Evaluation of deep tillage remediation in a construction easement on soil compaction and crop yield

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Evaluation of deep tillage remediation in a construction easement on soil compaction and crop yield

by

Erica Rae Neideigh

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Co-majors: Agricultural & Biosystems Engineering; Soil Science

Program of Study Committee:
Mehari Z. Tekeste, Co-major Professor
Robert Horton, Co-major Professor
Richard Cruse
Matthew Helmers

The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University
Ames, Iowa
2019

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DEDICATION

To my loving mother, Lila R. Neideigh, who fought and lost a long, hard battle with lung cancer. She was always my number one supporter and told me I could do anything I set my mind to. Her knowledge and strength still live within me, and give me the courage to face every new challenge that comes my way. I love you, until we meet again.
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NOMENCLATURE

\( A_p \) \hspace{1cm} \text{Area of plot harvested in ha}

\( \text{BD}_I \) \hspace{1cm} \text{Soil Bulk Density Control Reference}

\( \text{BD}_T \) \hspace{1cm} \text{Soil Bulk Density Subsoil Treatment Reference}

bu/ac \hspace{1cm} \text{Bushel per acre}

C \hspace{1cm} \text{Case (farm equipment manufacturer)}

CAN bus \hspace{1cm} \text{Controller Area Network}

CAT \hspace{1cm} \text{Caterpillar (heavy equipment manufacturer)}

CN \hspace{1cm} \text{Control North}

CS \hspace{1cm} \text{Control South}

CT \hspace{1cm} \text{Conventional Tillage}

DAPL \hspace{1cm} \text{Dakota Access Pipeline}

JD \hspace{1cm} \text{John Deere (farm equipment manufacturer)}

LSM \hspace{1cm} \text{Least Squares Means}

\( m_{Di} \) \hspace{1cm} \text{Dry mass of soil at representative depth, } i

\( m_g \) \hspace{1cm} \text{Mass of grain harvested in kg}

\( m_s \) \hspace{1cm} \text{Standard mass of grain in kg}

\( MC_g \) \hspace{1cm} \text{Moisture content of grain harvested as a decimal}

\( MC_s \) \hspace{1cm} \text{Standard moisture content of grain as a decimal}

Mg \hspace{1cm} \text{Megagrams}

MT/ha \hspace{1cm} \text{Metric ton per hectare}

NT \hspace{1cm} \text{No-Till}

NW \hspace{1cm} \text{Northwest}
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>P</td>
<td>Storage Zone of Topsoil Pile</td>
</tr>
<tr>
<td>$\rho_{BDi}$</td>
<td>Soil Bulk Density at representative depth, $i$</td>
</tr>
<tr>
<td>RCBD</td>
<td>Randomized Complete Block Design</td>
</tr>
<tr>
<td>ROW</td>
<td>Right-of-Way</td>
</tr>
<tr>
<td>$V_S$</td>
<td>Volume of the soil, constant = 228.01 cm$^3$</td>
</tr>
<tr>
<td>X</td>
<td>Zone X</td>
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<tr>
<td>$\bar{Y}_{Cmax}$</td>
<td>Max average crop yield of Controls in MT/ha</td>
</tr>
<tr>
<td>$Y_{Ni}$</td>
<td>Normalized yield of the treatment at $i$ in MT/ha</td>
</tr>
<tr>
<td>$Y_p$</td>
<td>Yield of grain harvested for plot in MT/ha</td>
</tr>
<tr>
<td>$\bar{Y}_{Pl}$</td>
<td>Average crop yield of the treatment at $i$ in MT/ha</td>
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<td>Z1</td>
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Pipeline installations have been reported to cause soil compaction. Recently, an energy transfer pipeline was installed across the upper Midwest of the United State that affected agricultural land throughout the state of Iowa. Long-term research is needed to determine the best management practices to remediate subsoil compaction, and restore topsoil productivity to allow for maximum crop yield recovery.

A five-year research study has been undergoing to evaluate the response of crop productivity and soil physical properties to subsoiling treatments in the construction Right-of-Way [ROW] on a farm field at Iowa State University. The specific objectives for this study are to: (i) investigate the effects of subsoiling depths as remediation practices of soil bulk density and crop yield, and (ii) determine if the crop yield is affected by soil disturbance from pipeline installation.

The experiment was set up in a Randomized Complete Block Design to investigate the subsoiling depths in three ROW zones designated by construction activities, and two adjacent unaffected zones. Soil bulk density samples were taken to quantify the soil compaction that occurred after heavy trafficking and pipeline installation, and proceeding subsoiling treatment. Crop yields (corn and soybean) were monitored in the subsequent years. Observed soil bulk density and crop yield values were statistically analyzed (P-value 0.05) with SAS statistical software to evaluate the effects of subsoiling treatments.

The soil bulk densities were found to be the highest in the ROW, indicating subsoil compaction from construction activities. The highest soil bulk density value (1.74 g/cm³) was found in the most heavily trafficked zone post-pipeline installation. Soil bulk density in the lightly trafficked zone had the highest soil bulk density value (1.74 g/cm³) after subsoil
treatments were applied, suggesting subsoil compaction was persistent regardless. Subsoiling treatment depth did not show statistical differences in the ROW for soil bulk density. Overall, the average soil bulk density observed within the ROW was significantly larger than those in adjacent unaffected areas.

Soybean yield in the year following pipeline installation had significant deficits in the ROW in comparison to the unaffected areas. The lowest observed crop yield was the heavily trafficked ROW zone (2.77 MT/ha), therefore showed the greatest deficit of -35.5%. However, soybean yields were not found statistically different between the two subsoiling depths. The corn yield in the following year also had significant deficits in the ROW verses the adjacent unaffected areas. The lowest observation of corn yield was again in the ROW heavy traffic zone (11.45 MT/ha). However, the maximum deficit for corn yield was only -23.3%, giving the impression that the crop yield is recovering from the soil disturbance. Again, no statistical difference was found in the subsoiling treatments for corn yield.

The first three years of this study showed significant differences in soil compaction and crop yield between the ROW and unaffected areas. Both soil compaction measurements and crop yield showed no signs of differences between subsoiling depths within the ROW. Differences in both years of crop yield indicated that the topsoil disturbance from pipeline installation did have a significant impact on the yield when compared to undisturbed areas. However, the different construction activities within the ROW did not prove to be distinct from one another when comparing crop yield. This however needs to be further investigated to determine the long-term effects of crop yield response to soil disturbance—including other soil biological, chemical and physical factors that affect yield.
CHAPTER 1. INTRODUCTION

Project Background

From the summer of 2016 through the spring of 2017, construction of a 1890 km (~1172 mi), 76 cm (~30 in) diameter, energy transfer pipeline project was completed from the Bakken region of North Dakota to Patoka, Illinois as shown in Figure 1.1. The underground pipeline stretches across the state of Iowa from Lyon County, in the upper-most northwest, to the southeastern corner in Lee County—totaling 560 km (~348 mi) through 18 counties (see Figure 1.1(a)). Included in these 560 km are several hectares (acres) of agricultural land. During construction, topsoil is scraped off and set aside in a pile along the easement. Topsoil is kept separated from the subsoil pile created when digging the pipeline trench. Controlled trafficking is practiced within the construction easement to avoid additional compaction in the subsoil. To restore the disturbed topsoil from construction activities, Dakota Access, LLC [DAPL] established an Agricultural Impact Mitigation Plan, in which remediation practices were to be followed as adopted and approved by the Iowa Utilities Board under Chapter 9 of the Iowa Administrative Code.

![Figure 1.1 Maps of DAPL across (a) Upper Midwest of the USA and (b) the state of Iowa (Source: Dakota Access Pipeline Facts, 2017)]
Although underground pipelines are not a new concept, limited research has been performed to understand the effects of soil disturbance and restoration practices have on agricultural production land. Knowledge gaps reported by Brynes in a 1982 state-of-the-art literature review are: A) “…no research [is] being conducted to evaluate the effects on agricultural soils of specific construction practices…including [both] timing of operations based on soil conditions and equipment variability,” B) “…no scientific information is available in the United States on the degree and extent of soil compaction by various kinds of equipment used in [powerline] construction and the subsequent effects on crop growth and yield on different soil types,”, and C) “…no scientific information [is] available in the United States [or Canada] on the effectiveness of tillage in alleviating soil compaction caused by heavy construction equipment.” Batey (2015) claims: “it is clear that preventative measures to limit compaction during installation of a pipeline are not a practical option; the only realistic course of action is to make a strenuous effort to alleviate the compaction prior to the replacement of the topsoil.”

With limited research, landowners throughout the state of Iowa are looking for answers beyond those presented in the Agricultural Impact Mitigation Plan. Specific questions posed addressed the impact of construction and subsequent restoration practices on the long-term crop yield and soil productivity? Currently, a five-year research project is in progress to study these effects at one pipeline installation location on an Iowa State University research farm field. Understanding the soil compaction issues during the construction phase and the effects of deep tillage treatments during the restoration of agricultural production land are critical to managing crop yield recovery.
Objectives

The main objective of this study is to evaluate crop yield (soybean and corn) and soil physical property (soil bulk density) in response to subsoiling treatments applied to different soil compaction zones associated with variable construction activities within the Right-of-Way [ROW]. The specific objectives of this study are to:

- Investigate the effects of subsoiling depths as remediation practices on soil bulk density and crop yield (soybean and corn) and
- Determine if the crop yield is affected by the soil disturbance after pipeline installation.

Thesis Organization

This thesis is organized into four chapters: Chapter 1 has introduced the background of the project, and the knowledge gaps this research is trying to fill, and will discuss previous research conducted on soil compaction and environmental effects associated with compaction; Chapter 2 identifies the previous management of the research site, the construction easement layout and installation practices, the project experimental design based on remediation practices, the field and laboratory experiments used to collect data, and the data analysis approach; Chapter 3 reports and evaluates the data collected from the first three years after pipeline installation, gives insight of weather and field conditions of each year, and a comprehensive discussion of findings regarding soil compaction and crop yield; and Chapter 4 discusses the overall conclusion of the project, and suggestions for future works needed in this area.
**Relevant Research**

Soil compaction is the rearrangement of particles in which the soil total porosity within the profile is reduced due to being pressed together which in-turn causes several effects on the surrounding environment. This phenomenon can be viewed as desirable or undesirable, depending on the application and industry. Desirable soil compaction primarily occurs in the construction industry while preparing foundations—where the goal is to increase soil strength and avoid slope failure or reducing the risk of settlement after the installation of sub-surface utilities. Alternatively, undesirable soil compaction is found predominantly in agricultural crop production.

Compaction in agricultural soils primarily occurs with heavy trafficking of machinery and equipment due to vehicle traffic for producing crops under high soil moisture conditions. To keep up with the growing demand for food, energy, and consumer products, agricultural machinery and vehicles have progressively been designed and built larger, leading to vehicles with greater axle loads (Raper, 2005). Håkansson and Reeder (1994) studied the effects of traffic by vehicles with high axle loads (> 10 Mg/axle) on soils with high soil moisture contents and found that this causes compaction in subsoils. Bakker and Davis (1995) found that the first loaded wheel pass alone is known to cause a major portion of total soil compaction. Although compaction may be visible from aboveground observations of soil deformation, compaction issues are a major subsoil problem that have several effects on the productivity of agricultural soils (Hamza and Anderson, 2005; Raper, 2005). Alakukku (1996a) reported subsoil compaction to a depth of 50 cm when studying the effects of one and four passes of a high axle load on clay soil during wet field conditions. Physically compacting soils increases the soil strength and bulk density, while reducing the soil porosity. Alakukku (1996a) also observed a reduction in the total porosity due to the applied heavy vehicle loads to nearly equal the macro-porosity. Studies in the
United Kingdom and Switzerland also reported that repeated trafficking of four and 10 vehicle passes reduced the macro-porosity by more than 50% and 74% relative to controls, respectively (Bullock et al., 1985; Schäffer et al., 2007).

Soil is composed of a system of pores varying in size, in which the size and distribution affects the root development of plants, and controls the movement of soil water, nutrient uptake. Root development in soil requires a continuous network of appropriately sized pores (Tracey et al., 2011). In heavily compacted soils, root penetration is restricted, due to the increase in soil strength, and therefore, roots explore weaker soil (Johansen et al., 2014). Taylor and Gardner (1963) found that cotton roots penetration were excessively restricted when the soil penetration resistance of measured 3.0 MPa and above. More recently, Brown (2012) studied the effects of different soil management practices on root development at a piedmont site in North Carolina. The roots growing in compacted soil were shorter and thicker in comparison to roots growing in tilled soil. There was a greater distribution of roots in the tilled soil profile than in the compacted soil. Because of poorly developed root systems, issues with nutrient and water uptake are also likely to occur in compacted soil.

Decreasing the pore size distribution due to compaction affects water and nutrient uptake (Tracey et al., 2011). A soil fertility characteristics study by Duncan and DeJoia (2011) found that there was not a significant change in the nutrient availability of topsoil that was removed, stored, and replaced on a pipeline ROW when compared to the adjacent undisturbed topsoil, indicating that a lack of nutrients was not the issue, but rather the uptake of nutrients by the plants. Soil hydrologic properties, such as hydraulic conductivity and infiltration rate, decreased with increasing compaction. In the subsoil, compaction had an effect on the drainage capacity. These factors contributed to the ponding of water on the soil surface and had the potential to
increase erosion from surface run-off (Tracey et al., 2010; Abu-Hamdeh, 2003). Observing the root development, movement of soil water, and nutrient uptake could help explain crop yield reductions in highly compacted soils.

Studies were performed to understand the relationship between compaction variables and crop yield. Isaac et al. (2002) found that soil cone index readings correlated with corn yield in Kansas. Soil cone index readings were noted as a more sensitive indicator of compaction than soil bulk density (Voorhees et al., 1978). However, Negi et al. (1981) found that silage corn yields significantly diminished when the soil bulk density exceeded 1.5 g/cm³ in a sandy loam soil in Quebec, Canada. Another maize (corn) yield study in Nigeria (Igoni and Ayotamuno, 2016) determined that crop performance was overall better in fields with lower levels of compaction. Johansen et al (2014) concluded that carrot and potato yields were reduced in soils with increased soil compaction in Nordic regions.

Shallow tillage, deep tillage (subsoiling), and controlled traffic are agricultural practices used to alleviate soil compaction issues. Deep tillage improves aeration to the subsoil profiles, while controlled trafficking helps reduce soil compaction in the field by limiting it to the trafficked lanes (Hamza and Anderson 2008; Raper, 2005). Hamza and Anderson (2008) reported that deep ripping at least 30 cm (~12 in) with a tine spacing of 30 cm increased the amount of available water in the soil and the soil water infiltration rates, decreased the soil bulk density and soil strength, and increased yield when compared to a control without deep tillage and to soil receiving shallow tillage of 15 cm (~6 in). Hamza and Anderson (2005) suggested that controlled traffic limited significant soil compaction to a portion of the field and helps to increase the overall crop yield by approximately 30%. Raper (2005) also noted that the
combination of subsoiling and controlled traffic increased cotton yield in Mississippi on irrigated and non-irrigated fields by 8.2% and 14.7%, respectively.

Although soil compaction can be alleviated by tillage practices, soil physical properties, such as air porosity, infiltration rate, and soil strength, can still be affected by soil compaction for up to a decade (Abu-Hamdeh, 2003; Johansen et al., 2014). A study on the effects of deep tillage on reclaimed mined land concluded that treatment enhances the infiltration only for a short time (Chong, 1996). Håkansson and Reeder (1994) state that “subsoil compaction is very persistent…[it] seems to be virtually permanent even in shrinking/swelling soils [it is] very difficult and often impossible to mechanically loosen to alleviate compaction below 40 cm (~16 in.).” Alakukku (1996b) validated this statement when evaluating the persistence of soil compaction due to high axle load traffic, reporting subsoil properties still have measurable changes nine years after traffic, despite crop and soil management practices and freeze-thaw cycles. The best practices to minimize subsoil compaction are: periodic deep plowing, controlled traffic, conservation tillage, and deep tap root crops in a crop rotation (Ishaq et al., 2001). However, soil types differ across fields, states, and countries, and different management.
CHAPTER 2. MATERIALS AND METHODS

Field maps were created, managed, and annotated with Ag Leader© Technology’s SMS™ Advanced software, Bluebeam© Revu©, and Microsoft © Excel©.

Site Description

The research plots for the experiment are located on the North Woodruff Field of the ISU research farms within the NW ¼ of Section 19 in the Washington Township of Story County, IA. The area of research dimension is 80 m (~280 ft) wide by 245 m (~800 ft) long and make up a total area of 2.1 ha (~5.1 ac) consisting primarily of two map unit soil series: Clarion loam (1.3 ha ~ 60.7%) and Canisteo clay loam (0.8 ha ~ 37.7%).

The Clarion loam is taxonomically classified as a fine-loamy, mixed, superactive, mesic Typic Hapludolls and consists of slopes from 2-6%, with an Iowa CSR2 of 88 and medium susceptibility to compaction. The Canisteo clay loam is taxonomically classified as fine-loamy, mixed, superactive, calcareous mesic Typic Endoquolls and consists of slopes from 0-2%, with an Iowa CSR2 value of 87 and low susceptibility to compaction. Figure 2.1 on the following page and Table 2.1 below show the soil series within the research area boundary and summary of attributes obtained from the Web Soil Survey [WSS] provided by the Soil Survey Staff of the Natural Resources Conservation Services [NRCS] and the United States Department of Agriculture [USDA]. See Appendix A for definitions and more detailed information from WSS.

Table 2.1 Summary of research area boundary from WSS

<table>
<thead>
<tr>
<th>Map Unit</th>
<th>Symbol</th>
<th>Area [ha]</th>
<th>Slope / Grade Range [%]</th>
<th>CSR2 Rating</th>
<th>Compaction Susceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarion</td>
<td>L507</td>
<td>1.260</td>
<td>2.0 - 6.0</td>
<td>88</td>
<td>Medium</td>
</tr>
<tr>
<td>Canisteo</td>
<td>L138B</td>
<td>0.783</td>
<td>0.0 - 2.0</td>
<td>87</td>
<td>Low</td>
</tr>
<tr>
<td>Nicollet</td>
<td>L55</td>
<td>0.033</td>
<td>1.0 - 3.0</td>
<td>91</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Construction Equipment Descriptions

Soil compaction from trafficking of heavy equipment is a function of the mass and nominal contact area of the equipment and the soil moisture conditions at the time of equipment trafficking. A high-load vehicle with a small nominal contact area can cause more soil compaction when compared to a vehicle with the same load and a larger nominal contact area. This is because the amount of pressure being put on the soil is higher due to the inverse relationship of area (refer to Equation 2.1). Wet soil moisture conditions also increase the soils susceptibility to soil compaction due to the decrease in friction between soil particles—allowing for them to rearrange more freely under a higher level of pressure.
\[ P = \frac{F}{A} \]

**Equation 2.1**

where \( P \) is Pressure

\( F \) is Force (load of vehicle)

\( A \) is Area (nominal contact area)

### Pipeline Installation Equipment

Heavy equipment operations occurring in the ROW were used for various construction activities for the installation of the pipeline. Construction activities included: topsoil removal, excavation of the pipeline trench, transportation of the pipe to the site, pipeline shaping (known in industry as bending), laying the pipe in the trench, and backfilling the trench after pipeline installation. Broad classification of the equipment used are: dozers, excavators, semi-trailer trucks, pipeline benders, and pipe layers. Table 2.2 describes the equipment used for this site and specifications, and construction activity it was used for (see Appendix B for pictures).

**Table 2.2 Construction equipment used for pipeline installation**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Classification</th>
<th>Tractive Device</th>
<th>Vehicle Weight [Mg]</th>
<th>Nominal Contact Area [m²]</th>
<th>Construction Use</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAT 349F</td>
<td>Excavator</td>
<td>Track</td>
<td>51.0</td>
<td>3.92</td>
<td>Trench excavation and backfilling; pipeline installation</td>
<td>B.1</td>
</tr>
<tr>
<td>CAT D7E LGP</td>
<td>Dozer</td>
<td>Track</td>
<td>28.2</td>
<td>1.84</td>
<td>Topsoil removal</td>
<td>B.2</td>
</tr>
<tr>
<td>CAT D8T S</td>
<td>Dozer</td>
<td>Track</td>
<td>39.8</td>
<td>1.79</td>
<td>Topsoil removal</td>
<td>B.3</td>
</tr>
<tr>
<td>CAT PL87</td>
<td>Pipe layer</td>
<td>Track</td>
<td>54.5</td>
<td>4.91</td>
<td>Pipeline installation</td>
<td>B.4</td>
</tr>
<tr>
<td>Pipe Bender 22-36**</td>
<td>Pipeline bender</td>
<td>Track</td>
<td>47.2</td>
<td>NA**</td>
<td>Pipeline shaping/bending</td>
<td>B.5</td>
</tr>
<tr>
<td>Semi-Trailer Truck (5-axles)</td>
<td>Transportation</td>
<td>Wheel</td>
<td>45.4***</td>
<td>NA**</td>
<td>Pipe transportation</td>
<td>B.6</td>
</tr>
</tbody>
</table>

*No specified brand of pipe bending equipment was documented; used conservative size of a Centurion brand pipe bender
**Not enough information can be found to report the contact area
***Conservative value for the maximum Iowa Department of Transportation allowable load (~9.1 Mg/axle)
ROW Topsoil Restoration Construction Equipment

The heavy equipment used for the ROW topsoil restoration consisted of dozers and excavators. The equipment was used to return the piled topsoil back onto the landscape. Table 2.3 describes the equipment used for this site and specifications (see Appendix B for figures).

Table 2.3 Construction equipment used for topsoil restoration in the ROW

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Classification</th>
<th>Tractive Device</th>
<th>Vehicle Weight [Mg]</th>
<th>Nominal Contact Area [m²]</th>
<th>Construction Use</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAT 349F</td>
<td>Excavator</td>
<td>Track</td>
<td>51.0</td>
<td>3.92</td>
<td>Topsoil restoration</td>
<td>B.7</td>
</tr>
<tr>
<td>CAT D6T</td>
<td>Dozer</td>
<td>Track</td>
<td>23.3</td>
<td>1.58</td>
<td>Topsoil restoration</td>
<td>B.8</td>
</tr>
<tr>
<td>LGP S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAT D7E</td>
<td>Dozer</td>
<td>Track</td>
<td>28.2</td>
<td>1.84</td>
<td>Topsoil restoration</td>
<td>B.9</td>
</tr>
<tr>
<td>LGP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deere 350G</td>
<td>Excavator</td>
<td>Track</td>
<td>38.2</td>
<td>3.24</td>
<td>Topsoil restoration</td>
<td>B.10</td>
</tr>
<tr>
<td>LC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Site Management and Experimental Design

Preceding Pipeline Installation Field Management

Information provided by the farm manager stated that field management used prior to the pipeline installation included conventional modern practices in a corn-soybean rotation. The area was farmed from E to W (90° to 270°), with a row spacing of 76 cm (~30 in).

After soybean harvest, the soybean area remained untilled and the residue undisturbed until the following spring. Dry fertilizer (P, K, and S) was applied as needed in the fall/winter at rates of 72 kg (~160 lbs), and 55 kg (~120 lbs) (unknown for S) typically in the forms for MESZ or MAP and elemental sulfur or gypsum. In the succeeding spring, 32 % UAN (approximately 64 kg (~140 lbs) of N) and pre-plant herbicide were applied, followed by tilling with either a 16 m (52 in) Case Tigermate II (see Appendix C Figure C.1) or John Deere 2210/2230 (see Appendix C Figure C.2) field cultivator (both had a 15 cm sweep spacing and coil tine harrow).
to a depth of 7.6 cm (3 in) and then planted corn. In more recent years, N was sidedressed at the V7 corn growth stage due to wet growing seasons.

Heavy tillage was applied in the fall after corn harvest to break up the corn stalks before the winter freeze with a John Deere 512 9-shank disc ripper (similar to that of Figure 2.4), angled roughly 10° off of the row direction. In the spring, a field cultivator (previously mentioned) was used to level the large soil aggregates created from the previous season’s tillage. Herbicide was applied, followed by another pass of the field cultivator, and finally soybeans were planted.

**Pipeline Installation Construction**

The ROW was oriented S57°E (bearing of 123°) to accommodate the direction of the underground pipeline, and is approximately 18 m (~160 ft) wide and roughly 0.5 m (~20 in) below the original undisturbed topsoil surface. Within the ROW, five construction zones were designated as: Z1, Z2, Z3, X, and P. A schematic of the easement is shown in Figure 2.2.

![Figure 2.2 Side view schematic of DAPL construction easement](Source: modified from FERC Golden Pass LNG Terminal and Pipeline Project image)
Z1 is located directly over the trench and where the pipeline lays—it is approximately 7.6 m (~25 ft) wide. Z2 is also approximately 7.6 m wide and is where the excessive heavy equipment traffic occurred. Z3 is the secondary route of heavy equipment and primary route of semi-trailer traffic carrying sections of pipe, and measures an approximate width of 7.6 m. Within the ROW at the research site, Z3 was relatively shallower than Z1 and Z2 by approximately 0.5 m, due to a berm that the topsoil was not removed from. X is a 15.2 m (~50 ft) wide zone where traffic was directed in order to take preliminary vertical soil stress to determine the effects of trafficking on deep soil compaction reported by Tekeste et al. (2019). X is also the designated zone to temporarily store the subsoil excavated from the trench in Z1. Lastly, P is the designated zone to pile the removed topsoil layer, in order to avoid mixing with the subsoil removed from the pipeline trench. P is 10.7 m (~35 ft) wide and the top soil was assumed to experience the least soil disturbance of all the zones in the ROW.

Since pre-construction data on soil physical properties and crop yield are not available, two undisturbed zones—adjacent on both the northern and southern sides of the ROW easement—are included into the experimental design. The zones are refered to as Control North [CN] and Control South [CS] for the northern and southern undisturbed zones, respectively. CN is approximately 18.2 m (~60 ft) wide, whereas CS is 15.2 m wide, and both are to be used as a comparison between the ROW and unaffected areas of the field. Research zones are designated as shown in Figure 2.3, and Table 2.4.
Table 2.4 Description of research site by designated construction zones and unaffected areas

<table>
<thead>
<tr>
<th>Key</th>
<th>Width [m]</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control South</td>
<td>CS</td>
<td>15.2 Original control zone, control zone adjacent to ROW of the construction easement</td>
</tr>
<tr>
<td>Zone X</td>
<td>X</td>
<td>15.2 Where force data was taken for heavy machinery and equipment investigations, subsoil pile storage</td>
</tr>
<tr>
<td>Zone 1</td>
<td>Z1</td>
<td>7.6 Pipeline/where the trench was dug; backfill with sand</td>
</tr>
<tr>
<td>Zone 2</td>
<td>Z2</td>
<td>7.6 Heavily trafficked zone, primary route of heavy machinery and equipment</td>
</tr>
<tr>
<td>Zone 3</td>
<td>Z3</td>
<td>7.6 Primary semi-trailer traffic, secondary route of heavy machinery and equipment, 0.5-m berm</td>
</tr>
<tr>
<td>Zone Pile</td>
<td>P</td>
<td>10.7 Area where the 0.5-m of top soil was piled to keep separate from the subsoil</td>
</tr>
<tr>
<td>Control North</td>
<td>CN</td>
<td>18.2 Secondary control zone, also adjacent to the ROW of the construction easement and P</td>
</tr>
</tbody>
</table>

Figure 2.3 Map of experimental field site showing designated construction zones and adjacent unaffected areas (Source: modified from Tekeste et al., 2019)

Post-Pipeline Installation Construction Remediation

Following the pipeline installation and prior to restoring the topsoil, two subsoiling treatment depths of [A] 30 cm (~12 in) and [B] 45 cm (~18 in) were applied within the ROW zones Z1, Z2, and Z3 in a Randomized Complete Block Design [RCBD] late October 2016. The treatments were applied parallel to the pipeline using a John Deere 8320R (see Figure C.3 in
Appendix C) traveling at 2.2 m/s (~5 mph) pulling a John Deere 915 [JD915] 5-shanks (76 cm spacing between adjacent shanks), and 3.8 m (~12.5 ft) wide, as shown in Figure 2.4. Each zone was divided into four experimental blocks in which the two subsoiling depths were assigned, giving a total of eight plots per zone. Each plot had two adjacent subsoiling treatment passes—each 3.8 m wide and 18.2 m (~60 ft) long—to give a 7.6 m by 18.2 m total area (~0.0139 ha (~0.0344 acre)) per plot. A 12.2 m (~40 ft) alleyway was left in between each successive plot to allow for the depth of the JD915 v-ripper to adjust accordingly.

![Figure 2.4 JD915 5-standard 76 cm spacing v-ripper used for subsoiling treatment](image)

The first pass within each plot was at a depth of 30 cm in order to alleviate the deep compaction that accumulated during construction. The depth of the additional two passes depended on the plot prescription of the RCBD, shown in Figure 2.5. Note that zones X and P are not part of the subsoiling experiment, yet were also tilled for remediation purposes in order to compare the effects of the soil disturbance that occurred within the ROW to that of the adjacent unaffected plots.
After the subsoiling treatments were completed, the separated and appropriately stored topsoil was restored within the ROW with Deere 350G and CAT 349F excavators, and CAT D6T LGP S and D7E LGP dozers, and a field cultivator. The ROW plots were then tilled in the fall with a Case 690 [C690] disk-ripper (Figure 2.6).
Additionally, deep tillage treatments were applied parallel to the ROW in the two designated unaffected [control] zones after corn harvest. A single pass with the JD915 5-shank ripper pulled by a John Deere 8260R [JD8260R] (similar to Figure C.3 in Appendix C) was done first to cut the leftover corn stalks into smaller pieces. CN and CS were then tilled with the C690 and JD8260R at 30 cm. and 45 cm, respectively. Figure 2.5 also shows the applied subsoiling and deep tillage treatments in the RCBD split-block experimental design.

**Post-Pipeline Installation Field Management**

After topsoil restoration, the ROW plots were not tilled prior to herbicide application and planting, whereas the adjacent unaffected areas had two soil finishing passes and then herbicide and planting. A corn-soybean rotation was continued as previously practiced, but was now planted parallel to the direction of the ROW [123°] instead of E to W [90° to 270°].

**2017 growing season**

Soybeans were planted in 76 cm rows parallel to the ROW on June 1, 2017 in 24 m (~80 ft) long by 7.6 m wide plots, and split to create two 12 m by 3.8 m plots. The split was to accommodate an additional tillage practice: Conventional Tillage [CT] and No-till [NT]. However, there were no differences in tillage application the first year prior to planting, and a
6 m (~20 ft) alley still existed as a buffer between the treatments. Figure 2.7 shows the plot prescription for the 2017 growing season. Soybean stubble was left untilled until Spring 2018 prior to next growing season.

![Diagram of experiment field plots layout for Fall 2017 treated as split plots](image)

**Figure 2.7** Experiment field plots layout for Fall 2017 treated as split plots

**2018 growing season**

In April 2018, a management decision was made to reduce plot lengths from 24 m to the original known treated area of 18.2 m (refer to Figure 2.7 from before). This shortened the splits from 12.2 m to 9.1 m (~30 ft) and returned the alleyway to a total length of 12.2 m. This decision was justified by wanting to ensure that the results in the NT split were not affected by 6 m of untreated area.
Tillage was conducted in the 9.1 m CT split perpendicular to the direction of the ROW at S33°W [~213°], while the NT split was left untouched, as shown in Figure 2.8. Corn was planted in 76 cm rows April 30, 2018 in parallel to the ROW within the 12.2 m plots only—the alleyways were planted perpendicularly to the ROW to help differentiate the beginnings and ends of the plots. A headland was also added and planted perpendicularly to easily determine the west-most boundary of the experiment. Tillage was applied post-harvest to cut up the corn stalks as part of the CT management practices.

Figure 2.8 Spring tillage applied perpendicular to the direction of plots and planting
Data Collection

Soil Bulk Density

Soil bulk density, defined as the mass of dry soil per unit bulk volume, was determined by taking core samples of an observed mass and known volume (~228.01 cm³). The core sampling method used a metal cylindrical sleeve that included a clear plastic liner that was pushed into the ground to a specified depth. The plastic liner was then sealed with rubber caps, and put in cold storage until ready to be cut into 5 cm increments—defined by ASABE Standards and accepted as an appropriate way to determine bulk density. The known volume of soil was weighed, then oven-dried and weighed again in order to determine the dry mass at the representative depths. Equation 2.2 shows the soil bulk density calculation at each representative depth:

\[
\rho_{BDi} = \frac{m_{Di}}{V_S}
\]

Eq. 2.2

where \( \rho_{BDi} \) is the soil bulk density in g/cm³ at the representative depth, \( i \)

\( m_{Di} \) is the dry mass of the soil at the representative depth, \( i \)

\( V_S \) is the volume of soil, which is assumed to be the same for all depths

All core samples were taken with a Giddings Machine Company truck-mounted, soil core sampling probe using a zero-contamination system, in which the inner diameter of the plastic liner measured 7.6-cm, shown in Figures 2.9(a) and 2.9(b). Samples were collected in the Fall post-harvest and pre-treatment of surface tillage from Blocks 1 and 3. These blocks were selected in order to account for both primary soil series found in each of the unaffected ‘control’ zones as shown in Figure 2.10. A total of 60 samples were collected: five zones with four replications, taking three samples per replication [5 x 4 x 3 = 60].
Figure 2.9 Soil core sampling method materials (a) truck-mounted Giddings soil probe and (b) plastic zero-contamination liner system

Figure 2.10 Soil map units superimposed over experimental field plots to determine and justify the blocks selected for subsampling to allow data in the unaffected areas [control zones] to be represented by both dominant soil types
Crop Yield

Crop yield was determined during harvest within the designated research plots with a 4-row John Deere 9450 [JD9450] (Figure 2.11) and HM800 (Harvestmaster) for the corn (*Zea mays* L.) and soybean (*Glycine max*) (years 2018 and 2017, respectively). Yield monitoring is a common practice in current precision agriculture technology to help understand the best inputs and management practices for crop growth. The yield monitoring equipment used on the JD9450 to measure grain properties was a weighing container equipped with a load cell for grain mass and a grain moisture sensor. CAN bus data from the combine harvester determine the velocity at which the machine is operating and along with the known head width allow the HM800 to calculate the harvested wet mass in pounds. The data collected in each plot are: pass, plot, time/date, wet weight of grain, and moisture content of grain.

![Figure 2.11 JD9450 combine equipped with HM800 used to harvest crop yield and record yield monitoring values](image)

Yield is commonly reported based on a standard moisture content for a given crop (known to the farming industry as dry-yield). The standard-yield can then be calculated by converting the observed grain wet mass to standard grain wet mass and dividing by the land area of the harvested grain. Equation 2.3 shows how to calculate harvest yield:
\[ Y_p = \frac{[1 - MC_g] \cdot m_g}{[1 - MC_s] \cdot m_s \cdot A_p} \]

Eq. 2.3

where \( Y_p \) is the Crop Yield for each plot in MT/ha

\( MC_g \) is the moisture content of the grain harvested in decimal form

\( m_g \) is the mass of the grain harvested in kg

\( MC_s \) is the standard moisture content for the grain harvested in decimal form

\( m_s \) is the standard mass of the grain harvest in kg/MT

\( A_p \) is the area of the plot harvested in ha

The standard moisture content for corn is 0.155, and for soybean is 0.13.

The four inner rows of the plots were harvested during a single harvest pass to ensure staying within the designated zones, and completed two passes per zone. The two passes were then averaged for each plot.

**Normalized yield**

Crop yield of corn is numerically higher than that of soybean and cannot be compared in this form. However, yield values can be converted to percentages allowing for comparison of field performances in different years, regardless of different crop inputs. Equation 2.4 shows how to calculate the normalized yield:

\[ Y_{Ni} = \frac{Y_{Pl}}{Y_{Cmax}} \]

Eq. 2.4

where \( Y_{Ni} \) is the Normalized Yield of the treatment at \( i \) in MT/ha

\( Y_{Pl} \) is the average crop yield of the plot of treatment \( i \) in MT/ha

\( Y_{C} \) is the maximum average crop yield of the plots of the Controls in MT/ha
Fall 2016

Construction of DAPL was in progress during the Fall of 2016, in which only core samples were taken from within the ROW and in the CS zone. CPT were not performed due to the lack of time and availability of equipment. No crop physiology and management data were collected. Weather data from the 2016 construction durations is presented in Appendix D.

Soil bulk density

90 cm (~3 ft) deep core samples were collected within the ROW prior to initiating construction remediation practices in Z1, Z2, and Z3, and from the south undisturbed CS. Nine samples were taken in each of the three construction zones for a total of 27 ROW samples on October 3, and 20 samples were collected in the unaffected zone on September 3. The core samples pulled from Z1 and Z2 were roughly 50 cm below the original soil profile. In Z3 and CS samples were taken roughly from the initial level of the original soil profile. The samples were not geospatially referenced, but could be used as “control” data to compare between the different zones as a pre-treatment condition and to help evaluate the effects of remediation practices in subsequent years.

Fall 2017

Soybean was planted on June 1, 2017 and monitored periodically by crop scouting and aerial imagery. Harvest was conducted on October 18 to collect yield data. Post-harvest soil bulk density data were collected. Weather data from the 2017 growing season is presented in Appendix D.

Soil bulk density

After the topsoil was restored in the ROW, 90 cm core samples were not sufficiently deep to investigate the compaction remediation effects of 45 cm subsoiling. Therefore, 120 cm deep core samples were taken in Blocks 1 and 3 throughout Z1, Z2, Z3, CS, and CN every 6.1 m. A
total of 60 samples were taken—12 in each previously stated zone—during early December through mid-late December and then stored in the freezer until ready to be cut, weighed, and oven-dried for bulk density calculations.

**Crop yield**

Soybean was harvested on October 18, 2017 in the five zones within the research plot boundary with the JD9450, which was calibrated by the ISU AEA Farm. Again, harvest data were collected twice within each 24 m long plot to allow for two separate yield calculations per pass to prepare for CT and NT in the following years in order to compare each zone and the applied subsoiling treatments. The two passes within each split were averaged together for a single crop yield value. After harvest weight and average moisture content were obtained in the field, yield was calculated on a standard moisture content mass basis for the CT plots only, due to untreated area in the NT plots.

**Fall 2018**

Corn was planted on April 30, 2018 and harvested on October 22, 2018. Weather data from the 2018 growing season is presented in Appendix D.

**Crop yield**

Corn was harvested on October 22 in the five zones with the JD9450, which was calibrated by the ISU AEA Farm. Harvest data were taken twice within each 9.1 m plot for the split-plot accommodation with the newly adapted CT and NT. After harvest weight and average moisture content were taken in the field, yield was calculated on a standard moisture content mass basis for each 6.2 m by 9.1 m plot.
Data Analysis

Due to varying moisture conditions and time of sample collection, data analysis was performed year-to-year. Analysis of Variance were carried out by **PROC GLIMMIX** in a full model first to determine the significant Main Effects and Interactions at a P-value of 0.05, and then a Partial Model to determine accurate estimates. Details of Fixed and Random Effects included will be discussed by year and model. **PROC GLIMMIX** was used due to missing values in the datasets to still allow LSM calculations, linear contrasts of the treatments, and LSMs pair-wise groupings with the **lines** statement.

Fall 2016

Preliminary data from the Fall of 2016 were taken from the ROW zones and the south unaffected area. The depths at which the soil bulk densities were observed are re-presented from Tekeste *et al.* (2019) by different averaged layers of interest, that will be discussed in more detail in the Results section of Chapter 3. The Fixed effect in the model was Zone and although no random effects were present, **PROC GLIMMIX** was used to produce the linear contrasts and LSMs pair-wise grouping. The soil bulk density was analyzed two different ways:

i. The soil profile referenced to the surface elevation of the control.

ii. The soil profile referenced to the surface elevation of applied subsoiling treatments.

Figures 2.12 and 2.13 show the analysis depths for (i) and (ii). Note that both of the data sets are analyzed with values observed after the pipeline installation was finished and before the subsoiling treatments were applied—representing the cumulative soil compaction from the construction activities in the ROW and the natural state of the adjacent unaffected [control] area.
Figure 2.12 Side view schematic of constant depths across the ROW and unaffected area of the soil bulk density data for analysis (i): reference to the surface elevation of the control (source: modified from FERC Golden Pass LNG Terminal and Pipeline Project image)

Figure 2.13 Side view schematic of variable depths across the ROW and unaffected area of the soil bulk density for analysis (ii): reference to the surface elevation of the applied subsoiling treatments (source: modified from FERC Golden Pass LNG Terminal and Pipeline Project image)
Fall 2017

Soil bulk density data and crop yields from the Fall of 2017 were taken from the ROW zones and the north and south unaffected areas. These were both analyzed by zone, subsoiling treatments, and the interaction of zone and subsoiling treatment. The soil bulk density was also analyzed by interest of different layers of depth—discussed in further detail in the Results section of Chapter 3. The Fixed effects for this model were Zone and Subsoil, and the random effects of Block and Replication—nested within the Block—are not included. The random effect error calculated is for the experimental unit. The soil bulk density samples were analyzed as:

iii. The soil profile referenced to the surface elevation of the control.

iv. The soil profile referenced to the surface elevation of applied subsoiling treatments.

Refer to Figures 2.12 and 2.13 to visualize the different depths for analysis of (i) and (ii).

Figure 2.14 Side view schematic of constant depths across the ROW and unaffected area of the soil bulk density data for analysis (i): reference to the surface elevation of the control (source: modified from FERC Golden Pass LNG Terminal and Pipeline Project image)
The soybean yield was analyzed using only the first half of the split plot, due to an untreated area in the second half (refer to Figure 2.7 on page 19).

**Fall 2018**

Crop yield data from the Fall of 2018 were taken from the ROW zones and the two unaffected zones and analyzed by zone, subsoiling treatment. Corn yield was analyzed in a split plot design due to the addition of the tillage treatment in the Spring of 2017. Tillage was not included in the models due to the scope of the study and only having a single year of NT practice on a traditionally CT farmed field. The Fixed effects in the model are again, the Zone and Subsoil and Random effects of Block and Replication are dropped due to a zero variance. The random effect error calculated is for the experimental unit.
Results

Fall 2016

Construction occurred from late August through the end of October. The rainfall amount in September was relatively high compared to the 30-year average.

Soil Bulk Density

Soil profile referenced to surface elevation of the control

The observed bulk density showed higher levels of compaction as depth increased in the soil profile for most of the zones, as shown in Figure 3.1 below. All three of the ROW zones showed higher levels of compaction than those found in the adjacent unaffected zone. Z2 had an average peak bulk density of 1.74 g/cm$^3$, and it had the highest layer average value, 1.69 g/cm$^3$. Z1 had the second highest average value, 1.67 g/cm$^3$, in the 35 cm layer, followed by Z3, 1.61 g/cm$^3$. The ROW zones were not significantly different from each other, but were significantly higher than that of the control (1.51 g/cm$^3$). Table 3.1 lists the calculated LSMs.

Table 3.1 Calculated LSMs of soil bulk density by layer for the first analysis (i): reference to the surface elevation of the control in 2016 prior to applied treatments (re-presented from Tekeste et al. 2019)

<table>
<thead>
<tr>
<th>Zone</th>
<th>BD$_1$ g/cm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[50, 85] cm</td>
</tr>
<tr>
<td>Z1</td>
<td>1.67$^A$</td>
</tr>
<tr>
<td>Z2</td>
<td>1.70$^A$</td>
</tr>
<tr>
<td>Z3</td>
<td>1.61$^A$</td>
</tr>
<tr>
<td>CS</td>
<td>1.51$^B$</td>
</tr>
</tbody>
</table>

*Means with the same letter are not significantly different
Figure 3.1 Observed soil bulk density by depth for the first analysis (i): reference to the surface elevation of the control in 2016 prior to applied treatments (re-drawn from Tekeste et al., 2019)

Soil profile referenced to elevation of the surface of subsoiling treatment

The bulk density was averaged between three layers of depth that were of interest:

1) [0, 30] cm (red),
2) [30, 45] cm (yellow), and
3) [45, 65] cm (dark blue) (see Fig. 3.4).

These were selected in order to determine the overall compaction of the effected soil profiles from the construction equipment and operations in the ROW. Layers (1) and (2) were the depths of the shallow and deep subsoiling treatments, respectively, and layer (3) was selected to quantify the compaction directly below the treatments. Figure 3.2 shows that overall Z1 and Z2 were categorized together with the highest level of compaction, whereas Z3 and CS were identified as significantly different for all three layers. Z2 had the highest level of compaction in...
each specified layer, while the control layers had the lowest bulk density values. Table 3.2 displays the calculated LSMs soil bulk densities at each layer and the significant difference between each of the zones and layers. Note that the LSMs are compared within each layer (column), not overall (matrix).

![Figure 3.2 Observed soil bulk density by depth for the first analysis (ii): reference to the surface elevation of the subsoiling treatments in 2016 prior to applied treatments](image-url)
Table 3.2 Calculated LSMs of soil bulk density by layers for the second analysis (ii): reference to the surface elevation of the subsoiling treatments in 2016 prior to applied treatments

<table>
<thead>
<tr>
<th>Zone</th>
<th>$B_{Dr}$ g/$cm^3$</th>
<th>[0, 30] cm</th>
<th>[30, 45] cm</th>
<th>[45, 65] cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z1</td>
<td></td>
<td>1.64A</td>
<td>1.69A</td>
<td>1.69A</td>
</tr>
<tr>
<td>Z2</td>
<td></td>
<td>1.66A</td>
<td>1.70A</td>
<td>1.70A</td>
</tr>
<tr>
<td>Z3</td>
<td></td>
<td>1.55B</td>
<td>1.57B</td>
<td>1.60B</td>
</tr>
<tr>
<td>CS</td>
<td></td>
<td>1.49C</td>
<td>1.41C</td>
<td>1.46C</td>
</tr>
</tbody>
</table>

*Means with the same letter within the column are not significantly different.

**Fall 2017**

The rainfall over the early months of the growing season was relatively low compared to the 30-year average, indicating a dry year.

**Soil Bulk Density**

*Soil profile referenced to surface elevation of the control*

Overall the controls had a significantly lower soil bulk density than the zones in the ROW. Figure 3.3 shows that the observed bulk density typically increased with depth, regardless of subsoiling treatment. However, although the 30-cm subsoiling treatment bulk density in Z1 was not significantly lower than the rest of the ROW zones, it is also not significantly different than the two controls. No documentation was recorded while taking or processing the samples, but it was believed that the 30-cm samples taken in B3 had a high percentage of sand, and therefore did not provide an accurate representation of the soil bulk density below the depth of 80-cm. Typically, a coarse-grained soil, such as sand, is used as backfill when native soil is not suitable (Pharris and Kolpa, 2007) and the presence of sand could explain these data.

Measurements were grouped into six layers: (1) [0, 15] cm (green), (2) [15, 30] cm (light blue), (3) [30, 50] cm (purple), (4) [50, 80] cm (red), (5) [80, 95] cm (yellow), and (6) [95, 115] cm (dark blue) (See Figure 3.3). These layers were strategically selected to see the
effects of surface tillage (1, and 2), effects of soil disturbance by removal (1, 2, and 3), effects of the different subsoiling treatments (4, and 5), and the persistence of subsoil compaction from the construction equipment and pipeline installation (6). The layers were analyzed together as a whole dataset, and individually. The overall soil bulk density calculated LSMs are listed in Table 3.3. Note that the LSMs are compared within each layer (column), not overall (matrix).

Table 3.3 Calculated LSMs of soil bulk density by layer for the first analysis (i): reference to the surface elevation of the control in 2017

<table>
<thead>
<tr>
<th>Zone</th>
<th>Subsoil</th>
<th>[0, 15] cm</th>
<th>[15, 30] cm</th>
<th>[30, 50] cm</th>
<th>[50, 80] cm</th>
<th>[80, 95] cm</th>
<th>[95, 115] cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z1</td>
<td>30</td>
<td>1.30&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>1.34&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>1.43&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.53&lt;sup&gt;A&lt;/sup&gt;</td>
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<td>1.50&lt;sup&gt;&lt;sup&gt;BC&lt;/sup&gt;&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>1.38&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>1.49&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.61&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.69&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.66&lt;sup&gt;&lt;sup&gt;AB&lt;/sup&gt;&lt;/sup&gt;</td>
<td>1.71&lt;sup&gt;&lt;sup&gt;AB&lt;/sup&gt;&lt;/sup&gt;</td>
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<td>Z2</td>
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<td>1.41&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>1.52&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.65&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.65&lt;sup&gt;&lt;sup&gt;AB&lt;/sup&gt;&lt;/sup&gt;</td>
<td>1.71&lt;sup&gt;&lt;sup&gt;AB&lt;/sup&gt;&lt;/sup&gt;</td>
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<td>1.42&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.52&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.62&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.66&lt;sup&gt;&lt;sup&gt;AB&lt;/sup&gt;&lt;/sup&gt;</td>
<td>1.70&lt;sup&gt;&lt;sup&gt;AB&lt;/sup&gt;&lt;/sup&gt;</td>
</tr>
<tr>
<td>Z3</td>
<td>30</td>
<td>1.36&lt;sup&gt;&lt;sup&gt;A&lt;/sup&gt;&lt;/sup&gt;</td>
<td>1.45&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.50&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.60&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.62&lt;sup&gt;&lt;sup&gt;AB&lt;/sup&gt;&lt;/sup&gt;</td>
<td>1.64&lt;sup&gt;&lt;sup&gt;AB&lt;/sup&gt;&lt;/sup&gt;</td>
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<td>45</td>
<td>1.41&lt;sup&gt;A&lt;/sup&gt;</td>
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<td>1.26&lt;sup&gt;C&lt;/sup&gt;</td>
<td>1.21&lt;sup&gt;C&lt;/sup&gt;</td>
<td>1.33&lt;sup&gt;B&lt;/sup&gt;</td>
<td>1.46&lt;sup&gt;&lt;sup&gt;BC&lt;/sup&gt;&lt;/sup&gt;</td>
<td>1.53&lt;sup&gt;&lt;sup&gt;ABC&lt;/sup&gt;&lt;/sup&gt;</td>
</tr>
<tr>
<td>CS</td>
<td>45</td>
<td>1.26&lt;sup&gt;BC&lt;/sup&gt;</td>
<td>1.27&lt;sup&gt;BC&lt;/sup&gt;</td>
<td>1.26&lt;sup&gt;BC&lt;/sup&gt;</td>
<td>1.32&lt;sup&gt;B&lt;/sup&gt;</td>
<td>1.36&lt;sup&gt;&lt;sup&gt;D&lt;/sup&gt;&lt;/sup&gt;</td>
<td>1.41&lt;sup&gt;&lt;sup&gt;C&lt;/sup&gt;&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Means with the same letter within the column are not significantly different

The soil disturbance of the top 50-cm had a significant effect on the bulk density, most noticeably below 15-cm. This could be possible because of the trafficking that occurred when restoring the topsoil post-construction and being too deep for tillage disturbance. The soil disturbance in the subsoiling layer of [50, 80] cm also showed significance in the ROW vs. the controls. However, below 80-cm, significance between the ROW and CN were not as distinct.

Since there was no significance in the interaction of Zone and Subsoil, nor the Subsoil as a Main effect, the subsoil could be pooled within the zone for the statistical analysis.
Figure 3.3 Observed soil bulk density by depth for the first analysis (i): reference to the surface elevation of the control in 2017
Soil profile referenced to surface of subsoiling treatment

The bulk density was averaged between the same three depths of interest from 2016:
(1) [0, 30] cm (red), (2) [30, 45] cm (yellow), and (3) [45, 65] cm (dark blue) (see Figure 3.4).

Overall the subsoiling treatments showed that the controls were significantly different than that in the ROW, but there were no significant differences between subsoiling treatments within each zone as shown in Figure 3.4. Table 3.4 has a summary of the LSMs soil bulk densities. Note that the LSMs are compared within each layer (column), not overall (matrix).

Since there was no significance in the interaction of zone and subsoil, nor the subsoil as a main effect, the subsoil error term could be pooled within the zone.

Table 3.4: Calculated LSMs of soil bulk density by layers for the second analysis (ii): reference to the surface elevation of the subsoiling treatments in 2017

<table>
<thead>
<tr>
<th>Zone</th>
<th>Subsoil</th>
<th>BD g/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[50, 80] cm</td>
<td>[80, 95] cm</td>
</tr>
<tr>
<td>Z1</td>
<td>30</td>
<td>1.54&lt;sup&gt;AB&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>1.69&lt;sup&gt;A&lt;/sup&gt;</td>
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<td>Z2</td>
<td>30</td>
<td>1.65&lt;sup&gt;A&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>1.62&lt;sup&gt;A&lt;/sup&gt;</td>
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<tr>
<td>Z3</td>
<td>30</td>
<td>1.41&lt;sup&gt;BC&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>45</td>
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</tr>
<tr>
<td>CS</td>
<td>45</td>
<td>1.27&lt;sup&gt;C&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>*</sup>Means with the same letter within the column are not significantly different
Figure 3.4 Observed soil bulk density by depth for the first analysis (ii): reference to the surface elevation of the subsoiling treatments in 2017
**Crop Yield**

The Controls had the highest observed soybean yield values of 4.30 and 4.16 MT/ha (~63.8 and 61.8 bu/ac) in CN and CS, respectively. The lowest yield was 2.77 MT/ha (~41.2 bu/ac) in Z2_30. Table 3.5 lists the LSMs yield of each treatment within each zone. Figure 3.5 shows the observed means of soybean yield by subsoiling treatments within each zone.

![Figure 3.5 Observed means of soybean yield by the interactions of subsoiling and zone in 2017](image)
Table 3.5 Calculated LSMs of soybean yield by the interaction of subsoiling and zone in 2017

<table>
<thead>
<tr>
<th>Zone</th>
<th>Subsoil</th>
<th>Yield MT/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z1</td>
<td>30</td>
<td>2.97&lt;sup&gt;CD&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>45</td>
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<td>Z2</td>
<td>30</td>
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<td>45</td>
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</tr>
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<td>CN</td>
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<td>4.30&lt;sup&gt;A&lt;/sup&gt;</td>
</tr>
<tr>
<td>CS</td>
<td>45</td>
<td>4.16&lt;sup&gt;AB&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Means with the same letter are not significantly different

Overall, the ROW yields were significantly lower than those of the Controls. The ROW zones also differed significantly from each other. The interaction between Zones and Subsoiling treatment was not found to be significant.

Fall 2018

The rainfall amount over the entire growing season was relatively high compared to the 30-year average, indicating a wet year.

**Crop Yield**

CN had the highest yield values of 14.95 and 15.49 MT/ha (~238.0 and 246.3 bu/ac) in CT and NT, respectively. The lowest yields were 11.46 and 11.95 MT/ha (~182.4 and 190.3 bu/ac) in Z2_45 for CT and NT, respectively. Table 3.6 displays the calculated LSMs of corn yield for each interactive treatment (subsoil x tillage) within each zone. Figures 3.6 and 3.7 shows the observed means of corn yield by subsoiling treatment within each zone for CT and NT.
Table 3.6 Calculated LSMs of corn yield by the interactions of subsoiling treatments, and zone and group by tillage treatment in 2018

<table>
<thead>
<tr>
<th>Zone</th>
<th>Subsoil</th>
<th>Yield MT/ha</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CT</td>
<td>NT</td>
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<td>13.04&lt;sup&gt;ABC&lt;/sup&gt;</td>
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<td>Z2</td>
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<td>CN</td>
<td>30</td>
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<td>13.76&lt;sub&gt;b&lt;/sub&gt;</td>
<td></td>
</tr>
</tbody>
</table>

*Means with the same letter within the column are not significantly different

Overall, the ROW yields were again significantly lower than the controls with no significant interaction effects from the subsoiling. Significance was observed between the two unaffected areas in the NT. It is unknown why the controls were statistically different than each other in the NT. Potentially, above average precipitation causes field conditions to be constantly wet and differences in landscape could be answers. CN is on top of the hill—giving it the advantage of a higher elevation and more gravimetric potential for runoff and drainage. CS is at the bottom of the hill—giving it the disadvantage of holding the excess water from runoff and not able to drain as quickly.

No significant differences were found in the subsoiling in either CT nor NT. Z2 produced the lowest yields in both tillage systems, while CN had the highest yield values.
Figure 3.6 Observed means of corn yield by the interactions of subsoiling treatments, and zone for CT in 2018

Figure 3.7 Observed means of corn yield by the interactions of subsoiling treatments and zone for NT in 2018
Discussion

Bulk Density

Both years showed a significantly higher soil bulk density within the ROW compared to the unaffected areas. However, an observation of a major shift in the controls’ bulk density throughout the soil profile was made from 2016 to 2017 (see Figure 3.8). Ultimately because of this observation, a model to analyze the differences from 2016 and 2017 was opted not to be developed. Instead, a visual assessment of the findings will be discussed. Only the soil profiles referenced to the elevation surface of the subsoil treatment will be examined in Z1 and Z2. Z3 will also look at the soil profile referenced to the elevation surface of the control since the subsoiling treatment was applied as well.

![Soil Bulk Density by Depth](image)

Figure 3.8 Soil bulk density by depth of the controls for comparison of 2016 and 2017
The bulk density within the ROW in the subsoiling treatments showed little to no difference from 2016 to 2017. Figure 3.9(a) shows the average Z1 and Z2. First, you will notice that overall the bulk densities in both zones in 2017 were slightly lower in comparison to 2016. Z1 does not show major changes in the bulk density until roughly 80 cm, and Z2 shows no major changes throughout. This gives the impression that the subsoiling treatment did successfully alleviate the compaction in Z1 and did not make a huge difference in Z2.

Figure 3.9 Soil bulk densities of (a) Z1 and Z2 2017 averages compared to Z1 and Z2 2016, (b) Z1 2017 subsoiling treatments compared to Z1 2016, and (c) Z2 2017 subsoiling treatments compared to Z1 2016
However, looking at Figure 3.9(b), it is observed that 45 cm subsoiling did not have an effect on compaction in Z1, yet 30 cm subsoiling did. This does not make sense, since the 30 cm subsoiling treatment would not have been applied below 80 cm. As mentioned before, the presence of sand could explain the drastic differences in Z1. Figure 3.9(c) shows minimal changes in bulk density for both subsoiling treatments in Z2.

Figure 3.10 shows the bulk density for Z3 in 2017 slightly lower than in 2016. The most noticeable difference is that the top 15 to 20 cm shows an inverse change. In 2016, the bulk density started high and then became lower with depth (until a certain point), unlike the other ROW zones. In 2017, the bulk density in Z3 behaved more like that of the other zones (ROW and Controls) in that it started lower and progressively increased with depth. A potential reason the data in 2016 started high and decreased with depth was that Z3 was heavily compacted from high axle loads. The samples were taken near the end of completion of the installation, and had many passes of heavy loaded traffic driving over it. A detailed analysis of the vertical soil stresses from the vehicle’s and heavy equipment’s applied loads was reported in Tekeste et al. (2019). No major differences in the subsoiling treatments imply that subsoiling depth in Z3 did not matter, and the average can be used as the comparative value. Overall, the bulk density in Z3 from 2017 is lower in comparison to the data collected in 2016. However, there was no indication that the subsoiling treatment was the cause. Recall that during construction Z3 had a berm (refer to Figure 2.2 on page 12) of roughly 50 cm that the heavy equipment operated on.
Figure 3.10 Soil bulk density of Z3 by depth for 2016 and 2017 (average and subsoiling treatments)

An interesting feature of Figure 3.10 involves the data in soil deeper than 55 cm. In theory, this should be roughly where the topsoil was not removed from in the ROW. Assuming moisture contents and field conditions did not have a significant impact on the data, the bulk densities below 55 cm were similar in 2016 and 2017. This implied that subsoil compaction was still persistent, regardless of having less topsoil removed. Also, recall that the bulk density of Z3 in reference to the surface elevation of the control showed no statistical differences at depths
below 50 cm in comparison to the other two zones in the ROW. Therefore, it can be inferred that subsoil compaction is present in these three ROW zones.

**Crop Yield**

Overall, the crop yield from each year was significantly lower in the ROW than in the Controls. Recall that the interaction between zone and subsoiling treatment was not significant in either year. However, in 2017 the 45 cm subsoiling in the ROW gave slightly higher yields than the 30 cm subsoiling, within each zone. Yet in 2018, the crops in the 45 cm subsoiling responded with lower yields in comparison to the 30 cm subsoiling—giving contradicting results. Therefore, two years of crop yield data did not answer whether or not subsoiling depth was critical for remediation purposes.

In 2018, the crop yield responded to the NT better than the CT. However, tillage was applied perpendicularly to the plots, therefore running up and down the hill, but the seeds were still planted parallel. A day after planting, a large rain occurred, and erosion was noticeable in the CT plots and not in the NT plots as shown in Figure 3.11 Later in the growing season, a large spot in one of the CT plots had no corn growing. These two observations suggested that the seeds planted in the CT plots were washed out by the runoff produced from the rainfall event. In addition to these observations, an intensive literature review on tillage effects on corn and soybean yield conducted by DeFlice et al (2014) observed that no-till yield improved after several years of continuous practice. DeFlice (2014) also stated “experiments conducted for a short number of years (less than 4 or 5) without prior years of NT in the NT plots probably do not provide a completely fair comparison to CT because the NT soils have not had time to stabilize.” Therefore, a single year of CT and NT crop yield data might not be reliable.
Figure 3.11 Evidence of runoff erosion from large rainstorm right after planting

**Normalized yield**

Differing crops from each year prevent building a model to analyze the yield data by year, in its current form. However, yields of different crops can be compared by the method of normalized yield. The treatment yields were normalized to the Controls in the experiment site. CT will only be discussed because of NT practices being established in less than a year of data collection.
Overall, yield values increased from 2017 to 2018 for the whole experiment. The highest yield increase occurred with 30 cm subsoiling in Z1 (+20.0%), and the only decrease in yield was the 45-cm subsoiling in Z1 (-3.2%). Z2 and Z3 showed a similar trend, the 30 cm subsoiling increased yield at least 3.9% more than the 45 cm subsoiling. Table 3.7 shows the average normalized yields for each year, average of the years, difference between the average of the years, and the difference between each year with respect to the controls’ maximum average. The color scales help to illustrate the differences in yield for each column. Red suggests the most unfavorable response in the column, whereas green indicates a positive response. Note color scales are to aid in understanding the differences between zones and subsoiling treatments within each designated column, not overall (matrix).

Table 3.7 Normalized yields compared to the maximum average of the controls

<table>
<thead>
<tr>
<th>ZONE/SUBSOIL</th>
<th>Normalized Yield (Control)</th>
<th>Yield Deficit Compared to Maximum Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone Subsoil</td>
<td>2017 2018 Average of years Difference between years</td>
<td>2017 2018 Average</td>
</tr>
<tr>
<td>1 A</td>
<td>69.2% 87.3% 78.2% 18.1% -30.8% -12.7% -21.8%</td>
<td></td>
</tr>
<tr>
<td>1 B</td>
<td>84.5% 79.9% 82.2% -4.6% -15.5% -20.1% -17.8%</td>
<td></td>
</tr>
<tr>
<td>2 A</td>
<td>64.5% 77.3% 70.9% 12.9% -35.5% -22.7% -29.1%</td>
<td></td>
</tr>
<tr>
<td>2 B</td>
<td>73.3% 76.7% 75.0% 3.4% -26.7% -23.3% -25.0%</td>
<td></td>
</tr>
<tr>
<td>3 A</td>
<td>71.2% 79.9% 75.6% 8.7% -28.8% -20.1% -24.4%</td>
<td></td>
</tr>
<tr>
<td>3 B</td>
<td>75.0% 79.9% 77.4% 4.9% -25.0% -20.1% -22.6%</td>
<td></td>
</tr>
<tr>
<td>CN A</td>
<td>100.0% 100.0% 100.0% 0.0% 0.0% 0.0% 0.0%</td>
<td></td>
</tr>
<tr>
<td>CS B</td>
<td>96.8% 93.3% 95.0% -3.4% -3.2% -6.7% -5.0%</td>
<td></td>
</tr>
</tbody>
</table>

The percentages above suggested that Z2 had the greatest yield deficits, and Z1 recovered the best, regardless of subsoiling treatment. Figures 3.12 and 3.13 illustrate Table 3.7 further.
Figure 3.12 Normalized yield organized by years

Figure 3.13 Normalized yield organized by treatment and zones
CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

The first three years of this study indicated differences in soil compaction and crop yield within the construction ROW zones and the adjacent unaffected zones. Overall, the soil compaction in the ROW has been reported as greater than the two adjacent unaffected areas, regardless of the subsoiling remediation practices. Crop yields in the last two years showed a decrease in yields for both soybean and corn, and minimal recovery was observed from the crop yield data from 2017 to 2018.

The investigations of soil compaction remediation and crop yield responses to the subsoiling treatments reported similar results after analysis:

- The subsoiling treatment depth did not show a significant difference in soil compaction remediation or crop yield responses in comparison to each other within the designated ROW zones.

- Also, the subsoiling treatments did not prove to be a significant remediation practice to alleviate subsoil compaction, nor did crop yield responses show significant differences in the three zones across the ROW.

- Additionally, soil bulk density and crop yield responses in the ROW zones showed that subsoil remediation practices were still not enough to restore the subsoil to similar unaffected conditions.

Similarly, crop yield responses were affected by the soil disturbance from pipeline installation and showed significantly lower values in the ROW zones compared to the adjacent unaffected areas. However, crop yield responses compared between the three ROW zones were not observed to be significantly different from each other.
Although differences have been noticed between the ROW zones and unaffected areas, these results are inconclusive. The subsoil at this site has only gone through two years of crop rotation and freeze-thaw cycles—which could aid in compaction remediation. However, differences in crop yield could also be due the landscape of experiment site, other biological and chemical soil factors, or weather variability.

Future work on this study and others alike, should include a closer look at management practices used during installation similar to that in Z3. In theory, removing less topsoil from the construction easement could be a preventative practice to keep subsoil compaction low. However, the subsoil bulk density of Z3 was observed to be just as high (if not higher in the preceding year) as the heavily trafficked Z2 in 2016 and layers four, five, and six in 2017. This brings up the question: can removing less topsoil protect the subsoil from additional compaction, or would this cause too much damage to the topsoil? Additionally, a long-term study on how the recovery of the topsoil’s structure would be of interest: how long does it take the disturbed 50 cm of topsoil to become and/or return to a soil structure prior to soil disturbance of pipeline installation? Or, would removing less topsoil (similar to Z3 in this study) help the recovery of the topsoil’s structure?

As a future soil management practice to restore the soil productivity, it will be worthy to investigate the effects of deep-rooted cover crops in addition to the deep tillage remediation practices. A future study as stated can help to investigate the potential benefits of cover crops to improve longer-term soil quality attributes, for instance to increase soil organic matter, to potentially reduce soil compaction with deep-rooted cover crops, and accelerate crop recovery over time in the pipeline construction sites.
REFERENCES


APPENDIX A. WEB SOIL SURVEY DEFINITIONS

Soil Susceptibility to Compaction:

Soils are rated based on their susceptibility to compaction from the operation of ground-based equipment for planting, harvesting, and site preparation activities when soils are moist. Soil compaction is the process in which soil particles are pressed together more closely that in the original state. Typically, the soil must be moist to be compacted because the mineral grains must slide together.

Interpretation ratings are based on soil properties in the upper 30 cm (12 in) of the profile. Factors considered are soil texture, soil organic matter content, soil structure, rock fragment content, and the existing bulk density. Each of these is thought to contribute to resisting the susceptibility of a soil to compaction when present. Organic matter in the soil provides resistance to compaction and the resilience to ameliorate the effects with time. Soil structure adds strength as discrete aggregates, and it is the aggregates that are deformed or destroyed by compactive forces. Thus, strong soil structure lowers the susceptibility to compaction. Similarly, rock fragments in the soil can bridge and provide a framework to resist compaction. Finally, if a soil is already fairly dense causing further compaction is more difficult.

Definitions of the ratings:

Low - The potential for compaction is insignificant. This soil is able to support standard equipment with minimal compaction. The soil is moisture insensitive, exhibiting only small changes in density with changing moisture content.
Medium - The potential for compaction is significant. The growth rate of seedlings may be reduced following compaction. After the initial compaction (i.e., the first equipment pass), this soil is able to support standard equipment with only minimal increases in soil density. The soil is intermediate between moisture insensitive and moisture sensitive.

High - The potential for compaction is significant. The growth rate of seedlings will be reduced following compaction. After initial compaction, this soil is still able to support standard equipment, but will continue to compact with each subsequent pass. The soil is moisture sensitive, exhibiting large changes in density with changing moisture content.

CSR2 Rating:

This attribute is only applicable to soils in the state of Iowa. Corn suitability ratings (CSR2) provide a relative ranking of all soils mapped in the State of Iowa according to their potential for the intensive production of row crops. The CSR2 is an index that can be used to rate the potential yield of one soil against that of another over a period of time. Considered in the ratings are average weather conditions and frequency of use of the soil for row crops. Ratings range from 100 for soils that have no physical limitations, occur on minimal slopes, and can be continuously row cropped to as low as 5 for soils that are severely limited for the production of row crops.

When the soils are rated, the following assumptions are made: a) adequate management, b) natural weather conditions (no irrigation), c) artificial drainage
where required, d) no frequent flooding on the lower lying soils, and e) no land leveling or terracing. The weighted CSR2 for a given field can be modified by the occurrence of sandy spots, local deposits, rock and gravel outcrops, field boundaries, and non-crossable drainage-ways. Even though predicted average yields will change with time, the CSR2 values are expected to remain relatively constant in relation to one another over time.

Map Unit:

A soil map unit is a collection of soil areas or non-soil areas (miscellaneous areas) delineated in a soil survey. Each map unit is given a name that uniquely identifies the unit in a particular soil survey area.

Reference

APPENDIX B. CONSTRUCTION EQUIPMENT PICTURES

Figure B.1 CAT 349F excavator used for pipeline installation and trench excavation and backfilling

Figure B.2 CAT D7E LGP dozer used for topsoil removal
Figure B.3 CAT D8T S dozer used for topsoil removal

Figure B.4 CAT PL87 pipe layer used for pipeline installation
Figure B.5 Pipe bender used on site

Figure B.6 Semi-trailer truck used for transportation of pipes
Figure B.7 CAT 349F excavator used to restore topsoil in ROW

Figure B.8 CAT D6T LGP S dozer used to restore topsoil in ROW
Figure B.9 CAT D7E LGP dozer used to restore topsoil in ROW

Figure B.10 Deere 350G LC excavator used to restore topsoil in ROW

Reference

APPENDIX C.   FARM MACHINERY AND EQUIPMENT FIGURES

Figure C.1 Example of a Case Tigermate II field cultivator used in pre-pipeline installation farm management practices

Figure C.2 Example of a John Deere 2230 field cultivator used in pre-pipeline installation field management practices
Figure C.3 Example of a John Deere 8R series tractor used in field operations

References


APPENDIX D. WEATHER DATA

Weather data obtained from the National Weather Service [NWS] Cooperative Observer Program [COOP] on the Iowa Environmental Mesonet [IEM] website. Station IA0200 AMES-8-WSW was used due to its proximity to the test site.

Construction Activity Data

Construction beginning and end months were used for the construction activity data in Table D.1 and Figure D.1, and yearly and monthly precipitation totals (cm) were used for the 30 year averages in Table D.1 and Figure D.1.

Table D.1 Total precipitation per month in cm for the duration of the construction

<table>
<thead>
<tr>
<th>Month</th>
<th>Construction Months [2016]</th>
<th>30 Year Avg [1988-2018]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUG</td>
<td>1.3</td>
<td>12.5</td>
</tr>
<tr>
<td>SEP</td>
<td>20.1</td>
<td>8.6</td>
</tr>
<tr>
<td>OCT</td>
<td>1.5</td>
<td>6.3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>22.9</td>
<td>27.4</td>
</tr>
</tbody>
</table>

Figure D.1 Total precipitation per month in cm for the duration of the construction
Growing Season Data

Exact planting and harvest dates were used for the growing seasons data in Tables D.2 and D.3 and Figure D.2 <https://mesonet.agron.iastate.edu/request/coop/fe.phtml>, and yearly and monthly precipitation totals (cm) were used for the 30 year averages in Table D.2 and Figure D.2 <https://mesonet.agron.iastate.edu/climodat/>.

Table D.2 Total precipitation per month in cm for the growing seasons and the 30 year average precipitation per month in cm

<table>
<thead>
<tr>
<th>Month</th>
<th>2017</th>
<th>2018</th>
<th>30 Year Avg [1988-2018]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAY</td>
<td>0.0</td>
<td>10.1</td>
<td>12.3</td>
</tr>
<tr>
<td>JUN</td>
<td>4.4</td>
<td>28.2</td>
<td>12.7</td>
</tr>
<tr>
<td>JUL</td>
<td>2.5</td>
<td>10.7</td>
<td>11.6</td>
</tr>
<tr>
<td>AUG</td>
<td>8.5</td>
<td>21.4</td>
<td>12.5</td>
</tr>
<tr>
<td>SEP</td>
<td>4.6</td>
<td>17.2</td>
<td>8.6</td>
</tr>
<tr>
<td>OCT</td>
<td>14.9</td>
<td>12.2</td>
<td>6.3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>34.9</td>
<td>99.8</td>
<td>64.0</td>
</tr>
</tbody>
</table>

Figure D.2 Total precipitation per month in cm for the growing seasons and the 30 year average precipitation per month in cm
Table D.3 Monthly averages of Growing Degree Days, highest observed temperature, lowest observed temperature, and average observed temperature

<table>
<thead>
<tr>
<th>Month-Year</th>
<th>Growing Degree Days</th>
<th>Highest Observed Temperature [°C]</th>
<th>Lowest Observed Temperature [°C]</th>
<th>Average Observed Temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>May-17</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Jun-17</td>
<td>22.3</td>
<td>33.3</td>
<td>9.4</td>
<td>22.8</td>
</tr>
<tr>
<td>Jul-17</td>
<td>24.8</td>
<td>34.4</td>
<td>13.9</td>
<td>24.4</td>
</tr>
<tr>
<td>Aug-17</td>
<td>19.4</td>
<td>30.0</td>
<td>9.4</td>
<td>20.8</td>
</tr>
<tr>
<td>Sep-17</td>
<td>18.6</td>
<td>32.8</td>
<td>6.7</td>
<td>20.4</td>
</tr>
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<td>Oct-17</td>
<td>11.0</td>
<td>27.8</td>
<td>2.2</td>
<td>15.3</td>
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<tr>
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<td>18.4</td>
<td>36.1</td>
<td>7.2</td>
<td>20.6</td>
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<td>Jun-18</td>
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<td>33.9</td>
<td>11.7</td>
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<td>23.6</td>
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<td>12.2</td>
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<td>11.7</td>
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<td>32.8</td>
<td>4.4</td>
<td>19.8</td>
</tr>
<tr>
<td>Oct-18</td>
<td>6.1</td>
<td>30.0</td>
<td>-3.3</td>
<td>10.5</td>
</tr>
</tbody>
</table>

Reference