Site-Specific Management Guidelines

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Site-Specific Soil Compaction Mapping Using a Digital Penetrometer

Summary

Soil compaction is generally defined as an increase of the natural density of soil at a particular depth. A density increase translates into less pore space, less plant available water, slower water transport, and a decrease in the root's ability to penetrate the compacted zone as it seeks out water and nutrients. Similarly, the increase in density due to compaction can serve to retard or divert the flow of water, resulting in ponding or excessive runoff. These factors may limit yield and inhibit effective site management for many crops. Compaction can be measured with penetrometers. Recent advances in digital penetrometer systems can provide users with a simple way to map soil characteristics over large areas in the field. This guideline discusses the impact of compaction on crop growth, methods to measure compaction, and techniques to solve compaction problems.

Introduction

Tillage implements or repeated trips over the field can cause plow pans or traffic pans. Plow pans and tillage pans can reduce yield potential by restricting the amount of soil available for the plant roots to explore. Tillage implements such as the chisel plow or spring-tooth harrow do not press down on the soil beneath them and therefore do not typically create plow pans. Whether or not a grower should be concerned with compaction depends on a few key issues (**Table 1**). Approaches for minimizing compaction include:

- Confine all wheel traffic to specific paths across the field (controlled traffic).
- Reduce the number of equipment passes in the field.
- Use equipment with the lowest practical axle weight.
- Fracture any compaction layer with deep ripping (or plowing).
- Do not work soil when it is too wet.
- Install drainage tile in wet areas.
- Avoid harvest operations when conditions are too wet, if possible.
- Follow management practices designed to increase soil organic matter (e.g., keep soil covered by vegetation or mulch)

Identifying the Area Requiring Treatment

To maximize the effectiveness of a water management practice or ripping, a site investigation that determines the depth, thickness, and soil type of a compacted layer across the field is needed. Proper site investigation enables optimal drainage tile placement or ripping of a compacted layer with a tillage implement.

Table 1. Issues related to understanding soil compaction.

Compaction Issue	Question
Intensity	How compacted is it? Severe with a high density or mild? Slight compaction may not inhibit crop growth or cause management problems.
Extent	Is the compaction across the entire field or only in selected areas? Is it the same everywhere?
Depth	At what depth does the highest compaction occur across the field?
Thickness	How thick is the compacted layer?
Time	How if at all does compaction change over the course of a year?

One of the primary reasons tile or ripping isn't always as successful as hoped is that the magnitude, extent, depth, and thickness of the compacted zone is not adequately mapped. If a compacted layer is only a few inches thick and at a depth easily reached by tillage equipment, then there is no need to install costly drainage tile. Maximum soil fracture/breakup will occur approximately one inch above the point of a typical ripper shank. If the depth of compaction can be easily determined, then the depth setting of the tillage implement can be optimized.

If a compacted layer below the tillage zone does not allow drainage, tile may not always improve the localized

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hydrology. It might be that a compacted layer is not fine grained, but a rather coarse soil better suited for drainage treatment. The proper penetrometer sampling procedure can maximize the effectiveness of such practices by making the field placement and installation process optimal. This can be achieved through the use of a new digital penetrometer design that measures not only compaction but also soil texture (described below).

Soil sampling and laboratory analysis are too inefficient and costly to adequately acquire the data necessary for mapping compacted zones. The typical result of this process is a handful of sample locations. Some form of spatial interpolation is required to estimate the soil properties at the unsampled locations. The number of steps involved in the traditional soil sampling process means an increase in the potential for errors. So how do you find and map these compacted layers both efficiently and effectively using a digital penetrometer?

Penetrometers and Compaction

The digital penetrometer is the best available technology for assessing soil compaction rapidly across a field. Since compaction is an increase in the density of soil, it is easily measured by determining the force needed to push the penetrometer through it. Generally speaking, the more dense the soil, the harder it is to push a probe through it. Although roots are able to find their way between structural features in their search for water and nutrients, there is no question that a dense soil makes this process more difficult (**Figure 1**). The penetrometer is the best available technology for predicting root penetration.

The current technology revolution that is sweeping the scientific and engineering community has made its way into subsurface mapping applications as well. Digital penetrometer data are easier to collect, analyze, store, reference, distribute, and use than ever before due to rapid advancements in the technology over the past few years. This makes the digital penetrometer more user friendly for traditional applications such as mapping soil compaction. Additional advancements in the design of new sensors for digital penetrometers have expanded the potential applications for this growing technology. Recent work has shown that innovative designs have resulted in penetrometers capable of mapping soil texture, moisture, and even real-time subsurface imagery (Rooney and Lowery, 2000; Rooney et al., 2000).

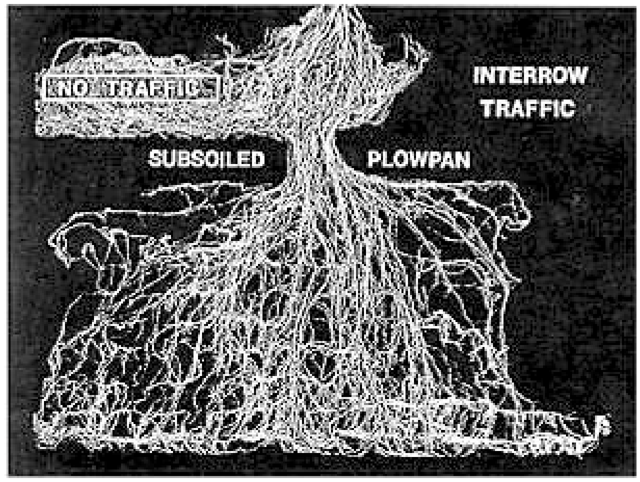

Figure 1. Root distribution of a cotton plant. Note how the roots gain access to the subsoil through a lower density zone created by a chisel-type tillage implement (Courtesy USDA National Tillage Machinery Laboratory).

Measuring bulk density at multiple soil depths is expensive. Since the data obtained with the digital penetrometer are more easily collected and analyzed, they are more useful. It has also been found through research that soil penetrometer resistance measurements are 10 times more sensitive as an indicator of soil compaction than are bulk density measurements. Since the penetrometer measures the soil compaction in the field, it more closely emulates the root's ability to explore the soil at that location under the same set of localized conditions. **Table 2** outlines several factors that need to be considered when thinking about using a digital penetrometer to assess (and map) compaction.

Table 2. Steps to consider when determining if compaction is present (in addition to mapping its location and extent).

Question	Answer
Probe Selection	Depends on the application of interest, budget, and processing capabilities (e.g., traditional tip force penetrometer or addition of friction sleeve measurement: GPS required for mapping purposes).
"Push" Platform	Depends on time of year samples will be taken, sample density, and depth of sampling (e.g., handheld, ATV-, trailer-, or truck-mounted).
Timing	Depends on the objective. When considering only compaction mapping – in-season when root growth is rapid is ideal (handheld or high clearance "push" platform).
Sampling Density (#/field)	If no previous information – grid sample; if there is previous experience or site knowledge – targeted sampling approach may be better.
Data Processing	Is it compaction? Rely on curve shape and "rule of thumb": low [less than 150 pounds per square inch (PSI)], medium (150-300 PSI), high (300-450 PSI), and heavy (450+ PSI).
Data Interpretation	Estimate an average compaction depth by visually inspecting each penetrometer profile. May need to confirm the presence of natural clay increase with depth by consulting USDA soil survey information or digging small test holes.
Action	Data may help in the determination of: 1) tile placement (depth and location) or 2) optimizing the depth setting of a primary tillage tool (e.g., ripper): set points one inch below calculated average depth of compaction for maximum soil fracture.

Applied Penetrometer Technology

Recent advancements in computer and digital technology have dramatically improved the practitioner's ability to collect, process, and analyze penetrometer data. Digital data loggers and depth measurement devices have enabled the real-time association of raw data output with depth of penetration and calibration factors. The result is that soil properties can be measured with an estimated error and mapped in the field. It is now possible to predict soil bulk density, texture, moisture, and color in the field without taking a sample. Of course, digital penetrometer data are not meant to replace traditional soil core sampling, but rather to optimize the location and depth of the samples that are taken. In fact, all digital penetrometer data can be made more accurate during post processing if samples from a few key locations are analyzed and used to perform a site-specific post-calibration of the penetrometer data. This may or may not be necessary depending on the application.

Penetration resistance is measured in force per unit area, or Cone Index (CI). The unit of measure is typically PSI, although scientific reports use kilopascals (kPa) or megapascals (MPa). Penetration resistance can generally be divided into four categories: low (less than 150 PSI), medium (150-300 PSI), high (300-450 PSI), and heavy (450+ PSI). A measure of 725 PSI (5,000 kPa) is usually considered to be the maximum value that roots can penetrate. Of course, this depends on the site conditions and crop type.

Plots similar to **Figure 2** can be generated within minutes of testing. In this example an increase in compaction occurs at about 8 in. (20 cm) and again starts to increase at about 20 in. (50 cm). The test in **Figure 2** took about 60 seconds to perform from a truck mounted hydraulic penetrometer.

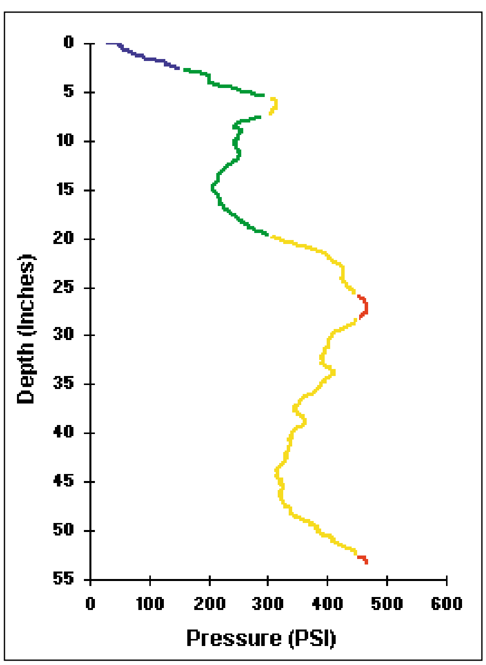

Figure 2. Compaction profile created from a penetrometer. Compaction categories are delineated by color (light=blue, medium=green, high=yellow, heavy=red).

Hundreds of digital penetrometer profiles can be generated in a single day, dramatically improving the spatial sampling for mapping soil layers. If a global positioning system (GPS) is used while collecting digital penetrometer information then depth as well as the extent of the area requiring treatment can be determined. **Figure 3** illustrates the type of compaction map that can be created. The map shows the horizontal and vertical distribution of compaction within a field. This information on the spatial distribution of compaction can help growers target areas for treatment or alter management practices. Hundreds of acres can be mapped in a single day in this way.

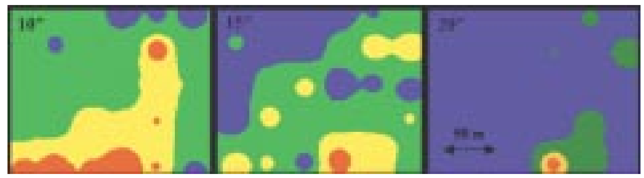

Figure 3. Compaction maps generated for three different depths (10, 15, and 20 in.). Compaction categories are delineated by color (light=blue, medium=green, high=yellow, heavy=red).

Impact of Soil Moisture on Penetrometer Readings

Soil moisture can in some cases impact the force required to penetrate the soil. Due to the heterogeneous nature of soil moisture distribution in both space and time, it is difficult to fully account for water content in penetrometer data without measuring it directly. The American Society of Agricultural Engineers (ASAE) specifically states in their published procedures for using penetrometers that, in order to obtain a better understanding of the forces that roots are subject to, it is desirable to perform tests at a time when the soil is at field capacity. That is, field tests should be conducted a few days after a significant rainfall event once gravity has drained the water from the soil profile. However, the ASAE also states that when using a penetrometer to determine other soil physical properties, drier conditions might be desirable for performing field measurements. For example, it is easier to distinguish soil horizon changes when the soil is dry, though the ability to penetrate the soil may be limited by the push platform and its weight.

Physical Property Penetrometer

In agriculture, the current penetrometer design specifications for measuring compaction are published by the ASAE. The primary design elements of the ASAE penetrometer are the cone-tip angle (30^0) and push rate (about 1.2 in./sec or 3 cm/sec). Very often the density of the soil does not change with depth or is subtle and not detectable with an ASAE penetrometer. Soil moisture, texture, mineralogy, structure, and organic matter also can increase or decrease the force necessary to push the penetrometer through a layer of soil. Because the ASAE penetrometer only measures one variable (tip force), it is not possible to determine multiple soil properties.

A Physical Property Penetrometer (PPP) has been developed to characterize and map soil texture and

Table 3. List of digital penetrometer vendors[1].

Vendor	Push platform	GPS compatible?	Data obtained	Contact information
Concord Environmental Equipment	ATV-mounted	Yes	compaction	218.937.5100 www.ceesoilsample.com
Spectrum Technologies	Handheld	Yes	compaction	1.800.248.8873 www.specmeters.com
Veris Technologies	Trailer-mounted	Yes	compaction	1.785.825.1978 www.veristech.com
Earth Information Technologies	ATV/handheld	Yes	compaction, texture, subsurface imagery	1-877-230-1430 www.earthit.com

[1]Note: This list of vendors is not exhaustive (more expensive penetrometers used more for research have not been included). It would be appreciated if knowledge about additional vendors were passed on to the authors.

compaction in the near surface environment. The PPP probe consists of a 0.8 in. (2 cm) diameter tip with a cone-tip angle of 60^0 and surface area of 1.24 in^2 (3.14 cm^2). A friction-sleeve 2.9 in. (7.4 cm) long is located directly behind the tip. An internal strain gauge calculates both the tip force and sleeve friction as the device is inserted into soil.

The PPP system has the ability to determine texture as well as compaction. For example, the tip force can increase due to the presence of sand and/or compaction. Because coarse soil creates less friction on the sleeve measurement, it is possible to distinguish between textures. Cohesive soils (fine textures) create greater sleeve friction. The ratio of sleeve friction over tip force can be used to rapidly estimate soil particle sizes. A University of Wisconsin-Madison study determined that the PPP could estimate the percent sand, silt and clay by about +/- 10 percent in real-time. The PPP system can be mounted on a light duty truck and is inserted into the soil using a hydraulic ram. Other designs would enable the user to mount a system on an all-terrain vehicle or hand-held device. There are several vendors that manufacture digital penetrometers (**Table 3**).

Conclusion

The digital data obtained with a penetrometer system can be integrated with a GPS to associate soil physical property information with landscape position and elevation. The digital penetrometer and GPS data can be integrated into a geographic information system (GIS) as well as statistically driven sampling routines to facilitate efficient and interactive on-the-fly mapping of soil attributes. This process facilitates a "smart" sampling and mapping approach as the optimal location of sample collection and depth of sample retrieval can be determined in the field.

When combined with landscape position, the digital penetrometer output can be associated with other spatially significant information such as crop yield and watershed maps. This ability to immediately visualize the penetrometer output and associate it with existing soil and landscape data increases the functionality and usefulness of the tool. As advancements continue to be made in both sensor design and data acquisition and analysis, the penetrometer will become more than just a great tool for measuring compaction. Information on new penetrometer sensors and soil mapping applications can be found at **www.earthit.com**. ■

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