RESEARCH EDITORIAL

doi:10.2489/jswc.70.5.279

Balancing energy, conservation, and soil health requirements for plant biomass

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The global importance of plant biomass for mitigating water and wind erosion, sustaining soil organic carbon (SOC), and providing animal feed and bedding is well recognized, but those needs are no longer the only factors influencing crop residue management decisions. As fossil energy sources diminish, the need for cellulosic derived liquid fuels is going to increase. Supplying bio-based fuels while simultaneously meeting food, feed, and fiber demands of more than nine billion people will require tremendous grain and biomass yield increases, as well as innovative crop residue management strategies for efficient agricultural operations. Our goal is to examine the challenges farmers, conservationists, and land managers face as they strive to manage crop residues without degrading soil health. Harvesting a portion of our nation's crop residues, such as corn (*Zea mays* L.) stover, to simultaneously provide liquid fuels and enhance agricultural operations will occur, provided it is done in a manner that sustains critical ecosystem and soil health services within the landscape. Harvest rates must be site-specific at subfield scales (Bonner et al. 2014a, 2014b) to ensure a sufficient amount of plant biomass remains at every harvest location to protect the soil surface from wind and water erosion and to sustain SOC throughout the profile. Protecting these soil health and ecosystem services before harvesting crop residue for any use is essential because SOC influences numerous chemical processes, including nutrient cycling, retention, and release to plants; physical properties, such as aggregate stability, surface crusting, water infiltration, and retention (Johnson et al. 2010; Wilhelm et al. 2007, 2010); and biological properties and processes, such as fungal:bacterial ratios (Lehman et al. 2014), soil enzyme levels (Stott et al. 2010), and resiliency (Lehman et al. 2015).

Why Are Cellulosic Biofuels Crucial?

To understand why development of cellulosic bioenergy is crucial, it is important to recognize that "energy" is defined as the ability to do work, while "power" refers to the rate at which work is done and reflects consumption of all forms of energy and not just electricity. Furthermore, the rate of work or power consumed per capita is also directly proportional to the rate at which wealth, defined as the Gross Domestic Product (GDP), increases (figure 1). The positive correlation between energy consumption and wealth production should not be surprising because the faster that work is accomplished (i.e., as power consumption increases), the more wealth is produced. Since the Industrial Revolution, humankind has accumulated wealth by using fossil fuels to provide the energy required for machines to do work.

Based on 2011 power use (17.7 TW), global per capita consumption averaged 2.5 kW (US EIA 2015), but at least 4 kW per capita is required for a more desirable quality of life (Dale and Ong 2014). Furthermore, a global average value of 2.5 kW per capita means that the great majority of the world's people subsist on significantly less than 4 kW per capita. They need much more power than they currently enjoy, but where will this power come from? Currently, approximately 85% of the world's energy comes from fossil fuel reserves (BP 2014), but those resources are being rapidly depleted as they are mined or extracted from the earth. When those mines and wells are depleted, wealth or per capita GDP will also disappear unless viable alternatives such as cellulosic biofuels are developed. We recognize there is tremendous uncertainty regarding long-term availability of fossil fuels, but current low oil prices are not likely to be with us very long. Short-term factors affecting current oil prices include (1) a very strong US dollar, (2) lingering worldwide economic weakness that is undermining the demand for oil, and (3) a willingness of Saudi Arabia, in particular, to use its domestic "savings account" to tide it over a temporary period of oil oversupply without reducing oil production. We emphasize the finite reality of fossil fuels because every individual oil field and all collections of oil fields on the planet exhibit the same peaking behavior (Aleklett et al. 2010): oil extraction rates rise, reach a peak, and then decline. Figure 2 highlights this behavior for the iconic oil state, Texas, and for the Alaskan North Slope. Oil extraction in Texas has declined by over 70% from its peak in the early 1970s, while oil extraction in Alaska is down about 65% from its peak in 1988. While oil production rates have been increasing recently in the Dakotas and Texas (figure 2), this is due to a spike in the production of shale oil, which is expected to follow the same trend, reaching peak production and then declining over time.

Peak coal and peak natural gas are yet to arrive, but they will come simply because these resources are not renewable. We are using them very rapidly, and nature is not replacing them. Peaking and the subsequent decline in extraction rates of nonrenewable resources is not a matter of politics, economics, or philosophy; it is a matter of physics and geology. Thus, even if fossil fuel extraction and consumption did not have increasingly severe environmental consequences, we would still need to be actively transitioning to renewable energy sources. As supplies of fossil fuels tighten and prices rise, billions of people on the planet will increasingly find themselves unable to access enough energy to ever obtain prosperity. They will be priced out of energy markets. Based simply on human energy needs and the reality that fossil fuel reserves are diminishing, we argue

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Figure 1
Global power consumption versus per capita Gross Domestic Product (GDP) (reproduced with permission from Dale and Ong [2014]).

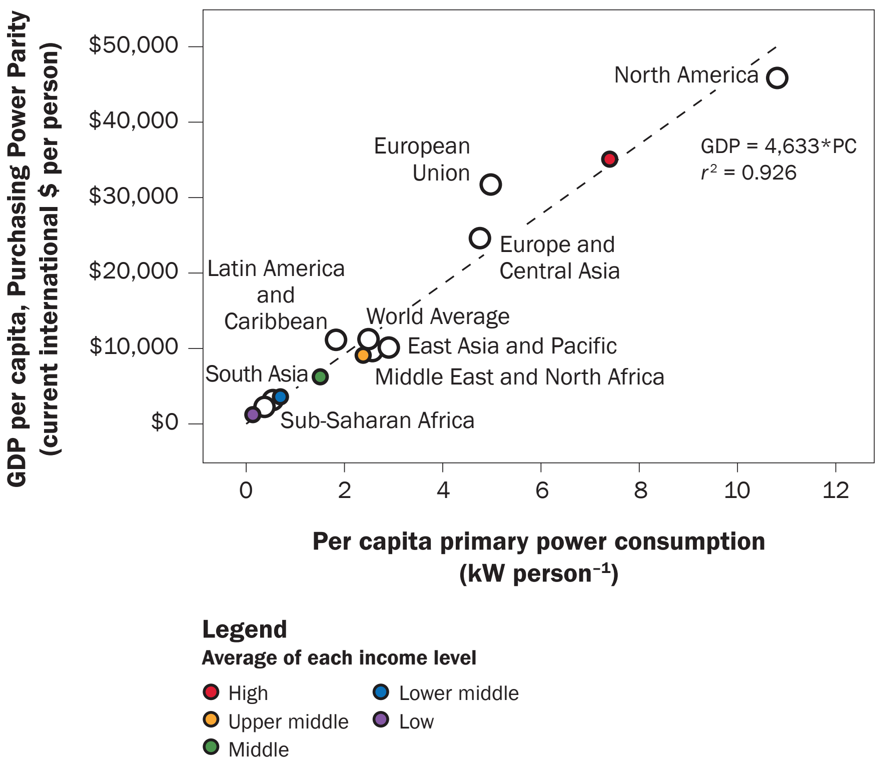
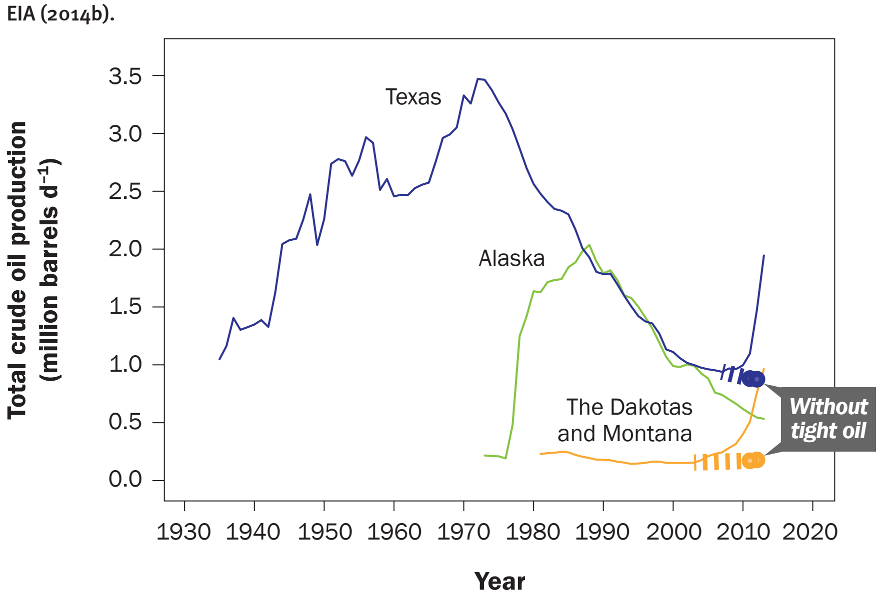


Figure 2
Yearly oil extraction rates in Texas, Alaska, the Dakotas, and Montana. Crude oil production data were compiled from US Energy Information Administration (EIA) (2014a) and the Railroad Commission of Texas (2014). Shale oil production data were compiled for the Eagle Ford and Barnett (Texas) and Bakken/Three Forks (North Dakota, Montana, and South Dakota) from reports by US EIA (2014b).



that aggressively developing sustainable, economic technologies to produce liquid fuels from plant biomass is no longer optional—it is mandatory.

Can't We Simply Increase Our Energy Efficiency?

Energy efficiency is often presented as an alternative to investing in biofuels. Increasing energy use efficiency is critically important, but it will only buy us more time to make the transition to renewable energy sources. Efficiency will also enable us to make better use of energy derived from more limited renewable resources. However, making more efficient use of nonrenewable resources means that it will only take longer to reach the "bottom of the barrel." Therefore, in their recent assessment regarding which renewable energy systems should be developed, Dale and Ong (2014) concluded that to answer that question, we must first realize that it is not "energy" we want, but the services that energy provides. Critical services include work, heat, cooling, illumination, and mobility. The first four of these services can be provided by renewable electricity derived from a variety of sources (e.g., solar, wind, hydro, tidal, geothermal, biomass, etc.). However, our options for obtaining energy for transportation are much more limited. Renewable electricity at best can currently provide only about half of the mobility services—mostly for personal and light duty transport vehicles (Dale and Ong 2014). Also, the current US infrastructure simply cannot support 100% conversion of passenger vehicles to electric power.

Furthermore, electricity cannot support the vehicles upon which most commerce depends. This includes all aviation, ocean shipping, and unless there are significant changes to the existing electrical systems and infrastructure, it includes most vehicles used for land freight (i.e., heavy truck and rail transport). Commerce is almost completely dependent on high-energy density liquid fuels. Similarly, the ability to perform work from mobile platforms (i.e., drills, plows, grain combines, and road construction equipment) is critical and depends overwhelmingly on liquid fuels. Currently, liquid fuels are derived almost entirely from petroleum, and thus, human wealth and many opportunities for development are solely dependent upon fossil fuels. As Dale and Ong (2014) concluded, the critical point is that large scale, renewable energy systems are no longer just a "good idea;" they are essential. If we do not implement these systems now, we can count on being poorer, perhaps much poorer, in the future. Over the next few decades, we must develop renewable energy systems at the multi-terawatt scale.

Midwestern Biomass: A Logical First Step

The midwestern United States is a highly productive region, with a temperate, subhumid climate. Average annual rainfall varies from about 1,000 mm (39.3 in) in the eastern and southern states (Ohio, Indiana, and Missouri) to just under 700 mm (27.5 in) in the northwest (Minnesota). Annual average temperatures exhibit a similar gradient ranging from 10.4°C, 13.7°C, and 12.4°C (50.7°F, 56.6°F, and 54.3°F) in Ohio, Indiana, and Missouri, respectively, to 6.3°C (43.3°F) in Michigan and 5.1°C (41°F) in Minnesota (Karlen et al. 2010).

A 2010 Soil and Water Conservation Society workshop identified four important midwestern characteristics with regard to producing biomass feedstock for advanced biofuels (Braun et al. 2011). They were (1) the dominance of corn and soybean (*Glycine max* L. Merr.) because of favorable soil resources, climate, and infrastructure; (2) recognition that although production of those crops has been successful, ecosystem services have been disrupted; (3) a growing demand for cellulosic feedstock for biofuel and other bio-products; and (4) increasing opportunities to diversify cropping systems to not only improve food, feed, and fuel productivity, but also to protect and/or restore ecosystem services.

Brick (2011) also identified several opportunities and challenges for increasing midwestern renewable energy by using biomass residuals (wastes). He made the following conclusions: (1) about 17% of the region's gasoline or 14% of the region's electricity could be obtained from ecologically sustainable biomass residuals; (2) technologies exist for managing animal manure to produce bioenergy; and (3) using a landscape-based framework would help quantify agricultural, energy, and environmental trade-offs inherent in bioenergy systems. However, trade-offs are not an inevitable feature of bioenergy systems. As described in more detail below, Dale and coworkers pointed out (2010) that there are "win-win" opportunities in utilizing crop residues for biofuels that can simultaneously improve SOC, produce large volumes of biofuels, reduce greenhouse gases (GHG), and maintain or increase animal feed resources.

Without question, the United States Midwest is well-positioned to produce cellulosic-based liquid fuels from many agricultural residuals, but in the near-future, the primary resource will undoubtedly be corn stover (US DOE 2011; Karlen et al. 2014). Simply stated, the vast area upon which corn is grown was the major reason the US Environmental Protection Agency (EPA) concluded corn stover was "the most economical agricultural feedstock…to meet the 16 billion gallon cellulosic biofuel requirement" associated with Renewable Fuel Standard Two (Schroeder 2011). From a producer's perspective, another reason for harvesting a sustainable portion of the corn stover is that as grain yields increase, crop residue management challenges and costs increase. This was documented by Plastina (2015) who showed that increasing tillage intensity to manage corn stover can increase annual production costs by US$45 to US$65 ha^{-1} (US$20 to US$30 ac^{-1}).

Farm Service Agency and Natural Resources Conservation Service Incentives Supporting Biomass Production

The United States Midwest is ecologically well-suited for producing a wide variety of biomass crops (Braun et al. 2011), but development of economically viable and socially acceptable industries for establishing, cultivating, harvesting, and using biomass for heat, power, biofuel, or bio-based products has been slow. For more than 30 years, and despite diminishing fossil fuel reserves, producing and using biomass was a classic "chicken or egg" challenge (USDA FSA 2011). With the exception of research and engineering activities leading to the 2014 launch of corn stover conversion facilities, there was no investment incentive to develop commercial-scale biomass facilities because there was no readily available energy crop supply. On the other hand, farmers had no reason to invest in producing energy crops for which there was no viable market. Finally, to reduce US reliance on foreign oil, improve domestic energy security, reduce carbon (C) pollution, and spur rural economic development and job creation, the USDA established the Biomass Crop Assistance Program (BCAP) as part of the 2008 Farm Bill.

The BCAP was reauthorized by the 2014 Farm Bill with an annual mandatory funding level of US$25 million for establishment, maintenance, and retrieval payments (USDA FSA 2014). Implementation is dynamic, and for Fiscal Year 2014, no funds were allocated for establishment or expansion that was not previously authorized. When fully funded, BCAP provides incentives to farmers, ranchers, and forest landowners to work with bioenergy facilities to establish, cultivate, and harvest biomass. If a proposed project area is chosen, producers can be reimbursed for up to 50% of the cost for establishing a perennial bioenergy crop. Producers can also receive up to five years of annual payments for herbaceous (nonwoody) crops, or up to 15 years of annual payments for woody crops. Matching retrieval payments for mitigating the cost of harvesting and transporting agricultural or forest residues that are not otherwise economically retrievable to end-use facilities are also available. BCAP eligible biomass materials currently include agricultural or crop residues (including herbaceous residues remaining in the field after harvest of conventional crops); woody agricultural residues, such as orchard waste that does not have an existing market; and woody forest residues removed directly from public forest land as byproducts of preventative treatments for reducing the threat of forest fires, disease, or insect infestation. These materials can only be removed from land with an approved conservation, forest stewardship, or equivalent plan (USDA FSA 2014). For the most current information on BCAP, readers should access the USDA Forest Service Agency's (FSA) BCAP website at http://www.fsa.usda.gov/bcap or visit their local FSA office.

The USDA Natural Resources Conservation Service (NRCS) Conservation Stewardship Program (CSP) and its enhancements, as well as the Environmental Quality Incentive Program (EQIP) are two other programs developed to support an overall federal biomass production program. Brief summaries of these programs as related to biomass production are presented in tables 1 and 2.

A unique aspect of the CSP is that financial assistance can be provided for existing environmental performance and additional environmental enhancements. Most other USDA programs provide assistance only for the application of new practices. However, as noted for the FSA-BCAP program, these NRCS programs are also dynamic. For example, at the national scale, CSP has at least 75 enhancements that are available to producers who have various resource concerns. Table 1 includes three enhancements that are applicable to biomass production. Two of them (SQL09 and ANM23) have a direct effect, while SQL12 has an indirect effect on biomass production incentives and benefits. Enhancements that have a direct effect have a specific influence on either the production practices or the biomass crop itself, while any enhancement that has an indirect relationship would affect biomass producers by influencing other natural resource concerns related to harvesting the biomass crop (e.g., corn stover harvest effects on wind and/or water erosion). Attention must be paid to the enhancement details. For example, SQL09 may or may not be compatible with the needs of industries seeking to develop reliable and sustainable biomass supplies because of biomass harvest restrictions during wildlife nesting periods. Again, as noted for BCAP, readers are advised to contact their local NRCS office to obtain current information regarding either CSP or EQIP.

Production, Soil Health, and Water Quality Issues Affecting Biomass Supplies

To support development of economically, environmentally, and socially acceptable biomass conversion industries, such as POET-DSM's "Project Liberty" (figure 3), rigorous soil and water conservation-oriented research needs to focus on multiple, interconnected goals including (1) providing producers with information needed to make appropriate crop residue harvest decisions; (2) evaluating long-term, site-specific soil health impacts of crop residue; (3) quantifying how biomass harvest affects water quality on tile-drained landscapes; (4) confirming the effectiveness of NRCS and FSA biomass support policies; (5) improving logistics associated with biomass harvest, storage, and transport; and (6) documenting that meeting society's food and fuel needs are compatible. Recent multilocation, multi-agency, and private sector investments through the Sun Grant Regional Partnership (Karlen and Johnson 2014) provide an example of how these seemingly complex issues can be addressed in a coordinated manner. The Corn Stover Team included the Agricultural Research Service (ARS) Resilient Economic Agricultural Practices (REAP) team, university faculty associated with the Sun Grant Association, and US Department of Energy (DOE) scientists and engineers. Collectively, research sites located in seven states from South Dakota to South Carolina provided 239 site-years of data with corn grain yields ranging from 5.0 to 14.3 Mg ha^{-1} (80 to 227 bu ac^{-1}) and averaging 9.8, 10.1, and 10.1 Mg ha^{-1} (156, 160, and 160 bu ac^{-1}) for the no, moderate, and high stover harvest rates (0, 3.9, and 7.2 Mg ha^{-1} [0, 1.7 and 3.2 tn ac^{-1}]), respectively (Karlen et al. 2014). The study also showed that compared to harvesting only corn grain, stover harvest increased nitrogen (N), phosphorus (P), and potassium (K) removal by at least 16, 2, and 18 kg Mg^{-1} (16, 2, and 18 lb tn^{-1}) of harvested stover. This increased nutrient removal may or may not affect fertilizer requirements depending on the current soil fertility status and long-term management history, but it does emphasize the importance of routine soil testing and monitoring of plant nutrient status to ensure crop productivity is not being impaired by the more intensive land use associated with both grain and stover harvest. The team also concluded that stover harvest decisions must be site-specific or even subfield specific (Bonner et al. 2014a, 2014b) to minimize residue management problems when yields are high and to encourage producers to adopt less aggressive or even no-tillage practices.

With regard to soil health, the study showed that if average grain yields were less than 11 Mg ha^{-1} (175 bu ac^{-1}), 10 years of continuous stover harvest, even with no-tillage practices, reduced particulate organic matter (POM) C accumulation (Karlen and Johnson 2014). Harvesting stover from areas with low average corn grain yields also shifted dry aggregate distributions toward smaller soil aggregates, which are more vulnerable to the erosive forces of wind and water.

Monitoring soil physical properties such as crusting, compaction, and aggregation at stover harvest sites is as important as measuring yield response and nutrient removal because one of the most frequently asked producer questions, regardless of how the harvested corn stover will be used (i.e., bioenergy, bioproducts, animal feed, animal bedding, or mushroom compost), is "how will it affect my soil health?" This is important because excessive harvest of photosynthetic C and/or oxidation of SOC through excessive tillage will inevitably deplete soil organic matter (SOM) and result in soil degradation (figure 4).

Another midwestern concern regarding stover harvest is the potential for adverse water quality effects. This reflects not only an increased potential for impairment due to greater runoff and soil erosion (Cruse and Herndl 2009), but also due to the extensive subsurface drainage network that has been installed throughout the Midwest (Dinnes et al. 2002). Installation of artificial drainage began in the mid-1800s in the eastern portion of the region and spread to the west during the late 1800s. As subsurface tile installation and digging of drainage ditches progressed, the length, drainage density, and channel frequency of intermittent streams in headwater areas of watersheds increased (Zaimes et al. 2006). Artificial drainage coupled with increased availability of N fertilizers (Dinnes et al. 2002) significantly increased productivity, but the overall impact on landscape hydrology also included a decreased capacity to store water and shorter water residence times that subsequently increased stream flow during peak rainfall events (Holden et al. 2004). The increased stream flow also translated into increased energy in the waters that further eroded and transported sediments, causing even greater stream bank erosion and channel incision (Menzel 1983; Schumm 1999; Zaimes et al. 2006).

Stover harvest does not necessarily mean that runoff, soil erosion, or nutrient leaching will have to increase. However, it will add another level of complexity to the farming operations and make it even more important to combine two or more management practices to reduce nutrient loss to field drainage (Dinnes et al. 2002). Use of cover crops, buffer strips, routine soil testing and plant analysis, and adopting subfield management with a mixture of perennial- and row-crops are among the NRCS and FSA recommended practices that could be adopted to prevent or mitigate water quality concerns associated with harvesting biomass.

Harvest, storage, and transportation (HST) logistics are still major challenges associated with biomass harvest because cellulosic feedstocks are inherently bulky, unstable, and difficult to transport. Fales et al. (2007) stated that HST logistics can account for 40% to 60% of liquid biofuel production costs. Similarly, Archer and Johnson (2012) concluded that biomass producers could profitably supply feedstocks only within a 32 km (20 mi) radius of the plant-gate. They also concluded that biomass supplies would increase significantly if prices were increased from US\$59 to US\$84 Mg^{-1} (US\$53 to US\$76 tn^{-1}). One approach for reducing

Table 1
Characteristics of the USDA Natural Resources Conservation Service (NRCS) Conservation Stewardship Program (CSP) and three of its enhancements with regard to supporting plant biomass production.

Program	Purpose	How it functions	How it's evaluated
CSP	To provide financial assistance to farmers who maintain and improve their existing conservation systems and/or implement new conservation activities that address priority resource concerns.	Participants earn CSP payments for conservation performance; the higher the performance, the higher the payment.	Environmental performance is measured using the Conservation Measurement Tool (CMT). The NRCS staff uses information provided by producers to evaluate existing practices and enhancements previously implemented, as well as new enhancements that are to be applied during a five-year contract period. "Points" are assigned to these activities so that the more points a producer garners, the greater the payment.
CSP enhancements with direct effects			
CSP-Soil Quality Enhancement Activity-SQL09	Conversion of cropped land to grass-based agriculture.	Participants convert cropped land to grass-based agriculture by establishing mixtures of perennial grasses, forbs, and legume species on land where annually seeded cash crops have been grown in monocultures. Benefits include reduced soil erosion, increased soil organic matter, potential carbon (C) sequestration, and improved water quality.	This enhancement requires a mixture of perennial grasses and forbs suitable to the site, even though the mixture may not be compatible with the needs for fuel production. Harvested fields must have and follow a plan to enhance wildlife, even though this may require delaying biomass harvest or even leaving portions of fields unharvested during wildlife nesting seasons.
CSP-Animal Enhancement Activity-ANM23	Multispecies native perennials for biomass and wildlife habitat.	This activity focuses on establishing native perennial vegetation for biomass production and wildlife habitat on existing crop, pasture, or rangeland area. Its benefits include establishing multispecies, native perennial vegetation that can be managed for both biomass and wildlife, thus providing both natural resource and financial benefits.	This enhancement requires a multispecies mix of native perennials that is based on suitability for the site and its benefits for biomass and wildlife. Once again, the mixture may not be compatible with biorefinery needs for fuel production. The fields must be managed for wildlife species of conservation concern as identified by the State and the State Wildlife Action Plans. Participation also requires development of management plans that addresses impacts on wildlife.
A CSP enhancement with indirect effects			
CSP-Soil Quality Enhancement Activity-SQL12	Intensive cover-cropping within annual crops.	To grow and manage seasonal cover crops of grasses, legumes, or forbs to maintain soil cover and other conservation benefits during all noncrop production periods in an annual crop rotation. The primary benefit is a reduction in wind and water erosion.	When managed appropriately, cover crops can restore and maintain soil productivity and soil quality by increasing organic matter; relieving compaction; improving soil tilth and fertility; fixing nitrogen (N; legumes), recycling nutrients in the soil profile; breaking pest cycles; and providing a habitat for soil biota, such as beneficial bacteria, mycorrhizal fungi, and earthworms (Singer et al. 2005). Adopting this enhancement will replace biomass harvested for energy production and thus provide multiple soil health benefits.

Table 2
Characteristics of the USDA Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) with regard to supporting plant biomass production.

Program	Purpose	How it functions	How it's evaluated
EQIP	To provide financial and technical assistance to agricultural producers to address natural resource concerns and deliver environmental benefits such as improved water and air quality, conserved ground and surface water, reduced soil erosion and sedimentation, or improved or created wildlife habitat.	EQIP financial assistance is available to biomass producers for (1) forage and biomass planting and (2) conservation crop rotation components. The former focuses on establishing a new stand or renovating a poor stand to introduced grass, native species or grass with legumes and/or forbs to extend the grazing season and provide soil cover. Land areas established under this practice may be harvested for biomass.	The conservation crop rotation practice requires incorporating two years of a high residue perennial crop into an existing rotation that does not include perennials. This may have limited applicability for some biomass producers because of the rotation requirement with row crops, but by developing new harvest technologies for separating leaf and stem components of alfalfa (USDA ARS 2013) this could be a very successful and profitable management strategy.

Figure 3
POET-DSM cellulosic conversion and grain ethanol facility near Emmetsburg, Iowa.

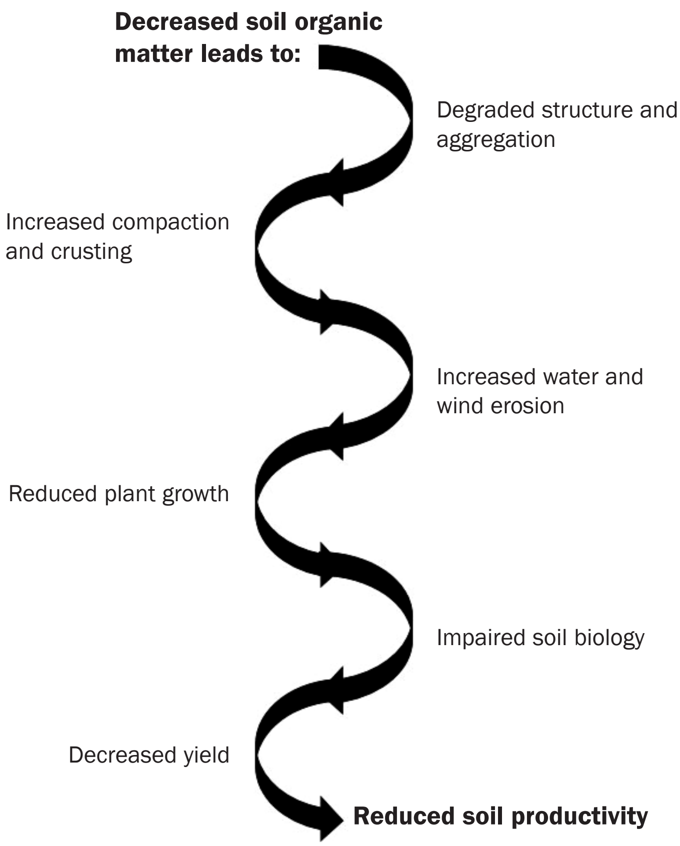
HST costs is to pursue development of depot/elevator preprocessing strategies such as the "Advanced Uniform" system (Hess et al. 2011). An example of this is the ammonia fiber expansion (AFEX, MBI International, Lansing, Michigan) system. This system was developed to process corn stover or switchgrass (*Panicum virgatum*) into pellets that can be managed as a commodity. The pellets have a bulk density about nine times greater than baled biomass, are stable for years, and can be easily stored and shipped (Hoover et al. 2014). Techno-economic analysis indicates that the AFEX system can be profitable in depots processing about 200 t (220 tn) of biomass per day (Campbell et al. 2012). In agriculturally intensive areas where crop yields are at levels where residue management is becoming a challenge, the analyses indicate that a profitable AFEX depot would require participation from less than 20% of the farms within a 10 km (6.25 mi) radius.

Modeling the AFEX system enabled Dale et al. (2010) to explore opportunities for increasing the potential of US croplands to provide biofuel feedstock by (1) double-cropping to produce additional cellulosic biomass and leaf protein concentrate as a substitute for soybean meal, and (2) using preprocessing of cellulosic biomass to increase its value as a ruminant animal feed and biofuel feedstock. Their results showed that restructuring US agriculture could result in more efficient land use and large environmental services. Without putting new land into production, the model showed that it was possible to produce animal feed that has a nutritional value per hectare that is equivalent to what is currently produced while either maximizing production of biofuel or reducing GHG emissions. By optimizing land use for multiple goals within agricultural watersheds (Eranki et al. 2013), a sixth concern regarding biomass harvest—potential food versus fuel competition—can be factually dispelled (Rosillo-Calle and Johnson 2011). Although many people believe that biofuel production will inevitably conflict with food production, the reality is that most of the agricultural land in the United States is used to provide animal feed, not crops for direct human consumption. We believe the same land use pattern exists among other countries/regions with large land bases (i.e., Canada, Brazil, Argentina, Australia, and the European Union). The answer is not to abandon crop residue harvest, but rather to utilize principles of soil and water conservation to design sustainable agricultural landscapes that produce food/feed and fuel from biomass while simultaneously restoring or maintaining soil health, water quality, and other ecosystem services.

By developing integrated biomass production systems, we are confident that SOM would increase, substantial net energy would be produced, net human and animal nutri-

Figure 4

A conceptual model of soil degradation beginning with the loss of soil organic matter due to excessive biomass harvest and/or tillage, erosion, grazing, or other poor management decision.



tional requirements would be met, GHG emissions would decline, and local communities would benefit socially and economically. By developing a distributed depot processing system (Hess et al. 2011), biofuel economics would improve through economies of scale and reduced transactional costs. Biomass pellets could be used for either animal feed (higher value) or fuel (lower value) with diversification protecting against economic shocks and fluctuating biomass yields due to increasing climate variability. Water quality as well as plant and animal biodiversity would also improve by having more perennial grasses on the landscape and increasing the use of cover- and double-cropping practices on current agronomic lands. Specific impacts on local water supplies will require site-specific evaluations that cannot be performed until specific potential biomass production sites can be identified.

We therefore suggest that those individuals who are critical of the three new bioenergy conversion facilities, the general concept of harvesting plant biomass, or the research and development activities supporting a biomass industry may have been asking the wrong questions. Biomass production advocates are not trying to impose a large, new demand for biofuels on the existing agricultural system without considering the real nature of that system. Our current agricultural system was designed to produce animal feeds. It does not produce nearly as much food for direct human consumption as it does feed for animals. It is not surprising that confusion and apparent conflict have arisen between "food versus fuel" proponents. The fact is that humankind needs both food/feed and fuel. Therefore, global landscapes will likely be more productive, and both producers and consumers will have a lot more fun, if we collaborate to improve land use by redesigning existing agricultural systems to produce essential biofuel feedstocks as well as food, feed, and fiber, while simultaneously protecting and/or enhancing soil health and generating large environmental and social benefits.

Research Needs for Sustainable Biomass Supplies

To sustainably provide food/feed and fuel from our soil and water resources, we have identified several research needs including the following: (1) developing effective and efficient strategies for adopting no-tillage practices and for incorporating cover crops into corn stover harvest systems; (2) developing innovative harvest, densification, uses, and site-specific placement guidelines for all biomass crops; (3) improving yield potential and biofuel characteristics of herbaceous and woody biomass cultivars; (4) quantifying habitat impacts of various crop residue harvest strategies; (5) quantifying runoff, nutrient, and pesticide losses associated with biomass harvest; and (6) developing management options and practices that will enhance the value of marginal lands.

The importance of developing improved landscape management strategies has increased exponentially since the beginning of 2015. Concerned about high nitrate-nitrogen (NO_3-N) concentrations in its primary drinking water source, the Des Moines Water Works (DWW) has filed suit in federal court against supervisors in three Iowa counties surrounding the POET-DSM conversion facility (figure 3). The suit does not implicate the bioenergy conversion facility or any of its stover collection practices, but rather focuses on nutrient runoff from farms and drainage districts within the three counties. The allegation is that record levels of NO_3-N entering the Raccoon River are creating an untenable hardship and will cost DWW up to US$70 million to mitigate. By aggressively pursuing the research objectives outlined above, developing multipurpose watersheds, and using subfield management strategies and sustainable HST strategies as discussed previously (Bonner et al. 2014a,b; Eranki et al. 2013), we are confident that farm families, biomass conversion facilities and their supporting industries, as well as the general public represented by the DWW can all benefit. By identifying economically and environmentally sensitive areas and replacing current row crop production practices with perennial grasses and cover crops, abundant supplies of biomass from appropriate corn stover harvest sites, perennial grasses, and cover crops will be available to help meet liquid fuel and other bio-product needs.

In summary, energy is essential for human well-being and, therefore, renewable energy is essential for long-term human well-being. Cellulosic derived biofuels are here to stay, and the need for sustainable supplies of plant-derived biomass is only going to increase. Liquid fuels produced from plant material are not optional—we must have them—but they must be economically, environmentally, and socially sustainable. The challenge that we as soil and water conservationists face is providing appropriate guidance so that this new demand can be met without having negative consequences on traditional ecosystem services provided by plant biomass. In fact, we have a historic opportunity to design and implement "win-win" agricultural practices that simultaneously improve soil health, reduce erosion, provide many ecosystem services, and reduce GHG while also producing large amounts of biofuels.

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Acknowledgements

Bruce Dale and Rebecca Ong gratefully acknowledge support from the Great Lakes Bioenergy Research Center (DOE BER Office of Science DE-FC02-07ER64494), from Michigan State University AgBioResearch, and the USDA National Institute of Food and Agriculture.

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