A Matter of Balance: Conservation and Renewable Energy: how soil quality is affected by removal of biomass?

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Introduction

- Energy paradigm is changing from petroleum to mixed renewable
- Sufficient energy available, but in diffuse form
- Can we be sustainable or at least minimize environmental footprint?
- Can we balance food, feed, fiber and fuel?

Biomass harvest

- Benefits
  - Renewable
  - Domestic
  - Reduces release of fossil CO_2
  - Additional farm commodity
- Risks
  - Decreased surface residues
  - Increased erosion
    - Off-site nutrient and sediments
  - Decreased SOM
  - Decreased productivity
  - Other – loss of winter cover, habitat

Cellulosic biomass

Interest in biomass for bioenergy

- Cellulosic ethanol – sugar platform
- Thermochemical – controlled combustion
  - Gasification
    - Dimethylether (DME)
    - Replace natural gas
  - Pyrolysis

    Bio oil, bio char, biogas

- other bio-based products

Biomass for bioenergy

Agriculture – 998 million tons

- Perennial energy crops – 377 million tons
- "Wastes" – 87 million tons
- Grain – 87 million tons
- **Crop residues – 428 million tons**
  - **Corn stover – 256 million ton**

Forestry – 368 million ton

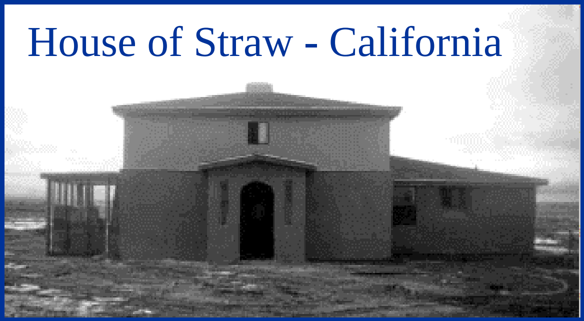
(projected estimates; Billion Ton Report, Perlack et al 2005)

Competing uses for crop biomass

Courtesy USDA photo gallery

Feed and bedding

Courtesy USDA photo gallery



http://www.eere.energy.gov/buildings/info/components/envelope/framing/strawbale.html

Construction material
Cooking and heating

http://www.unfpa.org/swp/2001/images/ch04_a.jpg

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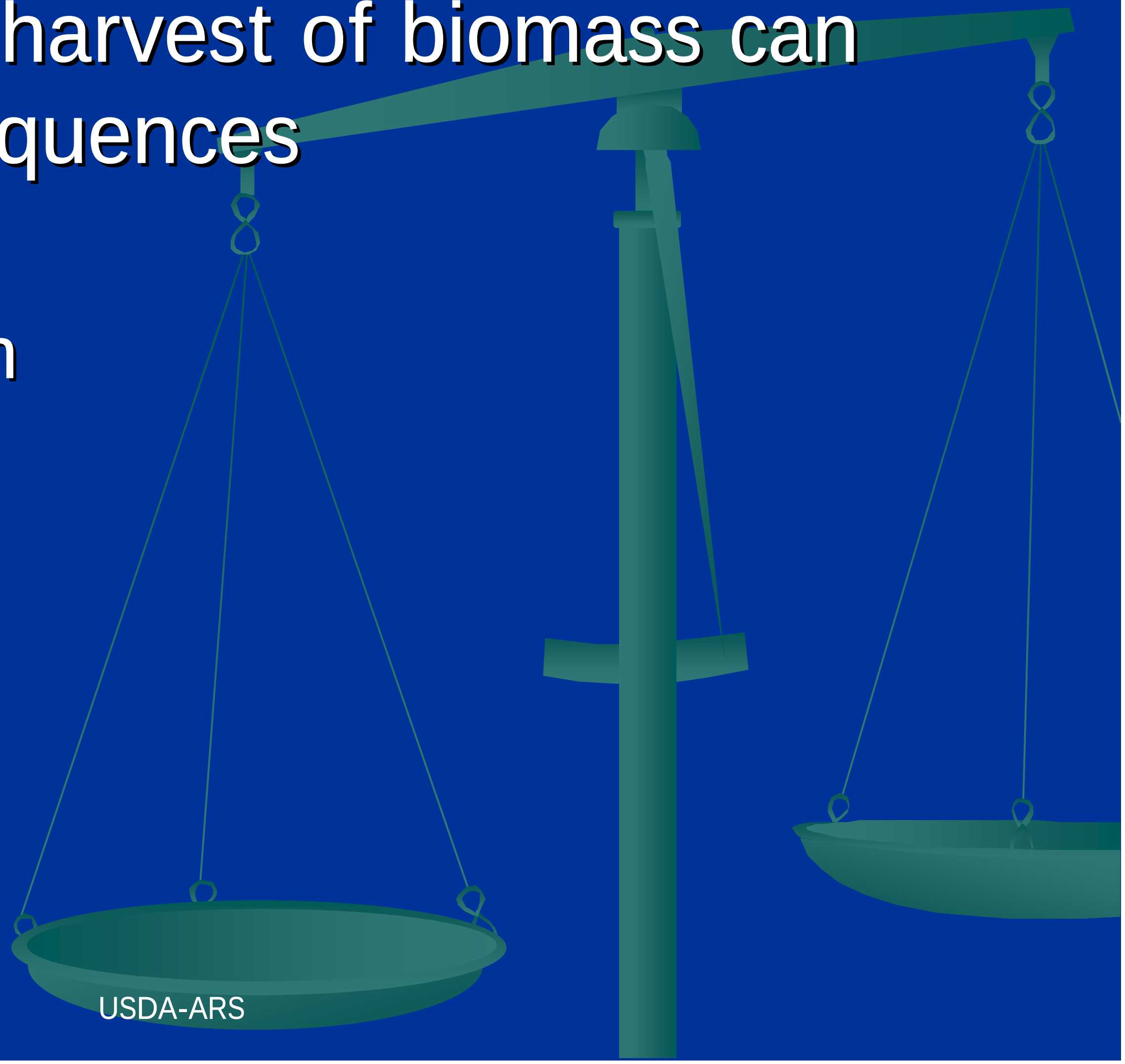
Taken to extreme

- Continued over harvest of biomass can have dire consequences
  - Erosion
  - Soil degradation
  - Desertification



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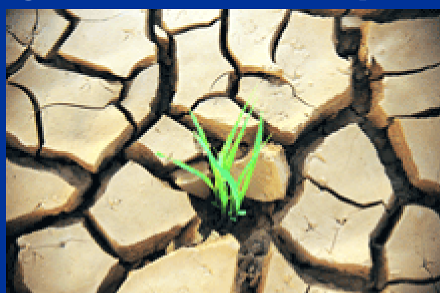
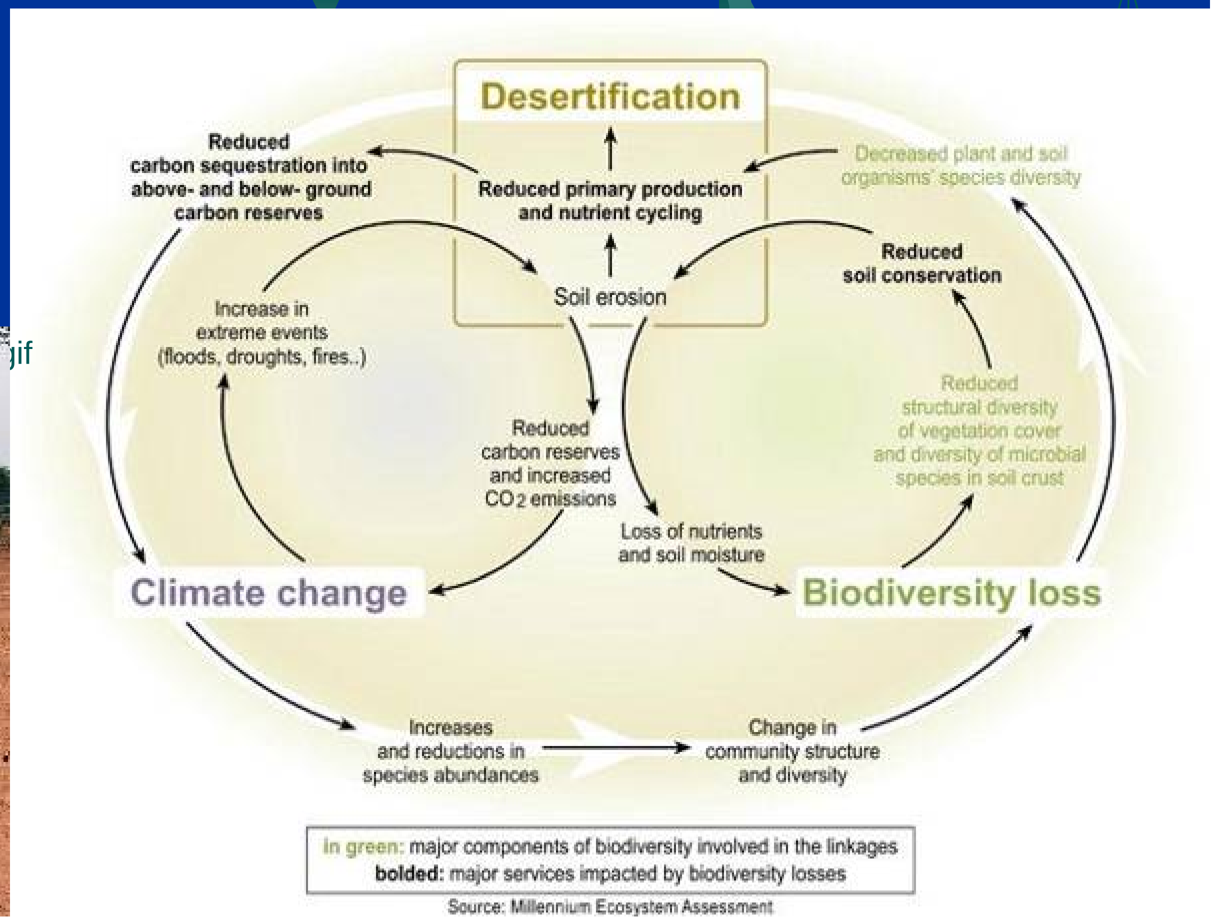
An extremely real example...

- The continual harvest of crop residues in the semi-arid region of West Africa has led to a spiral of land degradation, in which nutrients are not returned to the soil and rainfall is in short supply.
- However, when rain does fall, much of the soil washes away.
- Consequently, soil has little life, because there is little organic matter input.



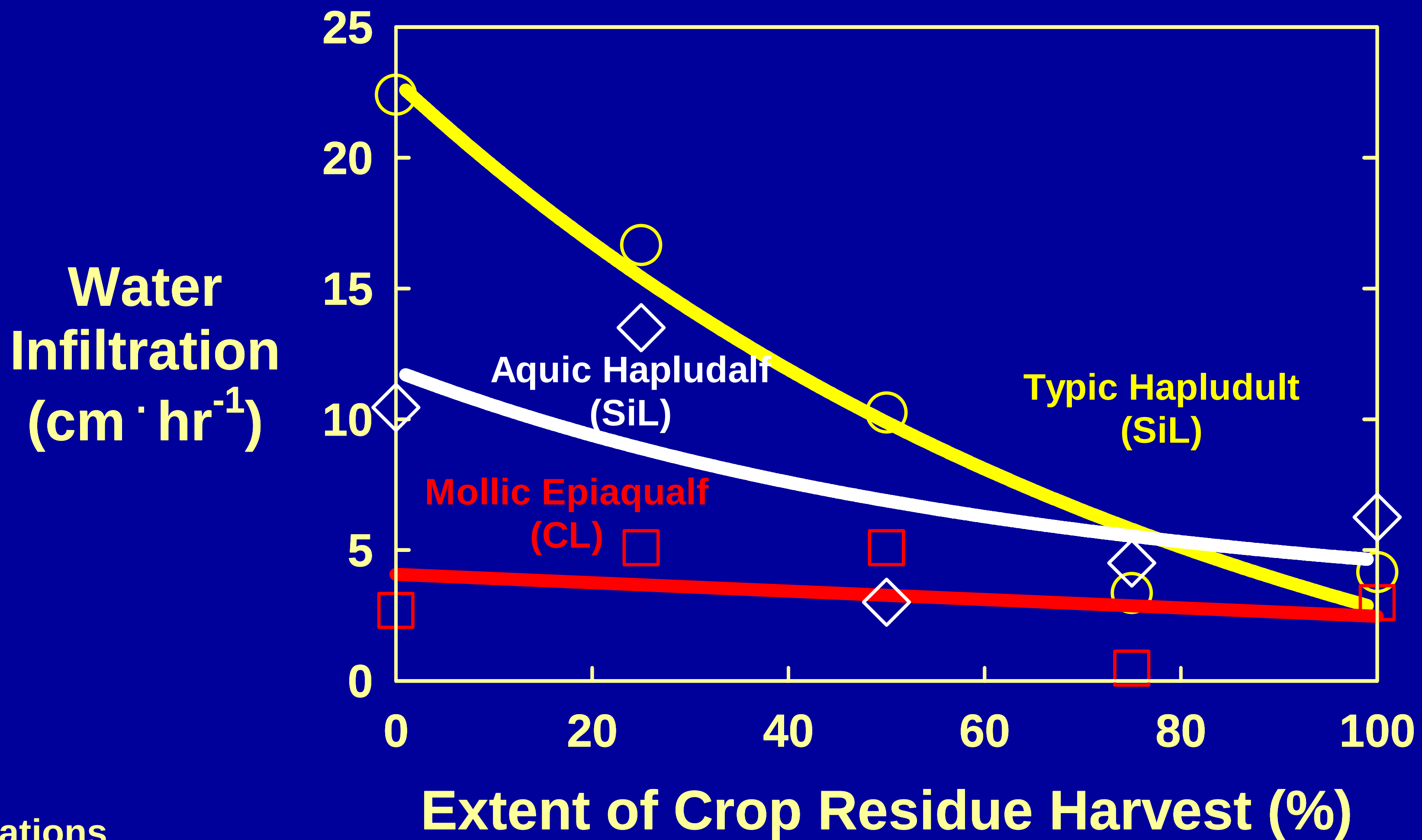
http://www.wmo.ch/pages/mediacentre/news/archive/images/desert.jpg



Soil roles of non-grain biomass

- protect the soil from erosion

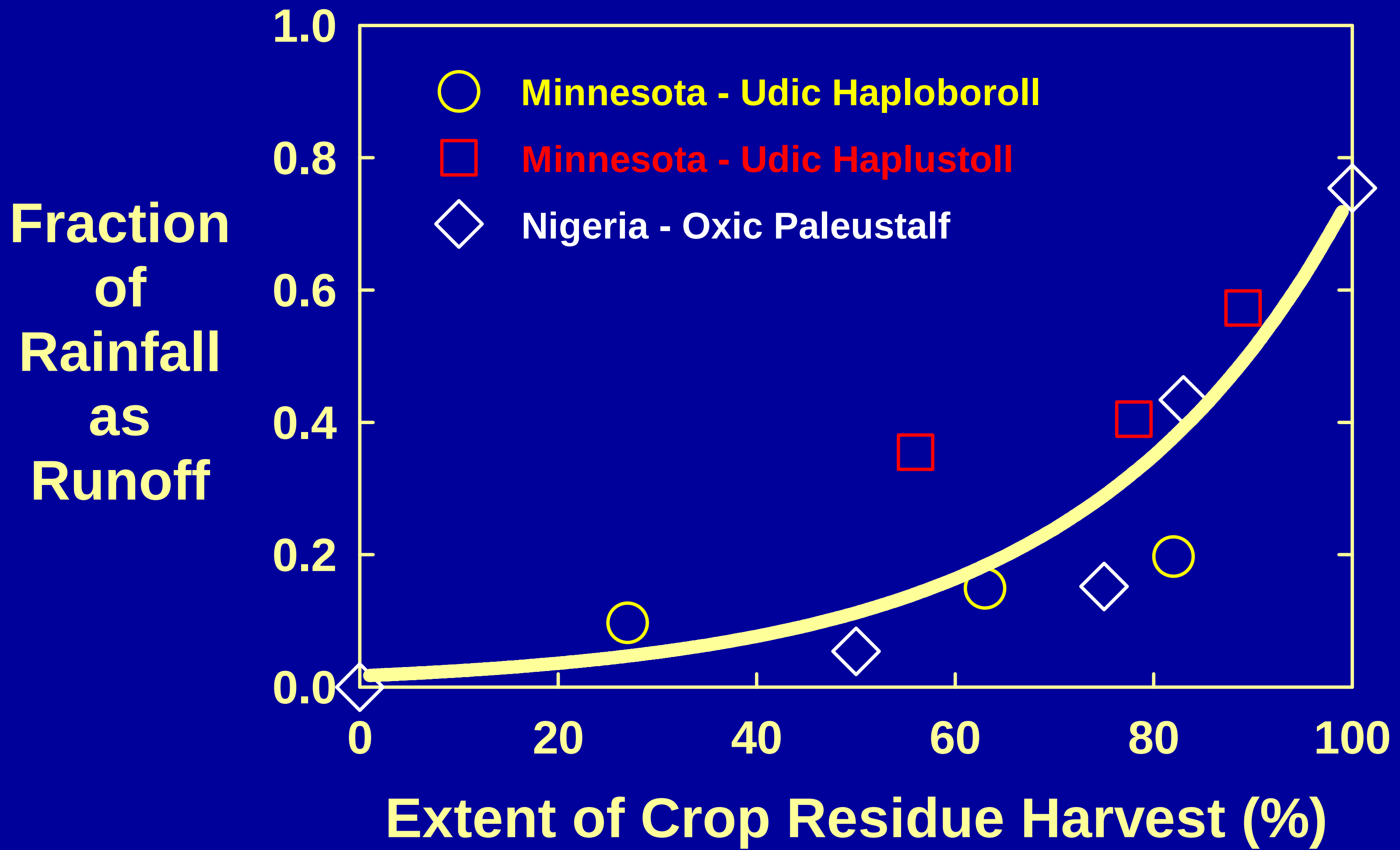
Water Infiltration Response to Crop Residue Harvest



Ohio
3 locations
2.5-yr study
Corn
No tillage

Data from Blanco-Canqui & Lal (2007) Geoderma 141:355-362

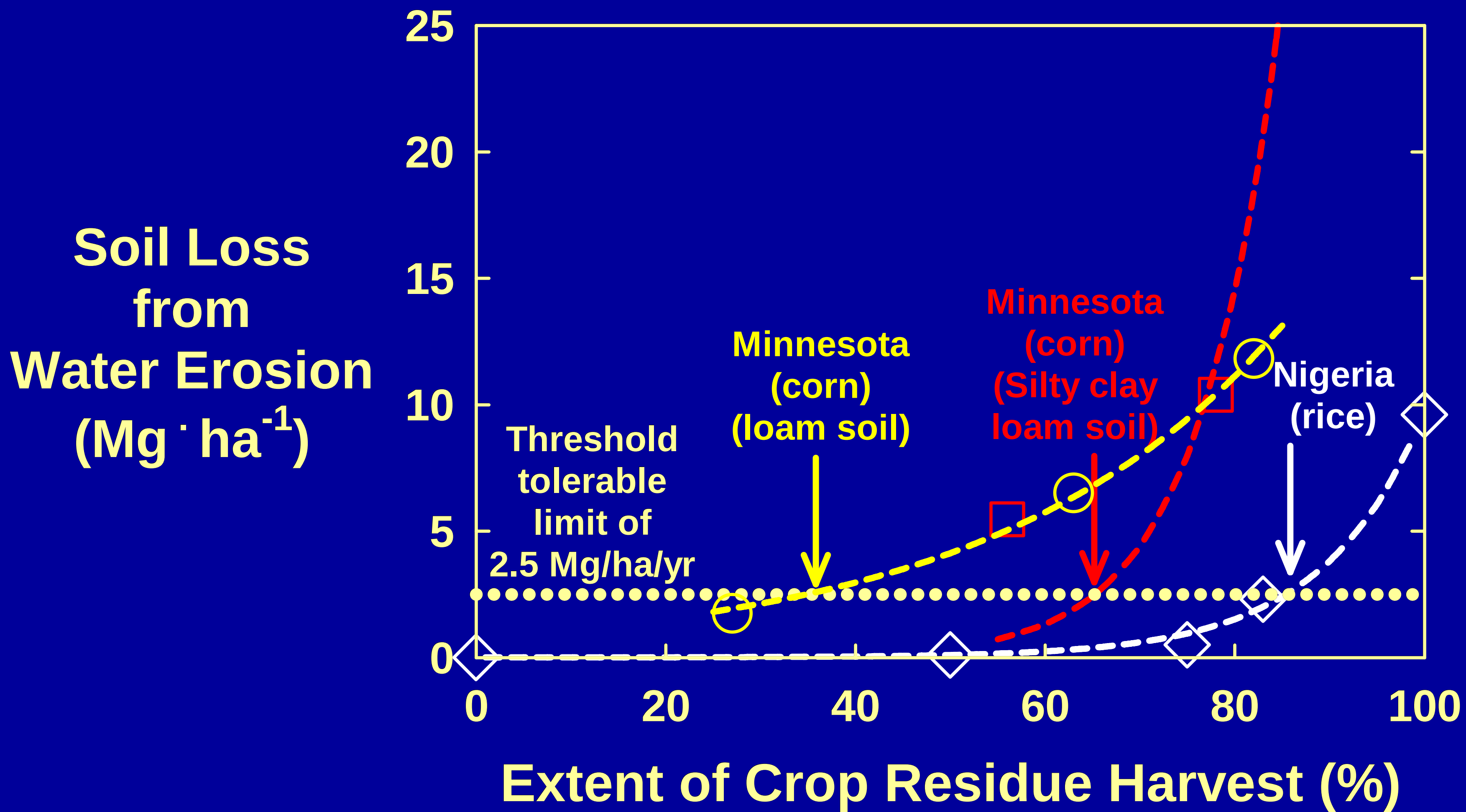
Water Runoff Response to Residue Harvest



Data from Erenstein (2002) Soil Tillage Res. 67:115-133

Data from Lindstrom (1986) Agric. Ecosyst. Environ. 16:103-112

Soil Erosion Response to Crop Residue Harvest

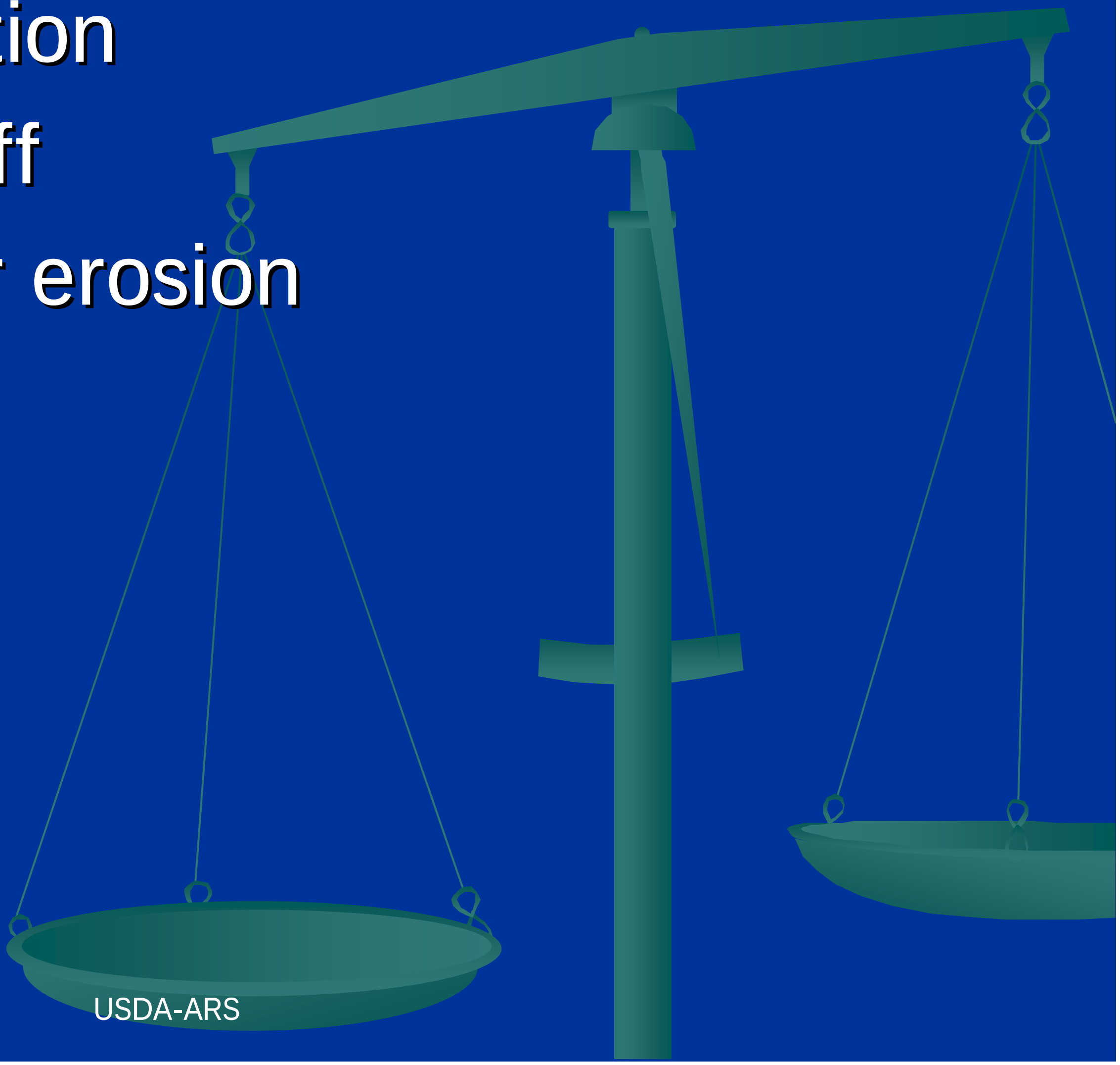


Data from Erenstein (2002) Soil Tillage Res. 67:115-133

Data from Lindstrom (1986) Agric. Ecosyst. Environ. 16:103-112

Excessive Biomass harvest

- Reduces infiltration
- Increases run-off
- Increased water erosion



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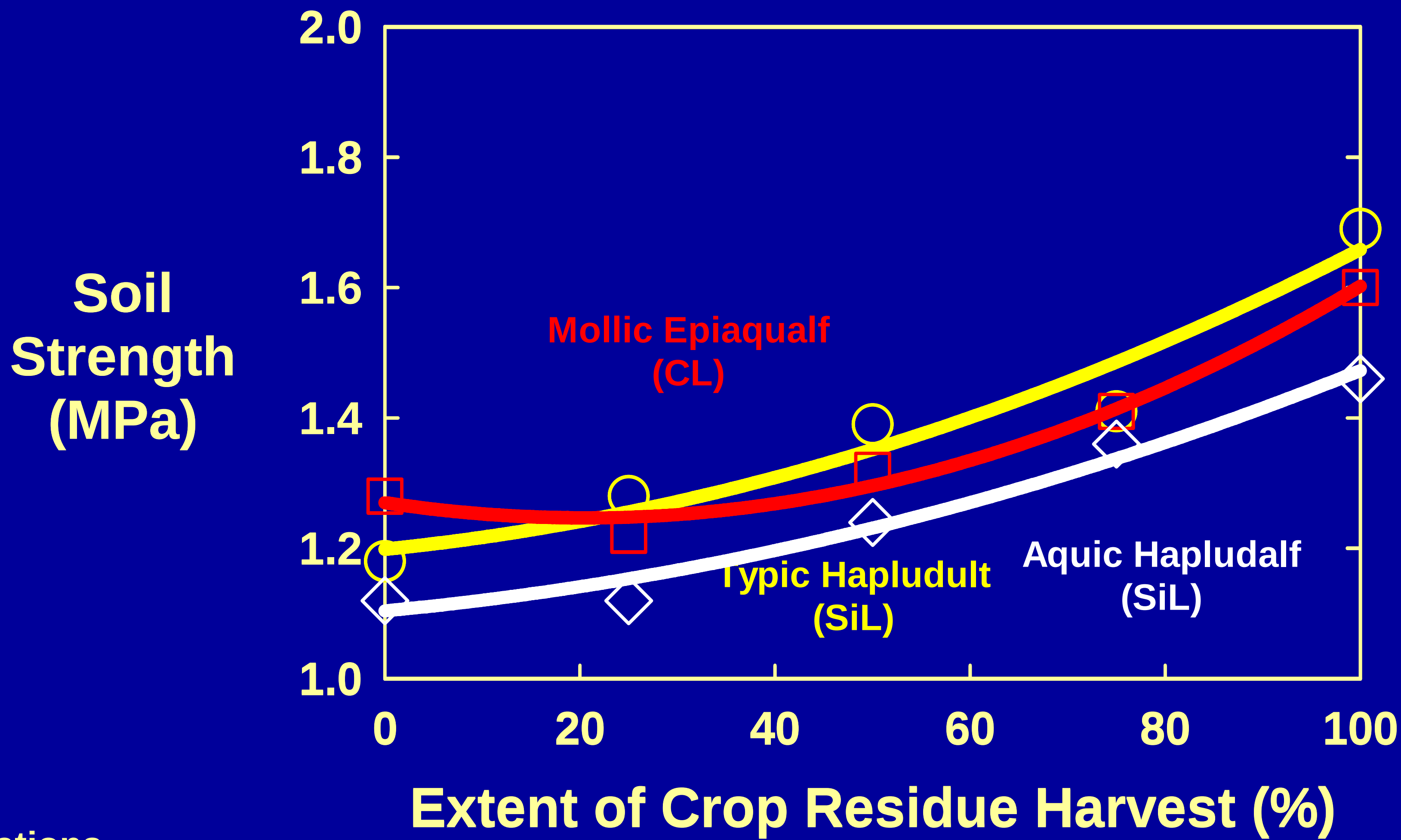
Soil aggregation response to non-grain biomass harvest

Soil	Years	Tillage	Biomass Removed	Biomass Retained	Citation
			Wind-erodible aggregates <1 mm %		
Sandy clay loam	4	Tilled	50	47	Malhi (et al., 2006)
Mollic Cryoboralf		No tillage	40	34	
Sandy Loam	5	Tilled	43	43	Malhi & Kutcher (2007)
Typic Cryoboralf		No tillage	33	30	
Clay Loam	5	Tilled	27	28	
Mollic Cryoboralf		No tillage	17	15	
Loam	6	Tilled	39	33	Singh & Mahli (2006)
Udic Boroll		No tillage	23	18	
Loam	6	Tilled	46	42	
Mollic Cryoboralf		No tillage	35	28	
Sandy Clay Loam	8	Tilled	17	11	Mahli & Lembke (2007)
Mollic Cryoboralf		No tillage	21	13	
Clay Loam	9	Tilled	73	52	Singh et al. (1994)
Udic Boroll					

Removing biomass increased the number of wind-erodible aggregate to 36% compared to 30%.


Tillage
Wind
Water
LaPorte, IN 2004
http://www.umanitoba.ca
Wakeeney, KS
L. Kucerik, 2004
MN, D. Reicosky
Morris, MN 2003
USDA-NRCS

Soil Strength Response to Crop Residue Harvest

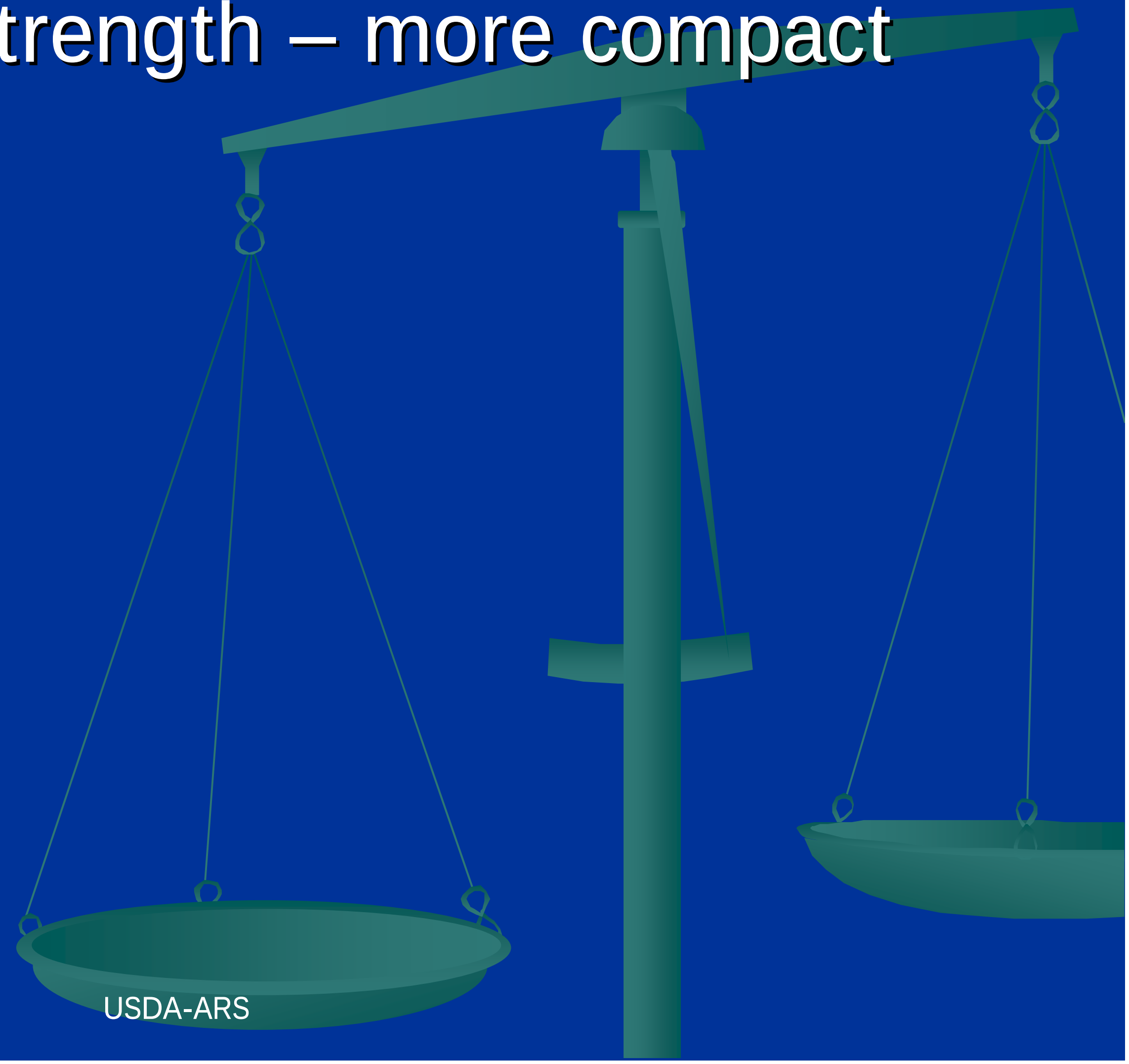


Ohio
3 locations
1-yr study
Corn
No tillage

Data from Blanco-Canqui et al. (2007) Soil Tillage Res. 92:144-155

Harvesting biomass

- Increased soil strength – more compact



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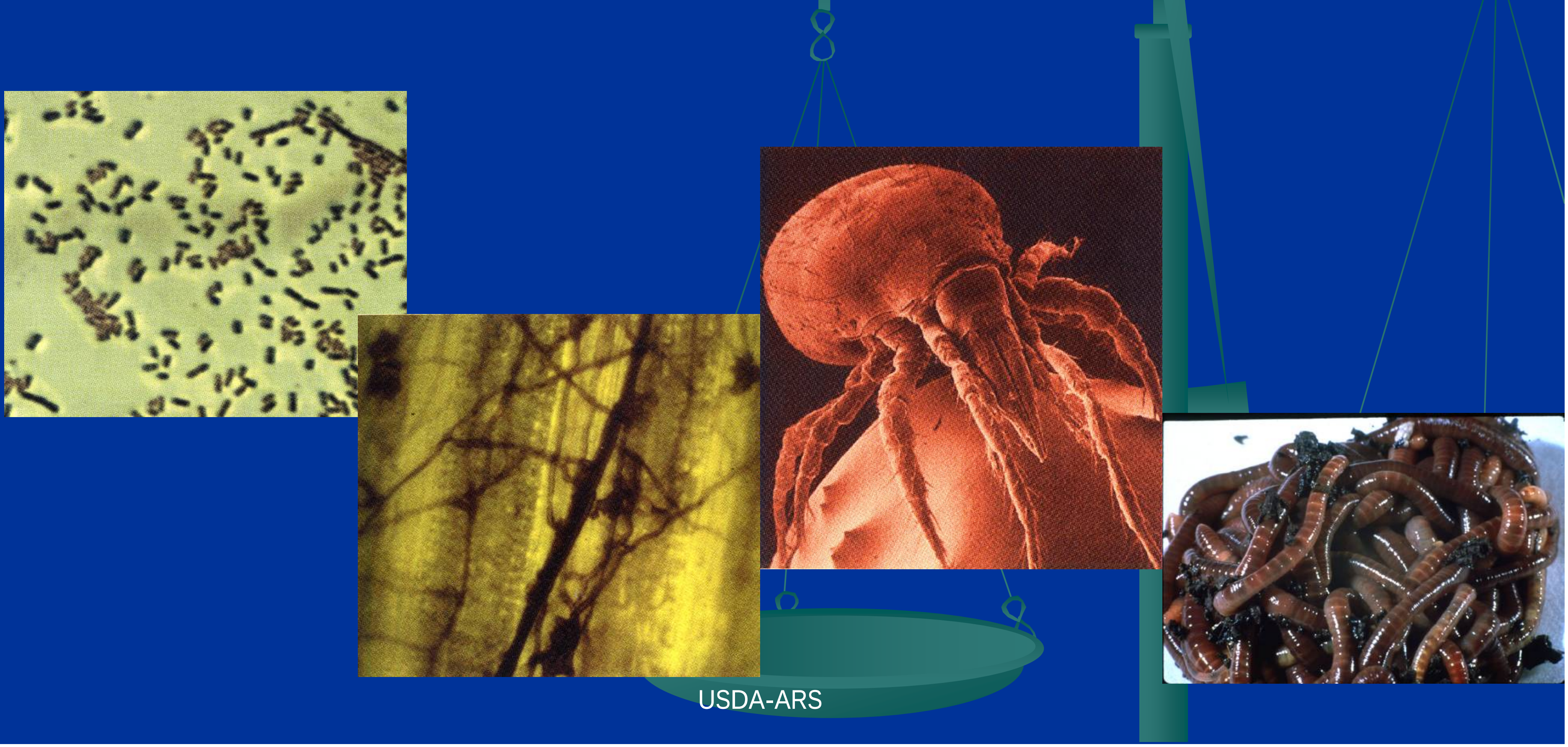
Primary roles of crop biomass

- provide C and other organic inputs to support the below ground ecosystem



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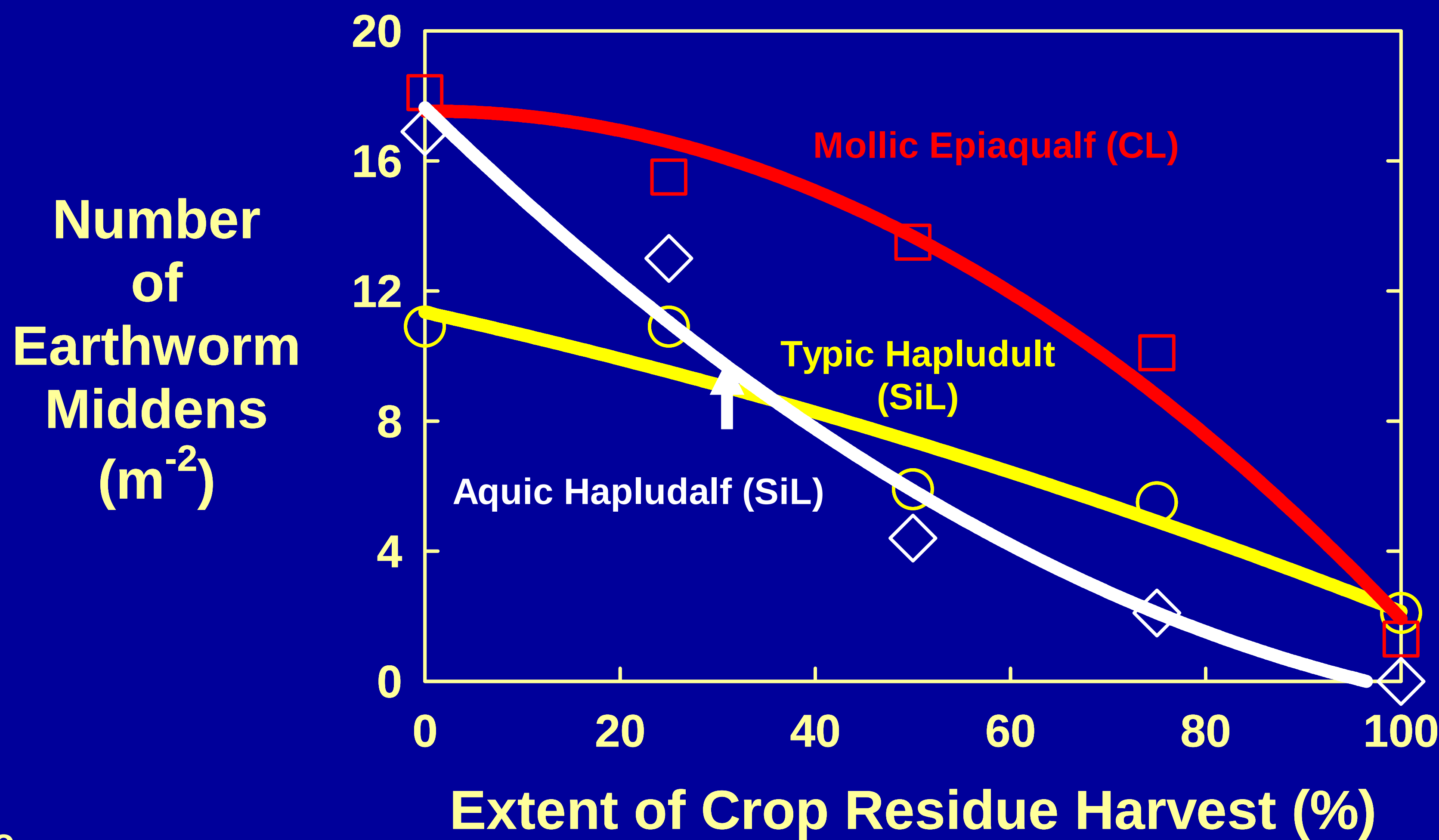
Soil biological response to non-grain biomass harvest

Soil	Location	Biomass: Removed	Biomass: Retained	Citation
		Earthworms (no m^{-2})		
Silty clay		1.2	2.0	
Silty clay loam	Finland	1.7	1.7	Nuutinen (1992)
Sandy loam		0.9	0.8	
Not reported	New Zealand	243	323	Fraser & Piercy (1998)
Silt loam	Wisconsin	53	78	Karlen et al., (1994)
		Microbial C (mg kg^{-1})		
Silt loam	Wisconsin	330	696	Karlen et al., (1994)
Loamy sand	Denmark	151	184	Debosz et al., (1999)
Sandy clay	Mexico	324	364	Limon-Ortega et al. (2002)
		Fungi (km g^{-1})		
Silt loam	New Zealand	3.0	4.0	Cookson et al. (1998)

Removal of biomass decreased indices of soil biological activity.

Soil Biological Response to Crop Residue Harvest



Ohio
3 locations
1-yr study
Corn
No tillage

Data from Blanco-Canqui et al. (2007) Soil Tillage Res. 92:144-155

Primary roles of crop biomass

- build and maintain soil organic matter/soil organic carbon

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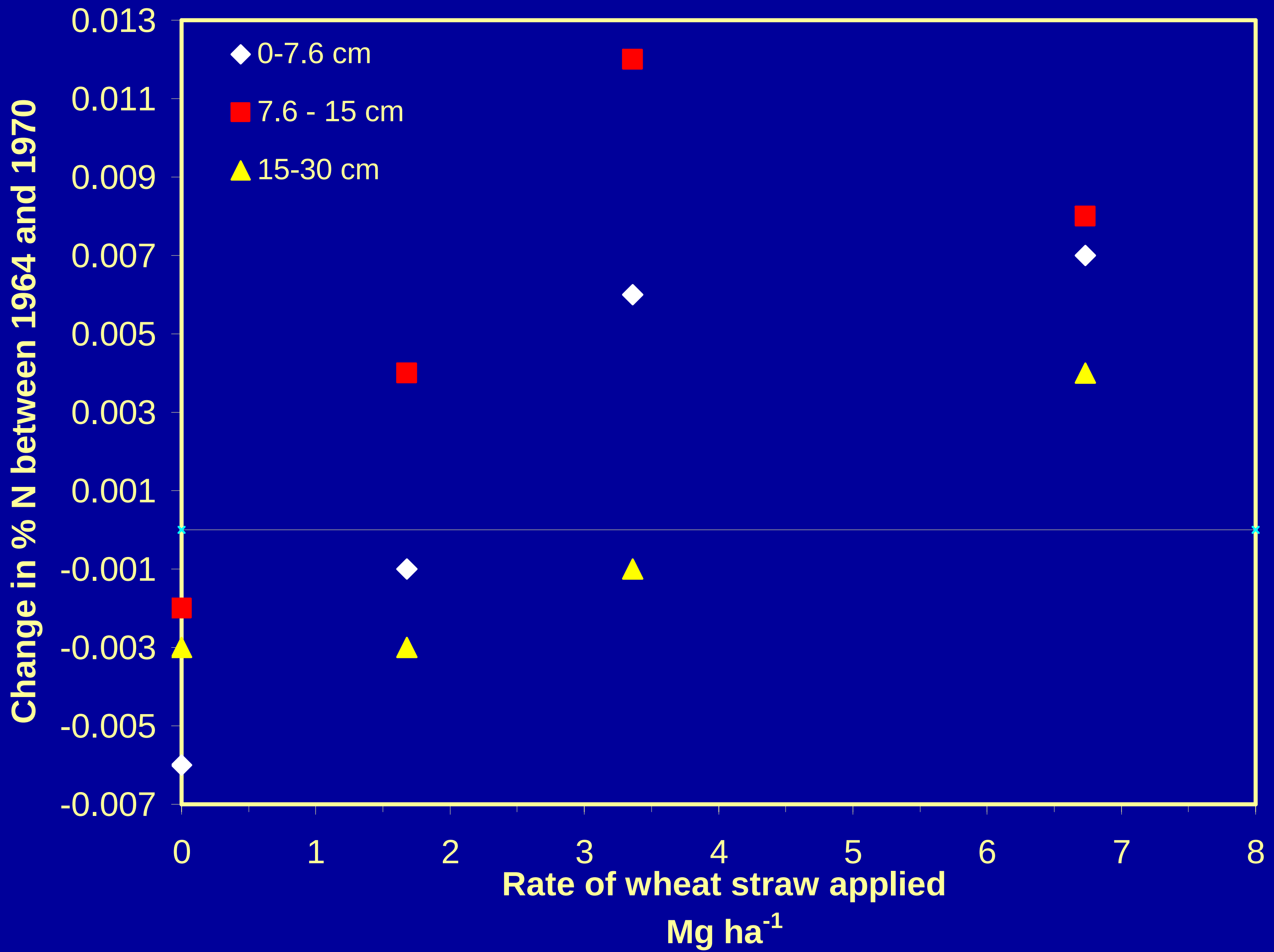
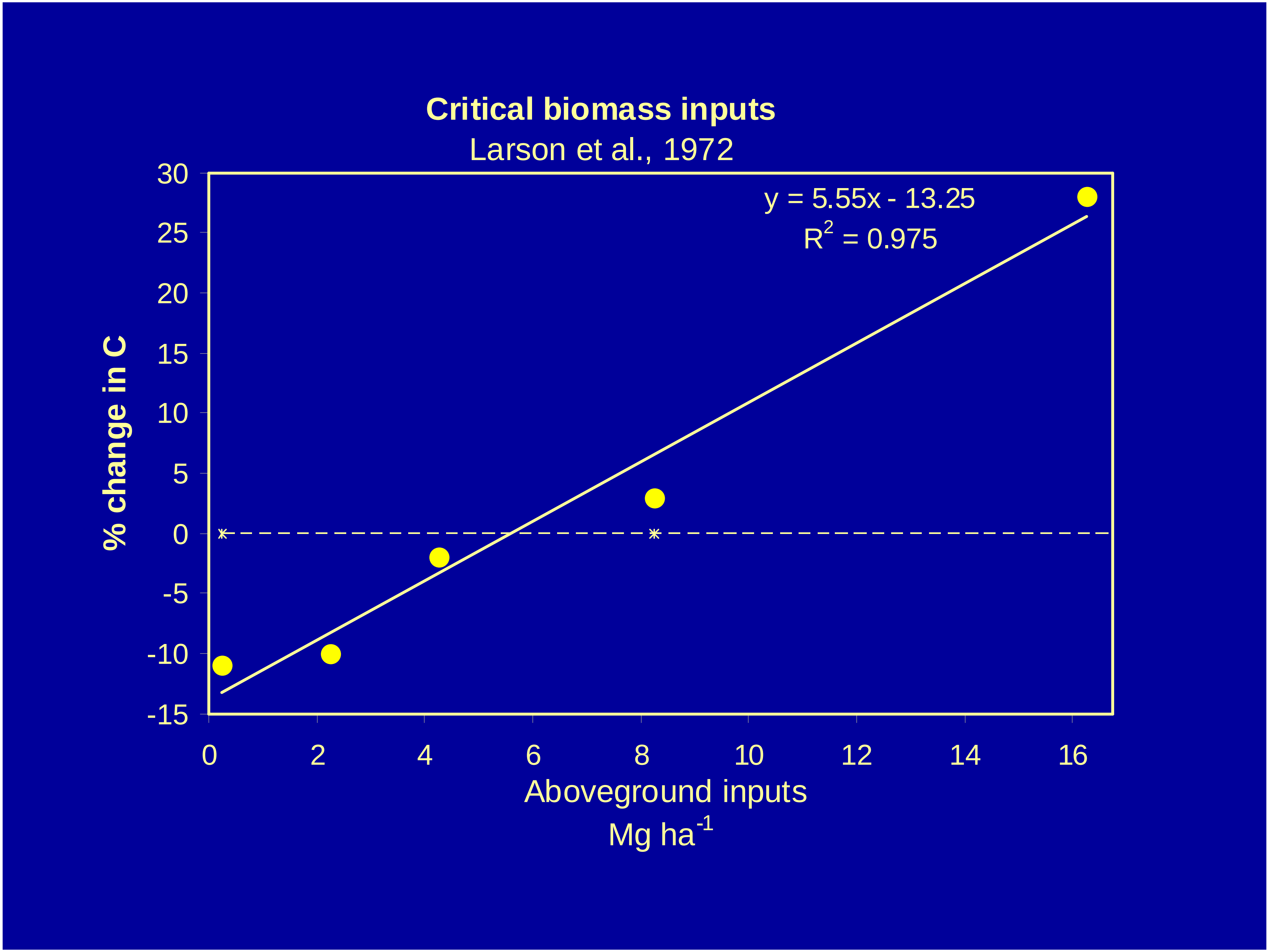
Soil N Response to Crop Residue Harvest



Black, 1973 SSSAJ 37: 943-946



Critical biomass inputs
Larson et al., 1972
y = 5.55x - 13.25
R2 = 0.975
% change in C
30
25
20
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
Aboveground inputs
Mg ha-1

Summary of soil response to biomass harvest

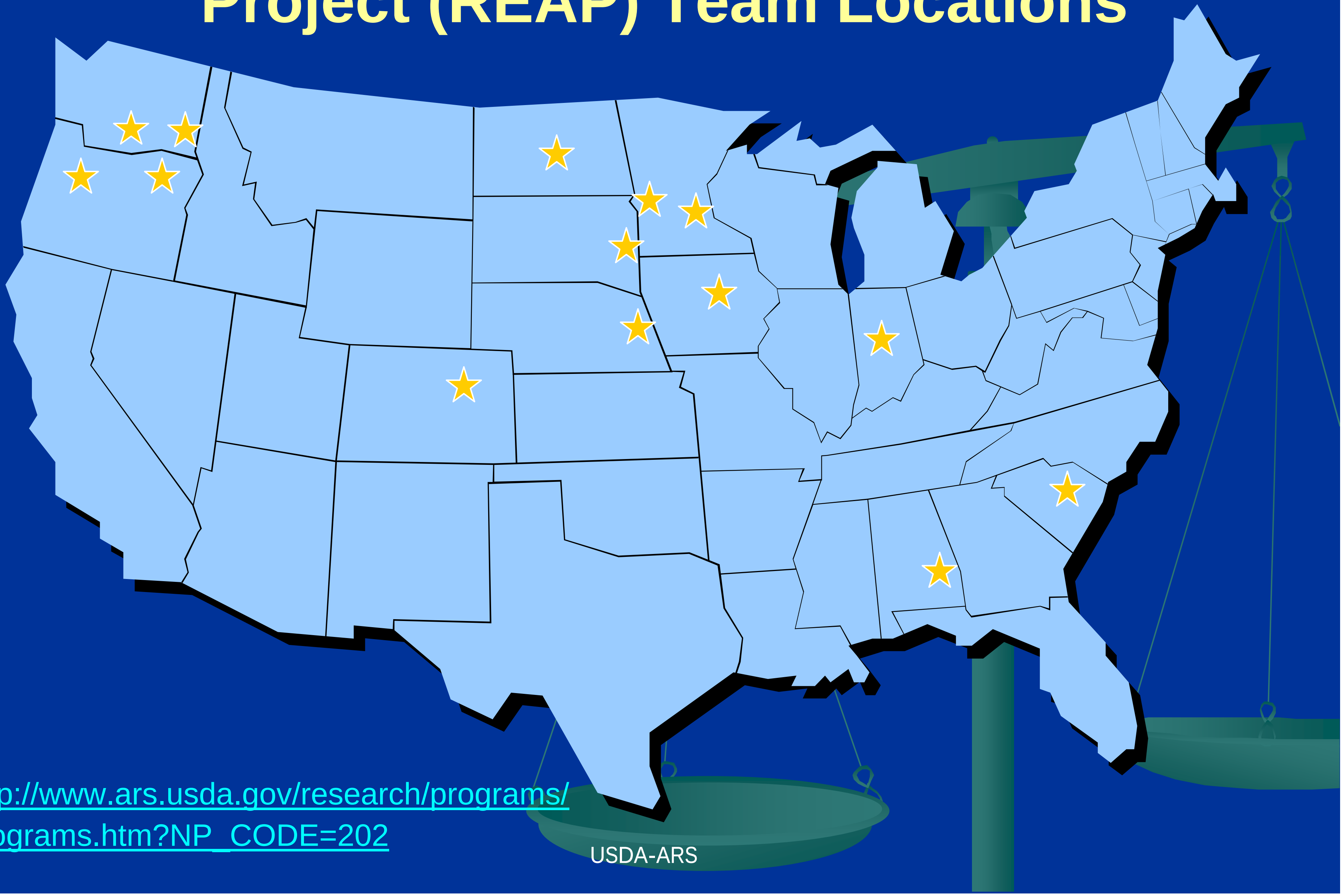
- Potential to negatively impact soil physical, chemical and biological properties of soil
- Increase risk of soil erosion
- Increase risk of losing soil organic matter
- Therefore potential to reduce productivity

Biomass management for Carbon (C) storage

- Storing C in soil – building humus
  - Nutrient cycling
  - Water holding capacity
  - Improve soil aggregation
  - Maintain soil productivity
- Remove CO_2 from atmosphere
- Improve resilience against erosion

Is there enough biomass to provide for all the soil needs and for energy?

USDA-ARS Renewable Energy Assessment Project (REAP) Team Locations



http://www.ars.usda.gov/research/programs/programs.htm?NP_CODE=202

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REAP goals

- Determine how much biomass needs to stay on the land to protect soil resource
- Compare short- and long-term economics of using biomass feedstock and soil organic input
- Provide recommendations and guidelines for sustainable biomass harvest

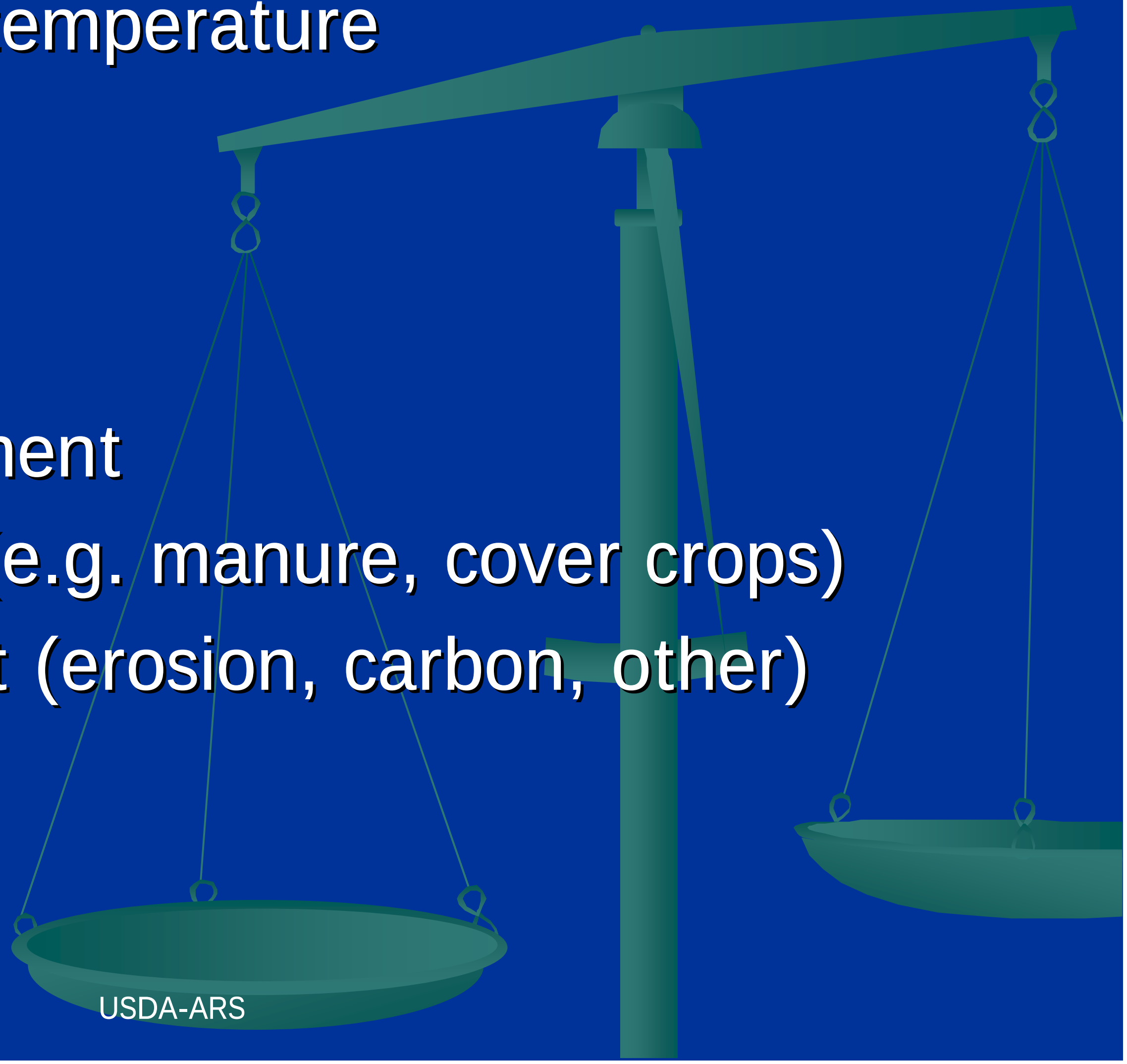
Products

- Guidelines for crop and soil management to ensure sustainable harvest
- Predictive tools for crop biomass harvest
- Tools to assess short and long-term trade-offs (environmental and economic)

Outcome: biomass energy industry based on sustainable management practices.

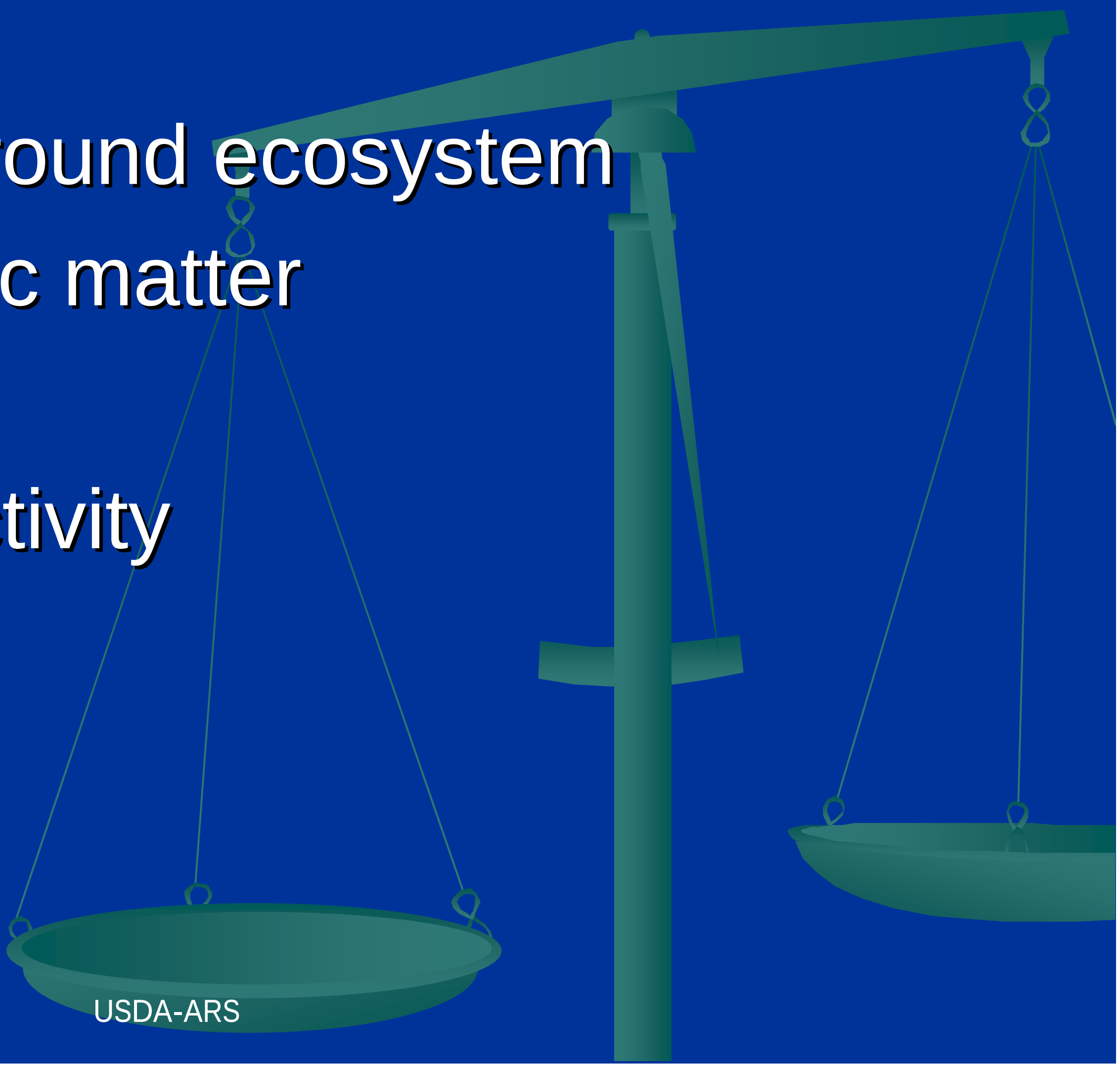
Minimum biomass inputs depends on

- Precipitation and temperature
- Crop
- Crop rotation
- Tillage
- Nutrient management
- Additional inputs (e.g. manure, cover crops)
- Limiting constraint (erosion, carbon, other)



How much biomass needs to stay in the field

- Prevent erosion
- Sustain belowground ecosystem
- Build soil organic matter
- Sequester C
- Maintain productivity
- Other



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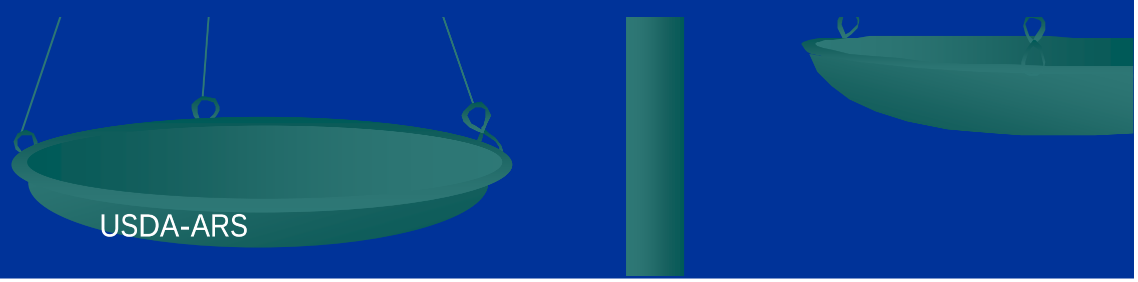
Residue removal and yield

State	Yr	Residue	Grain Yield response	Citation
IN	6	0, 1X and 2X remaining	None	Barber, 1979
IA	3	0, 66% 90% removed	None	Karlan, 1984
NE	4	0, 0.5, 1.0 to 1.5X	Decrease	Wilhelm et al, 1986
NE	11	0, 0.5, 1.0 to 1.5X	Decrease	Powers et al., 1988
IA	2	Removed over row	Increase	Kaspar, 1990
WI	7	Bare, 1X, 2X	Bare decreased (5/7) 2X decreased (6/7)	Swan, 1994
MN	13	0,1X	None or decrease	Linden et al, 2000
MN	29	Grain vs silage	None	Wilts et al., 2003
CN	30	Grain vs silage	decreased (3/4)	Hooker et al, 2003
OH	2.5	O, 50, 75, 100% removed	None or decreased	Blanco-Canqui and Lal, 2007

Harvestable stover based on erosion constraints and (1995-2000) corn management practices

Region	Avg. corn yield	Percentage Removed	Stover Collected	Stover Left
	Mg ha^{-1}	%	-----Mg ha^{-1}-----	
IA-MN	8.97	67.7	5.16	2.47
IL-IN	8.72	60.6	4.46	2.91
NE-Platte River	8.97	41.4	3.12	4.48

Based on Graham et al. 2007 AJ 99:1-11



Estimated minimum biomass inputs to prevent loss of SOC

Crop Rotation	Tillage	Minimum biomass	Cover
		Mg ha^{-1}	%
Corn continuous	MBP	7.6	5
Corn-soybean	MBP	12.5	5
Corn continuous	Chisel/NT	5.3	30-85
Corn-soybean	Chisel/NT	7.9	30-85
Wheat	MBP	4.5	5

Johnson et al (2006) JSWC 61(4) 121A-125A;
Johnson et al (2006) AJ 98:622-636

Other estimates of minimum input

- 7.4 Mg stover ha^{-1} yr^{-1}, SOC surface 15 cm – continuous corn, chisel plow, SD

Pikul et al., 2008

- 7.6 Mg stover ha^{-1} yr^{-1} surface 15 cm in corn/soybean rotation, conservation tillage, SD

Clay et al., 2006

- 2.1 Mg stover ha^{-1} yr^{-1} wheat rotation, No tillage. MT

Sainju et al 2006

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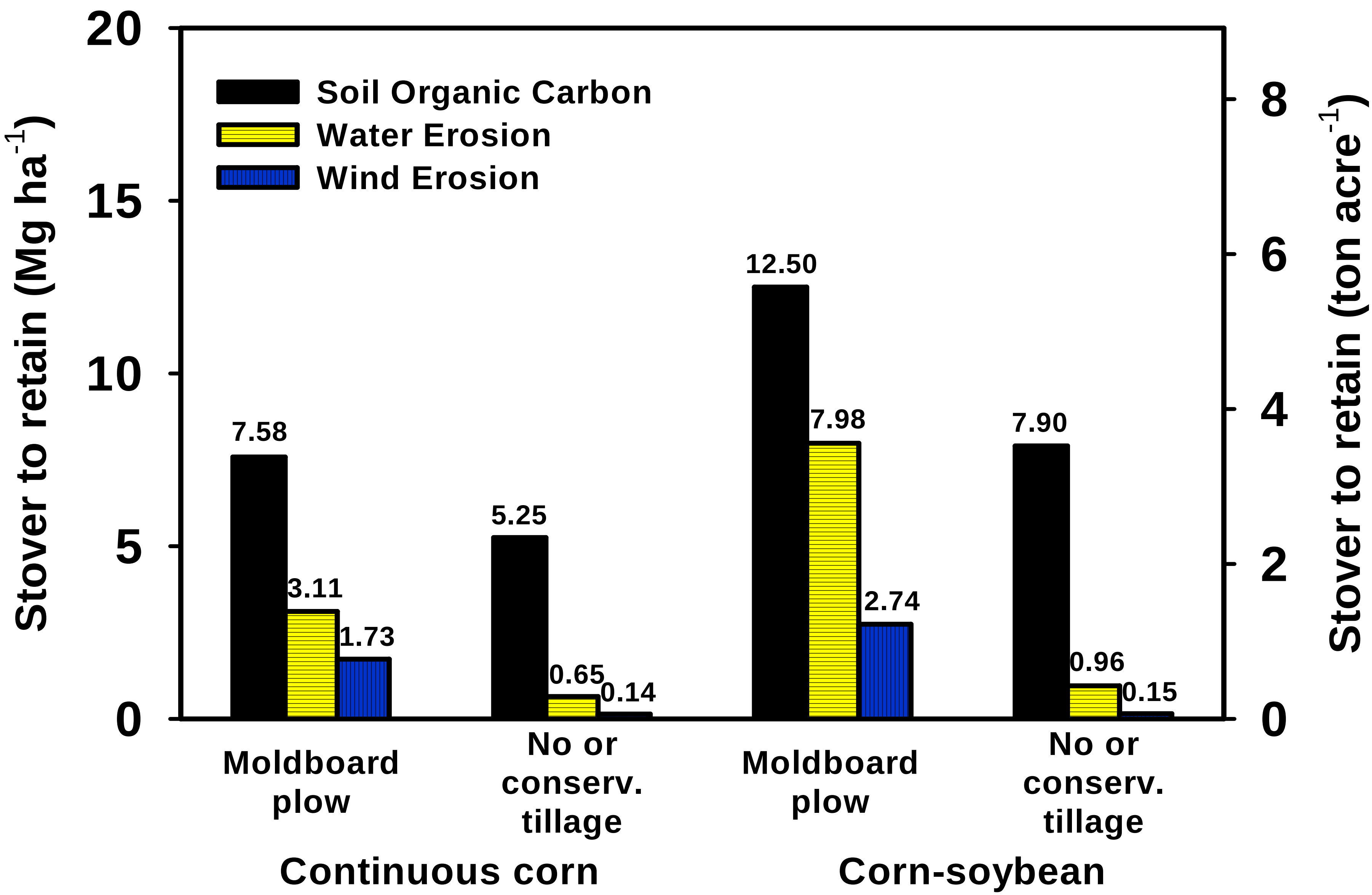
Maximum county average 2006 yield					
	Corn yield	Biomass yield	Min. biomass	In field	Harvested
States	----------Mg ha^{-1}		----------	--------%	---------
IA	12.1	9.13	5.3	57.9	42.1
MN	11.4	8.50	5.3	61.8	38.2
IN	11.2	8.45	5.3	62.6	37.4
IL	11.4	8.56	5.3	61.8	38.2

USDA-NASS; Johnson et al (2006) JSWC 61(4) 121A-125A; Johnson et al (2006) AJ 98:622-636

Example, assumes conservation tillage and continuous corn

Wilhelm et al., 2007, AJ



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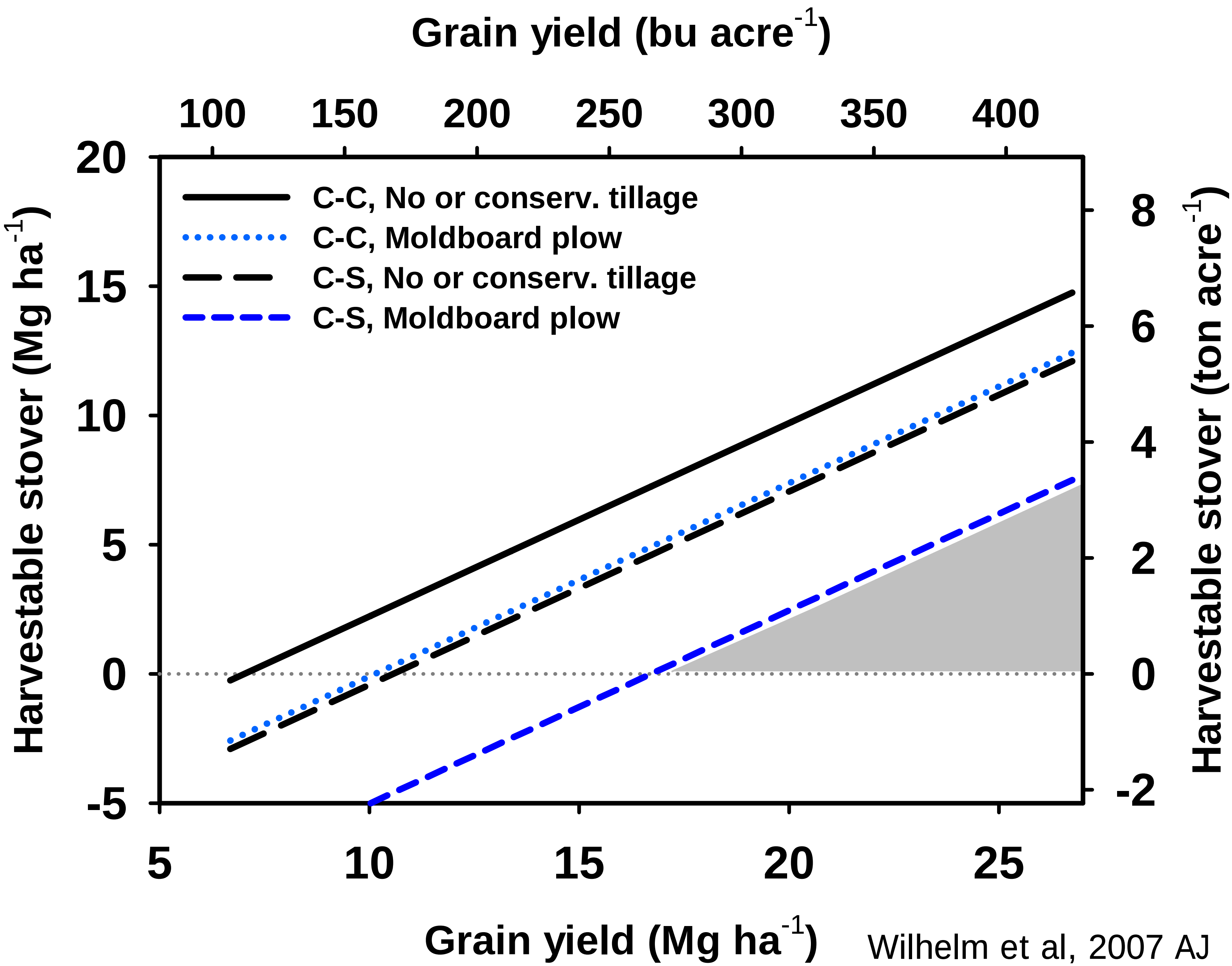
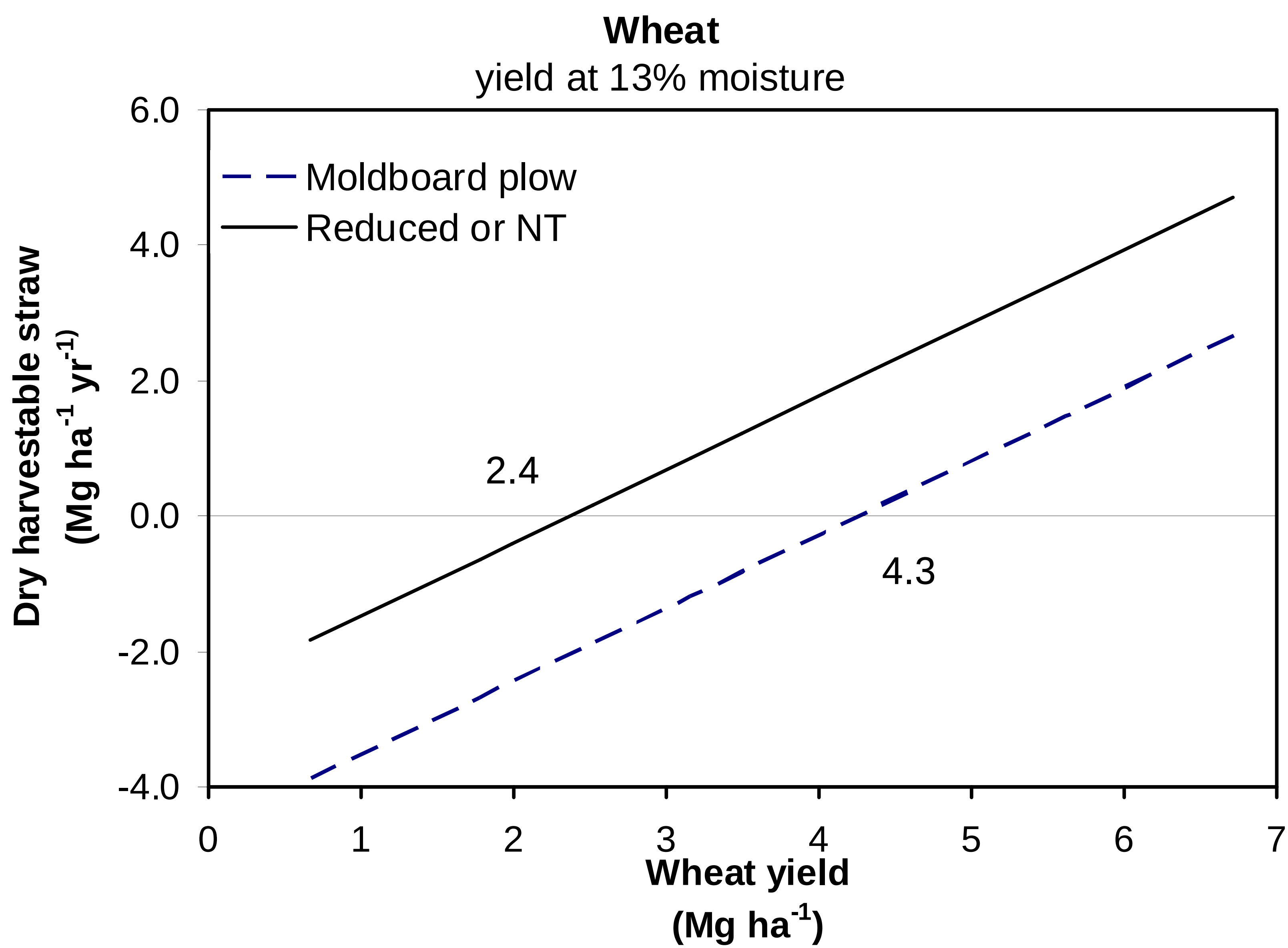


Wilhelm et al, 2007 AJ



Based on Johnson et al. 2006

Current projects

- Biomass removal study
  - Tillage:
    - No Till (Established 1995)
    - No Till (Established 2005)
    - Chisel Plow, spring disk
  - Removal rates: 0, 50, 75 and 100% of rows
  - Monitor: yield, biomass produced, returned, soil carbon (0-100 cm), infiltration

Current projects

- Carbon crop study: est. 2000, modified 2007
  - Rotation and biomass harvest treatments
    - Corn/soybean
    - C/S/W straw/stubble harvest and cover coprs
    - C/S/W/3-alfalfa
    - Perennial grasses – with biomass harvest
  - Biomass/yield production and return, soil C
  - No tillage

Summary

- Crop biomass
  - Building block soil organic matter
  - Organic matter improves
    - aggregation
    - Water holding capacity
    - Reduces compaction risk
    - Provide nutrients
    - Provides resilience against erosion
  - Protection against wind and water erosion

Summary

- No simple solution
- Challenge/opportunity
- Fossil fuels are not sustainable and have a huge environmental impact
- New paradigm, integrated renewables, environmentally and economically sustainable
- Conservation of energy

Its about the future: finding balance

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