Development of an On-The-Fly Mechanical Impedance Sensor and Evaluation in a Coastal Plains Soil

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ABSTRACT

Root-restricting soil layers reduce crop yields in the Southeastern United States almost every year due to temporary periods of drought. Subsoiling beneath these layers is an annual practice for most farmers in this region as a method of removing this barrier and improving rooting conditions. Currently, farmers could use a soil cone penetrometer to determine the depth of their root-restrictive layer in a few locations within a field and then set their tillage depth to exceed all of these. However, significant energy savings could be achieved if some method of sensing the depth of this layer was available on-the-go and adjustments could in turn be made to tillage depth. A prototype design of an on-the-fly mechanical impedance sensor was developed as a possible alternative to the cone penetrometer and as a method of sensing the depth of the root-impeding layer. Several versions of this sensor were evaluated in a sandy loam soil bin at the USDA-ARS National Soil Dynamics Laboratory. The sensor was able to detect compacted soil profiles in a similar fashion as the cone penetrometer. Further research with this sensor could lead to methods of quickly and easily mapping soil compaction within fields.

INTRODUCTION

Soil compaction in the southeastern United States is a difficult and expensive condition for producers in this region to manage. The Coastal Plains soils found in this region form natural and traffic-induced induced dense compaction, limiting root growth and the yield potential of crops (Raper, 1999). Tillage serves to reduce or alleviate the effects of soil compaction on crop growth and yield. Tillage treatments are applied to the soil based on cultural practices, rather than diagnostic evidence of compaction. Adjusting the depth of tillage to till only immediately below the depth of the compacted pan would be a more efficient approach to tillage, by reducing energy consumption of pulling the tillage tool deeper than necessary.

The cone penetrometer is the most widely accepted method of determining compaction within a soil profile. The cone penetrometer can locate the depth and magnitude of the root impeding layers within the soil profile. The cone penetrometer measures the resistance of the soil to the insertion of a conical tip. The term for this resistance is defined by ASAE Standard S313.2 (1998) as "Cone Index".

Many measurements must be taken with a cone penetrometer to accurately determine the variation of compaction within a field. Intensive sampling with a cone penetrometer is time prohibitive for field applications, due to the stop and go technique used to acquire data. A device is needed to measure soil properties in a manner similar to the cone penetrometer, but quick enough to be feasible for large-scale sampling. A tool to quickly determine soil strength within a soil profile has been developed at the USDA-ARS National Soil Dynamics Laboratory (NSDL). This tool is designed to measure soil compaction as the tool moves through the soil profile.

MATERIALS AND METHODS

An on-the-fly mechanical impedance sensor (OMIS) has been developed to measure soil compaction as the tool is pulled through the field. The tool designed for testing in this project, is similar in concept to a tool designed at North Carolina State University (Alihamsyah and Humphries, 1991). The OMIS records mechanical impedance force as the tool is pulled through the soil.

The OMIS is a straight tine beveled on the front edge to a 30^0 wedge (Figures 1 and 2). A section in the front of the tine was removed, and replaced with a tip, also machined as a 30^0 prismatic wedge. The sensing tip connects to the force transducer at the rear of the tine through an oversized hole drilled in the tine. The wedge angle of 30^0 for the tip, was chosen based on findings by Alihamsyah et al. (1990) that a 30^0 wedge is more suitable than the ASAE standard 30^0 cone for horizontal determination of soil strength.

Two tips were designed for testing of the OMIS. The 650-mm^2 tip is made from 25mm steel bar stock, with an effective base area of 650 mm^2 and protrudes 60 mm in front of the leading edge of the tine. The larger tip is made from 50 mm steel bar stock, with an effective base area of 2500 mm^2 and protrudes 30 mm in front of the leading edge of the tine. The leading edge of the 2500-mm^2 tip was brought closer to the leading edge of the tine.

The force transducer chosen for the OMIS is a SENSOTEC® GR3 load beam (SENSOTEC®, Columbus, OH 43228), with a 4.45 kN (1000 lb) measurement capacity. The transducer capacity was selected to accommodate the range of forces expected from the two tip designs. Data acquisition was accomplished with a Modcomp. For tests with the mechanical impedance sensor, the system was set to sample the force transducer twenty-five times per second.

Testing of the OMIS was conducted in the USDA-ARS NSDL indoor soil bins, which were selected because the moisture content of the soil can be easily controlled. The soil type in the indoor bin is Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudults). A completely randomized experiment with four treatment depths replicated four times was selected for testing the OMIS unit with both tips. The tine was pulled through the plots at approximately 0.45 m sec^{-1}. The plots were 1 m wide by 10 m long. The soil bin was prepared with tillage-induced pans at two depths within the soil profile. Bulk density measurements were taken at 5 mm increments to a depth of 300 mm. Ten penetrometer measurements were randomly taken per plot with a hydraulically operated penetrometer. This penetrometer has a computer-based data acquisition system and is capable of measuring mechanical impedance every 5 mm through the soil profile. The penetrometer measurements were averaged for an overall plot mean for comparison against impedance reading collected with the OMIS unit.

RESULTS

The OMIS was capable of predicting a soil profile similar to a cone penetrometer, however the forces were reduced in magnitude. The term "wedge index" was coined to describe the impedance values measured by OMIS. Wedge index is the measured resisting force divided by the base area of the prismatic wedge. This is the same principal used to define the term "cone index", as found in ASAE Standard S.313.2. The magnitudes of the wedge index as measured with OMIS were less than the cone index measured with the cone penetrometer (Figures 1 and 3). These findings were expected and agree with other research on horizontal measurement of mechanical impedance (Hartge et al., 1978; Alihamsyah and Humphries, 1991).

The penetrometer data indicated that the soil was in a state of severe compaction in both tests. Cone indexes greater than 5 MPa were found at some depths in the plots of the 650 mm^2 tip test. The plots in the 2500 mm^2 tip test had cone indexes approaching 7 MPa. The compaction existing in these test areas are much greater than the 2 MPa compaction levels found to limit root growth (Taylor and Gardner, 1963).

The force readings recorded during testing of the 650 mm^2 tip were less than forty percent of the capacity of the force transducer (Figure 1). With such low values, the inherent error of the transducer causes concern. Ideally, forces to be measured with transducers are fifty percent or greater of the measurement range of the transducer. Two options were examined to correct this problem. One option was to use a smaller force transducer, however the one selected was the smallest commercially available from the manufacturer. The option chosen was to resize the tip, which increased the forces measured by the transducer. The 2500 mm^2 tip had the opposite problem; at some treatment depths, the force values from the transducer were greater than the full scale range of 4.45 kN (Figure 3). However, the readings were not large enough to damage the force transducer. Also, the soil was prepared with an excessive amount of compaction above what may be typically encountered in field sampling.

The data from tests of both tip designs were analyzed with regression analysis to determine the best design for further testing and development. The data from the 650 mm^2 tip was found to be best fit by a second degree polynomial equation when compared to the cone penetrometer data (Figure 2). The data from the 2500 mm^2 tip was best fit by a linear relationship, when compared to the cone penetrometer data (Figure 4). Based on this finding, the 2500 mm^2 tip has been selected for further testing. Bulk density measurements were not found to correlate well with the cone penetrometer measurements or the OMIS measurements in either test.

CONCLUSIONS

Soil compaction can be quickly measured and utilized in a control loop to adjust tillage to the proper working depth to alleviate the compacted hardpan conditions found within the soil profile. Such a tool for measuring soil impedance has been developed at the USDA-ARS NSDL; this tool has been able to measure soil profiles similar to the cone penetrometer. In preliminary testing, the experimental OMIS unit has shown potential as a faster alternative to the standard cone penetrometer.

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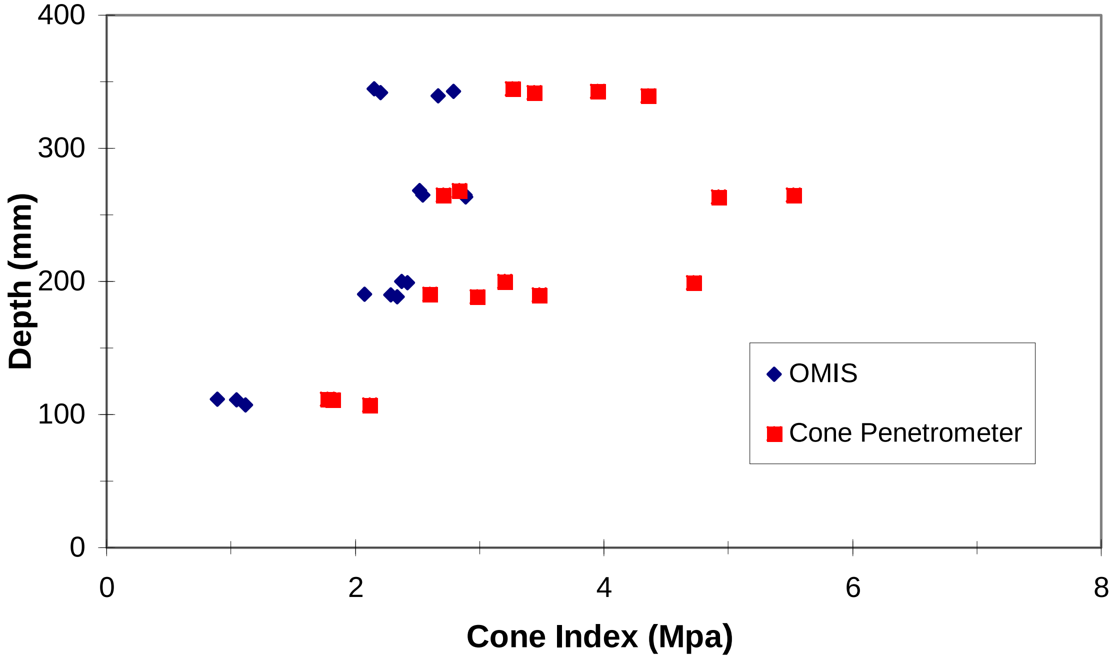

Figure 1. Mechanical impedance profiles as detected with the cone penetrometer and the OMIS unit with the 625 mm^2 tip.

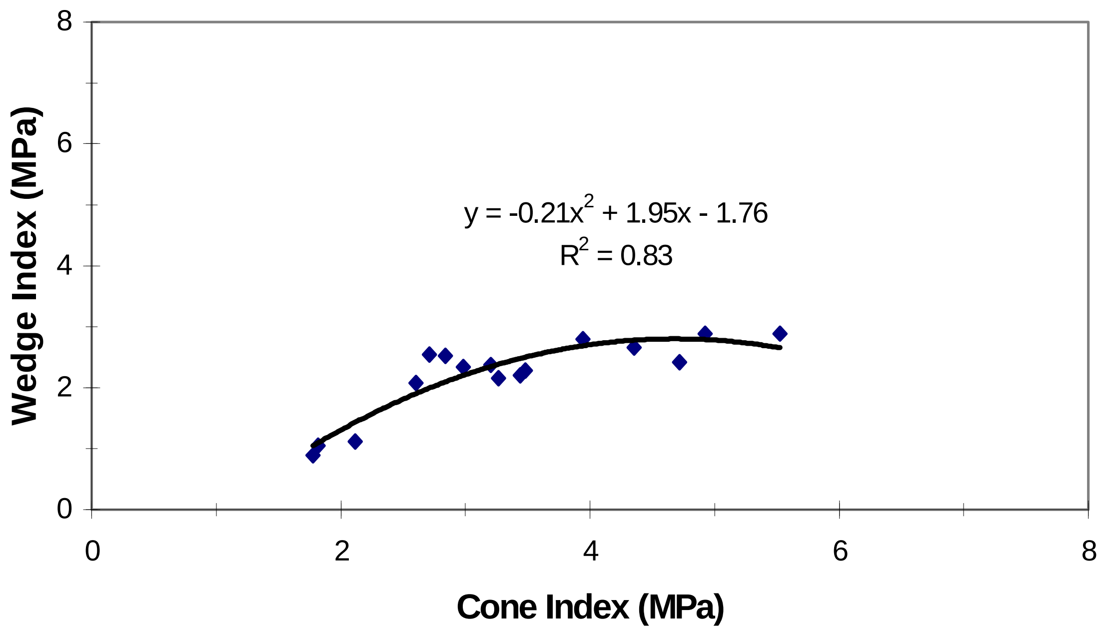

Figure 2. OMIS wedge index measured with the 650mm^2 tip compared to cone index.

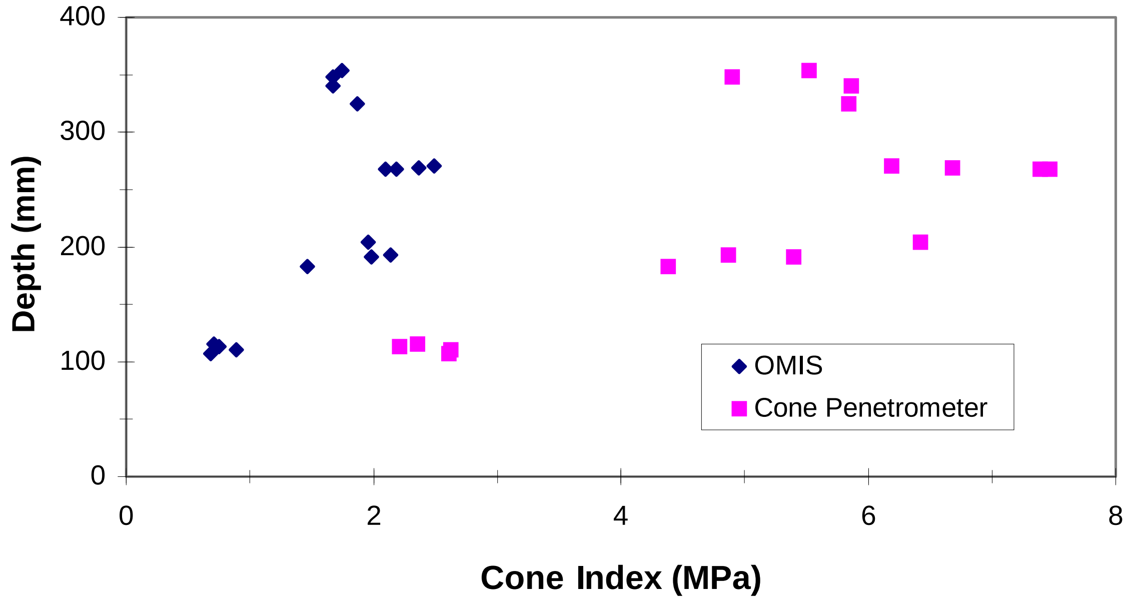

Figure 3. Mechanical impedance profiles as detected with the cone penetrometer and the OMIS unit with the 2500 mm^2 tip.

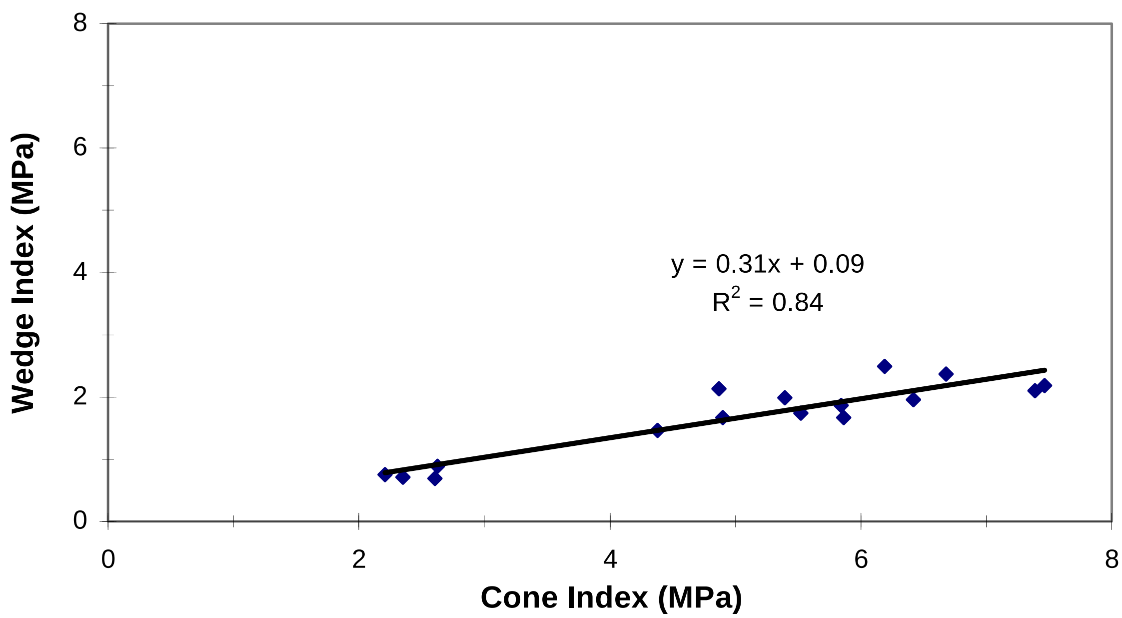

Figure 4. OMIS wedge index measured with the 2500mm^2 tip compared to cone index.