GROWTH OF BIOFUEL CROPS ON RECLAIMED MINED LAND IN WEST VIRGINIA

Jeff Skousen, Carol Brown, Travis Keene, Mike Marra
Division of Plant and Soil Sciences
West Virginia University

07/31/2014
Reasons for turning to Biofuel:

- High Energy Prices
- Energy Imports
- Concerns About Petroleum Supplies
- Greater Recognition of Environmental Consequences
Bioenergy

• Carbon sources derived from photosynthesis
• Less greenhouse gas emissions
• Less dependence on foreign sources for energy
• Supports rural economies
• Currently mandated by congress
Renewable Fuel Standard (RFS 1 & 2)

Transportation fuel sold in the US contains a minimum volume of renewable fuel....

• RFS 1 - 7.5 billion gal by 2012

2007 – Energy Independence and Security Act

• RFS 2 - 9 billion gal in 2008 to 36 billion gal by 2022

Americans use about 140 billion gallons of gasoline per year
**Food vs. Fuel**

40% of corn grain in the US was used for ethanol and distiller grains.

99% of ethanol was produced from corn.

World pop. > 7 billion
Malnutrition: approx. 800 million

**SOLUTION = Cellulosic Feedstocks**
12 Billion Gallons now (8%)
36 Billion Gallons in 2022 (26%)

Challenge to switch
Food vs. Fuel Debate

Solutions:
1) Grow Cellulosic Crops instead of Food Crops
2) Use marginal lands instead of farmland.
Marcellus Shale Gas Wells
Off-Shore Oil Drilling
Other Renewables
Wind and Solar
Biomass Feedstocks

**Starch / Sugar based Feedstocks**
- Corn grain
- Wheat
- Sugarcane

**Cellulosic Feedstocks**

**Ag Plant Wastes:**
- Corn Stover
- Cereal Straws
- Forest Residues

**Plant Wastes from Industrial Processes**
- Sawdust
- Paper Pulp
New Biomass Feedstocks

Cellulosic Feedstocks

Energy Crops

- Switchgrass
- Miscanthus
- Arundo
Plants to Fuel

The Basic Steps...

1. Convert feedstocks to simple sugars
2. Fermentation (???)
3. Recovery of Ethanol
West Virginia’s traditional energy production... 

COAL
Mining creates large expanses of reclaimed land.

- 54,000 acres of land reclaimed in Appalachia in 2010
- 75% is reclaimed to pasture/hayland
...much is underutilized and unmanaged
Why not reclaim land for biofuel production rather than pasture and hay land?

- Large uninterrupted tracts
- Good road networks
- Access to transportation hubs
- Land not previously in ag production
Switchgrass: a viable biofuel?
SWITCHGRASS
*Panicum virgatum* L.

- Warm season, perennial, bunch grass
- Native to North America
- Well adapted to a variety of sites:
  - pH 4.9 to 7.5
  - soils ranging from sand to loam
  - little to no fertilization or mgt
  - extensive root system
  - two ecotype
Switchgrass versus corn for ethanol production:

Advantages:

- Requires fewer inputs
- Perennial crop
- Conservation benefits
  - Reduced erosion
  - Improved water quality
  - Wildlife habitat
- Reduces impact on food and feed prices
- Can be grown on marginal acres
- Uses conventional hay equipment
- Lower green house emissions
- Sequesters atmospheric carbon

2008 1 29
Example of “Ideal” biofuel crop

**SPRING/SUMMER**
- Translocation from rhizomes to growing shoot
- Mineral nutrients

**FALL**
- Translocation to rhizome as shoot senesces
- Mineral nutrients

**WINTER**
- Lignocellulose dry shoots harvested
- Nutrients stay in rhizomes

Source Dr. Steve Long, UIUC 2005
Disadvantages:

- Slow and difficult to establish
- Currently no viable market for switchgrass as a biofuel
- Bulky and difficult to transport
- More costly to convert to ethanol?
Pelletizing switchgrass

- Reduces shipping costs
- Prepares crop for utilization as a feed stock
Other uses for switchgrass:

- Can be co-fired in coal plants
- Create synthesis gas through pyrolysis
- Burned outright for heat generation
- Carbon sequestration credits
### Switchgrass Yields

<table>
<thead>
<tr>
<th>Study</th>
<th>Yield (Mt ha(^{-1}))</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fike et al., 2006a</td>
<td>14.1</td>
<td>4 cultivars, 8 sites, 5 states (including WV)</td>
</tr>
<tr>
<td>Vogel &amp; Masters (1998)</td>
<td>14.9</td>
<td>3 states in Midwestern US</td>
</tr>
<tr>
<td>Fike et al., 2006b</td>
<td>14.2</td>
<td>Years 6 - 9 of production</td>
</tr>
<tr>
<td>USDOE (McLaughlin &amp; Kszoz 2005)</td>
<td>11 – 19</td>
<td>Cave-in-Rock; 10-year study in 13 states</td>
</tr>
<tr>
<td>Schmer et al., 2008</td>
<td>5.2 – 11.1</td>
<td>Marginal cropland</td>
</tr>
<tr>
<td>Mulkey et al., 2006</td>
<td>&lt; 7.5</td>
<td>CRP land in South Dakota</td>
</tr>
</tbody>
</table>

**Goal would be 5.0 Mt ha\(^{-1}\)**
What we know....

- Need **cellulosic** feedstocks (Food vs Fuel)
- Switchgrass can produce **good yields** on agricultural land and even on **marginal croplands**
- Ethanol production and fermentation process from switchgrass is ongoing and under research
Could switchgrass grow on land even poorer quality than marginal cropland? ... like reclaimed mine lands...??
1984
Reclaimed land
TX - Alamo

2000 – WV Highways

2008 – Marginal Agric Lands
Objective
To grow switchgrass on mined lands and determine yield

1. Two sites for years 2 to 6 (2008-2013)

Keep track of where these sites are!
Experimental design

• Three upland varieties of switchgrass
  – Carthage
  – Cave-in-Rock
  – Shawnee

• Three, 1-ac replications of each variety at each site (Hobet and Hampshire)
Hampshire
Seed was carefully measured for each plot

10 lbs PLS ac$^{-1}$

Seed was carefully measured for each plot
Hand seeding at Hobet
Soil and biomass samples

- **Clipped in October**

- **Biomass:** dried and then weights averaged

- **Soil:** dried and sieved to 2mm
  - Mehlich 1
  - % Fines
  - pH, EC
Results - Soils

Soil Chemical and Physical Properties

**Hobet (Poor Site)**
- 55% Fines
- pH = 8.0
- EC = 109 $\mu$S/cm
- P = 50 mg kg$^{-1}$ soil
- Ca = 2.0 cmol$_c$ kg$^{-1}$

**Hampshire (Good Site)**
- 74% Fines
- pH = 7.4
- EC = 421 $\mu$S/cm
- P = 8.0 mg kg$^{-1}$ soil
- Ca = 50 cmol$_c$ kg$^{-1}$
Results - Yield

Hobet (Poor site)

3rd Yr  6th Yr

All cultivars  Mt ha⁻¹

0.2  1.6
Results - Yield

Hampshire (Good site)

3rd Yr | 6th Yr
---|---
4.5 | 12.1

Mt ha⁻¹

All Cultivars

4.5 | 12.1
<table>
<thead>
<tr>
<th>Variety</th>
<th>6th Yr Hampshire</th>
<th>6th Yr Hobet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cave in Rock</td>
<td>19.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Carthage</td>
<td>5.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Shawnee</td>
<td>10.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Hampshire
Oct 2012 - 5th Year
About 9 Mt ha⁻¹
Hampshire
Oct 2013 - 6\textsuperscript{th} Year
About 12 Mt ha\textsuperscript{-1}
Hobet
Aug 2011 – 4th Yr
About 1 Mt ha⁻¹
Research Questions

Can switchgrass be grown on reclaimed surface mines?

Produce yields similar to agricultural soils?
What are our numbers?

Agricultural Land: \(13 \text{ - } 16 \text{ Mt ha}^{-1}\)

Cave-in-Rock at Hampshire: \(13 \text{ Mt ha}^{-1}\)

Shawnee at Hampshire: \(8 \text{ Mt ha}^{-1}\)

Shawnee at Hobet: \(2 \text{ Mt ha}^{-1}\)

Goal of 5.0 Mt ha\(^{-1}\)
What about clipping twice?
What about fertilizing?
Objective: Fertilizer for Switchgrass

1. Two sites (Black Castle and Coal Mac)
2. Cave-In-Rock switchgrass
Experimental Design - Fertilizer

• Four Treatments
  1. 0 kg N ha\(^{-1}\); 1.7 Mg ha\(^{-1}\) hydromulch
  2. 33.6 kg N ha\(^{-1}\); 1.7 Mg ha\(^{-1}\) hydromulch
  3. 67.2 kg N ha\(^{-1}\); 1.7 Mg ha\(^{-1}\) hydromulch
  4. 33.6 kg N ha\(^{-1}\); 3.0 Mg ha\(^{-1}\) hydromulch

Five, 0.4-ha blocks (four treatments/block)

WVDEP §38-2-9 minimum requirements =
- 67.0 kg N ha\(^{-1}\) and;
- 560 kg ha\(^{-1}\) of mulch.
Legend
Treatment
- 0 kg N ha$^{-1}$; light hydromulch
- 33.6 kg N ha$^{-1}$; light hydromulch
- 67.0 kg N ha$^{-1}$; light hydromulch
- 33.6 kg N ha$^{-1}$; heavy hydromulch
- Sampling Points

Black Castle
2011 - Switchgrass
New Plots established
at Coal Mac
2011 - Switchgrass
New Plots established
at Black Castle
What about other crops?

Miscanthus

Illinois
Photo credit John Caveny

China
Mendel
Giant Cane - *Arundo donax*
What about converting already established cool-season pastures to Biofuel crops?
Objective: Switchgrass, Miscanthus, Arundo growth on mined lands and determine yield

1. 20-year-old Mine Site.
2. Two switchgrass varieties (Kanlow, BoMaster)
   Two miscanthus varieties (public vs private)
   Arundo rhizomes (Illinois)
3. 5 reps.
4. Planted in 2010.

Keep track of where these sites are!
Each 0.4 ha or 1 acre

5 plots Kanlow
5 plots BoMaster
5 plots Miscanthus – private
5 plots Miscanthus – public
3 plots Arundo
Must Herbicide!
Ernst Conservation Seeds
Switchgrass

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Weight</td>
<td>47.995 lb</td>
</tr>
<tr>
<td>Lot Number</td>
<td>FFC6098</td>
</tr>
<tr>
<td>Date Tested</td>
<td>February 2010</td>
</tr>
<tr>
<td>Production Origin</td>
<td>KS</td>
</tr>
<tr>
<td>Genetic Origin</td>
<td></td>
</tr>
<tr>
<td>Pure Seed</td>
<td>93.40%</td>
</tr>
<tr>
<td>Other Crop</td>
<td>0.02%</td>
</tr>
<tr>
<td>Inert Matter</td>
<td>6.57%</td>
</tr>
<tr>
<td>Weed Seed</td>
<td>0.01%</td>
</tr>
<tr>
<td>Germination</td>
<td>77.00%</td>
</tr>
<tr>
<td>Hard Seed</td>
<td>0.00%</td>
</tr>
<tr>
<td>Dormant</td>
<td>10.00%</td>
</tr>
</tbody>
</table>

This seed has been treated with GAUCHOXT FUNGICIDE/INSECTICIDE. Do not use for feed, food, or oil purposes. Store away from feeds and foodstuffs. Exposed treated seed may be hazardous to birds. Dispose of all excess seed and packaging by burial away from bodies of water. Cover or incorporate spilled treated seeds.
Switchgrass drilled into killed sod
Miscanthus planting trial at Alton, WV
Sprigs
We had tree planters do the sprig planting.
Two months later
Arundo Planting at Alton
Alton Soils

70% Fines
pH = 7.5
EC = 368 μs/cm
P = 40 mg kg\(^{-1}\) soil
K = 0.2 cmol\(_c\) kg\(^{-1}\)
Ca = 3.2 cmol\(_c\) kg\(^{-1}\)
Switchgrass - Alton

<table>
<thead>
<tr>
<th></th>
<th>2nd Yr</th>
<th>3rd Yr</th>
<th>4th Yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kanlow</td>
<td>4.0 (2.6)</td>
<td>4.9 (1.1)</td>
<td>4.9 (3.5)</td>
</tr>
<tr>
<td>BoMaster</td>
<td>2.7 (1.5)</td>
<td>4.0 (3.1)</td>
<td>5.4 (9.8)</td>
</tr>
</tbody>
</table>

Goal of 5.0 Mt ha\(^{-1}\)
Kanlow Switchgrass - 3rd Yr
Alton

Looks like about 4 to 5 Mt ha$^{-1}$
Switchgrass – 2012 - 3rd Yr
Alton
Switchgrass – 2013 - 4th Yr

Alton – about 5 Mt ha⁻¹
<table>
<thead>
<tr>
<th></th>
<th>2nd Yr</th>
<th>3rd Yr</th>
<th>4th Yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>2.2 (2.0)</td>
<td>4.9 (3.0)</td>
<td>7.0 (6.6)</td>
</tr>
<tr>
<td>Private</td>
<td>6.5 (5.8)</td>
<td><strong>15.5</strong> (10.4)</td>
<td>11.1 (6.8)</td>
</tr>
</tbody>
</table>

Miscanthus - Alton

09/10/2012
Miscanthus – 2011 – 2nd Yr
Alton
7 Mt ha\(^{-1}\)

Reclaimed site for 20 years, so some soil material

11/02/2011
Miscanthus – 2012 - 3rd Yr
Alton – about 9 Mt ha$^{-1}$
Miscanthus – 2013 – 4th Yr
Alton – about 11 Mt ha\(^{-1}\)
Arundo - Alton

<table>
<thead>
<tr>
<th>Year</th>
<th>Mt ha$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd Yr</td>
<td>NA</td>
</tr>
<tr>
<td>3rd Yr</td>
<td>&lt;0.5 (0.1)</td>
</tr>
<tr>
<td>4th Yr</td>
<td>0.8 (1.2)</td>
</tr>
</tbody>
</table>
Arundo (Giant Cane) – 2013 – 3rd Yr

Alton
Arundo – Coal Mac

<table>
<thead>
<tr>
<th></th>
<th>2nd Yr</th>
<th>3rd Yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arundo</td>
<td>2.9 (1.6)</td>
<td>12.5 (8.5)</td>
</tr>
</tbody>
</table>

Mt ha⁻¹
What about larger areas?

- The Wilds, OH

Objective: Switchgrass and Miscanthus

1. Two sites (The Wilds and MWV)
2. Cave-In-Rock switchgrass
3. Miscanthus

Keep track of where these sites are!
Miscanthus rhizome
Planted
Planting at The Wilds, Ohio
Switchgrass establishment at MWV
Switchgrass establishment at The Wilds
THE WILDS
4,000 ha reclaimed land
Endangered Species
Prairie Restoration
Development
The Wilds

Wildflowers, Native Plants, Insects

Tall Grass Prairie
Endangered Species
– Columbus Zoo
300 acres
Warm-season Grasses!
Prairie and Agriculture Demonstration Site

This project is sponsored by:
The U.S. Department of Agriculture; Natural Resource Conservation Service’s Conservation Innovation Grant Program.
<table>
<thead>
<tr>
<th>Plant</th>
<th>MW</th>
<th>Wilds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switchgrass</td>
<td>752 (595)</td>
<td>1,045 (738)</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>201 (179)</td>
<td>559 (504)</td>
</tr>
</tbody>
</table>

Low Yield at the end of one growing season
How much ethanol can switchgrass potentially produce when grown on reclaimed surface mines?
Composition of biofeedstocks

Corn grain feedstock
• 72% starch

Cellulosic feedstock
• Cellulose
• Hemicellulose
• Lignin

• These are hydrolyzed into sugars
Sugars

Pentoses (C5)
- Xylose
- Arabinose

Hexoses (C6)
- Glucose
- Galactose
- Mannose

- Sugars are fermented into ethanol by yeast, lower efficiency for pentoses than hexoses
Potential Ethanol Yields

- ~300 gal ac⁻¹

Schmer et al. (2008)
Wet chemistry

• Procedures done in lab to determine the chemical constituents of biomass
• Must be done separately on individual samples
• Expensive and time consuming process
Near-Infrared Reflectance Spectroscopy (NIRS)

- Alternative to determine composition
- Been widely used in other agricultural areas
- Prediction based on sample spectra
Absorbance spectra of switchgrass

Absorbance = log(1/Reflectance)
Calibration eq. is needed

Wet chemistry

Sample

My Sample

PLS
Packing sample cells
Scanning sample using SpectraStar 2400
Theoretical ethanol yields from equations by Vogel et al. (2011)

1. Theoretical ethanol yield from all biomass hexoses:
HEXEL (L Mg⁻¹) = (((MAN+GAL+GLC+STA) × 0.57) + ((GLCS+FRU) × 0.51) + (SUC × 0.537)) × 1.267); assuming 100% conversion

2. Theoretical ethanol yield from pentose sugars:
PENTETL (L Mg⁻¹) = (ARA + XYL) × 0.579 × 1.267

3. Total theoretical ethanol yield from all biomass sugars:
ETOHTLT (L Mg⁻¹) = HEXEL + PENTETL

4. Total theoretical ethanol production from all biomass sugars:
ETOHTLTH (L ha⁻¹) = ETOHTLT × biomass production yield (Mg ha⁻¹)
Theoretical ethanol yield and production for cultivars at HA

<table>
<thead>
<tr>
<th></th>
<th>HEXEL</th>
<th>PENTETL</th>
<th>ETOHTLT</th>
<th>EthProd</th>
<th>NRELC6</th>
<th>NRELC5</th>
<th>NREL</th>
<th>EthProdNREL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L Mg⁻¹</td>
<td>L Mg⁻¹</td>
<td>L Mg⁻¹</td>
<td>L ha⁻¹</td>
<td>L Mg⁻¹</td>
<td>L Mg⁻¹</td>
<td>L Mg⁻¹</td>
<td>L ha⁻¹</td>
</tr>
<tr>
<td>CIR</td>
<td>274a</td>
<td>183</td>
<td>457</td>
<td>7348a</td>
<td>217a</td>
<td>162</td>
<td>380a</td>
<td>6092a</td>
</tr>
<tr>
<td>Carth</td>
<td>258b</td>
<td>173</td>
<td>430</td>
<td>1873b</td>
<td>196b</td>
<td>153</td>
<td>349b</td>
<td>1526b</td>
</tr>
<tr>
<td>Shaw</td>
<td>266ab</td>
<td>160</td>
<td>426</td>
<td>3988b</td>
<td>204ab</td>
<td>158</td>
<td>362ab</td>
<td>3405b</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.01</td>
<td>NS</td>
<td>NS</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>NS</td>
<td>0.02</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Mean</td>
<td>266</td>
<td>172</td>
<td>438</td>
<td>4403</td>
<td>206</td>
<td>158</td>
<td>364</td>
<td>3674</td>
</tr>
</tbody>
</table>

Using Vogel et al. 2011 eq.  
Using NREL eq.
Comparing ethanol yields

Cave-in-Rock: 7,348 L ha\(^{-1}\)
Shawnee: 3,988 L ha\(^{-1}\)
Carthage: 1,873 L ha\(^{-1}\)
Can switchgrass grow on reclaimed surface mines? What yields would we expect to see?

- **YES!**
- **6th year on good soils:** 10 to 16 Mg ha\(^{-1}\)
- **3rd year fertilized:** 3 to 5.5 Mg ha\(^{-1}\)
Does fertilization and mulch help increase yields?

- Double the fertilizer almost doubled yield!
- More hydromulch did not increase yield
What ethanol production target (L/ha) are achievable on reclaimed lands?

- Yields at Hampshire compared and exceeded both low yielding and high farms
Conclusions

Bioenergy crops could be grown on reclaimed land at profitable rates if...
Sustainable Energy Parks!

Potential Uses of Reclaimed Land

- Coal Mined
- Biomass Planted
- Forest and Grass
- Co-fired
Coal – Biomass Fired and Wind

Much Work To Do!
“The fuel of the future is going to come from fruit like that sumac on the road, or from apples, weeds, sawdust – almost anything. There is fuel in every bit of vegetable matter that can be fermented.”

*Henry Ford, 1925*
Summary of Sites

- The Wilds, OH
- Hampshire
- Alton
- Black Castle
- Hobet
- MeadWestvaco
- Coal Mac