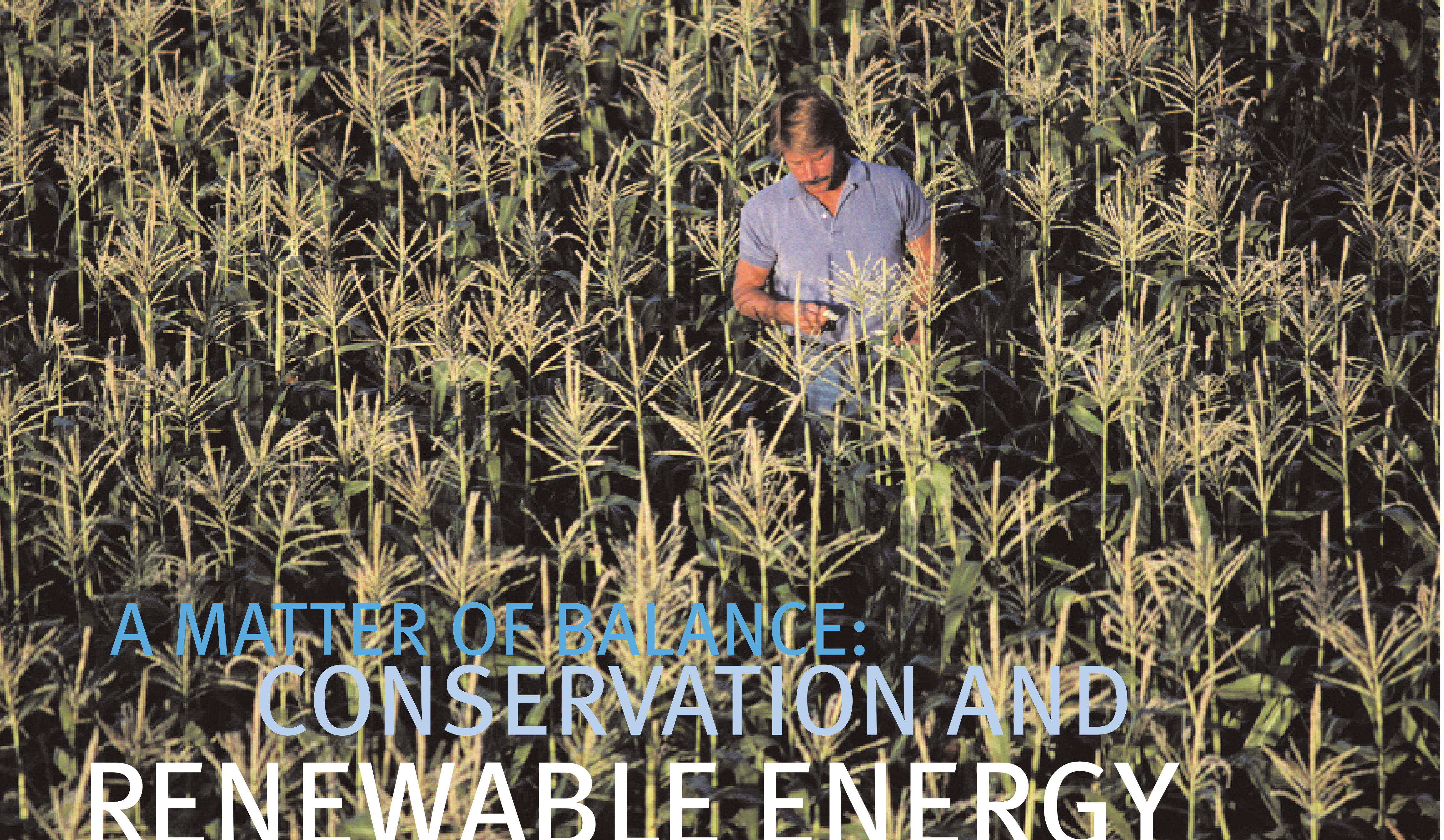


A MATTER OF BALANCE: CONSERVATION AND RENEWABLE ENERGY

By Jane M-F Johnson, Don Reicosky, Ray Allmaras, Dave Archer, and Wally Wilhelm

As communities and a country, we have a monumental task to solve the energy and global climate change problems, while maintaining our capacity to produce food, feed, and fiber for an ever increasing world population. The severity of these problems is exacerbated by the universal desire for an increased standard of living, which invariably translates to more energy use, greater demand for products, and higher quality diets (usually in the form of more fresh fruits and vegetables and more animal protein). Agriculture and forestry are in a unique position as we attempt to address these opposing problems in the most beneficial manner. To address the food and feed issue, agriculture will likely consume more energy and aggravate the energy consumption and climate change situation, at least in the short term. However, soils have a tremendous capacity to sequester carbon (C) (Figure 1), if managed wisely, offering agriculture an exceptional opportunity to remove carbon dioxide, a greenhouse gas, from the atmosphere. Use of agricultural biomass for energy can also be part of our energy solution. Research is being conducted to determine how much, when and where biomass can be removed without soil and/or environmental degradation. A balanced, sustainable approach is critical to solving the related problems of global warming, limited fossil fuel, and food production for the long term. No energy or global warming solution will be effective, however, conserving, curbing our high energy use habits, and including other renewable energy solutions (e.g. solar, wind) is necessary.

So what is agricultural biomass? Simply, agricultural biomass is any or all above-ground plant material that is not grain. It is also called crop biomass, crop residue, stover, or straw, even fodder. In the case of energy crops, such as switchgrass, biomass includes the entire above-ground part of the plant. In the Corn Belt, the major agricultural biomass is corn stover. Stover is corn stalks, cobs, and leaves left in the field after grain harvest. About one-half of the above-ground plant mass is grain and the other half is stover. Crops such as soybean or sugar beet, leave very little biomass in the field after harvest. Crop residues are sometimes referred to erroneously as debris, trash, or waste. These characterizations imply that stover has no value if allowed to remain on the land and is not wanted or used by the producer.

Why is agricultural biomass valuable? First, biomass left on the field protects the soil from wind and water erosion. Erosion removes the soil rich in organic matter and plant nutrients. Although the nutrient-rich topsoil is the most valuable soil component for crop production, it is devastating in lakes and waterways—supporting eutrophication and plugging stream channels. Secondly, biomass left on the field serves a critical role in supplying carbon and nutrient cycles with raw material and energy, and through the action of decomposing microorganisms, builds soil humus. Soil humus stores and cycles plant nutrients, buffers soil against compaction, improves water-holding capacity, helps soil resist wind and water erosion, and promotes soil productivity. Increasing soil carbon content is also an effective means to reduce carbon dioxide levels in the atmosphere. These benefits from crop biomass help preserve soil quality, water quality, and air quality.

Agricultural biomass is positioned as a major near-term ethanol feedstock (Perlack et al., 2005), and may be used for other forms of biopower, direct-firing, cofiring, gasification, and pyrolysis (www.nrel.gov/learning/re_biomass.html). Biomass can also be used for bio-products such as wood-like construction materials (Moskowitz, 2001) or as the source of carbon building blocks for new bio-degradable plastics. The Vision for Bioenergy and Biobased Products in the U.S. states that by 2030 biomass will provide five percent of the nation's power, 20 percent of the nation's transport fuel, and 25 percent of the nation's chemicals (USDOE, 2002). Perlack et al. (2005) estimated agricultural biomass could provide nearly a billion dry tons annually for bioenergy, and stated corn stover is the largest untapped source of agricultural biomass in the United States. Overall, they estimated that about 40 percent could come from crop biomass, 38 percent from perennial grasses, and the remainder coming from dry distillers' grain, manure, and other processing residues (e.g. sugar cane bagasse).

Careful consideration needs to be given to when, where, and how much crop biomass can be sustainably harvested for bioenergy. Perlack et al. (2005) recognized the need to determine the amount of crop residue that must remain on the soil to prevent loss of production capacity and soil functionality. Perlack highlights the need and challenges, the agricultural research community to provide answers by stating, "Removing any residue on some soils could reduce soil quality, promote erosion, and lead to loss of soil carbon which in turn lowers crop productivity and profitability."

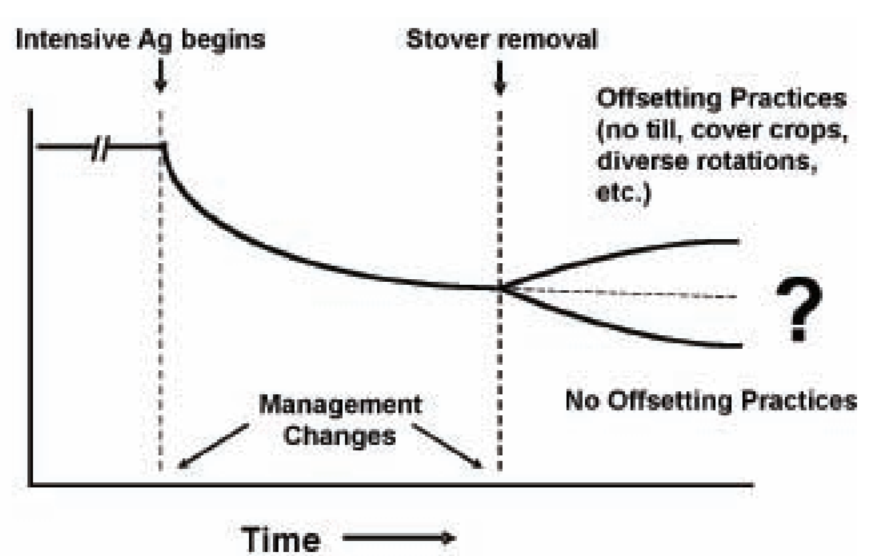
During the oil embargos of the 1970's, crop biomass was also viewed as an alternative for oil. Dr. William (Bill) Larson (1979) cautioned that "the need to maintain soil productivity should be our first consideration and only, once this criterion has been met, should crop biomass be removed for alternative purposes." More recently, Lal (2004) warned that removing crop biomass may jeopardize soil and environmental quality. As biomass is again viewed as an energy source, the short-term economic benefits need to be balanced against both short and long term soil and environmental risks (Wilhelm et al., 2004).

There are producer, consumer, and societal benefits of using biomass as a feedstock for ethanol production, gasification, or boiler fuel. Biomass can function as a domestic, renewable substitute for natural gas and coal. Through emerging technology it can be converted to ethanol and used as a transportation fuel. It may become an additional farm commodity and offer rural communities new industrial opportunities. The risks of removing too much biomass include increasing erosion, removing valuable topsoil, increasing run-off of nutrients and pesticides, and losing soil organic matter. These processes have environmental and production costs and lead to loss of productivity and a need for increased inputs. It is critical that we balance economic and energy opportunities with honest and complete assessments of environmental costs and identify who benefits from the economic return and who bears the environmental costs.

As the biomass industry develops, the benefits of keeping a portion of the biomass on the field must be given proper economic value. Appropriate harvest rates and harvest frequencies recommendations need to take into account the crop residue needed to maintain organic matter and prevent erosion. The risk of accelerated erosion has been included in some analyses, but most do not include the need for biomass to maintain soil humus or carbon levels. A recent literature review (Johnson et al., 2006) gives an initial estimate of biomass needed to maintain soil carbon levels. In most of the studies used for this analysis, fields were tilled with a moldboard plow, but a few were tilled with a chisel plowed or not tilled. When corn was grown continuous and soil tilled with a moldboard plow, 7.6 ±1.0 Mg stover ha^{-1} yr^{-1} were needed to maintain soil organic carbon; 5.3±0.1 Mg stover ha^{-1} yr^{-1} were needed to maintain soil organic carbon levels with use of a chisel plow or no tillage. By comparison, in western Minnesota returning 8.25 Mg stover ha^{-1} yr^{-1} (for 29 years) did not prevent soil carbon loss with annual fall moldboard plowing and secondary spring tillage (Reicosky et al., 2002).

How much stover is produced by a corn crop? Stover production can be estimated from grain yield and harvest index [HI; grain mass / (grain mass + stover mass)]. Modern corn hybrids have an HI of 0.53 (Johnson et al., 2006). For example, a crop with a grain yield of 9.8 Mg ha^{-1} (156 bu $acre^{-1}$) would have an estimated stover yield of 7.5 Mg ha^{-1} (Table 1). For comparison, average national corn yield in 2005 was 9.2 Mg ha^{-1} (147 bu ac^{-1}), while both Minnesota and Iowa averaged 10.9 Mg ha^{-1} according to the USDA-National Agricultural Statistic Service (www.nass.usda.gov:8080/QuickStats/index2.jsp). The amount of stover that could be harvested annually depends on minimum residue requirements, yield, tillage management, and cropping system (Table 1). In order to maintain soil C levels with the national average grain yield of 9.2 Mg ha^{-1}, it would have 7.0 Mg ha^{-1} stover. Therefore, no biomass harvest is recommended under moldboard plow tillage in either a corn and soy-

Figure 1.
Potential changes in soil carbon (C) due to management. Soils have lost 20 to 50 percent of original soil organic C levels, with some sites (e.g. eroded hill tops) losing as much as 70 percent since initiated intensive agriculture.



Credit: Wally Wilhelm, December 2005

bean rotation or continuous corn, or under any tillage system in a corn and soybean rotation. At this yield level, corn stover could only be harvested at a rate of 1.7 Mg ha^{-1} under continuous corn with chisel plow or no tillage. Our under-lying assumption is that corn and other crop residues should NOT be harvested from highly erodible lands even if erosion and soil organic C needs are met. Incorporation of cover crops into the system may increases the amount of biomass available to harvest according to simulation results reported by Kim and Dale (2005).

These preliminary estimates from a limited number of studies strongly support the immediate need for more field trials to understand the impact of removing biomass, especially in systems with conservation or no tillage and modern high yielding production practices and hybrids. The Renewable Energy Assessment Project (REAP) is a new cross-location effort by the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) to work with the Department of Energy (DOE) and the biomass ethanol industry to address that need by defining practices for sustainable production and harvest of crop residue as an ethanol feedstock. The project will result in guidelines for sustainable removal of residue and management practices to optimize residue collection while maintaining or improving soil productivity. This research will provide harvest rate recommendations and guidelines for different regions of the Corn Belt.

Summary

We still need an answer to the critical question 'How much crop biomass is needed to protect and maintain the soil resource, and correspondingly, how much can be harvested as renewable fuel'? Through photosynthesis and the processes of growth and translocation, plants use solar energy to transform carbon dioxide and water into grain and biomass. The latter is useful for nurturing the soil biology, maintaining soil properties important in soil quality, and also as a bioenergy feedstock. A practical compromise is needed for crop biomass to function effectively in the competing roles of soil conservation and renewable energy production. Economics and government policy will drive development of biomass for biofuel industries. However, we cannot afford to overlook the potential costs associated with wide-scale removal of crop residues from the land. These costs may not be readily apparent in the short term and economic impacts are not easily quantified. Thus far, society has failed to place economic value on ecosystem services provided by agricultural watersheds. We suggest a cautious approach to harvesting crop biomass for energy until science-based research provides answers and guidance to the critical questions of how much, when, and where to harvest crop biomass. Research is needed to provide land managers, the biomass industry, and action agencies with sound, scientifically based, field-tested guidelines for sustainable production and harvest of crop residues. This need is especially critical in light of the current economic pressures to find alternative energy sources and the short time-frame set by DOE for domestic renewable fuels to become a significant contributor to the nation's energy and product supply. As the biomass energy industry develops, we also strongly encourage energy conservation to achieve sustainable energy security.

Table 1: Estimates of corn stover available to harvest while maintaining soil organic carbon, assuming two common cropping systems continuous corn and corn-soybean rotation in the Corn Belt comparing moldboard plow and conservation tillage (chisel plow or no tillage). These estimates assume low erosions risk.

Corn			Corn Stover that can be harvested and maintain soil C			
	Grain	Stover †	Continuous corn		Corn – soybean	
			Moldboard plow tillage	Chisel plow or no tillage	Moldboard plow tillage	Chisel plow or no tillage
bu ac^{-1}	----------	----------	----------Mg ha^{-1}----------	----------	----------	----------
103	6.5	5.0	0.0	0.0	0.0	0.0
156	9.8	7.5	0.0	2.2	0.0	0.0
200	13.1	10.0	2.4	4.7	0.0	2.1
259	16.3	12.5	4.9	7.2	0.0	4.6
312	19.6	15.0	7.4	9.7	2.1	7.1
363	22.8	17.5	9.9	12.2	4.6	9.6
415	26.1	20.0	12.4	14.7	7.1	12.1
Minimum need to maintain for soil C‡			7.6	5.3	12.5	7.9

† Calculated using a harvest index of 0.53 (Johnson et al., 2006) and grain yield at 15.5 percent moisture and dry stover.
‡ Based Johnson et al., (2006), in a corn-soybean rotation, assuming a 2.4 Mg dry soybean residue ha^{-1}, which was estimated using a 2.3 Mg ha^{-1} yield (34.3 bu $acre^{-1}$) at 13 percent moisture (USDA-NASS, 2003) and a harvest index of 0.46 (Johnson et al., 2006).

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