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IDEAS & INNOVATIONS

Conservation considerations for sustainable bioenergy feedstock production: If, what, where, and how much?

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The Energy Independence and Security Act (EISA), investments in lignocellulosic biorefineries by both the Department of Energy (DOE) and commercial entities, as well as many other market, security, and policy drivers, have increased public interest in harvesting nongrain biomass (i.e., crop residues) from our lands. This interest is positive because it is creating investment and entrepreneurial opportunities in many rural communities. However, it has also raised concern among many conservationists because some proponents of lignocellulosic energy may not realize how many important ecosystem services crop residues provide to the land. Crop residues on the soil surface are the first line of defense against the erosive forces of wind and rain. Residues also provide the building blocks for soil organic matter (SOM). As SOM is increased, crop nutrients are cycled more efficiently, soil micro- and macroaggregates are created, soil structure is stabilized, and soil water retention is increased. All these soil functions contribute to increasing crop productivity, water quality and quantity, and air quality. Furthermore, because SOM is >50% carbon (C), building SOM partially mitigates rising levels of an important greenhouse gas carbon dioxide (CO_2) by C sequestration.

Fortunately, the scientific information base needed to answer the difficult questions of "if, where, and how much" residue can be sustainably harvested is not barren. Many conservationists will recall that harvesting biomass for bioenergy production was an important research topic during the late 1970s and early 1980s. In fact, many of our mentors (Allmaras et al. 1979; Larson 1979; Larson et al. 1972; Lindstrom 1986; Rasmussen et al. 1980) provided an excellent foundation upon which to build when interest in biomass was rekindled (Dipardo 2000; Perlack et al. 2005). Although, many of the original biomass harvest studies were terminated during the 1980s, several remnants were maintained as part of long-term management (e.g., tillage, crop rotation, fertility) studies at many USDA Agricultural Research Service (ARS), DOE, and university sites. This demonstrates once again the importance of long-term soil and crop management research. So, what do we know and is it possible to add bioenergy feedstock production to the services expected from our finite land resources?

Building on nearly 40 years of soil and water conservation research since the first energy crisis in 1973, we know that the answer is not simple. In fact, the best answer is, it depends! It depends on climate, soil type and topography, and land management and productivity (figure 1). Some land areas may be managed to provide both grain and biomass in a sustainable manner (figure 2). There are other land areas where periodic harvesting of perennial herbaceous or woody species, without growing row crops, will be necessary to achieve sustainable bioenergy feedstock production. Within a landscape, there may be areas that are simply too fragile to support removal of any biomass. To be economically, environmentally, and socially sustainable, bioenergy feedstock production systems must protect and preserve soil, water, air, plant, and animal (i.e., wildlife) resources while also providing viable economic opportunities for people throughout rural America. Therefore, the real question is not, can we have both bioenergy feedstock production and conservation? but rather, where and how can we have both feedstock production and conservation?

Our goal is to offer some general guidelines or principles that can be used to help answer the questions of, If, what, where, and how much? biomass can be sustainably harvested for energy uses. A starting point for answering the "if" question is erosion risk (table 1). If land is classified as highly erodible but still managed in row crops, residues should not be harvested and hopefully all appropriate conservation practices are in place, such as tillage

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Figure 1

Basic concepts for developing harvest guidelines (Andrews 2006).

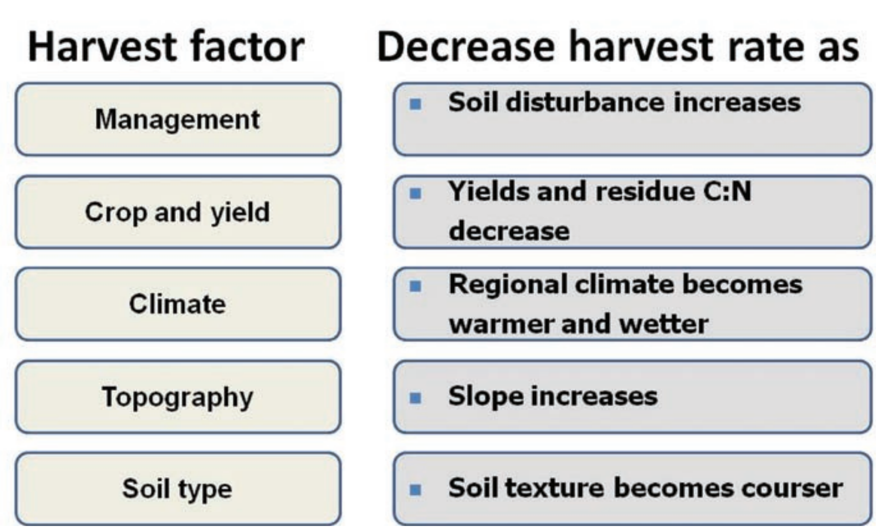


Figure 2

Complex landscapes provide opportunities for a range of biomass feedstock and food crop production. Beneficial conservation practices will vary across the landscape. Photo by Scott Bauer. Courtesy of USDA Agricultural Research Service image gallery.

Table 1

General guidelines for determining if residue could be harvested from agronomic crops (e.g., corn stover) or perennial species (e.g., switchgrass or hybrid poplar).

	Row crops	Perennials
Highly erodible land	Exclude form harvesting row crops, management strategies to protect against erosion recommended	Exclude from biomass harvest, management against erosion or other degradation recommended
Lands marginal (Conservation Reserve Program eligible acreage)	Exclude form harvesting row crops, management strategies to protect against erosion recommended	May be suitable for periodic harvest of perennial species (herbaceous and/or woody), provided sufficient cover is maintained for erosion protection
Agricultural lands—moderate erosion risk	Maybe suitable for limited harvest with compensatory management and soil organic carbon maintenance	May be suitable for periodic harvest of perennial species (herbaceous and/or woody), provided sufficient cover is maintained for erosion protection and soil organic carbon maintenance
Agricultural lands—low erosion risk	Maybe suitable for harvest based on soil organic carbon maintenance	May be suitable for harvest of perennial species (herbaceous and/or woody), provided sufficient cover is maintained for erosion protection and soil organic carbon maintenance

and residue management, crop rotation, and cover crops. The more susceptible a landscape, or even landscape position, is to wind and water erosion, the more restrictive management practices need to be to prevent soil erosion (figure 1). However, as erosion risk within the landscape position being evaluated decreases, maintenance of SOM will likely become the factor that limits stover harvest. It is the natural variation in landscapes that makes it very difficult to predict the amount of crop residue that must be left to protect soil and water resources at a field scale. For that reason, precision harvest of residues should be practiced. For instance, current estimates of the amount of biomass that should be left in the field (i.e., 6.25 ± 4.25 Mg ha^{-1} y^{-1} [2.8 ± 1.9 ton ac^{-1} yr^{-1}] [Johnson et al. 2006; Johnson et al. 2009]) have tremendous uncertainty. Therefore, while such averages provide science-based examples and facilitate discussions regarding sustainability, those values per se are not appropriate for field-scale management decisions. As averages change across a region and across a field due to topography or soil, the harvestable amount of residue will also change. For sustainable and precise harvest to occur, decision support tools that are both producer friendly and capable of providing field or subfield decisions are desperately needed.

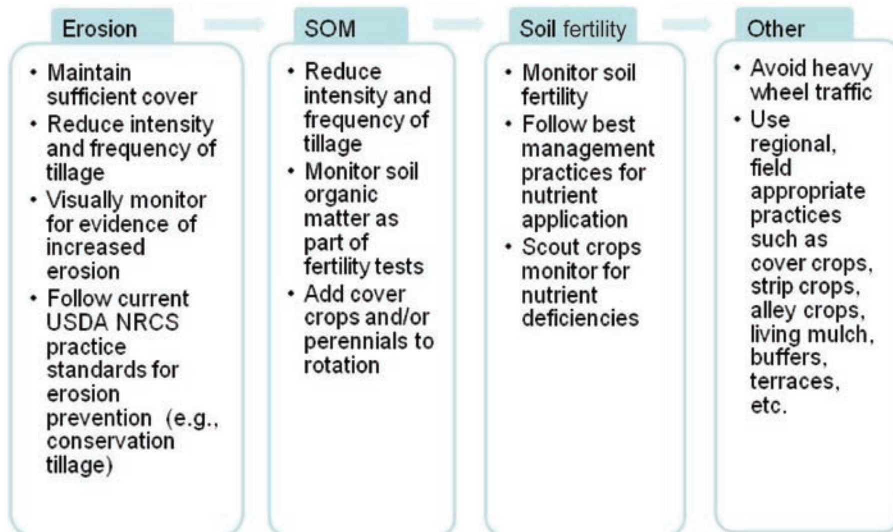
The USDA Natural Resources Conservation Service (NRCS) does not plan to create a National Conservation Practice Standard for crop residue removal because residue removal is not considered to be a conservation practice. Nevertheless, we know from both modeling and experimental data that resource degradation is very likely to occur if conservation practices to mitigate for residue removal are not implemented. Many such mitigating practices exist among the NRCS National Conservation Practice Standards. Therefore, in the near-term, producers are encouraged to work with their local USDA NRCS offices to examine case studies based on their soil, farming practices, and climatic conditions to determine if harvesting crop residues would cause undesirable damage to their soil quality.

The erosion model RUSLE2 in concert with the Soil Conditioning Index (SCI) can be used to integrate soil, climate, and biomass inputs and field operation and predict the impact of crop residue harvest on erosion amount and trend in SOM. The SCI is recognized as valuable tool for assessing potential changes in SOM (Abrahamson et al. 2007), but regionally sensitive, interactive tools are needed to fully determine how harvesting crop residues or adding perennials into their farming scenarios may impact soil quality, fertility, and productivity of their land. One example of an evolving decision aid is the I-FARM tool developed at Iowa State University (ISU 2010), which is a database-driven farming systems simulation model that predicts economic returns and ecosystem impacts of farm operations (van Ouwerkerk et al. 2007). I-FARM incorporates the RUSLE2 and SCI programming for predicting erosion and SOM trend. It is capable of integrating both crop and livestock components and can be used to simulate crop residue harvest.

Another potential limiting factor affecting the sustainable harvest rate of either crop residue or perennial feedstock is the increased amount of plant nutrients removed from the field. For corn, the stover cutting height or harvest of only cobs was shown to significantly affect the mass and nutrient content of the harvested material (Johnson et al. 2010; Wilhelm et al. forthcoming). Johnson et al. (2010) reported that at grain harvest, nutrient concentration averaged 5.5 g nitrogen (N) kg^{-1} (0.55% N), 0.5 g phosphorus (P) kg^{-1} (0.05% P), and 6.2 g potassium (K) kg^{-1} (0.62% K) in cobs; 7.5 g N kg^{-1} (0.62% N), 1.2 g P kg^{-1} (0.12% P), and 8.7 g K kg^{-1}(0.87% K) in the above-ear stover fraction; and 6.4 g N kg^{-1} (0.64% N), 1.0 g P kg^{-1} (0.10% P), and 10.7 g K kg^{-1} (1.07% K) in the below-ear stover fraction (stover fractions exclude cobs). These quantities of nutrients are removed in addition to those removed with the grain. The impact of harvesting corn stover or other crop residues on soil fertility depends on the nutrient concentration in the harvested biomass, the amount of biomass harvested, harvest frequency, and inherent fertility of the soil. Our general guideline is to utilize soil and plant analyses and to scout crops for nutrient deficiencies (figure 3).

Figure 3

Conservation and management guidelines for achieving sustainable residue removal rates.



Perennials generally offer several conservation benefits compared to high-intensity row crops, which is why they may be more suitable in some regions and on some landscape positions (Blanco-Canqui 2010). By virtue of their perennial nature, these crops reduce the frequency of, and potential degradation associated with, tillage. Perennials also capture solar radiation for a longer portion of the year compared to annual species (Baker et al. 2007). Switchgrass (*Panicum virgatum*), an herbaceous perennial being evaluated as a bioenergy feedstock, has a higher root density than annual crops (e.g., corn [*Zea mays* L.]) or even alfalfa (*Medicago sativa*) (Johnson et al. 2007a). Incorporating such perennial species into feedstock production systems can help stabilize soils, thus reducing erosion, improving water quality, increasing and improving wildlife habitat, and sequestering SOC (Johnson et al. 2007b). Care must be taken in the establishment year because soils can be very susceptible to erosion before the perennial is fully established. Similar to crop residues, harvest rate for perennials will need to be tailored to maintain sufficient cover for erosion control, and time of harvest will need to be optimized for stand maintenance and wildlife protection (e.g., avoiding harvests during nesting periods for ground-nesting bird species). Other interactions with wildlife will also need to be determined, and in some regions it may be beneficial to harvest in early spring, thereby providing soil protection and winter cover.

Fast growing woody perennials can be grown on marginal lands for biofuel, which simultaneously provides environmental services while relieving harvest pressures from natural forest (Johnson et al. 2007b). Woody perennials can help retain sediments, capture nutrients, and stabilize soils and stream banks. However, during planting and harvest, supplemental conservation practices may be necessary to avoid erosion and potential negative effects on water quality. Fortunately, planting woody species to form shelter belts and stabilize stream banks is already recognized as a conservation practice to reduce soil erosion (Brandle et al. 2004; Lowrance et al. 2002).

Undoubtedly, achieving sustainable bioenergy feedstock production is contingent upon soil and water conservation. In those areas where biomass harvest is reasonable, implementing mitigating soil conservation practices will facilitate the sustainability of biomass harvest. As readers of this journal know, implementing soil conservation practices is a prerequisite to providing the food, feed, fiber, and fuel needed for generations to come.

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