Biofuels and Sustainability Reports

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Grasslands, Rangelands, and Agricultural Systems

Rob Mitchell, Linda Wallace, Wallace Wilhelm, Gary Varvel, and Brian Wienhold

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Biofuels, generally defined as liquid fuels derived from biological materials, can be made from plants, vegetable oils, forest products, or waste materials. The raw materials can be grown specifically for fuel purposes, or can be the residues or wastes of existing supply and consumption chains, such as agricultural residues or municipal garbage. In this series of reports, sponsored by the Energy Foundation, we explore the production and use of biofuels from an ecological perspective. Each report addresses one aspect of biofuel production. The report topics are biodiversity and land use; forestry; grasslands, rangelands, and agricultural systems; and biogeochemistry. A capstone issue will present a synthesis of the ecological dimensions of biofuel production.

These reports, which were reviewed by an Advisory Committee, are based upon scientific manuscripts initially presented at a conference in Washington, DC, on March 10, 2008 (see www.esa.org/biofuels). The conference was hosted by the Ecological Society of America (ESA) and sponsored by a consortium of other scientific organizations, nongovernmental organizations, federal agencies, and the private sector. ESA also issued an official statement on the topic in January 2008, which can be found at:

http://www.esa.org/pao/policyStatements/Statements/biofuel.php

As innovations are made in the production and use of biofuels, ecologists worldwide will continue to actively monitor their impacts.

Cover photo credits: *This eastern Nebraska switchgrass field produced 6 tons of dry matter when harvested in early August. Inset: This switchgrass monoculture in eastern Nebraska is home to a diversity of species, such as Cope's Gray Tree Frog* (Hyla chrysoscelis)*. Photos by Rob Mitchell.*

Grasslands, Rangelands, and Agricultural Systems

Rob Mitchell, Linda Wallace, Wallace Wilhelm, Gary Varvel, and Brian Wienhold

Before European settlement, nearly all of the central United States was grasslands. In the span of about two hundred years, modern farming techniques and an increasing need for food have transformed the prairies into croplands planted with corn, wheat, soybean, and oats. But energy needs may transform the breadbasket of the nation once again, as native grasses return in the form of crops planted for biofuel production.

In this report, we will discuss how switchgrass (*Panicum virgatum* L.), a native perennial grass, may become the center of biofuel production in some parts of the Great Plains and Midwest. We will explore questions about the sustainability of growing biofuels in the grassland regions of the US, and discuss some of the specific environmental changes that have occurred in these areas and how the composition of crops used in biofuel production may continue to change the landscape. We will discuss how water cycles and soil organic carbon may be affected by the use of such perennial crops, and discuss relationships with nitrogen use. Further, we will explore the need for standardized protocols for life cycle analyses. And finally, we will outline some of the new research that may be needed to augment the sustainable success of cellulosic crops such as switchgrass.

Where are Grasslands and Rangelands Located in the US?

Grasslands are in every state of the US. There are some states, however, that are dominated by grasslands. Many of these states are located in the midregion of the US. Understanding what defines a grassland is a bit more complicated, though, than simply pointing to a section of the map.

The Glossary of Crop Science Terms (https://www.crops.org/publications/crops-glossary#) defines grassland as land on which the vegetation is dominated by grasses and more generally, any plant community in which grasses and/or legumes make up the dominant vegetation. Some of these grasslands are seeded pastures, which predominate in the eastern half of the US, whereas some of these grasslands are rangelands which predominate the western half of the US. The Society for Range Management defines rangelands as "lands on which the indigenous vegetation is predominantly grasses, grass-like plants, forbs or shrubs and is managed as a natural ecosystem. They include grasslands, savannas, shrublands, deserts, tundras, marshes and meadows." Typically, management inputs such as fertilizer and herbicides are limited on rangeland, whereas seeded pastures receive more of these inputs.

Less than 20% of the native grasslands of North America that existed prior to European settlement still exist today. For example, the tallgrass prairie once covered 140 million acres in North America, but today, less than 4% remains in native vegetation (Rahmig *et al.* 2008.) [See http://www.nrcs.usda.gov/technical/NRI/2003/national_landuse.html#SurfaceAreaTable, which provides data to calculate the change in nonfederal US grazing lands since 1982. They decreased nearly 6% from 1982-2003.] The grasslands, rangeland, and marginal cropland areas that occur east of the 100th meridian of the US have been at the center of discussions regarding the production of biofuels from perennial grasses (Fig. 1). This region is a focal area because it has both adequate precipitation and generally productive soils. Switchgrass is native to this region and has been

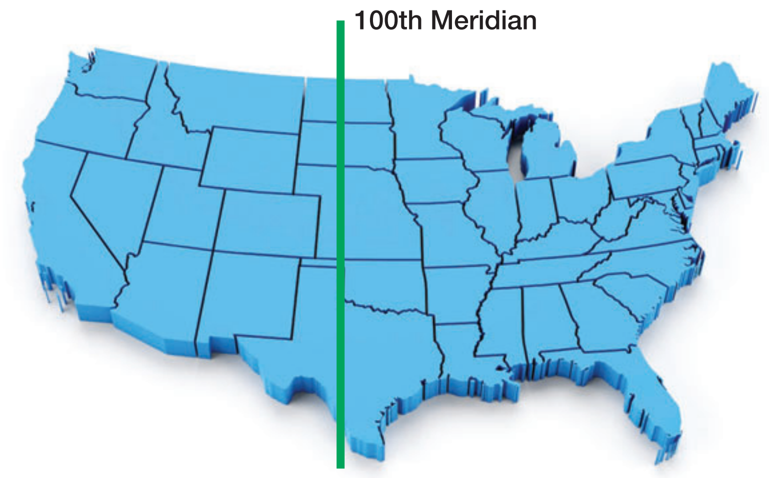

Figure 1. *An average of more than 20 inches of annual precipitation falls east of the 100th Meridian in the continental US.*

Figure 2. *Native tallgrass prairie in eastern Nebraska. A floristic analysis of this site identified nearly 400 species, sub-species, and varieties of vascular plants. Switchgrass grows in functional monoculture clones in native tallgrass prairies.*

identified as a model perennial grass for bioenergy production by the US Department of Energy (DOE).

Although switchgrass is a new crop to many people, it is a well known native species in the central US that has been studied by agricultural researchers in Nebraska since the 1930s (Fig. 2). It is a perennial that can be planted once and, with good management, harvested in perpetuity without replanting.

What *is* new about switchgrass is that it could be a major source of bioenergy. In 2006, President George W. Bush drew attention to switchgrass' energy-producing potential during his State of the Union address, citing the need to explore new energy options. As a new presidential administration has taken the helm, energy needs and congressionally mandated biofuel production increases are being actively addressed, and there is increased focus on and interest in the potential use of switchgrass.

In the past, many grasslands in the US were plowed and planted to corn, soybeans, wheat, and oats. These crops historically have been used as livestock feed and food, but some are now also being used as biofuel feedstocks. For example, corn was planted on 86 million acres in 2008, 79 million acres of which were harvested for grain with an average yield of 154 bushels per acre and total production of 12.1 billion bushels (National Agricultural Statistics Service, www.nass.usda.gov, 2009). Approximately 3.2 billion bushels were used to produce about 9 billion gallons of ethanol and 27 million tons of livestock feed (RFA 2009). Consequently, infrastructure for a grain-based biofuel production system is in place. Switchgrass could be grown on millions of acres that are marginally productive for corn and soybeans. However, the refineries do not currently exist to process switchgrass into biofuel. As the technologies for refining cellulosic biofuels such as switchgrass are developed, it is imperative that the planting, harvesting, and production of switchgrass are conducted in a sustainable manner.

Sustainability in Biofuel Production

As Buford and Neary (2010) stated, sustainability has become a buzz word in modern society, and because of its popularity, the term has taken on many meanings. Generally, sustainability is used to describe the ability to meet current needs in a manner that does not jeopardize the capacity of future generations to have their

Switchgrass: A Close Up View

Switchgrass is native to all states east of the Rocky Mountains, and most of the western states excluding Alaska, California, Hawaii, Oregon, and Washington. As its Latin species name *virgatum* (wand) implies, switchgrass grows wand-like in sandy or loamy soils and is known to occur in both wet and dry locations, developing bluish-green leaves and small seed heads which sway atop its tall three to ten foot stems.

Although in recent years it has been increasingly grown for ornamental purposes for the nursery trade, this grass is perhaps best known as one of the "big four" prairie grasses that provide food and cover for wildlife. The other grasses included in the "big four" are: big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), and Indiangrass (*Sorghastrum nutans*). Because of its wildlife and soil conservation value, switchgrass has long been grown in Natural Resources Conservation Service conservation plantings and buffer strips.

Switchgrass has been identified by DOE as the model perennial herbaceous cellulosic biofuel feedstock. (See Dale *et al*. (2010) for more information on feedstock options that are based on the cellulosic, hemicellulosic, or lignin components of plants.) Perennial crops such as grasses can provide environmental advantages compared to traditional annual crops such as reduced inputs, reduced erosion on marginal cropland, and enhanced wildlife habitat, but they, too, may require innovative management techniques in order to be economically and environmentally sustainable.

needs met (*See Our Common Future*, available at http://www.worldinbalance.net/intagreements/1987-brundtland.php.)

When evaluating a process or engineering system, the input and output of the system is examined along with the components, and the system is declared to be sustainable when normal operating efficiencies are attained. In agricultural ecosystems, several factors have been used to determine sustainability, including the net primary productivity of the plants grown there, the nitrogen content of those plants, soil fertility, and insect abundance. Researchers often have included species diversity, nutrient loss, soil loss, and economics in the list of factors for consideration.

When considering the question of sustainability and biofuels, the Ecological Society of America has concluded that sustainable production of biofuels must not negatively affect energy flow, nutrient cycles, and ecosystem services, and these factors must be considered in biofuel production systems (ESA 2008).

Energy produced from biomass feedstocks is held to a different standard than energy produced from petroleum since renewable fuels must have low greenhouse gas (GHG) emissions and highly positive energy values. The energy efficiency and sustainability of ethanol produced from cellulosic feedstocks has been measured as net energy value (NEV), net energy yield (NEY), and the ratio of the biofuel output to petroleum input [petroleum energy ratio (PER)] (Schmer *et al.* 2008). An energy model using estimated agricultural inputs and simulated yields predicted switchgrass produced 700% more output than input energy (Farrell *et al.* 2006). Validation of these modeled results with actual inputs from switchgrass grown on 10 farms at the field scale in Nebraska, South Dakota, and North Dakota produced 540% more renewable energy (NEV) than non-renewable energy consumed over a 5-year period and had a PER of 13.1 (Schmer *et al.* 2008). Average GHG emissions from switchgrass-based ethanol were 94% lower than estimated GHG emissions for gasoline (Schmer *et al.* 2008). These results help explain why switchgrass for bioenergy has garnered so much interest from policy makers and energy producers.

Ecosystem Services

Most switchgrass production will likely come from reallocating marginal land currently planted to other crops and from areas enrolled in the US Department of Agriculture's Conservation Reserve Program (CRP). Converting CRP land has caused some concern among ecologists who have suggested that the CRP has been a highly successful program for bird species recovery in the Great Plains and Midwest. (See Dale *et al.* 2010).

The land reallocated from other crops to switchgrass will most likely come from areas that are marginally productive for row crops. It is important to understand the feasibility of growing switchgrass on these marginal areas, and studies have been conducted on the biomass production of switchgrass and the potential ecosystem services provided by switchgrass on marginal sites. As an example, a 5-year study conducted on marginal land that qualified for CRP in Nebraska demonstrated that the potential ethanol yield of switchgrass was equal to or greater than the potential ethanol yield of no-till corn (Varvel *et al.* 2008). The study authors noted that growing switchgrass on marginal sites will likely enhance ecosystem services more rapidly and significantly than on the more productive sites.

A report published by DOE, known as the Billion Ton Report (Perlack *et al.* 2005), suggests that the US can annually and sustainably produce over one and a third billion tons of biomass by 2030. Although this report has been criticized and is being revised, it does reinforce that agriculture and forestry can provide large quantities of biomass in a sustainable manner. But land use choices and economics will dictate where and how biomass crops are grown and processed if policies do not specifically address biomass harvesting on areas that are currently valuable as wilderness, open space, or biodiversity hotspots.

Because so many bird species use the prairie grasses for nesting, the timing of harvest may prove to be an important factor in maximizing its ecosystem services, especially as it relates to grassland bird habitat (Fig. 3, cover). There is evidence that suggests harvesting

Photo by Rob Mitchell

Figure 3. *Harvesting a portion of switchgrass fields in early August (foreground) and delaying harvest until after a killing frost (background) provides structural diversity on the landscape.*

switchgrass is best conducted after a killing frost has occurred, due to the translocation of nitrogen as the plant enters dormancy. Harvesting switchgrass post frost may allow some nitrogen to be mobilized to the roots, rhizomes, and stem bases at senescence, and then re-mobilized for plant growth during the following growing season. This practice may reduce feedstock quality and quantity, but many scientists think the tradeoff is worthwhile and sustainable because the result may be biological nitrogen storage, reducing the need for nitrogen fertilizer application.

Monocultures vs. Diverse Species Mixtures

Switchgrass is one of several perennial grasses that could be grown in the Great Plains and Midwest as a biofuel feedstock. Although recent research suggests it is a sustainable and economically efficient feedstock, some have questioned if switchgrass is the best choice from an ecological perspective. Opponents of switchgrass monocultures contend that diverse mixtures of native plants are ecologically more beneficial and should be considered for biomass production. Although managed switchgrass monocultures produce 1.5 to 4 times more biomass than native tallgrass prairies, minimal research has been conducted that directly compares the ecological benefits of monocultures and mixtures. More research is needed to determine whether switchgrass monocultures meet all sustainability criteria in a manner similar to native polycultures. Empirical studies are needed that examine the energy balance, potential biofuel production, economic potential, GHG emissions, insect and wildlife components, the carbon and nitrogen cycles, as well as other sustainability metrics for monoculture and polyculture systems.

A 5-year farm scale study conducted on 10 farms showed that managed switchgrass fields would produce two times more ethanol than low input high-diversity (LIHD) prairie mixtures on sandy glacial outwash soils. The net energy yield from the field study was two times greater than the LIHD prairie plots that received no exogenous fertilization. In an evaluation of 34 grassland sites in the northeastern US, CRP grasslands with the greatest number of plant species had the lowest potential ethanol yield, whereas sites with a small number of grass species had the greatest potential ethanol yield. The low diversity CRP sites could produce more than 600 gallons of ethanol per acre while maintaining the ecological benefits of the CRP sites (Adler *et al.* 2009).

Monocultures and mixtures of different grasses and forbs may support different quantities and assemblages of wildlife and invertebrates. Monoculture grasslands may be more vulnerable to pests and pathogens, and general ecological theory suggests that the greater the diversity of the producer component, the larger the genetic, structural, and species diversity. In grasslands, this general theory is not a universal because some groups respond to structural diversity rather than species diversity. Studies have reported that bird and small mammal diversity were relatively unaffected by biofuel production in grasslands habitats.

Research comparing insect diversity in switchgrass monocultures to native prairie or high-diversity grasslands is limited. However, an interesting parallel can be drawn with buffalograss (*Buchloe dactyloides*), another native warm-season grass that was moved from native polycultures to turf monocultures. In native grasslands, buffalograss appeared to have few pest issues, but as buffalograss increased in lawns, new insect pests emerged (Baxendale *et al.* 1999). The long-term exposure of switchgrass to pests and pathogens native to North America, the broad genetic background, and the initial pathogen screening conducted during cultivar development will likely limit the negative impacts of native pests (Mitchell *et al.* 2008). However, given the similarities between buffalograss and switchgrass, similar pest issues may occur (Schaeffer 2009).

Growing switchgrass on marginally productive cropland provides a significant improvement in environmental services when compared with annual row crops. The excellent biomass production, economic potential, energy balance, soil erosion prevention, GHG emissions, carbon sequestration, ethanol yield potential, and long-term research on switchgrass monocultures outweighs the potential shortcomings when compared with polycultures. Potential significant problems associated with switchgrass monocultures that have not been thoroughly studied include insect and disease issues and increases in invasive species. Conducting the volume of research necessary to address all potential problems with switchgrass monocultures and to make comparisons with all possible combinations of native polycultures would require 15 to 20 years of research, would cost millions of dollars, and would delay the deployment of a biomass energy production system that is a quantum improvement over current agricultural practices on marginal lands and current transportation fuel and energy production systems.

Nitrogen and Water

The switchgrass nitrogen (N) cycle is strongly influenced by the amount and type of N applied. Nitrate is the most mobile form of N and is readily leached from the soil into surface and ground waters, but applying N at a rate that is less than biological immobilization will avoid contaminating water supplies. Since switchgrass production for biofuels requires the removal of large quantities of biomass from fields every year, some N fertilizer application will be required to replenish the soil, optimize production, and maintain quality stands. In order to reduce N leaching, fertilizer rates should be based on the difference between the biological demand and available soil N. Harvesting a switchgrass field producing 5 tons per acre of dry matter with a N concentration of 1.2% will remove about 120 pounds of N per acre. Because of the mineralization potential of some soils, atmospheric N deposition, and residual soil N from previous crops, N application rates for switchgrass harvested after a killing frost should be about 12-14 pounds of N per acre for each ton of expected biomass, less than half of the N applied to corn. However, due to the deep rooting ability of switchgrass, soil samples must be taken to a depth of 4 to 6 feet to determine available soil N so fertilizer is not over-applied.

Almost no work has been done on the hydrologic effects of feedstock production. In choosing what to grow and where to grow it, available water quantity, and the effect of a crop on water quality emerge as critical limiting factors. Some crops demand more water than others in order to be viable or economically profitable. Furthermore, management of any crop can alter sediment loads as well as the N and phosphorus (P) that are carried in runoff water from fields or watersheds. Much is known about water quantity issues required for crop growth at the local farm scale, and there is broad consensus that, given future issues with water quality and quantity, dedicated bioenergy crops should be grown where irrigation is not required, generally east of the 100th meridian. Additionally, processing the harvested crop into biofuel will have water demands that must be considered in the life cycle assessment of biofuel production.

Less is known about the links between water quality and bioenergy crops, especially at the watershed scale. This is due in part to the lack of watershed scale bioenergy production, as well as monitoring systems and time-series data needed to conduct analyses. But when considering the broader scale impacts of crop and cultivation choices, Gulf Coast hypoxia (low oxygen concentration), which is largely due to excessive N fertilizer use in annual row crops, provides a ready example, as summarized by Dale *et al.* (2010).

Dale *et al.* note that hypoxia occurs naturally in many waterways, but the size of the hypoxic zone in the Gulf of Mexico has grown considerably in the last fifty years. The Hypoxia Advisory Panel of the Environmental Protection Agency's Science Advisory Board reviewed the problem in 2007, and noted that there are opportunities to reduce N and P usage throughout the contributing region. The panel recommended converting to alternative rotation systems, and cropping systems which would increase the use of perennials. They also recommended the promotion of environmentally sustainable approaches to biofuel crop production, such as no-till farming, the reduced use of fertilizer, and the use of riparian buffers in targeted areas of the basin.

Since switchgrass harvested after a killing frost requires about half as much N fertilizer as corn, even if switchgrass fields are initially planted only as stream buffers around conventional farm systems, then regional water quality could be improved by reducing sediment loads and N concentration in runoff, resulting in improved water quality in waterways such as the Gulf of Mexico.

Avoiding water and soil contamination with excess N is important since excess nitrate can undergo denitrification to form nitrous oxide, a greenhouse gas which the Intergovernmental Panel on Climate Change has noted is 296 times more effective at trapping heat than carbon dioxide. Less nitrous oxide is produced when nitrogen is provided naturally by nitrogen-fixing plants such as legumes rather than through applied fertilizer. Therefore, a mixture which includes legumes that provide nitrogen to the system would produce less nitrous oxide and would have reduced GHG emissions. However, research is needed to evaluate the potential nitrous oxide emissions from fertilized grasslands.

Soil Organic Carbon

To fully understand the importance of grasslands and the carbon cycle, it is essential to understand that soil is not static. Soil, as with the ecosystem as a whole, is a dynamic system, constantly in flux and subject to change.

In order to maintain the essential microscopic life that exists in the soil, regular additions of organic residue are necessary. In natural systems, the additions are made in the form of litter fall and plant decomposition. Farmers add organic matter to agricultural systems in the form of a crop residue, green manure, animal manure, or other organic material which becomes a source of nutrients and energy for soil organisms. The decomposition of organic matter forms humus (the organic component of soil that provides nutrients for plants), and microbes release nutrients that are available for plant use, resulting in long term soil stabilization and carbon storage. Large quantities of carbon can be sequestered in soils.

Simply stated, green plants use solar energy to convert CO_2 and water into plant matter. This net primary

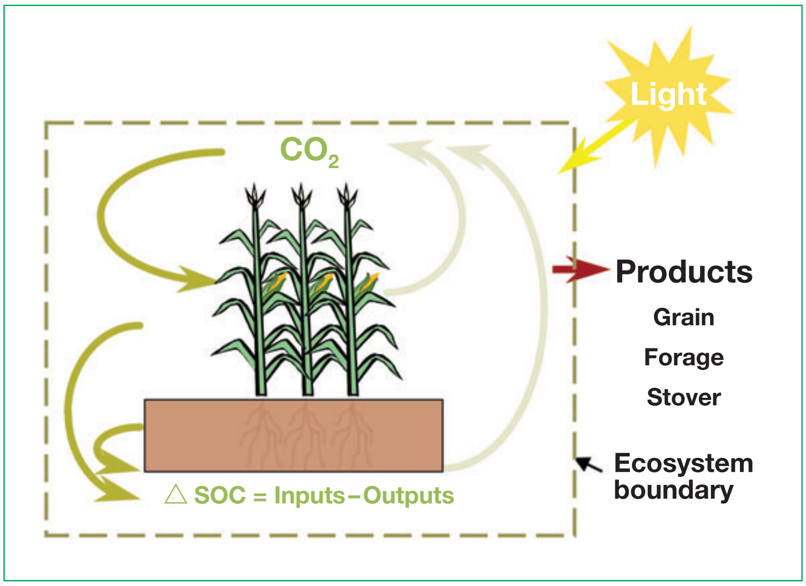

Figure 4. *A simplified carbon cycle for a managed ecosystem.*

production and ecosystem service results in crops for human use (Fig. 4). Other biomass from the crops such as roots and leaf litter remain and decompose as described above. Soil organisms convert the litter to soil organic carbon (SOC). Respiration from both the primary producers and soil microbes returns a portion of the fixed CO_2 to the atmosphere. In the process of decomposition and mineralization, nutrient elements are returned to the soil where they can be used by future crops.

This can be described in a simple equation:

Change in soil organic carbon = Carbon inputs – carbon outputs

Carbon inputs must balance or exceed the outputs to sustain or maintain the system. If this balance does not occur, the SOC declines and the productivity of the entire system declines. The conversion of grasslands to annual cropland that occurred after European settlement has greatly reduced SOC. By most estimates, about half of the SOC present in pre-agricultural grasslands and productive forest soils has been lost through farming.

Some of the demand for biofuel feedstocks may be met by crop residues such as corn stover and wheat straw. Collecting crop residues for biofuel feedstock will reduce the carbon inputs to the system normally provided by the residues, increasing the demands for SOC. Looking back at the simple carbon equation, if all other practices remain unchanged and carbon inputs decrease, then SOC will decline. The gradual drop in carbon stored in soils must be considered in the lifecycle analysis of the fuel to get a complete picture of the impact of fuel production on atmospheric carbon levels.

However, management practices can be implemented that will reduce or negate the decline in SOC. Reduced tillage and the creative application of other practices may reverse the negative outcomes of managing systems to meet the goals of modern society, which include food, feed, fiber, and fuel production. For example, changing from conventional tillage where the crop residue is incorporated into the soil to conservation tillage where the crop residue is left on the soil surface consistently reduces soil erosion losses in the eastern Great Plains and Midwest by 75%. Consequently, if crop residues are used as biofuel feedstocks, a portion of the residue must remain to protect against soil erosion. Perennial crops such as switchgrass can take large quantities of CO_2 from the atmosphere and increase soil carbon sequestration by "injecting" organic matter into deep soil layers. Deeply rooted species such as switchgrass are more capable of increasing soil carbon than are shallowly rooted row crops such as corn. Switchgrass sequesters carbon deep in the soil profile (below one foot) because its roots can extend to a depth of 10 feet. Carbon stored at depths below one foot is more permanent since carbon stored near the soil surface is more easily returned to the atmosphere than is deeper soil carbon.

Water and Switchgrass

Switchgrass is very water use efficient, especially compared to cool-season grasses or crops such as soybean. However, switchgrass' water use efficiency (WUE) is very similar to corn when the whole corn plant, not just the grain, is used. [WUE measures the productivity of a crop relative to the unit of water used in production.] For example, Kiniry *et al.* (2008) compared the WUE of switchgrass types and corn on three different soils at four locations in Iowa, Missouri, Texas, and Nebraska. They reported that switchgrass was 1.8 to 5.0 times more efficient than corn grain production, but was only 1.05 times more efficient averaged across all sites if the total aboveground biomass for corn was compared. However, because only about half of the total corn stover can be removed and used for biofuel production, switchgrass becomes significantly more efficient when compared on an available biofuel feedstock basis.

Estimates focused on understanding exactly how much water is needed to produce large amounts of switchgrass have varied widely. Berndes (2008) estimated that 11-171 tons of water will be required per gigajoule of electricity or ethanol produced using lignocellulosic feedstocks. This is a wide ranging estimate, partly because there are currently wide variations in both WUE and in the efficiency of feedstock conversion technologies. The WUE of switchgrass has varied by 30% when considering factors such as soil type, climate and growing conditions. Additionally, there is significant WUE variation among switchgrass strains. Lowland varieties produce more biomass than upland varieties under rainfed conditions in the central Great Plains. Since switchgrass for bioenergy will not be irrigated, the importance of WUE is limited. The real value in understanding the WUE of different switchgrass populations is in the identification of strains with improved biomass potential.

BioRefining: The Present Reality

Although the option of growing switchgrass for fuel seems promising for many environmental and economic reasons, one large production/distribution obstacle remains. The refineries needed to process cellulosic biofuel do not exist at the large commercial scale. This challenge is illustrated by the renewable fuels standard in the Energy Independence and Security Act of 2007, which calls for production of 100 million gallons of cellulosic biofuel per year in 2010, increasing to one billion gallons per year in 2013.

While the prospect of designing and building these refineries and creating the infrastructure needed to process cellulosic biofuel seems daunting, researchers are quick to point out that a unique opportunity exists in the biofuel industry. Because conversion research on cellulosic biofuels is still relatively new, the opportunities to develop sustainable, efficient, and clean systems for processing are wide open. By promoting best management practices and developing plants for biofuels in the most environmentally efficient way as well as in optimal geographic locations, the development of these energy sources can be as sustainable as possible from the very start of production.

Some researchers have cautioned that although the desire to perfect growing methods and production systems is laudable, policymakers will need to balance this goal against the need to begin producing alternatives to fossil fuels soon. Investing in long term research and monitoring, establishing standardized LCAs, and providing a stable regulatory environment may help achieve a balance between expediency and sustainability.

Specific Research Needs

Perennial feedstocks such as switchgrass appear to be ecologically sustainable, especially if they are used in place of annual crops. Managing switchgrass for bioen-

Life Cycle Assessments: Is Switchgrass a Carbon Neutral Biofuel Option?

Switchgrass may be one of the most carbon neutral options for biofuel production, implying that there are ways to grow switchgrass and produce biofuel without causing a net release of carbon. The answer to whether a biofuel is carbon neutral or not depends on how the equation is written or where the boundaries are drawn for computing carbon inputs and outputs in agricultural systems: what the analysis includes or excludes.

Attempting to account for the entire production system, including the burning of fossil fuels for transportation and field preparation, makes the carbon equation more complex. Life Cycle Assessments (LCAs) have been performed by numerous research teams using multiple criteria and input parameters. Most have studied the conditions under which switchgrass, or any other biofuel, could either be neutral or even possibly carbon negative (resulting in net carbon uptake by crops and soils).

There are no accepted protocols or even set rules for deciding which management system components to include or exclude from LCAs. This absence of continuity presents a challenge for both scientists and policymakers. As noted in the first report in this series, an active debate is taking place among researchers about this aspect of assessment. Most of the controversy centers around whether or not to include external components of the management systems that may not be spatially linked to crop production (e.g. fire as a land management tool, indirect land use changes) when calculating the carbon footprint of a crop. [See Dale *et al*. (2010).]

There are also temporal considerations that may affect the outcome of LCAs, because a great deal of carbon is lost from the soil when a field is first plowed and planted. This C loss could be reduced or eliminated if growers use no-till or reduced-tillage techniques.

A very important step in the growth of the biofuel industry will be the establishment of standardized LCAs. Decisions will need to be made regarding the components or classes of components to include or exclude for all comparative studies. Until such work is completed the issue of carbon neutrality will remain controversial and answers regarding sustainability will remain relative or elusive.

It is also important to note that a specific LCA cannot be completed based only on a feedstock. The analysis also depends on key variables including: (1) the biofuel output, (2) inputs such as fertilizer and pesticides, (3) soil carbon sequestration, (4) the efficiency of the conversion facility, including the possibility that it is powered by residual lignin versus fossil fuels, (5) what previous land use is displaced (corn, pasture, forest, etc.) and (6) the initial level of biologically-based carbon storage (forest, row crop, or pasture).

ergy could be an energetically positive and environmentally sustainable production system throughout much of the central Great Plains and Midwest east of the 100th meridian. But switchgrass is not a one-size fits all bioenergy feedstock.

Research is now needed on mixed-species systems that include switchgrass, particularly if the goal is to reduce nitrogen fertilizer inputs, produce biomass for bioenergy, keep (LCA) carbon costs low, and manage and maintain both restored and native prairie ecosystems.

Although a great deal of information regarding many of the biofuel options is currently available, a common tool for measuring their efficiency and sustainability does not really exist. Until common techniques are used, questions about the long-term sustainability of all agro-ecosystems will be difficult to answer unequivocally. Therefore, we propose that the following activities take priority in our research programs:

- Establish long-term agricultural research (LTAR) sites composed of candidate bioenergy feedstocks in major regions across North America as suggested by Liebig *et al.* (2008);
- Establish field-scale research projects for candidate bioenergy feedstocks focusing on standardized LCAs that incorporate all establishment and management inputs, including labor;
- Promote the scale-up of cellulosic ethanol plants and feedstock production systems using best management practices for the best candidate feedstocks within the major agro-ecoregions;
- Promote research that makes direct, long-term comparisons to determine the best candidate feedstocks for the next generation of cellulosic bioenergy production systems, and
- Collect field data from replicated field trials to validate modeling efforts.

Suggestions for Further Reading

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