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Soil hydraulic properties influenced by corn stover removal from no-till corn in Ohio

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Abstract

Corn (*Zea mays* L.) stover removal for biofuel production and other uses may alter soil hydraulic properties, but site-specific information needed to determine the threshold levels of removal for the U.S. Corn Belt region is limited. This study quantified impacts of systematic removal of corn stover on soil hydraulic parameters after 1 year of stover management under no-till (NT) systems. These measurements were made on three soils in Ohio including Rayne silt loam (fine-loamy, mixed, active, mesic Typic Hapludult) at Coshocton, Hoytville clay loam (fine, illitic, mesic Mollic Epiaqualfs) at Hoytville, and Celina silt loam (fine, mixed, active, mesic Aquic Hapludalfs) at South Charleston. Interrelationships among soil properties and saturated hydraulic conductivity (K_{sat}) predictions were also assessed. Earthworm middens, K_{sat}, bulk density (ρ_b), soil water retention (SWR), pore-size distribution, and air permeability (k_a) were determined for six stover treatments. Stover treatments consisted of removing 0 (T100), 25 (T75), 50 (T50), 75 (T25), 100 (T0) and adding 100 (T200)% of corn stover corresponding to 0, 1.25, 2.50, 3.75, 5.00, and 10.00 Mg ha^{-1} of stover, respectively. Stover removal reduced the number of middens, K_{sat}, SWR, and k_a, and increased ρ_b at all sites ($P < 0.01$). Compared to normal stover treatment (T100), complete stover removal (T0) reduced earthworm middens 6-fold at Coshocton and about 14-fold at Hoytville and Charleston. Geometric mean K_{sat} decreased from 3.1 to 0.1 mm h^{-1} at Coshocton, 4.2 to 0.3 mm h^{-1} at Hoytville, and 4.2 to 0.6 mm h^{-1} at Charleston while soil ρ_b increased about 12% in the 0–10-cm depth at Coshocton and Hoytville from T100 to T0. The SWR for T0 was about 70% of that for T100 and 58% of that for T200 at 0 to -6 kPa suctions across sites. The log k_a for T200, T100, and T75 significantly exceeded that under T50, T25, and T0 at Coshocton and Charleston. Differences in the number of middens, ρ_b, SWR, K_{sat}, and k_a between T100 and T200 were not generally significant although the T200 retained slightly more water for the 0 to -100 kPa at Charleston and had higher k_a at Hoytville compared to T100. Measured parameters were strongly correlated, and k_a was a strong K_{sat} predictor. Stover harvesting induces rapid changes in soil hydraulic properties and earthworm activity, but further monitoring is needed to ascertain the threshold levels of stover removal for soil-specific conditions.

Keywords: No-till; Corn stover removal; Saturated hydraulic conductivity; Earthworm middens; Bulk density; Soil water retention; Air permeability

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1. Introduction

Corn stover is a potential feedstock for biofuel production as an alternative to conventional fuels (Pacala and Socolow, 2004). Corn stover availability in the U.S. Corn Belt region (Nelson, 2002) and implications of stover use for biofuel production on a global scale (Lal, 2005) are being extensively assessed. One major implication is that stover harvesting for biofuel reduces the amount of crop residue left on the soil surface needed to maintain soil quality. The soil physical environment is highly sensitive to changes in surface residue cover (Kladivko, 1994). Corn stover mulch protects the soil surface from raindrop impact, reduces evaporation, moderates soil thermal properties, enhances biological activity, increases soil organic matter content, recycles nutrients, and improves the overall soil structure and quality (Wilhelm et al., 2004).

Intensive removal of stover as biofuel may negatively affect soil hydraulic properties. Partial stover removal (e.g., 25–30%) may be feasible, but site-specific information on the threshold removal rates for maintaining soil water retention and transmission characteristics is limited. Some estimates indicate that 20–50% of stover can be safely removed from the U.S. Corn Belt region, but these estimates are based only on the requirement to control soil erosion (Nelson, 2002; Kim and Dale, 2004). Soil erosivity is intimately linked to soil hydraulic properties as well as topographic and cover factors. Thus, the high variability of these erosion-based stover removal rates within the same region implies that threshold removal rates needed to maintain/enhance soil hydraulic properties may vary among soils. Information on the quantity of removable stover based on field experimentation for representative soils in the U.S. Corn Belt region is lacking for developing guidelines to meet energy and soil quality needs. Conducting site-specific studies on stover removal effects on soil quality remains a high research priority (Wilhelm et al., 2004).

There have been many studies on residue management for diverse tillage and cropping systems (e.g., Lal et al., 1980; Dabney et al., 2004). Most studies have two constraints relative to their usage for evaluating stover removal effects. First, they often report interrelated residue-tillage management effects and, in many cases, results are confounded with different cropping systems (Sharratt, 1996; Singh et al., 1996). A better understanding of the role of residues on soil hydraulic properties entails separating the residue effects from those of tillage-cropping systems. Experiments specifically designed to assess stover removal effects under the same tillage and cropping systems, such as NT continuous corn, are needed to quantify the effects on soil quality. Second, stover removal impacts on soil hydraulic properties are inconsistent and often contradictory. For example, Karlen et al. (1994) reported no significant difference in saturated hydraulic conductivity (K_{sat}) under NT corn with stover maintained, removed, and doubled in a 10-year study of silt loams. Conversely, Findeling et al. (2003), in a 4-year study, showed that K_{sat} increased linearly with increasing rates of stover cover on a sandy loam. Thus, additional studies clarifying stover removal effects on a wide range of soils are warranted.

Formation and preservation of earthworm macropores in NT systems are well known (Bohlen et al., 1997; Butt et al., 1999; Shipitalo and Butt, 1999). Since stover left on the soil surface provides an abundant food source and habitat to earthworms responsible for macropore network development, its removal from NT systems may reduce earthworm populations and the number of surface-connected macropores. Earthworm burrowing and feeding activities enhance soil structure and macropore development, recycle essential nutrients, and control rates of SOC turnover and water–air flow in the soil profile (Bohlen et al., 1997). Surface sealing of open and continuous macropores due to stover removal can be a major factor in reducing near-surface parameters of water flow and gaseous diffusion and transport such as K_{sat} and air permeability (k_a; Ela et al., 1992; Loll et al., 1999). The k_a and K_{sat} are functions of macropore structure and are key indicators of soil structural development (Loll et al., 1999). Changes in earthworm populations and soil macroporosity and their relations to K_{sat}, k_a and soil water retention (SWR) resulting from systematic stover removal are poorly understood. Effects of removing wheat (*Triticum aestivum* L.) and soybean (*Glycine max* L.) residues have been investigated (Pikul and Allmaras, 1986; Skidmore et al., 1986), but few studies have assessed corn stover removal impacts on soil hydraulic properties (Karlen et al., 1994). Corn stover removal may affect soil properties differently from that of wheat and soybean residues because stover is coarser, less decomposable, and thus remains longer on the soil surface (Mankin et al., 1996).

Prediction of K_{sat} for NT soils managed with differing levels of stover cover can be an important alternative to direct K_{sat} measurements, which are often costly and laborious. There are a number of empirical (Rawls et al., 1993) and conceptual (Marshall, 1958; Lebron et al., 1999) equations to predict K_{sat}. Use of such equations for evaluating stover management