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Corn residue, tillage, and nitrogen rate effects on soil properties

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ABSTRACT

Harvesting corn (*Zea mays* L.) residue for use as a biofuel feedstock may alter important chemical and physical properties of soils. Long-term residue removal, linked with tillage and fertilizer practices, could lower soil organic carbon (SOC), as well as increase soil compaction and susceptibility to erosion. A study initiated in 2006 included three levels of residue removal (none, partial, or full removal), two tillage treatments (no-till or chisel plow), and two N application rates (134 and 268 kg N/ha). These experiments were established in continuous corn (CC) at four Illinois sites, with treatments remaining in the same plots each year. In the spring at the beginning of the eighth growing season, we measured total carbon stocks (SOC), water aggregate stability (WAS), soil bulk density (BD), and penetration resistance (PR). Results showed that with all crop residue retained in the field, SOC stocks 13% lower under chisel tillage than in no-tilled plots, but removal of some or all of the residue lowered the SOC levels of no-tilled plots to those of tilled plots. On average for the studied depths, no-till plots had 5% and 39% higher BD and PR, respectively, than tilled plots, and residue removal significantly increased PR under no-till. Regardless of tillage treatment, the highest WAS values were found without residue removal at the lower N rate and with partial removal at the higher N rate. The higher N rate slightly lowered the BD under partial removal of residue for both tillage treatments at both studied depths. Our results indicate that residue harvest generates modest changes in soil properties under continuous corn, likely smaller than the effects of tillage and N fertilizer use in these systems. But as long as residue amount and tillage practices are sufficient to limit losses of soil by erosion to acceptable levels, we believe that corn residue represents a viable feedstock for a sustainable bioenergy industry in the U.S. Midwest.

1. Introduction

With growing interest in biofuel alternatives to petroleum, corn residue has become a leading candidate feedstock for lignocellulosic ethanol production. The United States Department of Energy (DOE) considers residue—the above-ground stalks, leaves, and vegetative residues that remain after grain harvest—a feasible option because of its wide availability and low cost (Perlack et al., 2011). In the United States, farmers planted 38.6 million hectares of corn in 2013; estimates of annually harvestable residue range from 58.3 million to 100 million metric tons (USDA-NASS 2013; Graham et al., 2007; Gallagher and Baumes, 2012). While few lignocellulosic ethanol refineries have begun operations in the Midwest with corn residue as the sole feedstock, the scale of residue harvest could increase in the region as refineries attempt to meet federal mandates for production, currently set to reach 61 billion liters by 2022 (Energy Independence and Security Act, 2007).

The commercial use of residue may provide supplemental income from the sale of baled residue, reduced incidence of corn diseases, and better seed placement and germination in fields where corn residue is removed. Pathogens that cause stalk rot and leaf blights overwinter on corn refuse, so clearing a field of residue can help reduce the incidence of disease the following season (White, 1999). Corn residue may also have an autotoxic effect on seedlings that slows development (Singh et al., 2010). Furthermore, cooler soil temperatures persist in the spring for longer periods of time under residue cover, and with warmer soils, corn seedlings may grow faster in soils without residue cover (Swan et al., 1987).

Despite the agronomic benefits of removing residue, the long-term sustainability of residue harvest is unclear. Over 13 years of continuous corn, SOC remained unchanged under residue harvest in no-till plots, but increased by 14% when residue was returned to

Abbreviations: PR, penetration resistance; BD, bulk density; WAS, water aggregate stability; SOCs, soil organic carbon stocks; SOCc, soil organic carbon concentration.

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no-till plots (Clapp et al., 2000). Using the natural abundance of the ^{13}C isotope, these researchers also reported that the average half-life of relic SOC was 122 years in plots where residue remained and high N rates (200 kg N/ha) were used; this half-life was lowered to 71 years in the absence of N fertilizer, and was further lowered, to 49 years, by the combination of residue harvest and no N added. In contrast, several studies have shown that N fertilizer and residue harvest had no effect on SOC within the same tillage treatment (Reicosky et al., 2002; Wilts et al., 2004; Hooker et al., 2005) yet no-till plots had more SOC stock compared to tilled plots with no residue harvest (Hooker et al., 2005).

Tillage could increase the rate of residue decomposition by mechanically breaking down residues to increase the surface area of residue exposed to soil microbes and by incorporating residue into the soil where microbes and moisture are more plentiful. This might contribute to faster additions to the SOC pool, but could also disrupt soil macroaggregates that protect relic SOC, thereby increasing the loss of relic SOC (Hammerbeck et al., 2012). The conversion of virgin land to farmland has been estimated to result in the loss of 50% of the original SOC during the first 25 years of cultivation in temperate climates (Matson et al., 1997). However, after the initial conversion to farmland, SOC stocks may reach a new equilibrium and resist further decline (Buyanovsky et al., 1994; Plante and Parton, 2007). Several studies have shown tillage to have little effect on SOC, though tillage can change the distribution of SOC in the soil profile (Dolan et al., 2006; Blanco-Canqui and Lal, 2008).

Fertilizer N could affect SOC by increasing plant growth, thereby increasing the amount of biomass returned to the soil and by providing the substrate needed for microorganisms to consume materials with high C:N ratios (Gregorich et al., 1996). Several studies have reported increased SOC in continuous corn with N application rates ranging from 120 kg N/ha to 280 kg N/ha (Varvel, 1994; Studdert and Echeverria, 2000; Liebig et al., 2002; Jagadamma et al., 2008). Compared against the SOC level measured before a 13-year experiment was initiated, SOC did not decrease only under both N fertilization and residue return (Allmaras et al., 2004). There is some disagreement over the role of N fertilizers in SOC storage, as other researchers have posited that high concentrations of N could enable micro-organisms to more readily consume relic SOC (Mulvaney et al., 2009).

In addition to their role as the primary source of C inputs, crop residues and their management have significant impacts on soil physical properties including bulk density (BD), root penetration resistance (PR), and water aggregate stability (WAS). Observing lower BD under higher nitrogen fertilizer rates, Jagadamma et al. (2008) suggested that by inducing greater biomass production, which in turn increases the porosity of the soil in the root zone, N fertilizers may indirectly contribute to lowering BD. Wander and Bollero (1999) observed that BD and PR were significantly higher under no-till compared to conventional-till systems. Retention of residues generally increases the number and stability of soil aggregates which in turn promotes SOC stabilization (Buyanovsky et al., 1994; Paustian et al., 1997). In fields where a quarter or more of residue was removed, soil macroaggregates were reduced by 40% (Blanco-Canqui and Lal, 2009). Moebius-Clune et al. (2008) found that tillage had more effect than residue harvest on studied soil properties, with aggregation significantly less stable under residue harvest than under residue return in a no-till system.

Our objective of this study was to determine the effects of residue removal in combination with tillage and N rate on soil SOC stocks, WAS, BD and PR in order to identify potential impacts of long term use of these management practices on soil quality parameters that may influence future productivity.

2. Materials and methods

2.1. Field sites

Field experiments were established in the fall of 2005 following uniformly-cropped corn at four University of Illinois Crop Sciences Research Centers located near DeKalb (41°55′N, 88°45′W), Monmouth (40°54′N, 90°38′W), Perry (39°46′N, 90°44′W), and Urbana, IL (40°6′N, 88°12′W). Soil types were Flanagan silt loam (fine, smectitic, mesic Aquic Argiudolls) at DeKalb and Urbana, Muscatune silt loam (fine-silty, mixed, superactive, mesic Aquic Argiudolls) at Monmouth, and Clarksdale silt loam (fine, smectitic, mesic Udollic Endoaqualfs) at Perry. Full description of each of these soil orders can be found at the official USDA-NRCS query website (Soil Survey Staff, 2014). Briefly, all three soil series are silt loam soils with a slope of about 2%, formed in thick loess over till. Flanagan series consists of dark colored, somewhat poorly drained soils, developed in 1–1.5 m of loess over loam till under prairie vegetation. Permeability is moderate and surface runoff is slow to medium. Muscatune series consist of dark colored, very deep soils developed in loess 2–3 m thick over till under prairie vegetation. Muscatune soils are somewhat poorly drained with moderate permeability and low surface runoff potential. Clarksdale soils are very deep, somewhat poorly drained soils formed in 1–3 m loess over till under mixed prairie and forest vegetation. Mean annual precipitation ranges from 890 to 914 mm, and the mean annual temperature from 10.6 to 11.1 °C (Illinois State Water Survey, 2010).

2.2. Experimental layout and field methods

The experimental design was a split–split plot arrangement in a randomized complete block with four replications, and all treatments remained in the same place each year. Main plots consisted of one of three levels of corn residue removal (full, partial, and none) in the fall following harvest. Then, subplots were tilled with a chisel plow or similar implement or left undisturbed. In the spring, tilled plots were leveled with secondary tillage before planting, and no-till plots were slot-planted with no tillage of any kind. Rates of N fertilizer (134 and 268 kg N/ha) were assigned to sub-subplots, and applied as 28% urea-ammonium nitrate (UAN) solution either at planting or before the crop reached the 5-leaf stage. Sub-subplots were eight, 76-cm rows (6.1 m) wide by 9.1–13.1 m long, depending on location.

Residue removal and tillage treatments were implemented in the fall of 2005, and N fertilizer treatments commenced in 2006, the first year of cropping. Full removal of residue involved chopping the residue with a rotary mower at a height of 5 cm, raking the residue into windrows, which were removed. Partial removal of residue was achieved by raising the setting of the rake to a height of 7 cm and running it through unchopped residue to produce windrows about half the size of those from plots with full removal of residue; much of the residue remaining was segments of lower stalk still attached at the root. These smaller windrows were removed and the remaining residue was chopped with a rotary mower at a height of 5 cm. In plots with no residue removed, residue was chopped with a rotary mower at a height of 5 cm. The intent was to simulate full and partial removal of residue using the same methods and equipment that producers might use. Averaged across locations, years, tillage systems, and N rates it was estimated that 7.6, 4.2, and 0.8 Mg/ha of residue remained with no, partial, and full removal of residue, respectively (Coulter and Nafziger, 2008; adjusted for subsequent yields).

The chisel plow tillage system used in this study involved chisel plowing to a depth of 25 cm in the fall after residue removal, followed by field cultivating to a depth of 9 cm just before planting. Each year, corn was planted 4–5 cm deep at 81,500 seeds/ha with a