Influence of Corn Stover Harvest on Soil Quality Assessments at Multiple Locations Across the U.S.

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Abstract
Corn (*Zea mays* L.) stover has been identified as a biofuel feedstock due to its abundance and a perception that the residues are unused trash material. However, corn stover and other plant residues play a role in maintaining soil quality (health) and enhancing productivity, thus use of this abundant material as feedstock must be balanced with the need to protect the vital soil resource. Plant residues provide physical protection against erosion by wind and water, contribute to soil structure, nutrient cycling, and help sustain the soil microbiota. Replicated plots were established on productive soils at several locations (IA, IN, MN, NE, PA, SD, and SC) and a multi-year study was carried out to determine the amount of corn stover that can be removed while maintaining the current level of soil quality for each soil. These sites represented a range of soil types and climatic conditions, and have been ongoing for and least five years with some much longer studies. All sites had at least three levels of stover harvest: grain only (control), maximum removal (90-100%) and a mid-range removal rate (~50%). Data from 4 sites are presented (IA, IN, MN, and NE). The Soil Management Assessment Framework (SMAF) was used to score and assess changes in selected soil quality indicators. Data shows that removal at the highest rates resulted in some loss in soil quality with respect to soil organic carbon and bulk density. These sites were converted to no-till when the experiments were initiated, thus SOC accrual because of the shift in tillage management appeared to balance any losses due to feedstock harvest.

Keywords: Soil organic carbon, bulk density, soil quality index

Introduction
Due to its plentiful supply, corn (*Zea mays* L.) stover has been identified as an important feedstock for cellulosic ethanol production (Perlack et al. 2005), which is needed to offset a portion of 14 million barrels of oil consumed daily in the U.S. as transportation fuel (National Academy of Sciences (NAS) 2009). While corn stover is abundantly available, with about 35 million ha of corn planted each year, there is a perception that it is trash, an unused material left behind after harvest. The Billion Ton Report (BTR)(Perlack et al. 2005) did recognize the need to leave sufficient crop residues on the soil surface to

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protect against wind and water erosion. Soil scientists have raised the concern that excessive feedstock harvest could reduce crop yields, either directly or indirectly, through reductions in soil organic carbon (SOC) and other nutrients concentrations as well as decreasing overall soil quality (Wilhelm et al. 2010). Soil organic carbon has been reduced by 30-50% of pre-cultivation levels due to tile drainage, intensive tillage systems, and use of monoculture or simple two crop rotations such as corn/soybean (Schlesinger 1985). Declining SOC levels negatively impact a number of vital soil ecosystem functions, including plant productivity, nutrient cycling, soil structure, and water infiltration and storage.

Cropland soil quality can be impacted by the interaction of a number of factors such as climate, soil type, and management practices such as soil tillage and crop rotations. To evaluate the impact of these factors on critical soil ecosystem functions, soil quality assessment tools are needed. These assessment tools need to be sensitive to changes in management as well as taking into account differences in inherent soil attributes (Stott et al. 2011). Monitoring changes in soil quality should give indications of the long term impact of stover removal on soil quality.

One such assessment tool is the Soil Management Assessment Framework (Andrews et al. 2004), which is available in Excel format, and focuses on how well the soil is functioning. It uses measured data for dynamic soil indicators to assess management effects on soil ecosystem services using a three-step process that includes indicator selection, indicator interpretation, and integration into an index. The SMAF uses soil taxonomy as a foundation for assessment, allowing for the modification of many of the scoring indicator values to be based on soil suborder properties. Soil quality and its assessment are soil and site specific, and depend on a variety of factors such as inherent soil characteristics, landscape and climatic influences, and human values such as intended land use, management goals, and environmental protection. The SMAF includes soil physical, chemical, and biological indicators that are management-sensitive, and therefore dynamic. Currently, SMAF includes 13 indicators with scoring curves consisting of interpretation algorithms. Those used in this study included bulk density (BD), electrical conductivity, pH, extractable P and K, SOC, and β-glucosidase (BG) activity (Andrews et al. 2004; Stott et al. 2010; Wienhold et al. 2009).

The objective of this paper is to examine changes in selected soil quality indicators that have occurred over time from experiments that included as a component the impact of corn stover removal on soil ecosystem services.

Methods

Four study sites from across the U.S. were used in this study (Tables 1-4). All sites included a minimum of two corn stover levels, 0 and 50% removal, with 3 sites having additional levels. No-till practices were included at all sites. Crop rotations varied from site to site, and included continuous corn, corn-soybean (*Glycine max* L.), and corn-soybean-winter wheat (*Triticum aestivum* L.). Data were derived from both published and unpublished sources. The soil analytical data presented were gathered using standard methodologies that were the same across all the sites. Soil quality indicator scores were calculated with SMAF. Changes (Δ values) were calculated by subtracting the initial value from the latest value available. For example, the change in SOC would be calculated as $\Delta SOC = SOC_{final} - SOC_{initial}$. Changes in the SMAF indicator scores were calculated in a similar manner.

Results and Discussion

A study in Ames, IA (Karlen, 2011;Table 1) observed significant decreases in the SMAF SOC indicator scores in the near-surface (0-15 cm) soil, but all treatments suffered a similar drop, hinting that there were other factors at play other than the removal of corn stover for biofuel feedstock. The SMAF bulk density indicator scores were improved. Nutrition-related indicators, which are easily managed through amendments, remained substantially unchanged, regardless of the level of feedstock harvest.

Table 1. Response of selected SMAF soil indicator scores after 5 years of corn stover harvest near Ames IA. The dominant soils were a Canisteo silty clay loam for the continuous corn and a Clarion loam for the rotational corn system, all under no-till management. Sampling depth was 0-15 cm. The change in indicator scores were calculated as the difference between the score first and last years. A difference ≥ 0.10 was significant. Data and SMAF calculations from Karlen et al. (2011).

	Change in SMAF Indicator Scores after 5 Years						ΔIndex
Continuous Corn	**SOC[1]**	**BD**	**pH**	**EC**	**P**	**K**	**SQI**
Whole Plant[2]	-0.34	0.23	0.01	0.00	0.00	0.01	-0.01
Upper half	-0.31	0.19	0.00	0.00	0.00	0.08	0.00
Lower half	-0.29	0.18	0.01	0.00	0.00	0.12	0.01
No removal	-0.33	0.10	0.01	0.00	0.00	0.06	-0.02
Corn in Rotation with Soybean							
Whole Plant	-0.03	0.06	0.00	-0.05	0.00	0.04	0.01
Upper half	0.01	0.11	-0.01	0.00	0.02	0.22	0.06
Lower half	0.08	0.15	0.00	0.00	-0.02	-0.01	0.03
No removal	-0.17	0.13	0.00	-0.08	0.00	0.20	0.02

[1]Abbreviations: SOC, soil organic carbon; BD, bulk density; EC, electrical density; ΔSQI, change in soil quality index, calculated using the Soil Management Assessment Framework.
[2]Portions of the corn stalk that were harvested for biofuel feedstock.

In West Lafayette, IN (DE Stott, unpublished data; Table 2), the ΔSOC concentrations increased in the 0-30 cm layer, probably due to the conversion to no-till, even so, the increase in SOC for the 100% stover removal rate was significantly lower than the other treatments, and the increases overall were much lower in the 30-60 cm layer. The changes in the SMAF SOC indicator scores were not significantly different between treatments. Bulk density increased in the top layer, but the changes in the SMAF bulk density indicator scores were negligible. However, in the 30-60 cm depth, the indicator scores were significantly decreased, with the 75 and 100% removal rates significantly lower than the 0% removal rate.

Table 2. Changes in selected soil indicators after 6 years of corn stover removal from continuous corn sites in West Lafayette, IN. The dominant soil was a Chalmers silt loam with no-till management initiated at the beginning of the experiment. The values represent changes in soil indicator values and SMAF soil indicator scores after 6 years of corn stover removal. A change in the SMAF score ≥0.1 is significant. Data from Stott, DE, unpublished.

Stover Removal Rate	ΔSOC[1] (g kg^{-1})	ΔSOC Score[2]	ΔExt. P (mg kg^{-1})	ΔExt. P Score	ΔBulk Density (g cm^{-3})	ΔBulk Density Score
0-30 cm sampling depth						
0%	2.3	0.07	17.67	0.10	0.25	-0.04
50%	2.6	0.10	43.00	0.03	0.27	-0.06
75%	2.1	0.06	18.33	0.22	0.20	-0.01
100%	1.5	0.04	29.17	0.17	0.19	-0.02
30-60 cm sampling depth						
0%	0.1	0.00	-0.33	0.00	0.21	-0.23
50%	0.3	0.01	-1.33	-0.04	0.35	-0.34
75%	0.5	0.01	1.00	-0.12	0.23	-0.40
100%	0.6	0.02	-3.00	0.02	0.22	-0.41

[1] Abbreviations: SOC, soil organic carbon, PNP, *p*-nitrophenol released; Δ=amount of change, calculated by subtracting the initial value from the value after 6 years.
[2] Indicator scores calculated using the Soil Management Assessment Framework.

For sites near Mead, NE (Follett, 2012), there were decreases in SOC concentrations in the surfaces layers over 9 years, translating into a significant drop in the SMAF SOC indicator score, however there were slight increases in the lower layers. Both treatments had a weighted mean 0.13 increase in SOC indicator score over the 150-cm profile during the 9-yr period. Bulk density scores also dropped for both treatments. The 50% removal treatment had a slightly greater drop in bulk density over the 150-cm profile.

The Morris, MN study (JMF Johnson, unpublished data; Table 3) was interesting due to the inclusion of a corn-soybean-wheat rotation and in the use of established no-till. Changes in the SMAF SOC, bulk density, and β-glucosidase activity (an enzyme involved in cellulose degradation) indicator scores were minor. Extractable P and K indicator scores (data not presented) showed no significant differences.

Table 3. Changes in selected soil indicators after 9 years of corn stover removal from continuous corn sites near Mead, NE. The dominant soil was a Yutan clay loam - Tomek silt loam mix. The values represent soil indicator values and SMAF soil indicator scores measured initially and after 9 years of no-till management and corn stover removal. A change in the SMAF score ≥0.1 is significant. Data from Follett, 2012.

Removal Rate	Depth of sampling (cm) 0-5	5-10	10-30	30-60	60-90	90-120	120-150
	Soil Organic Carbon (g kg^{-1})						
Initial	28.6	31.2	2.3	1.4	1.9	3.0	5.0
0%	21.8	30.3	8.5	7.2	10.7	15.8	24.2
50%	24.4	30.4	8.9	7.3	11.0	15.7	24.1
	SMAF[2] SOC Indicator Score						
Initial	0.62	0.71	0.03	0.02	0.03	0.03	0.04
0%	0.37	0.68	0.07	0.06	0.09	0.19	0.46
50%	0.46	0.69	0.07	0.06	0.10	0.18	0.45
	ΔSMAF SOC Indicator Score						
0%	-0.26	-0.03	0.04	0.03	0.07	0.15	0.42
50%	-0.16	-0.03	0.05	0.03	0.07	0.15	0.41
	Soil Bulk Density (g cm^{-3})						
Initial	1.20	1.34	1.36	1.29	1.32	1.35	1.39
0%	1.33	1.45	1.45	1.32	1.35	1.37	1.71
50%	1.32	1.45	1.43	1.35	1.40	1.44	1.45
	SMAF Bulk Density Indicator Score						
Initial	0.80	0.49	0.46	0.59	0.53	0.48	0.41
0%	0.51	0.35	0.35	0.53	0.48	0.44	0.23
50%	0.53	0.35	0.37	0.48	0.40	0.36	0.35
	ΔSMAF Bulk Density Indicator Score						
0%	-0.29	-0.15	-0.11	-0.06	-0.05	-0.03	-0.19
50%	-0.27	-0.15	-0.09	-0.12	-0.13	-0.12	-0.07

[1] Abbreviations: SOC, soil organic carbon; Δ=amount of change, calculated by subtracting the initial value from the value after 6 years.
[2] Indicator scores calculated using the Soil Management Assessment Framework (SMAF).

Shifting from conventional to no-till before the start of corn stover harvest for biofuel feedstock was helpful in maintaining near-surface SOC at levels that has not degraded the soil ecosystem functions in which SOC is involved, however SOC levels in lower depths were lower with sustained feedstock harvest. In addition, bulk density indicator scores have decreased. Nutrient and chemical scores, such as extractable P and K, and pH, saw very little change, which would be expected as these can be modified by managing inputs. There were some indications (data not presented) that concentrations of trace elements such as copper and zinc, were becoming a concern with continued feedstock harvest, and may need to be addressed in the future to maintain comparable yields.

Table 4. Changes in selected after 6 years in Morris, MN. The dominant soils were Barnes loam and Aastad clay loam. For the SMAF indicator scores, a change ≥0.10 was significant. Data from Johnson, JMJ, unpublished.

			Depth of Sampling (cm)									
			0-20	0-60	0-20	0-60	0-20	0-60	0-20	0-60	0-20	0-20
Removal Rate	Crop[1]	Tillage[2]	Δ SOC(%)[3]		Δ SOC SMAF Score[4]		Δ Bulk Density (g cm^{-3})		Δ Bulk Density SMAF Score		Δ β- gluc.	Δ β- gluc. SMAF Score
0	**C**S	Chisel	0.01	-0.05	0.00	-0.02	0.07	0.05	-0.07	-0.08	-125	-0.08
50			0.08	0.13	0.03	0.02	0.12	0.04	-0.11	-0.04		
75			0.16	0.09	0.06	0.00	0.08	0.01	-0.10	0.01		
100			0.07	0.09	0.03	-0.01	0.01	0.04	-0.03	-0.06	-139	-0.09
0	**C**S	Est. NT	0.11	0.04	0.04	0.00	0.01	-0.12	0.01	0.07	-183	-0.20
50			-0.04	0.10	0.00	0.01	-0.04	0.03	0.03	-0.07		
75			0.10	0.15	0.04	0.02	-0.13	0.02	0.18	-0.01		
100			0.18	0.24	0.07	0.04	-0.09	-0.10	0.18	0.15	-157	-0.14
0	C**S**	Chisel	-0.01	0.13	-0.01	0.01	-0.05	-0.08	0.10	0.06	-134	-0.09
50			0.04	0.20	0.01	0.01	-0.04	0.01	0.06	-0.04		
75			0.12	0.20	0.05	0.03	-0.05	0.21	0.03	-0.08		
100			0.08	0.20	0.03	0.02	0.04	0.01	-0.02	-0.03	-130	-0.09
0	C**S**	Est. NT	0.21	0.16	0.08	0.03	-0.11	-0.04	0.08	0.06	-193	-0.21
50			0.03	0.23	0.01	0.03	-0.04	0.04	0.08	0.00		
75			0.11	0.05	0.04	-0.01	-0.02	0.09	-0.01	-0.15		
100			-0.06	0.07	-0.03	-0.01	-0.06	0.06	0.08	-0.08	-168	-0.17
0	CS**W**	New NT	0.22	0.26	-0.10	0.00	-0.36	-0.01	-0.21	-0.14	-64	-0.03
50			1.25	0.49	0.02	0.02	-0.01	0.03	0.01	-0.02	17	0.04
75			1.97	0.62	0.02	0.02	-0.02	0.01	0.01	0.01	16	0.04
100			1.85	0.61	0.04	0.02	0.01	0.08	-0.01	-0.07	-69	-0.04

[1] Crop Rotation, crop at time of sampling is in bold, C=corn, S=soybean, W=wheat.
[2] Tillage, primary tillage, Est. NT=no-till established for 11 yr before experiment; New-NT, no-till established at beginning of experiment.
[3] Abbreviations: SOC, soil organic carbon; SMAF, soil management assessment framework, β-gluc, β-glucosidase activity reported as mg *p*-nitrophenol released g^{-1} soil hr^{-1} incubation; Δ=amount of change, calculated by subtracting the initial value from the value after 6 years.

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