Bio-Feedstock Production and Development
Department of Agronomy
Purdue University

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Bioenergy Research: Statement of the Problem

Current U.S. plans for energy security rely on the diversion of feed grains to ethanol production and the conversion of large acreages of marginal land to the production of cellulosic biomass.

To ensure the sustainable production of biofuels, studies are needed to conduct comparative analyses of the productivity potential and the environmental impacts of these biofuel crops and management systems.

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Bioenergy Research: Fundamental Agronomic Issues

Long-term sustainable biofuels production with the concomitant protection and improvement of air, soil, and water resources requires a concerted effort by the scientific community to gain knowledge regarding the comparative production potentials and environmental impacts of biofuel cropping systems.

U.S. agriculture has extensive experience with intensive maize production and both the grain and the stover can be used in energy production, but removing the majority of the aboveground biomass from a farm field may negatively impact air, soil, and water quality.

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Bioenergy Research: Fundamental Agronomic Issues

In addition, herbaceous perennials including novel species such as *Miscanthus* imported from Europe and low-input native systems represent alternatives that may offer discrete advantages over maize ethanol and soy biodiesel.

However, at present, research on water, nitrogen (N) and carbon (C) cycling in these candidate biomass systems is fragmented and incomplete, a critical barrier to profitable, sustainable, and environmentally benign on-farm implementation of the U.S. biofuel agenda.

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Case Study: Crop Combinations for Grain/Biomass (Ohm, Snyder, Vyn, Buckmaster, Dobbins)

- Goal: We will determine total biomass production potential and biomass utilization qualities from combinations of important Midwest U.S. grain/biomass crops.
- Wheat winter cover crop harvested at heading, mid-grain fill, and maturity (early May, early June, early July)
  - No-till corn – grain/silage (May, June)
  - " soybean – grain (May, June)
  - " sorghum–grain/silage (May, June, July)
  - " sweet sorghum – silage (June, July)
- Biomass yield and digestibility, crude protein and other quality measurements of utilization are determined.

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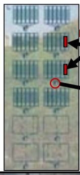
Case Study: Research at the Agro-Biofuel / Environment Interface

S.M. Brouder, R.F. Turco, J.J. Volenec and G. Ejeta, Agronomy Dept., Purdue Univ.; D.R. Smith, USDA-ARS, NSERL

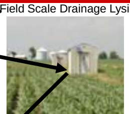
	Maize	Switchgrass	*Miscanthus*	Sorghum	Native Prairie
Key System Features	➢Model Annual ➢Known Standard ➢Existing on and off farm infrastructure ➢Biodiesel when rotated w/ oil crop	➢Model Perennial ➢Existing management knowledge from forages ➢Low input / high yield	➢Alternative Perennial ➢Putative high yield, high N use-efficiency ➢European / Asian candidate crop	➢Alternative Annual ➢Management analogous to corn ➢Adapted to marginal lands ➢Expected high resource use efficiency	➢Adapted Perennial ➢Low or no chemical inputs ➢Biodiversity ➢Visceral appeal
Production Questions	➢N / residue management for continuous corn + stover ➢Stover optimization ➢Management for dual (grain + biomass) purpose	➢Management for non-forage uses (e.g. N rates, harvest time / #s of cuttings)	➢All aspects of input management, esp. N ➢Genetic diversity (single germplasm) ➢Vegetative propagation	➢Management for dual (grain + biomass) purpose esp. N, harvest frequency ➢Novel Purdue material (high biomass, grain, sugar)	➢Long-term viability / sustainability of yields ➢N, P, pH limited system
	➢Life cycle analysis needed for all systems: Foundation of profitability is the net energy balance in the field				
Environment Questions	<u>For all candidate species / systems</u> ➢Soil C:N cycling and carbon sequestration, soil degradation and sustainability, resource conservation ➢System water economy: Total water use and water use efficiency (lbs of water / lb of feedstock) ➢System N economy: Total N requirement and N use efficiency (lb of feedstock / lb of N) ➢C & N environmental losses and air / water degradation: System impacts on greenhouse gases and water pollution <u>Critical related issues</u> ➢Other ecological services: wildlife habitat, biodiversity, diversified landscapes ➢Valuation of all ecological services: Economic analysis of environmental impacts and policy creation (e.g. N and C credits, "Cap and Trade")				

Case Study: Productivity Analysis and Environmental Footprints of Candidate Biofuels Species and a Low-input, Big Bluestem-dominated Prairie

The Scientific Approach



Field Scale Drainage Lysimeters



Purdue University Water Quality Field Station

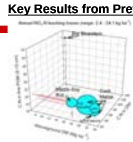
- Unique, highly-instrumented, in-field laboratory for integrated studies of agricultural productivity and environmental impacts
- Fully Integrated Team Approach: Agronomy, Physiology, Ecology, Soil Sciences (Microbiology, Chemistry, Physics, Hydrology), Crop Breeding & Genetics

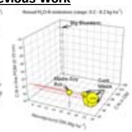
WQFS Research Capabilities: Can understand biomass and grain yields, biomass composition, and radiation, Water and N use efficiencies of cropping systems in the context of …

Capabilities Cont. Nutrient (C and N) losses to surface waters in tile drainage water, and

Capabilities Cont. Greenhouse gas (CO_2, CH_4 and N_2O) emission from soil

Key Results from Previous Work





- Cropping systems that have high NO_3 leaching losses can have low N_2O emissions (e.g. fall manure, F, bubble size indicates mass loss).
- Low input systems (e.g. big bluestem) have low N_2O and NO_3 losses but biomass yields are restricted.
- Adding N to any system including perennial native species such as switchgrass will increase biomass and environmental N losses.

New Biofuels Research

Biofuel Treatments	Anticipated Outcomes
1) Low-input prairie 2) Maize grown in rotation with soybean using rec. N rates 3) Continuous Maize using rec. N rate w/o residue removal 4) Continuous Maize plus residue removal using rec. N rates 5) Miscanthus using best known N management 6) Switchgrass using rec. N rates 7) High yielding & biomass sorghum using rec. N rates	Cropping systems-level analysis of switchgrass, *Miscanthus*, sorghum, and maize-based and low-input native prairie feedstock yields, water use efficiency, soil C & N losses to water and as greenhouse gasses.

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ARP Mission-Oriented Res. Prgm.
Department of Agronomy
Agric. Research Prgm. Office
Center for the Environment

Case Study: Develop and Characterize Sorghums with Enhanced Biomass Conversion Properties (Ejeta et al.)

- Genetic variation to exploit:
  - Sweet sorghums
  - Stay-green
  - High biomass
  - Brown mid-rib (low lignin)
- Genetics of sweet sorghums; Cell wall composition
- DNA markers for further breeding
- Develop germplasm with stacked traits
- Collaborate in fiber-fuel conversion studies

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Case Study: Assess Nitrogen Use Efficiency of Alternative Sorghum Lines for Biofuels Use(Ejeta et al.)

- Knowledge on optimizing management of sorghum for biofuels production (not grain) is scant
- Nitrogen impacts yield and quality, but also has environmental consequences if mis-managed
- Morphology and phenology of biofuels sorghums is drastically different from feed sorghums
  - Photoperiod-sensitive sorghums
  - High biomass, dual-purpose sorghums
  - Sweet sorghum
  - Sweet sorghum x *bmr* sorghum

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Case Study: Increasing Oil Content in Soybeans to Benefit Biodiesel Production (LeRoy et al.)

- Can oil content be increased at the expense of carbohydrate without reducing protein?
- Can oil content be increased by manipulating the positive correlation between oil and carbohydrate irrespective of seed protein?
  - Research Objectives Include:
    - Mapping and confirming QTL for oil and protein in populations with diverse levels of oil, protein & carbohydrate
    - Determining genetic correlations among oil, protein, carbohydrate, and yield
    - Developing germplasm with high oil content *per se* and high oil with protein that meets primary meals market specifications

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Case Study: Increasing Oil Content in Soybeans to Benefit Biodiesel Production (LeRoy et al.)

- Breeding Material and Future Plans:
  - Transgressive segregates for oil concentration from Elite x Elite crosses were used as high oil parents to develop the mapping populations
  - Oil concentrations from crosses are >25% (dry wt) versus 20 to 22% for normal lines
  - Future plans include a study of the correlations among clogging sterol glucosides, oil concentration, and linolenic acid content

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Case Study: Global Economic and Environmental Impacts of a Substantial Increase in Biofuels (Zhuang, Hertel, and Tyner)

- Objectives

1. To build and incorporate an explicit biomass energy sector within the GTAP analytical framework and data base (Global Trade Analysis Program).
2. To provide an analysis of the impact of renewable fuel standards and other policies in the US and EU, as well as alternative biofuel policies in other parts of the world, on changes in production, prices, consumption, trade and poverty.
3. To evaluate environmental impacts of alternative policies for bioenergy development focusing on:
   a) the feasibility of alternative methods of producing bioenergy
   b) the potential for new lands to contribute either to biofuels production, or to the production of displaced crop and forestry products
   c) the environmental consequences of policy scenarios, with a particular emphasis on water availability and greenhouse gas emissions

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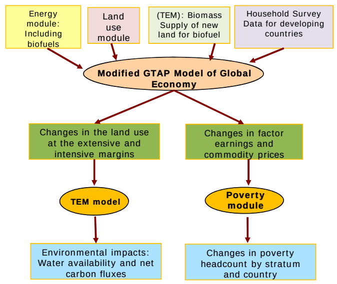
Case Study: Global Economic and Environmental Impacts of a Substantial Increase in Biofuels (Zhuang, Hertel, and Tyner)

Analytical Tool



Case Study: Biomass and Cell Wall Components of Switchgrass in Response to Water Deficit (Jiang, Yao, Volenec)

Objectives

- Determine biomass yield of contrasting switchgrass (lowland and upland) populations in response to water deficit
- To identify and characterize expression of key genes involved in cell wall formation and changes in lignin and polysaccharide composition

Case Study: Biomass and Cell Wall Components of Switchgrass in Response to Water Deficit (Jiang, Yao, Volenec)

Results

- Leaf and stem dry weight (per tiller) of upland (Cave-in-Rock) and lowland (Kanlow) switchgrass grown under deficit irrigation of 100% evapotranspiration (ET) (control), 80% ET, 60% ET, and 40% ET

	Cave-in-Rock		Kanlow	
ET (%)	Leaf	Stem	Leaf	Stem
	g			
100	0.50	22.9	0.90	24.1
80	0.51	23.5	0.85	21.0
60	0.43	23.0	0.83	16.6
40	0.43	18.9	0.83	15.8

- Gene expression of maize cellulose synthase (*ZmCesA1*) in Cave-in-Rock switchgrass tissues. C, D, R represent the well-watered control, drought, and recovery, respectively; 2 and 4 represent days of treatment; 12 and 24 represent hours after recovery. *18S*, a constitutively expressed gene as a marker gene.

Closing Thoughts…..
Programmatic Development Beyond Bioenergy

- Bioenergy is one of the current "darlings" of the research community, but may not remain so at relatively low fuel prices, and if innovation research leads to improved global energy security and sustainability
- So what is the "umbrella" under which faculty in the Department of Agronomy, the College of Agriculture, and Purdue University can continue to have impact on some of societies greatest/grandest challenges at the interface of agriculture and the environment?

Closing Thoughts….. The Umbrella Structure to Position the Department to Address Long-term Global Challenges

- Consider creation of a Purdue University "Hallmark" program in Agroecology that is regionally, nationally and internationally recognized for its humanitarian contributions achieved through interdisciplinary research and education at the intersection of agriculture and the environment.
- Such a program entails a seamless approach seeking to understand and manage for simultaneous optimization of productivity, natural resource use efficiency and environmental integrity

Closing Thoughts……. Why Agroecology at Purdue?

Several megatrends are producing an increasingly strong signal that such programming will be the next essential investment area for academia. These include:

1) the increasingly universal understanding/acceptance of the existence of anthropogenic global climate change and its linkages to agriculture

2) continued growth in population/per capita consumption outstripping productivity increases and approaching the limits of the natural resource base

3) failure of biotechnology to provide a stand-alone panacea to global agricultural problems

Closing Thoughts…….Purdue's Opportunity in Agroecology

- We already have some of the required expertise, several faculty are interested in programmatic growth, and we have unique field facilities/capabilities.
- Geographically we are ideally located to conduct hypothesis-driven research on and educate students about some of the world's most intractable problems linked to agricultural input use efficiency, cycling of N, C, and water in farming systems, and degradation of soil, water, and air quality
- Our opportunity is time-sensitive; PU can be a lead institution or we can wait to participate in a piecemeal fashion where we follow the lead of peer institutions

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Closing Thoughts…….Benefits to Purdue

- Creation of an Agroecology Program will heighten PU's visibility within the state and beyond for our capabilities in addressing "Grand Challenge" questions.
- It will create a platform from which we can link to efforts in other states as a strong or leading partner in collaborations addressing energy and Homeland Security, climate change, deployment of biotechnology solutions, mitigation of environmental degradation and preservation of the natural resource base.
- This heightened visibility is critical to boosting success in competition for extramural resources including IGERT and National Needs Fellowship programs, large facility grants such as NSF supported center and observatory grants (e.g. NEON, Critical Zone Observatories, etc.), and spontaneous public and private funding opportunities such as the recent BP/Bioenergy Sciences Center.

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