Corn Stover to Sustain Soil Organic Carbon Further Constrains Biomass Supply

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ABSTRACT

Sustainable aboveground crop biomass harvest estimates for cellulosic ethanol production, to date, have been limited by the need for residue to control erosion. Recently, estimates of the amount of corn (*Zea mays* L.) stover needed to maintain soil carbon, which is responsible for favorable soil properties, were reported (5.25–12.50 Mg ha^{-1}). These estimates indicate stover needed to maintain soil organic carbon, and thus productivity, are a greater constraint to environmentally sustainable cellulosic feedstock harvest than that needed to control water and wind erosion. An extensive effort is needed to develop advanced cropping systems that greatly expand biomass production to sustainably supply cellulosic feedstock without undermining crop and soil productivity.

The United States has embarked on an ambitious program to develop technology and infrastructure to economically and sustainably produce ethanol from biomass. Corn stover, the aboveground material left in fields after corn grain harvest, has been identified as a primary biomass source (Perlack et al., 2005). Stover, and other crop biomass or residue, is frequently referred to as "trash" or agricultural waste, suggesting it has minimal value (Lal, 2004). However, when returned to the land, crop residue replenishes soil organic carbon (SOC) that typically has been reduced 30 to 50% of pre-cultivation levels (Schlesinger, 1985) through crop production activities. Soil organic carbon retains and recycles nutrients, improves soil structure, enhances water exchange characteristics and aeration, and sustains microbial life within the soil. Sparling et al. (2006) reported that crop yield and the value of environmental services (C and N sequestration) were greater for soils with greater SOC. Limited research has shown that removing stover reduces grain and stover yield of subsequent crops and further lowers soil organic matter levels (Wilhelm et al., 1986). The critical role stover plays in preventing erosion and maintaining or replenishing SOC has been acknowledged. However, the amount of stover required to sustain productivity, soil structure, and nutrient cycling has not been quantified. Furthermore, the dynamics by which biomass is converted to SOC is a topic of intense current research.

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Accepted methods exist to estimate the amount of crop residue needed to protect cropland from water and wind erosion. To date, sustainable harvest levels have been defined as the amount of crop residue above that needed to keep soil loss below the tolerable limit "T" (Graham et al., 2007; Perlack et al., 2005)]. No comparable algorithm exists to estimate the amount of crop residue needed to prevent loss of SOC. Johnson et al. (2006a) used several literature reports on change in SOC with various levels of crop residue removal to estimate source carbon needed to maintain SOC. They reported that under corn production and moldboard plow tillage 3.0 ± 1.0 Mg C ha^{-1} yr^{-1} (n = 6) was needed to maintain SOC and with no tillage or chisel tillage 2.1 ± 0.1 Mg C ha^{-1} yr^{-1} (n = 3) was needed. Under soybean [*Glycine max* (L.) Merr.], production, 2.0 ± 0.9 Mg C ha^{-1} yr^{-1} (n = 3) was needed to maintain SOC with all tillage practices. These estimates were converted to stover input by assuming both corn and soybean residue was 40% carbon (Fig. 1A). Mass of stover needed to keep soil loss less than T from water and wind erosion were estimated with Revised Universal Soil Loss Equation, version 2 (RUSLE2) (USDA-ARS, 2003a) and Wind Erosion Prediction System (WEPS) (USDA-ARS, 2003b) simulations, respectively (Fig. 1A) for soils in selected counties in the Corn Belt (Table 1). Stover produced beyond the amount needed to address these environmental services could be removed for other uses (Johnson et al., 2006b). Figure 1B shows harvestable stover at various corn grain yield levels limited by the need to sustain SOC. These estimates assume a harvest index [mass of grain/(mass of grain + mass of stover)] for corn of 0.53 (Johnson et al., 2006a).

Crop management practices greatly impact the rate of organic matter decomposition and erosion (Fig. 1A). As a consequence, harvestable stover varies widely with cropping practice (Fig. 1B). Although most estimates of harvestable stover (Graham et al., 2007) or the nation's capacity to produce feedstock to generate target ethanol production levels (Perlack et al., 2005) have fully considered limitations placed on stover removal by the need to control erosion, none have considered SOC dynamics the limiting factor. Under all of the conditions considered here, stover needed to maintain SOC was greater than that required to control erosion. This conclusion is supported by comparing results from Graham et al. (2007) with those of Johnson et al. (2006a).

This report emphasizes the need to further evaluate the validity of widely circulated estimates of U.S. cropland capacity to sustainably supply feedstock for the emerging cellulosic ethanol industry (Perlack et al.,

Abbreviations: K, soil erodibility; RUSLE2, Revised Universal Soil Loss Equation, version 2; SOC, soil organic carbon; T, tolerable soil loss; WEPS, Wind Erosion Prediction System.

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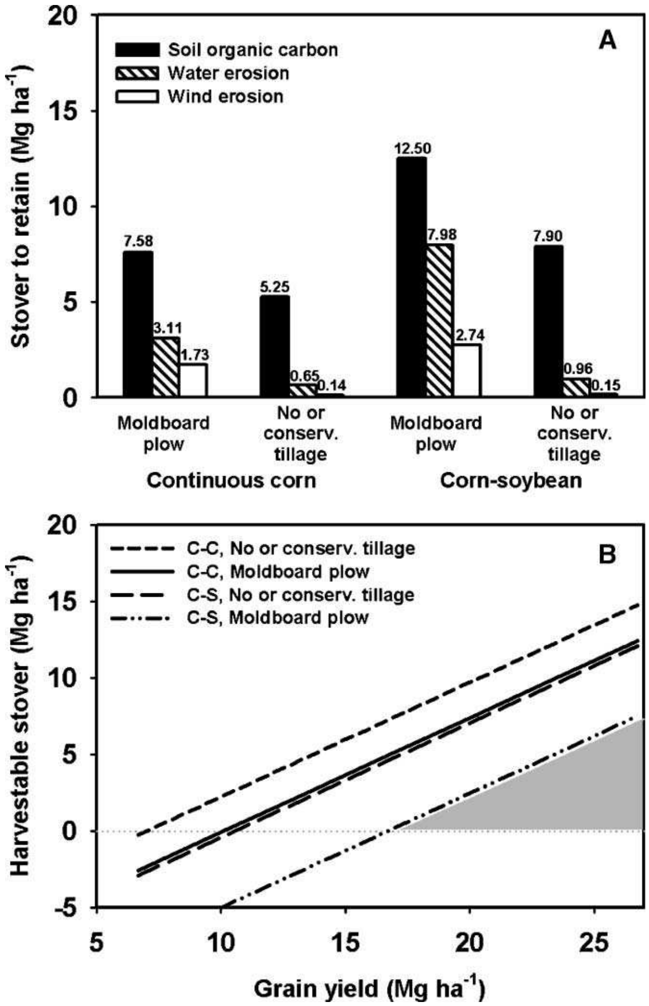

Fig. 1. (A) Estimated amount of corn stover needed to maintain soil organic carbon (SOC) content [solid black bars, (Johnson et al., 2006a)]; Revised Universal Soil Loss Equation, version 2 (RUSLE2) (USDA-ARS, 2003a) estimated amount of corn stover needed to limit water erosion within the accepted tolerance, T (bars with diagonal lines); and Wind Erosion Prediction System (WEPS) (USDA-ARS, 2003b) estimated amount of corn stover needed to limit wind erosion within the accepted tolerance, T (white bars), with various production practices. (B) Estimated amount of sustainably harvestable corn stover with various production practices and grain yield levels limited by the need to maintain SOC. For example, stover in the shaded area would be sustainably harvestable under moldboard plow tillage in a corn–soybean (C-S) rotation (short and long dashed line). Long dashed line: Harvestable stover under no-till or conservation tillage with a corn–soybean rotation. Solid line: Harvestable stover under moldboard plow with a continuous corn (C-C). Short dashed line: Harvestable stover under no-till or conservation tillage with continuous corn.

2005). Great urgency exists to gather reliable data to confirm our calculations and to expand these computations to a broader range of cropping systems and agricultural regions. This report should be viewed as an example of the type of comparisons that are needed at the regional (ideally at the field) level for multiple feedstocks; thereby, generating truly sustainable biomass feedstock production and harvest guideline. In addition, an extensive effort is needed to develop crops and advanced cropping systems that greatly expand biomass production and provide a sustainable supply of cellulosic feedstock without further reducing SOC and undermining the productive capacity of our soil. To address these needs in a timely manner, considering the speed with which the broader energy industry is pursuing cellulosic-based fuels, national and state energy policies and agronomic research investment priorities must be modified to reflect the immediate need to develop sound guidelines for sustainable biomass harvest and production practices that sustain crop productivity and the soil resource. The significance of this challenge cannot be overstated. Soil organic matter content, critical to crop production functions of the soil (Lal, 2004), increases slowly in response to improved management. Because of this slow response and the variable nature of SOC measurements, time is required to confidently measure the direction of SOC change in response to soil and crop management practices. Even starting today means that reliable empirical results may not be available until 2017, the time established by the "Twenty in Ten" plan announced in the 2007 State of the Union Address for a 20% reduction in U.S. gasoline use (Bush, 2007).

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Table 1. Summary of sites and conditions used to estimate aboveground crop biomass needed to reduce water and wind erosion to less than the tolerable limit (T). Biomass needed to control water erosion was determined with Revised Universal Soil Loss Equation, version 2 (RUSLE2) (USDA-ARS, 2003a), wind erosion with Wind Erosion Prediction System (WEPS) (USDA-ARS, 2003b). Counties were selected based on average corn yield. The soil within each country was selected based on its use for agricultural production, slope, erodibility (K†), and T.

				Biomass needed for water erosion control				Biomass needed for wind erosion control			
				Corn–corn		Corn–soybean		Corn–corn		Corn–soybean	
Location: state, county	Soil	Slope	T‡	Plow	Conserv.	Plow	Conserv.	Plow	Conserv.	Plow	Conserv.
		%	Mg ha^{-1}								
IA, Story	Kossuth silty clay loam	0–2	11.2	3.59	0.92	11.79	1.37	0.06	0.06	0.06	0.06
IL, DeKalb	Fox silt loam	2–4	9.0	9.25	1.35	11.79	1.79	0.06	0.06	0.06	0.06
IN, Kosciuska	Morley-Glywood Complex loam	1–4	9.0	7.51	1.23	11.79	1.64	0.06	0.06	0.06	0.06
MI, St. Joesph	Kalamazoo loam	0–6	9.0	3.16	0.82	3.16	0.82	0.10	0.06	0.06	0.06
MN, Dakota	Port Bryon silt loam	2–6	11.2	0.06	0.06	2.45	0.08	0.06	0.06	0.06	0.06
MN, Freeborn	Hayden loam	2–6	11.2	0.11	0.08	3.38	0.08	3.38	0.08	3.38	0.06
NE, Buffalo	Holdrege silt loam	3–5	11.2	3.74	0.09	11.79	0.96	3.74	0.06	11.79	0.96
OH, Seneca	Mermill loam	0–2	9.0	2.09	1.08	11.79	1.42	0.06	0.06	0.06	0.06
SD, Minnehaha	Moody-Nora silty clay loam	2–6	11.2	0.06	0.06	0.06	0.06	0.06	0.06	0.09	0.06
WI, Rock	Dresden silt loam	2–6	9.0	1.56	0.81	11.79	1.35	9.76	0.81	11.79	0.06
			mean	3.11	0.65	7.98	0.96	1.73	0.13	2.74	0.15
			SE	0.99	0.17	1.58	0.21	1.00	0.08	1.54	0.09

† Erodibility was 0.32 for all soils in this study.
‡ T is the tolerable soil loss; value varies depending on depth of A horizon.