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Douglas L. Karlen
United States Department of Agriculture

Stuart J. Birrell
Iowa State University, sbirrell@iastate.edu

Adam Wirt
POET-DSM

Nathan Schock
POET-DSM

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Abstract

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Disciplines

Agriculture | Bioresource and Agricultural Engineering | Soil Science

Comments

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CORN STOVER HARVEST STRATEGY EFFECTS ON GRAIN YIELD AND SOIL QUALITY INDICATORS

Douglas L. Karlen[1] Stuart J. Birrell[2], Adam R. Wirt[3] and Nathan Schock[3]

[1] USDA-Agricultural Research Service (ARS), National Laboratory for Agriculture and the Environment (NLAE), 2110 University Blvd., Ames, Iowa USA 50011-3120
[2] Department of Agricultural and Biosystems Engineering, Iowa State University (ISU), Ames, IA 50011
[3] POET, 4615 Lewis Ave., Sioux Falls, S.D. 57104

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Abstract

The development of technologies to use cellulosic biomass as a feedstock for biofuel production was recognized as an important research focus because cellulose is a more widely-available feedstock than corn starch. Our objective was to compare various corn (Zea mays L.) stover harvest strategies to determine which would be most sustainable. A complete block design with 2 ha plots, each replicated three times, was imposed on a 50 ha (125 acre) Clarion-Nicollet-Webster soil Association site near Emmetsburg, Iowa, U.S.A. before harvesting the 2008 corn crop. Hand samples were collected from a 1.5 m^2 area in each plot to establish the potential amount of above-ground biomass that could be potentially harvested using one of seven stover harvest strategies. Surface soil samples (0 to 15 cm) were analyzed following each harvest to monitor fertility changes and to make subsequent fertilizer recommendations. Grain yields averaged 11.4, 10.1, 9.7, and 9.5 Mg ha^{-1} in 2008, 2009, 2010, and 2011, respectively, but were not significantly affected by stover harvest treatments. Relative yield for the various treatments ranged from 97 to 107% of the conventional treatment for which none of the residue was harvested. Four-year average stover yields ranged 1.0 to 5.2 Mg ha^{-1} which was 12 to 60% of the above-ground biomass. Three years of plant tissue data at anthesis indicated N management needed to be improved as the values were below the critical concentration of 27 g kg^{-1}. Sulfur concentrations were just barely above the critical value of 15 g kg^{-1}. Soil test analyses showed substantial field variability but no significant stover harvest treatment effects. There was a slight decrease in soil organic carbon, unrelated to the stover harvest treatments, that is attributed to the intensity of tillage and crop yields that were lower than expected. Overall, this study is consistent with other studies in the U.S. Corn/Soybean Belt that indicate to sustain soil resources within this region, corn stover should generally not be harvested if average grain yields are less than 11 Mg ha^{-1} (175 bu ac^{-1}). Strategies for achieving those levels include implementing more rigorous soil-testing and plant analysis programs, installing tile drainage where needed, improving overall nutrient management programs, reducing tillage intensity, incorporating cover crops and rotating corn with other crop such as soybean [Glycine max (L.) Merr.], small grain, or forage.

Introduction

The U.S. EPA identified corn stover, the aboveground material left in fields after grain harvest, as “the most economical agricultural feedstock … to meet the 16 billion gallon cellulosic biofuel requirement” (Schroeder, 2011). They estimated that 7.8 billion gallons of ethanol would come from 82 million tons of corn stover by 2022, which is consistent with conclusions reached by the U.S. Department of Energy (2011). A major reason that corn stover was identified as an important feedstock because of the vast area upon which corn is grown in the Midwestern U.S.A. However, corn stover has many other functions within the soil. Therefore, if (1) yields are low, (2) an excessive amount is harvested for any use, or (3) tillage intensities are too aggressive, harvesting stover may decrease the amount of carbon (C) returned to the soil to a level that will not be sufficient to sustain soil organic carbon (SOC), soil aggregation, or other soil quality indicators.

To help resolve the emerging questions regarding the sustainability of stover harvest, a private-public research project involving POET-DSM Advanced Biofuels, Iowa State University (ISU), and the USDA-Agricultural Research Service (ARS) was initiated in 2008. Seven stover harvest strategies were evaluated, even though none were an exact match to what POET-DSM ultimately decided to ask their residue suppliers to follow. Fortunately, treatments 4 and 6 bracket the recommended practice of simply turning off the residue chopper/spreader and then baling the windrow that is created. Furthermore, two of the most critical questions being asked about stover harvest for any use including bioenergy, bio-products, animal feed or bedding, regardless of the specific harvest strategy being followed, are (1) will it reduce subsequent crop yields, and (2) will it degrade soil quality by increasing erosion, decreasing soil organic matter, depleting soil fertility, or having any other adverse environmental effects? Our objective for this report is to summarize the first four years of data being collected to answer these sustainability questions.

Methods and materials

A 50 ha field study was designed and initiated in 2008 to complement on-going work by POET-DSM with farmers, researchers and equipment dealers on harvest, transportation and storage logistics of corn stover. Seven treatments: conventional – no stover harvest (Treatment 1); cob only (Treatment 2); plant material other than grain (MOG) collected directly (Treatment 3) or by direct-baling (Treatment 4); a two-pass harvest and baling operation (Treatment 5), and a high-cut (just below the ear – Treatment 6) or low-cut (10-cm stubble height – Treatment 7) were established using a single-pass, dual stream biomass harvester developed based on a John Deere 9750 STS combine at ISU and evaluated for their effects on crop productivity and soil productivity for four years.

Field management was carried out by POET-DSM employees based on soil and crop management guidelines provided by the research team. To assess plant nutritional response, 10 whole plant samples were collected at V6 growth stage and “ear leaf” (actually opposite and below the primary ear) samples were collected at anthesis. Plant samples were dried at 40° C, ground to pass a 1 mm screen and submitted to a commercial laboratory for P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn analyses. Total carbon (TC) and total N (TN) concentrations were determined within the NLAE analytical laboratory by dry combustion using a Carlo-Erba NA1500 NCS elemental analyzer (Haake Buchler Instruments, Paterson, NJ).

Prior to harvest, hand samples were from a 1.5 m^2 area in each plot to establish the potential amount of above-ground biomass that could potentially be harvested. Samples were fractionated into five components: (1) ear shank upward; (2) below the ear leaving a stubble height of 10 cm; (3) dropped leaves, tassels, and stalk components; (4) cobs; and (5) grain. Weights for the non-grain components were summed to estimate the above-ground biomass. The grain weight was divided by the sum of all five fractions to estimate the harvest index (HI).

During harvest, corn grain was separated by the combine and routed to the grain tank. Stover passed through the combine and into a chopper/blower system that deposited the material into a trailing wagon that was equipped with load-cells. Corn grain was transferred from the combine to a weigh-wagon after harvesting each plot. Weights were recorded for both grain and stover while sub-samples were collected to determine the water content. The dual-pass rake and bale operation was carried out by first harvesting the grain and then having a local cooperator rake and bale the residue on those three plots. Several bales from each plot were also sampled and composited for analysis. An electronic moisture meter was used for grain, but for stover, the samples were dried at 70º C in a forced air oven until they reached a constant weight. Grain yield is reported at a constant water content of 155 g kg^{-1}, while stover yields are reported at a water content of 0 g kg^{-1}. Relative grain yield was calculated by dividing grain yield for each of the stover harvest treatments by the yield for the no-removal treatment for each replicate. Stover samples were ground to pass a 2 mm screen before sub-sampling and grinding again to pass a 0.5 mm screen. They were also analyzed for TC and TN within the NLAE and by a commercial laboratory for the other elements listed previously.

Following harvest each autumn, several 119 cm^3 soil cores were collected randomly and composited for each 2.5 ha plot. Samples were dried, crushed and passed through a 2 mm screen and analyzed through a commercial laboratory for pH, P, K, Ca, Mg, B, Cu, Fe, Mn, and Zn concentrations. A subsample was also analyzed by the NLAE analytical laboratory for TN and TC concentrations. For samples with pH values greater than 7.3, inorganic C (IC) was also determined (Wagner et al., 1998). Total organic carbon (TOC) values were then calculated as the difference between TC and IC with the latter being considered zero for samples with pH <7.3.

Yield, plant analysis, and soil-test data were analyzed using a General Linear Model with SAS Version 9.2 software. Seasonal (Year), treatment, and treatment by year effects were evaluated. Least Significant Difference (LSD) values were used to separate mean values for factors with statistically significant F values at $P \leq 0.1$.

Results and discussion

Corn grain yield showed significant ($P \leq 0.1$) seasonal effects averaging 11.4, 10.1, 9.7, and 9.5 Mg ha^{-1} in 2008, 2009, 2010, and 2011, respectively, but there were no statistically significant differences among stover harvest treatments and the treatment by year interaction was not significant at $P \leq 0.1$ (Table 1). The relative grain yield among harvest treatments was also non-significant with only a slight trend (7%) for increased grain yield where the maximum amount (STS Low-cut) of residue was harvested. Several factors undoubtedly contributed to the gradual decline in yield including excessive early-season rainfall in 2010 and severe wind damage in August 2011 that resulted in a substantial amount of lodging and reduced the yield potential. Other possible factors include a combination of the highly variable soil fertility status across the field as well as the well-established yield penalty (Karlen et al., 1994) associated with continuous corn production, since the site was last planted to soybean in 2006.

Measured amounts of harvested stover and the fraction of above-ground material collected are presented in Table 2. The initial business model for POET-DSM had been to use only the cob fraction as feedstock for cellulosic bioenergy, but that plant fraction accounted for only 12% of the above-ground biomass. That value was lower than expected but in the range reported by Halvorson and Johnson (2009) and Wienhold et al. (2011). The potential amount of above-ground stover, estimated from the hand samples collected from each plot, averaged 9.9, 8.4, 8.0 and 7.6 Mg ha^{-1} in 2008, 2009, 2010, and 2011, respectively. Subtracting the 5.24 Mg ha^{-1} of corn stover estimated by Wilhelm et al. (2009) as the amount of needed to sustain soil organic carbon levels, the sustainable amount of harvestable stover averaged 2.1, 1.4, 1.2, and 1.0 Mg ha^{-1} for 2008,

Table 1. Average and relative corn grain yields as affected by various stover harvest treatments near Emmetsburg, Iowa, U.S.A.

Treatment	2008	2009	2010	2011	4-Year Mean	Relative Yield
	----------- Mg ha^{-1} -----------					
Conventional – no removal	11.3	9.8	9.5	9.9	10.1	1.00
Cobs only	11.2	9.6	9.5	9.9	10.0	1.00
MOG bulk collection	11.6	9.6	9.6	9.8	10.2	1.01
Single-pass baling of MOG	---	10.2	9.7	8.3	9.4	0.97
Two-pass baling	11.1	10.5	9.8	9.3	10.2	1.01
STS High-cut	11.2	10.7	8.8	9.4	10.0	0.99
STS Low-cut	11.8	10.6	11.1	9.6	10.8	1.07
LSD$_{(0.1)}$	NS				NS	NS

Table 2. Average stover yield and percent collected as affected by harvest treatment near Emmetsburg, Iowa, U.S.A.

Treatment	2008	2009	2010	2011	4-Year Mean	% Collected
	----------- Mg ha^{-1} -----------					
Conventional – no removal	0.00	0.00	0.00	0.00	0.00	0
Cobs only	1.04	1.47	1.12	0.44	1.02	12
MOG bulk collection	1.50	2.02	1.31	1.47	1.57	19
Single-pass baling of MOG	---	1.95	1.78	2.02	1.92	24
Two-pass baling	5.05	3.36	3.24	5.06	4.18	50
STS High-cut	4.70	4.14	3.74	3.84	4.10	50
STS Low-cut	5.00	5.61	5.49	4.83	5.23	60
LSD$_{(0.1)}$	0.17				0.20	0.04

2009, 2010, and 2011, respectively. This indicated that an average of only 17% of the above-ground biomass could be sustainably removed from this site, which is much less than the 60% removal needed to increase the relative grain yield (Table 1).

It is important to note that this is only one research site and there are several soil and crop management practices that could be used to increase the amount of stover that could be harvested in a sustainable manner. First, there was substantial variation in soil fertility across the 50 ha research site, as evidenced by highly significant ($F \leq 0.0001$) replicate effects that are illustrated by the 4-year mean soil-test P and K values for each of the stover harvest treatments (Figure 1). This shows that before producers consider harvesting crop residue in addition to their grain, soil- testing and a rigorous nutrient management plan should be in place. Also, as the excessive rainfall event of 2010 confirmed, this research site would have benefitted by having tile drainage to prevent crop loss in areas where rainfall and runoff accumulate. Nutrient management could also be improved as indicated by the three-year average concentrations for four critical plant nutrients (Table 3). Although there were no significant differences among the harvest strategies, tissue N content during anthesis was below the critical level and S concentrations were barely above the value established for that nutrient.

Soil organic carbon (SOC) content was also monitored because of its importance in sustaining soil resources and the potential impact that harvesting crop residues could have on that indicator of resource sustainability (Johnson et al., 2009; Wilhelm et al., 2007). There were no significant stover harvest effects, but seasonal and replicate effects where highly significant ($F < 0.0001$) and the Least Significant Difference (LSD) value for the data shown in Figure 2 was 2.0.

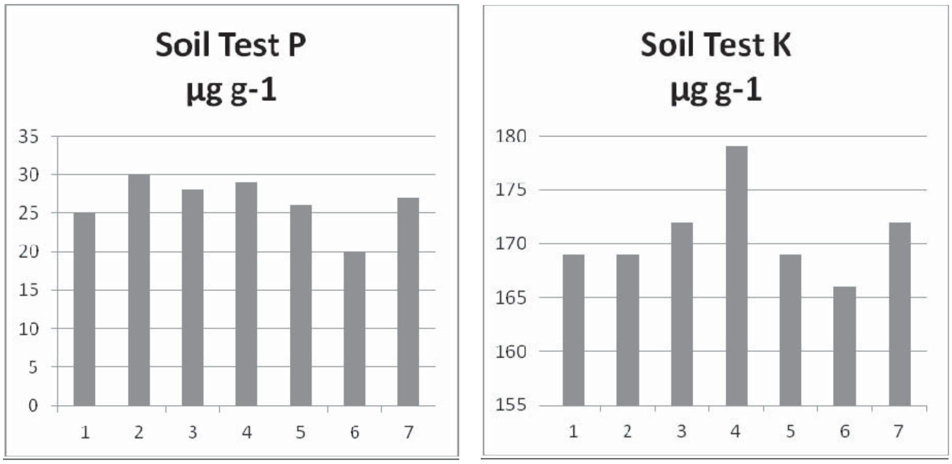
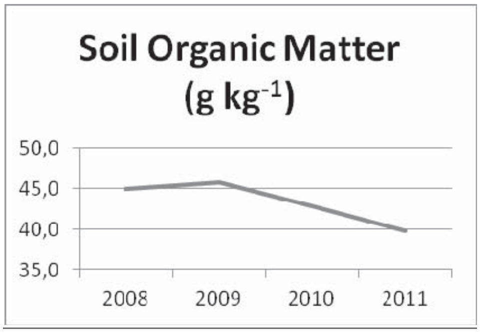


Figure 1. Four-year mean soil-test P and K values for seven stover harvest treatments (none, cobs only, MOG, single-pass bale, two-pass bale, STS-high, and STS-low) evaluated near Emmetsburg, Iowa, U.S.A.

Table 3. Three-year average (2009 – 2011) ear leaf nutrient concentrations for the various stover harvest treatments near Emmetsburg, Iowa, U.S.A.

Treatment	N	P	K	S
		--------------- mg kg^{-1} ---------------		
Critical Value	**27.0**	**2.50**	**17.0**	**1.50**
Conventional – no removal	23.6	2.80	18.5	1.60
Cobs only	25.2	2.50	19.1	1.60
MOG bulk collection	24.8	2.80	19.2	1.60
Single-pass baling of MOG	24.0	2.80	18.9	1.60
Two-pass baling	25.9	2.80	18.7	1.60
STS High-cut	24.4	2.70	18.8	1.60
STS Low-cut	24.8	2.60	18.5	1.60
LSD$_{(0.1)}$	NS	NS	NS	NS

Figure 2. Soil organic carbon trends at a research site used to evaluate various stover harvest treatments near Emmetsburg, Iowa, U.S.A.



Again as stated above, the intensity of tillage (i.e. fall chisel plowing followed by one or two passes with a field cultivator in spring) and having crop yields that were lower than expected because of excessive early-season rainfall in 2010 and severe wind damage in 2011 undoubtedly were the primary factors contributing to the decline in SOC. Improved soil and crop management practices are crucial for production systems that include both grain and stover harvest. As stated previously, for this location, use of more intensive management practices including split fertilizer applications, building up soil-test nutrient levels, planting cover crops, reducing tillage intensity, and using crop rotations would likely increase the amount of stover that could be harvested in a sustainable manner. For other locations, producers may want to implement site-specific landscape management practices (Muth, 2012) that integrate multiple feedstock materials.

Summary and conclusions

These four years of bioenegy feedstock production data are consistent with other studies indicating that to sustain soil resources in the U.S. Corn/Soybean Belt stover should rarely be harvested if average grain yields are less than 11 Mg ha^{-1} (175 bu ac^{-1}). Obviously, improved management practices could change this recommendation.

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