Impacts on Soil of Large-scale Crop Residue Harvest for Biofuel Production.

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There is soaring interest in the production of fuel from green plants, for both economic and environmental reasons. Global oil production has peaked or soon will, but demand continues to increase, putting upward pressure on gasoline and diesel prices. At the same time, growing recognition of the climatic impact of rising atmospheric CO2 concentrations is providing additional incentive to replace fossil fuels with biofuels. To this point, most emphasis has been on ethanol fermentation from corn grain. Of course there are a multitude of other uses for corn, most notable as feed for livestock and poultry, but even if the entire US corn crop were dedicated to ethanol it would represent only a fraction, perhaps 10-12%, of the fuel use of the nation. Hence there is a need to find other bio-based fuel sources. Improvements in processing technology and continued increases in oil prices are enhancing the feasibility of producing ethanol from ligno-cellulosic sources, which could include a number of potential substrates. One which has received some attention is corn residue, also known as stover, a general term for the non-grain, above-ground portion of the corn plant.

A recent assessment, known informally as *The Billion Ton Report* (Perlack et al, 2005), has concluded that something on the order of 980 million tons of biomass could potentially be gathered and processed into ethanol on an annual basis, sufficient to satisfy 30% of the nation's liquid fuel needs. A substantial portion, of this hypothetical harvest is corn stover. Implicit in this is the assumption that this material is currently a waste by-product of corn production. Indeed, this has historically been the view of many farmers as well; for example, the attachments on a corn planter that clear crop residue from the row are commonly known as trash whips. However crop residues, particularly corn stover, play a critical role in sustaining healthy, productive soils, and Perlack et al (2005) acknowledge that these must be considered in any proposal for large-scale biomass utilization. There are two primary concerns associated with removal of corn stover: erosion control and maintenance of soil organic matter.

Crop residues protect the soil surface against both wind and water erosion. The degree to which this is true depends on a number of variables, including soil type, residue type, and topography, but extensive research over many years and locations has documented these erosion-prevention benefits. The authors of the RUSLE2 model, used by NRCS and other agencies throughout the world for erosion prediction, state that "Ground cover is probably the single most important variable in RUSLE2" (Foster et al., 2003). Sediment loss from farm fields eventually affects crop productivity, and sediment transport has significant negative offsite effects. These include increased turbidity and siltation of rivers and reservoirs and eutrophication due to phosphorus that is carried along with the suspended soil particles. It has been speculated that the erosive effects of residue removal might be minimized by practicing no-till, but research has shown substantial increases in runoff and sediment loss in such systems (Wilson et al, 2004), with all protective benefits of no-till gone by the second year following initiation of corn residue harvest or removal (Dabney et al, 2004).

A less obvious function of corn stover is that it serves as a precursor to soil organic matter (SOM). SOM is a key component of a healthy soil, positively affecting its water holding capacity, cation exchange capacity, and structure (Karlen et al, 1998). Unfortunately SOM, even in its most stable forms, is subject to microbial degradation, so a certain amount of fresh carbon input is necessary to maintain a stable SOM level. Research conducted at multiple locations by the USDA-ARS during a previous period of interest in biofuel production in the 1970's produced some general guidelines for the amount of returned residue needed for sustainability in conventional corn and corn/soybean production systems (Larson, 1979). The principal criterion in this effort was erosion protection rather than maintenance of SOM. They did not have the benefit of recently developed GIS databases such as SSURGO, so they restricted their scale of analysis to the major land resource are (MLRA) level. Within each MLRA they used information about corn yields, rainfall data, mean slope, and mean soil erodibility to generate estimates of soil loss as a function of tillage practice, crop rotation and amount of residue returned to the soil, using the Universal Soil Loss Equation (USLE). These estimates were then compared to "tolerable" soil loss rates to estimate the amount of residue that could be safely harvested under different tillage and rotation scenarios. They concluded that approximately 49 million tons of corn residue could be taken without significant deleterious effects.

Some 25 years later, Perlack et al. (2005) estimated that under current practices that harvest could be 75 million tons. Widespread adoption of conservation tillage techniques has been one factor in this increase in the hypothetical safe level of corn stover removal, but the primary element has been steadily rising yield. Mean corn grain yield has been increasing over the past 35 years at an average annual rate of 90 kg ha^{-1}, while total planted acreage and harvest index (the ratio of grain yield to total above-ground biomass) have remained relatively stable. Surprisingly this has occurred without an increase in fertilizer use, and appears to be due to a variety of factors, including genetic advances, warmer temperatures, better weed and insect control, increased irrigation in some areas and increased tile drainage in others. If this steady rate of increase is projected forward, it suggests a 50% increase in yield over the next 40 years, a substantial factor in the Perlack et al. (2005) projection that 170-250 million tons of corn stover could eventually be available for biofuel production.

Can this be accomplished without deleterious effects on soil? Johnson et al. (2006) estimate that the minimum above-ground C that must be retained to maintain SOM levels under corn production is 2-3 Mg C $ha^{-1}yr^{-1}$, depending on tillage practice. Because below-ground processes are much more difficult to track, there is substantial uncertainty surrounding this number, and any temporal trends associated with it. West and Post (2004) have summarized data from a wide variety of soil sampling experiments in agricultural systems and have concluded that conversion from conventional tillage to conservation tillage sequesters, on average, 54 ± 19 g C $m^{-2}y^{-1}$. Since adoption of conservation tillage techniques has been steadily increasing, this would suggest that soil organic matter levels may be increasing as well. However, Baker et al. (2006) have questioned the methodology that has been employed in nearly all of these tillage studies, in which only the near-surface soil (30 cm or less) is sampled. They note that in the few tillage studies where the entire root zone has been sampled, there is no conclusive evidence that conservation tillage has produced an increase in total soil C. Rather, it appears to produce a change in the distribution of C, with relatively more near the surface and less in the deeper layers in conservation tillage systems.

Thus, no-till and related tillage practices may do little to *directly* mitigate rising atmospheric CO2 levels. However, they may have substantial indirect benefit by improving the sustainability of soils subjected to biofuel-related corn stover removal. From the standpoint of soil quality and productivity, it can be argued that surface layer soil C content is more important than the total amount of C in the profile. After all, the known benefits of soil organic matter, including its effects on cation exchange capacity, water-holding capacity, and soil structure have their greatest impact when expressed in the surface few cm. Consequently, the ability of no-till to maintain or increase surface-layer carbon *and* protect against erosion suggest that it will be an important component of stover harvest farming systems. However, there are other problems associated with no-till that have limited its acceptance. No-till soils tend to be cooler and wetter in the spring due to the layer of residue on the surface, making it more difficult to plant and slowing emergence. This has particularly been a factor in the northern portions of the corn belt. Also, compaction can become a problem in the absence of tillage. Stover removal for biofuel should improve spring soil warming and drying, but it could aggravate compaction, due to the additional wheel traffic involved (Wilhelm et al., 2004).

The overall, integrated impact of substantial corn stover removal on soils remains unclear, but there are obvious concerns. However, it may be possible to implement new farming practices that will allow harvest at the levels envisoned by Perlack et al. (2005) without increased erosion or loss of SOM. These include a reduction in tillage intensity, inclusion of cover crops and companion crops, the use of higher-yielding cultivars, and innovative harvest techniques. Research to develop and test these approaches is currently underway at a number of USDA-ARS locations, with the goal of developing production systems and guidelines within the next five years for substantial, yet sustainable, stover harvest that protects soil resources and water quality.

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