the cone into the ground on the other end. Using these penetrometers was a cumbersome operation best completed by two people; one to push the penetrometer into the ground and read the force on the dial indicator, and the other to record probe depth and force.

The hand-held electronic cone penetrometers evaluated by MTDC can be operated by a single person. Each model electronically records the force required to push the probe into the ground and depth reading for computer download and analysis. As the probe is pushed into the ground, the force recorded by the electronic load cell is used to calculate the cone index, a number derived from the frictional forces on the cone's surface as it is pushed into the ground. The cone index is a relative indicator of the soil's strength, typically recorded in kilopascals or pounds per square inch. The penetrometer is able to calculate the probe's depth by determining the time it takes to bounce a signal from an ultrasonic transducer off a metal target on the ground, and back to the transducer. A data logger records the soil's strength and the probe's depth. For accurate readings, the penetrometer must be inserted into the ground at a steady speed of about 30 mm s^{-1}.

II. MATERIALS AND METHODS

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 (Fig. 1). Some common direct measures of soil compaction include: dry bulk density, dry specific volume, void ratio, and porosity (Culley, 1993). In addition, an increase in soil compactness can be detected using indirect measures that rely on either increase in soil strength (mechanical impedance to penetrating objects) or reduction in interconnected pore spaces (fluid permeability). While the direct measures tend to assess the *state* of soil compactness, the indirect measures indicate changes in *behavioral* response frequently (but not always) related to soil compactness (Johnson and Bailey, 2002).

With advances in precision agriculture, spatial variation of soil compaction has been under focused investigation bymany researchers. It has been recognized that the recommended methods for direct measures of soil compactionare labor-demanding and cost-prohibiting for large-scalefield mapping. Therefore, determination of indirect measures along with their geographical coordinates has becomea more appealing alternative (Gaultney, 1989). In recent years, different prototypes of soil compaction sensor systems are developed for mapping certain predictors of soil compaction. Current soil compaction sensor systems are based on soil strength sensors, fluid permeability sensors, water contentsensors, or their combinations (Fig. 2).

The objectives of this publication are to: (1) review recently reported concepts of soil compaction sensor systems, (2) discuss the short comings of on-the-go sensing options using soil failure mechanics, and (3) identify the priority for evolved sensors development.

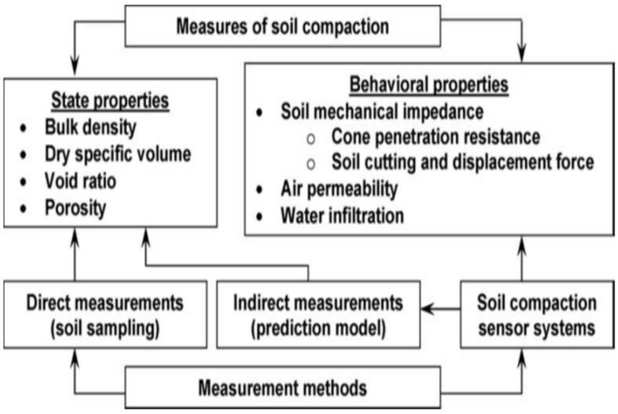


Fig. 1. Principles of soil compaction measurement.

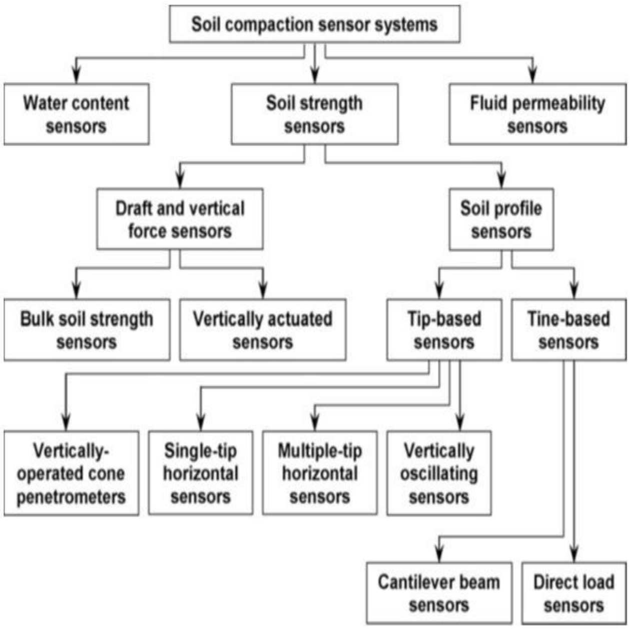


Fig. 2. Classification of soil compaction sensor systems.

Many researchers have attempted to simplify the usage of the penetrometer by various complicating design concepts (Raper *et al.,* 1999). Made hand-pushed type penetrometers with digital data recording systems.

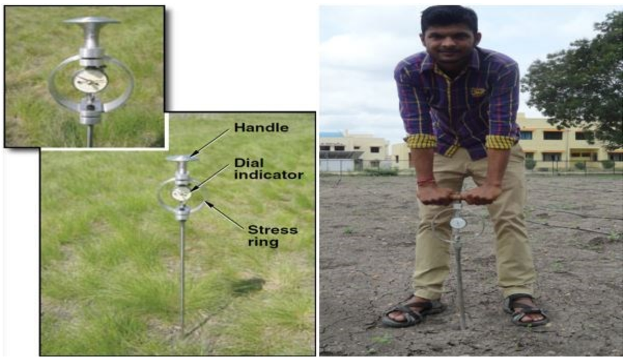


Fig. 3. Hand push type penetrometer

Fig. 4. Recording type penetrometers

Mouazen *et al*. (2004) designed and developed a tractor-based sensor system for online continuous measurement of the spatial variation in soil compaction. (Hemmat and Adamchuk (2008) and Kumar and Mehta (2013) reviews conducted on recording cone penetrometer with hydraulic cylinders, portable cone penetrometers driven by electrics motors. However, manual operations, complicated measurement techniques, time consuming and limited sampling always become the measurement constraints for the application of the available penetrometers. The soil cone index is important in classifying terrain and the soil penetration resistance profile with the depth for quantifying the degree of soil compaction. It also contributes in providing a common system of characterizing soil properties from which it may be possible to determine wheel numeric value or mobility number for predicting tractive performance (Wismer & Luth, 1974; Brixius, 1987; ASAE, 2000b).

Shear stress of soil is made up of the frictional resistance met by soil particles when they are forced to slide over one another or to move out of interlocking positions, the extent to which stresses or forces are absorbed by solid–solid contact among the particles, cohesive forces related to chemical bonding of clay minerals, and surface tension forces within the moisture films (Morgan, 1986). In situ measurement of soil shear stress is carried out with special equipment known assoil shearometer. Measurements were conducted by pushing the shearometer vane into soil surface until theblades were covered and a clockwise rotation rate washthen applied to ensure that failure developed within 5–10 s (Zimbone *et al.,* 1996). Many in situ measurement techniques of torsional and penetration resistance have been used to measure the soil surface shear (Rauws & Govers, 1988). However, the employed measurement techniques were complicated, time consuming and difficult to apply for large-scale measurement. Furthermore, relationships between the various measurement techniques for shear resistance were often not available and the data collected by various employed methods were not easy to compare (Zimbone *et al.,* 1996). The shear stress of soil is important in quantifying the potential soil shear failures cause by tires and tracks of agricultural machinery. Bekker (1969) and Wong (2001) developed empirical traction prediction equations for tires and tracks based on soil shear stress.

Boon *et al*., (2005) A tractor-mounted, automated soil penetrometer–shearometer unit was designed and developed for the purpose of simultaneous in situ measurements of soil penetration resistance and shear stress (Fig. 3). The automated soil penetrometer–shearometer unit utilises both commercial penetrometer and shearometer. The overall construction of the unit was made up of the main frame to support the moving carriage sub-assemblies, two moving carriage sub-assemblies to support penetrometer and shearometer, the gear driving mechanisms to support the traverse movements of the moving carriages, and the three-point hitch attachment to support the main frame and provide attachment to the tractor. The motion controls for the penetrometer–shearometer unit were performed by the programmable logic controller (PLC) unit and other external electronics and sensing devices. Two high-torque stepper motors were used to drive the penetrometer and shearometer moving carriages in the vertical axis direction while another one low-torque stepper motor was used to drive the rotating spindle of the shearometer. A personal computer data acquisition and differential global positioning system (DGPS) on-board tractor were used to assist in real-time measuring, displaying, and recording the tractor position, soil penetration resistance, and soil shear stress during the field sampling operation. Field test of the automated soil penetrometer–shearometer unit was conducted together with data collection on soil moisture content, terrain slope, and tractor–implement performance parameters. Spatial maps produced from the collected data showed considerable site-specific variation in the measured parameters over the field.

Fig. 5. The instrumented tractor with mounted soil penetrometer – shearometer unit

Sun-Ok Chung *et. al.,* (2012) developed a motorized digital cone penetrometer that could penetrate upto 50 cm. The penetrometer was small and light device enough to be transported manually to allow movement on wet–paddy fields and narrow greenhouse inter–rows. The penetrometer included 3 cone tips to reduce data collection time, an electrical motor to push the cone tips into the soil, an encoder to measure penetration depth, a frame and rubber wheels and a CPU to control the motor and log sensor data and DGPS (Fig. 4). The prototype sensor could detect vertical cone index variations and peaks similar to a hand–operated commercial unit, but they were less erroneous, represented actual soil strength levels better and reduced nugget variances significantly, due to a stable penetration rate and angle.

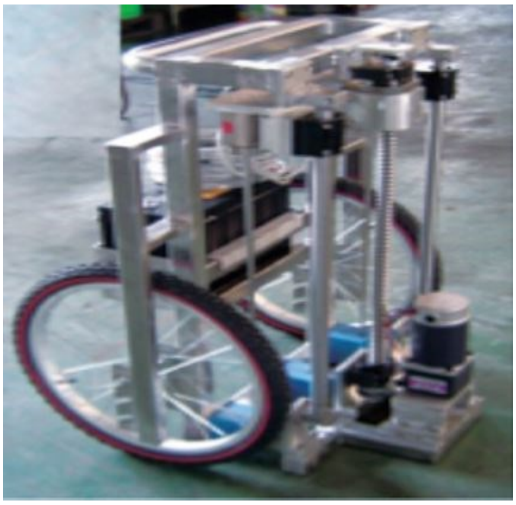


Fig. 6. Motorized digital cone penetrometer

Fount as *et al*., (2013) A five point penetration resistance system was designed and developed connected with a GPS antenna to estimate soil compaction variability across the field (Fig. 5). The proposed construction was mounted on the tractor three point hitch and used tractor's hydraulic system to support the penetration procedure. The apparatus was used to examine the penetration resistance of the soil in a field incorporating five different tillage methods. The experiment took place in two successive years for measurement comparison reasons, in a field cultivated with sunflower. During the tests, the system proved to be fast, robust and reliable for gathering soil compaction information and depict the inherent soil compaction variability across the field. Regarding GPS accuracy it was observed that the accuracy of the GPS was high when the elevation was ±0.5 m between two subsequent readings. Obviously, the best way to perform the measurements would be to connect the system with an RTK-GPS to achieve higher accuracy (Fig. 6). Although the concept of developing a hydraulically assisted, multiple-probe soil cone penetrometer has been also considered by Raper*et al.* (1999), the present described system has the advantage of collecting fast and reliable penetration resistance data with also geo-referenced signature utilizing the GPS receiver. This could be a useful asset for generating soil penetration resistance maps. Due to the steady growth of precision agriculture research and applications, the demand for detailed soil compaction information is increasing. The information gathered could help explaining crop and yield variability and plan consequently tillage operations for alleviating the most compacted areas. Boon *et al.* (2005) has also proposed the use of a GPS assisted penetrometer. Their implication consisted of one penetrometer probe and one shear stress vane, which were highly correlated and from those they developed equations to predict tractor draft forces.

The introduction of a five penetrometer probes can be used togather analytical penetration resistance information quickly, which is normally a time consuming and effort demanding task. Furthermore, unlike horizontally operating implications (Sun*et al.,* 2006), that are single point units, the simultaneous use offive probes makes possible the creation of two dimension resistance profiles. Finally, the field validation for two years within as trip tillage operation depicted the different penetration resistance around the crop row. In other cases, it could be used to detect soil compaction under wheel traffic. In situations where row position is not important, the average value from all probes can be used to achieve even greater precision in determination of cone index.

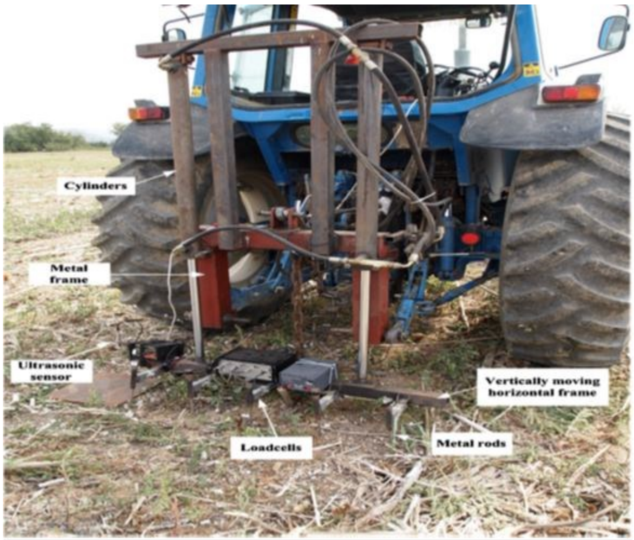
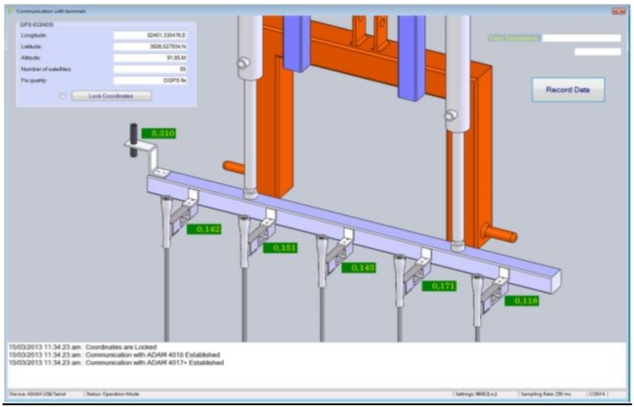


Fig. 7. Penetrometer mounted on a tractor with rods in the soil.



Longitude 02401.339476.E
Latitude 3826.527934.N
Altitude 91.95.M
Number of satellites 05
Fix quality DGPS fix

15/03/2013 11:34:23 am : Coordinates are Locked
15/03/2013 11:34:23 am : Communication with ADAM 4018 Established
15/03/2013 11:34:23 am : Communication with ADAM 4017+ Established

Device: ADAM USB/Serial | Status: Operation Mode | Settings: 9600,E,n,1 | Sampling Rate: 250 ms | COM4

Fig. 8. Communication user interface (the numbers in the bars are in voltage (V).

III. CONCLUSION

Spatially variable soil compaction often causes inconsistent growing conditions in many fields. Various soil compaction sensor systems have been deployed to obtain geo-referenced maps of certain state and behavioral properties (e.g., soil strength, water content, air permeability) related to compaction. Among the different types of Penetrometer a five point penetration resistance system proved to be fast, robust and reliable for gathering soil compaction information and depict the inherent soil compaction variability across the field. Regarding GPS accuracy it was observed that the accuracy of the GPS was high when the elevation was ±0.5 m between two subsequent readings. Obviously, the best way to perform the measurements would be to connect the system with an RTK-GPS to achieve higher accuracy. This could be a useful asset for generating soil penetration resistance maps. Due to the steady growth of precision agriculture research and applications, the demand for detailed soil compaction information is increasing. The information gathered could help explaining crop and yield variability and plan consequently tillage operations for alleviating the most compacted areas.

Soil compaction restricts the root and crop development and results in a reduction in crop yield. A great amount of variability in the depth and thickness of hardpan layers of the different regions. However, farmers till the soil at constant depth leading to higher tillage costs. Optimum tillage depth may be shallower in some parts of the field. Variable depth tillage could be beneficial in optimizing the production costs. The aim of this study was to understand if the variable depth tillage is feasible. The energy savings of 56.4% and fuel savings of 33.8% could be achieved by adopting the variable-depth tillage system over the uniform and constant-depth (conventional) tillage. Therefore, VDT is recommended due to its advantages on energy and fuel savings.

REFERENCES

[1] Al-adawi S.S. and Reeder R. C. 1996. Compaction and subsoiling effects on corn and soybean yields and soil physical properties. *Transactions of the ASAE*, 39(5) 1641-1649.

[2] ASAE Standards (2000b). EP542 FEB99. Procedures for using and reporting data obtained with the soil cone penetrometer. *http://www.asae.org: 987–989*. Accessed on 10 July 2002

[3] Bekker M G (1969). Introduction to Terrain-Vehicle Systems. The University of Michigan Press, Ann Arbor, USA

[4] Boon, N.E., Yahya A, Kheiralla, A.F., Www, B.S. and Gew, S.K., 2005, A Tractor-mounted, Automated Soil Penetrometer–shearometer Unit for Mapping Soil Mechanical Properties, *Bio-systems Engineering,* 90(4), 381- 396.

[5] Bowen, H.D., and C.G. Goble, 1967, Environment requiremetns for seed and emergence. *Transactions ASAE,* 25: 1169-1172.

[6] Brixius W W (1987). Traction equation predictions for bias ply tires. *ASAE* Paper No. 87-1622, St. Joseph, MI, 8pp.

[7] Culley, J.L.B., 1993. Density and compressibility. In: Carter, M.R. (Ed.), Soil Sampling and Methods of Analysis. *Lewis Publishers*, Boca Raton, FL, USA.

[8] Gaultney, L.D., 1989. Prescription farming based on soil property sensors. ASAE Paper No. 89-1036. *ASAE*, St. Joseph, MI.

[9] Hemmat, A and Adamchuk., 2008, Sensor systems for measuring soil compaction: Review and analysis, *Computers and Electronics in Agriculture, Science Direct* (63) 89-103.

[10] Johnson, C.E., Bailey, A.C., 2002. Soil compaction. Advance in Soil Dynamics, vol. 2. *ASAE*, St. Joseph, MI, pp. 155–178.

[11] Manish Kumar and Mehta C.R., 2013, sensors for hard pan determination-A review, *Agricultural Engineering Today*, 37(4), 17-26.

[12] Morgan R P C (1986). Soil Erosion and Conservation. (Davidson ed). University of Strathclyde, UK

[13] Munsuz, N., 1985, Soil mechanic and technol, *A.U. Agricultural Faculty,* Ankara (260) 1985

[14] Mouazen A M; Anthonis J; Saeys W; Ramon H. 2004. An Automatic Depth Control System for Online Measurement of Spatial Variation in Soil Compaction, Part 1: Sensor Design for Measurement of Frame Height Variation from Soil Surface. *Bio-systems Engineering*, 89 (2), 139–150.

[15] Johan Arvidsson and IngeHakansson, 2014, Response of different crops to soil compaction short term effects in Swedish field experiments. *Soil and Tillage Research*, (138) 2014, 56- 63.

[16] Raper R L; Washington B H; Jarrell J D (1999). A tractor mounted multiple-probe soil cone penetrometer. *Applied Engineering in Agriculture*, 15(4), 287–290

[17] Rauws G; Govers G (1988).Hydraulic and soil mechanical aspects of rill generation on agriculture soils. *Journal of Soil Science*, 39, 111–124

[18] Spyros Fountas, Dimitris Paraforos, Chris Cavalaris, Christos Karamoutis, Theofanis A. Gemtos, Nawaf Abu-Khalaf, and Aristotelis Tagarakis, 2013, A five-point penetrometer with GPS for measuring soil compaction variability. *Computers and Electronics in Agriculture*, 96 (2013) 109–116

[19] Sun–Ok Chung, Jin–Woong Cho and Takeo Yamakawa, 2012, Development of a Motorized Digital Cone Penetrometer, *J. Fac. Agr., Kyushu Univ.,*57 (2), 399–404

[20] Sun, Y., Schulze Lammers and Ma, D., 2004. Evaluation of a combined penetrometer for simultaneous measurement of penetration resistance and soil water. *Journal of Plant Nutrition, Soil Science*, 167: 745-751.

[21] Sun, Y., J. Lin and Ma, D., 2007. Measurement of penetration force using a hall-current-sensor. *Soil Tillage Research,* 92: 264-268.

[22] Vaz C MP; Bassoi L H; Hopmans JW(2001). Contribution of water content and bulk density to field soil penetration resistance as measured by a combined cone penetrometer–TDR probe. *Soil and Tillage Research*, 60, 35–42

[23] Wismer R D; Luth H J (1974). Off-road traction prediction for wheeled vehicles. *Transactions of the ASAE*, 17(1), 8–10

[24] Wong J Y (2001).Theory of Ground Vehicles, *3rd Edition*. John Wiley, New York Zimbone S M; Vickers A; Morgan R P; Vella P (1996). Field investigations of different techniques for measuring surface soil strength. *Soil Technology*, 9, 101–111.