Is Rangeland Biofuel Production Ecologically Sustainable?

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Ecological Sustainability

- Recent statement released by the Ecological Society of America states that sustainable biofuel production must not negatively affect
  - Energy flow
  - Nutrient cycles
  - Ecosystem services including biodiversity, habitat use, clean air and clean water (quality & quantity)

Energy Analysis

- Most work in this area has involved modeling studies with little empirical work
- No empirical work done on native prairie vs planted monoculture or polyculture
- Largest single empirical study is Schmer et al., 2008

Relying solely on models can lead to erroneous conclusions

Kutscher 2007

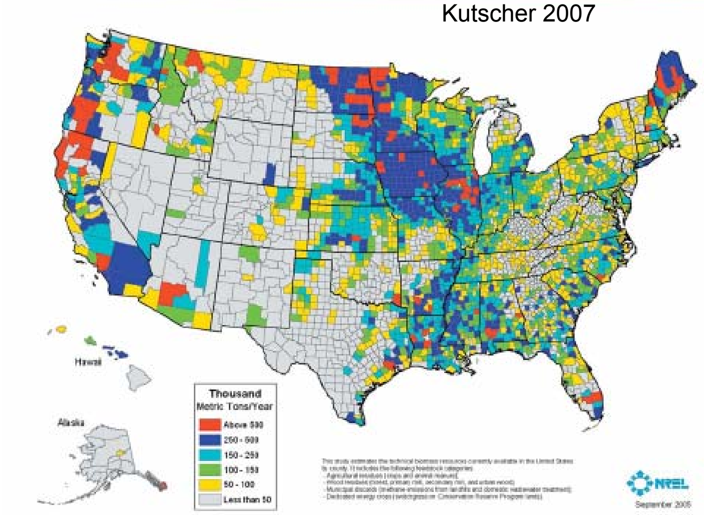
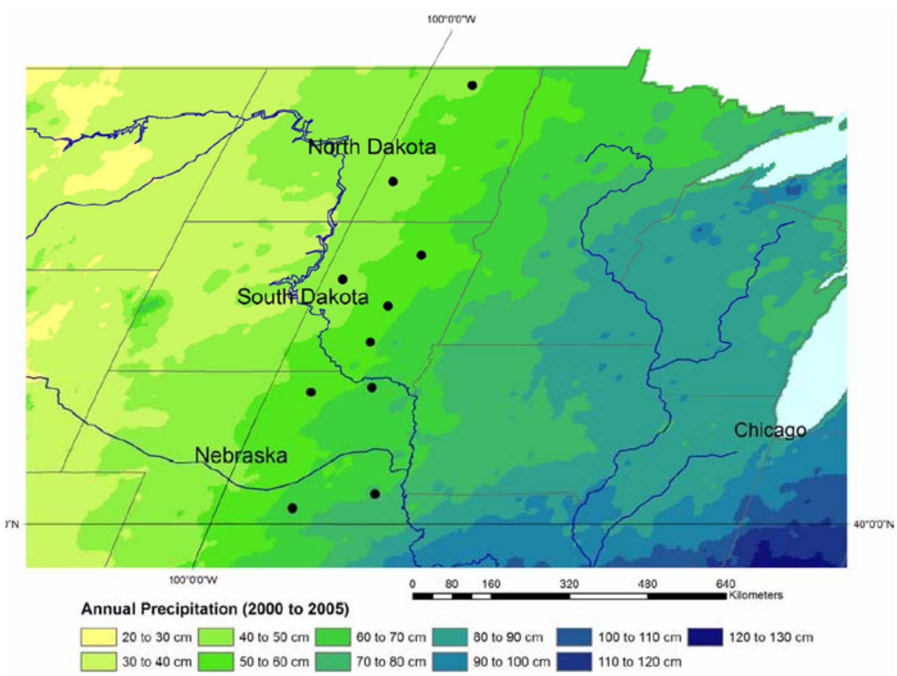


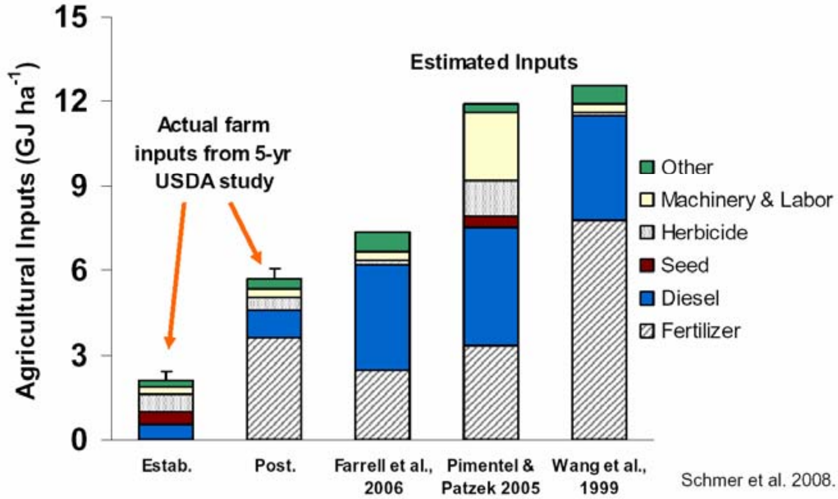
Figure 1. Distribution of biomass resources available by county in the United States [19].

Farm-scale Switchgrass Study

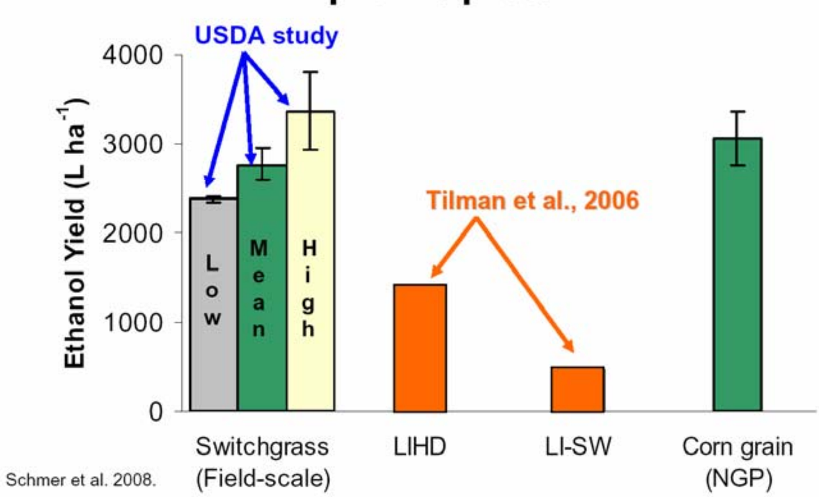
- A farm-scale trial was initiated in 2000 to determine economics and energy analysis for producing switchgrass.
- 10 locations in NE, SD, & ND ranging from 8 to 23 acres.
- Managed and harvested with commercial farm equipment.
- Fields were harvested in early August or after a killing frost.
- Producers recorded all inputs.
- Costs include labor & land.



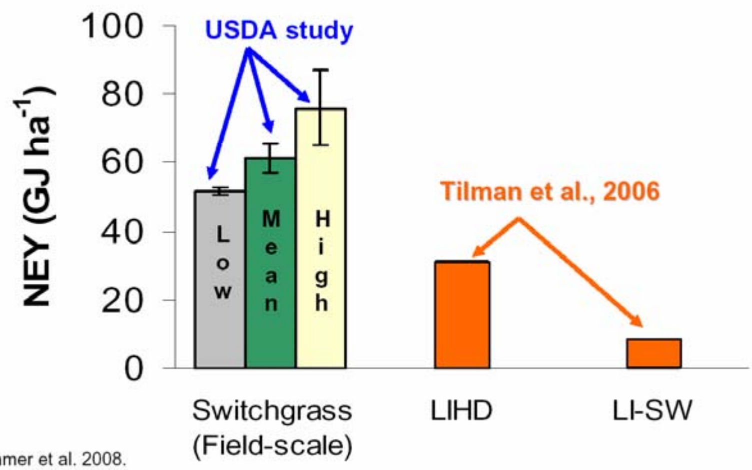
Models Over-estimate Switchgrass Energy Inputs



Managed switchgrass fields produced 2-times more ethanol yield than man-made prairie plots

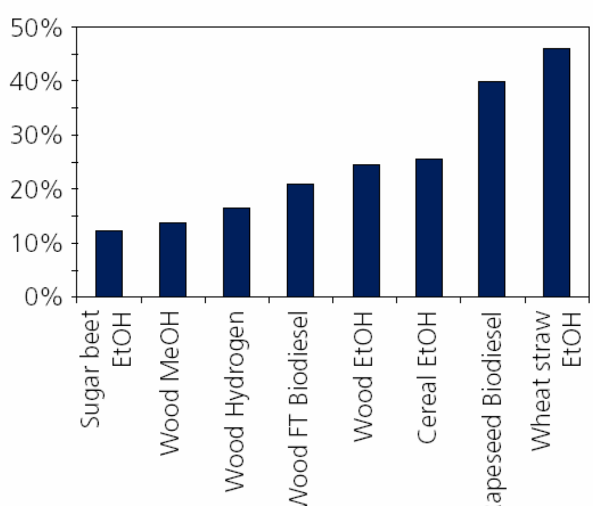


Net energy yield from managed switchgrass fields was 2-times greater than man-made prairie plots



Schmer et al. 2008.

Figure 5.2 Percentage of UK arable land area needed to supply 5% of energy demand by transport in 2001, on an energy content basis.



British Academy of Sciences, 2007

Land required to produce feedstock for a 50 million gallon (190 ML) cellulosic ethanol plant in a 25 mile (40 km) radius

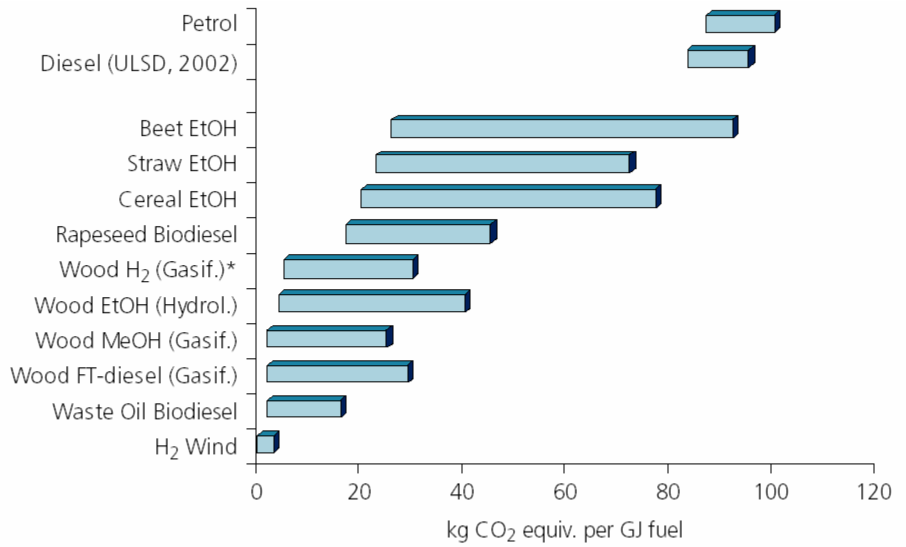
Feedstock Yield tons/acre (Mg/ha)	Acres	% of Land Area
1 (2.2)	625,000	50
2 (4.5)	312,500	25
3 (6.7)	208,333	17
4 (9.0)	156,250	12
5 (11.2)	125,000	10
7.5 (16.8)	83,333	6.6
10 (22.4)	62,500	5

A 50 million gallon plant requires 625,000 tons of feedstock/year at 80 gallons/ton.

Nutrient Cycles

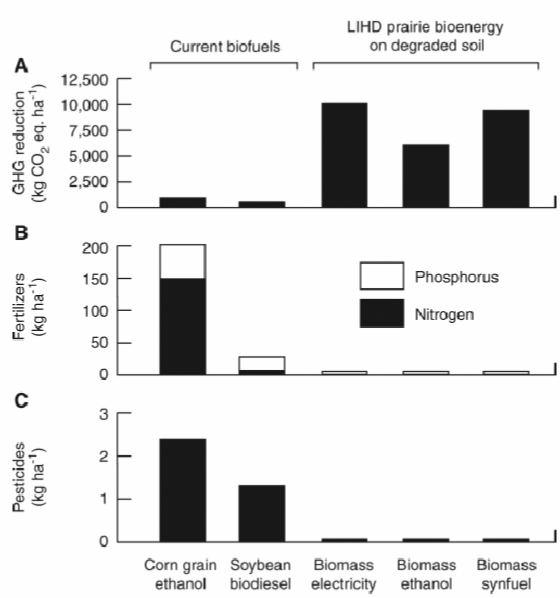
- Two key cycles to consider are carbon and nitrogen cycles
- Whether or not monoculture rangeland biofuels (primarily switchgrass) are carbon neutral or not also not well-studied empirically. Most studies are modeling efforts
- Nitrogen cycle effects strongly influenced by amount and type of fertilizer used
- Almost no work done on hydrologic effects of feedstock production

Greenhouse Gas Production

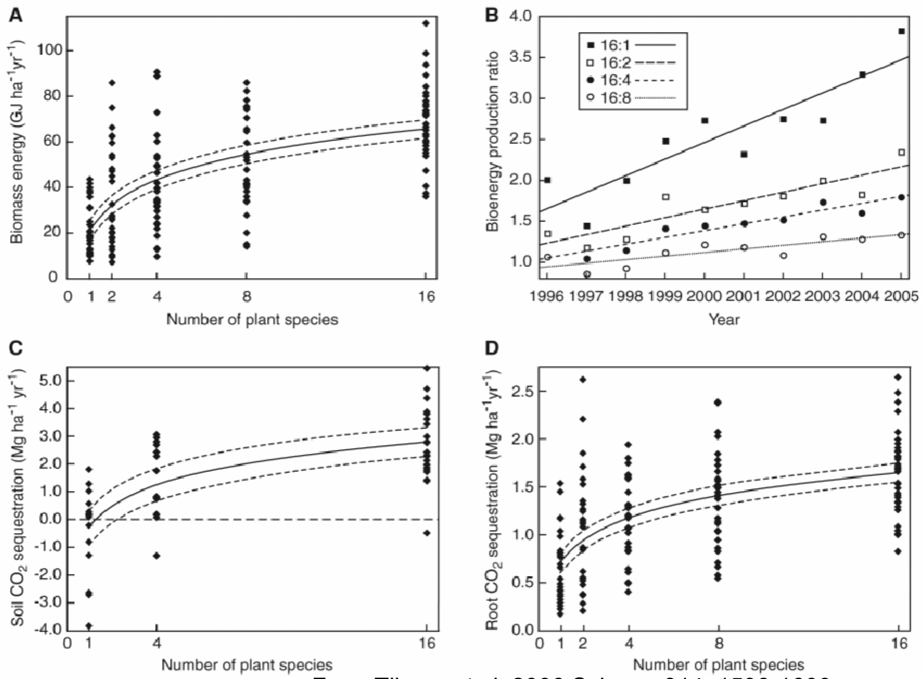


British Academy of Sciences, 2007

Fig. 3. Environmental effects of bioenergy sources. (**A**) GHG reduction for complete life cycles from biofuel production through combustion, representing reduction relative to emissions from combustion of fossil fuels for which a biofuel substitutes. (**B**) Fertilizer and (**C**) pesticide application rates are U.S. averages for corn and soybeans (*29*). For LIHD biomass, application rates are based on analyses of table S2 (*10*).



From Tilman et al. 2006. *Science* 314: 1598-1600



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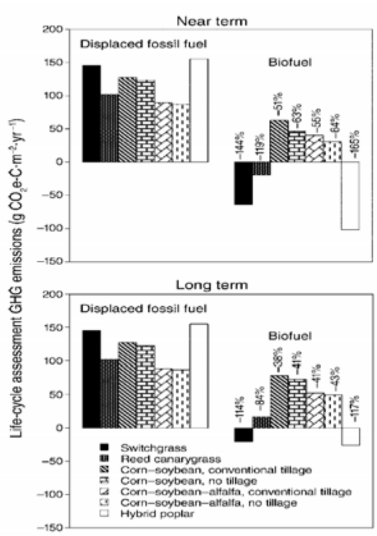
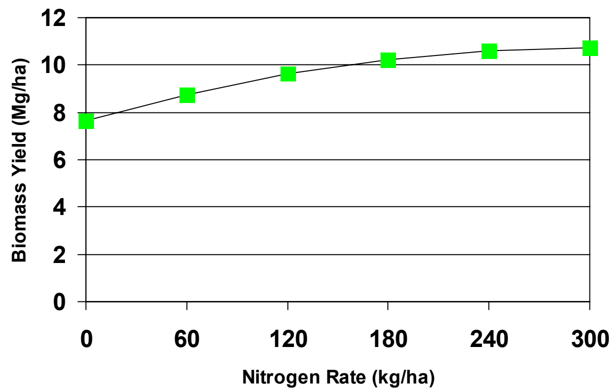


FIG. 5. Comparison of the life-cycle greenhouse-gas (GHG) emissions associated with the quantity of gasoline and diesel displaced by ethanol and biodiesel produced from the cropping systems (displaced fossil-fuel C [C_{dff}]) with the quantity of GHG emissions associated with the life cycle of biofuel (ethanol and biodiesel) production (feedstock-conversion C [C_{FC}] + C_{CH_4} + direct C_{N_2O} + indirect C_{N_2O} + chemical-inputs C [C_{CI}] + agricultural-machinery C [C_{AgMa}]); near-term includes change in system C [ΔC_{sys}]). The percentage reduction in GHG emissions was calculated as the difference in the biofuel emissions and fossil-fuel emissions displaced from biofuel produced by a given crop expressed as a percentage of the displaced fossil-fuel emissions.

Life-cycle Greenhouse gas emissions from different monoculture systems

Adler et al. 2007

Switchgrass N Response Curve



Switchgrass N response curve developed from first harvest 'Cave-in-Rock' switchgrass grown in 1994 and 1995 at Mead, NE and Ames, IA (Vogel et al., 2002. Agron. J. 94:413-420).

Fertilizer trade off: Yield v. Ash

TABLE 6

Response of concentrations of N, P and K in total dry matter to additions of these nutrients as fertilizer

Nitrogen[1]			Potassium[2]			Phosphorus[3]		
Annual fertilizer addition (kg N/ha)	Annual DM production (Mg/ha)	% N in total DM	Annual fertilizer addition (kg K/ha)	Annual DM production (Mg/ha)	% K in total DM	Annual fertilizer addition (kg P/ha)	Annual DM production (Mg/ha)	% P in total DM
0	27.9	0.61	0	14.4	0.52	0	24.2	0.12
500	44.5	0.90	224	32.7	0.70	73	35.1	0.14
1000	41.8	1.23	448	38.0	1.05	147	37.8	0.17
2000	44.5	1.43	896	42.6	1.70			
			1792	48.8	2.50			

[1]Data from Ferraris, 1980.
[2]Data from Vicente-Chandler *et al.*, 1962.
[3]Data from Figarella *et al.*, 1964.

Samson et al., 2005

"Nitrogen rates of 56 and 112 kg ha^{-1} tended to boost yield without promoting large increases in grass and broadleaf weed species." (Mulkey et al. 2008) – Also found that these rates produced least ash for plants harvested after killing frost

Fertilizer trade off: Yield v. N_2O

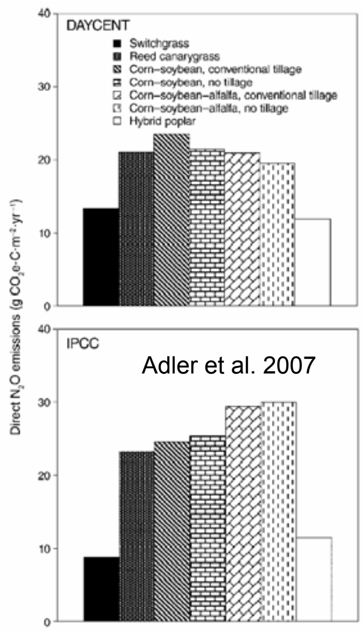


FIG. 3. DAYCENT (Del Grosso et al. 2001*a*) and Intergovernmental Panel on Climate Change (IPCC 2000) calculated direct N_2O emissions from bioenergy cropping systems.

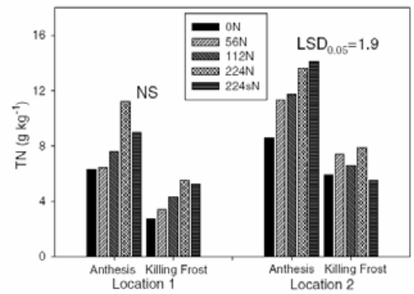


Fig. 1. Nitrogen rate × harvest timing interaction effect on total N (TN) concentrations of two warm-season grass mixtures in South Dakota. Values are averaged across harvest year. Fisher's protected LSD (0.05) values, to compare across N rate and harvest time, are shown above the respective bars for each Location. NS = not significant at 0.05 level of probability.

Mulkey et al. 2008

Effects on Nitrogen Cycle: NO_x

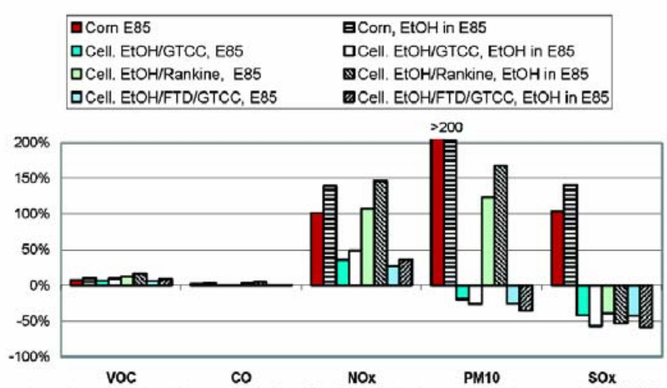


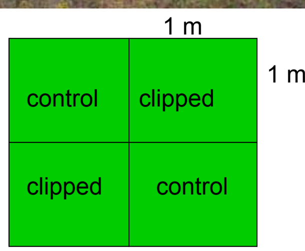
Figure 6. Percent change in total criteria pollutant emissions from Bio-EtOH production options relative to gasoline in ICE SI vehicles per mile driven (negative value means reduction).

Wu et al. 2006

Ecosystem Services

- Biodiversity
  - Increases in resistance and resilience of systems
  - Protection of populations and species
- Clean Air, Water
  - Reductions in erosion
- Increases in trophic diversity
  - Habitat usage

Grassland response to global warming



- Work done at University of Oklahoma by Dr. Yiqi Luo and his colleagues has shown that grassland ecosystems are actually very tolerant of global warming

Switchgrass response to global change

- Unpublished data from Wallace show that switchgrass went extinct in low productivity site after exposure to drought and warming.
- By looking at production of all species present (over 60) we can see that system as a whole was less effected by drought and warming than were individual species.

Switchgrass Physiology

Knapp 1985

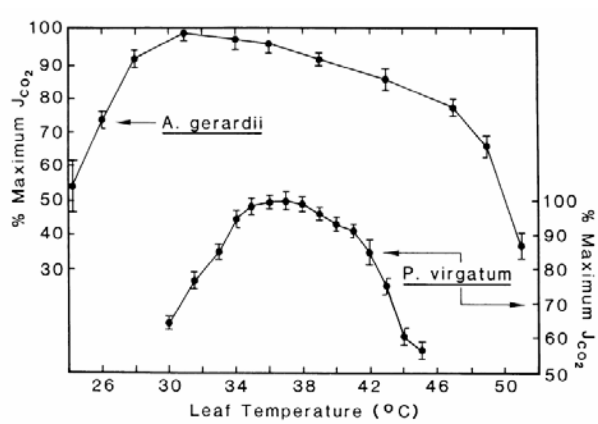
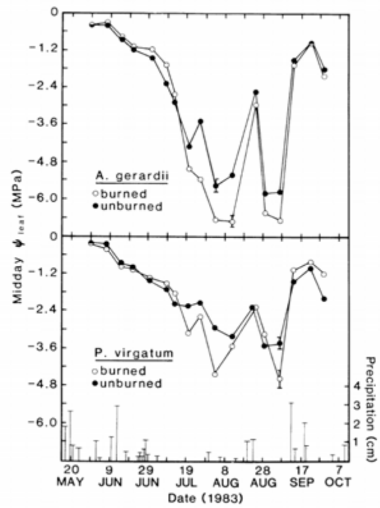


FIG. 2. Relationship between leaf temperature and CO_2 uptake (J_{CO_2}) in *Andropogon gerardii* and *Panicum virgatum* in June 1983. Data for burned and unburned sites were pooled and vertical bars represent ±1 standard error of the mean and n = 6–8 leaves from separate tillers. The vapor pressure deficit of air entering the chamber was 1.5–2.0 kPa and was not held constant at higher temperatures.

Switchgrass Physiology



Knapp 1985

FIG. 3. Seasonal course of midday leaf water potential (ψ_{leaf}) in *Andropogon gerardii* and *Panicum virgatum* in burned and unburned plots during 1983. Vertical bars show the maximum standard error of the mean. Also, along the bottom axis, the seasonal pattern of daily precipitation at the study site.

Studies of mixtures

- Mulkey et al. 2008 found that a mixture of big bluestem and switchgrass outperformed switchgrass alone. Found that indiangrass was less competitive and disappeared from the mixture in two SD sites.

Habitat Use

Species Diversity

- Insects
- Wasp parasitoids
- Soil macrofauna
- Pollinators

Structural Diversity

- Birds
- Small mammals
- Soil macrofauna

Erosion and nutrient loss

- Growth of perennial rather than annual feedstocks dramatically cuts erosion losses
- Growth of diverse feedstocks and their effects on erosion is not well studied in comparison with monoculture plots

Recommendations

- Head to head comparisons of monoculture v polyculture feedstock production systems are extremely rare – particularly looking at native grasslands or managed hay meadows
  – Compare rates of production, inputs required, net economic gain, net ecosystem stability, nutrient and energy flows and ecosystem services across a number of years and in multiple locations

Recommendations

- Take data from this large synoptic sampling design and input into predictive, mechanistic models to see
  – How production systems fare under different disturbances
  – How production systems fare under climate change
  – How production systems fare under different economic climates, as well
- Look for ecological and economic set points and see what relationships one has to the other