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Evaluation of the Clemson instrumented subsoiler shank in coastal plain soils

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ABSTRACT

Most sandy soils in coastal plains of the southeastern USA have a compacted zone or hardpan which limits root penetration below the plowing depth, reducing yields, and predisposing plants to drought stress. The hardpan layer exhibits a great amount of variability in depth and thickness in this region. Real-time, sensor-based, site-specific tillage could achieve significant savings in energy requirements for subsoiling and increase crop yields. Replicated tests were conducted to evaluate the performance of the Clemson instrumented subsoiler shank under actual field conditions. The instrumented subsoiler shank was calibrated against cone penetrometer readings on three coastal plain soil types. A strong positive correlation between soil strength values measured with the penetrometer and the instrumented subsoiler shank was observed ($R^2 = 0.89–0.97$). On average, the shank index values (measured horizontally) were about 50% less than the corresponding cone index values (measured vertically). The effect of soil moisture content on shank-penetrometer correlation was not significant ($\alpha = 0.05$). It is possible to determine the depth and thickness of the hardpan layers with the instrumented subsoiler shank either for real time control of subsoiling location and depth or for generating site-specific tillage maps.

1. Introduction

Soil compaction limits root penetration which in turn reduces yield, and makes plants more susceptible to drought stress. Many studies have determined the critical soil strength values that prevent root penetration and plant growth for various crops. Taylor and Gardner (1963) determined the typical value of cone index that stops root growth of cotton plants as 2.07 MPa (300 psi). Most sandy soils in coastal plains of the southeastern USA typically have a compacted zone or hardpan (with cone index values above 2.07 MPa) about 15- to 35-cm deep and 5- to 15-cm thick. Farmers in this region rely heavily on the use of annual uniform-depth deep tillage to manage subsurface soil compaction which improves yields (Garner et al., 1989; Khalilian et al., 1991, 2004). There are several drawbacks to this approach to manage subsurface soil compaction. Farmers do not usually know if annual subsoiling is required, where it is required in a field, nor the required depth of subsoiling. In addition, there is significant variability in depth and thickness of hardpan layers from field to field and also within a field (Raper et al., 2000a,b; Clark, 1999; Gorucu et al., 2006). Therefore, applying uniform-depth tillage over the entire field may be either too shallow to fracture the hardpan or deeper than required resulting in excess fuel consumption.

Ideally, depth and thickness of the hardpan layer needs to be determined for the optimum tillage depth to remove the hardpan layer. In addition, there is little to gain from tilling deeper than required to fracture the compacted layer and in some cases, penetration into the clay layer may be detrimental (Garner et al., 1986). Measurement of soil compaction has traditionally been conducted by a soil cone penetrometer (a stop-and-go procedure) which provides highly variable discrete point measurements. This approach generally provides a poor characterization of hardpan depth if the field is large unless an impractically large number of samples are collected.

A number of researchers have attempted to develop equipment for continuous measurement of soil strength at multiple depths (Glancey et al., 1989; Alihamsyah et al., 1990; Adamchuk et al., 2001; Khalilian et al., 2002; Hall and Raper, 2005; Siefken et al., 2005; Chung et al., 2006; Andrade-Sanchez et al., 2007, 2008).

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Although these systems have potential to significantly reduce the cost of data collection for research and production use, they are still in development stages and more data are needed under various soils and operating conditions to increase their potential use by producers and researchers. The equipment for continuous measurement of soil strength (cited in literature) has not been tested under southeastern coastal plain sandy soils. Real-time, sensor-based, site-specific tillage could achieve significant savings in tillage frequency and energy and increase crop yields in this region (Gorucu et al., 2001; Abbaspour et al., 2006).

Researchers at Clemson University have developed an instrumented subsoiler shank to measure mechanical impedance of soil at multiple depths over the entire top 45-cm of soil profile while moving through the soil (Khalilian et al., 2002). Considerable soil variation occurs within and across production fields in the Southeastern USA which could affect the performance of the on-the-go soil compaction mapping system. The Clemson instrumented subsoiler shank was designed specifically for coastal plain soils condition for detecting depth and thickness of soil hardpans.

2. Objectives

The overall purpose of the work was to determine the accuracy of the instrumented subsoiler shank in detecting the depth and thickness of the hardpan layers as compared to the cone penetrometer method with these specific objectives: (1) to determine the effects of soil moisture on subsoiler shank performance, (2) to calibrate the instrumented subsoiler shank against cone penetrometer readings on three coastal plain soil types and (3) to evaluate the performance of the subsoiler shank under actual field conditions.

3. Materials and methods

3.1. Equipment

The Clemson instrumented subsoiler shank (Fig. 1) consisted of five 7.5-cm long sections attached to the subsoiler shank using load cells (Khalilian et al., 2002). The width of each section was 2.5 cm and the face of each section was flat and perpendicular to the direction of travel. Two compression load cells (Model MS-SP-COMP, 8896-N National Scale Technology, Huntsville, Ala.) were used in each 7.5-cm section to measure horizontal force acting on the subsoiler shank. The sum of two load cells was used to calculate the total force acting on each section. Each section was calibrated in the lab by applying known forces and measuring output voltages. It should be noted that, the shank thickness, shank position on the frame and sharpening angle of the subsoiler shank may affect the horizontal forces measured for field data. LogBook/360 data logger (IOTech, Inc., Cleveland, Ohio) with GPS support was used for data collection. The data logger was equipped with 16 analog inputs, two 8-channel strain gage modules, and a 4-channel frequency input card. Soil strength data was collected at 100 Hz. A Trimble AgGPS-132 receiver (Trimble Navigation Limited, Sunnyvale, Calif.) with "fast rate" option (10 Hz) was used to determine the position of the subsoiler shank in the field. This unit contains both OmniSTAR and Beacon differential technology. Gage wheels were used to control the depth of the subsoiler shank in a way that the lower part of the bottom instrumented section on the subsoiler shank always would run at a depth of 45-cm. This system did not measure mechanical impedance of the top 7.5-cm of the soil profile.

A DGPS-based, hydraulically operated penetrometer system mounted on a John Deere Gator was used to quantify geo-referenced soil resistance to penetration (Fig. 2). Soil compaction values were calculated from the measured force required pushing a 130-mm^2 base area, 30-degree cone into the soil (ASAE S313.3, 2006).

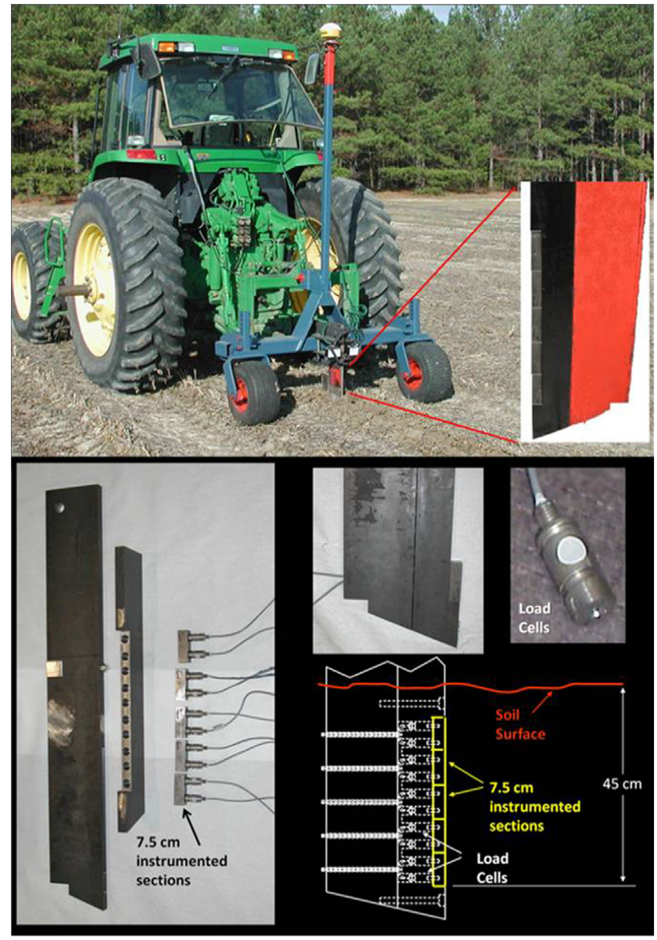

Fig. 1. The Clemson instrumented shank (top) and schematic diagram (bottom).

Fig. 2. Hydraulically operated, penetrometer system with DGPS unit.

Probe depth was measured using a circular potentiometer attached to the penetrometer with a sprocket and chain. A rod and an electric switch were used to detect the soil surface. A 16 bit data acquisition system (KPCMCIA-16AI-C, Keithley Instruments, Inc., Cleveland, Ohio) was used to read penetration data, depth and switch status 20 Hz. A program written in TESTPOINT software (Measurement Computing Corporation, Norton, Mass.) collected the GPS location and penetrometer data.