The Compaction Problem

Sensors address soil compaction variations

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It has long been recognized that soil must be managed properly to sustain productivity. Soil is a complex medium composed of solids (mineral particles and organic matter), liquid (soil water), and gas (air entrained in soil pore spaces). The percentage of pore space and the balance of water and air in the soil matrix are physical conditions important for plant root growth. Many soil management activities are directed toward maintaining or improving these and other soil physical properties.

Soil compaction refers to an increase in the bulk density of the soil as a result of applied loads or pressure. Compaction increases soil strength and decreases aeration, reducing the ability of plant roots to grow. Although some compaction is from natural causes, it is compaction as a result of mechanically applied forces such as traction or tillage that has caused increasing concern as agricultural machinery has become larger and tillage practices have changed in recent decades. Because of this, agricultural engineers have made major efforts toward reducing the compaction caused by tires, tracks, and tillage implements, and developing tillage machines and systems to ameliorate compaction problems.

Direct field measurements of compaction are difficult, so the strength of the soil in resisting penetration has often been used as a surrogate measurement. The design and use of a standard device to measure this resistance, the soil cone penetrometer, is described in ASAE Standard S313.3 and ASAE Engineering Practice EP542. When using a penetrometer, soil strength is described by cone index (CI), the ratio of the force required to push the penetrometer into the soil to the base area of the cone.

Researchers collect soil strength measurements with a recording cone penetrometer. *(Photo by Scott Bauer, courtesy of USDA-ARS)*

Precision agriculture and compaction

Today many producers are employing precision agriculture technologies to map spatial variations in crop yields within fields. Once they see how variable yields are in their fields, producers want to understand what causes yield variations and what they can do to improve low-yielding areas. For many soils and cropping systems, compaction is a likely cause of yield depression in some parts of fields, and taking action to reduce compaction may be warranted. Since this will usually involve some form of deep tillage, mapping the location and depth of compacted areas and targeting the tillage only to the areas that need it, and only to the needed depth, can improve efficiency and reduce fuel usage costs.

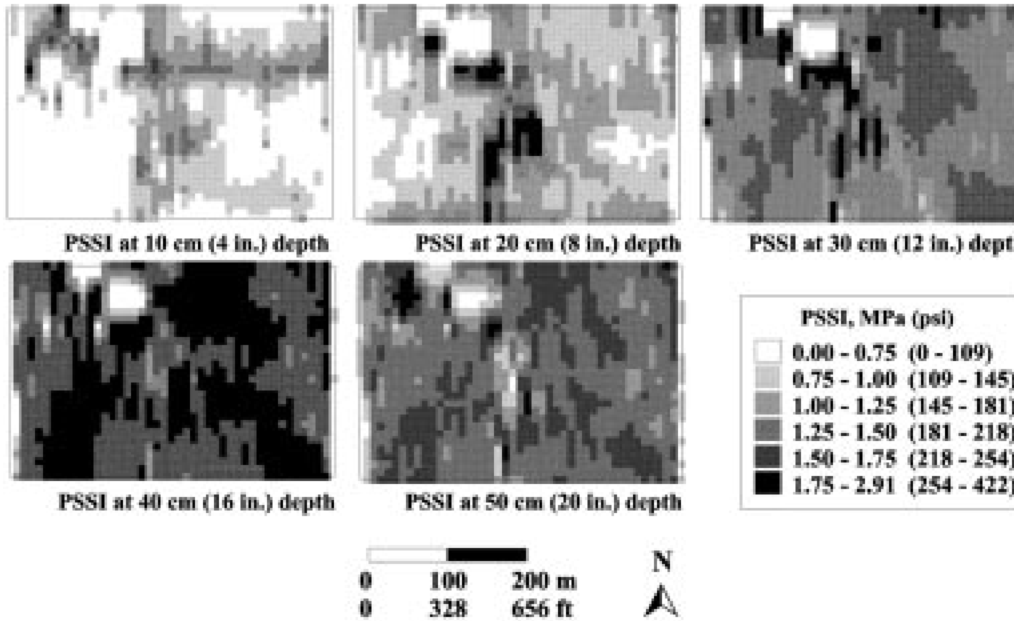
Side view of the SSPS raised out of the ground, showing the five sensing tips.

Although the standard cone penetrometer can be used to quickly describe compaction status at a single point, moving through a field and collecting data at enough places to create a map would be difficult and time-consuming. Even if a mechanized, tractor- or trailer-mounted penetrometer were used, data collection would still be a slow, stop-and-go operation. A horizontally operating sensor that could measure penetration resistance while being pulled across the field by a tractor would be a much better way to generate a soil strength map showing compaction differences. In addition to our work, a number of other researchers have developed prototypes of such sensors, including agricultural engineers at the University of California-Davis, the University of Nebraska, North

Carolina State University, and the USDA-ARS National Soil Dynamics Lab in Auburn, Ala.

The Missouri soil strength profile sensor

The "soil strength profile sensor," or SSPS, developed by the USDA-ARS and University of Missouri engineers provides measurements of soil strength at five depths in the soil profile – 10, 20, 30, 40, and 50 cm (4, 8, 12, 16, and 20 in.). Five prismatic tips protruding from the front of a narrow vertical blade are connected to miniaturized load cells inside the blade that measure the soil forces acting on the cutting tips. From the force data, a prismatic soil strength index (PSSI) is calculated, similar in concept to the CI from the cone penetrometer.



Soil strength (PSSI) maps created with the SSPS for a 12-ha (30-acre) field in central Missouri. In this field, PSSI values are highest at the 40-cm (16-in.) depth, and variations appear to be related to soil differences rather than management factors.

The whole device is attached to a tractor three-point hitch, and a customized data collection system records load cell outputs along with GPS location data as the tractor pulls the SSPS through the field. Using the force and GPS data, PSSI maps can be created for each of the sensing depths.

In soil bin and field tests, the prototype SSPS provided reliable and repeatable data. Large variations in PSSI within producers' fields, both from location to location and as a function of depth, have been observed When looking at whole-field patterns, much of this variation has seemed to be related to soil properties such as texture, rather than to management practices. However, the intensive data collection possible with the SSPS will allow future research to look more closely at the effects of wheel tracks and other management-induced variability likely to be present at smaller scales.

Since penetrometer CI measurements have historically been reported in studies that relate agronomic results to compaction, it is important to be able to relate PSSI data to CI data. Generally, significant linear relationships between PSSI and CI have been found, but they are different for different soil textures and depths. This may be because the mechanisms of soil disturbance are somewhat different for the vertically operating penetrometer and the horizontally operating SSPS. Additional data collection and mathematical modeling are needed to more clearly define these relationships.

Closing the loop

Once sensors are avilable that can efficiently assess compaction differences within fields, producers will want to use these data to make management decisions. Maps from on-the-go sensors can be used directly to identify target areas for site-specific and/or variable-depth tillage. In the future, perhaps these data can be used along with the many other spatial data sets that can be obtained for a field – multiple years of yield maps, topographic maps, soil type maps, soil fertility data, remote sensing images, etc. – in combination with some type of decision support system to determine the optimum management actions for each location within the field. Such a system that could simultaneously manage soil physical and chemical properties, pests, and other yield-affecting factors would bring us closer to an optimum implementation of precision agriculture. R

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