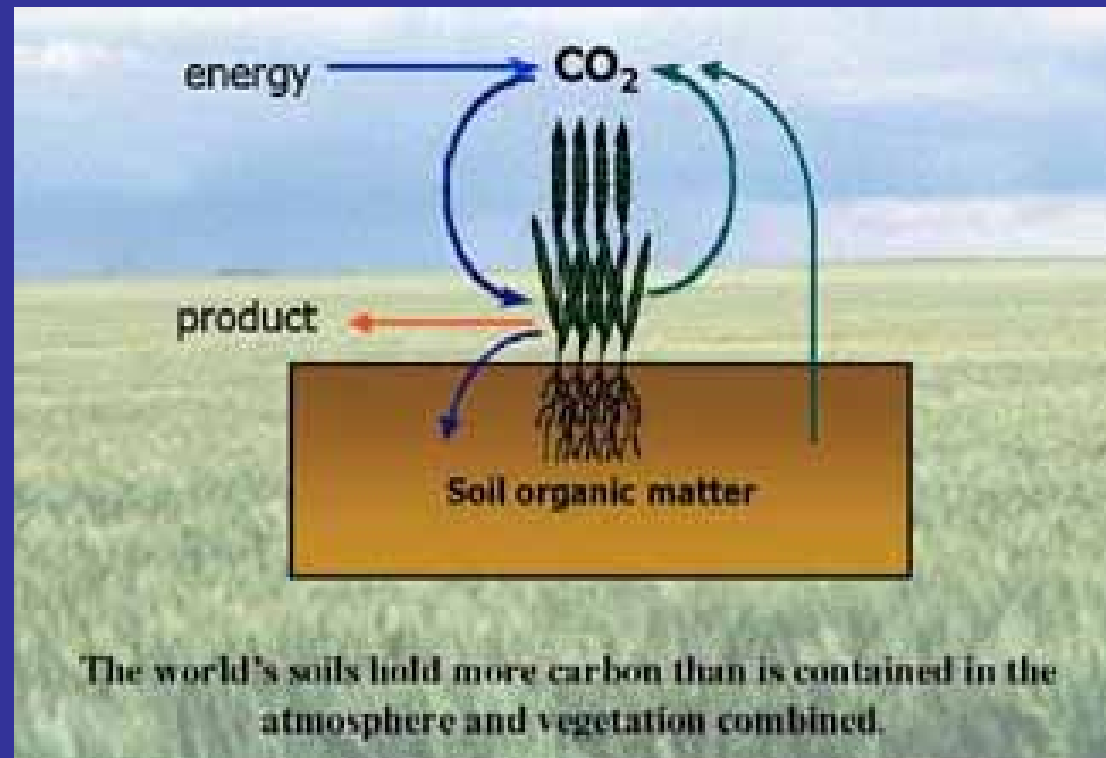


Economics of Soil Carbon Sequestration Through Biomass Crops



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Mitigating Climate Change: Role of Cropland

Soil carbon sequestration in agricultural soils

- Conservation tillage and perennial grasses

Renewable energy: dedicated energy crops (grasses)

- Co-firing biomass with coal in coal-based power plants

Policy and Market-Based Incentives

- Renewable Portfolio Standards
- Pilot carbon credit programs
 - Chicago Climate Exchange
 - Illinois Conservation Climate Initiative
 - Regional Greenhouse Gas Initiative
 - Power plants seeking low cost C offsets

Dedicated Energy Crops : Switchgrass and Miscanthus

- Adaptable to wide range of growing conditions
- High yielding perennials
- Low initial and annual input requirements
- Compatible with row crop production
 - require conventional equipment; winter harvests



Soil Carbon Sequestration Potential

Conservation Tillage:

Potential is small: 0.3-0.5 MT/ha/yr

Perennial grasses: 3 times higher

0.94-1.4 MT/ha/yr

Co-firing Grasses in Coal-Fired Power Plants

Low percentages (5-15%) of
co-milled biomass with coal

Carbon emissions per kwh
less than 10% of those with
coal



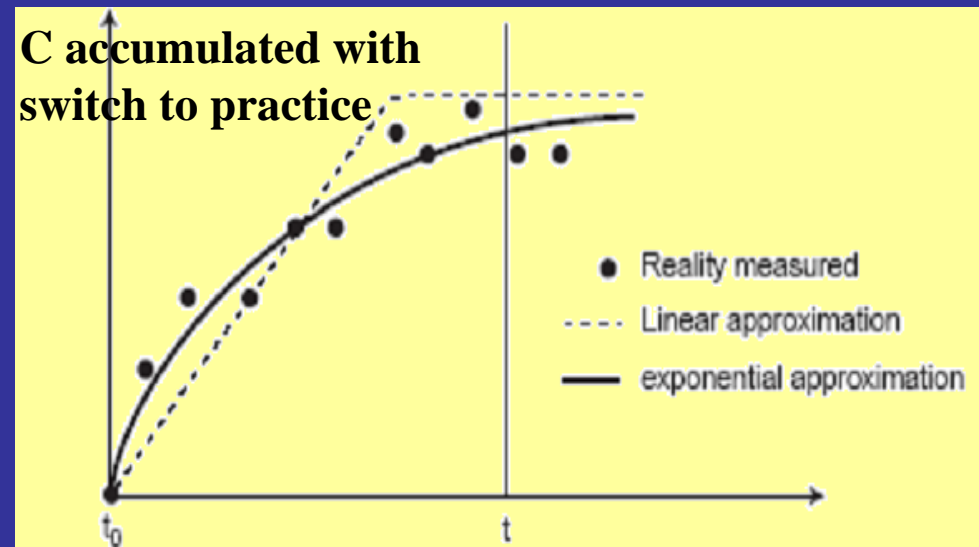
Spatial and Temporal Dimensions

Profitability of crops and tillage practices varies over space and time

- Productivity, costs and prices of row crops
- Productivity and costs of perennials – age specific
- Location of end uses (power plants) for bio-energy

Carbon sequestration rates

- Existing stocks of carbon that vary across space
- Non-linear C accumulation function
- Upper bound to sequestration capacity
- Reversible and asymmetric



Research Problem

Develop a spatial and dynamic land allocation model to examine (in the context of Illinois 2003-2017):

- Allocation of cropland to achieve carbon sequestration objectives cost-effectively
- Implications of alternative dynamic paths of sequestration on costs of sequestration and land allocation
- Trade-off between the payments for multiple environmental services: bioenergy and carbon sequestration
- Policy implications for inducing soil sequestration
 - Magnitude and design of subsidies
 - Temporary vs. permanent mitigation strategy

Related Literature: Carbon Sequestration

Carbon sequestration with forestation of agricultural land/forest management

Carbon sequestration in agricultural cropland

- conservation tillage in Iowa (Pautsch et al.)
- Continuous cropping or permanent grasses in Montana (Antle et al.)

- Incorporate spatial heterogeneity
- Exogenously specified carbon price
- Linear accumulation rates without explicit upper bounds
- Static framework
- Temporary sequestration

This Study

- Incorporates a non-linear carbon response function in the economic model to endogenously determine carbon prices
- Inter-temporal dependence of carbon sequestration rates and age-specific spatially differentiated land use decisions
 - Accounts for carbon sequestration and bio-energy contribution of perennial grasses.
 - Micro-data at the county level on carbon stock levels, crop productivity and power plant location

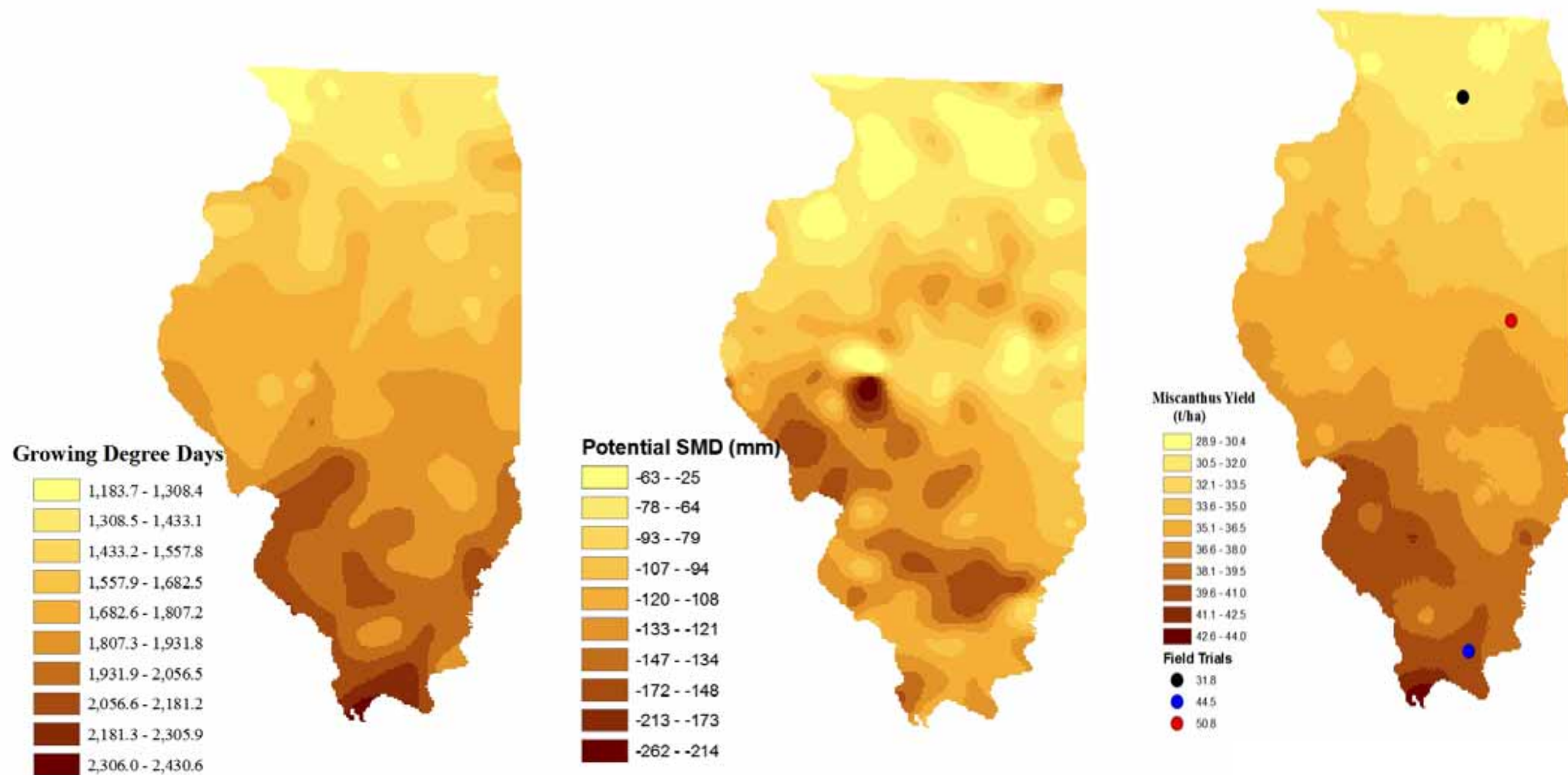
Economic Model

- Objective: Allocate land among 4 row crops, 3 perennials, 2 tillage choices, 18 rotations to maximize discounted value of profits over a 15 year period
- Dynamic: Returns and carbon emissions in the next period depend on decisions in this period and with age of perennials
- Spatial: Returns and carbon emissions/sequestration vary over 102 Illinois counties
- Constraints on
 - Capacity of power plants for co-firing bio-energy
 - Location of existing coal based power plants
 - Crop rotation possibilities
 - Cropland availability
 - Ease of conversion of land from one use to another
 - Sequestration rates with each land use

Data for Illinois

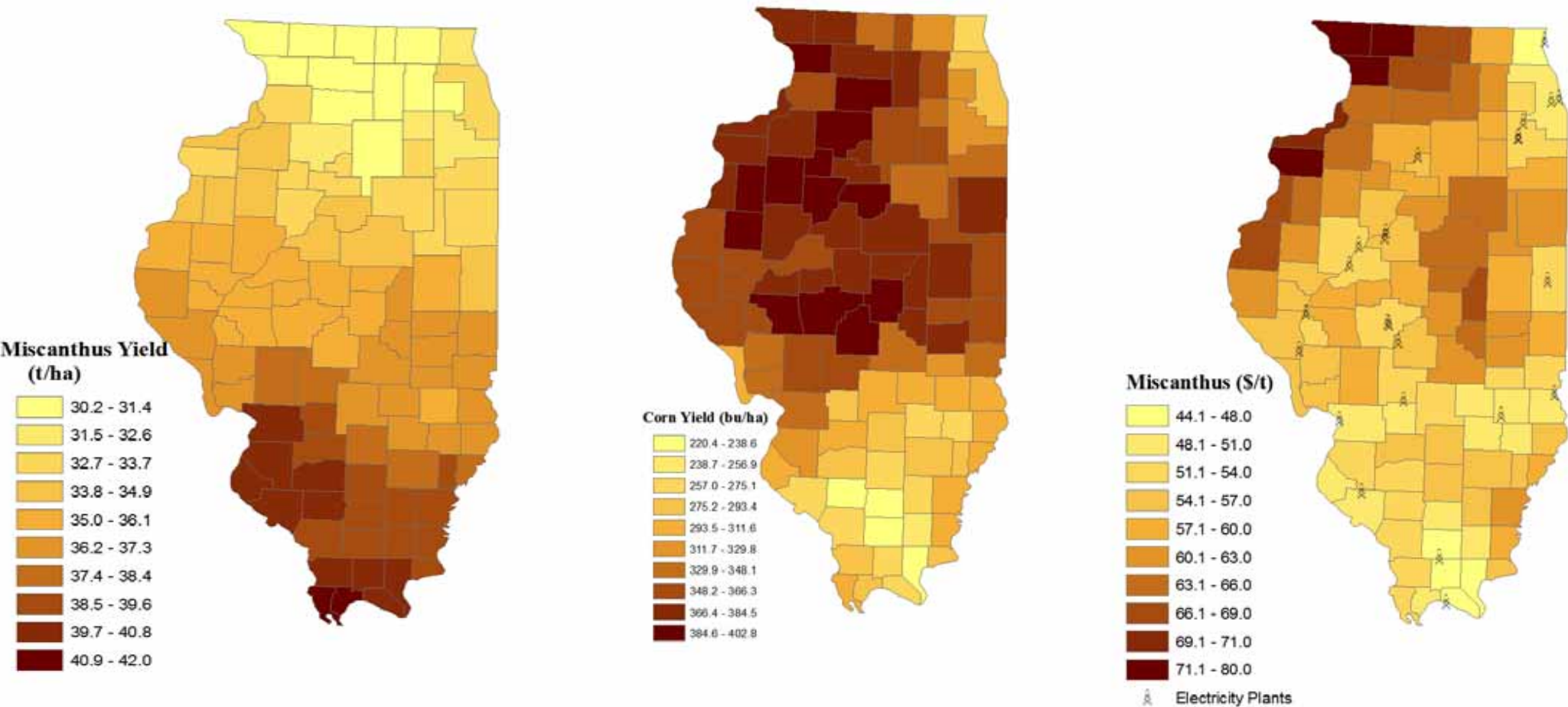
- Yields
 - Simulated yield of Miscanthus and Switchgrass
 - Historical climate, soil moisture, solar radiation
 - Historical average yields of conventional crops
- Costs of production by county, tillage and rotation
- Revenues for row crops based on loan rates
- Revenues for energy crops
 - Location of power plants; heat content; cost of coal energy
- Carbon stocks by county
- Carbon accumulation functions
 - Negative exponential function
 - 70% of potential saturated in 10 years
 - Linear function
 - 100% of potential saturated in 20 years

Growing Conditions for Miscanthus in Illinois

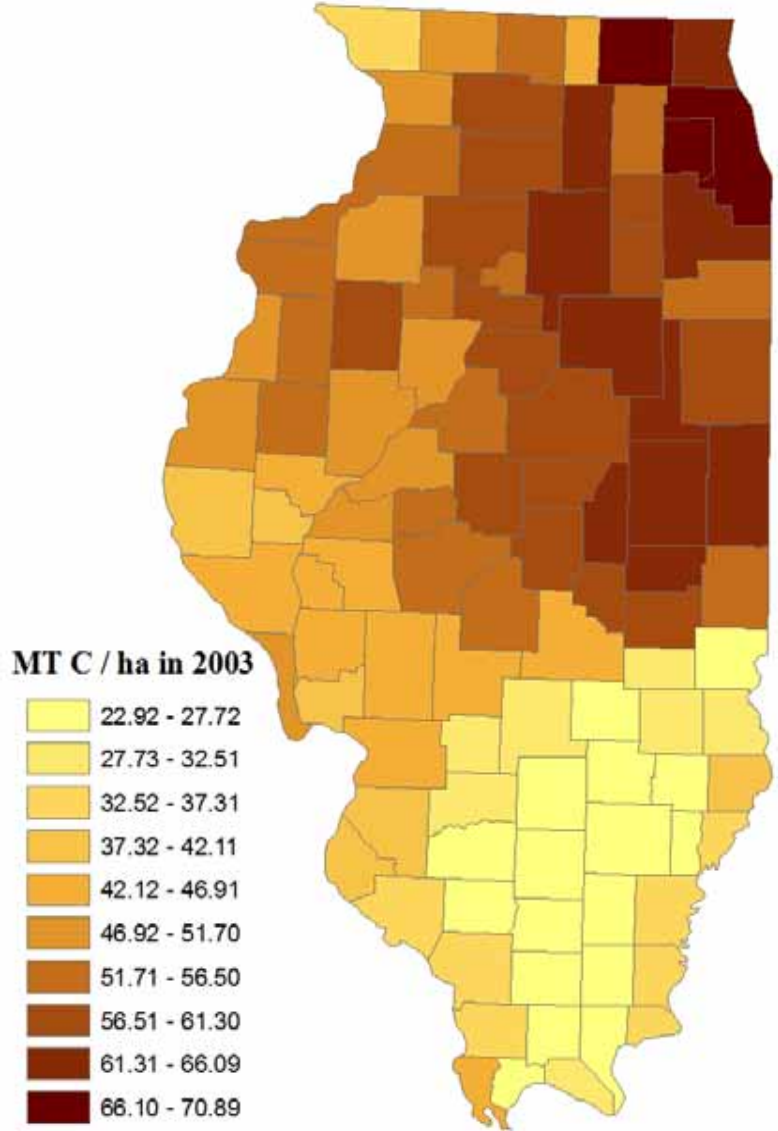


- Yield of Miscanthus simulated using 30 year climate data on solar radiation, temperature, frost dates, precipitation, soil evaporation and water holding capacity at 2 sq km level
- Temperature most important factor in leaf expansion with optimal water and nutrients

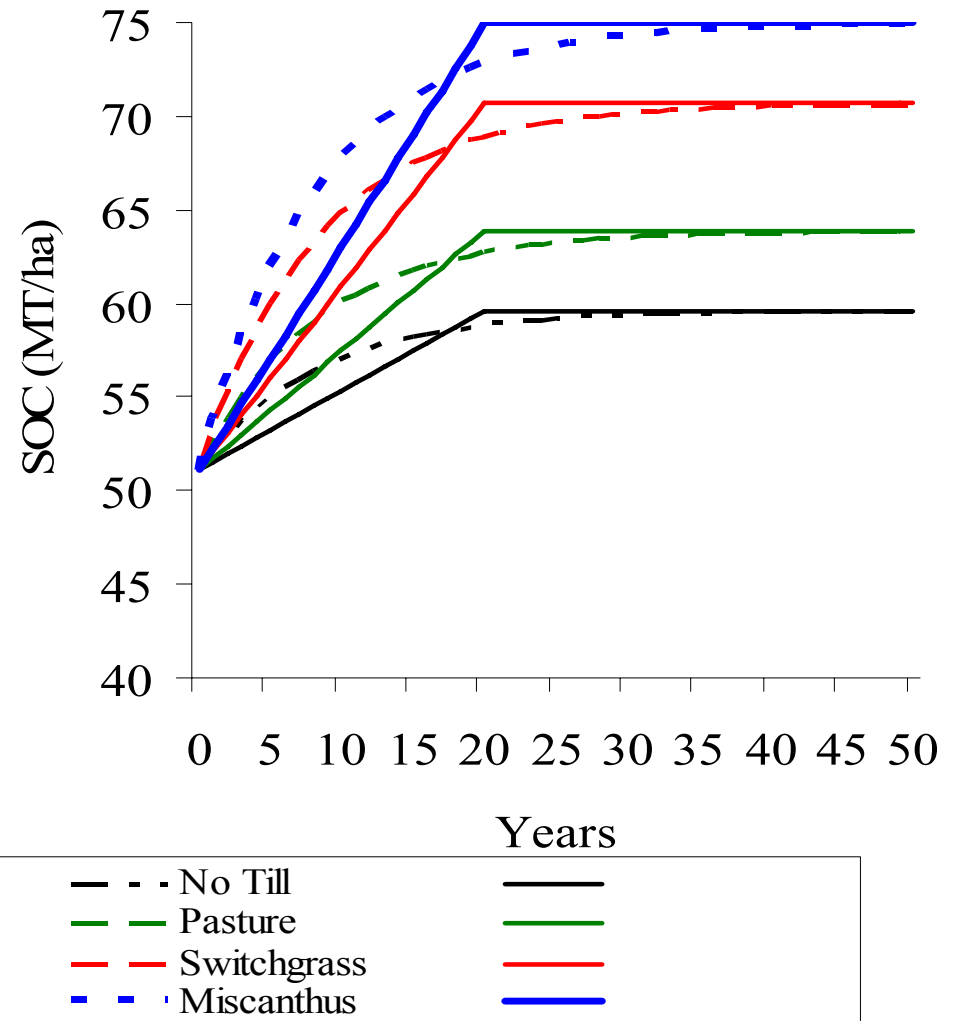
Yield/Hectare and Costs of Production



Baseline Stock of Soil Carbon



Accumulation Soil Carbon Response Functions: Linear Versus Negative Exponential



Bio-Energy Production with No Carbon Constraint

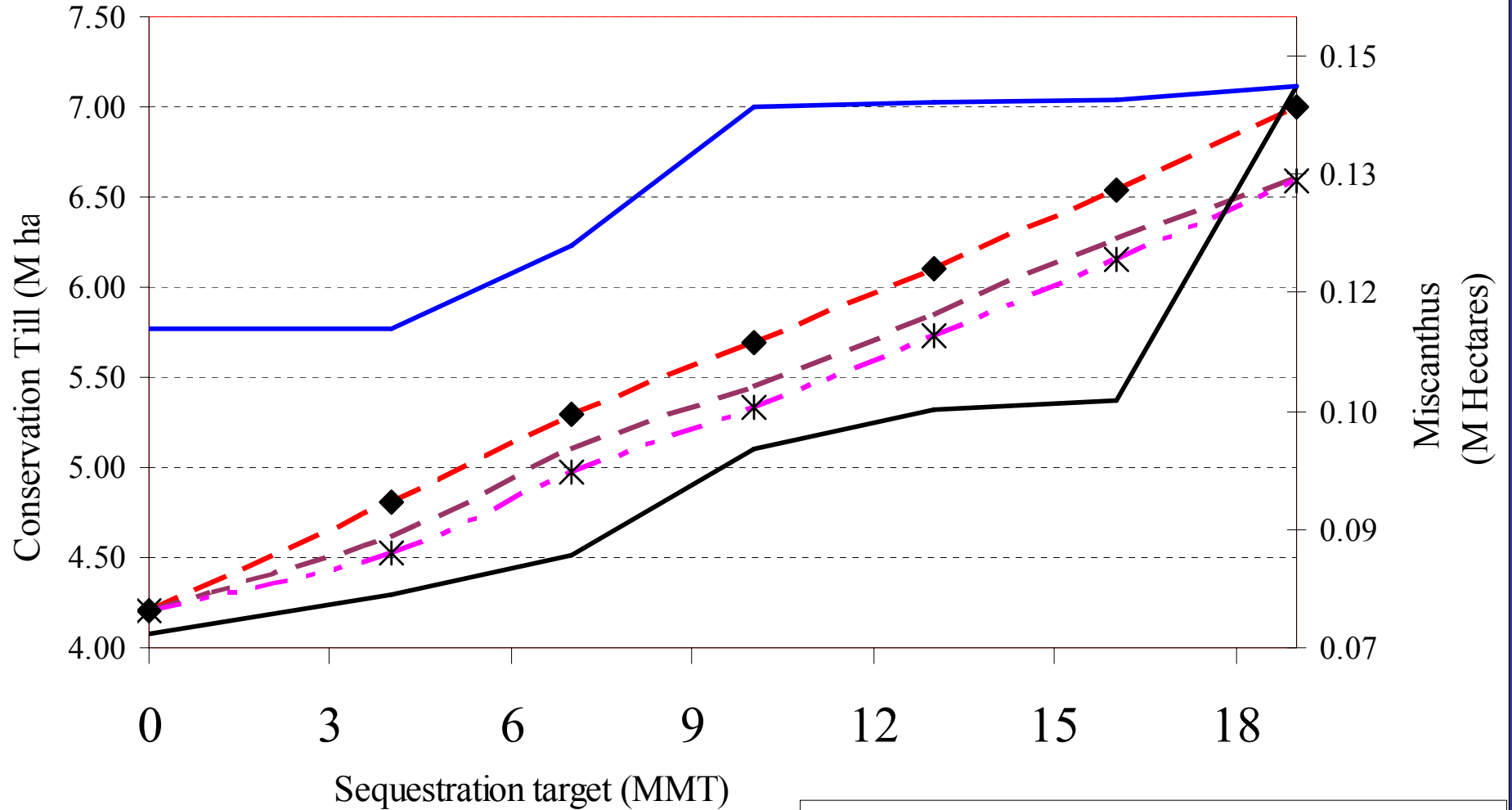
Bio-Energy Price per MBTU	< \$2.485	\$2.985	\$3.385
Carbon Sequestration in 15 years (MMT)	15.96	16.86	17.44
By Conservation till (%)	92.95	86.92	82.99
By Miscanthus (%)	0.00	6.37	10.65
Land under conservation till (%)	45.07	44.61	44.29
Land under Miscanthus (%)	0	0.77	1.19
Biomass Supply (MMT with 15% moisture)	0	1.96	2.94
Electricity generated with bio-energy (%)	0	2.5	3.8
Maximum distance for transportation of biomass (miles)	0	32.94	52.32
Discounted present value of bio-energy subsidy (\$M)		515.21	943.83

Maximum price a power plant would be willing to pay for biomass based on energy content: \$1.185/MBTU

Costs of Meeting Alternative Targets for Carbon Sequestration

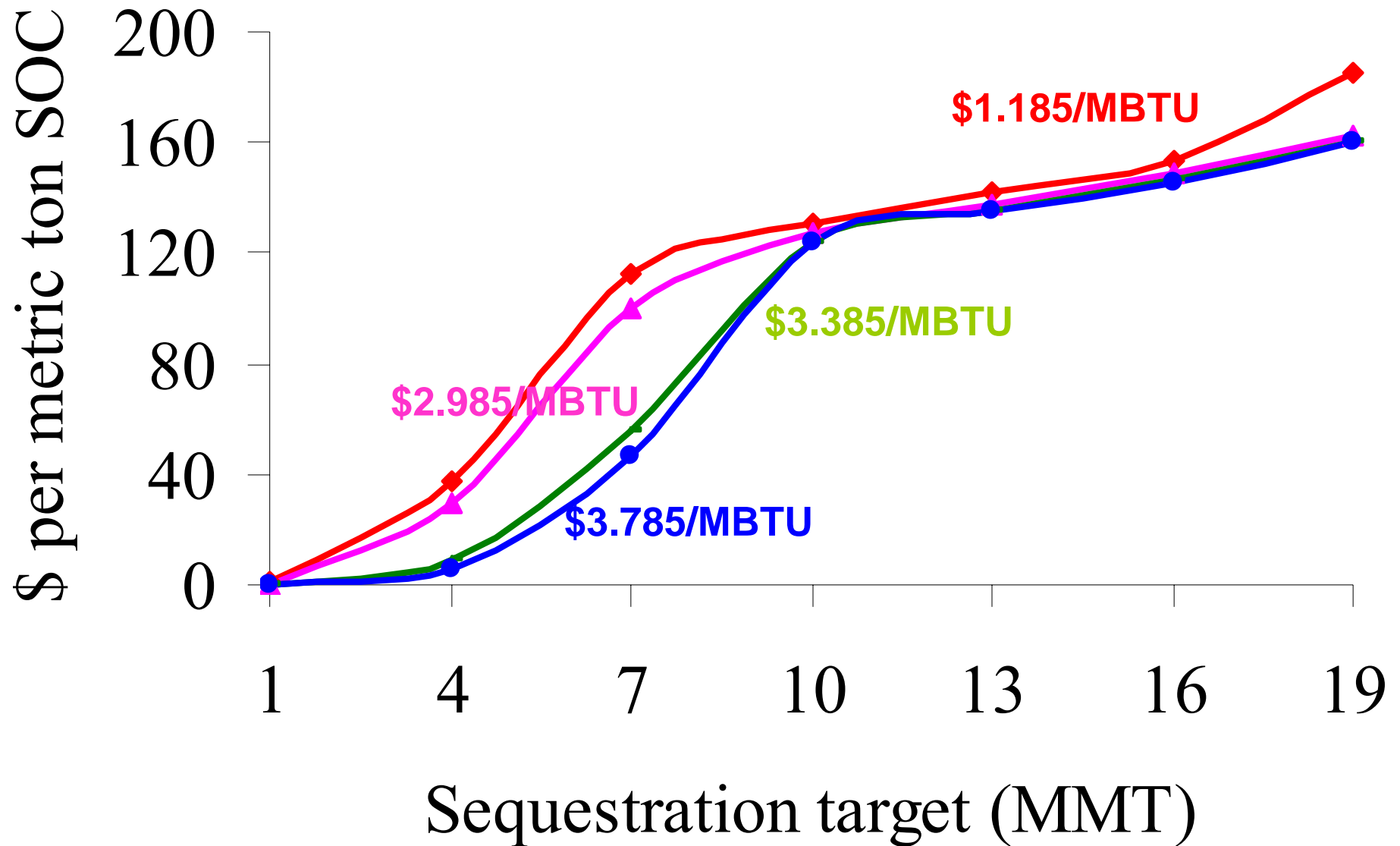
Carbon Sequestration Target	10 MMT			19MMT		
Bio-Energy Price per MBTU	< \$2.485	\$2.985	\$3.385	< \$2.45	\$2.985	\$3.385
By Conservation till (%)	93.46	87.42	83.84	95.14	87.83	87.83
By Miscanthus (%)	0.00	6.06	9.64	0.00	7.33	7.34
Land under conservation till (%)	61.04	58.52	57.25	75.15	70.77	70.77
Land under Miscanthus (%)	0	1.02	1.49	0	1.51	1.51
Electricity generated with bio-energy (%)	0	3.3	4.7	0	4.8	4.8
Max. distance for transportation of biomass (miles)	0	37.85	52.32	0	80.75	80.75
Marginal cost of carbon sequestration (\$/metric ton)	130.60	127.39	123.87	185.07	160.47	160.47
Discounted present value of carbon subsidy to Miscanthus (\$M)	0	200.53	309.92	0	411.49	411.49
Discounted present value of carbon subsidy to conservation till (\$M)	1231.3	1001.2	858.6	3410.4	2547.1	2546.9
Discounted present value of bio-energy subsidy (\$M)	0	647.38	1120.5	0	928.92	1135.35
Total Subsidy (\$M)	1306.0	1921.3	2359.2	3516.3	3978.04	4184.2

Area Under Conservation Tillage and Miscanthus

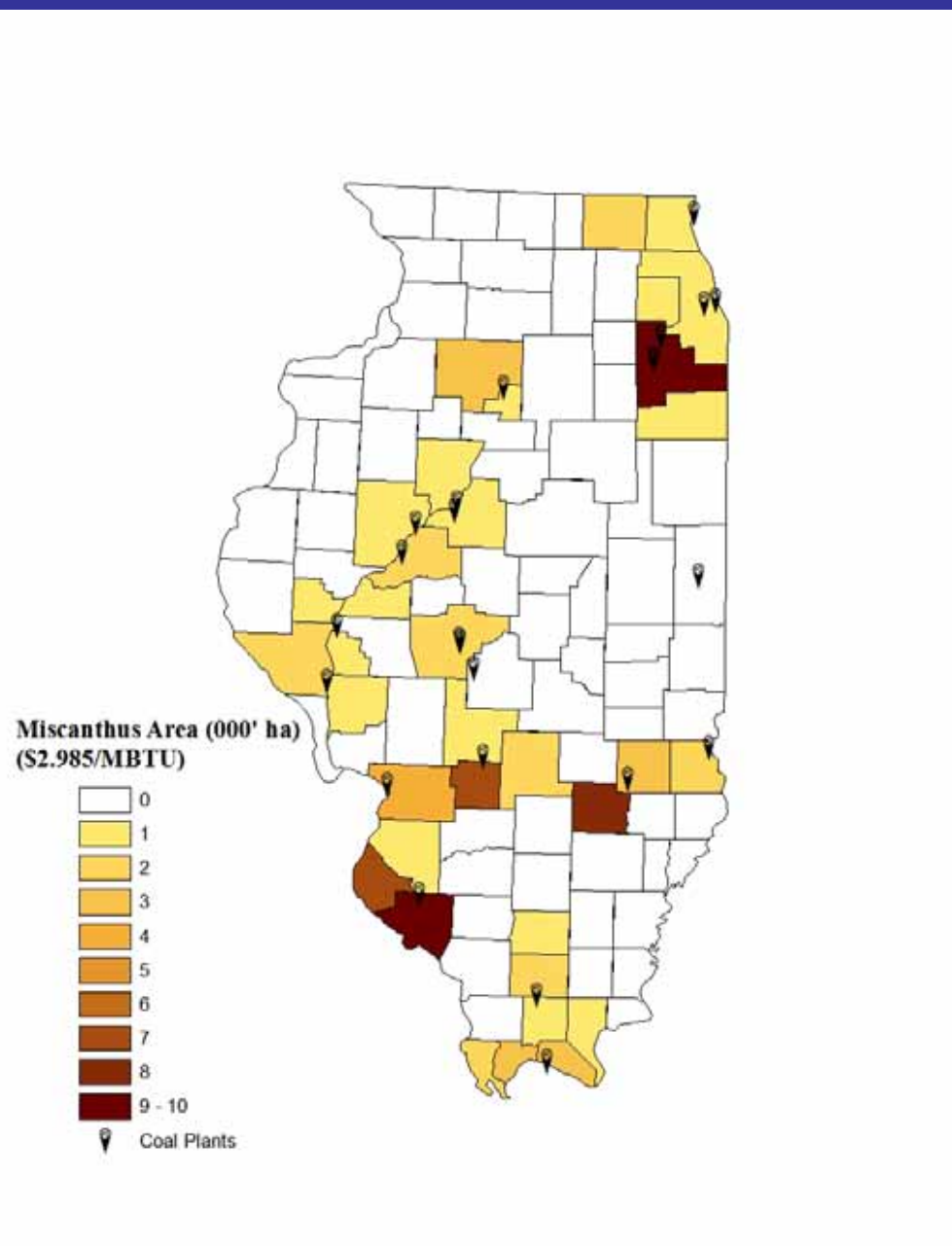


- ◆— Conservation Tillage; No Bio-Energy
- ◆— Conservation Tillage; Bio-Energy Price \$2.985
- *— Conservation Tillage; Bio-Energy Price \$3.385
- Miscanthus Area; Bio-Energy Price \$2.985
- Miscanthus Area; Bio-Energy Price \$3.385

Marginal Cost of Sequestration



Area under Miscanthus Production with Bio-Energy Price of \$2.985/MBTU and No Carbon Constraint



Increase in Area under Miscanthus Production with Bio-Energy Price of \$2.985/MBTU and 10 MMT Carbon Constraint

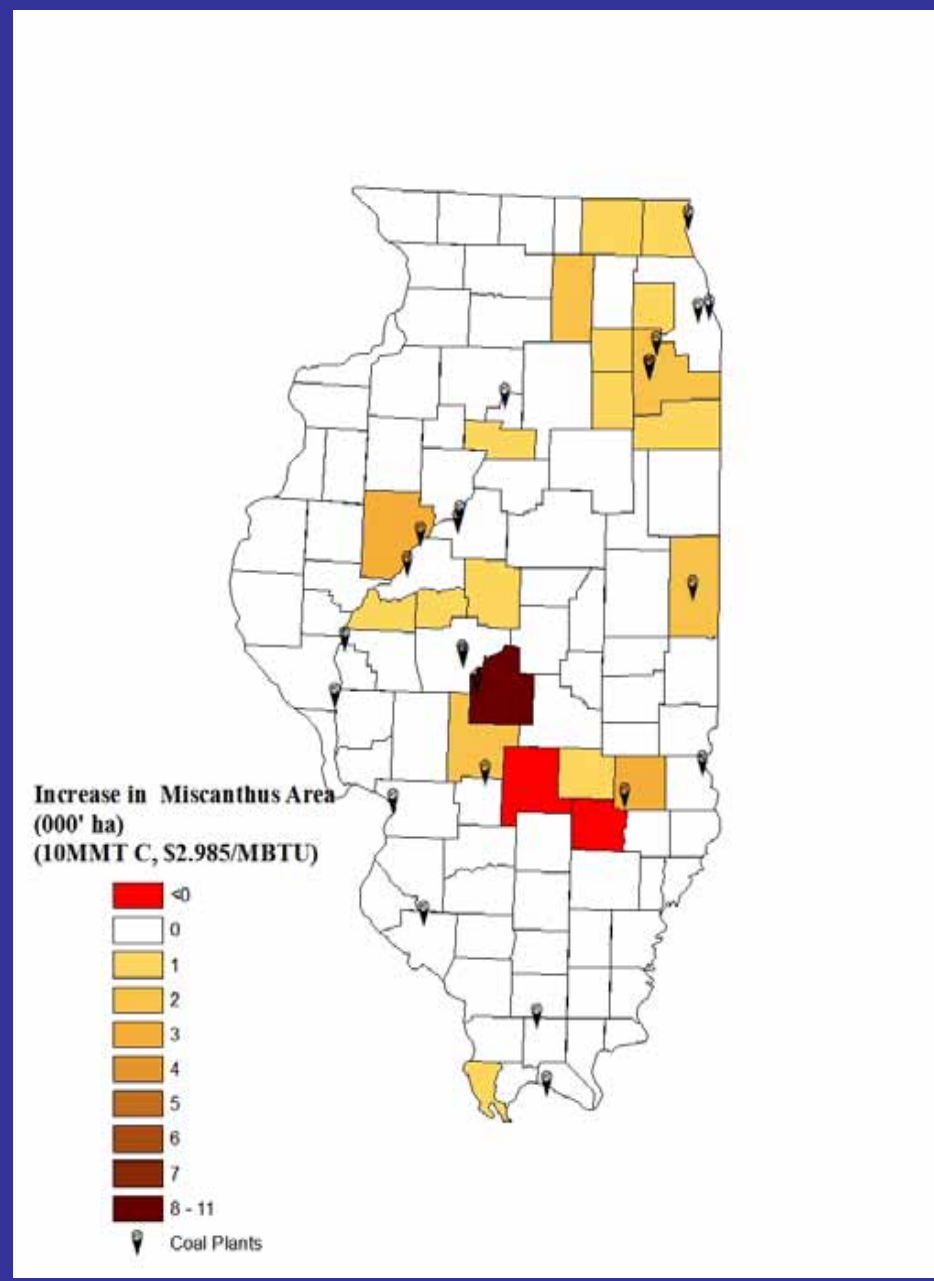


Fig. 9: Percentage Cropland under Conservation Tillage with No Carbon Constraint

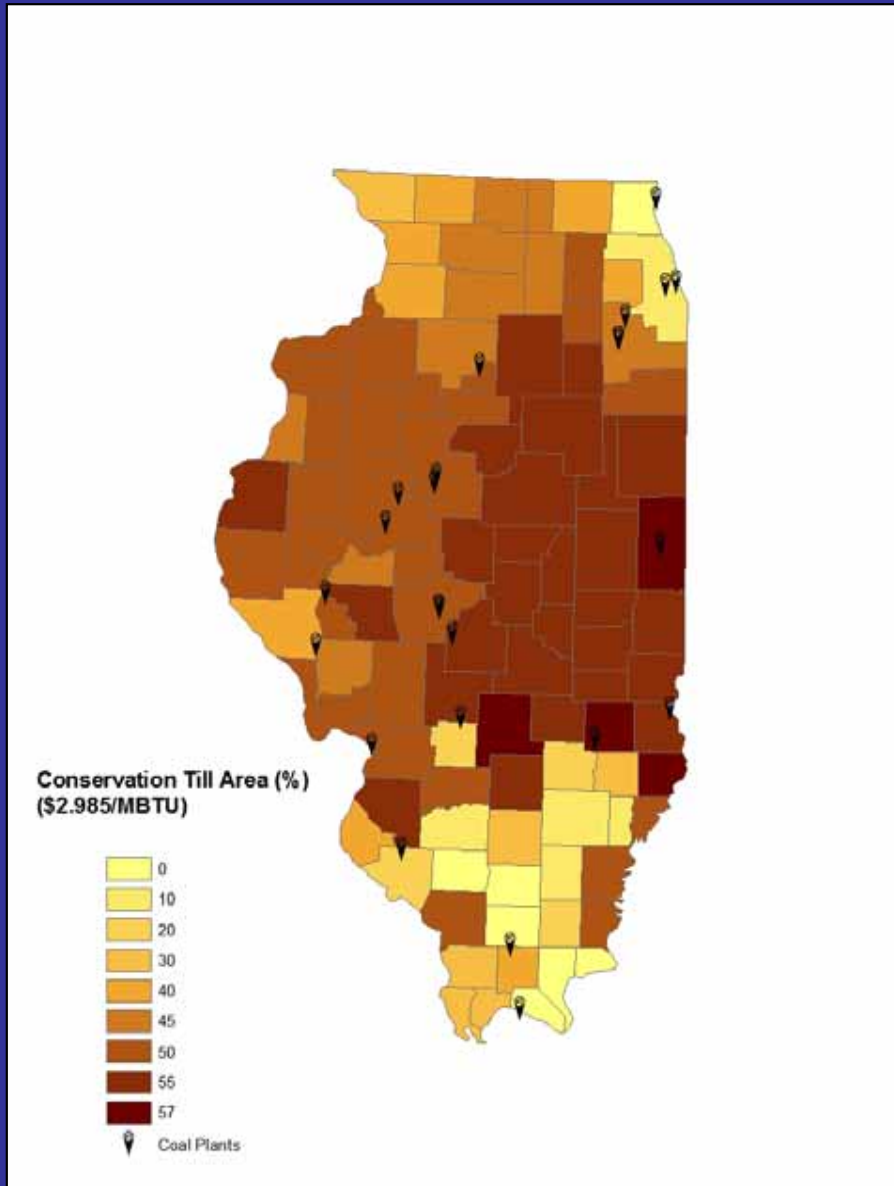
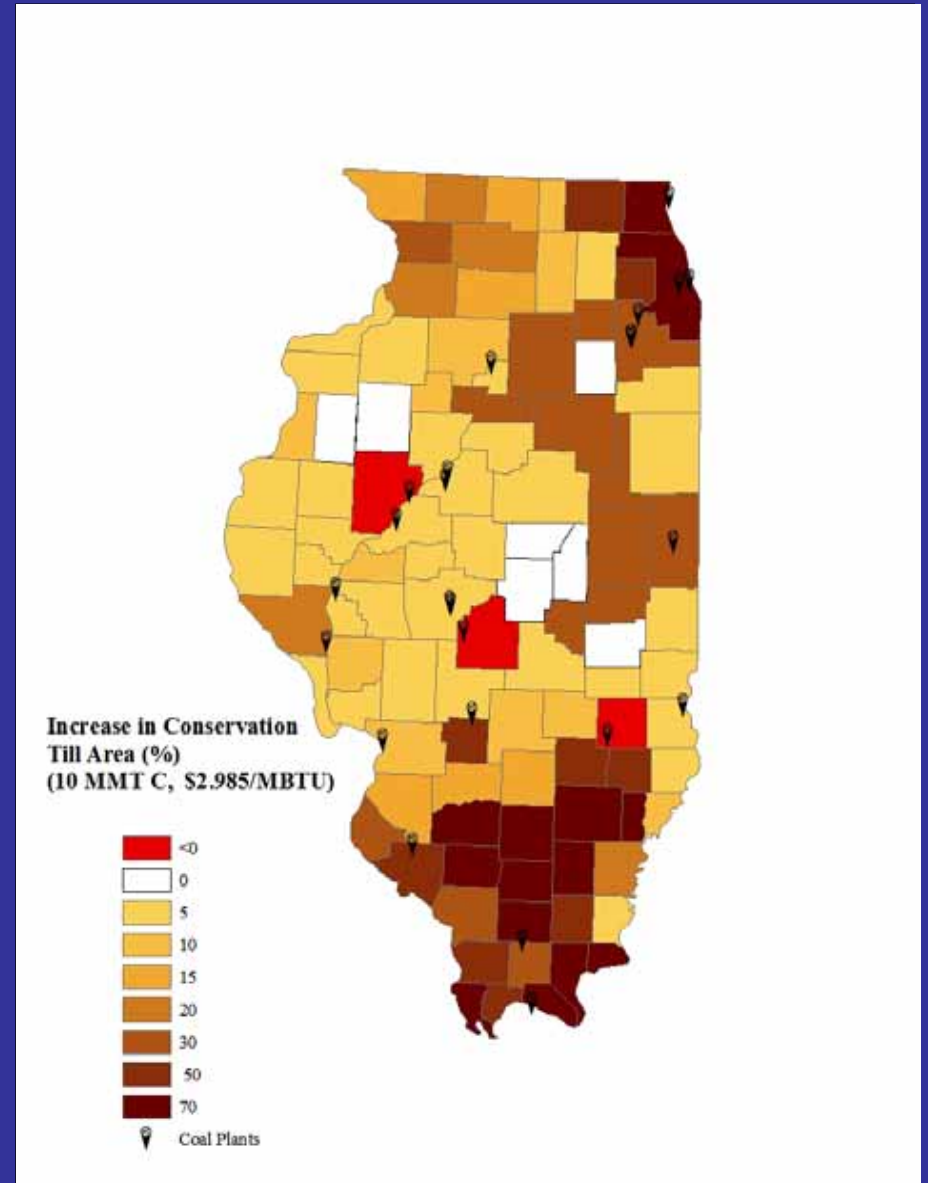


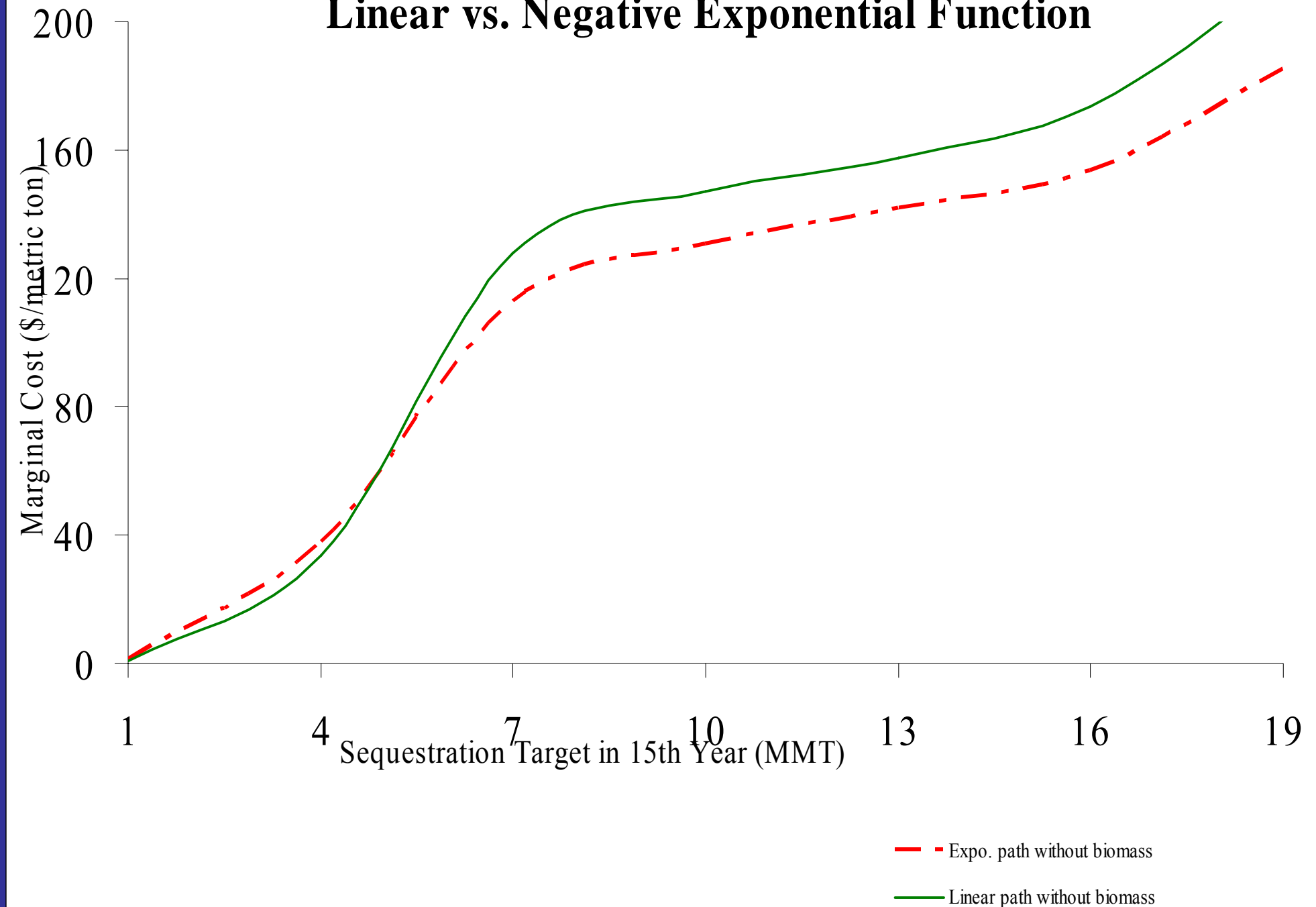
Fig. 10: Percentage Increase in Cropland under Conservation Tillage with 10 MMT Carbon Constraint



Alternative Scenarios

	Exponential Sequestration Function	Linear Sequestration Function	Exclusion of Terminal Returns to Land	Valuing Carbon Emission Displacement
Carbon Mitigation in 15 years	10MMT; Bioenergy Price \$2.985/MBTU			
Carbon Sequestration (%)	100%	100%	100%	53
Carbon Displacement	-	-	-	47
Land under conservation till (%)	58.52	57.91	74.22	54
Land under Miscanthus (%)	1.02	1.02	0.76	0.43
Biomass Supply (MMT with 15% moisture)	2.56	2.55	1.94	1.06
Electricity generated with bio-energy (%)	3.3	3.3	2.5	1.4
Maximum distance for transportation of biomass (miles)	37.85	37.85	32.94	26.4
Marginal cost of carbon sequestration (\$/metric ton)	127.39	142.89	32.69	52.7
Total Payments (\$ M)	1921.3	2075.50	650.5	527.6

Marginal Cost of Sequestering Soil Carbon: Linear vs. Negative Exponential Function



Conclusions and Policy Implications

- Spatial mix of land allocation to conservation tillage and perennials depends on carbon stock levels, location of power plants and bio-energy subsidy
- Conservation tillage the dominant approach for soil carbon sequestration despite bio-energy subsidies
- Fairly high bioenergy subsidies needed to induce a switch to energy crops for electricity generation
 - Unless both carbon sequestration and emissions reduction are valued
- Carbon subsidy payments overestimated with a linear sequestration path assumption
- Temporary sequestration for 15 years costs 25% of permanent sequestration