Task 1. Estimating Biomass Feedstock Production Potential

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Objectives

- Estimate future biomass production potential based on an aggressive yield improvement program
  - Economic Issues
    - Feedstock cost/Mg for biorefinery economics
    - Producer profit and level of participation
  - Resource Issues
    - Land area for feedstock supply per plant
    - Carbon savings/sequestration
    - Fossil energy displacement/savings
    - Soil and ground water quality
    - Wildlife habitat

Research Strategy

- Evaluate 7 decades of breeding gains in corn to establish yield gain potential

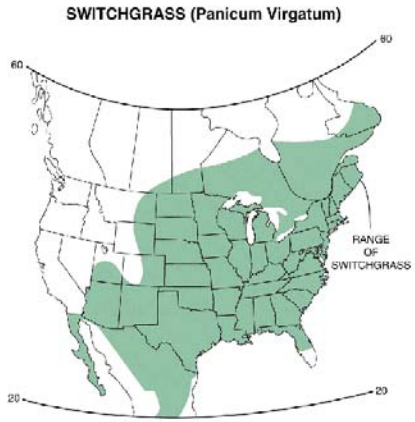
- Project switchgrass yield gain trajectory
  - 10 y of yield baseline evaluation in the field
  - Comparative genetics and physiology
  - 10 y of switchgrass breeding research

Some Advantages of Dedicated Energy Crops

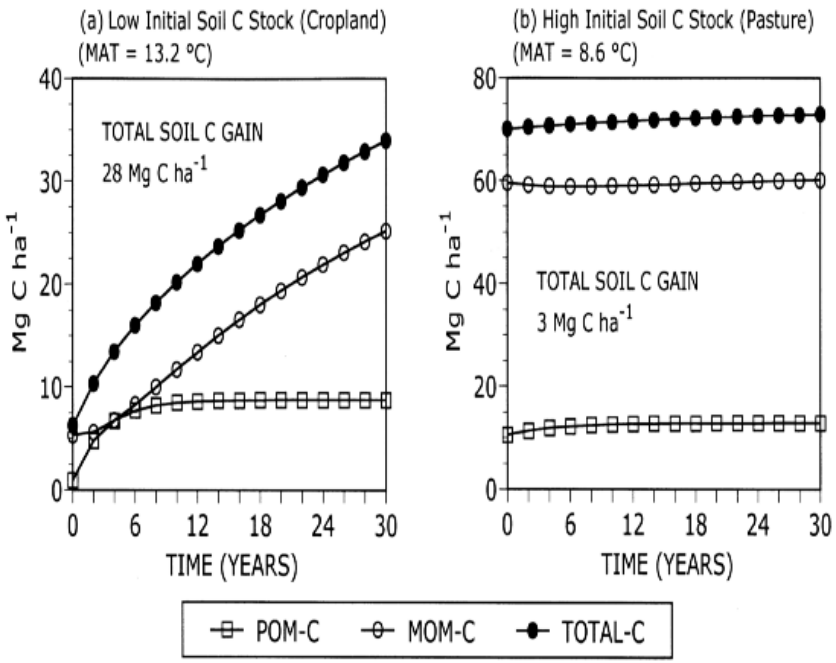
- Feedstock quality/consistency/dependability
- Regional diversity of sites and participants
- Significant benefits to the agricultural industry
- Strong societal benefits
  - Net fossil energy displacement
  - Greenhouse gas reduction rate
  - Farm economy/government subsidy gains

Attributes of Switchgrass

- Native perennial grass - Farm-compatible - High yield and energy efficiency- Ecological and economic gains for agriculture



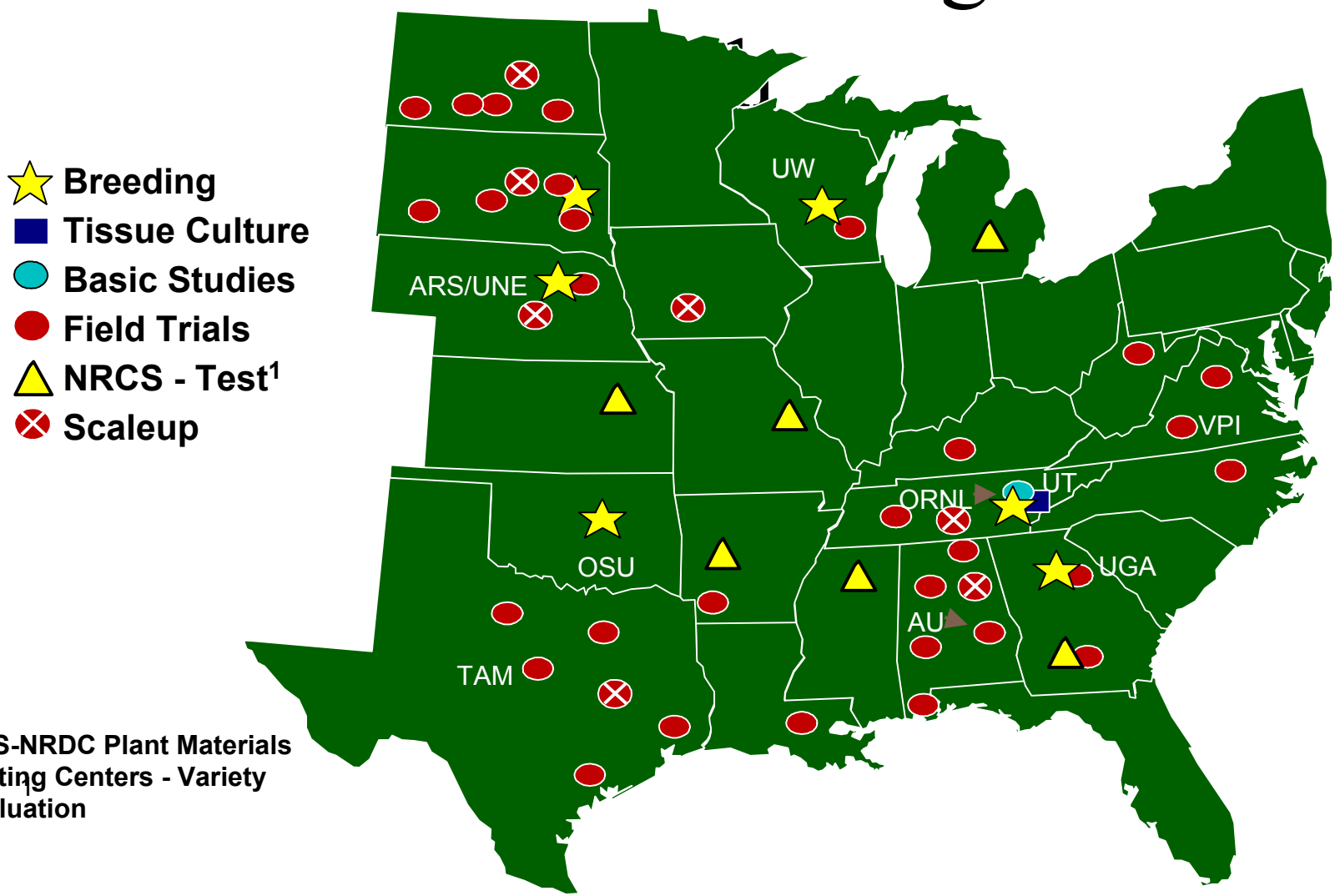
Switchgrass can significantly improve soil quality, stability, while storing soil carbon



Analytical Resources

- **Field Research** - >10 Years of switchgrass productivity, breeding, and ecological research and development
- **ALMANAC** - A physiologically-based crop production model parameterized for switchgrass
- **POLYSYS** - A regional econometric model to project feedstock supply, economics, and impacts on conventional crop production

ORNL - BFDP Switchgrass



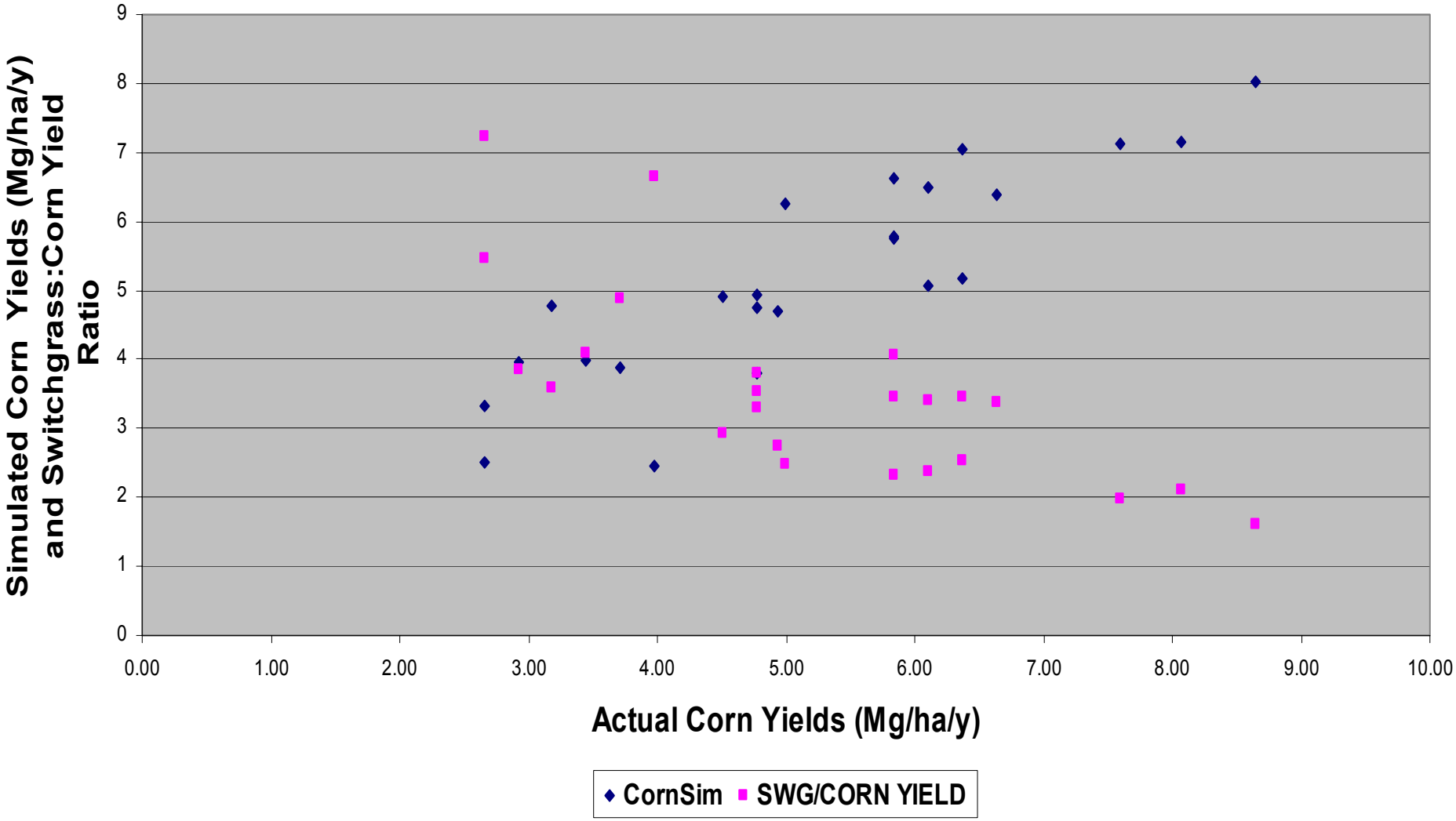
Modeling Crop Production Levels and Impacts

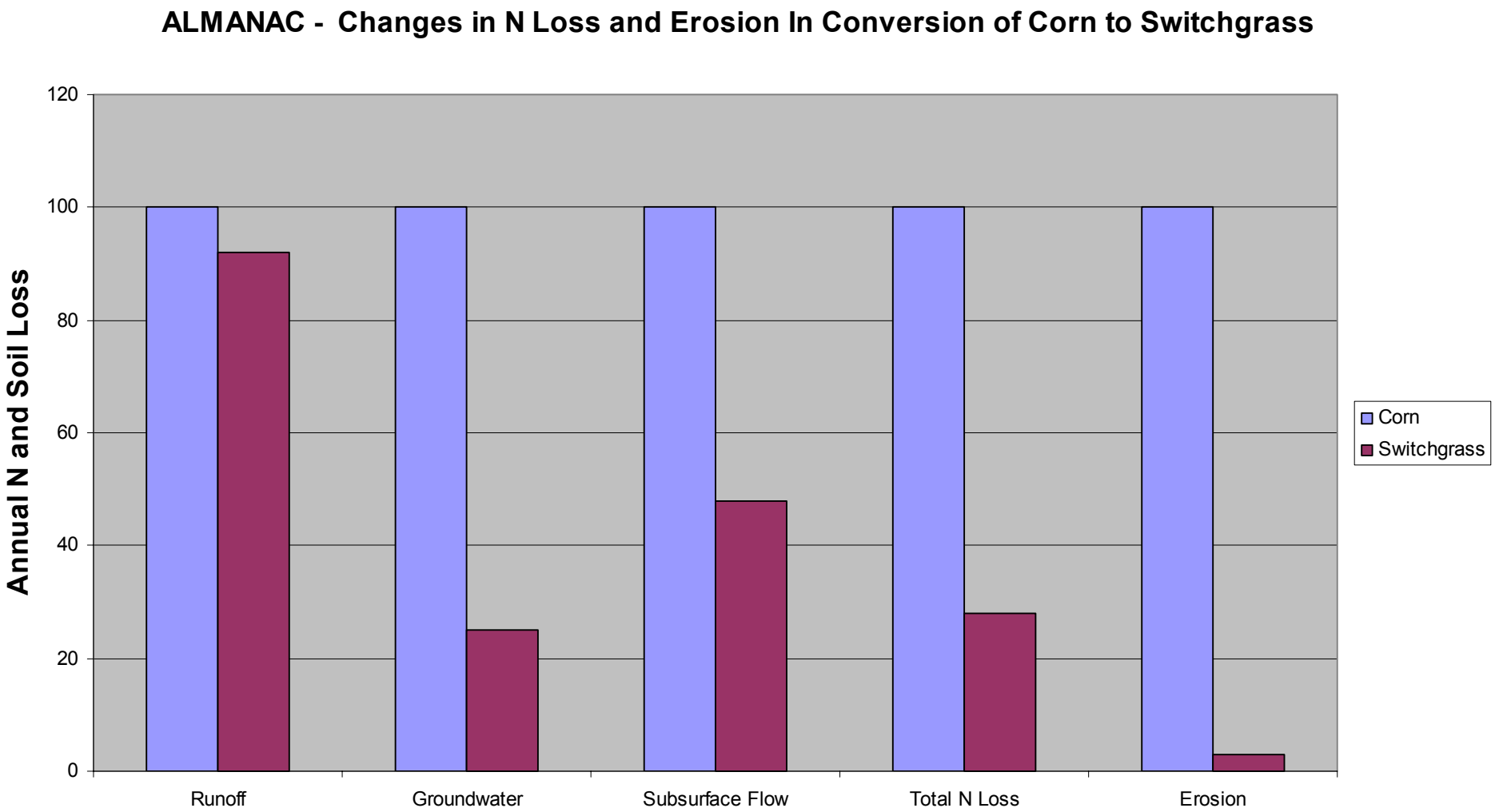
- ALMANAC
  - Crop production and resource use
  - Canopy light interception
  - Soil depth, water, and nutrient supply
  - Site specific radiation,rainfall,and temperature
- POLYSYS
  - Econometric model for agricultural policy
  - Competitive profit/land among crops
  - 305 regional supply districts
  - Includes production levels costs and govt. subsidy impacts.

ALMANAC Yield Comparisons with Field Data

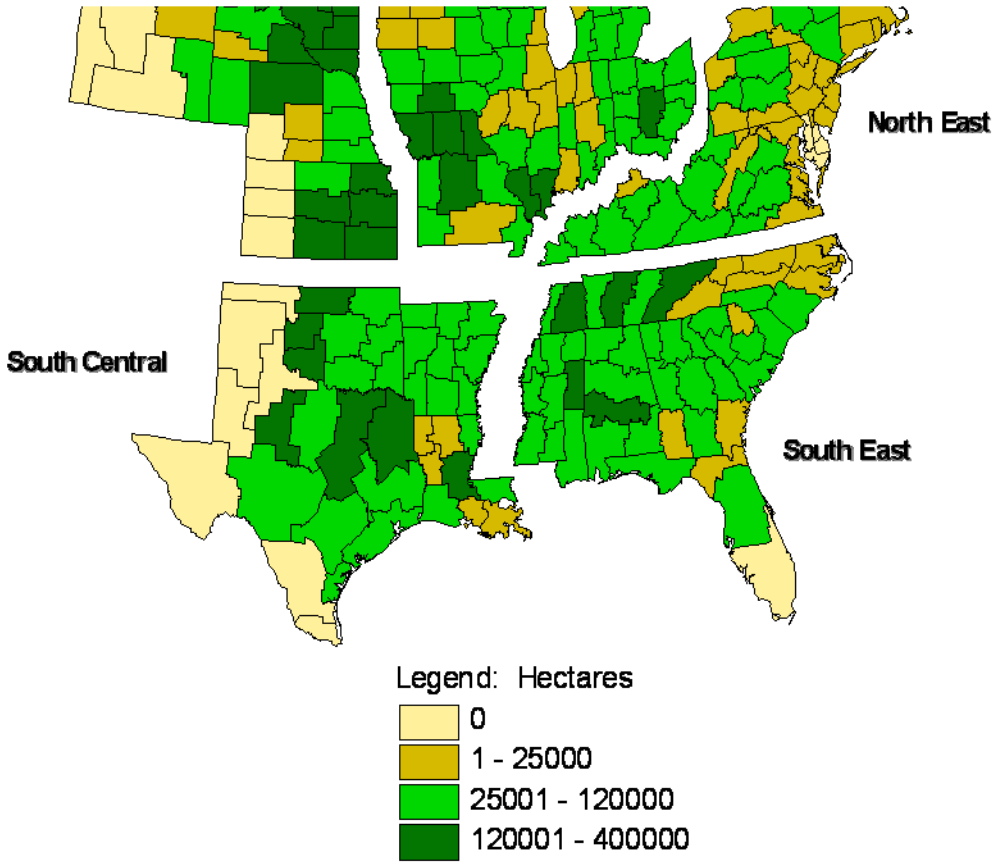
SITE	Conditions	Field Yield (Mg/ha)	ALMANAC Yield (Mg/ha)
Blacksburg,VA	6 yr avg.	12.3	12.0
Meade,NE	2 yr avg.	13.4	13.8
Beeville,TX	1993 2 cut	11.8	11.7
	1994 2 cut	16.7	15.7
	1993 1 cut	13.6	13.6
	1994 2 cut	18.0	10.2
Tallasee,AL	9 yr avg. 2 cut	10.5	10.6
	9 yr avg. 1 cut	10.1	10.2

Simulated Annual Yield of Corn and Switchgrass Using ALMANAC
6 States, 27 Soil Types, 13 Years




ALMANAC - Changes in N Loss and Erosion In Conversion of Corn to Switchgrass
Annual N and Soil Loss
120
100
80
60
40
20
0
Runoff
Groundwater
Subsurface Flow
Total N Loss
Erosion
Corn
Switchgrass

POLYSYS Projections - Potential switchgrass production density within the U.S. by agricultural supply cells. Distribution and density based on conversion to switchgrass production at a farmgate price of $44 Mg^{-1} ($55 Mg^{-1} delivered).



Projected gains to agriculture from POLYSYS simulations of switchgrass farmgate prices

Farmgate Price ($/Mg)	30.3	44.0	52.4
M of hectares Planted to switchgrass	3.1	16.8	21.3
Increased farm revenue ($ M)	1311	5925	7745
Reduced govt. Subsidies ($ M)	1253	4035	5770
Sum of Benefits ($ B)	2.5	9.9	13.4

What have we learned from 70 years of corn breeding?

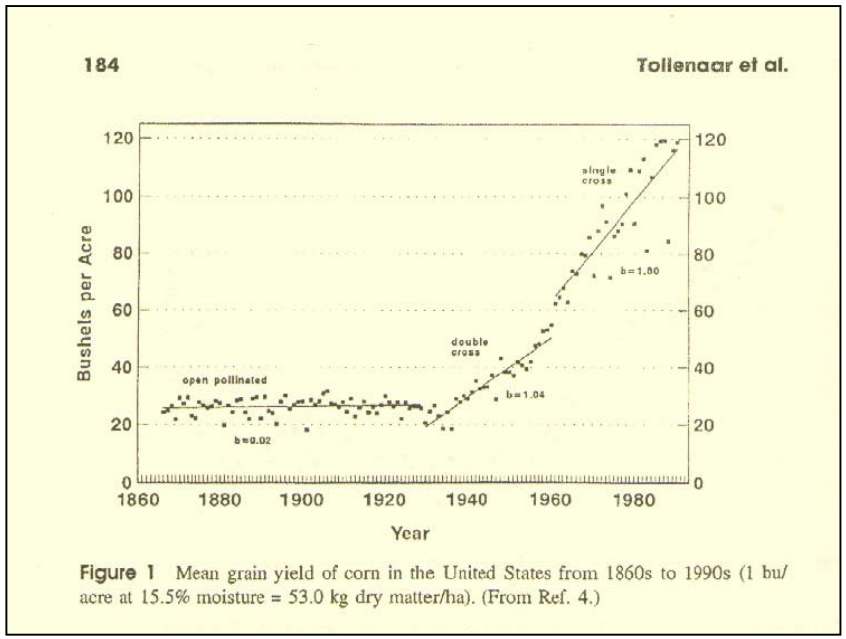
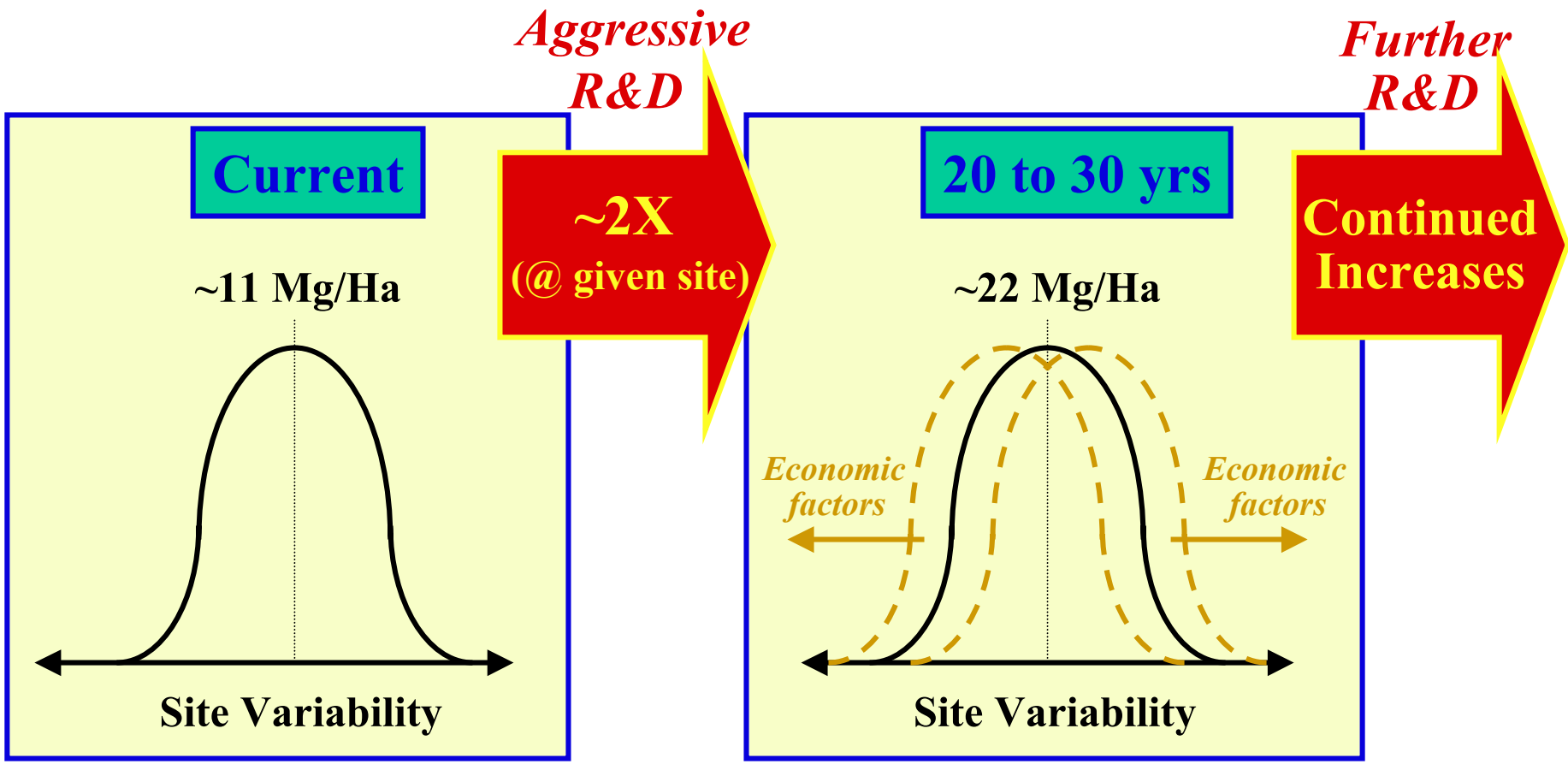


Figure 1 Mean grain yield of corn in the United States from 1860s to 1990s (1 bu/acre at 15.5% moisture = 53.0 kg dry matter/ha). (From Ref. 4.)

- Breeding gains have been approximately linear over time. 5-6X gain in 60 y
- Relative gains have decreased over time
- Improved management contributed ca. 45%
- Physiological efficiency has improved with yield

Comparative Traits of Corn and Switchgrass

- **Corn**
  - C4 annual grass
  - Yield potential (grain)
    - 25 Mg/ha - theoretical
    - 15-20 Mg/ha - actual field
    - 5-6 Mg/ha – US commercial
  - Yield Gains
    - 3-6%/y 1930's
    - 1.3-1.8%/y 1990's
- **Switchgrass**
  - C4 perennial grass
  - Yield Potential (plant)
    - 47 Mg/ha(max plant), 51.6 Mg/ha (Model)
    - 16-22 Mg/ha actual field
    - Commercial ?
  - Yield Gains (recent)
    - 5-7 %/y Southeast
    - 1-2%/y Midwest


Aggressive R&D
Current
~11 Mg/Ha
Site Variability
~2X
(@ given site)
20 to 30 yrs
~22 Mg/Ha
Economic factors
Economic factors
Site Variability
Further R&D
Continued Increases

Implications for a 5000Mg/d Biorefinery of 22 Mg/ha vs 11 Mg/ha yield

- Feedstock supply area per facility decreases by 50%
- Maximum feedstock transport distance for 10% land area use decreases from 44mi to 31.2 mi
- With subsidy recycle, feedstock cost could decrease by more than $25 /Mg

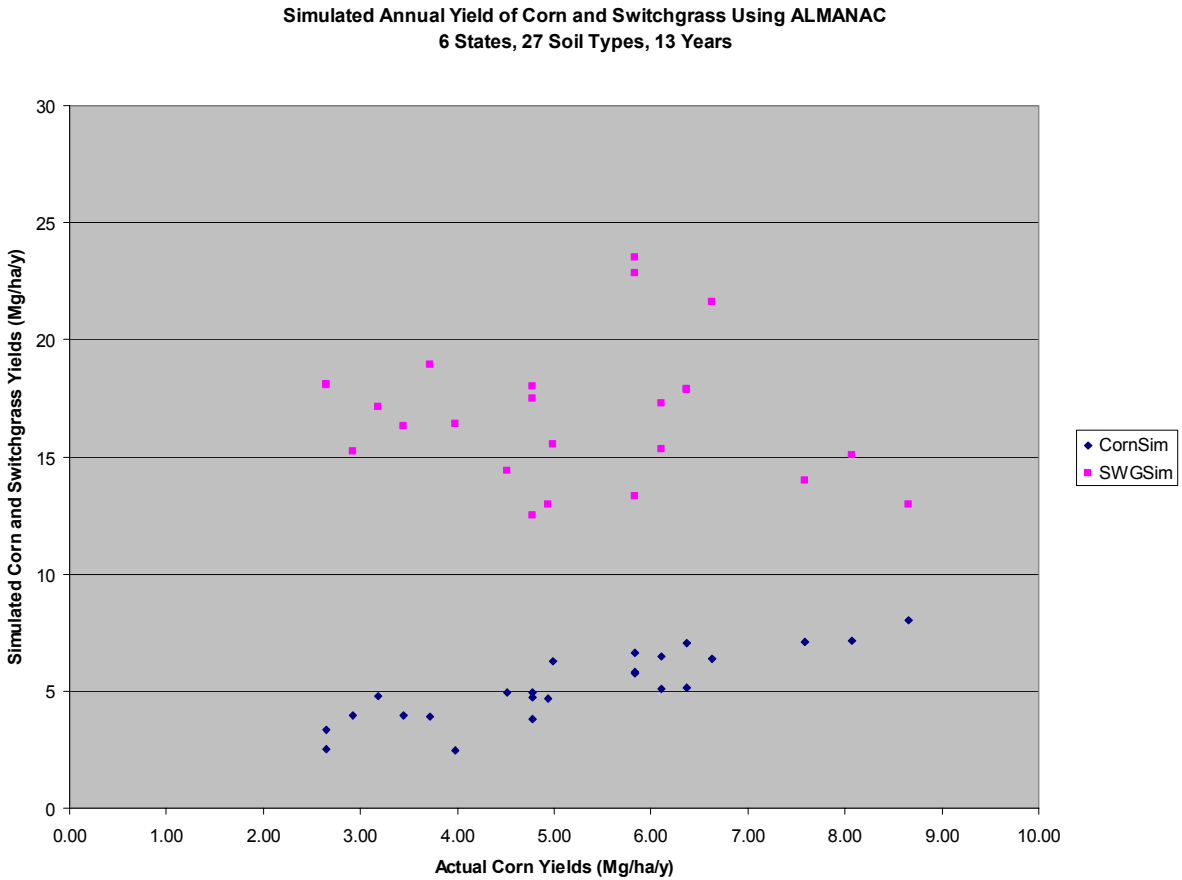
Additional Analytical Tasks

- Distribution of potential switchgrass production acreage at increased yields
- Sensitivity of price and profit to yield
- Sensitivity of yield/supply area to climate
- Changes in farm income and government price supports at higher yields/profitability
- Ecological issues - N and water use, C storage, wildlife edge increases

Estimating Future Switchgrass Yields
(Mg/ha)

51.6	ALMANAC theoretical
47	Maximum single plant –unwatered nursery
34	Best small plot –single year
15-22	*****Projected field-scale yield in 20 y *****
22	Typical best small plot each year for each of 3 regions in SE/SC
15	Current regional small plot average
9.4 11.1	POLYSYS average US at $44/Mg ($53.8 delivered) “ “ at $30.3/Mg ($37.3 delivered)
9-22	Current range - - - field-scale

Simulating Corn and Switchgrass Yields with ALMANAC



Economic Implications of Yield Improvement

-10 Y POLYSYS run - Feedstock price $40/Mg-

- Yield Gain - 11.1 > 14.8 Mg/ha + 34%
- Hectares planted - 9.3 > 12.3Mha + 21%
- Net gain in farm income - $1.2B
- Reduced Govt support needs - $2.23B
- Potential price credit - $24.7/Mg
- Total gain (income + govt support savings)

  Vs. conventional crops **$8.22B/Y**