Crop yield and greenhouse gas responses to stover harvest on glacial till Mollisol

Jane M-F Johnson[A] and Nancy W. Barbour[A]

[A]USDA-Agricultural Research Service, North Central Soil Conservation Research Laboratory, 803 Iowa Ave., Morris, MN 56267, Email jane.johnson@ars.usda.gov, nancy.barbour@ars.usda.gov

Abstract
Producing clean renewable energy and reducing climate change are important and interrelated issues. Corn stover is targeted as a potential non-food bioenergy feedstock, especially in the Midwest United States. Crop residue management impacts soil water and temperature dynamics, which in turn can impact many soil processes. Stover harvest is expected to reduce soil cover and has the potential to reduce crop yield and impact carbon dioxide (CO_2) and nitrous oxide (N_2O) emission. Corn and soybean were grown from 2005 to 2009 in rotation on plots managed without tillage. After corn grain harvest, stover was harvested from 0 of 8 (0%), 4 of 8 (50%), 6 of 8 (75%) and 8 of 8 (100%) rows using a forage harvester with a 76-cm swath. All soybean stubble was returned to the field. Two cycles of stover harvest did not reduce corn or soybean yield or alter CO_2 or N_2O emission. Thus, these results suggest that harvesting residue will not influence CO_2 or N_2O emission in the field.

Key Words
Corn stover removal, nitrous oxide, bioenergy, carbon dioxide.

Introduction
Renewable bioenergy is one strategy for addressing the interrelated challenges of reducing dependence on finite, foreign fossil fuel sources while mitigating global climate change. Non-food plant materials such as crop residues and bioenergy crops (herbaceous and woody) are anticipated to serve as bioenergy feedstocks (Biomass Research and Development Board 2008; Perlack *et al.* 2005). Use of biomass for energy can reduce CO_2 emission when used as a substitute for fossil fuels, but potential risks (e.g., loss of soil quality and productivity) need to be minimized. There are instances of crop yield and soil quality rapidly declines in response to harvesting residue (Blanco-Canqui and Lal 2007; Blanco-Canqui *et al.* 2007; Wilhelm *et al.* 1986). Tillage and residue management influence many physical, chemical and biological soil properties (Johnson *et al.* 2009), thus it can be difficult to predict their impact on emissions (Petersen *et al.* 2008). Residue absorbs the energy of raindrop impact, increases infiltration, and presents a barrier to evaporation (Flerchinger *et al.* 2003; Sauer *et al.* 1996; Unger and Parker 1976). Therefore, residue covered soils may remain wetter and cooler than when a residue layer is absent (Johnson and Lowery 1985; Unger 1988). Harvesting crop residue for bioenergy changes the soil microclimate, soil susceptibility to erosion, organic matter available for microbial activity and C sequestration, and may also change methane (CH_4) and N_2O flux. The objectives of this research were to one) assess the impact of corn stover harvest rate on subsequent corn and soybean yield; and two) monitor the CO_2, N_2O and CH_4 emission from soil with maximum stover harvested or all stover returned.

Material and Methods
The study site was on the Swan Lake Experimental Farm (45.682^o lat and 95.802^o long, elevation 357 m), with a mean annual temperature of 5.8^{o}C and mean annual precipitation of 645 mm. Native vegetation for the region is tall grass prairie. The soil series in the experimental area are predominately a Barnes loam (fine-loamy, mixed, superactive, frigid Calcic Hapludoll) and an Aastad loam (fine-loamy, mixed, superactive, frigid Pachic Hapludoll). The experimental area is nearly level with <2% slope. The parent material is glacial till from the Des Moine Lobe deposited during the Wisconsin glaciations. Texture analysis and baseline bulk density, pH, total C, organic C, total N, P (Olsen extract for calcareous soils) and K were determined on soil collected in the fall of 2005 using standard soil protocols (Table 1).

The plot area has been managed without tillage since 1995, primarily in continuous corn. Since 2005, the plots have been in a corn-soybean rotation, with both phases grown each year. All soybean stubble was returned to the field. Stover was harvested from 0 of 8 (0%), 4 of 8 (50%), 6 of 8 (75%) and 8 of 8 (100%) rows using a forage harvester with a 76-cm swath. Harvest rows are shifted across the plot, such that the

Table 1. Base-line texture analysis summary of biomass removal plots at Swan Lake research farm plots, soil samples collected in the of fall 2005.

Depth	Sand	Clay	Silt	Bulk density	pH_{CaCl2}	Total C	Organic C[a]	Total N	P[b]	K
cm	(--------------%		-----------)	Mg/m^3		(-----------g /kg		-----------)	(--- mg /kg---)	
0 to 5	43.2	23.5	33.4	1.37	6.06	27.9	27.5	2.43	34.9	178
5 to 10	42.1	24.4	33.4	1.41	6.27	20.9	20.4	1.87	17.2	132
10 to 20	41.5	21.6	36.9	1.44	6.48	21.1	20.6	1.89	15.0	130
20 to 30	39.1	21.6	39.3	1.51	6.73	15.9	14.9	1.39	8.3	142
30 to 60	42.5	20.6	36.9	1.41	7.46	18.3	6.6	0.67	3.9	139
60 to 100	42.7	20.6	36.7	1.58	7.73	25.8	1.3	0.25	3.0	115

[a]Organic C determined by the difference between total combustible C and inorganic C as these are calcareous soils. [b] Olsen Phosphorus extraction for calcareous soils.

same rows are not repeatedly harvested. Based on the amount of biomass remaining in the field we estimated that 40 to 90% of the stover biomass was removed when 8 of 8 rows were harvested (data not shown). The dry mass of material harvested was determined. In plots with no stover removal, stover yield was determined by harvesting residue from two 2-m row sections; this stover was returned to the harvest site (except for a small subsample used for moisture determination). The rate of GHG (CO_2, N_2O and CH_4) emission was monitored from planting 2008 to planting 2009 in the 0 and 100% residue harvest in both phases of the rotation (corn and soybeans). Samples were collected using closed-vented chambers with anchors driven at least 8 cm into the soil (Hutchinson and Mosier 1981; Johnson *et al.* 2010) using a stratified sampling with weekly sampling during the spring-thaw and after management events (e.g., N-fertilizer application or tillage), and 14-day sampling intervals at other times. The concentration of CO_2, N_2O and CH_4 were determined by GC-TCD, GC-ECD and GC-FID, respectively (Johnson *et al.* 2010). Treatments were arranged in a randomized complete block design with four replicates. The effect of residue removal on yield and emission was assessed with a mixed model, with replication as a random term and removal rate as a fixed term.

Results and Discussion

Residue cover at planting was inversely proportional to the amount of corn stover harvested (data not shown). The impact was still noticeable during the next corn phase with there being less protection against erosive forces when the residue was harvested. Harvesting corn stover did not cause an appreciable or consistent impact on corn grain, stover or soybean yields after one or two cycles of corn stover harvest (Table 2). The first year of corn stover harvest depended upon the rotation phase and tillage. Corn (grain and stover) yield in 2007 reflects the impact of harvesting corn stover in 2005, while corn yield in 2008 reflects one cycle of harvesting corn stover (2006). Soybean yields in 2008 and 2009 reflect the impact of two stover harvest events, while yields in 2006 and 2007 reflect only one cycle of stover harvest. Reduced yield after only one cycle of stover harvest has been reported, due to increased evaporation and reduced infiltration (Blanco-Canqui and Lal 2007; Wilhelm *et al.* 1986), but others found no yield differences after repeated silage (Wilts *et al.* 2004) or residue harvest (Barber 1979). Under our experiment conditions, two cycles of harvesting corn stover, did not cause a detrimental impact on crop yields.

During the 2008 cropping season (May/2008 to April/2009), soil respiration was greater during the summer months (June to September) compared to the winter months (November to April) (Fig. 1). In general, the rate of CO_2 emission was unaffected by the returning or harvesting corn stover. At most sampling dates, there was relatively little N_2O emission. However, N_2O emission was observed in early spring (2009) when fluxes

Table 2. Corn grain, stover and soybean yield response, 2005 is the baseline yield before treatments.

Rate	Corn grain				Corn stover				Soybean				
	2005	2006	2007	2008	2005	2006	2007	2008	2005	2006	2007	2008	2009
	(-----------------------						Mg/ha						-----------------------)
0	9.5	7.3	7.9	7.5	7.1	5.7	7.9	6.4	3.2	2.7	2.6	3.3	2.3
50	6.8	8.1	7.4	9.7	5.1	5.2	7.4	7.3	3.5	2.9	3.0	3.3	2.2
75	7.4	8.3	8.4	8.2	5.6	5.5	7.8	7.0	3.5	2.7	3.1	3.6	2.6
100	8.5	7.5	5.7	9.1	6.4	5.4	7.5	6.8	3.4	1.9	2.9	2.9	2.5
	NA[a]	NS	NS	NS	NA	NS	NS	NS	NA	NS	NS	NS	NS

[a]NA = not appropriate, NS=not significant at $P \leq 0.05$

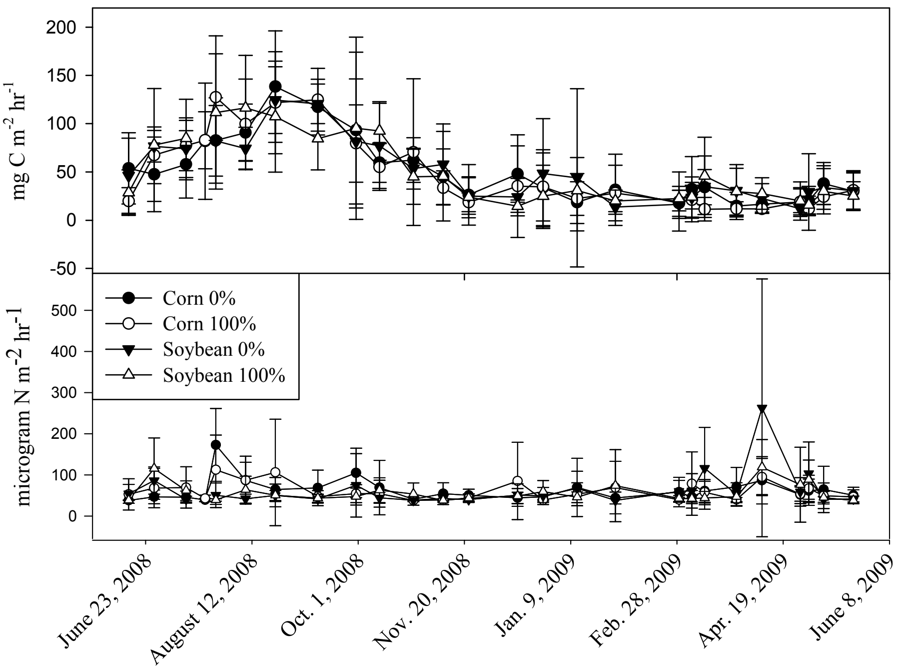

Figure 1. CO_2 - C (top) and N_2O-N (bottom) measured from May 21, 2008, to April 28, 2009. Each point is the average of four replications with two collars within each plot.

Table. 3. Cumulative GHG gas emission from May/2008 to April/2009 collected from two residue treatments, no rows harvested (0) or all rows harvested (100) from both crops.

	Corn		Soybean	
Removal rates	0	100	0	100
kg C /ha from CO_2	4230	4110	4260	4230
kgN /ha from N_2O	5.14	5.01	5.14	4.70

were highly variable and the plots varied in the amount of surface thawing, and standing water in or near the collar. We suspect that application of anhydrous ammonia fertilizer on June 23, 2008, is the reason we observed more N_2O from corn than from soybean on July 1 and July 15, 2008. Integrated for a full year, there were no differences between crops or residue treatment on the flux of CO_2 or N_2O (Table 3). Methane flux (consumption and release) were very small with concentrations at or near the detection limit of the gas chromatograph (data not shown).

Conclusion

In the short term, harvesting corn stover did not reduce corn or soybean yield. However, reduced soil cover increases the risk of soil erosion. The annual CO_2 and N_2O emission was not appreciably altered after only two cycles of harvesting corn stover. To assess more fully the impact of stover harvest on climate change also requires measuring changes in soil organic C, but measurable changes in soil organic carbon are slow and have not yet been assessed. The impact of long-term repeated corn stover on crop yield and GHG emission still needs to be studied.

References

Barber SA (1979) Corn residue management and soil organic matter. *Agronomy Journal* **71,** 625-627.

Biomass Research and Development Board (2008) Increasing feedstock production for biofuels: economic drivers, environmental implications, and the role of research. www.brdisolutions.com/Site%20Docs/Increasing%20Feedstock_revised.pdf

Blanco-Canqui H, Lal R (2007) Soil and crop response to harvesting corn residues for biofuel production. *Geoderma* **141,** 355-362.

Blanco-Canqui H, Lal R, Post WM, Izaurralde RC, Shipitalo MJ (2007) Soil hydraulic properties influenced by corn stover removal from no-till corn in Ohio. *Soil and Tillage Research* **92,** 144-155.

Flerchinger GN, Sauer TJ, Aiken RA (2003) Effects of crop residue cover and architecture on heat and water transfer at the soil surface. *Geoderma* **116,** 217-233.

Hutchinson GL, Mosier AR (1981) Improved soil cover method for field measurement of nitrous oxide fluxes. *Soil Science Society of America Journal* **43,** 311-316.

Johnson JMF, Archer DW, Barbour NW (2010) Greenhouse gas emission from contrasting management scenarios in the Northern Corn Belt. *Soil Science Society of America Journal* **74,** 396-401.

Johnson JMF, Papiernik SK, Mikha MM, Spokas K, Tomer MD, and Weyers SL. (2009) Soil processes and residue harvest management. In 'Carbon management, fuels, and soil quality Taylor and Francis' (Eds R Lal, B Steward) pp. 1-44. (LLC: New York, NY).

Johnson MD, Lowery B (1985) Effect of three conservation tillage practices on soil temperature and thermal properties. *Soil Science Society of America Journal* **49,** 1547-1552.

Perlack RD, Wright LL, Turhollow A, Graham RL, Stokes B, Erbach DC (2005) 'Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply'. (US Department of Energy and US Department of Agriculture: Washington, DC). www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

Petersen SO, Schjønning P, Thomsen IK, Christensen BT (2008) Nitrous oxide evolution from structurally intact soil as influenced by tillage and soil water content. *Soil Biology and Biochemistry* **40,** 967-977.

Sauer TJ, Hatfield JL, Prueger JH (1996) Corn residue age and placement effects on evaporation and soil thermal regime. *Soil Science Society of America Journal* **60,** 1558-1564.

Unger PW (1988) Residue management effects on soil temperature. *Soil Science Society of America Journal* **52,** 1777-1782.

Unger PW, Parker JJ (1976) Evaporation reduction from soil with wheat, sorghum, and cotton residues. *Soil Science Society of America Journal* **40,** 938-942.

Wilhelm WW, Doran JW, Power JF (1986) Corn and soybean yield response to crop management under no-tillage production systems. *Agronomy Journal* **7,** 184-189.

Wilts AR, Reicosky DC, Allmaras RR, Clapp CE (2004) Long-term corn residue effects: Harvest alternatives, soil carbon turnover, and root-derived carbon. *Soil Science Society of America Journal* **68,** 1342-1351.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.