Emerging BioFuel Crops and Technology

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ABSTRACT

United States energy policy requires 36 billion gallons of ethanol by the year 2022, with 21 billion gallons coming from cellulosic feedstocks. This has served as a catalyst for ramping up technological advancement with 2nd gerneration biofuel crops including perennial warm season grass crops and other non-food crop bioenergy sources. Further complicating the issue is the convergence of several factors that significantly increase the production demand on global agricultural systems. These factors include increased population levels, increased affluence and commensurate increases in demand for diets higher in meat protein, and utilization of agricultural commodities for renewable fuels. This presentation will focus on recent advancements in bioenergy crops including crops designed for marginally productive lands not currently managed for food crop production. Additionally, the presentation will assess the environmental aspects of alternative liquid fuel production, particularly in the area of net greenhouse gas (GHG) production, and carbon sequestration potential. As we move to cellulosic sources of feedstock for ethanol production, questions arise on the potential soil carbon and greenhouse gas implications in cropping systems where corn stover or other plant biomass is removed. On the somewhat marginal soils typical of the Great Lakes Region, we calculate that a minimum of 7,500 lb of corn stover is needed per acre in each cycle of a corn-soybean rotation just to maintain soil organic matter at current levels.

INTRODUCTION

World population and energy demand is increasing each day. However, global fossil fuels are finite in supply and become increasingly more expensive to extract as supplies are diminished. To meet the needs of our society, both food and fuel, continual research on alternative, renewable energy sources is imperative. A better understanding of how soil and landscape features affect energy crop quality component yield is necessary to maximize efficiency in bioenergy cropping systems. Additionally, exploration into environmentally sustainable bioenergy crop production on marginal land is vital to meeting future demand for food, feed, fiber, and fuel. BioEnergy crops can be characterized in the following four systems:

Grain-based annual systems. In much of the upper Midwest agriculture has evolved into grain-based annual cropping systems, primarily corn-soybean rotations. These systems produce high yields of commoditized grains that are easily transported to centralized biodiesel or ethanol refineries, now established or under construction throughout much of the region. Improvements in annual crop biofuel yield and system sustainability can be realized by advancing production and breeding parameters to emphasize biofuel yield components as opposed to the historical emphasis on food components. The long history of annual crop production systems in the

Midwest makes this system a reasonable experimental check with which to compare the sustainability and performance of other novel production systems.

Perennial systems. Aboveground net primary production in herbaceous perennial systems rivals that of continuous corn in the upper Midwest, and these systems have the added advantage of continuous plant cover during parts of the year that soil would otherwise be bare. This provides an effective catch crop to attenuate nitrate leakage and diminish phosphorus runoff and erosion. These systems also have the advantage of permanent no-till, which builds soil carbon by allowing living root biomass to persist from year to year and allows carbon to accumulate in soil aggregates. While annual crops can also be no-tilled, rarely are the carbon benefits fully realized because periodic tillage generally occurs. Under perennial systems, annual photosynthetic efficiency can be maximized using a combination of warm and cool season grasses (including switchgrass and other C4 species). In less productive land, woody perennial systems such as short-rotation poplar clones can be grown successfully.

Native grassland system. Recent reports suggest that biofuels derived from low-input, highly diverse mixtures of native perennial grasses can provide more useable energy and additional ecosystem services than conventional cropping systems. More research is needed to verify these claims. Theoretically, growers could reap the economic benefit of grassland production during hot summer months when cool-season species are quasi-dormant. Conversely, cool season grasses would increase biomass production in the early and later parts of the growing season. These native systems could restore and maintain populations of native tallgrass prairie plant species that persist only in isolated refuges in most of North America, and provide ecosystem services similar to those from perennial systems (above) but with added biodiversity benefits.

Integrated system**.** The magnitude and structure of U.S. agricultural production systems are such that an integrated approach to incorporating biomass energy crops into existing cropping systems based on food and fiber production is perhaps the most likely model to succeed. Such an approach facilitates agronomic, economic, and ecological diversity and thus minimizes risk. An example scenario would be the integration of perennial warm season grasses into an existing corn and soybean rotation. Complex rotations are known to provide benefits not available to continuous or even simple rotations. Thus, the integration of biofuel crops, particularly perennial crops, would be expected to boost yields of other rotational crops including corn and soybean.

Environmental Aspects of BioEnergy Cropping Systems

Renewable fuels produced from feedstocks generated on America’s farms offer many environmental advantages. Based on research conducted at Michigan State University and elsewhere, ethanol is a far superior alternative to petroleum-based fuels, particularly with regard to environmental global warming potential (GWP). The figure below shows the net GWP of corn stover biofuel cropping systems, relative to the gasoline the biofuels would displace. A negative net GWP value means that the system is actually taking greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxides (NOx) out of the atmosphere. A positive net GWP value means that greenhouse gases are being added to the atmosphere and net global warming potential increases.

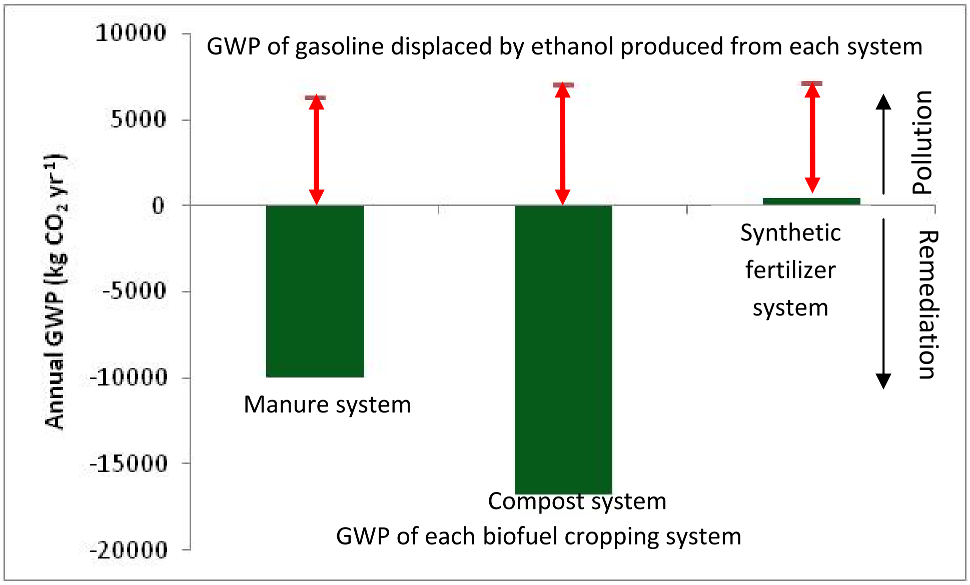

Figure 1. Net global warming potential (GWP) of corn cellulosic biomass biofuel cropping systems (kg of CO_2 equivalents ha^{-1} yr^{-1}) (bars) compared to the GWP of the proportionate amount of gasoline displaced by the ethanol produced in each system ha^{-1} yr^{-1} (arrows) as affected by manure, compost, or synthetic fertilizer amendments. Annual crop system net GWP data represents annual average of a corn-soy rotation; ethanol yield calculated @ 300 L Mg^{-1} corn biomass. Gasoline displaced was calculated as 0.7x the ethanol produced by each respective cropping system. CO_2 values for displaced gasoline were obtained from 40 CFR 600.13.

The data clearly show that the biofuel systems improve GWP relative to using gasoline. How can this be? The mechanism involved is based on photosynthesis. Carbon that is released to the atmosphere from combusting biofuels is carbon that was photosynthetically produced in the first place. In other words, the corn and switchgrass that produced the ethanol acquired the carbon from the air to make the starch and cellulose that produced the ethanol. Of course, some new carbon (from petrochemical sources) was used in the manufacturing and transporting of the fertilizers, herbicides and other inputs to grow the corn and switchgrass, and petrochemicals were also used in field operations to plant and harvest the crops and to process them into ethanol. All these inputs need to be included in the evaluation of net GWP and this explains why annual crop systems that do not return sufficient crop residue to the soil can have a slightly positive GWP. However, if good management practices are used in raising the crop, the crop input carbon debt can be overcome, even to the point where carbon is actually removed from the atmosphere. This is made possible by properly managing the carbon present in the crop residue. Conservation-based farming practices such as no-till can result in net carbon removal from the atmosphere by sequestering (storing) carbon in the soil. Perennial crops such as switchgrass have more extensive root systems relative to annual crops and subsequently partition more photosynthetically derived atmospheric carbon into the soil.

The same process explains how cropping systems using manure can have a net negative GWP. When appropriately used as a soil amendment, manure can effectively transfer atmospheric carbon to the soil. Carbon emissions associated with manure include, CH_4 emissions (flatulence) from the livestock, CH_4 and NOx generated during manure storage and application, and the diesel and gasoline used in gathering and land applying the manure. The CH_4 (and NOx) emitted from livestock and stored manure must be included as a net carbon emission since the atmospheric warming potential of CH_4 is greater than that of the CO_2 from which the carbon originated. The CO_2 released and organic carbon in manure is not assessed as a net emission since it was photosynthetically derived in the first place. Conversely, when gasoline is combusted, the carbon that is emitted into the atmosphere is new carbon, carbon that was safely sequestered (for millions of years) far below the earth's crust. All this new carbon deposited in the atmosphere from years of burning petroleum-based fuels is a major source of our global warming problem today. Every time we choose biofuel as an alternative to gasoline, we displace a new carbon emission from the gasoline with a recycled carbon emission. This direct analysis clearly shows the smaller environmental footprint of biofuels relative to petroleum based fuels.

BioEnergy Crops on Marginal Lands

The increased demand for biofuel crops and concomitant expected rise in biofuel and food crop commodity prices will almost certainly drive marginal lands that have been idle into crop production due to the increased demand and price for biofuel crops. Examples of such marginal lands include land currently in the USDA Conservation Reserve Progarm (CRP) of which Michigan and Indiana currently have 275,000 and 315,000 acres enrolled, respectively. Other types of marginal lands include regulatory "brownfields" of which Michigan has an estimated 300 sites.

The advantages associated with bringing marginal land into production for biofuel crops include relatively lower land cost, non-displacement of land currently used for food production, and opportunities for rural economic development. Concerns include lower productivity and economic returns, crop quality, and the potential for increased environmental risk associated with farming these marginal soils. Research is needed to develop environmentally sound agronomic practices for bringing marginal nonproductive lands into biofuel production. The following table compares various crop yields in an agricultural productive area (East Lansing) with a more marginal soil (Lake City). The results indicate significantly lower yield potential of typical marginal soils. However, depending on the particularly yield limiting factor associated with the marginal soil, a crop can usually be found that minimizes the expected yield loss. For example, the Lake City soils are considered marginal due to their inherent course texture and low waterholding potential. Therefore, a winter annual crop, canola in this case, does fairly well since it more efficiently matches the seasonal water availability associated with the droughty Lake City soils.

		Marginal	
Crop	yr/source	yields	% of E.L
Corn grain	05-06/GRT	127 bu/A	-33%
*Corn stover	99-00/LC	3.3 ton/A	-18%
**Perennial grass cspg	04-06/LC	5.9 ton/A	-65%
***Perennial grass wspg	05/LC	4.5 ton/A	-42%
Soybean	04-06/GRT	31 bu/A	-44%
***Canola	07/LC	2600 lb/A	ns
*estimated from silage data			
**multiple cut system			
***single season data			

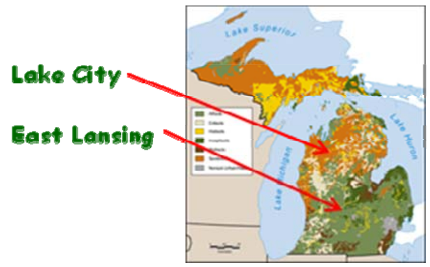

Table 1. Historical crop yield and expected reduction in yield of a marginal soil (Lake City) compared to an agriculturally productive soil (East Lansing).

Properties of Selected Biofuel Crops

Forage Sorghum (*S. bicolor x S. sudanense*) - Cellulosic (Midwest)and/or Starch (Southwest) Ethanol

- Dedicated biomass sorghums
- Ethanol yield: cellulose 72 gal/ton or 50 to 150 gal/ac from grain
- Grain starch and/or cellulose to ethanol conversion
- Grown in Kansas, Texas, Nebraska, Oklahoma and Missouri
- Water-efficient, drought- and heat-tolerant
- 30- inch rows grain, drilled cellulose, 1-2" depth

Sweet Sorghum (*Sorghum bicolor (L.)* Moench)- Grain and Cellulosic Ethanol

Stalk Sugar → Ethanol

- 8-12 feet in height
- Ethanol Yield: 400 gal/ac
- Sugars are directly "juiced" from the stalks
- Low fertilizer input required
- Fermentation has to follow harvest immediately, no option of storage
- Can be grown in Texas, north to Wisconsin, West to Kansas, Iowa and Minnesota

Cellulosic Ethanol

- Bagasse can be used to produce cellulosic ethanol or combusted for heat energy

Corn (*Zea mays L.*)

Grain → Ethanol

- This plot is a High Total Fermentable (HTF) ethanol hybrid
- Corn requires relatively large agricultural inputs including fertile land
- 300- 550 gal/ac (2.8 gal/bu)
- U.S Ethanol production in 2007: 6.6 billion gallons
- Net Energy Balance (NEB) ~25%

Stover → Cellulosic ethanol

- 380 gal/ac
- What is the sustainable amount of stover we can remove? Depends on soil, topography, crop rotation & tillage practice (need to leave 3.5 ton/acre in field for SOM maintenance)
- Benefits of stover:
  - Erosion Protection , increased soil organic matter II No-till, moisture retention, nutrient cycling.

Switchgrass (*Panicum virgatum L.*) -Cellulosic Ethanol

- Native to North America
- C_4 Perennial Grass can grow all over North America up to a latitude of 55ºN
- Efficient Water Use
- High Yield Potential on marginal croplands
- Ethanol Yield of 450 gal/ac
- Multiple harvest options
- A single annual harvest will optimize efficiency; harvest timing needs to be considered for stand maintenance and optimizing cellulosic ethanol
- Switchgrass produced 540% more renewable than nonrenewable energy consumed
- Switchgrass ethanol emitted 94% less GHG than gasoline

Miscanthus (*Miscanthus x giganteus*)- Cellulosic Ethanol

- 11 -14ft in height when mature
- Originated in Asia
- 10 t/ac dry weight yield possible
- Up to 1500 gal/ac
- Good for carbon sequestration and building soil organic matter
- Established with rhizomes planted ~4" deep, 3ft apart and 3ft row spacing
- Low tolerance of frost
- No major pests/diseases
- Can be grown on marginal soils (w/lower yields) in a 10 year rotation
- Has been established successfully in Ohio, Michigan,
- Indiana, Illinois & Quebec

Hybrid Poplar (*Populus spp.*)- Ethanol

- Height: 90 feet in six years
- Poplars grown in short rotation forestry (SRF) can produce up to 10 dry tons/acre/year
- 700 gal/ac
- Potential increase annual yield to 1000 gal/ac
- Sub-species can grow in climates ranging from the sub-tropical Florida to sub-alpine areas in Alaska & northern Canada
- Planted with cuttings at a depth of 8-10" with top bud exposed
- pH of Soil 5.5 to 7.8
- Benefits: soil stabilization, organic matter inputs

Canola (*Brassica napus*)- Biodiesel

- Both spring and winter varieties
- 40% oil and 23% protein
- Oil yield: 122 gal/ac
- Cetane Rating: 55
- Cloud Point: 25 ^{0}F
- Energy: 17930 BTU's/lb
- Fits well into cereal-based rotations
- Susceptible to heat damage
- Well-suited for cooler climates in such regions as the northern plains and the Midwest
- Susceptible to White mould Sclerotinia, Blackleg and Aster Yellows

Soybean (*Glycine max*) - Biodiesel

- 20% oil and 40% protein
- 62 gal/ac
- Cetane Rating: 53
- Cloud Point: 25 ^{0}F
- Iodine value (IV)→130
- Energy: 17437 BTU's/lb
- Net Energy Balance → 93%
- GHG emissions of soybean biodiesel are 59% those of diesel fuel
- Production results in negative environmental impacts

Sunflower (Helianthus annuus)- Biodiesel

- Native to North America
- Oilseed hybrids -> 3 main fatty acid types: linoleic, mid-oleic (NuSun) or high oleic
- U.S. production (2006-2007): 0.92 million tons
- Growing regions: North Dakota (70%), South Dakota (15%), Kansas (6%), Minnesota, Colorado, Texas & Nebraska
- Deep penetrating roots ->relatively drought tolerant
- 38-50% oil and 20% protein.
- 102 gal/ac
- Cetane Rating: 52
- Cloud Point: 45 ^{0}F
- Energy: 17930 BTU's/lb
- A 2,000 lbs/ac yield requires approx. the same N, P & K as 40 bushels per acre of wheat.