# SPATIAL VARIATION OF THE DEPTH OF THE ROOT-RESTRICTING LAYER IN AN UPLAND SOIL OF NORTHERN MISSISSIPPI’

R.L. Raper, E.B. Schwab
Agricultural Engineer, Engineering Technician
USDA-ARS National Soil Dynamics Laboratory
Auburn, AL

S.M. Dabney
Research Agronomist
USDA-ARS National Sedimentation Laboratory
Oxford, MS

## ABSTRACT

The root-restricting layers present in most Southeastern soils prevent adequate root growth into the soil profile. Reduced root elongation contributes to temporal drought stress which annually limits yield potential in this region. Many farmers combat this layer of soil by annually subsoiling, usually to a depth of 25-40 cm. However, the depth of this root-restricting layer varies greatly from field to field and also within the field. Knowledge about the variation of the depth of this layer will help to determine if application of a uniform tillage depth is the most effective method of soil compaction amelioration.

A tractor-mounted multiple-probe soil cone penetrometer was used to determine the depth of the root-impeding layer in several fields in Alabama and Mississippi. The root-restricting layer was found to vary greatly in most fields. For one field in northern Mississippi, measurements of hardpan depth were found to vary mainly due to traffic effects, but were also found to be sensitive to soil moisture. The depth of hardpan was also found to be somewhat spatially dependent, and the semivariogram was fitted reasonably well by a spherical model. This spatial dependence in the depth of hardpan in this Southeastern field potentially indicates that applying tillage to a uniform depth to an entire field in this region could result in excessive expenditures of tillage energy.

## 1.0 INTRODUCTION

Significant differences in crop yield has been found in many parts of the U.S. using Global Positioning Systems (GPS) and yield monitors. Attempts to explain reasons for these differences have largely centered on pest and nutrient variability. In many areas of the country, these research efforts have been partly successful with site-specific applications of pesticides and/or nutrients which have helped to increase yields in lower yielding areas of the field. In some cases, abandonment of low-

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producing areas has also improved the overall profitability of the producer.

However, soil variability is considered a likely culprit causing extremely variable yields, particularly in the Southeastern U.S. Ultisol, which is the predominate soil order found in this region, is highly weathered and in many cases do not provide adequate moisture storage for successful crop production. Inadequate amounts of topsoil create limited reservoirs of moisture. Soil compaction caused by natural forces or by vehicle traffic also limits the ability of plant roots to penetrate to depths of soil that sustain plants during common short-term droughts.

Many producers in the Southeast must resort to some form of annual deep tillage to break through this hardpan layer and allow crop roots to penetrate to looser, moister soil. This tillage event can be fairly expensive, both in environmental and productivity cost terms. Excessively deep tillage can cover valuable crop residue which can increase surface erosion and also waste tillage energy. Some studies have also found that excessively deep tillage can slightly decrease crop yields, perhaps due to excessive soil disturbance (Raper et al., 1998). Excessively shallow tillage can also be expansive in reduced crop yields if it is not performed to an adequate depth to disrupt the hardpan profile.

Therefore, the objectives of this study were:

1. To develop an effective procedure to determine the depth of hardpan,
2. To determine the effect of traffic, soil moisture and elevation on depth of hardpan, and
3. To determine the variation in depth of hardpan of a selected Southeastern U.S. field.

## 2.0 METHODS

A soil cone penetrometer is the most common method of determining differences in soil strength, or soil compaction, and also is the most likely candidate for determining the depth of the hardpan layer. This device's construction is defined by ASAE Standard S313.3 (1999a) as a 30° cone with two sizes of either 12.83 mm diameter for hard soil conditions or 20.27 mm diameter for soft soil conditions. The cone is attached to a shaft that is attached to a load cell that measures the force required to push the cone into the soil. The force data measured as the soil cone penetrometer is forced into the soil is converted to a pressure by dividing by the cross-sectional area of the base of the penetrometer. This pressure is referred to as cone index and is usually reported in terms of MegaPascals (MPa) occurring at a particular depth of soil.

Many different versions of this device have been developed, although most are similar in that they are manually pushed into the soil at a constant rate and the data is either manually, graphically, or electronically recorded. However, operator errors and the large number of data required for adequate measurements beckon for quicker and automatic methods of data acquisition. Another problem with data collected by a soil cone penetrometer is that the data differs relative to row position across an entire field. This is largely due to nonuniform tillage and traffic applications. A tractor-mounted multiple probe soil measurement system (MPSMS) has been developed at the USDA-ARS National Soil Dynamics Laboratory that facilitates the acquisition of this data (Figure 1; Raper et al., 1999). This machine allows five different measurements to be obtained within a relatively short period of time across entire row positions; (1) in a trafficked row middle, (2) midway between a trafficked row middle and the row, (3) in the row, (4) midway between the row and the non-trafficked row middle, and (5) in the non-trafficked row middle.

Using the soil cone penetrometer to sense the depth of the hardpan layer requires experience with its use and familiarity with cone index data. Usually this layer of extremely compacted soil is found when the cone index data rises quickly and then decreases. Taylor and Gardner (1963) found that when the cone index values exceed 2 MPa, plant roots can no longer proliferate. Therefore, some researchers have determined that the depth of the root-impeding layer is the depth where this 2 MPa value occurs. However, the effect of moisture content can alter this value greatly. If at all possible, ASAE Engineering Practice EP 542 (1999b) advises collecting cone index data in saturated soil conditions. This practice is not always practical, however, and the depth of the occurrence of the peak value is sometimes taken as the depth of the root-impeding layer.

To investigate the soil strength variability present in upland soils of northern Mississippi, a small field at the Nelson Farm near Senatobia, MS was selected that had been the subject of long-term research by the USDA-ARS National Sedimentation Laboratory. This 1.56-ha field was managed with conventional tillage (chisel, disk twice) for 90-cm row soybean production Soils were primarily Grenada silt loam (fine silty, mixed, thermic, Glossic Fragiudalf), with some areas of Memphis and Loring series. The MPSMS was used to acquire soil strength data on an approximate grid of 30 m x 30 m. Immediately following this sampling procedure, a complete set of soil moisture data was also collected at the same locations at depths of 15 and 30 cm with a TDR probe. A range level was also used to determine the differences in topography more accurately than could be accomplished with GPS.

Correlations were performed to determine the potential relationships between depth of hardpan, soil moisture, and elevation. These statistical analyses were made using SAS software (SAS Institute, 1998). Semivariograms were also calculated for these data to determine their spatial dependence using GS+ (Gamma Design Software, 1999).

## 3.0 RESULTS AND DISCUSSION

Soil strength data showed two peak values of cone index that required some discrimination (Figure 2). The upper peak that occurred at a depth of approximately 20 cm was considered a hardpan while the second peak that occurred at a depth of approximately 50 cm was considered a fragipan. These soils are prone to fragipan formation at this approximate depth. Throughout this field, a SAS procedure that searched for the peak value as the criteria for the hardpan was used to sort the data and predict depth of hardpan formation. The criteria used to locate these depths of hardpans consisted of locating at least 3 consecutive data points that were greater than 0.05 MPa from previous data points and ensuring that the magnitude of cone index was greater than 1.0 MPa. This procedure was successful in locating hardpan depths for 59 of the 61 locations sampled in the 1.56-ha field. The other two locations for which no predictions were made showed little evidence of a root-restricting hardpan layer.

Because the data was collected with the MPSMS, we retained the ability to discriminate between depths of hardpan caused by wheel traffic. Figures 3 and 4 show contour graphs of the hardpan depths in the sampled field. Segregated row middles were maintained in this field and the cone index measurements obtained were analyzed for differences caused by vehicle traffic. It was obvious from these graphs that much shallower hardpans were found when the row middles were trafficked. Using data collected in the trafficked row middles gave an average predicted depth of hardpan of 0.217 m compared to the data collected in the non-trafficked row middles which gave an average predicted depth of hardpan of 0.280 m (Table 1). We therefore determined that vehicle traffic caused the hardpan profile to move closer to the soil surface by 0.063 m, additionally restricting root growth and water movement. This conclusion was further evidenced by the data shown in Figure 5 which was a histogram of the hardpan depths measured with the two sets of data; one collected in the trafficked middles and the other collected in the non-trafficked middles. It is interesting to note that the hardpan was mostly normally distributed about the mean with the data obtained in the non-trafficked middles, while the influence of vehicle traffic greatly skewed the data toward the soil surface into a non-normal pattern.

To test the hypothesis that site-specific soil moisture affected depth of hardpan measurements, correlations were run between each of these measurements (Table 2). Those data showed that the depth to the hardpan measurements obtained in the non-trafficked row middles only correlated with the soil moisture data obtained in the O-30 cm depth range (Pr.‹0.052). The depth to the hardpan measurements taken in the trafficked row middles only correlated with the soil moisture data obtained in the O-15 cm depth range (Pr.5 0.069). The soil moisture data taken in the O-30 cm depth range was found to correlate well with elevation (Pr. < 0.018). These data can perhaps be explained by previous rainfall events. It had not rained for several days prior to obtaining the cone index and soil moisture measurements. The moisture that was in the soil profile had drained to the lowest elevation of the field and was then present in the deeper soil profile. This reasoning would also explain why the non-trafficked depth to hardpan values would correlate well with the soil moisture data collected in the O-30 cm range, and not with the soil moisture data collected in the O-15 cm range. In the trafficked row middles, soil moisture was largely retained at the shallower depth and had not penetrated beyond the 15-cm depth.

The depth to hardpan data was next checked for spatial dependence. Table 3 shows the spherical models that most closely fit the depth to hardpan data obtained in the trafficked and non-trafficked middles. The spherical model for the depth of hardpan in the non-trafficked middle was more closely fitted and showed a higher degree of spatial structure than the depth of hardpan in the trafficked middle. This was evidenced by a much higher correlation coefficient and (sill-nugget&ill value. The latter value for the non-trafficked middle indicated a high degree of spatial structure and was relatively close to 1.OO which was the best theoretical fit possible. The range of the depth of hardpan in the trafficked middle was 36.8 m which can be an effective criteria for determining sampling distances. Figure 6 showed the relatively good fit of the depth of hardpan in the non-trafficked middle while Figure 7 showed a more cyclical behavior and poor fit of the depth of hardpan in the trafficked middle. It is likely that the depth to hardpan in the trafficked middle is mostly micro-variability caused by human interaction and exceeds the macro-variability that naturally occurs in the field as measured by the depth to hardpan in the non-trafficked middle.

It may be surmised from the successful modeling of the depth to hardpan in the non-trafficked middles that this data was somewhat spatially related. It may be reasonable to consider altering this parameter with some form of site-specific tillage that may be more efficiently applied than uniform tillage. Also, it seems that the depth to hardpan found in the trafficked middles was not spatially dependent, at least not at the distances of our measurements. This result was reasonable because we often find more variation in cone index values across a crop row from an non-trafficked row middle to a trafficked row middle due to vehicle traffic than we can find across an entire field due to natural conditions.

## 4.0 CONCLUSIONS

The following conclusions can be drawn from this research study:

1. A reasonable method was developed to determine the depth of the hardpan in the upland soils of northern Mississippi. This procedure found reasonable depths of hardpans in 59 of 61 measurements of cone index.

2. Traffic was found to decrease depth to the hardpan depth by 0.067 m. Elevation was found to have no statistical relationship to depth of hardpan in non-trafficked soils or in trafficked soils. Soil moisture measured in the O-l5 cm depth range was found to be closely correlated with the depth of hardpan in trafficked soils and soil moisture measured in the O-30 cm depth range was found to be closely correlated with the depth of hardpan in non-trafficked soils..

3. A spherical model was found to fit the semivariogram of the depth to hardpan data collected in the non-trafficked middles with reasonable accuracy. It can be concluded that this data was somewhat spatially related and it may be feasible to consider applying site-specific technology to ameliorate this site-specific root-impeding layer.

## 5.0 REFERENCES

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Table 1. Descriptive Statistics of Depth to Hardpan, Soil Moisture, and Elevation

| | Mean | Standard Deviation | Min Value | Max Value | Number of Values | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Depth to Non-Trafficked Hardpan, (m) | 0.280 | 0.104 | 0.12 | 0.55 | 59 | 0.76<br>(0.31 se)† | -0.22<br>(0.61 se) |
| Depth to Trafficked Hardpan, (m) | 0.217 | 0.084 | 0.12 | 0.55 | 59 | 1.61<br>(0.31 se) | 3.13<br>(0.61 se) |
| Soil Water (0-15 cm depth), (%) | 34.5 | 2.308 | 28.9 | 38.6 | 61 | -0.41<br>(0.31 se) | -0.35<br>(0.61 se) |
| Soil Water (0-30 cm depth), (%) | 35.0 | 1.347 | 31.5 | 37.9 | 61 | -0.21<br>(0.31 se) | -0.19<br>(0.60 se) |
| Elevation, (m) | 150.1 | 1.91 | 146.2 | 152.7 | 61 | -0.41<br>(0.31 se) | -0.89<br>(0.61 se) |

† se indicates standard error

Table 2. Correlation Coefficients Between Depth to Hardpan, Soil Moisture, and Elevation.

| | Depth to Trafficked Hardpan | Depth to Non-Trafficked Hardpan | Elevation | Soil Moisture (0-15 cm) | Soil Moisture (0-30 cm) |
|---|---|---|---|---|---|
| Depth to Trafficked Hardpan | 1.0<br>(0.000)◊ | 0.0666<br>(0.6226) | 0.0425<br>(0.7492) | -0.2403<br>(0.0693) | -0.0390<br>(0.7693) |
| Depth to Non-Trafficked Hardpan | 0.0666<br>(0.6226) | 1.0<br>(0.000) | -0.2063<br>(0.1169) | 0.0965<br>(0.4712) | 0.2540<br>(0.0522) |
| Elevation | 0.0425<br>(0.7492) | -0.2063<br>(0.1169) | 1.0<br>(0.000) | -0.0862<br>(0.5125) | -0.3010<br>(0.0184) |

◊ Values in parentheses are levels of significance.

Table 3. Descriptive Semivariogram Statistics for Depth to Hardpan Measured in the Non-trafficked Middle and in the Trafficked Middle

| | Model | Nugget $(m)^2$ | Sill $(m)^2$ | Range (m) | Regression Coefficient | (Sill-Nugget)/Sill |
|---|---|---|---|---|---|---|
| Depth to Non-Trafficked Hardpan | Spherical | 0.0021 | 0.0112 | 36.8 | 0.92 | 0.818 |
| Depth to Trafficked Hardpan | Spherical | 0.0009 | 0.0071 | 17.0 | 0.15 | 0.870 |

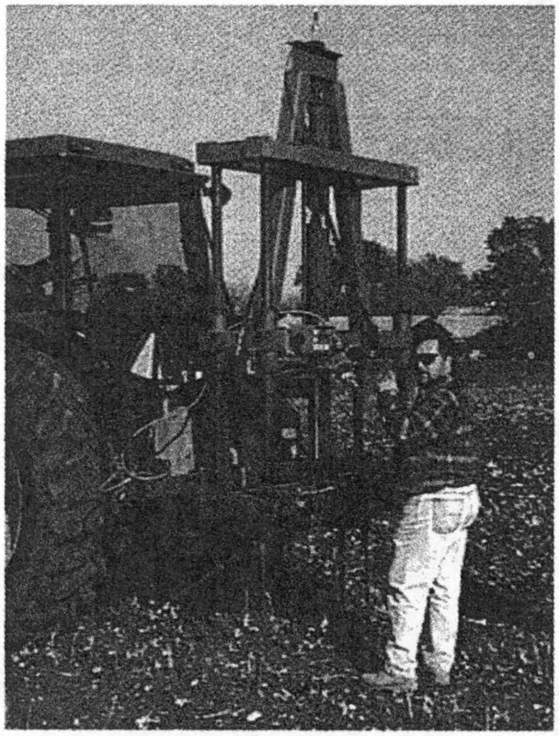

**Figure 1**. Multiple-probe Soil Strength Measurement System Developed at the USDA-ARS National Soil Dynamics Laboratory.

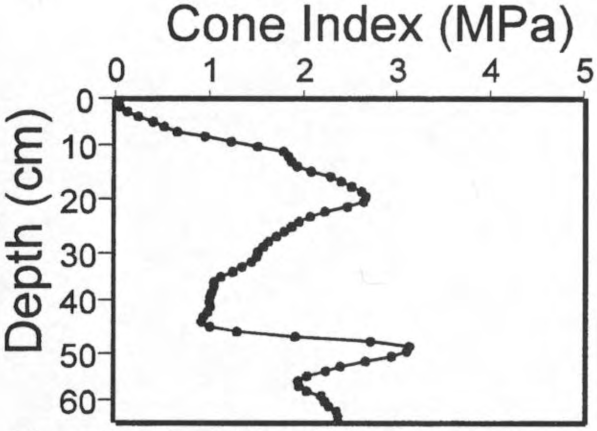

**Figure 2**. Selected Cone Index (Mpa) Profile of Uplands Soil of Northern Mississippi

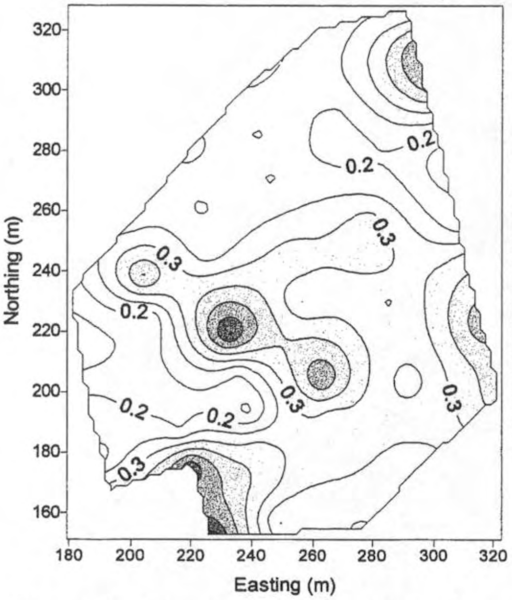

**Figure 3**. Contour Graph of Depth of Hardpan Layer as Measured in the Non-trafficked Row Middle.

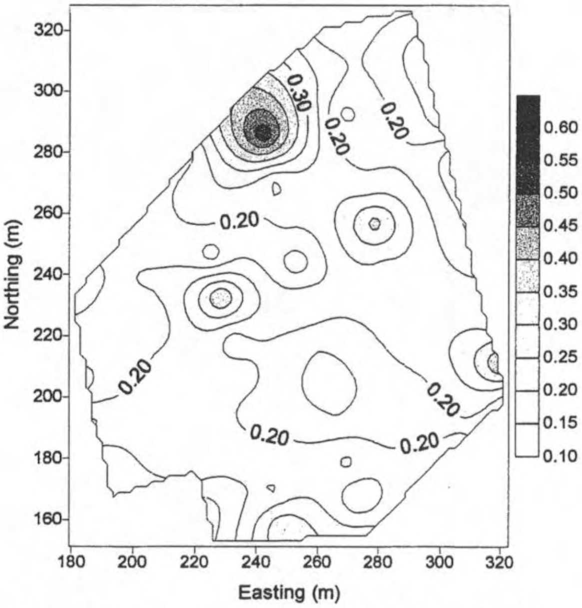

**Figure 4**. Contour Graph of Depth of Hardpan Layer as Measured in the Trafficked Row Middle.

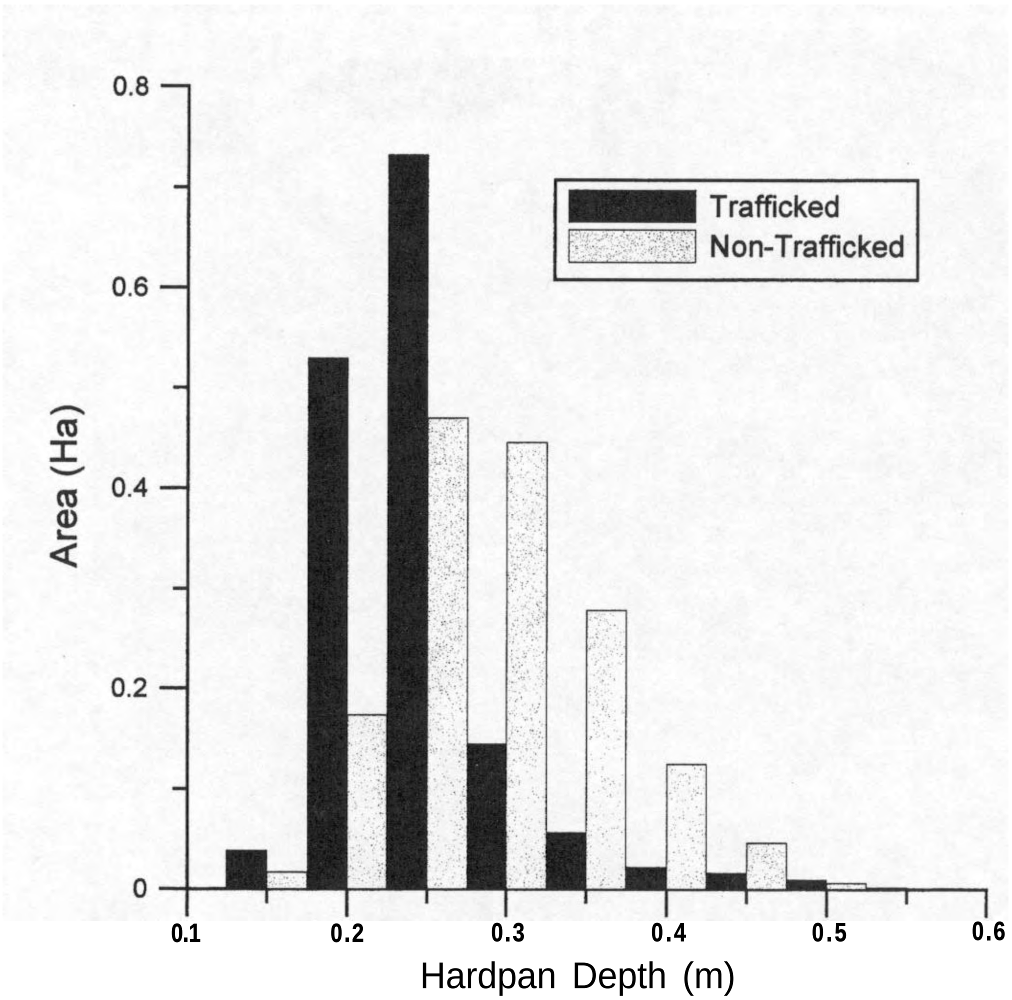

Figure 5. Frequency Distribution of Hardpan Depths Measured with the Two Sets of Cone Index Data.

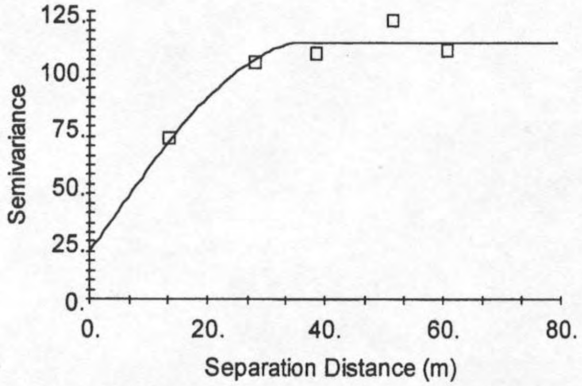

**Figure 6**. Omnidirectional Semivariogram of Hardpan Depth Measured in the Non-trafficked Middles.

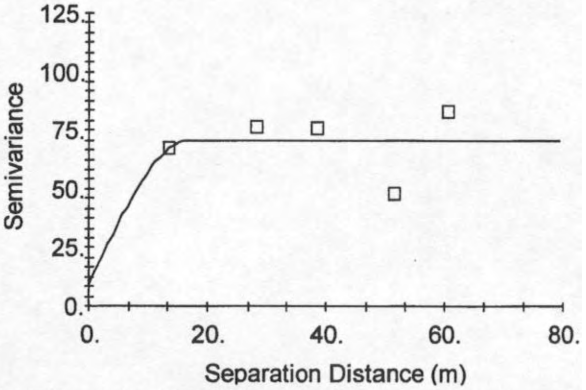

**Figure 7**. Omnidirectional Semivariogram of Hardpan Depth Measured in the Trafficked Middles.