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Corn stover harvest changes soil hydrology and soil aggregation

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ABSTRACT

In the United States, commercial-scale cellulosic-ethanol production using corn (*Zea mays* L.) stover has become a reality. As the industry matures and demand for stover increases, it is important to determine the amount of biomass that can be sustainably harvested while safe-guarding soil quality and productivity. Specific study objectives were to measure indices of soil hydrological and aggregate stability responses to harvesting stover; since stover harvest may negatively impact soil hydrological and physical properties. Responses may differ with tillage management; thus, this paper reports on two independent studies on a tilled (Chisel field) and untilled field (NT1995 field). Each field was managed in a corn/soybean (*Glycine max* [Merr.]) rotation and with two rates of stover return: (1) all returned (Full Return Rate) and (2) an aggressive residue harvest leaving little stover behind (Low Return Rate). Unconfined field soil hydraulic properties and soil aggregate properties were determined. Hydrological response to residue treatments in the Chisel field resulted in low water infiltration for both rates of residue removal. In NT1995 field, Full Return Rate had greater capacity to transmit water via conductive pathways, which were compromised in Low Return Rate. Collectively, indices of soil aggregation in both experiments provided evidence that the aggregates were less stable, resulting in a shift toward more small aggregates at the expense of larger aggregates when stover is not returned to the soil. In both fields, aggressive stover harvest degraded soil physical and hydrological properties. No tillage management did not protect soil in absence of adequate residue.

1. Introduction

In the United States corn (*Zea mays* L.) stover is the most abundant crop residue. Historically, unless harvested as animal feed or bedding, crop residues were returned to the land (Johnson et al., 2006). On the land, crop residues provide surface cover, raw materials for building soil organic matter, and contribute directly and indirectly to aggregate formation (Blanco-Canqui et al., 2007; Pikul et al., 2009; Six et al., 2000), which in turn may interact with soil hydrological properties (Benjamin et al., 2008; Rawls et al., 2004) and other soil properties (e.g., Benjamin and Karlen, 2014; Blanco-Canqui and Lal, 2009; Johnson et al., 2011; Lal and Stewart, 2010). In 2014, commercial cellulosic-ethanol production became a reality (http://poet.com/pr/first-commercial-scale-cellulosic-plant), which at least locally will increase the demand for cellulosic feedstocks and may result in potential environmental risk and soil degradation unless carefully managed to avoid over-harvesting (Archer and Johnson, 2012). Negative impacts on soil properties will impede society's ability to meet the expanding global demand for food, feed, fiber and fuel (Andreev et al., 2013).

As demand for stover or other crop residue increases to meet emerging (i.e., energy) and historical (animal bedding or other uses) needs, it becomes increasingly critical to have a clear understanding of how reducing the rate of crop residues remaining in the field impacts soil properties. Management without tillage and aggressive stover harvest reduced particulate organic matter, increased the erodible-sized dry aggregates, and left the soil surface exposed to erosive forces compared to returning all stover (Johnson et al., 2013). Harvesting stover can impact soil hydrological properties negatively because of changes in physical characteristics, such as reduced porosity and aggregation (Blanco-Canqui and Lal, 2009; Cibin et al., 2012; Osborne et al., 2014), and

Abbreviations: ASW, aggregates from a class-size that remain stable in water; DASD, dry aggregate size distribution; EF, erodible fraction; MWD, mean weight diameter.

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increased surface sealing or crusting (Blanco-Canqui and Lal, 2009). As reviewed by Blanco-Canqui and Lal (2009) and by Johnson et al. (2010), less stover on the soil surface can impact soil microclimate increasing soil temperature and evapotranspiration; thus, if coupled with less infiltration crop production could be adversely impacted during periods of limited rainfall.

A key factor for increasing agricultural production, related to stover harvest, is proper soil and water management (Hatfield and Sauer, 2011; Westfall et al., 2010). The process of water infiltration through surface soil under rain-fed conditions is a complex interaction among precipitation intensity, soil type, surface condition, and extent that soil is covered by crop residues (Langhans et al., 2011). Retaining corn stover or wheat straw improved water infiltration in both tilled and no-till fields (Govaerts et al., 2007), while low residue return resulted in an increased risk for run-off (Wienhold et al., 2011). Literature reviewed by Blanco-Canqui and Lal (2009) noted conflicting impacts on water filtration in response to residue cover related to interaction among tillage, soil profile characteristics, and water repellency. Conservation practices including reduced or no tillage can increase soil coverage, provided residues are not aggressively harvested (Baumhardt et al., 2012). However, conservation or no tillage practices may not avoid a loss of soil quality when stover is aggressively harvested (Stewart et al., 2015).

In the United States, national estimates of how much residue biomass may be sustainably harvested typically assumed that the land would be managed without tillage (Graham et al., 2007; Perlack et al., 2005; US DOE, 2011). In northern states such as Minnesota, no-tillage management has not been extensively adopted (Johnson et al., 2005) because of farmers' concerns regarding crop productivity. Therefore, this paper reports results from two independent studies that were established in 2005, one on a field managed with tillage (Chisel field) and a second field without tillage since 1995 (NT1995 field). The long term objective of this research is to provide producers with tools to answer the question "How much biomass can be sustainably harvested from a given field while still maintaining soil quality and productivity?" The specific objectives addressed were to measure indices of soil hydrological and aggregate stability responses to harvesting stover. Implications and importance of hydraulic and soil physical properties and their interactions in regards to water and erosion will be discussed.

2. Materials and methods

2.1. Site description and characterization

The study was conducted on two fields (Chisel and NT1995) at the Swan Lake research farm near Morris, MN (45°41′N, 95°48′W). This area is characterized by cold winters and warm summers; mean temperature in January and July, −13.1 °C and 21.7 °C, respectively, thirty year (1971–2000) mean precipitation is 645 mm (NOAA-NCDC, 2002). Soils were formed on till plains and moraines from Des Moines Lobe deposited during the Wisconsin glaciations. Based on USDA-SCS (1971) soil maps as previously described by Johnson et al. (2013), three replicates of the Chisel field were on Barnes soils (Fine-loamy, mixed, superactive, frigid Calcic Hapludoll), and the fourth replicate was on an Aastad (Fine-loamy, mixed, superactive, frigid Pachic Hapludoll). All four replicates in the NT1995 field were mapped as Barnes soil.

In 2005 similar, but independent stover harvest studies (details on harvest treatments and mechanism are described in Section 2.2) were established on adjacent fields (∼0.5 ha). These fields differed in tillage management and are referred to as Chisel and NT1995 fields (Johnson et al., 2013). For at least 10 years prior to establishment, both experimental fields had been planted to continuous corn or a corn/soybean rotation. Every year and field, both crop phases of the corn/soybean rotations were present such that each field had two crops, four harvest treatments, and four replications for a total of 32 (6 m × 15 m) plots. Within each experiment, replicates were arranged in a randomized complete block design. Those plots planted to corn in 2005 were subjected to stover return treatment in odd-years, with the balance having stover harvested during the corn phase in the even-numbered years. Therefore, in 2012 when these soil hydrological measurements were made, those in corn during odd-numbered years had been subjected to four stover-harvest cycles, while those in corn during even-numbered years had three stover-harvested cycles.

2.1.1. Chisel field

Beginning in the fall of 2005 the Chisel field was managed with annual autumn chisel plowing (≈20 cm) and one or two disk passes (≤15 cm) in the spring to prepare the seedbed (Johnson et al., 2013). Prior to 2005, the field was managed with annual autumn inversion tillage using a moldboard plow.

2.1.2. NT1995 field

As the name NT1995 implies this field has been managed without tillage since 1995, providing a site to study the effect of stover harvest rate in an established no-till field. This is useful because the "Billion Ton Report" based harvest rates on the assumption that fields would be managed without tillage (Perlack et al., 2005). Since 2005, disturbance has been limited to knife injected fertilizer (∼6 cm).

2.2. Corn stover harvest rate treatments

Both the Chisel and the NT1995 fields had similar corn stover treatments initiated in the fall of 2005, as described by Johnson et al. (2013). Only data from plots representing the two harvest extremes will be presented: the control in which only corn grain was harvested and all the corn stover was returned >7 Mg ha^{-1} (Full Return Rate) and an aggressive harvest resulting in <2 Mg ha^{-1} (Low Return Rate) stover left in the field. Return rate was determined by collecting corn stover remaining after harvest in a known area. From 2005 to 2008, in the Low Return Rate treatment stover was removed using a single-row flail-knife forage harvester cutting as close to the soil surface as possible. Since 2009 when a one-pass combine designed to improve the efficiency of harvesting corn grain and material other than grain (Isaac et al., 2006) became available, it has been used for subsequent harvests. This one-pass combine returned similar amount of residue but reduced harvest time compared to the forage harvester. Total stover yield was determined from a 1.5 m^2 area at physiological maturity, and was reported as dry mass per area based on oven-dried (60 °C) to constant mass. Grain yield was based on harvest with a two-row plot scale combine, and is presented at 15.5% standard moisture.

2.3. Soil properties

2.3.1. Soil baseline parameters

In both fields, baseline (2005) soil samples were collected using a hydraulic probe to 100 cm as recommended by Liebig et al. (2010). Three soil cores were taken per plot, and were divided into six increments (0–5, 5–10, 10–20, 20–30, 30–60, and 60–100 cm). One core was used for determining soil bulk density at intervals below 10 cm. In the surface 0–5 and 5–10 cm increments, a hand-held soil probe was used to collect a sample for bulk density. Soil texture was determined using the hydrometer method (Day, 1956; Page et al., 1986). Soil pH (1:1$CaCl_2$) (Thomas, 1996), total C (LECO TRU-SPEC CN analyzer; LECO Corporation, St. Joseph, MI), and