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Impact of soil compaction due to wheel traffic on corn and soybean growth, development and yield

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ABSTRACT

As the size and weight of agricultural equipment have increased significantly in the past few decades, the severity and depth of compacted zone may have increased proportionately. Past research indicates that soil compaction affects crop growth and grain yield. Very few studies have been conducted in North Dakota (ND) to understand soil compaction under the current machinery, and its effect on crop growth and yield. The research was conducted on a no-till crop field at Jamestown, ND, USA for 2013 (corn) and 2014 (soybean) growing season. The objective of this study was to evaluate the effect of wheel traffic on soil strength indices and its impact on crop emergence, development and yield. The study also evaluated the effect of winter freezing-thawing cycle on soil compaction in the study field. The experiment consisted of five soil transects and two traffic conditions based on machinery traffic in the field for both years such as most trafficked (MT) rows and least trafficked (LT) rows, laid out in a randomized complete block design with three replicates in strip-plot with space for corn season in 2013, and for soybean season in 2014. Data collected included soil resistance or cone index (CI), soil bulk density, soil moisture content, plant emergence, plant height and grain yield. The results showed that CI values followed a similar pattern for different soil transects up to 37.5 cm depth and then increased sharply. An average CI of 1.19 MPa was noted over the whole profile at 0–45 cm depth for the study area and not significantly different between MT and LT rows for both years. Moderate compaction resulted in early emergence of corn plants in MT rows by 175% compared to LT rows. The plant height didn't show any significant difference between MT and LT rows for both years. The yield data showed significant difference between the soil transects, but no difference was observed between MT and LT rows in both 2013 and 2014 season. The interactions between soil transects and traffic conditions were not significantly different for all soil and plant related dependent variables. The freeze-thaw cycle occurred during winter from 2013 to 2014 and 2014 to 2015 alleviated soil resistance over the whole soil profile at 0–45 cm depth. Results show that different crops grown in a no till field are not very much influenced by wheel traffic. The study also suggests that moderate compaction occurred after harvest in a no till field could be alleviated by the effect of freeze thaw cycle.

1. Introduction and background

Soil compaction is considered as an important concern in modern agriculture due to increase in size and weight of the machinery routinely used for agricultural practices. Most of the large parts of equipment used in agriculture today, due to their size and weight, have the potential to compact soil at deeper layers (personal communications with Jody DeJong Hughes, University of Minnesota). Several years ago, compaction would have been relatively shallow because farm equipment weighed less and many cover crops were grown in rotation (DeJong-Hughes et al., 2001). The heavier equipment used today for different agricultural practices have the potential to increase the severity of compaction problems.

Some of the indicators of soil compaction include soil strength, cone index (CI), bulk density, porosity, moisture content, plant growth, development and yield (Batey, 2009; Hamza and Anderson, 2005). Soil compaction has a negative impact on crop growth and water flow (Lowery and Schuler, 1991; crop yield (Perumpral, 1987; Wells et al., 2005) and root growth, development and distribution (Taylor and Gardener, 1963; Unger and Kaspar, 1994). The measurement of soil

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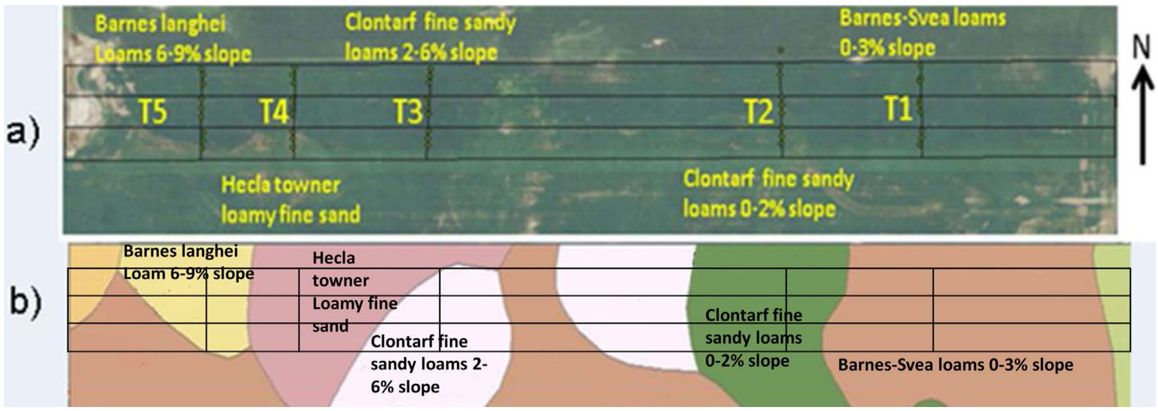

Fig. 1. Layout of a) study plots and b) soil map overlaid on an aerial image. The strip plots run along the length of the field, along with the five transects identified for data collection.

compaction is usually performed using a cone penetrometer through CI readings which is a measure of soil resistance and the degree of compaction. The CI values greater than 2 MPa could correspond to soil conditions and could limit root growth and plant development (Hamza and Anderson, 2005; Murdock et al., 1995; Taylor and Gardner, 1963). The moisture content and bulk density are most important soil parameters affecting soil resistance (Ayers and Perumpral, 1981). Fulton et al. (1996) assessed spatial variability of CI and bulk density in a silt loam soil and found very little correlation between bulk density and CI at high soil moisture content.

The prime concern about soil compaction to the farmers is its impact on crop yields. Crop yield losses due to compaction have been well documented for different crops. Soil compaction can reduce corn yield significantly (Bicki and Siemens, 1991; Lowery and Schuler, 1994; Ngunjiri and Siemens, 1995). The corn yield reduction due to severe and moderate compaction was approximately 50 and 25% respectively (Gaultney et al., 1982). However, a study by Gelder et al. (2007) analyzing soil compaction by wheel traffic on Clarion-Nicollet-Webster soil showed that compaction had no effect on corn yield, and plant emergence. Similar studies for soybean crop showed a yield reduction of 250–450 kg ha^{-1} under light to heavy equipment traffic (Botta et al., 2010). The weather also has an impact on soil compaction and crop yield. Raghavan et al. (1979) stated that corn yield reduced up to 50% in a wet year due to vehicle traffic whereas in a typical dry year, the losses amounted up to 30%. Significant crop yield differences between different compaction treatments have been studied for various crops. Deep tillage resulted an increased in soybean yields in non-trafficked areas by 3–6.9% in 1991 and 1.5–3.0% in corn yields in 1992 (Reeder et al., 1993). Tolon-Becerra et al. (2011) analyzed the effect of three different tillage regimes (direct sowing, chisel plough and moldboard plough) on soil compaction and for corn yield and stated that yield decreased by about 15% with high soil compaction level in direct sowing tillage system compared to the other two tillage systems.

The annual freeze-thaw cycle over winter is one of the processes affecting soil compaction and can alter the physical properties of soil and its structure. The freeze-thaw cycle can naturally alleviate compaction due to expansion of water in the pore space and contraction during freezing and thawing. Jabro et al. (2014) testified that freeze-thaw cycle alleviated soil compaction up to a depth of 30 cm in a clay loam soil in Montana. The top soils (5–12 cm) practice experience more than one freeze-thaw cycle per year. Henry (2007) and Unger (1991) witnessed soil penetration resistance and bulk density reduction in agricultural soils during winter because of frequent freeze-thaw cycles. Several studies have indicated that repeated freeze-thaw cycle loosens soil structure, alleviate soil compaction, and improve soil aggregation, physical and hydraulic properties of soil (Edwards, 2013; Fouli et al., 2013; Sahin et al., 2008). The farm equipment used today have the potential to compact soil down to 120 cm (personal communications with Jody DeJong Hughes, University of Minnesota). Soil compaction was not alleviated at the bottom of the plow furrow in Nicollet silty clay loam soil in Minnesota by the annual freeze-thaw cycle (Voorhees, 1983). Most regions in ND experienced an average air temperature below freezing and the soil freezes to depths greater than 1 m. Not many studies have been done to evaluate the effect of freeze-thaw cycle on soil compaction in this region.

In the last few years in ND, the crop acreages have been expanding at a fast rate due to higher crop commodity prices, short season varieties available, and the slightly longer crop season in ND in recent years due to change in climate. Therefore, knowing the potential problems involved in corn and soybean cultivation and finding ways to improve the production would certainly benefit the growers and crop consultants. Soil compaction is one of the growing concerns in agricultural fields in ND today and so far, very few studies have been conducted in ND to understand soil compaction under the current machinery, and its effect on crop growth and yield. Based on the above discussion, the objectives of this study were: a) to evaluate the impact of heavy machinery traffic on soil resistance indices such as CI, depth of maximum CI and average CI at whole investigated soil depth (0–45 cm) in MT rows and LT rows with respect to machinery passes pattern in the field; b) to evaluate the effect of machine traffic on corn and soybean growth, development and yield in MT and LT rows; c) to evaluate the effect of winter freeze-thaw cycle on soil resistance indices.

2. Materials and methods

2.1. Description of the study area

The study was conducted in a no-till commercial crop field at Jamestown in ND in 2013 and 2014 crop seasons. The field was planted with corn in 2013 and soybean in 2014 growing seasons. The study area of the field included 12 ha, and was divided into three strip plots running the entire length of the field along the direction of the rows (Fig. 1). According to Soil Survey Division (2014), five soil transects were identified for data collection based on different soil series and the difference between slopes in the similar soil series in the study area. The five soil transects covered in the study area were namely: Barnes-Svea loams (0–3% slope) (T1), Clontarf fine sandy loam (0–2% slope) (T2), Clontarf fine sandy loam (2–6% slope) (T3), Hecla Towner loamy fine sands (T4) and Barnes Langhei loams (6–9% slope) (T5). The soil transects T1 and T5 consisted of loamy soils, T2 and T3 with fine sandy loam soils and T4 predominantly composed of fine sands. The study area varied in elevations ranging from 461 m to 464 m. The study area has a humid continental climate and the annual growing season is from April 1 to September 30 with an average maximum and minimum temperature of 20° C and 10° C respectively. The year 2014 was cooler and wetter than 2013 season with most of the rain falling in May and