Water quality effects of crop residue removal for cellulosic ethanol production

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Abstract

Crop residues have been identified as a prime feedstock for large-scale cellulosic ethanol production. Therefore, understanding the impacts of widespread residue harvest on soil and environment is essential to establish soil-specific residue harvest rates. We assessed the effects of variable levels of corn residue removal on runoff and soil erosion on a regional scale across three locations (Colby, Hugoton, and Ottawa) in Kansas. Five residue treatments that consisted of removing 0, 25, 50, 75, and 100% of corn residue after harvest were studied for losses of runoff, sediment, soil organic carbon (SOC), total N and P, NO_3-N, NH_4-N, and PO_4-P. Simulated rainfall at a rate of 76.2 mm/h in Colby and Hugoton, and 91.4 mm/h in Ottawa was applied for 30 min. Results of this regional study showed that runoff volume, SOC, and total N and P concentrations increased with increase in residue removal at all locations. In contrast, NO_3-N, NH_4-N, and PO_4-P concentrations in runoff increased with decrease in residue removal rate, most likely due to nutrient leaching from residues. Our results suggest that high rates of residue removal for cellulosic ethanol production will increase sediment, SOC, and total nutrient loss in runoff, potentially resulting in soil and environmental degradation.

Key words

Stover, bioenergy, eutrofication, fertility, management, *Zea mays* L.

Introduction

There exists a rising need for the development of alternative fuels from renewable sources in order to reduce dependence on non-renewable energy sources, mitigate net emissions of greenhouse gases, and provide energy to an ever-increasing population (Energy Information Administration 2009). With advances in cellulosic conversion technology, plant biomaterial such as crop residues can now be efficiently used as a feedstock for the production of cellulosic ethanol (Gray *et al.* 2006). Residue removal, however, can accelerate soil erosion, resulting in the transport of non-point source (NPS) pollutants into neighboring waterways (Blanco-Canqui and Lal 2009). While complete removal of crop residues from agricultural fields for biofuel production may jeopardize crop productivity as well as soil and environmental quality, a partial removal of residues without adverse effects may be possible in some soils. To date, experimental data on the permissible levels of corn residue removal are limited. Studies on a regional scale are needed to determine soil-specific residue removal rates that will minimize the erosion of soil, organic carbon, and nutrients from agricultural fields, thus limiting the extent of soil and environmental degradation. Thus, the objectives of this study were to determine the effects of variable levels of crop residue removal on losses of sediment, organic carbon, total nitrogen (N) and phosphorus (P), nitrate (NO_3-N), ammonium (NH_4-N), and phosphate (PO_4-P) in runoff from three different locations in Kansas.

Materials and Methods

Site and treatment descriptions

This study, initiated in March 2009, was performed on three contrasting sites in Kansas including (1) Northwest Research Extension Center in Colby, (2) a private producer's field near Hugoton, and (3) East Central Experiment Field in Ottawa. These sites differ in soil texture, climate, and management (Table 1). A randomized complete block design with five treatments was replicated three times, resulting in 15 plots of 6 x 6 m that were laid out at each site. The five treatments consisted of removing 0, 25, 50, 75, and 100% of the corn residue after harvest. Corn residue is redistributed following harvest at each location. Percent residue removal is estimated by dividing the plots into quadrants, raking the appropriate residue amount off of each plot, and thoroughly redistributing the remaining residue to ensure an even cover. Corn was planted at all sites in May 2009. Plots were demarcated using colored flags placed at the corners of each plot. Two sites (Ottawa and Colby) were managed under no-till while the site at Hugoton was under strip-till.

Additionally, the site in Ottawa is rain-fed, while the sites in Colby and Hugoton are under center-pivot irrigation systems. All sites had slopes ≤ 3%.

Table 1. Soil, climate, and management characteristics of the three study sites

Location	Management	Avg. annual precipitation (cm)	Soil series	Taxonomic classification
Colby	No-till continuous corn Irrigated	47.0	Ulysses silt loam	Fine-silty, mixed, superactive, mesic Aridic Haplustolls
Hugoton	Strip-till continuous corn Irrigated	45.7	Hugoton loam	Fine-silty, mixed, superactive, mesic Aridic Argiustolls
Ottawa	No-till continuous corn Rain-fed	81.3	Woodson silt loam	Fine, smectitic, thermic Abruptic Argiaquolls

Rainfall simulation

Rainfall simulation was conducted in the spring of 2010 to determine runoff, sediment, organic carbon and nutrient losses from all treatment plots across the three study sites. A rainfall simulator with a 30WSQ stainless steel nozzle (Teejet Corp., Dillsburg, PA; Miller 1987) inside an aluminum frame applied rain on 2.5 m² runoff subplots from a 2.5 m height. Plastic tarps were used around the simulator to reduce wind influence on the trajectory of raindrops. Water was supplied to the simulator from a 3,785 L tank through the use of an electric pump. Dry and wet-runs were performed in each plot. Dry runs were done 24 h before wet runs in order to ensure uniform antecedent soil moisture in all treatment plots. Simulated rainfall was applied for 30 minutes at an intensity of 91.4 mm/h in Ottawa, and 76.2 mm/h in Colby and Hugoton. These intensities represent storms with a 5 yr return period for the three locations.

Runoff subplots were bordered with 0.5 cm thick steel plates inserted into the soil to a depth of 5 cm. A V-shaped runoff collector was installed at the downslope end of the plots to direct runoff into graduated buckets inserted in collection pits. The runoff collectors and collection pits were covered during simulations to avoid direct collection of rainfall. Runoff was collected separately in 10 min intervals after initiation of rainfall, resulting in 3 large samples for each 30 min simulation. Three subsamples of runoff from each time interval (0-10, 10-20, and 20-30 min) were collected for the analysis of sediment concentration, sediment-associated-SOC, and nutrients, respectively.

Collected runoff was stirred to ensure the suspension of sediments, and a 1 L subsample was taken for sediment concentration determination. Two more subsamples were taken for chemical analysis: a 100 mL unfiltered sample for total N and P, and a separate 15 mL sample passed through a 0.45 µm filter for NO_3-N, NH_4-N, and PO_4-P determination. The samples were placed on ice in an insulated cooler, transported to the lab, and analyzed within 1 week. Sediment was determined gravimetrically by oven drying runoff subsamples at 60°C, in accord with Blanco-Canqui *et al.* (2004). The oven-dried sediment mass was used to calculate sediment loss (in g/m²) for each plot. SOC content of sediment load was determined by the dry combustion method (Nelson and Sommers 1996). Standard chemical analyses were used for nutrient determination. All data were analyzed using a one-way ANOVA model with residue removal rate as the treatment (SAS Institute 2008). Differences between means were tested using a protected LSD at the 0.05 probability level (SAS Institute 2008).

Results

Runoff volume, sediment load, and organic C

Preliminary results from this study suggest that runoff volume is largely influenced by residue harvest. On average, runoff depth increased from 1.40 mm with 0% removal, to 18.8 mm with 100% removal in Colby. In a similar study, Blanco-Canqui *et al.* (2009) found that runoff volume and sediment load tended to increase with increase in residue removal from no-till wheat plots in Kansas. Compared to 0% removal treatments, sediment loss increased threefold with residue removal rates as low as 50% (Blanco-Canqui *et al.* 2009). This is in agreement with results observed by Lindstrom (1986) with no-till corn in Minnesota. Blanco-Canqui *et al.* (2009) also observed increased SOC loss in sediment as residue removal increased, with a fourfold increase in SOC loss at 75% removal when compared to 0% residue removal treatments.

Total N and P

Blanco-Canqui *et al.* (2009) observed significant losses of total N and P with residue removal levels greater than 75%. Likewise, Lindstrom (1986) found that concentrations of N, P, and K in sediment contained in runoff decreased with decrease in residue removal rate. In both cases, the losses of total N and P were positively correlated with sediment loss.

NO_3-N, NH_4-N, and PO_4-P

No significant impacts of residue removal on NO_3-N, NH_4-N, and PO_4-P concentrations in runoff water from no-till plots were observed by Blanco-Canqui *et al.* (2009). However, preliminary results from the current study suggest that concentrations of NH_4-N, NO_3-N, and PO_4-P in runoff water may tend to increase with decreased residue removal rate. These results can be explained partially by the longer contact time between water and residues, and the increased leaching of nutrients from residues at lower residue removal rates (Schreiber 1999).

Discussion and conclusion

Crop residues play an integral role in minimizing soil erosion and the transport of NPS pollutants into neighboring waterways. Residues prevent soil crust formation and enhance infiltration by shielding the soil surface from the impact of raindrops. Adequate residue cover, therefore, is necessary in order to minimize runoff and limit losses of sediment, SOC, and nutrients from the soil. Results from this study suggest that on certain soils, relatively low levels of residue removal may substantially increase soil erosion, losses of NPS pollutants into surface water, and decrease soil fertility. Further investigation of residue removal in a wide variety of soils, crops, and climates are needed in order to better determine threshold removal levels on a regional scale.

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