QUANTIFYING SOIL TRAFFICABILITY IMPROVEMENTS PROVIDED BY SUBSURFACE DRAINAGE FOR FIELD CROP OPERATIONS IN LOUISIANA

T. S. Kornecki, J. L. Fouss

ABSTRACT. *A field experiment was conducted on a Commerce silt loam (alluvial) soil near Baton Rouge, Louisiana, to study the effects of subsurface drainage on soil trafficability for two different water management systems: surface drainage only and subsurface drainage. Following a 30–mm rainfall event there was a significant difference in the decrease of soil moisture at a 10–cm depth directly above the subsurface drains compared with midway between drain pipes spaced at 15 m. Differences in soil moisture content between subsurface drained and surface drained only plots were not statistically significant, however, the plots that were subsurface drained had trafficable conditions one day sooner than the surface drained only plots. Soil strength values above the subsurface drains were consistently higher than at the mid–point between drains and soil strength increased as water table depth increased. A portable capacitance volumetric soil moisture meter was evaluated in this project for the accuracy in obtaining soil moisture content in the field. Results have shown that there was no correlation between the soil moisture obtained* in situ *by the volumetric moisture meter and by analysis of soil samples.*

Keywords. *Subsurface drainage, Trafficability, Soil moisture, Soil strength.*

Trafficability is a significant factor in carrying out farm field operations, especially after rainfall events when poor trafficability can cause delays in planting, cultivating, harvesting, and transporting of field crops such as sugarcane and corn. In southern Louisiana high rainfall intensities can cause interruption and delays in agricultural activities, particularly when heavy equipment is used (e.g., corn or cane combine harvesters). Generally, in agriculture, good soil trafficability can be defined as the ability of soil to support wheel traffic and provide traction without causing damage to the soil structure beyond limits that would negatively affect proper crop root growth (Paul and De Vries, 1979).

Poor trafficability not only potentially causes serious degradation of soil structure but also can cause economic losses to the farmer. According to Stone and Ekwue (1993), soil compaction reduces soil aeration, prevents moisture penetration, reduces fertilizer and chemical utilization and inhibits plant root growth. Compacted soil diminishes oxygen flow in soil causing anaerobic conditions and suffocation of roots (Carter and Camp, 1983). High annual precipitation (1500 mm) in southern Louisiana with high intensity rainfall on the silt loam (alluvial) soils lead to high water tables and soil saturation for extended periods in most years. Because of flat terrain and limited or poor drainage outlets for surface drainage ditches (subsurface drainage systems are not commonly installed in southern Louisiana), the water table can quickly rise and remain near the soil surface for several days following rainfall. Thus, it is often impossible to resume farm field operations before two or more days after rainfall. Meredith and Patrick (1961) reported that for typical silty–clay soils in Louisiana, soil compaction by tractors and heavy equipment increased bulk density and decreased both noncapillary porosity and water permeability. According to Hopkins (1968), soil compaction also reduced root penetration. Field operations like tillage, planting, and harvesting are adversely affected by poor trafficability by creating delays of these activities. This problem is especially critical for soils with higher clay content. Hillel (1980) stated that farm machinery can get bogged down and cultivation tools can become completely clogged by the soft, sticky, wet clay soil particles. One common and successful method to improve trafficability, widely used in the Midwest, is the installation of subsurface drainage on agricultural production land. Previous research in the Lower Mississippi River Valley (LMRV) (Carter and Camp, 1983; Fouss et al., 1987) has shown that subsurface drainage installed on a USDA sugarcane field research site improved soil aeration, increased depth of the root system, enhanced the crop growth and yield, and allowed the resumption of farming activities to begin sooner after rainfall than on fields with surface drainage only.

Several trafficability studies were conducted to find the relationship between soil moisture and soil strength (Paul and De Vries, 1979; Earl, 1996) and to assess trafficability using a cone penetrometer. Bornstein and Hedstorm (1982)

Article was submitted for review in February 2001; approved for publication by the Soil & Water Division of ASAE in July 2001.

Contribution from the Soil and Water Research Unit, Mid South Area, USDA, ARS, 4115 Gourrier Ave., Baton Rouge, LA 70808. The use of trade names in this publication does not imply endorsement by the USDA, ARS of the products named, nor criticism of similar ones mentioned.

The authors are **Ted S. Kornecki, *ASAE Member Engineer***, Agricultural Engineer, and **James L. Fouss, *ASAE Fellow Engineer***, Research Leader and Supervisory Agricultural Engineer, USDA–ARS Soil and Water Research, Baton Rouge, Louisiana. **Corresponding author**: T. S. Kornecki, USDA–ARS–Soil and Water Research, 4115 Gourrier Ave., Baton Rouge, LA 70808–4499; phone: 225–578–0745; fax: 225–389–0327; e–mail: tkornecki@ars.usda.gov..

evaluated the drainage effectiveness and trafficability response using tensiometers and cone penetrometer measurements; they stated that improved trafficability developed more rapidly in the spring on a slowly permeable silty clay soil when subsurface drainage of the soil profile was provided. They also found that a good correlation existed between soil moisture and soil strength in the 0– to 15–cm depth range. Hanson (1996) reported that soil strength increased with increasing bulk density and decreased with increasing soil–water content. Feddes and Van Wijk (1976) calculated the number of days when the soil was workable in the 0– to 5–cm soil surface layer based on tensiometer readings for a water tension of 100 cm. However, no known research has been conducted to address trafficability for the unique Louisiana conditions where high rainfall intensity and shrinking–swelling clay soils are both contributing factors for major trafficability problems. Typically, Louisiana soils of the Lower Mississippi River Valley are less permeable in the top layers (surface layer) because of higher clay content; permeability typically increases with depth in the soil profile. Potentiometers were not chosen to measure soil–water suction in the research reported here because the soil interface contact with the porous ceramic sensor tip is often separated in the shrinking/swelling clay soil and thus would provide erroneous results.

OBJECTIVES

The primary objective for this field study was to evaluate trafficability improvements provided by subsurface drainage in comparison to only surface drainage for the unique Southern Louisiana weather and alluvial soil conditions.

The secondary objective was to evaluate the accuracy of a portable soil moisture meter for *in situ* soil moisture measurements at a 10–cm depth by comparing portable meter readings with gravimetric moisture content determined from collected and oven dried soil samples. Using a portable moisture meter was desirable to obtain moisture readings for different depth increments (e.g. 5 cm) at which soil cone penetrometer readings (soil strength) were obtained. These measurements were important in this study to develop the relationship between soil moisture and soil strength. Obtaining soil samples from different depths is a tedious and time consuming process; thus a portable, affordable, and reliable soil moisture meter for the alluvial soil is needed for future research to fully develop the technology to quantify and predict trafficable conditions in a given field.

MATERIALS AND METHODS

The field study was conducted at the USDA–ARS Ben Hur research site near Baton Rouge, Louisiana. The soil is classified as a Commerce silt loam; however, the topsoil layer contains the highest amount of clay (about 27%) that is the primary cause of the trafficability problem. Table 1 shows the Commerce silt loam soil characteristics for different horizons; the top layer with the highest clay content is the least permeable. Following rainfall, the topsoil layer is saturated and water often stands on the surface making wheel traffic impossible. With increasing depth in the soil profile, the permeability increases as clay content decreases (table 1). The layout of the experimental plots and sampling locations are shown in figure 1. Each plot was precision graded to a 0.2% slope. The subsurface drained plots had 100–mm diameter corrugated plastic pipes installed at a depth of 1.2 m and spaced 15 m apart on a uniform grade of 0.2% (drainlines were orientated parallel to the 0.2% precision graded surface slope). The subsurface drainage sump–pump at the drainage outlet was set to discharge subsurface drainage to maintain the water table depth 30 cm above the drainline or a water table depth of about 60 cm. Two locations were sampled in the subsurface drainage plots above the drainline and at the midpoint between drainlines. For the surface drainage plots, the measurements were obtained at the plot center and 7.5 m from the center to compare with the results from the subsurface drainage treatment.

Table 1. Soil properties for Commerce silt loam at Ben Hur site near Baton Rouge, Louisiana.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Permeability (cm/h)	Soil Type Classification
0–28	36.0	37.0	27.0	1.0	Clay loam
28–74	50.0	36.5	13.5	1.5	Silt loam
74–153	50.0	39.5	10.5	2.7	Loam

One of four rainfall events prior to the trafficability experiment occurred on 15 March 2000, and totaled 20 mm. This rainfall occurred after an extended dry period (last major storm of 56 mm was recorded on 20 December 1999) but the amount of rain did not cause soil saturation or runoff. On 17 and 18 March 2000, two small rainfall episodes were recorded on–site with 4–mm depth for each event and low intensity lasting approximately 2.5 hours for each event. These events were followed by the larger final rainfall event the next day on 19 March producing 30 mm in a duration of 5 hours and average intensity of 6 mm/h. Water from the first three separate rainfalls infiltrated and increased soil moisture, and the rainfall on 19 March 2000 caused complete saturation and runoff with water standing between rows, making it difficult to walk due to sinking, and impossible to drive any equipment on–site. The experiment began 8 hours after rainfall stopped and repeated once each day until changes in soil moisture and soil strength were negligible. This storm event was the only opportunity to conduct this study, since severe drought conditions were observed during spring, summer, and fall of 2000. Four depths were sampled (5, 10, 15, and 20 cm) at each measurement point to determine soil moisture and soil strength changes with depth. The measurements were obtained at the bottom of the crop inter–row where tractor and equipment tires were driven. To evaluate the performance of the soil moisture meter, soil samples were taken at the 10–cm depth. Soil water content was measured gravimetrically and *in situ* with an “Aquaterr

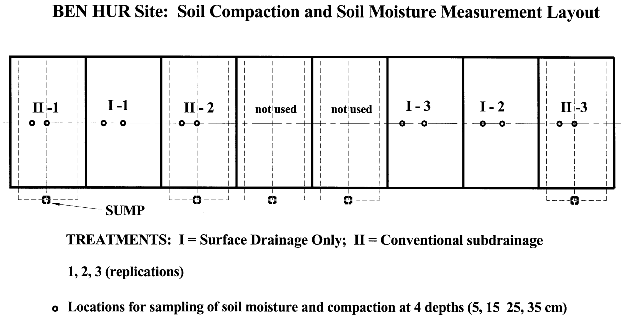

Figure 1. Experimental layout for trafficability study.

200” soil moisture meter from Spectrum Technologies. The “Aquaterr” measures capacitance of the soil–water matrix and is calibrated to indicate volumetric water content. Soil penetration resistance was measured using the “Investigator” soil compaction meter also from Spectrum Technologies. The compaction meter is equipped with an ASAE size B (12.83–mm diameter) standardized cone (ASAE, 1999), a load cell sensor calibrated in kPa units, a depth monitor, and a data–logger. All data were analyzed using SAS–General Linear Model at 5% significance level (SAS Institute Inc., 1999).

RESULTS AND DISCUSSION

The soil strength data and moisture content were obtained at four depths with a portable meter, however, the results were reported only for the 10–cm depth where soil samples were obtained for correlation with the moisture meter readings. There was no correlation between soil moisture from sampling and from the portable moisture meter. Thus, the relationship between soil strength and soil moisture at different depths read with the poor performing meter were not reported to avoid making erroneous conclusions. For the subsurface drained plots, figure 2 shows the soil strength distribution at the plot center (above the drain) and the mid–point between drains after the 30–mm rainfall event. The average soil strength values above the drain were higher than at the mid–point between drains throughout the measurement period. Comparing soil strength versus time (days) from the rainfall event, soil strength (kPa) was significantly different (p–value range from 0.0001 to 0.0438) for both treatments (subsurface drainage and surface drainage) with respect to time after rainfall for all depths. Comparison of soil strength between subsurface drained and surface drained plots showed a significant difference (p–value = 0.0056) in soil strength at the 5–cm depth only (see table 2).

For the subsurface drainage plots, there was a significant difference in gravimetric soil moisture content directly above the drainlines compared to the midpoint between drains at the 10–cm depth (p–value = 0.0001); this relationship is shown in figure 3 where the soil moisture above the drains was consistently lower than at the midpoint between drains. However, for the surface drainage only plots, there was no significant difference (p–value = 0.42) in gravimetric soil moisture content at the plot center and 7.5 m from the center versus time after rainfall (see fig. 4). The breaking point in soil trafficability improvement i.e. “trafficable conditions,” for which the tractor with equipment was able to enter the field study without visible slippage, sinking and without soil stuck to tires, was the increase of soil strength to approximately 1660 kPa at the 10–cm depth. This value corresponds with 24% gravimetric soil moisture content for Commerce silt loam soil. In terms of time elapsed from the rainfall, trafficable conditions were observed on the third day for subsurface drainage plots, and fourth day for surface drainage plots after the 30–mm rainfall. This observation was based on the actual operation of an 85–hp tractor with rear–mounted “bush–hog” mower through the test area of the field plot. For plots with subsurface drainage, trafficable conditions were observed one day sooner than for surface drained only plots; (i.e., the same tractor–mounted mower was successfully operated on these plots three days after rain).

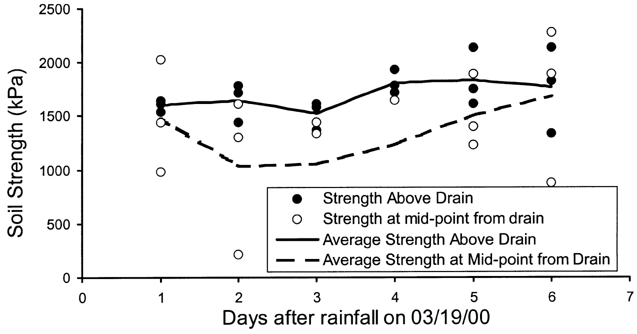

Figure 2. Soil strength above drainline and 7.5 m from drainlines.

Table 2. Soil strength vs. depth for subsurface drainage and surface drainage only plots.

Depth (cm)	Treatment Means (Soil Strength, kPa)		P value 5% Significance Level
	Subsurface Drainage	Surface Drainage	
0	786.5	660.1	0.2272
5	1288.2	965.4	0.0056
10	1512.8	1508.9	0.9726
15	1388.3	1570.1	0.0659
20	1329.0	1395.1	0.4617

There was no correlation between soil moisture meter readings and gravimetric soil moisture content obtained through the sampling and drying process (fig. 5). This data indicates that the soil moisture meter did not produce repeatable results for our soil conditions; (R–square = 0.031,

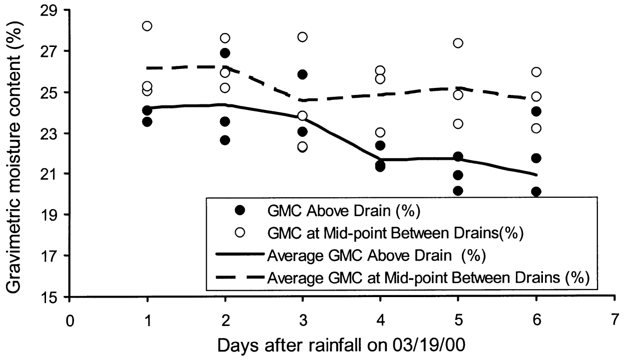

Figure 3. Gravimetric Moisture Content (GMC) above the drainline and 7.5 m from drainline at a depth of 10 cm.

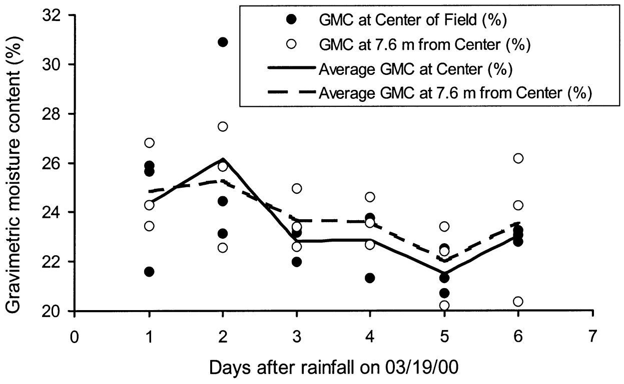

Figure 4. Gravimetric soil moisture content at center of the field and 7.5 m from the center for surface drainage plots.

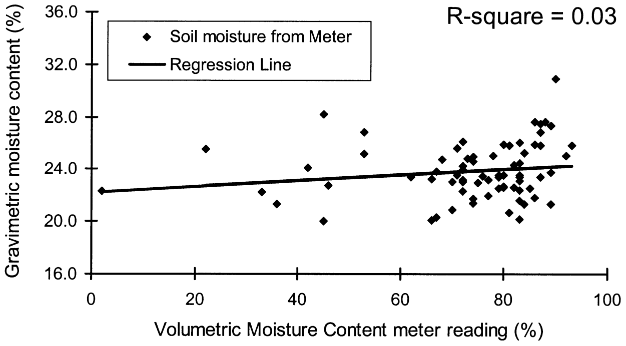

Figure 5. Linear regression between gravimetric moisture content and volumetric moisture content from Aquaterr meter.

C.V.= 8.9%). The major problem with the soil moisture meter was that after each calibration procedure the moisture readings in the same areas and depths in the field were not repeatable. Another problem was poor access to remove soil particles that were trapped in the opening between the stainless steel frame and the surface of the sensor element. After cleaning with water, a problem still existed with drying of soil particles trapped between the sensor and the stainless steel frame. Cleaning, removing soil particles, and calibrating the instrument took a considerable amount of time, greater than the time actually spent in obtaining soil samples. This instrument is not an appropriate tool to obtain consistent and repeatable results for our research purposes.

Statistical analysis also showed a poor correlation (R–square = 0.15, C.V.= 31%) between soil strength and gravimetric soil moisture at the 10–cm depth, however, soil strength decreased as gravimetric soil moisture increased. The relationship between water table depth and soil strength at a depth of 10 cm for both drainage treatments as a function of days elapsed after rainfall was more meaningful and is shown in figure 6. For subsurface drainage plots, soil strength increases as water table depth increases. However, for surface drainage only, soil strength values were decreased for two days and increased on the fourth day matching the soil strength values for subsurface drainage plots. This can be explained by a higher (shallower) water table for surface drained plots for the first three days after rain and the influence of evaporation and wind action in removing moisture from the top soil layers on the fourth day when the water table was lower (87 cm from the surface). The relationship between water table depth and gravimetric moisture content at a depth of 10 cm for both drainage treatments as a function of days elapsed after rainfall is shown in figure 7. For subsurface drainage, soil moisture is generally lower throughout the test than for surface drainage plots and soil moisture content at the 10–cm depth decreased as water table depth increased.

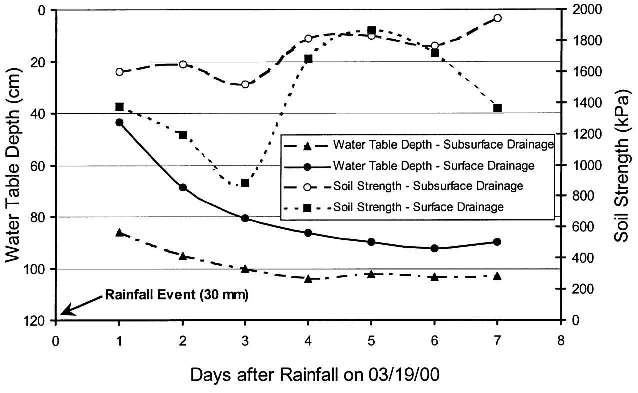

Figure 6. Soil strength at 10–cm depth and water table depth vs. time from rainfall for surface and subsurface drainage plots.

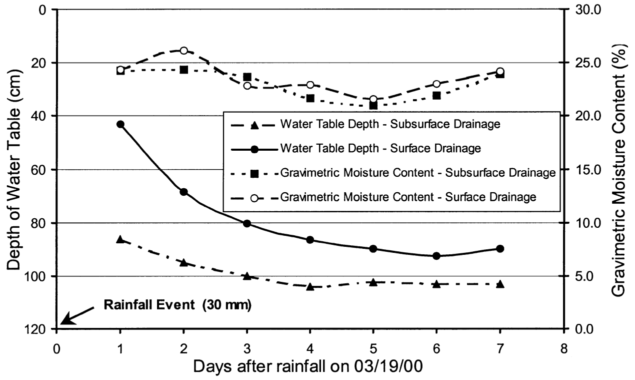

Figure 7. Soil moisture content at 10–cm depth and water table depth vs. time after rainfall for subsurface drainage and surface drainage plots.

CONCLUSIONS

Soil strength increased faster after rainfall on plots with subsurface drainage. For fields with subsurface drainage, soil moisture content of the alluvial soil at the 10–cm depth decreased faster following rainfall than for surface drained fields. There was a significant difference between soil moisture content directly above the drainline versus at the mid–point between drainlines. This initial investigation yielded documented results that plots with subsurface drainage provided better trafficable conditions (shown by actual operation of a tractor–mounted mower over the test area) than plots with surface drainage only. Future trafficability research should involve measurements of soil moisture and strength over the whole plot area to determine the spatial distribution of these trafficability parameters. Also, future study should include the identification or development of a reliable, portable soil moisture meter to quickly and accurately assess soil moisture content in the alluvial Commerce silt loam with a top layer having high clay content. This would eliminate the need to obtain soil samples from different depths for laboratory analyses.

ACKNOWLEDGEMENTS

The authors wish to express appreciation and thanks to Daniel Moriasi, Research Associate of the Biological and Agricultural Engineering Department, Louisiana State University, and to David Daniels, Engineering Technician of the USDA, ARS, Soil and Water Research Unit, for their technical assistance in collecting and processing data.

REFERENCES

ASAE Standards, 46th Ed. 1999. S313.3. Soil penetrometer. St. Joseph, Mich.: ASAE

Bornstein, J., and W. E. Hedstorm. 1982. Trafficability factor in a silty clay loam soil. *Transactions of the ASAE* 25(5): 1240–1244.

Carter, C. E., and C. R. Camp. 1983. Subsurface drainage of an alluvial soil increased sugarcane yields. *Transactions of the ASAE* 26(2): 426–429.

Earl, R. 1996. Prediction of trafficability and workability using tensiometers. *J. of Agricultural Engineering Research* 63: 27–34.

Feddes, R. A., and A. L. M. Van Wijk. 1976. An integrated model–approach to the effect of water management on crop yield. *Agricultural Water Management* 1: 3–20.

Fouss, J. L., R. L. Bengston, and C. E. Carter. 1987. Simulating subsurface drainage in the Lower Mississippi Valley with Drainmod. *Transactions of the ASAE* 30(6): 1679–1688.

Hillel, D. 1980. *Introduction to Soil Physics*. New York: Academic Press, Inc.

Hanson, G. J. 1996. Investigating soil strength and stress–strain indices to characterize erodibility. *Transaction of the ASAE* 39(3): 883–890

Hopkins, R. M. 1968. Penetration of plant roots as affected by soil compaction and soil oxygen content. MS thesis. Louisiana State University, Baton Rouge, La.

Meredith, H. L., and W. H. Patrick, Jr. 1961. Effects of soil compaction on subsoil root penetration and physical properties of three soils in Louisiana. *Agronomy Journal V* 53(3): 163–167.

Paul, C. L., and J. De Vries. 1979. Effect of soil water status and strength on trafficability. *Canadian Journal of Soil Science* 59(3): 313–324.

Stone, R. J., and E. I. Ekwue. 1993. Maximum bulk density achieved during soil compaction as affected by the incorporation of three organic materials. *Transactions of the ASAE* 36(6): 1713–1719.

SAS Institute Inc. 1999. SAS User's Guide Statistics, Version 8. Cary, N.C.: SAS Institute.