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Corn residue, tillage, and nitrogen rate effects on soil carbon and nutrient stocks in Illinois

María B. Villamil *, Emerson D. Nafziger

Department of Crop Sciences, University of Illinois, 1102 S. Goodwin Ave., Urbana, IL 61821, USA

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ABSTRACT

Removal of crop residues for use as ethanol production feedstock might deplete soil carbon and nutrient pools in site- and management-specific ways. We investigated the effect of residue removal (RR), tillage (T), and N fertilizer rate (Nr) after five years of continuous corn (*Zea mays* L.) on total soil carbon (TC) and nutrient stocks at four sites within Illinois. The experimental design was a split–split plot arrangement of treatments in a randomized complete block design with four replications, and all treatments remained in the same place each year. Main plots consist of one of three levels of corn residue removal (RR: full, partial, and none); split plots were two tillage systems (T: chisel tilled and no-till) and split–split plots were four N fertilizer rates (Nr: 67, 134, 201, and 268 kg N ha^{-1}). The highest TC stocks were found under no-till without residue removal; removing any residue under no-till lowered TC to the levels found under chisel tillage. Removing residue in tilled soils produced higher TC values similar to the levels found with no residue removal and no-till. Residue removal tended to lower P and lowered K and EC in the surface 15 cm soil. Tillage decreased the N and K stocks in the surface soil. Increasing the rate of N fertilizer lowered P, K, and pH, generally in an increasing, curvilinear manner, but the response of EC was concave, increasing at the highest N rate used. These responses were closely related to corn grain yields, indicating that the amount of nutrient removed by harvest of grain and residue and the amount of residue retained after harvest affect TC and nutrient stocks in Illinois soils. This information will help producers and policy makers to make better decisions regarding the feasibility of harvesting corn residue, and on agronomic practices that might accompany residue removal in order to prevent soil nutrient depletion.

1. Introduction

Maize crop residues are considered the leading candidate feedstock for cellulosic ethanol production in the U.S. due to their high volume and availability within concentrated areas of production in the Midwestern U.S. (Graham et al., 2007; James et al., 2010; U.S. DOE, 2011; Karlen and Huggins, 2014). The first cellulosic ethanol conversion facility with corn stover as the feedstock started production in September 2014 (POET-DSM, 2014) with more facilities underway in the Midwest region (Advanced Ethanol Council, 2012). To accompany this development, the 2014 Farm Bill authorized the Biomass Crop Assistance Program to provide financial incentives to producers for residue harvest (Agricultural Act of 2014).

Despite the availability of corn residue, producers and researchers equally have raised concerns about the sustainability of this practice due to its potential to decrease soil productivity (Wilhelm et al., 2007; Karlen et al., 2011a,b; Tyndall et al., 2011; Karlen and Huggins, 2014). Tyndall et al. (2011) conducted a survey among Iowa farmers to identify constraints to adoption of residue harvest within their cropping systems. Producers fear that residue harvest could compromise crop yield in the short term through loss of fertility, and in the long term via increased erosion and soil organic matter losses (Tyndall et al., 2011). Recent literature reviews have highlighted the vital role of residues in a wide range of agricultural functions and the potentially detrimental consequences of removal from their agricultural systems (Wilhelm et al., 2004; Blanco-Canqui and Lal, 2007; Moebius-Clune et al., 2008; Blanco-Canqui, 2010; Karlen and Huggins, 2014). Researchers have cautioned that for residue removal to be sustainable it should be managed to avoid compromising the provision of ecosystem services, crop yields and soil productivity, closely related to the maintenance of soil organic carbon (SOC) and nutrient pools (Johnson et al., 2013). Residue left in the field in warmer, drier regions benefits crop yields and soil productivity by preserving water, lowering soil temperature, increasing soil organic matter and nutrient pools, and improving aggregation and stability in order to decrease wind and water erosion. In temperate regions with more fertile soils and more rainfall, however, leaving high amounts of residue in the field may not represent such an advantage, particularly under continuous corn production (Coulter and Nafziger,

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Abbreviations: SOC, soil organic carbon; TC, total carbon; TN, total nitrogen; P, available phosphorus; K, exchangeable potassium; EC, electrical conductivity; RR, residue removal; T, tillage; Nr, fertilizer N rates.

* Corresponding author at: Department of Crop Sciences, University of Illinois, 1102 S. Goodwin Ave., Urbana, IL 61801, USA.
E-mail address: villamil@illinois.edu (M.B. Villamil).

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2008). High levels of residue in the field interfere with planting and emergence by a combination of factors that include reduced soil temperature and higher water content, both of which can delay field operations and vegetative development after planting. In addition, high-residue systems show increased weed infestation, more N immobilization due to the high C/N ratio of corn stover, and more inoculum for many common corn diseases (Mann et al., 2002). To formulate decision support systems for producers interested in this residue management alternative, the amount of residues available for removal should be carefully determined taking into account the combined effects of soil type and topography, climatic conditions, crop rotation, tillage options, and fertilization practices. This information is critical in the Midwest region to discern in what systems residue harvest is possible, or even beneficial, and at what rates. In a recent report highlighting the achievements of the Sun Grant Regional Partnership, Karlen et al. (2014) summarized the effect of three levels of residue harvest on grain yield and nutrient removal from several sites around this maize-intensive region. The authors found that, in general, moderate harvest of the corn stover resulted in a slight increase in grain yield at 50% of the sites. Average grain yields under no-till were significantly lower than yields under conventional tillage when stover was left in the field, but not when it was harvested. Though the report represents a valuable contribution to the understanding of the effects of residue removal the high variability of the data and the different treatments evaluated at each site have so far precluded an in depth analysis of these trends. Of the experimental sites established within this regional partnership, only the sites in Illinois (Coulter and Nafziger, 2008) and Minnesota (Linden et al., 2000; Clapp et al., 2000; Dolan et al., 2006) provide information on factors that are likely to interact with residue removal, such as tillage options, and fertilizer nitrogen (N) additions. Specifically for Illinois, Coulter and Nafziger (2008) reported on the effect of three residue removal rates (no removal, partial, full), tillage (chisel, no-till) and four N rates (67 to 258 kg N ha^{-1}) on corn yield under continuous corn production across four sites and two consecutive years. In environments with lower rainfall and lighter-textured soil, corn grain yield responded negatively to residue removal and N fertilization only under no-till, likely due to increased water retention that increased the crop response to N. On heavier-textured soils with abundant rainfall, yields were similar between chisel plow and no-till with full residue removal, yet yields were higher with tillage with no or partial removal of residues. In addition, residue removal lowered N fertilizer requirements across tillage systems in these productive environments, probably due to a decline in N immobilization (Coulter and Nafziger, 2008). Building on this previous research, we proposed here to explore the effects of residue removal rates, tillage, and N fertilization on total carbon (TC) and nutrient pools within two depths at four experimental sites around Illinois, after five years since the initiation of the experiments. Results from this research can assist Illinois farmers interested in harvesting corn stover for biofuel production to make better decisions to ensure maintenance of soil productivity in their operations.

2. Materials and methods

2.1. Field sites and experimental layout

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. All soils are somewhat poorly drained, with a slope between 0 and 1%. Mean annual precipitation ranges from 890 to 914 mm, and the mean annual temperature from 10.6 to 11.1 °C. At each site, 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 (Coulter and Nafziger, 2008). Main plots consist of one of three levels of corn residue removal (RR: full, partial, and none) in early November after grain harvest, with full removal accomplished by chopping stalks and raking them off the plots, and partial removal done by raking without chopping stalks. Split plots were two tillage systems (T: chisel tilled and no-till). Primary tillage was conducted with a chisel plow to a depth of 25 cm during the fall and after crop harvest each year. Split–split plots were four N fertilizer rates (Nr: 67, 134, 201, and 268 kg N ha^{-1}) side dressed as 28% urea-ammonium nitrate (UAN) solution at the third leaf stage. Split–split plots were eight, 76-cm rows (6.1 m) wide by 8.1 to 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. A detailed description of treatment implementation and plot management is available in Coulter and Nafziger (2008).

Based on several periodic measurements, we estimated residue removal for the full and partial removal treatments at 90 and 50%, respectively. We used a harvest index of 0.52, and combined residue nutrient content reported by Sindelar et al. (2013) with grain and stover yields in that same study (Sindelar et al., 2012) to estimate N, P, and K content of stover at 5.13, 0.23, and 5.66 kg Mg^{-1}, respectively. These were multiplied by stover dry weight and times removal rates to give estimated nutrient removal over the 5-year period preceding soil sampling. Samples were taken at maturity in these trials, and so represent maximum values for N and K, which would be expected to decline as residue weathers in the field after harvest. In the current study, residue removal normally followed harvest by several weeks to a month, and it's likely that this lowered removal values.

2.2. Soil sampling and lab procedures

Soil sampling was conducted following harvest after the fifth year of establishment to assess the effect of residue removal, tillage and N rate effects on total carbon (TC) and nutrient stocks. Three samples per sub-subplot were taken with hand-held soil probes 20 mm in diameter, to a depth of 30 cm, and cores were divided into 0–15 and 15–30 cm depth segments. Samples were air-dried and sieved to <2 mm before analysis by standard methodology recommended for the North Central Region (NCR, 1998). Soil pH and EC were determined 1:1 in water. Air dried soil sieved to pass a 0.25-mm screen was used for determinations of available P (Bray 1), and extractable K (atomic absorption). Air-dried, finely-ground samples were used to determine TC and total nitrogen (TN) by dry combustion on a Costech Elemental Analyzer (Model ECS 4010, Costech Analytical Technologies, Inc. CA). Two subsamples were taken with a slide-hammer probe with a 5 cm core diameter in each sub-subplot and at each depth to obtain bulk density values (Mg/m^3) via the core method (Blake and Hartge, 1986) to then convert TC and nutrient concentrations (TN, P, and K) to a basis of weight per unit area (Ellert and Bettany, 1995).

2.3. Statistical analysis

Data was analyzed using the MIXED procedure of SAS software version 9.4 (SAS Institute Inc., 2013). Residue removal (RR), tillage (T), and N rates (Nr) were considered fixed effects, while replicates (blocks within sites and sites) were considered random effects. Significance of random effects was calculated with a Wald Z test statistic using the COVTEST option in the MIXED procedure. Depth (D) was analyzed using a repeated measures technique with variance-covariance structure VC, variance components, selected on the basis of the lowest Akaike's Information Criteria (Littell et al., 2006). Exact p-values from the analysis of variance for each studied variable are reported in Table 1. Pre-planned estimates were used for mean comparison purposes setting the probability of Type I error or alpha level (α) at 0.05.