**Growing the Bioeconomy:**
*Solutions for Sustainability*

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IMAGINE THE POSSIBILITIES

**Michigan Location:**
*East Lansing Hannah Community Center*
*819 Abbott Rd * East Lansing, MI 48823*

2009 BIO eConference
Growing the Bioeconomy
Solutions for Sustainability

# *Agronomics of producing Switchgrass and Miscanthus x giganteus*

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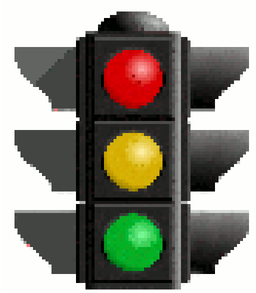
# Main drivers for cellulosic-based renewable fuels

- Government Policy 36 M gal by 2022
- Feedstock/Refinery costs (+ -)
- Food vs. Fuel
- Environmental issues
- Net energy return

# Main drivers for cellulosic-based renewable fuels



Government Policy

\+ -

Feedstock/Refinery costs

Food vs. Fuel

Environmental issues

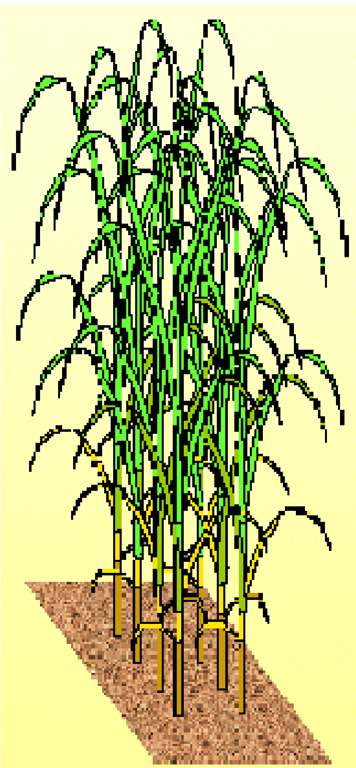
Net energy return

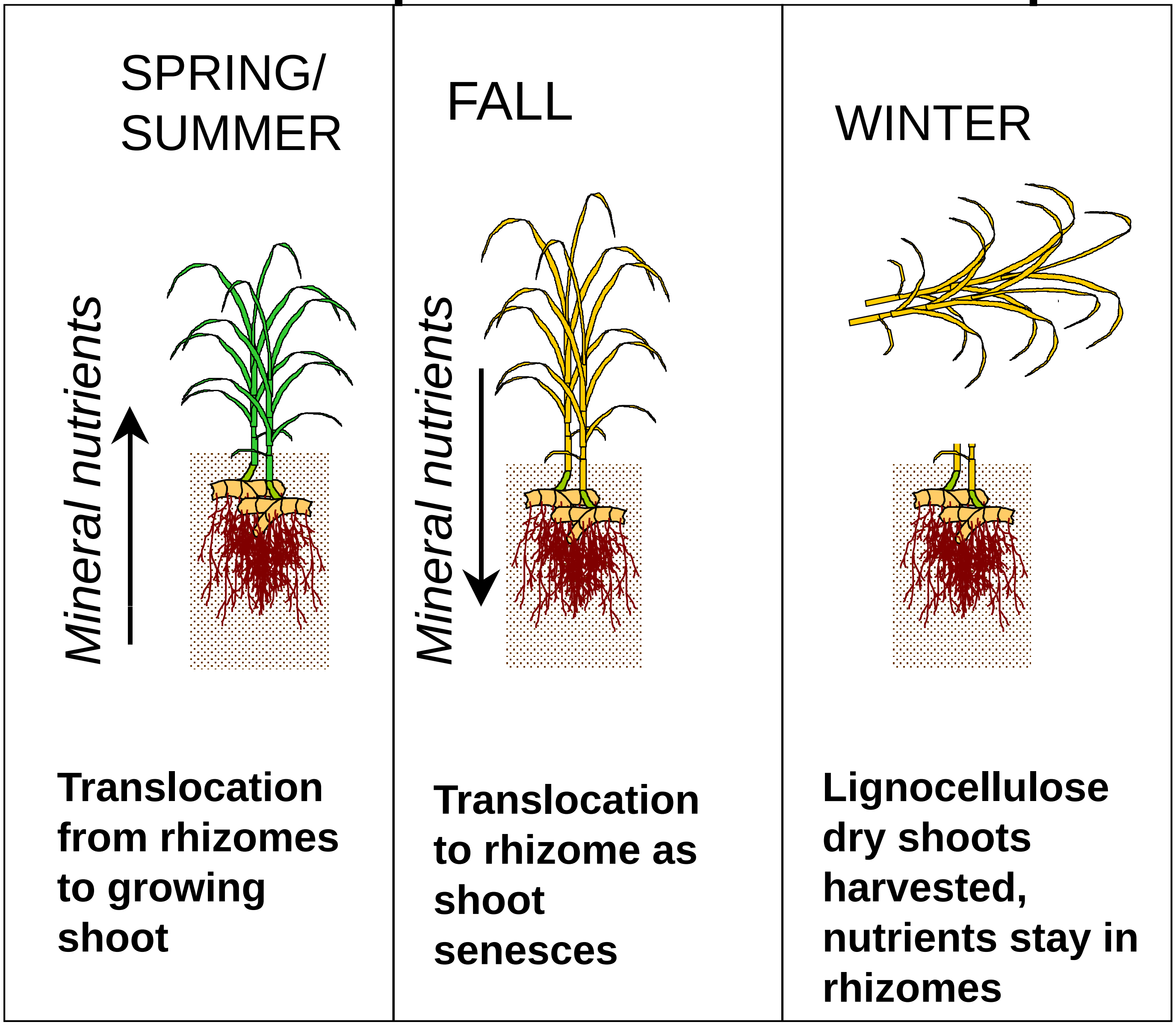
# Ideal traits of a biomass energy crop

- $C_4$ photosynthesis
- Long canopy duration
- Accessible cellulose in shoots
- Recalcitrant carbon in roots
- Perennial
- Ease of rotation
- No known pests or diseases
- Provide wildlife habitat
- Rapid spring growth (out compete weeds)
- Rapid fall drydown
- Sterility
- Partitions nutrients to roots in fall
- Aggressive root system sequesters carbon
- High water use efficiency
- Multiple use (animal feed)
- Use existing farm equipment

Source: modified from Raghu et al. Science 313:1742

# Example of “Ideal” biofuel crop






Source Dr. Steve Long, UIUC 2005

# Ideal traits: crops

Switchgrass

Miscanthus

Annual grass

# Ideal traits: crops compared

| | Switchgrass | Miscanthus | Annual grass |
|---|---|---|---|
| •$C_4$ photosynthesis | | | |
| •Long canopy duration | | | |
| •Accessible cellulose in shoots | | | |
| •Recalcitrant carbon in roots | | | |
| •Aggressive root system | | | |
| •Perennial | | | |
| •Ease of rotation | | | |
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| •Rapid spring growth | | | |
| •Rapid fall drydown | | | |
| •Sterility | | | |
| •Partitions nutrients to roots in fall | | | |
| •High water use efficiency | | | |
| •Multiple use (animal feed) | | | |
| •Use existing farm equipment | | | |
| Score | 10 | 10 | 6 |

# Bottom Line ???

Environmental

$$$

Grower

Biorefinery

# Bottom Line $$$

Environmental

$ incentives shaped nationally in farm and energy policy

Grower

$ dynamics shaped locally by cropping system, soils, climate, market flexibility

Biorefinery

$ price function of national supply-demand with a localized price basis


Miscanthus x giganteus

# *Miscanthus x giganteus: origin*

- The genus *Miscanthus* includes a group of more than 10 grass species.
- Miscanthus species are native to Southeastern Asia, China, Japan, Polynesia,and Africa and are currently  distributed throughout temperate and tropical areas of the world.
- Cultivars of *M. sacchariflorus, M.sinensis, their hybrids, and other miscanthus* species are grown in NorthAmerica as ornamental crops.
- The miscanthus genotype with the greatest biomass potential is a sterile, hybrid (*Miscanthus x giganteus) likely* of *M. sacchariflorus  (tetraploid) and M. sinensis (diploid)* parentage.
- The cross between the tetraploid and diploid produces a triploid which is unable to produce viable seed.
- Both *M. sacchariflorus and M. sinensis* have escaped cultivation and can be invasive in the landscape.
- Because *Miscanthus x giganteus hybrids are unlikely to* produce seed they are less likely to be invasive than other varieties.

(top) Miscanthus *sinensis* (diploid) and (bottom) Miscanthus *sacchariflorus* (tetraploid). M. *sinensis* and M. *sacchariflorus are p*arents of Miscanthus x giganteous (center) which is a sterile triploid.

# *Miscanthus giganteus: life cycle*

- *Miscanthus x giganteus is a perennial,* warm-season grass with a C4 photosynthetic pathway. Unlike most C4 species, photosynthesis and leaf growth can be sustained at relatively low temperatures (as low as 43°F).
- Because *Miscanthus x giganteus is sterile it* must be propagated vegetatively from rootstock.
- *Miscanthus x giganteus grows as a*bunchgrass and will spread slowly with short rhizomes. It has erect stems, 5 to12 feet tall.
- Dry matter accumulation increases rapidly during June, July, and August,reaching its maximum dry matter yield in late-summer.
- Autumn frost stops annual growth of miscanthus. Regrowth in Michigan begins in May.
- Miscanthus has a lengthy stand life. Replanting is necessary after 15 years.

# Progression of *Miscanthus giganteus growth in Michigan*

Rhizomes (used for planting)


Initial growth (Year 1)

Mid summer (Year 2)

Early fall (Year 2)

Mature plant inflorescence

# *Miscanthus giganteus: adaptation*

- ***Miscanthus x giganteus is adapted to*** **a wide range of soil conditions, but is most productive on soils well suited for corn production. Its biomass yield will be limited on shallow, droughty, cold, and waterlogged soils.**
- **Biomass production is positively linked to seasonal precipitation and can decline considerably under waterstressed conditions.**
- ***Miscanthus x giganteus has been*** **grown in Europe from southern Italy (37° N latitude) to Denmark (56° N latitude). It may not be adapted as far north in North America because the continental climate of North America is colder during the winter than in Europe.**
- **In North America** ***Miscanthus x giganteus plantings have been established*** **successfully in Ohio, Michigan, Indiana, Illinois, and Quebec. In the winter of 2008-09 we had near complete winter kill at Arlington Wisconsin, but near total survival at Michigan locations.**

# Site Selection

- Most productive on soils well suited for corn production.
- Biomass yield will be limited on shallow, droughty, cold, and waterlogged soils.
- Winter kill has been observed at various sites depends on:
  - winter conditions- multiple freeze-thaw cycles,
  - harvesting in the first year

# *Miscanthus giganteus: establishment*

- *Miscanthus x giganteus produces no* seed, so it must be established vegetatively by planting divided rhizome (rootstock) pieces. This process results in high establishment costs relative to crops established from seed.
- The planting rate is one transplant per three square feet or about 4,000 plants per acre.
- As with other vegetatively propagated crops, dry soil moisture conditions at and following planting greatly decrease establishment success.
- Establishment success may be limited by death of plants in the first winter after planting. European research suggests new plantings of *Miscanthus x giganteus may not survive* where soil temperatures fall below 26˚F at a depth of one inch.  Research is ongoing in Michigan to determine winter survivability.
- *M. sinensis and M. sacchariflorus* plantings have overwintered the first year in northern Europe where air temperatures have been as low as 0˚F. Winter survival does not appear to be a problem in the second and subsequent years.

# *Miscanthus giganteus: fertility needs*

- Like corn and other grass crops, Nitrogen will likely be the largest fertilizer requirement for Miscanthus.
- Fertilizers are not needed in the first two years. Their application will create greater weed-growth during establishment. Maintenance fertilizer rates are required in later years.
- The harvest strategy of waiting until after frost will minimize N fertilizer need since the plants will translocate protein (N) to the roots where it is available for new shoot growth the following spring. It will require relatively low annual rates to support growth.

Nitrogen applications of 50-75 lbs. per acre are often used in multi-year research studies.

- Fertilization rates for phosphorus and potassium should be adjusted to replace the amounts exported in harvested biomass. Annual estimated phosphorus removal is 1.5 lbs. per ton of biomass removed. Potassium removal is 12 lbs. per ton.

# *Miscanthus giganteus: harvest*

- **Miscanthus biomass is harvested at the end of the growing season. Harvests can be taken between maturity in the fall and plant regrowth the following spring.**
- **Late winter and spring harvests result in higher quality feedstock for combustion, but lower yields due to field losses.**
- **Research in Europe and Illinois shows a 30 to 50 percent yield reduction when harvest is delayed from autumn to late winter.**
- **Mowing during the growing season harms plant growth and regeneration by depleting rootstock.**
- **Dry matter yield of miscanthus in the establishment year is generally less than one ton per acre, which is insufficient to merit harvest.**
- **Research in Europe has shown dry matter yields of 4.5 to 11.2 tons per acre in non-irrigated, fully-established miscanthus with average yields of 8.4 tons per acre. The highest yields are reported in southern Europe, generally south of 40° N latitude.**
- **There is no documentation of miscanthus yield in Michigan. Research in Illinois has resulted in 10 to 15 tons per acre with tonnage decreasing at more northerly latitudes.**

# Weed Management in Miscanthus

# Miscanthus

- Stand establishment critical
- Planting
  - Seedbed preparation
  - Time of planting
  - Row spacing
- Mowing
  - Remove annual weeds
- Tillage – rotary hoe, harrow
- Herbicides – No labeled products!

# MSU research – No labeled Products!

PRE-emergence

- Atrazine
- Dual Magnum/Harness/Outlook
- Prowl
- ALS herbicides
- HPPD inhibitors

- Potential Injury
  - Command

POST-emergence

- Atrazine
- 2,4-D / Banvel
- Buctril
- Permit (only ALS inhibitor)
- Laudis/Impact

- Potential Injury
  - Callisto
  - ALS herbicides

**No labeled products**

Sources:

Growing Giant Miscanthus in Illinois
http://miscanthus.illinois.edu/wp-content/uploads/growersguide.pdf

Miscanthus Hybrids for Biomass production
http://www.extension.iastate.edu/Publications/AG201.pdf

# Switchgrass Agronomy

# Introduction

- Switchgrass (Panicum virgatum L.)
- Warm season ($C_4$) perennial
- Cross pollinated, pollen is dispersed by wind
- Two major ploidy levels: tetraploid (2n=4x=36) lowland and octaploid (2n=8x=72) upland.
- Polymorphic: Lowland and Upland Ecotype

# Switchgrass (*Panicum virgatum*)

1991 the decision to pursue switchgrass as a "model" or "prototype" bioenergy crop was made based on the economic and environmental assessments by the Oak Ridge National Laboratory's Biofuels Feedstock Development Program (1984-1991)

– $C_4$ - High Water and Nitrogen Use Efficiency
– High yields potential even on relative poor quality sites, deep rooting characteristics
– Significant capacity to improve soil quality by sequestering carbon & reduced soil erosion
– Reduced fertilizer and pesticide requirements relative to conventional annual crops.

**Source: ORNL/TM-2007/109**

# Switchgrass Ecotypes

| Upland Ecotype | Lowland Ecotype |
|---|---|
| **Developed on higher, 'mesic' sites.** | **Developed in lower lying, 'hydric' sites, more sensitive to moisture stress** |
| **Adapted to mid- to northern latitudes** | **Adapted to lower latitudes** |
| **Octaploid- (2n=8 x =72)** | **Tetraploid – (2n=4x=36)→Have a restriction site in their chloroplastic genome (serves as a genetic marker)** |
| **Longer root length and internodes** | **Bunch form, larger root diameter** |
| **Shoots: originate from more active rhizomes and basal nodes of previous-year culms** | **Shoots: originate from buds on rhizomes** |
| | **Taller, coarser , tick stems, long, wide bluish-green leaves with long ligules, large panicles** |

**Parrish and Fike (2005)**

# Switchgrass Biology

- Outcrossing species with pre- & postfertilization incompatibility mechanisms
- Reproduces by seed and some vegetative propagation
- Behaves as a determinate plant
- Develops in response to accumulated temperature (GDD's) (vegetative growth) and day length (reproductive growth)
- Short day plant →flowering triggered when days become shorter
- Highly influenced by genotype X environment interactions due to great genotypic variability
- $C_4$ Native Prairie grass, Northern limit is $51^0$ N (Jefferson et al. 2002)
- Can tolerate a wide pH range: 4.9-7.6

# Growth & Development

- Germination and growth is inhibited at temperatures <20°, and so producers could follow recommended corn seeding dates for their area.
- Growth in the establishment year depends on: soil moisture, fertility, competition from weeds.
- Heading dates and seed ripening is highly variable amongst cultivars
- Flowering: ~ 12 day period and peak pollen shed occurs from 10am-12pm or 12-3pm.

# Productivity and Persistence

- Tolerates a pH of 3.9 to 7.6
- Mycorrhizae→ requires the establishment of a symbiotic relationship with arbuscular mycorrhizal fungi (AMF) in its roots for successful establishment and persistence.
- Indigenous/native AMF so inoculation is not practical unless soil is severely degraded.

# Switchgrass Agronomy

- Difficult to Establish due to weed competition and seed dormancy/morphology
- Takes 3 years to reach full yield potential
- Seeding Rate: 8-10 lb/acre Pure Live Seed
- Acceptable stand: 1-2 plants $ft^{-2}$
- No nitrogen is put down establishment year
- Soil moisture may be more critical than temperature
- Emergence may be more rapid at later planting depths
- single annual harvest : stand maintenance and optimizing cellulosic ethanol (low moisture content, low alkali earth metal concentration)
- Can be direct-cut chopped, swathed, wind-rowed and baled

# Switchgrass - Establishment

•Seeding rate: 200-400 pure live seeds/meter (PLS/m)→ We typically use 8-8.5 lbs/ac → Use seeds with a germination rate and that are no older than 3 years

•Minimum germination temperature: 10$^{o}$ C (50$^{o}$ F), however planting in the fall (late enough that it won't germinate) or early spring MAY be advantageous as it could aid in breaking seed dormancy.

•Seeds should not be planted deeper than 1-2cm (0.25"-0.5") in a firm seed bed

•No-till seeding can be very effective

• Conduct a soil test prior to establishment: and correct for lime if soil is acidic, P & K.

• Nitrogen is not applied in the establishment year

• Switchgrass is slow to establish -N fertilization in the year of establishment will only fertilize the weeds leading to stand encroachment and possible stand failure.

# Switchgrass Agronomy-Fertility Management

Although switchgrass can tolerate low fertility it does respond to N fertilization and responds to P only in very low P soils.

Recommended N fertility depends on:
→Location-moisture/temperature regimes, latitude
→Cultivar
→Harvest management

# Switchgrass Agronomy-Fertility Management

When managed for biomass production in the Midwest:

•80 lb acre N is a common recommendation

At MSU no yield response observed above this level w/limited research.

Excess nitrogen can be lost in surface run off or leached to ground water.

Contribute to GHG fluxes, provide nutrients for competing weeds

Fertilization should occur **in the late spring**

N fertilizer applied before switchgrass “green-up” may benefit $C_3$ ‘invaders’ these plants will compete with switchgrass for nutrients and also deplete the moisture reserves of the soil

# Weed Management in Switchgrass

# Switchgrass

- Stand establishment critical
- Proper planting
  - Seedbed preparation
  - Time of planting
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- Mowing
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**No labeled products**

# Projected biofuel yield

| Crop | Ps | Bu/wt | Crop Yield | Biofuel | EtOH or oil/bu | EtOH or oil yield/A |
|---|---|---|---|---|---|---|
| Corn | C4 | 56 lb | 150 bu/a | EtOH | 2.8 gal | 420 gal |
| **Corn + Stover | | 56 lb | 150 bu/a<br>3.5 ton | EtOH | 2.8 gal<br>72 gal/ton | 420<br><u>252</u><br>672 gal |
| Switchgrass | C4 | NA | 8 ton/a | EtOH | 72 gal/ton | 576 gal |
| Miscanthus | C4 | NA | 10 ton/a | EtOH | 72 gal/ton | 720 gal |
| Sugarcane | C4 | NA | | EtOH | | 600 gal |
| Soybean | C3 | 60 lb | 40 bu/a | Diesel | 1.5 gal | 62 gal |
| Sunflower | C3 | 27 lb | 50 bu/a | Diesel | 1.5 gal | 77 gal |
| Canola | C3 | 50 lb | 42 bu/a | Diesel | 2.9 gal | 120 gal |
| Palm trees | C3 | | | Diesel | | 587 gal |
| Jatropha | C3 | | | Diesel | | 250 gal |

# Environmental Benefits

-Carbon Sequestration

-Reduced $NO_3^-$ contamination in surface and groundwater

- Reduced soil splash, surface runoff, rills and gully erosion

- Switchgrass ethanol emits 94% less GHG than gasoline (Schmer et al. 2008)

*thank you
for your
attention*