Balancing Bioenergy Opportunities on Your Natural Resources Base

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Abstract

American farmers are now being asked to produce food, feed, fiber, and fuel. My goal is to provide you, as soil and crop consultants, information that will help your clients achieve these multiple goals in an economically and environmentally sustainable manner. We will review the potential unintended consequences of increasing corn grain production for ethanol and discuss developments for harvesting corn stover as a cellulosic feedstock. The importance of maintaining or increasing soil carbon and its potential to limit the amount of crop residue that can be removed is discussed. Initial results from Iowa show a average yield penalty of 10% where corn (*Zea mays* L.) was grown for the third consecutive year and a 50% reduction in soybean (*Glycine max* (L.) Merr.), where corn stover was removed from a site with low soil-test P, K, and organic matter. We'll conclude with ideas for how producers might balance the multiple demands being placed on their time and natural resource base, thus enabling the nation to address bioenergy, water quality, carbon sequestration, erosion, wildlife, and other community issues in a truly sustainable manner.

Current Situation

Grain Ethanol

With an average 15% increase in corn planted in Illinois, Indiana, Iowa, Ohio, Michigan, Minnesota and Wisconsin for 2007 (NASS, 2007), almost every Midwestern crop consultant has undoubtedly been affected by bioenergy or the bioeconomy during the past year. For some, this rapid increase in corn acreage may be reminiscent of the "fencerow-to-fencerow" era of the 1970s, except perhaps that today, there are fewer fencerows! For others, this may just be the beginning of an era that will certainly be filled with change. Currently, 97% of domestic ethanol production uses grain-based feedstocks, but advances in research, science, and technology are expected to increase the use of biomass to produce ethanol. For the U.S. Corn and Soybean Belt, this may not create a noticeable change in current cropping practices, since corn stover is projected to be one of the first cellulosic feedstocks used for these new ethanol production processes and as a substitute for natural gas. But what about the externalities and what should you, as soil and crop advisors, focus on through your guidance and recommendations?

Interest in the production of renewable fuels has been increasing since 1973 when an oil embargo sent fuel prices soaring. Development has expanded rapidly in recent years because of steadily advancing technologies for converting crops into ethanol and biodiesel, strong support by commodity groups for biofuels as a market for corn and soybean, and our nation's steadily increasing demand for liquid transportation fuels. Having been included in the president's proposed budget for Fiscal Year 2008, bioenergy discussions seem to be occurring everywhere.

Globally, there is concern, uncertainty, and confusion raising concerns such as: (1) whether for biofuels, the cure, is worse than the disease (Doornbosh and Steenblik, 2007); (2) how biofuels will affect food costs (Muller et al., 2007); and (3) whether or not agrofuels are truly sustainable (Biofuelwatch, 2007).

In the upper Mississippi River basin, there is growing concern about the rapid increase in corn grain production for ethanol because continuous corn typically loses more N than a corn-soybean rotation. Weed and Kanwar (1996) reported losses of 52 lb N ac^{-1} from continuous corn receiving 143 lb N ac^{-1} compared to 26 lb N ac^{-1} from a corn-soybean rotation where corn received 120 lb N ac^{-1}. Kanwar et al. (1997) showed that to achieve a 20% reduction in N loss, N fertilizer rates had to be reduced to below recommended levels (i.e., 97 lb N ac^{-1} for continuous corn and 79 lb N ac^{-1} for rotated corn). Randall et al. (1997) also measured a 25% difference in nitrate-N (NO_3-N) concentration between continuous corn (32 mg L^{-1}) and a corn-soybean rotation (24 mg L^{-1}), but their largest reduction in NO_3-N leaching occurred when alfalfa (*Medicago sativa*) was incorporated into the rotation. Many other examples of how soil and crop management affect NO_3-N leaching in Midwestern soils can be found in Dinnes et al. (2002). Similarly, Karlen et al. (2006) reported that lowest soil quality index values (SQI) and 20-year average profit (excluding government payments) were associated with continuous corn grain production. Rotations that included at least three years of forage crops had the highest SQI values. Development and deployment of cellulosic technologies that could use forage crops as a feedstock would provide an important market and help re-diversify the Midwestern landscape.

Not all of the projected increase in corn grain acreage for ethanol production will come at the expense of soybean because of the proven benefits of crop rotation for controlling disease and pest problems. Some, perhaps as many as 8 million acres, will come from land currently enrolled in the Conservation Reserve Program (CRP), idle, or being managed for pasture or hay (Wisner, 2007). Environmentally, this potential land use change is of concern because much of this land is also highly erodible and was intentionally taken out of row-crop production to reduce soil erosion losses. This would also increase the potential for P losses since the difference in annual P loss between perennial vegetation and row crops is often estimated at approximately 1 lb P ac^{-1} yr^{-1}.

Lignocellulosic Ethanol

The "Billion Ton Report" (Perlack et al., 2005) provided estimates of the lignocellulosic materials potentially available for conversion to bioenergy and provided the spark for an exponential increase in the amount of research being conducted to more accurately quantify the sustainable amount of available materials. For the Midwest, corn stover was the initial material to be targeted. A study by Graham et al. (2007) identified central Illinois, northern Iowa/southern Minnesota, and the Platte River Valley in Nebraska as sites with sufficient stover to allow 1.1 million tons to be harvested each year to support large biorefineries without causing erosion to exceed the tolerable soil loss (T). They also concluded that with current crop rotation and tillage practices, ~30% of all corn stover could be collected for less than \$30 ton^{-1}. A key "driver" in many assumptions such as these is that crop residue appears to some as a waste (or trash) that is not being used in modern corn grain production systems for anything other than protecting the land from ravages of wind and water erosion.

Protecting soil resources from wind-, water-, tillage- or irrigation-induced erosion is important and cannot be emphasized enough when advising landowners and operators. But it is not the only role that crop residues have in sustainable soil management systems. Crop residues are the main source of carbon returned to the soil and through which several essential plant nutrients are cycled (Wilhelm et al., 2004). It is well documented that crop production practices have resulted in the loss of soil carbon (Johnson et al. 2006) and that adoption of no-tillage or more diverse rotations that produce and retain more residue can at least sustain and often reverse this trend (Figure 1).

To quantify the full impact of harvesting crop residues on soil resources, the USDA-ARS formed a multi-location Renewable Energy Assessment Project (REAP) team. The research

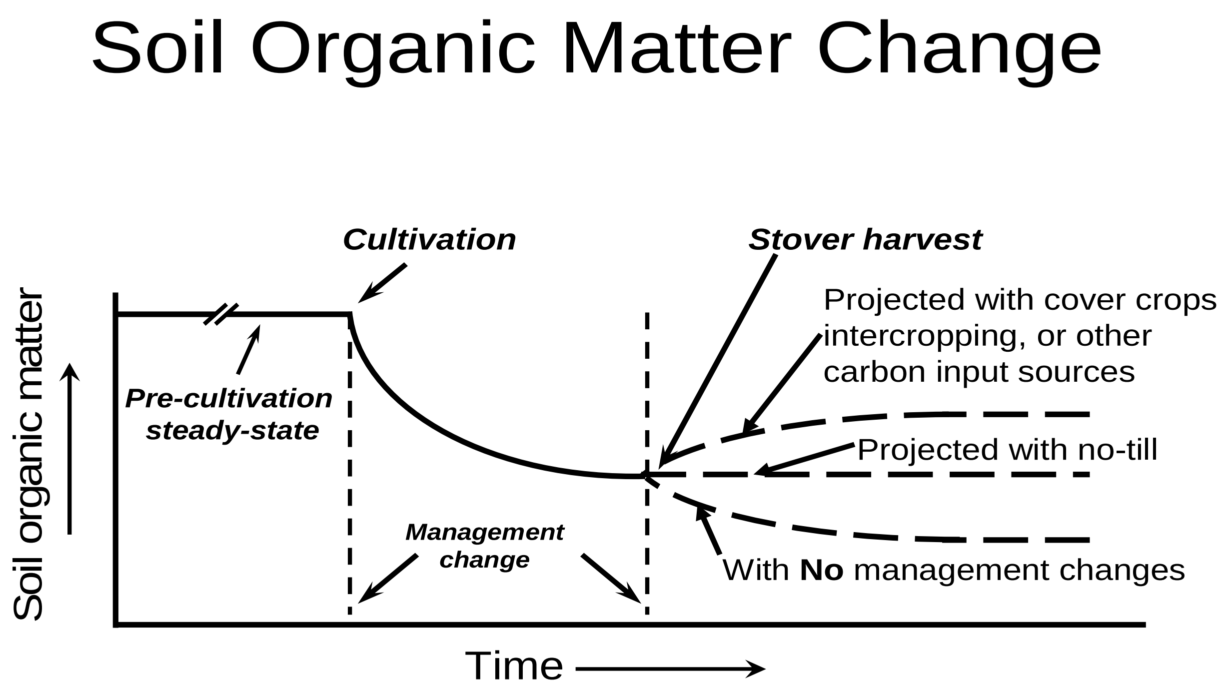

Figure 1. Conceptual diagram of how agriculture has affected soil organic matter and what may occur following various strategies for crop residue removal.

hypothesis for this team is that "biomass feedstock harvest rates and management strategies can be designed to ensure the soil resource meets the demands for food, feed, fiber, and fuel." The team's goals are to: (1) determine the amount of crop residue needed to protect the soil resource, (2) compare short- and long-term economic value of biomass as a bioenergy feedstock and as a soil carbon source, and (3) provide recommendations and guidelines for sustainable biomass harvest to the Department of Energy, producers, and other cooperators.

One of the first REAP team products was an assessment of the literature and erosion models to estimate how much corn stover is needed to not only limit wind and water erosion to within the tolerance limit (T), but also to maintain soil carbon (Wilhelm et al., 2007). Many factors contribute to establishing these amounts, but among them the predominant form of primary tillage and crop rotation are two of the most influential. A general relationship illustrating the magnitude of stover retention required for these various purposes is shown in Figure 2. For all tillage by crop rotation combinations, the amount of corn stover needed to sustain soil carbon levels exceeded that required to limit soil erosion. The same data were subsequently used

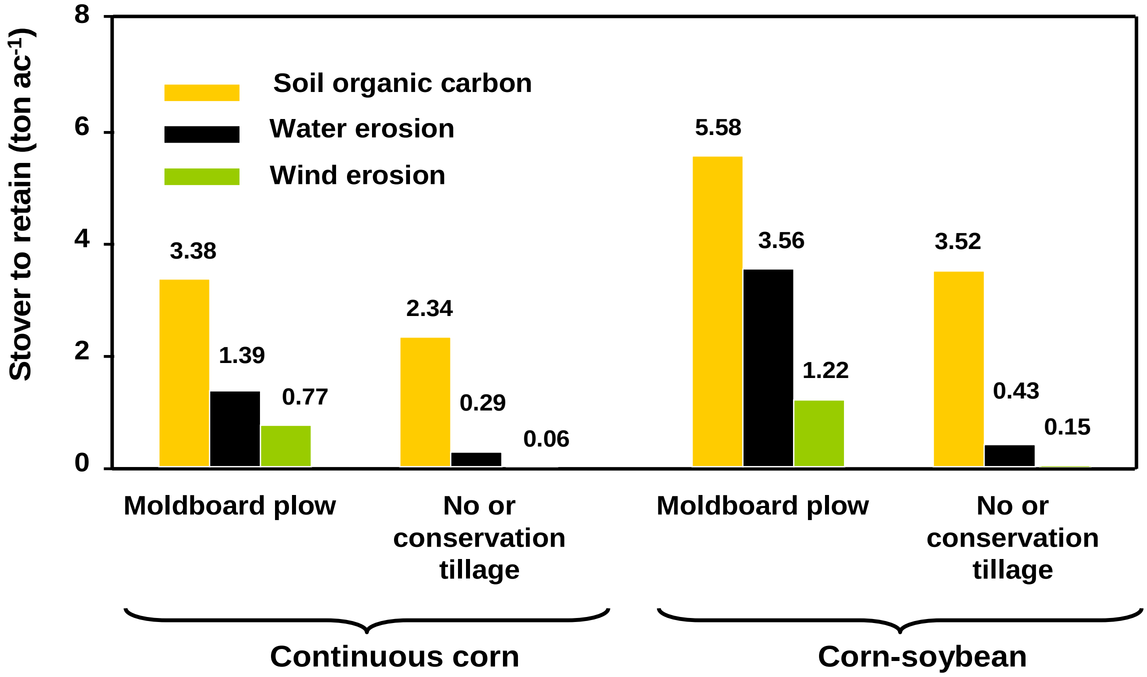

Figure 2. The amount of corn stover required to limit wind and water erosion to tolerable (T) levels or to retain soil carbon. Adapted from Wilhelm et al., 2007.

to produce a general graph illustrating the relationship between grain yield and estimated amount of harvestable corn stover (Figure 3). This example, currently based on very limited data suggests that if corn grain yields are less than 150 bu ac^{-1}, there probably will not be sufficient crop residue to sustainably harvest some and still support all of the critical functions needed to sustain the soil resource. It also illustrates that as tillage intensity increases (e.g., moldboard tillage), corn grain yields may need to be greater than 250 bu ac^{-1} before sustainable stover harvest should be considered for a corn-soybean rotation. It should be noted, however, that this is not “the” harvest guideline for corn stover removal, but rather a model or template that will need to be adjusted for different climatic regimes, management practices, and perhaps even spatially across large fields. Additional REAP team projects are ongoing and can be followed by searching the ARS Webs ite http://ars.usda.gov using the keyword REAP.

Biomass Research at Ames, IA

Biomass studies were initiated with the Idaho National Laboratory and Dr. Stuart Birrell (Iowa State University (ISU), Department of Agricultural and Bio-Systems Engineering) in 2005. Corn stover was harvested from an ISU research farm site where bulk corn and soybean were being grown. Studies were established for both continuous corn and a rotated corn and soybean site. Using a one-pass harvesting system (Figure 4), corn grain and: (1) the top 50% of the plant, (2) the bottom 50% of the plant, (3) all harvestable stover, or (4) no stover were removed (Figure 5). For

Figure 4. A prototype one-pass grain and stover combine developed by Dr. Birrell at Iowa State University, Ames, IA.

Figure 5. Stover remaining after collecting all harvestable material (left, next to standing corn) compared to removal of no residue (right).

the continuous corn site, grain and stover were harvested again according to the same treatments in 2006. Meanwhile, soybean was grown without additional fertilizer inputs on the rotated site. Where corn was grown for the third consecutive year, the overall field average declined by 10%, reconfirming previous studies (Kanwar et al., 1997; Karlen et al., 2006) that continuous corn is not a sustainable farming operation. For the rotated site, soybean yield measurements in 2006 showed a surprising 50% decrease where corn stover had been removed in 2005 compared to where it was returned to the soil (Table 1). Further investigations suggest the low soil-test P, K,

Table 1. Rotated corn grain, stover, and subsequent soybean yield near Ames, IA

Stover Harvest Scenario	’05 Corn	’06 Soybean

	Grain (bu/ac)	Stover (t/ac)	Grain (bu/ac)
Whole plant	197	3.17	32.4
Cob & top 50%	192	2.05	41.4
Bottom 50%	221	0.80	40.9
Grain only	239	-----	46.7
$LSD_{(0.1)}$	26	0.47	8.9

and organic matter at this site before any stover removal treatments were imposed may have contributed to this response, even though soil-test levels among the treatments were not significantly different (Table 2). The rationale for this suggestion is that removing stover will significantly increase removal of nutrients such as P and K compared to harvesting only the grain. Also, without using other management practices such as cover cropping harvesting crop residue from soils that are already low in soil organic matter will be depleted even more rapidly.

Table 2. Soil-test values when crop residues were first removed in autumn 2005.

Stover Harvest Scenario	Total Organic C	pH	Mehlich 3Ext. P	Mehlich 3 Ext. K
	--- % ---		--- ppm ---	--- ppm ---
Whole plant	1.92	6.65	24	100
Cob & top 50%	1.87	6.72	19	80
Bottom 50%	1.91	6.64	26	124
Grain only	1.92	6.70	24	74
$LSD_{(0.1)}$	ns	ns	ns	ns

What Lies Ahead?

As soil and crop consultants, you will undoubtedly be asked a multitude of questions regarding bioenergy and the broader bioeconomy. The sustainability of soil, water, and air resources as well as farm families, rural communities, and numerous investment opportunities will be brought to your attention. In responding to these questions, the term “conservation” should be first and foremost. As outlined by the North Central Sustainable Agriculture Research and Education bioenergy position paper (http://www.sare.org/ncrsare/bioenergy.htm), I would encourage you to stress energy-use-efficiency (including all aspects of energy conservation), strive to help identify bioenergy ideas and technologies that are truly sustainable, and actively participate in balanced discussions regarding the sustainability of current bioenergy investments.

Also consider developing a holistic vision for addressing not only bioenergy issues, but also water quality, carbon sequestration, soil health, wildlife habitat, and rural communities. By starting with watersheds within which you advise your clients, begin introducing the merits of not tackling these problems independently, but as an integrated system. This will require being current with market opportunities that are outside the traditional commodity crops. As emerging technologies for using cellulosic feedstocks are developed, identify places for perennial crops that could perhaps stand “wet feet” during the spring yet be harvested for biomass during the fall near watercourses. Farther away from the watercourses, develop transition strategies that include cover crops and/or intercrops to capture and recycle nutrients and reduce runoff and/or leaching of water that is not used by the primary crop. Finally, with environmental protection in place to protect water resources, strive for maximum sustainable production of commodity crops in areas where the leakage of the soil and crop production system can be captured before contaminating water resources and wasting essential plant nutrients. Such a change in rural landscapes would also enhance opportunities for wildlife to nest and reproduce, improve overall rural aesthetics, and increase economic opportunities within the rural communities. The path will not be easy, but the consequences of inaction are not tolerable!

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