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Energy Issues Affecting Corn/Soybean Systems: Challenges for Sustainable Production

The corn/soybean production system models the complexities involved in the generation, supply, distribution, and use of energy. (Photo images from Shutterstock.)

Abstract

Quantifying energy issues associated with agricultural systems, even for a two-crop corn (*Zea mays* L.) and soybean (*Glycine max* [L.] Merr.) rotation, is not a simple task. It becomes even more complicated if the goal is to include all aspects of sustainability (i.e., economic, environmental, and social). This Issue Paper examines energy issues associated with and affecting corn/soybean rotations by first defining the size of the system from both a U.S. and global perspective and then establishing boundaries based on the Farm Bill definition of sustainability. This structured approach is essential to help quantify energy issues within corn/soybean systems that are themselves best described as "systems of systems" or even "systems within ecosystems" because of their complex linkages to global food, feed, and fuel production.

Two key economic challenges at the field and farm scale for decreasing energy use are (1) overcoming adoption barriers that currently limit implementation of energy-conserving production practices and (2) demonstrating the viability of sustainable bioenergy feedstock production as part of a landscape management plan focused not only on corn/soybean production but on all aspects of soil, water, and air resource management. It is also important to look beyond direct energy consumption to address the complex economics affecting energy issues associated with corn/soybean systems. To help address the complex energy issue, life cycle assessment is used as a tool to evaluate the impact of what many characterize as a simple production system. This approach demonstrates the importance of having accurate greenhouse gas and soil organic carbon information for these analyses to be meaningful.

Traditional and emerging market and policy forces affecting energy issues within corn/soybean systems are examined to project the effects of increasing bioenergy demand associated with the Energy Independence and Security Act of 2007. Uncertainty with regard to biofuel policy is a major factor affecting energy issues in all aspects of agriculture. This uncertainty affects investments in biofuel production and energy demand, which together influence commodity prices,

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price volatility for food and feed, and agricultural energy decisions.

The authors conclude by offering an approach, including decreased or more efficient energy use, that can enhance all aspects of sustainability. Their strategy, defined as a "landscape vision," is suggested as an agricultural system approach that could meet increasing global demand for food, feed, fiber, and fuel in a truly sustainable manner.

Introduction

Industrial growth and development, electrification, rapid advances in transportation options, and cheap, abundant energy resources during the twentieth century allowed many in the United States to become very complacent regarding both the amount and sources of energy being used. All sectors of the global economy, including agriculture, are now being affected by that growing demand for energy because of the critical role energy plays in maintaining national security, economic prosperity, and environmental quality (NAS 2009). Understanding the complexity of energy issues affecting agriculture and all other industries is becoming more important as world demand for food, feed, fiber, and fuel increases and the reliability of traditional energy sources (especially oil) becomes more uncertain because of political instability and finite supplies. Increasing recognition of global climate variability (e.g., ICCAC 2011) and the fact that U.S. dependence on foreign oil has increased from 40% in 1990 to 56% in 2009 are just two of the driving forces encouraging everyone to examine their energy future (CAST 2010; NAS 2010).

Quantifying energy issues within any system is difficult, but attempting to do so within the constraints of sustainability (i.e., economically viable, environmentally benign, and socially acceptable) is crucial if humankind is to begin addressing the scientific, technical, economic, social, and political elements that must be transformed to change how energy is generated, supplied, distributed, and used (NAS 2010). This Issue Paper addresses energy issues within the corn/soybean production system as a model for understanding the complexities that must be addressed. The goal is to identify research, development, and policy needs, questions, benefits, and opportunities for both increasing energy efficiency and producing bioenergy in landscapes dominated by corn/soybean production systems. Therefore, this paper will explore energy issues associated with tillage, crop rotation, cover crops, and linkages among food, feed, fiber, and fuel production for this cropping system.

U.S. and Global Corn/Soybean Production—1950 to 2010

As reported by Johnson, Allmaras, and Reicosky (2006), corn and soybean yields were low and constant until after the 1930s. Then, starting with the development of hybrid corn; increased use of commercial nitrogen (N), phosphorus, and potassium fertilizers; and development of many mechanical (planters, pickers, combines), chemical (pesticides, insecticides), and most recently genetic engineering technologies, yields rose steadily through public and private research and development efforts. Corn production (USDA–NASS 2011) rose from approximately 50 million megagrams (Mg; 2.0 billion bushels) during the 1930s to 1.55 billion Mg (12.6 billion bushels) during the past five years (2007–2011) with no change in harvest area (33.2 million hectares [ha] or 81.99 million acres). The increased production was primarily because of improved tolerance to high plant populations and abiotic stress (Duvick 1992). Furthermore, the estimated genetic corn yield potential of 25 Mg/ha (400 bushels/acre) (Evans and Fischer 1999; Tollenaar 1983; Tollenaar and Lee 2002) still has not been achieved across a large area of land, so additional increases in yield per unit area and total corn production are anticipated as transgenic crops continue to improve herbicide tolerance and insect resistance (Duvick 2005).

There also was a major land use change (Karlen 2004) as the area devoted to soybean production increased 500% from 6.1 to 31.9 million ha (15 to 79 million acres) between 1950 and 2010 (CAST 2009; USDA–NASS 2011). As a result of these changes, the corn/soybean rotation became the dominant land use in the midwestern United States during the latter half of the twentieth century (Karlen, Dinnes, and Singer 2010). The development of highly efficient animal production systems, new products, and an increased global market demand for corn, soybean, and animal products all accompanied this increase in corn/soybean supplies. These cropping system changes helped ensure a consistent, uniform commodity supply for agricultural industries; however, with regard to soil and water conservation they raised many concerns (Karlen, Dinnes, and Singer 2010), and with regard to energy consumption they transferred the demand from biomass-supported human and animal power to power sources largely dependent on fossil fuels.

Based on 2003 data from the Food and Agriculture Organization (FAO 2010), U.S. corn (maize) accounted for 40% of the global production. For soybean, a major shift occurred between 1961 when the United States accounted for 69% (18.5 million Mg) of global production and 2005 when the United States provided only 40% of the 206 million Mg (Centrec Consulting Group 2007). Brazil (25%) and Argentina (19%) are now major world soybean producers. These global perspectives are included to show why it is very difficult to quantify energy issues in what, to many, might seem to be a simple corn/soybean rotation but in reality is part of a very complex global agricultural production system, especially in the context of sustainability.

The Definition and Goals of Sustainable Agriculture

For this Issue Paper, the term "sustainable agriculture" (SA) is defined according to U.S. Code Title 7, Section 3103, which states that SA is an integrated system of plant and animal production practices having a site-specific application that will, over the long term,

- satisfy human food and fiber needs;
- enhance environmental quality and the natural resource base upon which the agriculture economy depends;
- make the most efficient use of nonrenewable and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
- sustain the economic viability of farm operations; and
- enhance the quality of life for farmers and society as a whole.

This definition (USDA–NIFA 2009) is a central element of the legislation for the U.S. Department of Agriculture (USDA) Sustainable Agriculture Research and Education (SARE) program of the National Institute for Food and Agriculture. It also is the basis for the North Central Regional SARE Administrative Council's position on energy, which stresses the use of the following (SARE n.d.) for developing sustainable biofuel production systems:

- energy conservation and efficiency
- energy-efficient production practices
- non-biomass renewable energy sources
- alternative biomass feedstock production systems
- environmental impact of bioenergy production
- community and rural development impacts of bioenergy production
- local and regional economic impact of biofuel production
- whole farm integrated energy systems

Achieving all these goals is a major reason that quantifying energy issues for any agricultural system is such an arduous task.

What Energy Issues Affect Corn/Soybean Systems?

One of the greatest challenges associated with defining critical energy issues for corn/soybean systems is determining how and where to set the system boundaries. This occurs because corn/soybean production systems literally consist of a "system of ecosystems" that includes a well-coordinated mechanical production chain that in itself can be characterized as a "system of systems" (SOS). The International Council on Systems Engineering has defined SOS as "a system of interest whose system elements are themselves systems; typically these entail large-scale interdisciplinary problems with multiple, heterogeneous, distributed systems" (Duffy et al. 2009).

Starting with the corn/soybean production system itself, there are multiple subsystems, including tillage, seedbed preparation, fertilization, and weed control. Each subsystem (e.g., fertilization) encompasses other systems such as mining, manufacturing, transportation, and marketing that will all have costs associated with fossil energy. For example, Shapouri and colleagues (2010) estimated the energy cost of N fertilizer alone to be 57 MJ kg^{-1} N (57 megajoule per kilogram N) (see also Snyder, Bruulsema, and Jensen 2007; West and Marland 2002). This type of information may help quantify some energy issues associated with corn/soybean systems. Shapouri, Duffield, and Graboski (1995), however, cited estimates of the energy cost of N fertilizer varying from 52 to 87 MJ kg^{-1} N, depending on the calculation procedures. Important considerations include the time period for which energy information was collected, because industry energy efficiency has changed over time; the differences in formulation of N fertilizer assumed; and whether or not calculations used the same heating values for various energy sources (Shapouri, Duffield, and Graboski 1995; Snyder, Bruulsema, and Jensen 2007).

The increased supply of corn/soybean has many different uses, including the production of biofuels. With regard to energy, biofuel production has been promoted for its potential mitigation of greenhouse gases (GHGs). The rationale is that corn/soybean-derived biofuels are helping to at least stabilize atmospheric carbon dioxide (CO_2) concentrations by first absorbing CO_2 during photosynthesis and then returning the same molecules to the atmosphere during combustion.

This argument is not always accepted because as part of a complex SOS, every change in crop production or management influences both energy consumption and CO_2 emissions (Nelson et al. 2009). For example, to decrease energy use and soil erosion while simultaneously decreasing CO_2 concentrations by increasing C (carbon) sequestration, greater adoption of no-tillage practices for corn/soybean rotations has been encouraged. As pointed out by Baker and colleagues (2007), however, adopting no-tillage alone may not be sufficient to increase soil C retention, and without an increase in sequestration there would be no mitigation of CO_2 concentrations. Quantifying energy issues is thus dependent on understanding the interconnected effects of crop sequence, tillage, nutrient management, water use, infiltration rate, management decisions, and many other factors that affect all ecosystem services (Blanco-Canqui and Lal 2007; Karlen et al. 2009).

The example just given illustrates

that to quantify energy issues for what may seem to be a simple corn/soybean rotation is really a very complex process that requires a systematic approach to (1) define the problem, (2) identify all factors potentially affected by any solution, (3) develop concepts for solving the problem, and (4) quantify tradeoffs associated with each potential solution (Karlen et al. 1994). One method being used to help address this complexity, especially for bioenergy programs, is life cycle assessment (LCA). This seems to be a good approach, but it is not an end in itself because of the uncertainty associated with complex systems and the difficulty in establishing the specific boundaries for analysis.

Food, Feed, Fuel, and Environmental Interactions

Currently the U.S. transportation sector consumes approximately 14 million barrels of oil per day, 9 million of which are used in light-duty vehicles (NAS 2009). Recognizing that consumption likely will increase, the Energy Independence and Security Act (EISA) of 2007 mandated that a portion of domestic fuel consumption be met with biofuel, which is currently supplied primarily by ethanol from corn grain or biodiesel from soybean. Diversion of corn, soybean oil, and/or other food crops (e.g., wheat [*Triticum aestivum* L.] or peanut [*Arachis* spp.]) has stimulated debate regarding competition between food, feed, and fuel (Naylor et al. 2007; Nonhebel 2005; Trostle 2008) and with respect to potential social, economic, and environmental effects.

In contrast, development of a grain-based ethanol industry has been praised for its impact on crop prices and the beneficial effects it has for rural economies (Parcell and Westhoff 2006). From the perspective of farmers and small rural communities, development of ethanol plants created greater local demand for commodity crops and higher prices for corn/soybean and other crops. Local investment and control of ethanol and biodiesel plants has reinvigorated many small midwestern communities by providing well-paying employment opportunities, but some argue that the number of jobs added to the local economy is overestimated (Low and Isserman 2009), especially because many biodiesel plants are operating well below their constructed capacity.

Passage of the Renewable Fuels Standard (RFS; currently updated to RFS2) as part of the EISA of 2007 triggered many studies, including one by Gallagher (2010) to determine how the 56.8 billion liter (15 billion gallon) per year contribution from corn starch-based ethanol to the 136.3 billion liter (36 billion gallon) RFS mandate would affect the U.S. corn market. The analysis made projections in world corn and soybean markets, including effects of technology that will result in yield increases and use of the by-product dry distillers grain (DDG) as a replacement for corn feed demand. Based on those assumptions, increased corn (maize) production on foreign lands was projected to account for only a small fraction (6%) of the increased grain demand associated with meeting the RFS mandate. As with energy issues, however, the “indirect land use change” issue connected to global changes in crop production is also very complex. Increased soybean production associated with the corn/soybean system is often a major factor in many LCA projections related to the RFS2 legislation, but although this topic is very important, it is beyond the scope of this Issue Paper and should be addressed by future independent studies.

Economics of Corn/ Soybean Systems

Key Challenges at Each Scale

At the field and farm scale, two key challenges affecting energy use within corn/soybean systems are (1) overcoming barriers to adoption of energy-conserving production practices and (2) improving the viability of bioenergy production. The degree to which energy issues are captured in the market influences decisions at the farm scale. Energy costs represented more than 44% of total operating costs for U.S. corn production and 22% for soybean production in 2004 (Shoemaker, McGranahan, and McBride 2006). Prices for energy-intensive inputs (e.g., fertilizer, herbicides, fuel) directly influence profitability, providing an incentive for producers to adjust their use of these inputs in response to changing energy prices. Fortunately, farmers have historically shown an exceptional ability to make technical and managerial changes that improved crop productivity when faced with increasing energy prices (Cleveland 1995).

Decreasing Tillage

Fuel inputs can be lowered by decreasing tillage (Figure 1). The relative profitability of less intensive tillage systems, such as strip-tillage and no-till compared to conventional tillage, is site specific and varies depending on soil, climate, and drainage conditions (Al-Kaisi and Yin 2004; Archer and Reicosky 2009; Chase and Duffy 1991; Vetsch, Randall, and Lamb 2007; Yin and Al-Kaisi 2004; Yiridoe et al. 2000). Although the decision to decrease tillage is strongly influenced by economic returns, the presence of adjustment costs and risk means that producers will not be willing or may not have the capital to invest in new tillage and planting equipment without some guarantee for a premium in profits above what would be earned by their existing tillage system (Kurkalova, Kling, and Zhao 2006). There are several ways this perceived need for premiums could be overcome, including

1. ensuring large enough energy price changes that adopting less intensive tillage systems is sufficiently more profitable than current tillage systems,
2. lowering producer risk through stabilization policies such as insurance,
3. providing better information about the economic impacts of decreasing tillage, and
4. lowering the adjustment costs of adoption (e.g., through technology improvements or subsidizing conservation tillage during the transition from current management practices).

Note also that social and environmental impacts of agricultural practices may have public costs and benefits that are not reflected in the market. Recognizing that these impacts are important in terms of social welfare and long-term sustainability, policies and incentives may be implemented to

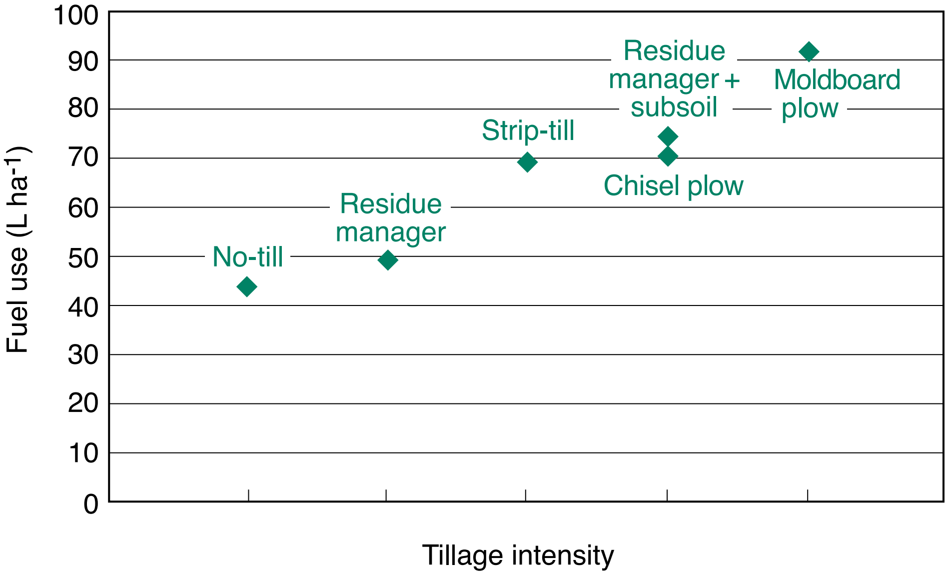

Figure 1. Fuel use as related to tillage intensity (data from Archer and Reicosky 2009).

address these impacts. Discussion in this section, however, focuses on the private market impacts on farm decisions.

Optimizing Nitrogen Use Efficiency

Nitrogen fertilizer represents a significant energy and cost input for corn production. Decreasing N fertilizer use per unit of production could greatly lower energy requirements for agriculture. Several methods for decreasing N fertilizer use per unit output have been identified, including the use of crop rotations, cover crops, and/or manure; banded and decreased fall applications of fertilizer; and increased use of soil testing, site-specific applications, and N stabilizers or inhibitors (Dinnes et al. 2002). These management practices, however, all may incur a cost at the farm level. Increases in N fertilizer prices provide a market incentive for producers to decrease N fertilizer use. Two critical questions with regard to the effects that the various methods for decreasing fertilizer rates will have on energy issues associated with the corn/soybean production system are (1) Will the savings in N fertilizer expense offset the costs associated with implementing those practices? and (2) Will the decreases in N rate also lower crop productivity? An alternative strategy for improving N use efficiency would be to increase yield per unit input.

It often has been suggested that producers apply more N fertilizer than is agronomically needed (Sheriff 2005). The observed applications, however, may be economically rational when considerations of substitutability of other farm inputs, opportunity costs, and uncertainty about soil and weather conditions are included (Sheriff 2005). This points to the potential for improving N use efficiency by decreasing uncertainty about soil and weather conditions, as well as lowering costs of obtaining information regarding soil nutrient status.

It is also important to consider interactions among input use decisions at the field level. Although decreasing tillage lowers fuel use, increasing fuel prices will improve the economic viability of less intensive tillage systems. Because of the energy used in the manufacture of N fertilizers and herbicides, however, prices for these inputs are correlated with fuel prices (Liska and Perrin 2011). Both field research and producer survey data indicate potential significant interactions between tillage systems and herbicide or N fertilizer use (Archer, Halvorson, and Reule 2008; Day et al. 1999; Fuglie 1999; Martin et al. 1991; Stecker et al. 1995). These interactions may help enhance energy decreases under increasing energy prices when decreased tillage leads to lower herbicide or N fertilizer use, or these interactions may lower the benefits of decreased tillage if this leads to higher levels of herbicide or N fertilizer use.

Shifts in corn production practice from 2001 to 2005, a period of rising energy costs, indicated statistically important increases in conservation tillage and no-till, with producers also indicating that they had decreased N fertilizer rates (Daberkow, Lambert, and Musser 2007). It could not be determined, however, if these shifts were specifically caused by increasing energy costs. These examples highlight some of the economic complexity associated with corn/soybean systems and the energy issues related to them, as well as the need to look beyond direct energy impacts. These examples also provide a challenge to identify economically viable management practices that can simultaneously decrease producer dependence on tillage, excessive herbicide, or N-fertilizer inputs, while significantly increasing corn and soybean yield.

Market Linkages

The rapid increase in the use of corn grain for ethanol production has resulted in close linkages between energy and corn markets, an association that is expected to continue as long as demand for ethanol is not constrained, such as by the limit on blending ethanol with gasoline (Tyner 2010; Tyner and Taheripour 2008). This linkage also extends to markets for other crops, including soybean, due in part to competition for land among crops and to competition between crops as inputs for feed and manufacturing (Muhammad and Kebede 2009), as well as through effects of oil prices on currency exchange rates (Harri, Nalley, and Hudson, 2009).

With increasing energy prices, the value of corn for ethanol production also increases. The prices of many production inputs, however, tend to increase as well. When the values of production and inputs both increase, there may be little economic benefit to changing input levels (e.g., N fertilizer) inasmuch as economic optimum is often determined as a function of the ratio of output to input prices (Bullock and Bullock 1994; Pannell 1990). There may be incentives, however, for gathering more information (e.g., soil testing and plant analysis) because these tools can be used to help avoid under- or over-application of N fertilizer.

When crop and fertilizer prices are high, applying an incorrect amount of fertilizer has a greater impact on profitability, so the benefit of avoiding incorrect applications increases. So long as the benefits from obtaining this information exceed the costs of obtaining it, adoption would improve farm profitability (Fuglie and Bosch 1995). Research has shown that soil testing may be complementary with crop rotation, presumably by decreasing uncertainty about the effect of soybean on N levels for the subsequent corn crop (Wu and Babcock 1998). Adoption of both soil testing and crop rotation could have economic, nutrient use, and energy use benefits that once again illustrate the need to consider broader crop production impacts and interactions when seeking to optimize energy use efficiencies within corn/soybean or other cropping systems.

As attention shifts to cellulosic sources for bioenergy production, the economic viability of cellulosic ethanol production depends on the total cost of ethanol being competitive with other liquid transportation fuels. Crop residues have been identified as a potential low-cost source of bioenergy feedstocks. Removal of crop residues, however, could lead to declines in soil fertility and productivity, a decrease in soil C, and an increase in soil erosion (Blanco-Canqui and Lal 2009). Alternatively, potential benefits could include a decrease in nitrous oxide (N_2O) emissions from the soil and decreased N losses due to leaching (Kim and Dale 2005). Replacement of nutrients removed through crop residue harvest and lost through heightened erosion increases the costs producers must recover in selling bioenergy feedstocks and increases the energy inputs needed to produce those feedstocks. Improving the economic viability of cellulosic ethanol will require lowering costs and improving efficiencies at all levels of the supply chain, from feedstock production to conversion and distribution. This includes finding ways to lower nutrient replacement needs and using coproducts in the best manner to improve system efficiency (e.g., for process energy, feed, or value-added products).

Farm-level Scale

Expanding from the field to farm level, additional considerations become important. There has been a general trend in the United States toward larger, more specialized farms (Dimitri, Effland, and Conklin 2005). Although scale economies have led to larger farm sizes, there seem to be potential economic benefits to diversification (Chavas 2008; Morrison et al. 2004). Diversification could help increase energy efficiency of corn/soybean systems by taking advantage of production synergies (e.g., rotations to use nutrients better and to disrupt pest cycles; integration of crops and livestock [even though the owner/operators may be different] to use feed and manure better). Diversification, however, can make management more complex (Chavas 2008), and there is evidence that producers tend to adopt technologies that decrease managerial intensity, particularly if labor is limited or the farm relies heavily on off-farm income (Fernandez-Cornejo et al. 2007). The challenge is to develop farm diversification or other energy-saving technologies that producers are willing to adopt. This also requires developing an understanding of the social impacts (e.g., health insurance) at the farm household level.

Regional Scale

When expanding beyond the farm level to regional and larger scales, a key challenge is meeting the multiple demands for food, feed, fuel, and ecosystem services. At the broader scale, changes in energy prices or policies can lead to shifts that affect both crop and input prices. Analysis of impacts of corn ethanol expansion has illustrated the importance of understanding the supply and demand responses, including effects of technological change (Gallagher 2010). The result may be not only changes in management but changes in land use. Effects on energy issues will depend on where these changes occur. Locations of land use change and interactions with management also have a critical impact on provision of ecosystem services, such as differences in GHG emissions (Kim, Kim, and Dale 2009) or services related to biodiversity and wildlife habitat (Gottfried, Wear, and Lee 1996).

An attraction of using crop residues as bioenergy feedstock is that this feedstock could be produced without requiring additional land. This may not be the case, however, if crop residue removal decreases grain yields, thus requiring additional land to be brought into production. An added concern with using crop residues as a bioenergy feedstock is whether or not sufficient quantities would be available for harvest while still protecting the soil resource (Wilhelm et al. 2010).

It has been suggested that an additional or alternative source of bioenergy feedstock may be short-rotation woody crops or perennial grasses (e.g., poplar [*Populus* spp.], willow [*Salix* spp.], switchgrass [*Panicum virgatum*], or Miscanthus [*Miscanthus* x *giganteus*]) grown on sensitive, marginal, degraded, idle, or abandoned lands (Blanco-Canqui 2010; Campbell et al. 2008; Lemus and Lal 2005; Paine et al. 1996; Schmer et al. 2008; Tilman, Hill, and Lehman 2006). Because these lands often have low productivity for annual crop production or are not currently being used for crop production, using these lands for bioenergy production could decrease the need to bring additional lands into annual crop production. These lands also may be where production of perennial feedstock is more profitable than annual crop production (McLaughlin et al. 2002; Walsh et al. 2003).

Increasing perennial production on the landscape, particularly on sensitive lands, could provide additional ecosystem service benefits (Tilman, Hill, and Lehman 2006). Initial modeling also questioned whether or not those benefits would be derived if the plants were harvested, but after sampling ten farms in the central and northern Great Plains, Liebig and colleagues (2008) showed that soil organic C increased significantly within both the 0 to 30 centimeter (cm) and 0 to 120 cm depth increments. Accrual rates averaged 1.1 and 2.9 Mg per hectare per year (ha^{-1} yr^{-1}) (4.0 and 10.6 Mg CO_2 ha^{-1} yr^{-1}), respectively; however, there was substantial variation across sites, emphasizing the need for additional long-term field studies. Some research has indicated that riparian buffers harvested for bioenergy can be managed to decrease runoff and sediment transport (Sheridan, Lowrance, and Bosch 1999).

One important consideration is the payment amount that producers, particularly those who specialize in corn/soybean production, will receive for establishing and growing perennials on sensitive lands for bioenergy use. These payments may be higher than would be indicated by comparing returns from current annual cropping because of the need for more intensive or diversified management skills. Another concern is that although land devoted to perennials can be converted back to row crops if feedstock prices decrease, at least one establishment year is required to convert cropland back into a perennial crop such as switchgrass.

Another major challenge associated with accounting for the provision of ecosystem services as part of an overall energy analysis is that, even though management decisions (e.g., what crop to plant) are made at the farm level, this is not necessarily the scale at which ecosystem services (e.g., wildlife numbers or filtering and buffering effects) are generated or where the benefits are realized (Fischer, Turner, and Morling 2009; Gottfried, Wear, and Lee 1996; Lant et al. 2005). Increasing the value of ecosystem services to the farmer, through ecosystem service markets or policy incentives, could indirectly lower energy use associated with corn/soybean production by providing additional economic incentives to decrease soil erosion and prevent nutrient and pesticide losses to the environment.

It is also possible, however, that these incentives could result in practices that lower production, either through decreased yields or by taking land out of crop production (and shifting production to less productive regions). If that is the case, increasing the value of ecosystem services could increase energy use per unit of production. A key challenge is to predict accurately and to understand the interactions that might occur, including effects on land use and management decisions.

Research and Development Needed to Meet Economic Challenges

Key research needs include finding ways to lower adoption barriers for energy-conserving practices. Important facets of adoption include characteristics of the learning process, potential adopters, and conservation practices (Pannell et al. 2006). Achieving net reductions in energy use will require identification and development of practices that are not only more efficient but also economically superior. This includes research that decreases uncertainty associated with adoption of energy-conserving practices and provides opportunities for producers to learn about different production practices and to develop skills for using those practices. Some examples are developing technologies that lower the cost of soil testing, gathering information related to soil nutrient status, decreasing costs of precision agriculture technologies, and applying the information to develop better knowledge and tools for using ecological processes to enhance corn/soybean production.

The 2010 assessment of North American soil fertility developed with data from 4.4 million soil samples analyzed by private and public soil-testing laboratories illustrates this type of activity (Fixen et al. 2010). Unfortunately, those data show that soil nutrient levels in some prime production areas are not being maintained. Current agricultural management practices are mining nutrients. Correcting this situation with expanded use of soil testing and replacement of nutrients removed by crops is crucial for rebuilding depleted nutrient levels. For optimum production, it is important to maintain soil productivity and to improve the efficiency of use for all inputs, including energy. These actions also are crucial for maximizing returns to land, labor, and capital used in every production system. Furthermore, these benefits accrue across all scales of analysis, from individual fields to farms, to regions, to states, to nations, and thus globally.

Another research need is the development of management systems that allow agricultural production to meet the multiple demands of food, feed, fiber, fuel, and ecosystem services in the best ways possible. This will require planning beyond a single field or farm; to achieve true sustainability, broader economic impacts and provision of ecosystems services extending to local and regional landscapes also must be included. For example, by adopting site-specific management, a portion of current crop residues could be used for bioenergy production, and there are several scales at which perennials could be grown on the landscape. These scales include using buffer strips on marginal lands within production and bordering fields, in whole fields of marginal land (e.g., Conservation Reserve Program [CRP]), or in large tracts of marginal land. Simply stated, these production alternatives will be driven by economics, because if farmers can make more money on a piece of land by growing switchgrass than by growing corn or soybean, they will grow switchgrass. From a bioenergy investment perspective, this emphasizes the need for stable and predictable policies on which all management decisions can be made.

Environmental Challenges Facing Corn/Soybean Systems

Key Issues at Each Scale and Risks Involved

When quantifying energy issues associated with agricultural systems, two of the key environmental risks and challenges are climate change and land conversion. This is especially true in the redesign of existing systems to produce biofuels for transportation, in addition to the food, feed, and fiber that they already deliver to a global market.

Rising temperatures increase evaporation and generally cause an increase in the amount of water in the atmosphere. Locally, fluctuations in rainfall patterns compared to the past 30-year normal could cause either drought or higher precipitation in corn-growing regions. Recent data show that the Corn Belt region has experienced a trend toward higher precipitation events (ICCAC 2011; Karl, Melillo, and Peterson 2009). These statistics also match the observed record floods of 2008 in Iowa and Illinois and in the Missouri River Valley in 2011. Increasing temperatures lengthen the growing season, which can increase yield, but higher temperatures can also increase plant respiration, disrupt plant reproduction (i.e., pollination) and lower yields (Karl, Melillo, and Peterson 2009). In general, climate change impacts are wide ranging and will affect all cropping systems, thus reinforcing the need for quantitative, long-term research to fully understand those effects.

Internationally, greater industrial-scale demand for bioenergy could increase economic pressure to convert native ecosystems to agricultural systems (Naylor et al. 2007; Searchinger et al. 2008). To minimize deforestation for agricultural expansion in places such as Brazil, overall productivity from agricultural lands must be increased to meet fuel, feed, fiber, and food needs. Failure to develop more productive systems will likely ensure that in the long term, native ecosystems will be diminished even more than they are now (Hassan, Scholes, and Ash 2005; UNEP 2009). The United Nations Environmental Programme projects global biofuel expansion by 60 to 80 million hectares (Mha), or even 166 Mha, by 2020. This is equivalent to between 4 and 11% of the current arable land or 1 to 3% of total global agricultural land (UNEP 2009).

Further decreases in native ecosystems could easily increase the rate of species extinction and potentially lead to the irreparable losses of biodiversity that are of concern to many people today. In addition, conversion of native ecosystems to agricultural uses often is associated with a large loss of C through both the destruction of standing biomass associated with trees, grasses, and forbs within the natural system and the oxidation of soil organic C when the area is disturbed through tillage or other processes. The newly released C is quickly oxidized to CO_2, which is recognized as a leading driver of climate change.

In the United States, the land conversion issue is controversial because of different assumptions regarding potential soil and crop management practices that might be used by land managers and decision makers. Further conversion of native tallgrass prairie is quite limited because nearly all of the area that can be converted to cropland has been tilled. Most remaining areas of tallgrass prairie are too rocky, shallow, steep, sandy, or isolated in small patches to be farmed economically.

The potential impact of returning CRP land to crop production is being vigorously debated among different groups. For example, Fargione and colleagues (2008) calculated that converting central U.S. farmland that had been enrolled in the CRP for 15 years to a corn ethanol production system would decrease both standing biomass and soil carbon, thus creating a biofuel carbon debt that would take 48 years to repay. The assumption associated with this estimate, however, was that tillage would be used for the conversion. This may not be accurate because technology now exists to make the conversion using no-till practices. Field studies by Follett and colleagues (2009) provide data showing that use of no-till farming practices to convert CRP grasslands to grain crop production does conserve the soil organic carbon (SOC) that was sequestered during the time period that the land was in the CRP. The potential conversion of CRP land in the United States is also controversial because of its wildlife and other ecosystem service benefits. The most satisfactory option for addressing these differences would be a science-based approach that addresses all ecosystem services, including biofuel feedstock production, in a comprehensive economically, environmentally, and socially acceptable manner.

Life Cycle Assessment as a Tool

Life cycle assessment is a method for evaluating the full environmental impact of any industrial production system. It is now being used to evaluate the GHG emissions from the production of biofuels relative to conventional petroleum fuels. Recent passage of the Low Carbon Fuel Standard of California and the EISA both require decreases in GHG emissions from biofuels compared with gasoline. Because of the flexibility of LCA, it is an appropriate method for attempting to gauge the total GHG intensity of fuels and the degree to which different fuels will decrease emissions that cause climate change (Liska and Perrin 2009). Life cycle assessment has yet to be required by legislation to monitor non-biofuel food crops, although emerging marketing methods used by Walmart will use LCA to quantify the environmental impact of food products (Walmart 2011).

To understand the LCA process, users must first determine the sum of GHG emissions from the use of fossil fuels in biofuel production. This is relatively straightforward using USDA statistics, although data for the biofuel industry are more scarce (Liska et al. 2009). In addition to both direct and indirect fossil fuel use, GHG emissions in the form of N_2O from N fertilizer contribute roughly 36% of cropping GHG emissions from corn, although great uncertainty exists (Liska and Perrin 2011).

Changes in SOC may be a large source of GHG emissions from biofuel production (Wortmann et al. 2010), but the science of soil C dynamics has been questioned in recent years with controversial and conflicting data (Baker et al. 2007). Overall, the results seem to differ because of production practices, depth of soil sampling, and the agroecosystem within which the research was conducted (Blanco-Canqui and Lal 2008; Varvel and Wilhelm 2011; Verma et al. 2005). Fortunately, there is greater data congruence concerning SOC dynamics and residue removal. Summaries of recent field studies show that SOC is consistently lost when crop residues are removed at excessive rates (Anderson-Teixeira et al. 2009; Blanco-Canqui and Lal 2009; Wilhelm et al. 2007); however, there is a large amount of variability in the results and continued, long-term studies (e.g., Karlen 2010; Karlen et al. 2011) are needed to help quantify SOC changes associated with crop residue harvest.

The nexus of biofuels, climate change, and land use conversion has become an important LCA issue for biofuels (Searchinger et al. 2008). So-called "indirect land use change" from the production of biofuels assumes that corn taken out of the market is partially replaced by crop expansion and deforestation abroad. But there is a high level of uncertainty in projections of additional GHG emissions from land use change for inclusion in the corn-to-ethanol life cycle, ranging from 14 to 104 grams CO_2 equivalent per megajoule (MJ) of energy in ethanol (Wang et al. 2011). Overall, these assumptions have numerous areas of contention at present and are dependent on actions and policies of independent countries. Because of the uncertainties involved, it may not be possible to reliably model the indirect effects of biofuels outside of the country in which they are produced.

Research and Development Needed to Prevent Environmental Problems

From an LCA perspective on biofuel production, one of the most critical factors for determining net GHG emissions is likely to be changes in SOC. Long-term field data remain limited (e.g., Follett et al. 2009; Liebig et al. 2008) because quantifying SOC changes associated with crop residue removal is a long-term process that requires substantially more investment in research, especially on marginally productive cropland. The Agricultural Research Service (ARS) Renewable Energy Project and Sun Grant Regional Partnership are two sources of information that are beginning to provide some of the field data needed to quantify long-term effects of residue harvest on SOC (e.g., Karlen 2010; Karlen, Birrell, and Hess 2011; Karlen et al. 2011; Wilhelm et al. 2010), but additional studies are needed.

The best strategy to resolve the large uncertainties associated with geographical variations in climate, soil, and management practices is to fully support critical long-term field research to quantify and better understand the subtle relationships between crop residue removal and SOC loss. Furthermore, where cost effective, management of crop rotations and residue, as well as manure from livestock, can play a role in maintaining soil C (Fronning, Thelen, and Min 2008). Alternatively, after biofuel production the return of a stable C residue in the form of biochar could be important for helping to maintain SOC and decreasing overall GHG emissions from biofuel systems (Lehmann and Joseph 2009). Thus, in addition to a more comprehensive approach for estimating SOC loss, more research is needed on management strategies that maintain or even enhance SOC levels.

Market and Policy Issues for Corn/Soybean Systems

Agricultural commodity markets traditionally have been influenced by energy price movements through production and distribution costs. Changes were felt both directly in fuel costs and through other inputs such as N fertilizer produced with natural gas. Beginning in 2006, the price surge in a wide range of commodity prices signaled the emergence of a new relationship, encouraged by state and national energy policy, between agricultural and energy markets. With it came a surge in demand for feedstocks from the agricultural sector to be used for energy production. Some saw biofuels as a means to decrease C emissions, increase energy independence, and raise farm income. Others noted that the new demand for commodities to produce biofuels could lead to higher food prices, potentially undermining food security and bringing about unintended environmental consequences from expanding crop acreage that may actually result in greater C emissions. They also called into question the use of policy initiatives to promote the transformation of food crops into energy.

The increase in prices during this period threatened to push millions of additional people toward hunger and undernourishment (FAO 2008). As a result, a large number of studies were conducted to examine the share of the increase that could be attributed to biofuel production, and these studies have resulted in a wide range of conclusions (CEA 2008; Collins 2008; Trostle 2008). During this same period, the United States, the European Union, and Brazil continued and expanded support programs for biofuel production. During 2009, prices fell from those highs but remained well above historic levels. During 2010, wheat crop failures in Russia and lower corn yields in many areas of the United States again raised concerns regarding the impact of biofuel production on food prices. These events highlight the importance of understanding how the world's biofuel production and energy policies influence commodity prices and how they may contribute to price volatility in agricultural markets.

Several studies (Elobeid et al. 2006; Gallagher, Otto, and Dikeman 2000; Meyer, Westhoff, and Thompson 2008; Westhoff, Thompson, and Meyer 2008) have shown the area and price effect to date of various renewable fuel policies on agricultural commodity prices. Given the relative size of petroleum and biofuel markets, it was previously assumed that linkages among petroleum, gasoline, ethanol, and corn, as an example, would be tightly bound because demand for ethanol and therefore feedstock supplies would be highly elastic (Tyner 2007; Tyner and Taheripour 2008). Over certain ranges or prices and given time to adjust, demand for feedstocks to produce biofuels may be highly elastic and stabilize corn prices with respect to *shocks*[1] that originate in agricultural markets, but the level at which the price stabilizes is contingent on the price of petroleum and therefore subject to its fluctuations. With petroleum second only to agricultural markets in price volatility (Regnier 2007), the net effect on price volatility, even under a very elastic relationship, is unclear.

To support the U.S. biofuel industry, subsidies often have been provided to encourage production and consumption of biofuels derived from corn/soybean oil. The policy followed during recent decades historically has been a subsidy provided to biofuel blenders. A portion of the subsidy is passed back to the producers, which encourages further biofuel production, and part of the subsidy is passed forward to consumers, lowering the price and encouraging consumption. This policy, although intended to promote biofuel production, has in essence become a subsidy that encourages greater fuel consumption to support driving more vehicle miles, which is in contrast to rising oil prices that discourage additional driving (Lapan and Moschini 2009). Subsidies such as this also are government expenditures that totaled approximately six billion dollars in 2010. As environmental concerns have increasingly become a motivation for biofuel use, policies that in essence subsidize consumers for driving more miles are being looked on less favorably by many people concerned about U.S. federal expenditures.

The Energy Policy Act of 2005 established nationwide use mandates for biofuels in the United States, and these mandates were further expanded by the EISA. If continued, these mandates will require more than a doubling of renewable fuel consumption in the United States during the next decade. Much of

[1] Italicized terms (except genus/species names and published material titles) are defined in the Glossary.

the growth beyond 2010 could come from "second generation" biofuels, which excludes corn starch-based ethanol under current legislation (Service 2010). Several feedstocks thought to be viable sources for cellulosic biofuel production, such as dedicated grasses or crop residues, however, will continue to influence corn and soybean acreage into the future.

Similar quantitative mandates for biofuel programs in the European Union set a target of 10% renewable fuel inclusion by 2020 (EUC 2009). These quantitative mandates have the effect of creating a highly inelastic segment of demand (Figure 2), which means the quantity of fuel consumed is being dictated and not responding to market signals, and thus price movements can be exaggerated. Such mandates, while adding certainty for biofuel producers and feedstock suppliers, mean this segment of demand is less able to respond to feedstock supply shocks such as drought, causing a large rise in agricultural prices even when petroleum prices are stable. It is left to other grain users (e.g., food and feed) to adjust consumption. This again has the potential for leading to increased commodity price volatility.

Additional proposals that span other energy sectors, such as the U.S. House of Representatives bill HR2454, which is often referred to as "Cap and Trade," will expand the role of quantitative mandates influencing the agriculture sector. Under renewable portfolio standards for electrical generation, the use of biomass to cofire with traditional feedstocks in electrical generation could put cap and trade policy in direct competition with biofuel policy. If approved, this bill could add additional rigidity to commodity demand and accompanying volatility in corn/soybean prices.

While the United States has pursued biofuel policies at a national level, several states have or are proposing their own policies. Some states, such as Missouri, have a minimum blend requirement for ethanol; as the national mandate grows, this policy becomes less important. New state proposals could be far more influential. California's Low Carbon Fuel Standard mandates a reduction in GHGs emitted from the transport sector in the state

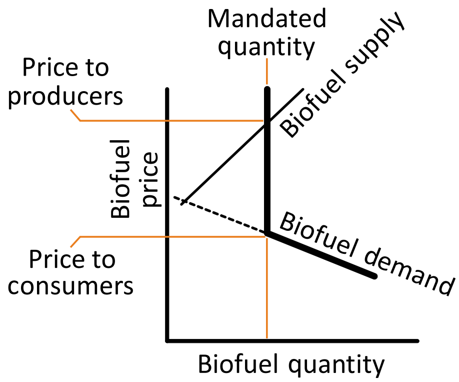

Figure 2. Quantitative mandates produce a highly inelastic demand when they are binding.

and, instead of categorizing fuel types into four classes, establishes a GHG reduction score for each fuel pathway or alternative to fuel such as electric vehicles. Should the separate system be employed, it could greatly alter the fuel pathways being used to comply with the national RFS, and fuels and technology of the greatest value in California could spur production. Should other states follow California's move, greater quantities of total biofuels than required under the RFS2 may be necessary and thus could have important quantitative effects on the sector.

Key Challenges at Each Scale

At the scale of state and national policy, the part of the total RFS2 mandate that corn starch ethanol can access is capped at 56.8 billion liters (15 billion gallons), which represents an approximate 25% increase in production when compared to the 45.4 billion liters (12 billion gallons) produced in 2009. The RFS2 biodiesel mandate, for which soybean oil can be used, grows a little over 50% after 2010 to a total volume of 3.8 billion liters (1 billion gallons). So although there will be continued growth in the production of these two fuels, much of the mandated volume coming directly from corn/soybean has already been met. But the RFS2 mandate requires another 79.5 billion liters (21 billion gallons) of biofuels to be derived from other feedstock materials (e.g., corn stover, switchgrass, Miscanthus, sorghum, sugarcane [*Saccharum* spp.] bagasse), and production of those materials could impact corn and soybean acreage. Furthermore, the RFS2 mandate represents minimums, and should petroleum prices rise to levels reached in 2007, the market could easily increase demand for biofuels to levels exceeding these quantitative minimums. This remaining growth in biofuel production directly from corn/soybean, coupled with the potential for simultaneous growth in both oil and agricultural commodity prices, represents the primary policy and market challenges for corn/soybean-based energy systems.

As was seen in 2007, the simultaneous rise in both petroleum prices and food prices, along with increased use of corn for ethanol, attracted increased scrutiny of policies that encouraged diversion of food and feed crops to production of biofuels. Although numerous studies concluded this was but one factor contributing to the rapid rise in food costs (CEA 2008; Collins 2008; Trostle 2008), it is fair to say corn ethanol- and soybean oil-based biodiesel took a public image hit (Selfa et al. in press; Skipper et al. 2009). Even if a starch-based process were in place that would result in the 50% GHG reduction score needed to qualify as a GHG mitigation strategy, it is legislatively prohibited from doing so and thus suffers from the label of old technology. The biofuel industry will continue to grow under current policy and at such a scale in the United States that the perception of causal linkage among petroleum prices, biofuel demand, and commodity prices will continue to add uncertainty to the market regarding the continuation of the quantitative biofuel mandates.

Another real concern is the ability of the motor fuel infrastructure to handle an increased volume of ethanol and biodiesel. To date the "*blend wall*" has been a concern, because conventional vehicles previously were limited to a maximum 10% ethanol inclusion in motor fuels, with an aggregate gasoline market of approximately 548.9 billion liters (145 billion gallons) per year, according to the Department of Energy. As a result, this market is being saturated quickly.

The transition to higher blends such as E85 (up to 85% ethanol) requires new dispensing infrastructure and specialized vehicles. This investment takes time, and with the possibilities of mandate waivers, policy changes, and expansion of lower-level blend constraints, investment by motor fuel dispensers remains a risky prospect. Recently the Environmental Protection Agency (EPA) allowed for up to 15% blends in conventional vehicles produced in 2002 or later, but it isn't clear if this ruling will alleviate the bottleneck. The bifurcation of the conventional vehicle market may raise consumer confusion, and fuel retailers have expressed concerns that such bifurcation exposes them to consumer complaints and lawsuits resulting from misfueling.

The EPA waived the cellulosic biofuel mandate in both 2010 and 2011 (Lane 2010; Service 2010). Should the hurdles in economic cellulosic biofuel be overcome and should a significant portion of that supply be in the form of ethanol production, the blend wall limit to total U.S. market demand for ethanol would more likely be hit and thus create additional hurdles that will affect the distribution and consumption of biofuels produced under current domestic mandates. Development of advanced drop-in fuels may help alleviate this issue, but substantial research and development is still needed to make such fuels viable.

Research and Development Needed to Meet Market Challenges

Advancements in corn/soybean yield through increased productivity will help alleviate supply concerns, but issues associated with GHG profiles, alternative feedstock supplies, and efforts to overcome bottlenecks in use are all targets for additional research and market development.

The corn production system is capable of contributing additional feedstock, from corn residue to the *pericarp* removed before fermentation, for use in the production of cellulosic ethanol. The use of either of these feedstocks could produce a fuel that could qualify as an advanced biofuel and, depending on the process, perhaps a cellulosic biofuel (which depends largely on SOC dynamics, as shown earlier). Corn oil removed during the dry grind ethanol process, or subsequently spun out of the distillers grains, could both provide a biodiesel feedstock and potentially expand the use of the distillers grains into other livestock types where the oil content may be an impediment. The use of these additional feedstocks would increase the output of ethanol per ha of corn production and lessen competition with or even enhance food, feed, and fiber production.

For soybean oil-based biodiesel, the way forward is less clear. Only increases in seed yield or oil content are likely to produce additional quantities of biodiesel per ha and lessen competition for food use. A more likely path for increasing biodiesel production is to use other feedstock materials. In the review by Johnson and colleagues (2007), the authors stated that several species from the mustard family (*Brassicaceae*) could be viable candidates for biodiesel and other advanced fuel production. Potential crops include oilseed rape (*Brassica napus* L.), crambe (*Crambe abyssinica*), lesquerella (*Lesquerella fendleri* [S. Wats.]), camelina (*Camelina sativa* L.), pennycress (*Thlaspi arvense* L.), castor bean (*Ricinus communis* L.), and Cuphea spp. (plant family Lythraceae), and they are currently under investigation. An advantage for crambe and camelina is that neither is currently being grown widely in the United States and, because they are both being developed for industrial uses, conversion to biodiesel will not compete directly with soybean or other edible-oil crops.

A second alternative that has already been seen is the extensive use of animal fats in combination with soybean oil. Another option, depending on the region, would be to use double-cropping of an oil crop with a conventional summer crop or even to double-crop two oilseed species. Finally, substantial effort also is being given to second generation feedstock materials such as algae. All of these oil sources are attracting attention and may lead to more competition for soybean oil in the biodiesel sector, thus decreasing price volatility for soybean oil.

Economically, the biofuel industry has already signaled a willingness to forgo extension of the blenders' credit and has offered an alternative focused on investment credits to improve infrastructure for the dispensing of higher-level blends. Current availability of E85 pumps is limited geographically to the Midwest in states that represent only a small share of motor fuel consumption (RFA 2005–2011). This represents only part of the demand constraint. Flex fuel vehicles remain a small share of the overall vehicle fleet and, unless high-level blends are priced based on energy equivalence or below, the incentive to purchase E85 vehicles or use those already on the street will be limited.

A Landscape Vision for Sustainable Corn/Soybean Systems

Developing a landscape vision (Figure 3) that blends multiple feedstock streams is one strategy for engineering more sustainable and energy-efficient corn/soybean production practices. The premise for this vision is that rather than focusing solely on energy issues associated with the corn/soybean system, the challenge could be addressed through coordinated efforts that also

- provide sustainable grain and biomass feedstock supplies for the bioenergy industry,
- increase C sequestration,
- protect water quality,
- increase productivity and profitability,
- lessen producer and environmental risk,
- promote biodiversity,
- improve wildlife habitat, and
- enhance rural community development by creating new industries and entrepreneurial opportunities.

This approach also could facilitate balancing the economic drivers and sustainability factors (Figure 4) needed to have sustainable feedstock supplies.

The landscape vision for sustainable resource management is built on experiences with field-scale precision farming (Kitchen et al. 2005; Lerch et al. 2005). It begins by geo-referencing a site and developing a detailed soil survey, a digital elevation model, and soil fertility maps. Information such as current land tenure, community access

Figure 3. A landscape management vision serves to more fully integrate economic, environmental, and social aspects of agriculture into agronomic systems to produce food, feed, fiber, and fuel sustainably. (Photo courtesy of USDA–Natural Resources Conservation Service.)

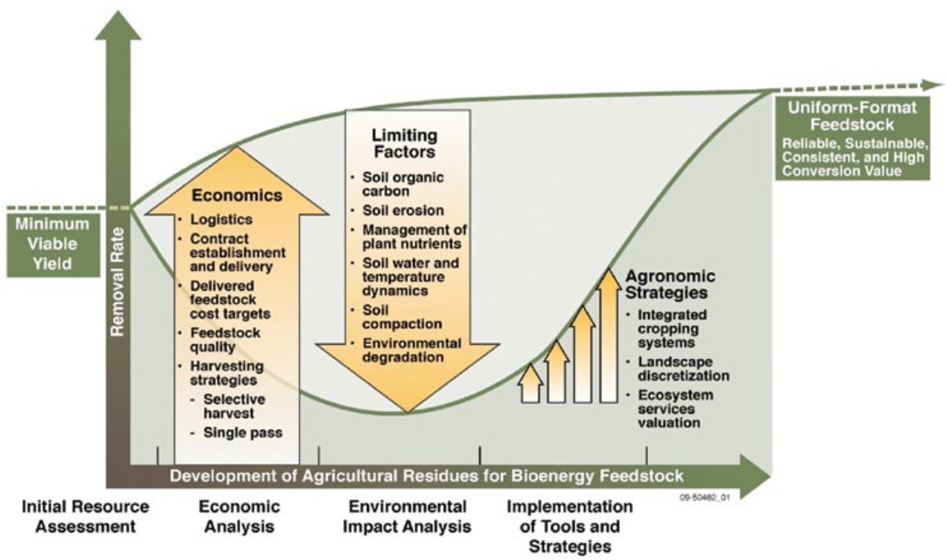

Figure 4. An illustration of competing economic drivers and environmental sustainability forces that must be balanced to achieve sustainable cellulosic feedstock supplies to support the transition from fossil to renewable fuels (from Wilhelm et al. 2010; used with permission of Mary Ann Liebert, Inc., Publishers).

relationships, soil resource and drainage patterns, soil quality status, crop rotation and distribution patterns, economic conditions, conservation practices, wildlife, and human restrictions and concerns is then added as “layers” to the base maps. Karlen, Dinnes, and Singer (2010) discussed this approach with regard to the development of biofuel production schemes that could enhance ecosystem services. One hypothetical scenario would be to establish woody species such as poplar trees near streams, grass and legume species in a buffer area between the streams and cropland, and then high-yielding diversified rotations of annual and perennial crops that would meet food, feed, and fiber needs. Where climatically possible, erosion and C loss could be partially mitigated by using cover crops or living mulches. The crucial point is that plant species variation across the landscape would be much greater than the corn/soybean-dominated landscapes that currently exist throughout much of the midwestern United States.

Incorporation of red clover or alfalfa to serve as a cover crop and/or green manure could significantly alter energy flow in current corn/soybean systems, because these crops have been shown to have an N replacement value ranging from 70 to 121 kg N ha^{-1} (Liebman, M. 2010. Personal communication). Based on an N fertilizer cost of 57 MJ kg^{-1} N (Shapouri et al. 2010), this level of synthetic N replacement would represent a fossil fuel savings ranging from 4 to 10 gigajoule ha^{-1}, which is equivalent to the energy content of 104 to 274 cubic meters of natural gas (Oak Ridge National Laboratory 2009). Food and feed supplies would not be endangered because there still would be intensive row-crop production areas established using best management practices. This establishment would occur with the awareness that if fertilizer recovery was less than desired, there would be a substantial buffer (lignocellulosic) production area lower on the landscape to capture residual nutrients and sediment.

Development of multiple feedstock streams for sustainable biofuel production could be coupled with greater use of coproducts from current corn/soybean biofuel production systems. This might include using manure generated by animals consuming the DDGs as a fuel source for methane production via anaerobic digestion. Wind energy also could be captured and used to decrease the current energy flow associated with corn/soybean production and/or conversion systems.

Implementing an integrated feedstock vision is not without its own challenges, but its strength is the opportunity to begin addressing multiple environmental and production issues by striving for a more balanced agricultural ecosystem. Development of an integrated landscape vision is feasible and could be done efficiently and economically if there is a desire and public willingness to do so. Agriculture in its fullest capacity has the potential to address multiple economic, environmental, and social goals in a sustainable manner (Karlen, Dinnes, and Singer 2010). The key is recognizing that current agricultural practices, developed using an industrial model of component separation for efficiency, are not necessarily consistent with ecological models of redundancy (an ecological term that is sometimes referred to as functional compensation, meaning that more than one species can perform a given role).

Summary and Conclusions

This Issue Paper focuses on critical energy issues affecting corn/soybean systems by first establishing the global production framework for these crops; then reviewing the Farm Bill criteria defining sustainability; and finally examining economic, environmental, and market factors affecting energy use and efficiency. An integrated landscape vision is then offered as one strategy for developing more sustainable and energy-efficient corn/soybean systems. With regard to economics, a critical need is to find profitable ways to decrease adoption barriers for energy-conserving practices. Some possible approaches would be to identify management strategies that would lessen uncertainty associated with adoption of energy-conserving practices and to provide opportunities for producers to learn about different corn/soybean production practices and develop skills for using those practices.

Two environmental risks and challenges affecting energy issues associated with corn/soybean systems, especially with regard to their role in bioenergy production, are climate change and land conversion. These issues are examined by using LCA as a tool. One of the most critical research needs associated with this tool is to develop consistent system boundaries when comparing biofuels and fossil fuels. With regard to market forces, advancements in corn/soybean yield through increased productivity will help alleviate supply concerns. But issues associated with GHG profiles, alternative feedstock supplies, and efforts to overcome bottlenecks in use are all critical topics needing additional research, development, and policy evaluations.

Finally, the most visible energy issue affecting corn/soybean systems is the fact that the emerging biofuel industry is changing daily because of the increased recognition that current energy supply sources are finite and often located in areas that may or may not have political stability. Although controversial and not fully understood, the effects of rising GHG concentrations are another consideration affecting energy issues associated with this cropping system. In response, many conferences and workshops have been held to address multiple questions associated with the emerging biofuel industry. Some recent examples include a Soil and Water Conservation Society-sponsored event that focused on "Sustainable Feedstocks for Advanced Biofuels" in which all aspects of production, harvest, storage, and transport of biofuels feedstocks were examined. Another is the development of Regional Bioenergy Research Centers by the USDA–ARS and the USDA–Forest Service. Despite those and many other actions, several questions and long-term needs remain unanswered. These include the need to

1. develop protocols for quantifying energy flow through complex systems that are themselves either "systems of ecosystems," "systems of systems," or both;
2. quantify real versus perceived effects of no-tillage on C sequestration and the associated GHG mitigation value;
3. find ways to decrease adoption barriers for energy-conserving practices;
4. develop integrated landscape management plans that maximize the productivity, the efficiencies of land, water, and nutrient use, and the profitability while simultaneously conserving or minimizing energy flow;
5. develop more comprehensive quantitative estimates of changes in SOC from crop residue removal and resulting GHG emissions;
6. develop policies and incentives that encourage more holistic land management and facilitate rural development and entrepreneurial opportunities for agriculture;
7. develop integrated usage of renewable fuels and coproducts; and
8. develop consistent federal, state, and local policies for bioenergy development to provide guidance for private and public investment.

Addressing these needs and answering many other questions will enable legislation such as the EISA of 2007 and other subsequent laws to be implemented. The answers also will help increase energy, nutrient, and water use efficiencies associated with corn/soybean cropping systems and collectively help ensure that the United States truly achieves the ultimate goal of having energy independence and security.

Glossary

Blend wall. The maximum possible volume of ethanol that can be blended into U.S. motor gasoline. Initially set at 10% by volume, it was recently raised by the EPA to 15% for vehicles built in 2002 or later.

Pericarp. The outer wall of a fruit or, in this case, the corn kernel that protects the seed or germ itself. It is made up of a tough outer skin, the fleshy middle layers, and the innermost layer, known as the endocarp, that surrounds the seeds.

Shocks. Unanticipated changes in commodity supply or demand associated with yield variation that is not expected because of the occurrence of drought, flooding, abnormal temperatures, conflict, or even perfect weather that causes anticipated yields to deviate from the "normal" or long-term "trend."

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