# Riparian and Upland Forest Buffers Water and Soil

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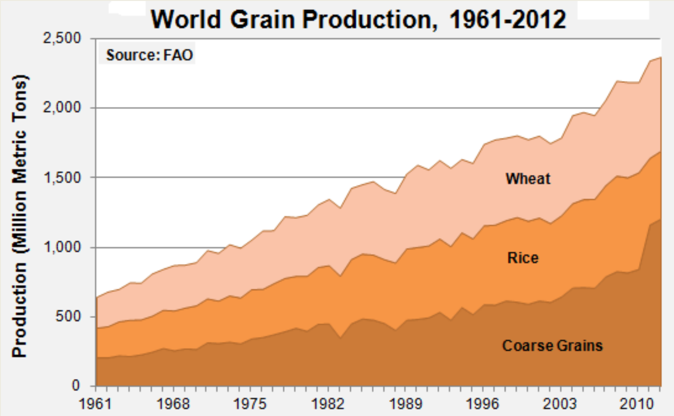
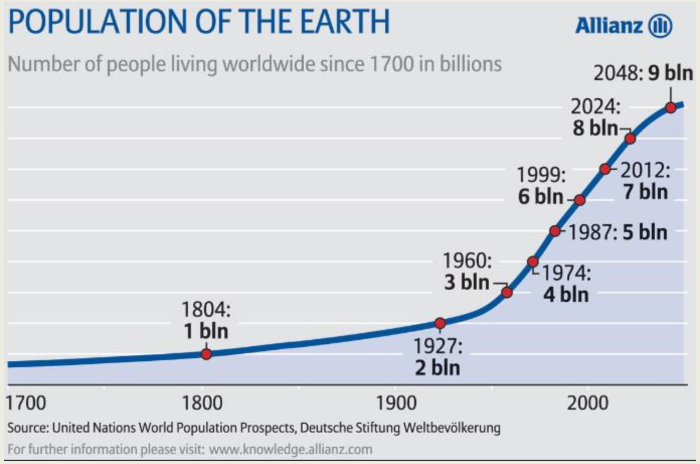
*A Global Center for Agroforestry, Entrepreneurship and the Environment*

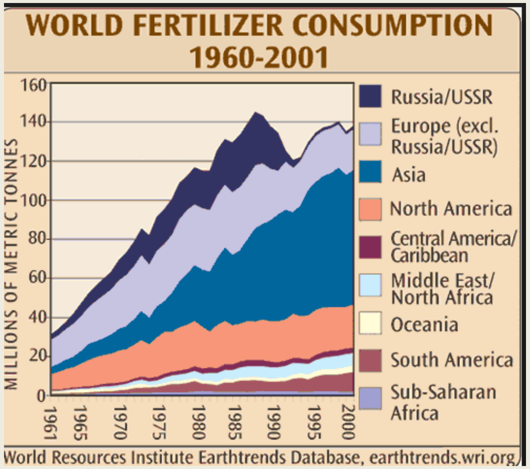
From 1950 to 2012, the number of people fed by a single U.S. farmer increased from 19 to 155.

Globally, food grain production grew from 630 million tons in 1950 to 2.4 billion tons in 2012.

During the same period fertilizer and agrochemical use also increased with more forest clearing.



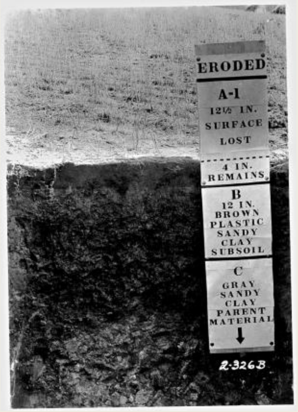



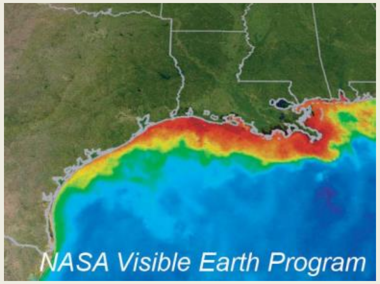



# Overview

**Challenges**

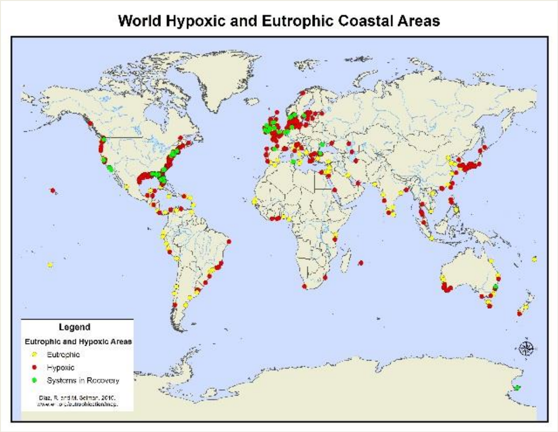
**Produce**
**Resources**
**Changing Climate**

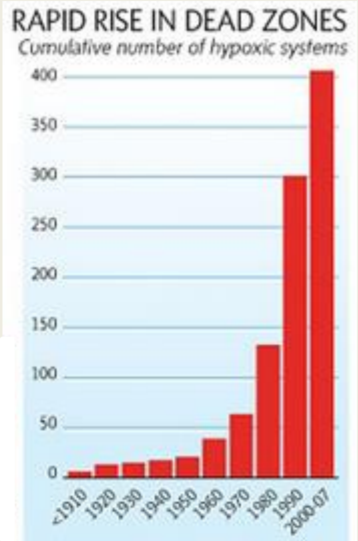



Water Quality | Soil Quality

**Produce while maintaining or Improving the Quality of Water and Soil**



# The challenge to produce enough food will be greater over the next 50 years than in all human history

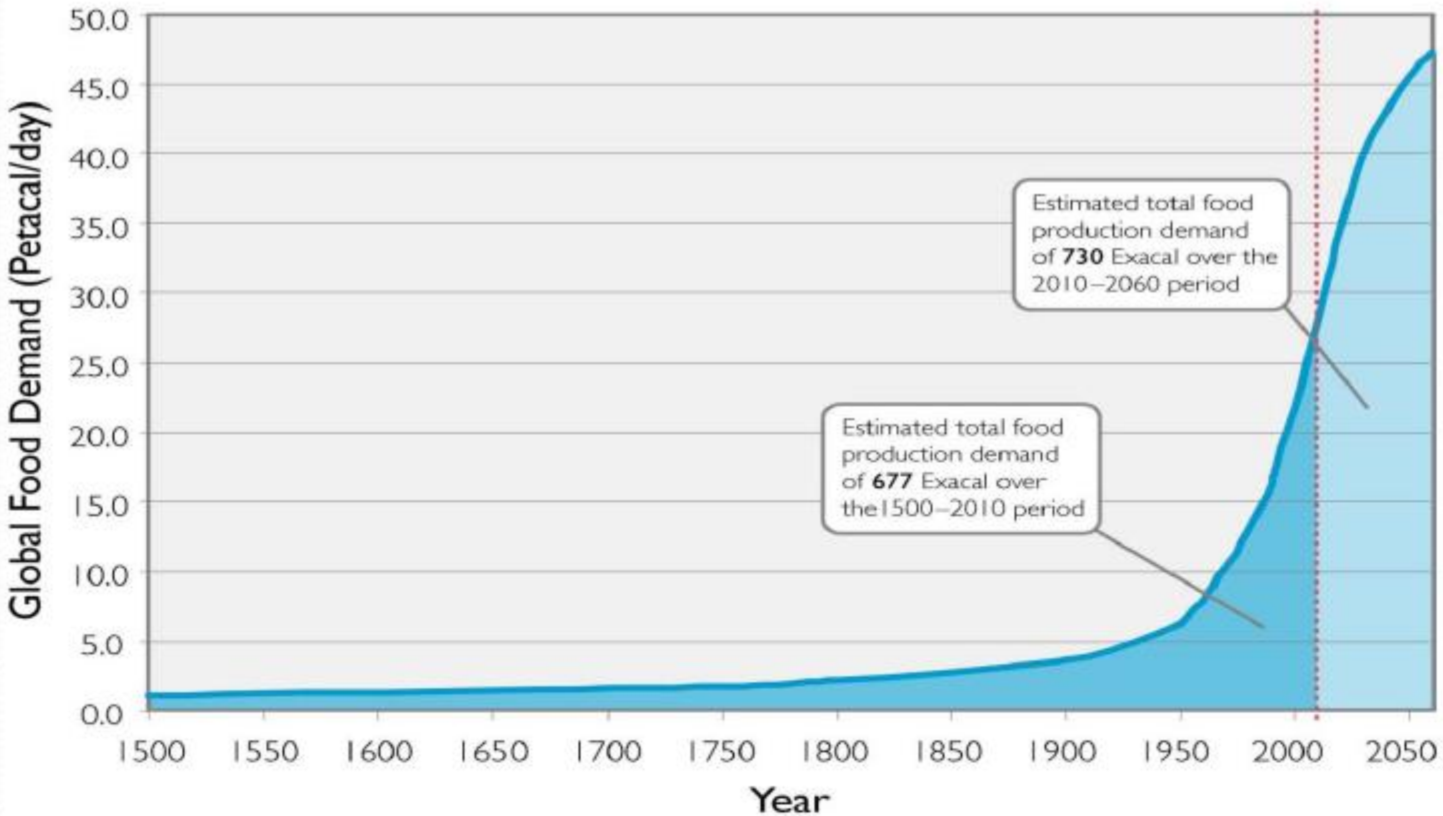


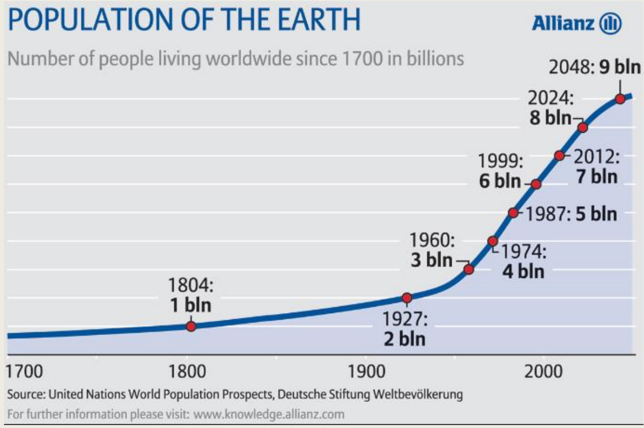

Figure 1. Explanatory notes:

- Based on data from FAOSTAT and UN Population Division, with simple scenario modelling from CSIRO 2009 (BA Keating, unpublished)
- Assumes growth trends in per capita food consumption growth in developing countries (currently 2668 kcal per capita per day) are maintained such that current developed country food consumption levels (3331 kcal per capita per day) are reached by 2050
- Assumes that diversion of food products (or production resources) to biofuels grows from current levels to 15% by 2050
- Assumes no food wastage prior to 1920 ramping up to current estimates of food wastage of 30% and these are not reduced going forward.
- A Petacal is $10^{15}$ calories, an Exacal is $10^{18}$ calories.

# Demand for high quality food

3 billion people

Middle class expansion (next 20 yrs)




Soy

(2000L/kg)

Water

Corn

(650L/kg)

73% more meat
By 2050

[1]United Nations Secretary-General's High-level Panel on Global Sustainability (2012). Resilient People, Resilient Planet: A future worth choosing. New York: United Nations.

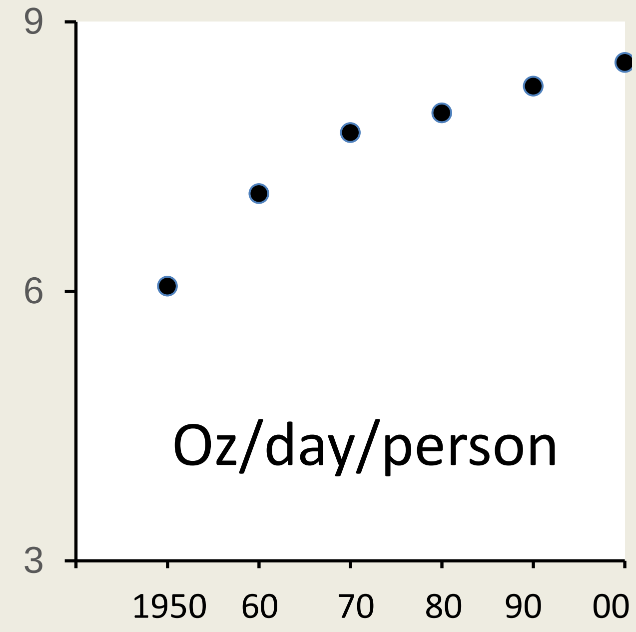
# Meat consumption, Soil and Water

3 billion People * 4 oz/day

750,000,000 lb meat/day

~1300 lb/animal

500,000 animals/day



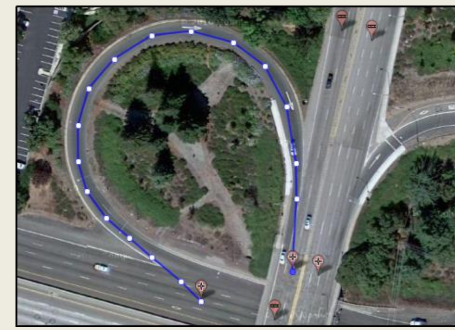

USDA/Economic Research Service, www.ers.usda.gov

# Land Limitation/Productivity

**Share of land use that remained the same, 1982-2007**

| | 5-year periods | | | | | 25-year period |
|---|---|---|---|---|---|---|
| | 1982-87 | 1987-92 | 1992-97 | 1997-02 | 2002-07 | 1982-2007 |
| | *Percent* | | | | | |
| Cropland | 93 | 92 | 95 | 93 | 96 | 78 |
| Pasture/rangeland | 95 | 96 | 95 | 96 | 98 | 86 |
| Forestland | 98 | 98 | 98 | 98 | 99 | 92 |

Source: USDA, Economic Research Service calculations based on USDA's Natural Resources Conservation Service, National Resources Inventory data (2009).

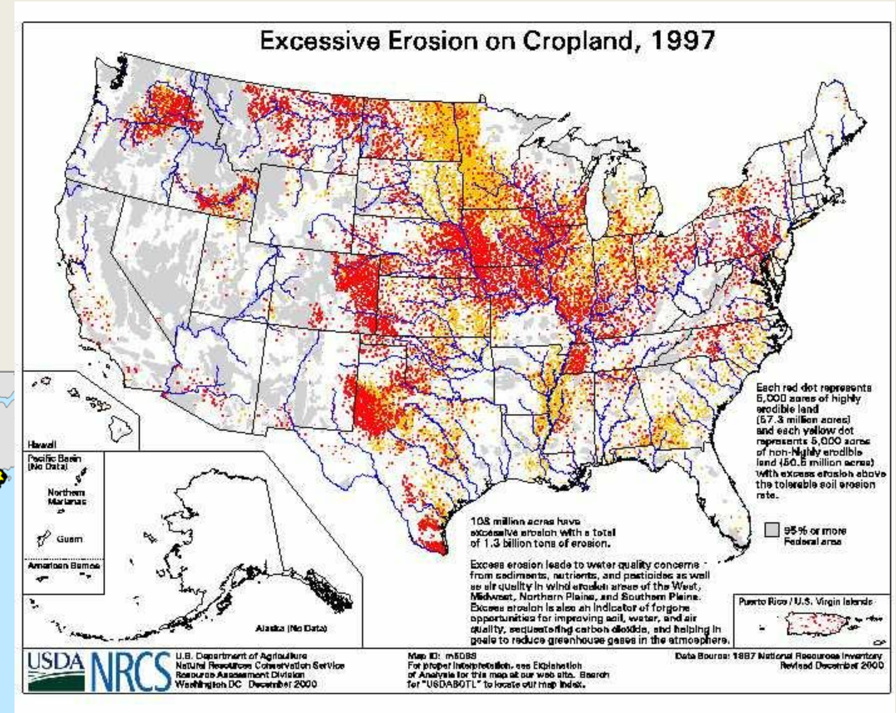


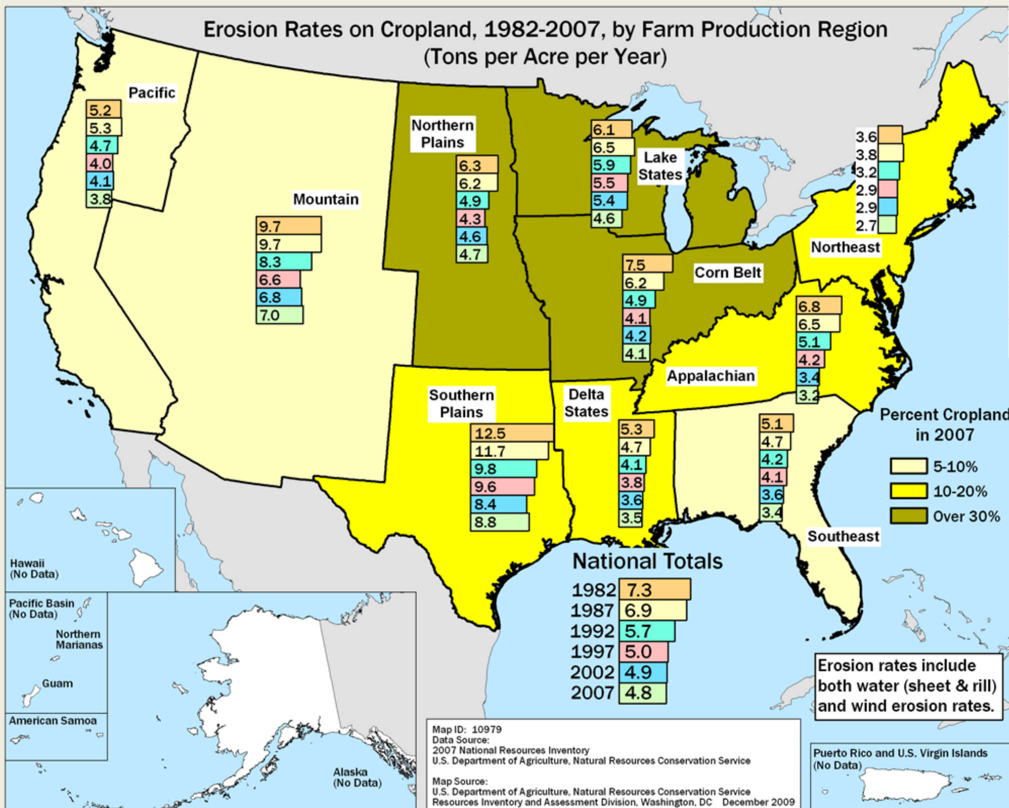
Cynthia Nickerson, Robert Ebel, Allison Borchers, and Fernando Carriazo. 2011. Major Uses of Land in the United States, 2007. USDA. Economic Information Bulletin 89

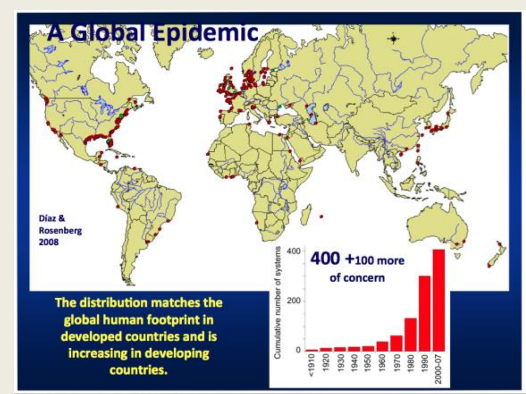
**41 million ac Ag land in US 1982-2007**

**7% more by 2030**

# Actual soil erosion rates are greater than the upper limit of tolerable soil erosion.



# Midwest US Erosion in 2011

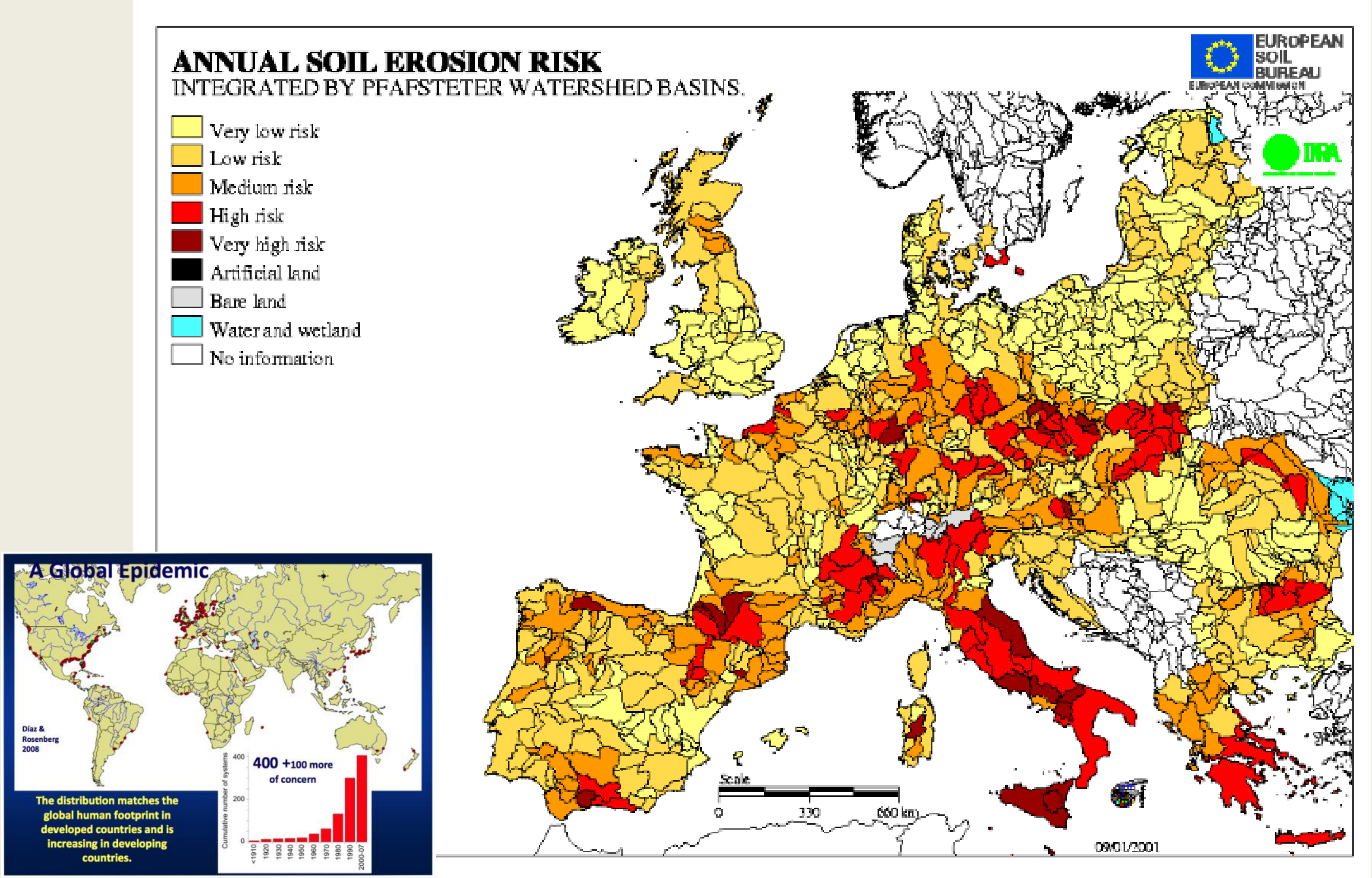
Erosion from Midwest cropland is up to 12 times higher than the federal government's estimates.

Erosion threatens the production, increases water pollution from the Mississippi River to the Gulf of Mexico.

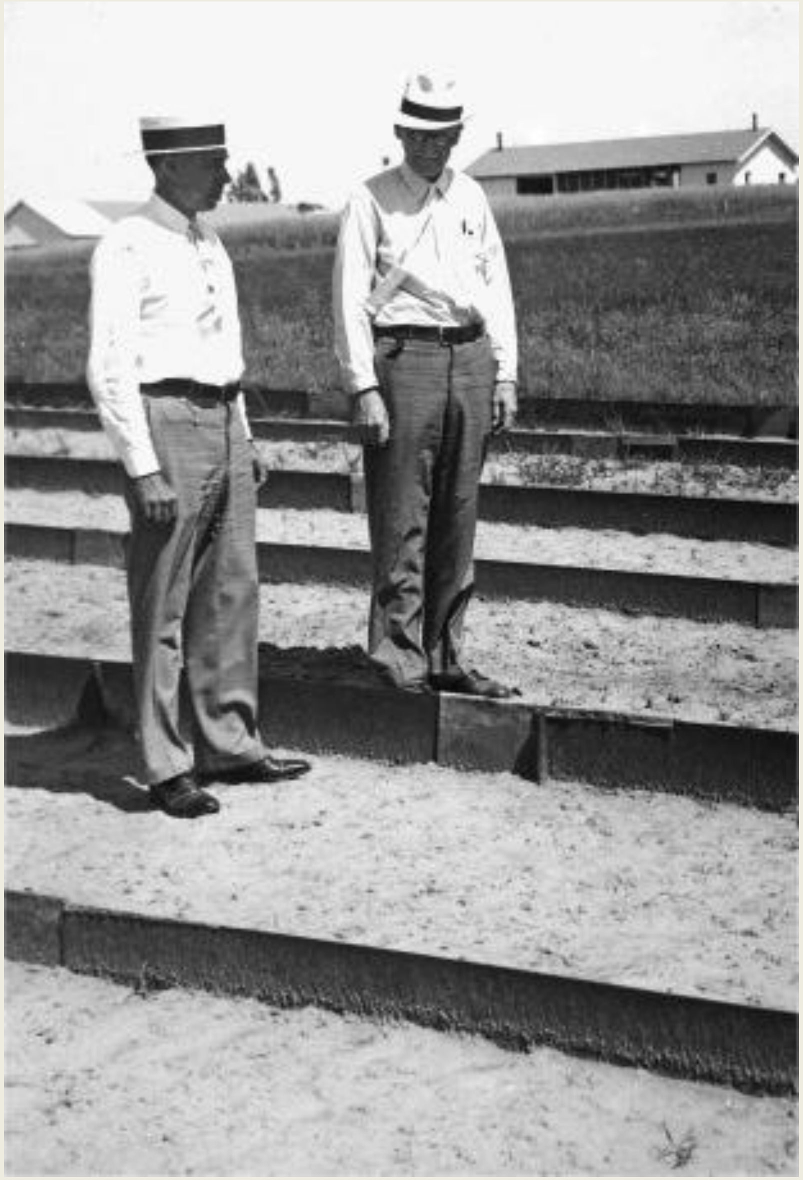
Economists put the cost of soil erosion between $60 and $100 billion per year.

*Cox et al. 2011 Losing Ground.* Environmental Working Group.

# Actual soil erosion rates for tilled, arable land in Europe are, on average, 3 to 40 times greater than the upper limit of tolerable soil erosion.



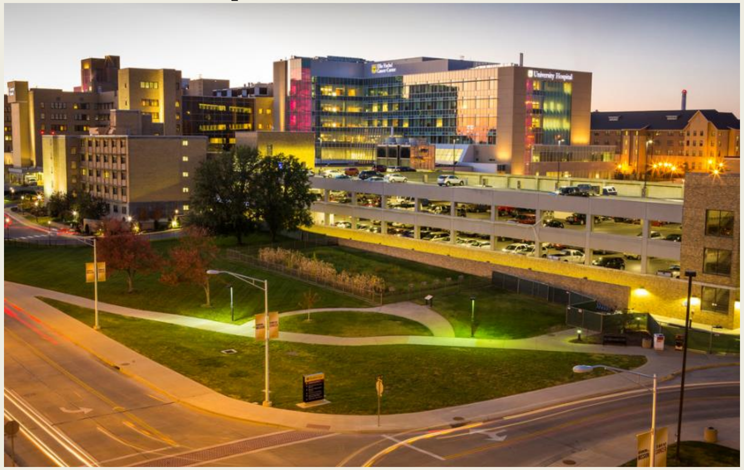
# Historic Duley-Miller Erosion Plots



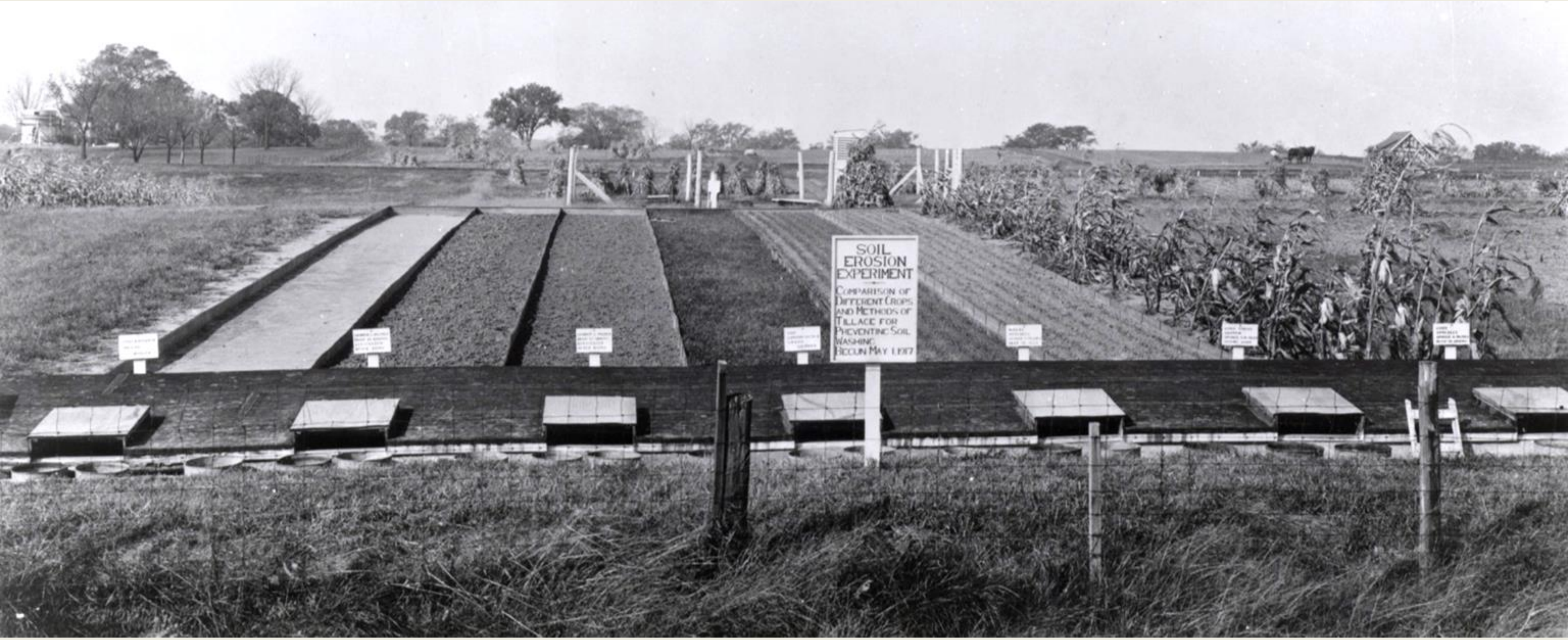
Soil Erosion Plots (~1937)
**Frank L. Duley, and Merritt F. Miller**

The first plots in the USA for measuring runoff and erosion as influenced by different crops was established in 1917.

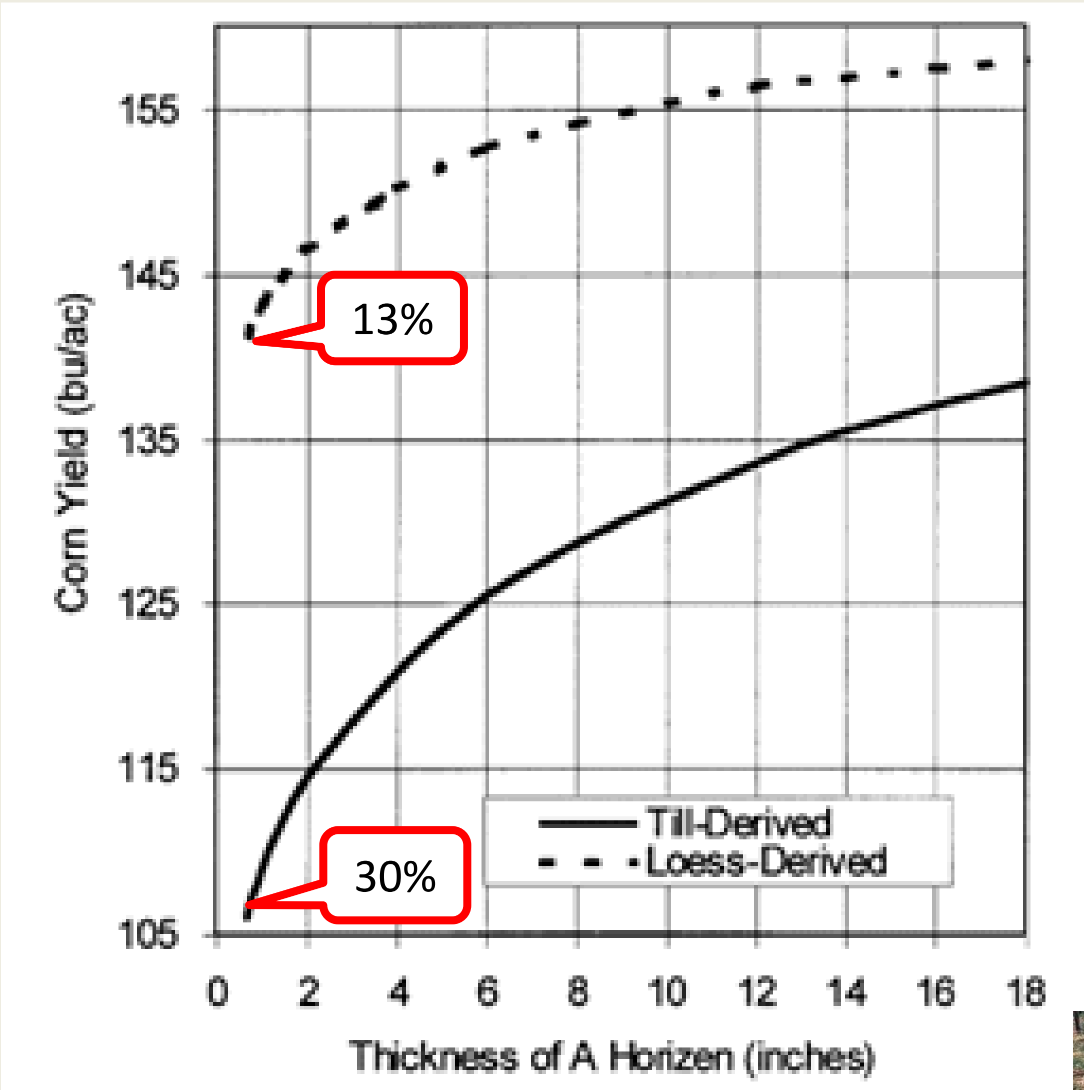
The plots were used to help develop the Universal Soil Loss Equation (USLE, RUSLE)

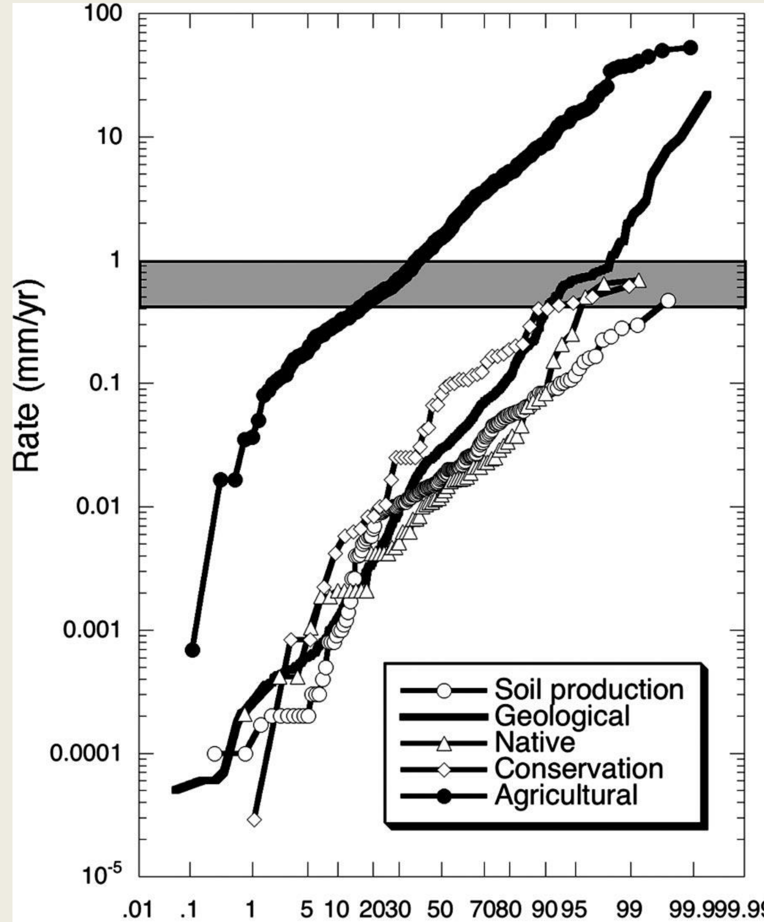


# Historic Duley-Miller Erosion Plots



# Soil Erosion and Productivity



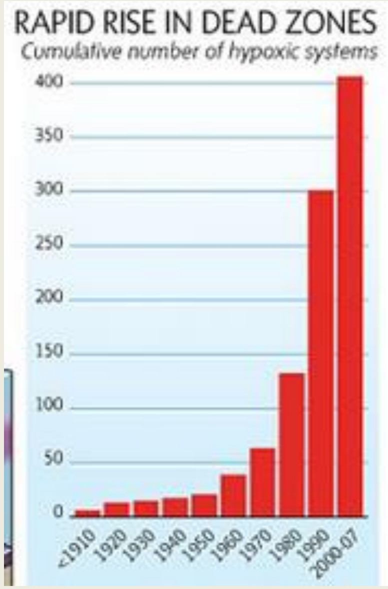

Montgomery, 2007

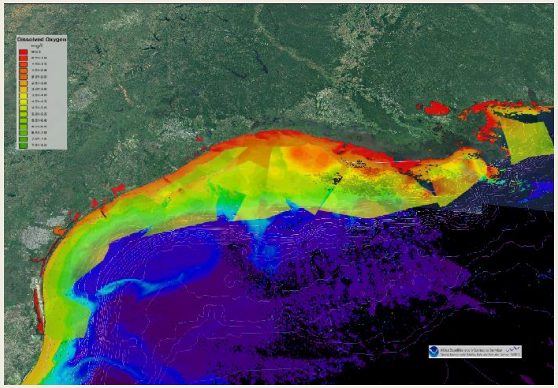
Al-Kaisi 2001. Soil erosion and crop productivity: topsoil thickness

# Water Quality:

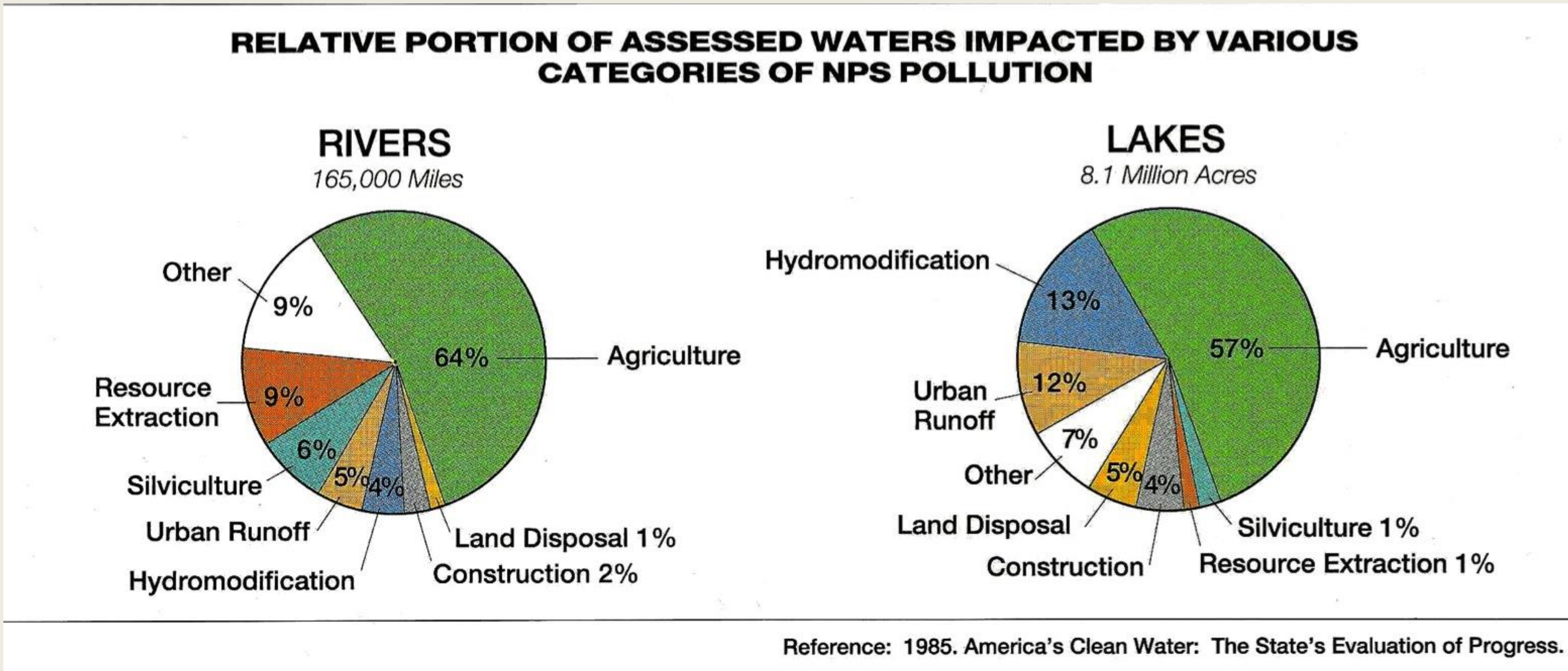
| Water Body | Total size | Assessed (% of total) | Impaired (% of assessed) |
|---|---|---|---|
| Rivers | 3,533,205 miles | 16% | **44%** |
| Lakes | 41.7 million acres | 39% | **64%** |
| Estuaries | 87,791 square miles | 29% | **30%** |

USEPA, 2013

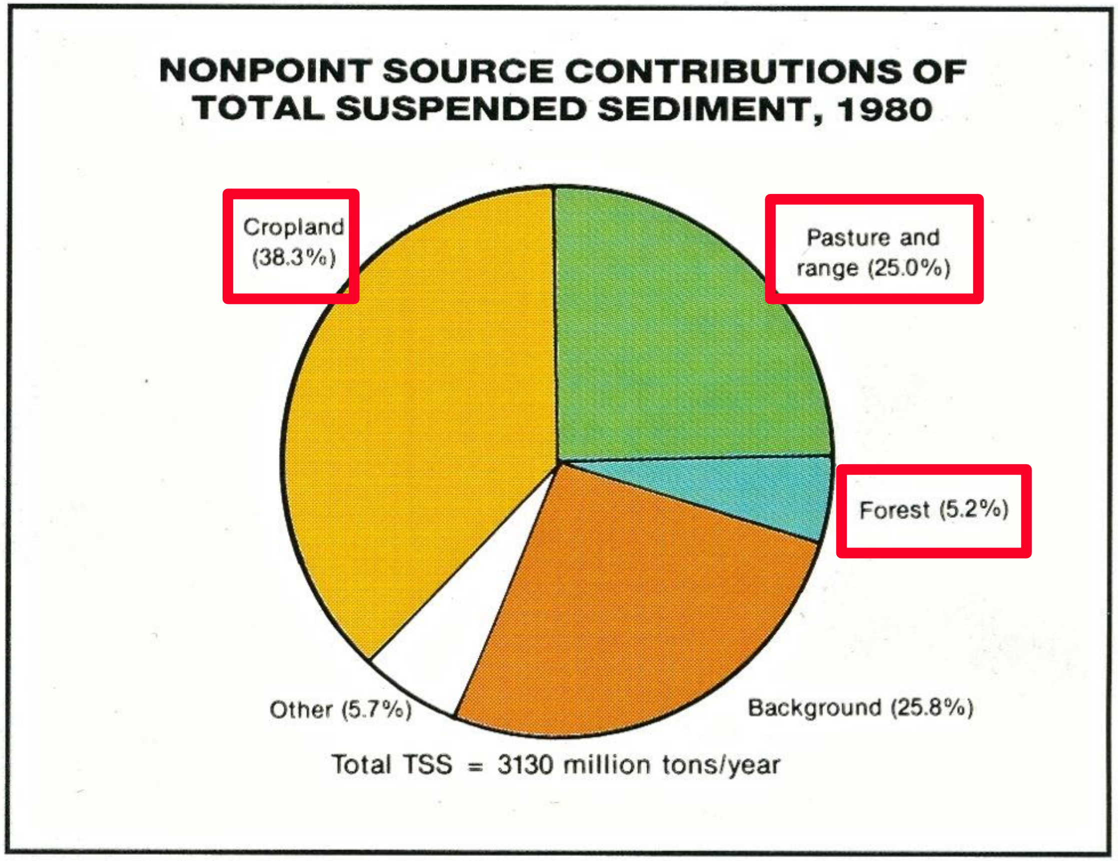


# Source: Nonpoint Source Water Pollution

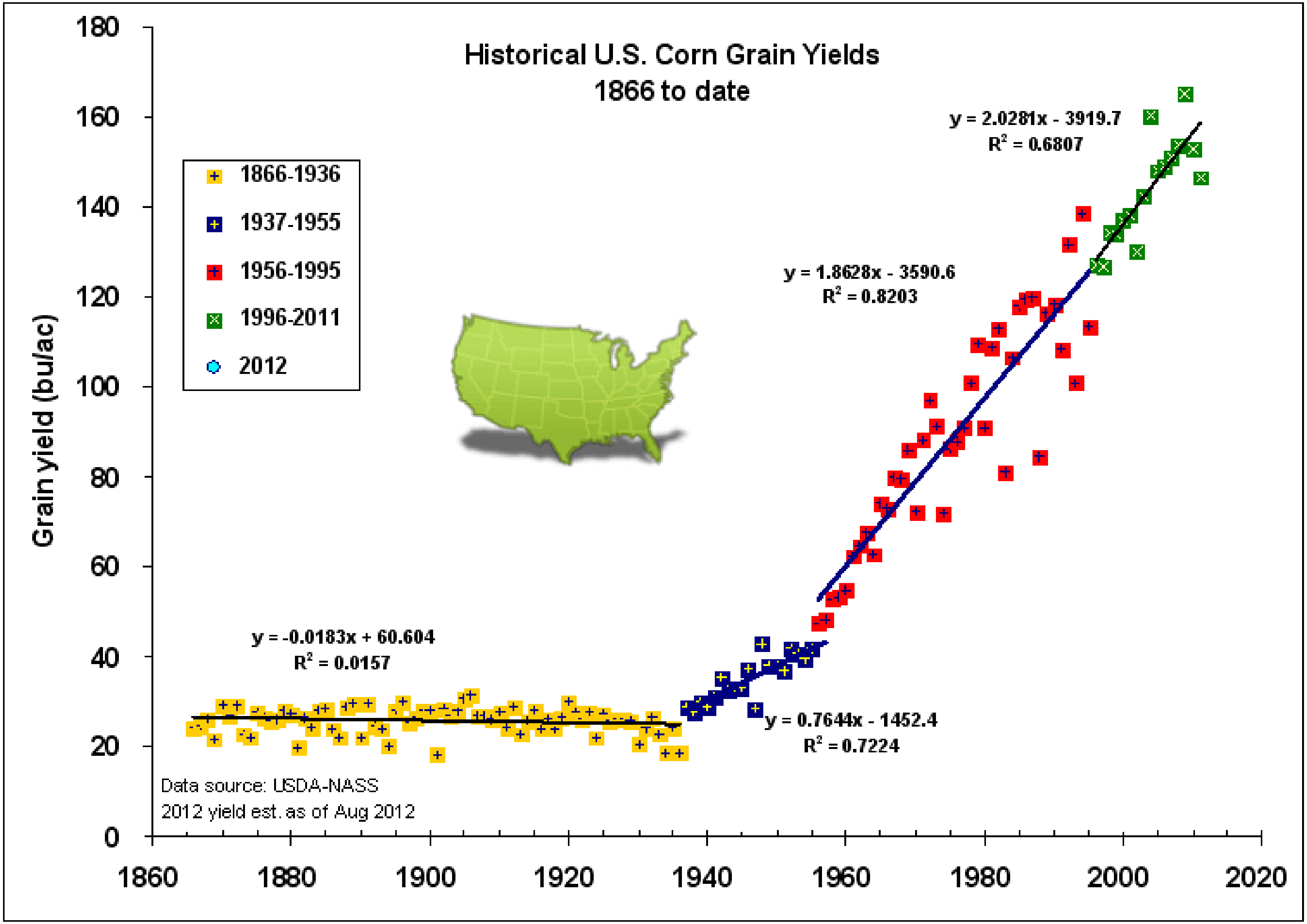


# Nonpoint Sediment Source by Land



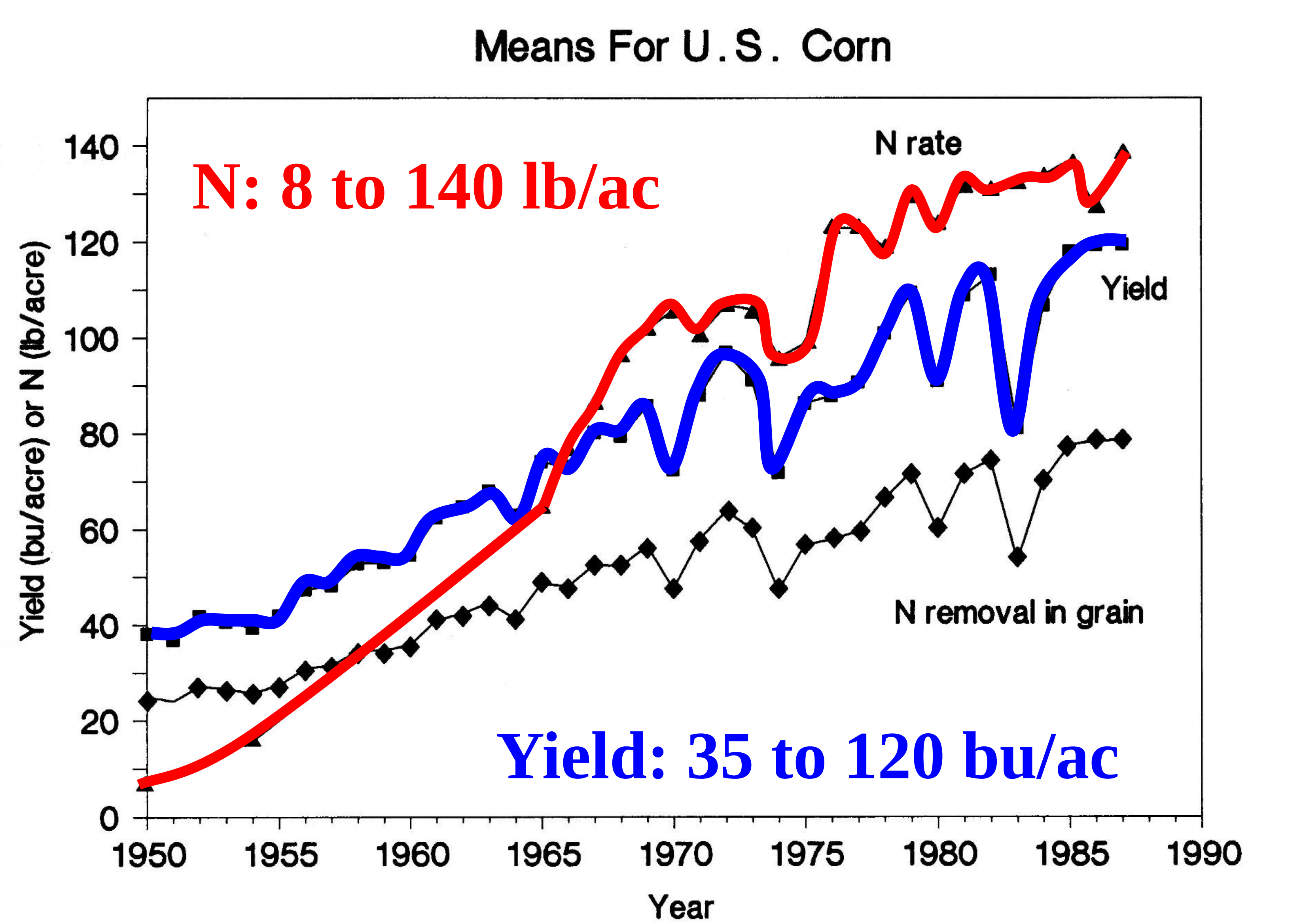

Reference: 1989. Environmental Trends, Council on Environmental Quality.

*From:* Welsch, D. 1991. Riparian forest buffers: Function and design for protection and enhancement of water resources. U.S. Department of Agriculture Forest Service Report NA-PR-07-91



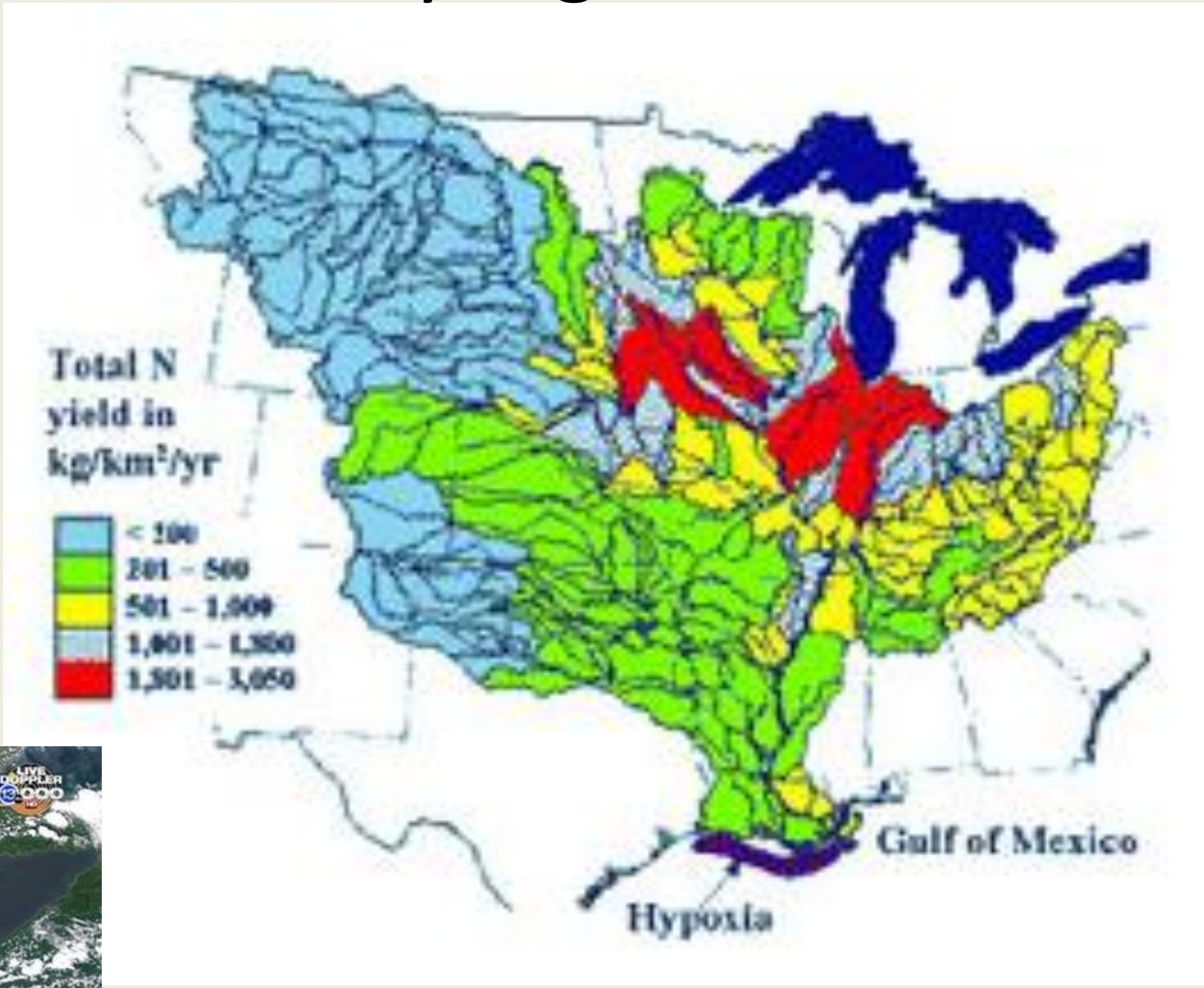

http://www.agry.purdue.edu/ext/corn/news/timeless/YieldTrends.html

# US Corn Production and Fertilizer use from 1950 to 1990




**Follett et al., 1990**

# Total N contribution by regions

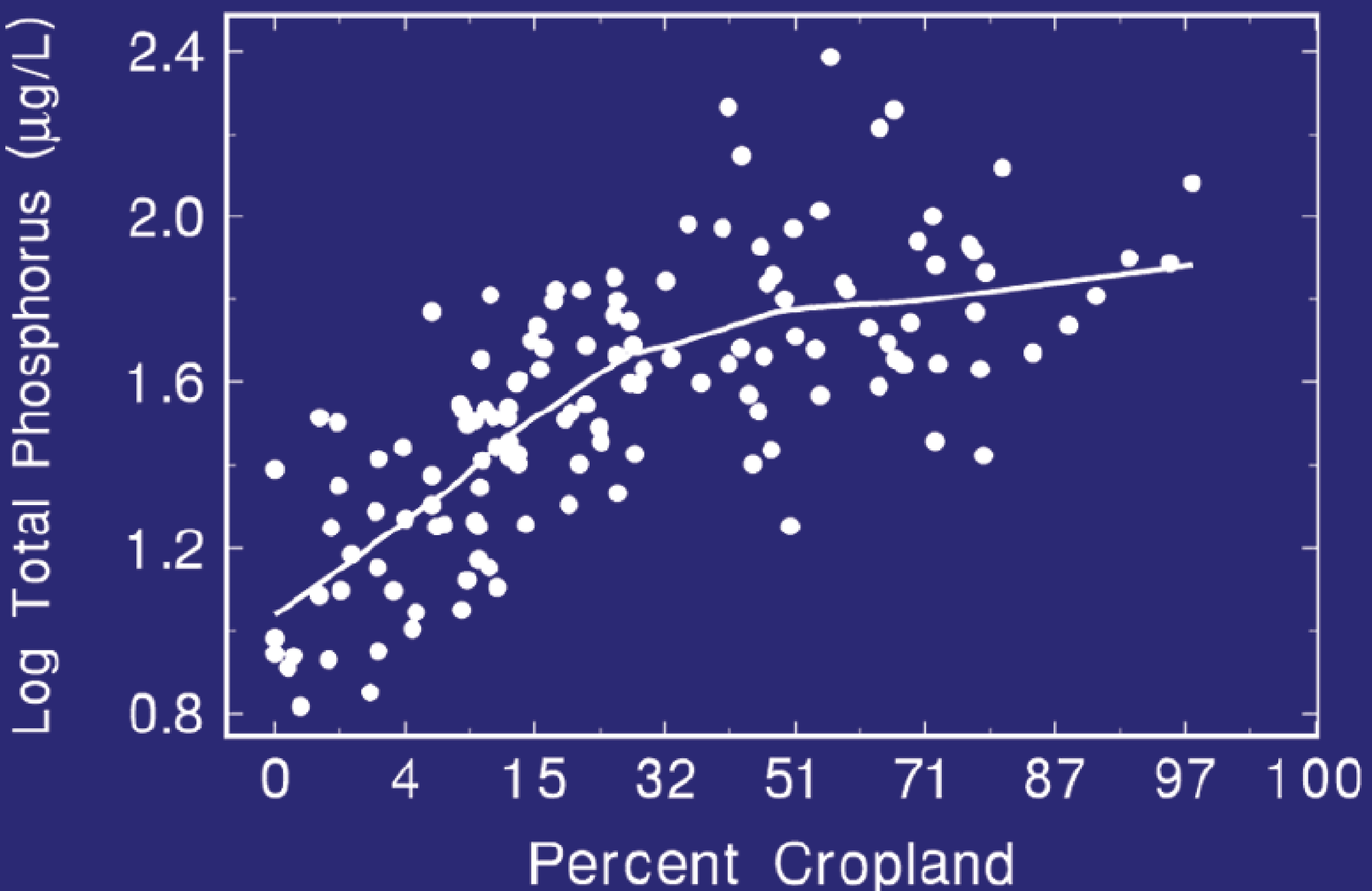




Donald Boesch, University of Maryland

# Summer Mean Phosphorus vs. Row Crop

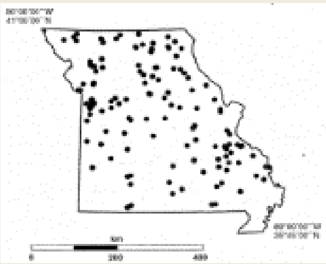
(variance from reservoir volume and flushing rate)

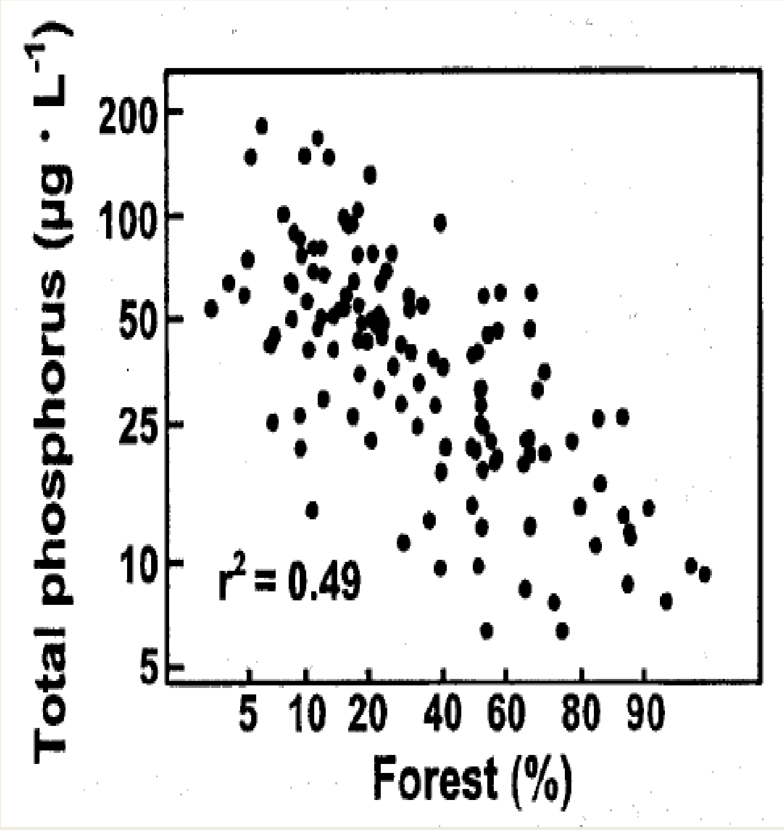


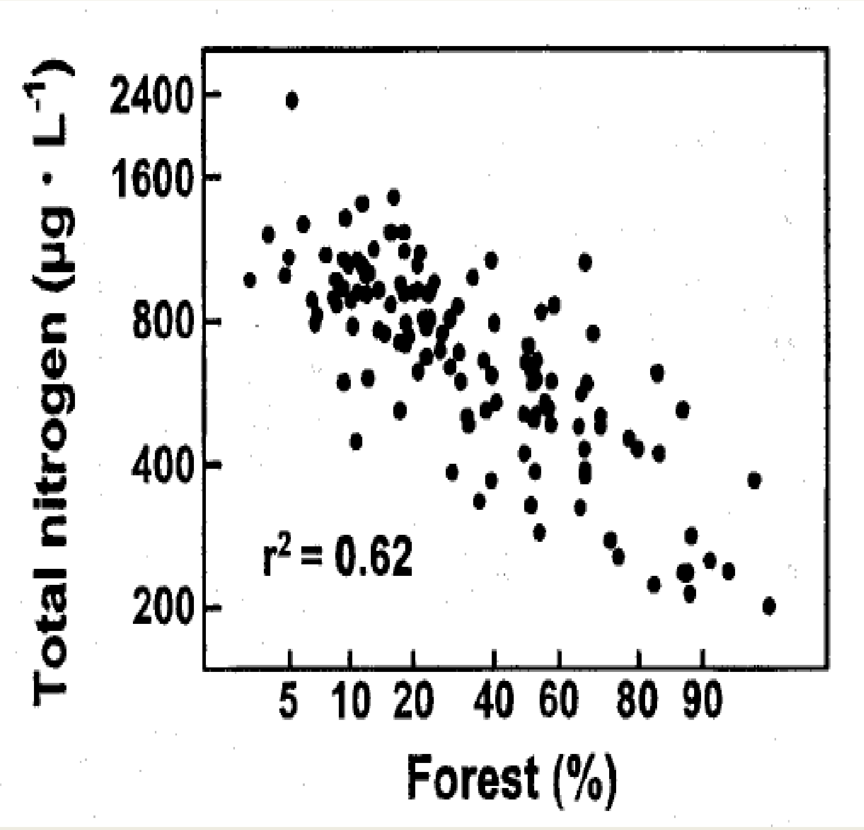

Jones et al

# Missouri Lakes

# Forest vs. Phosphorus & Nitrogen








Jones et al., 2004

# Observed Change in Very Heavy Precipitation

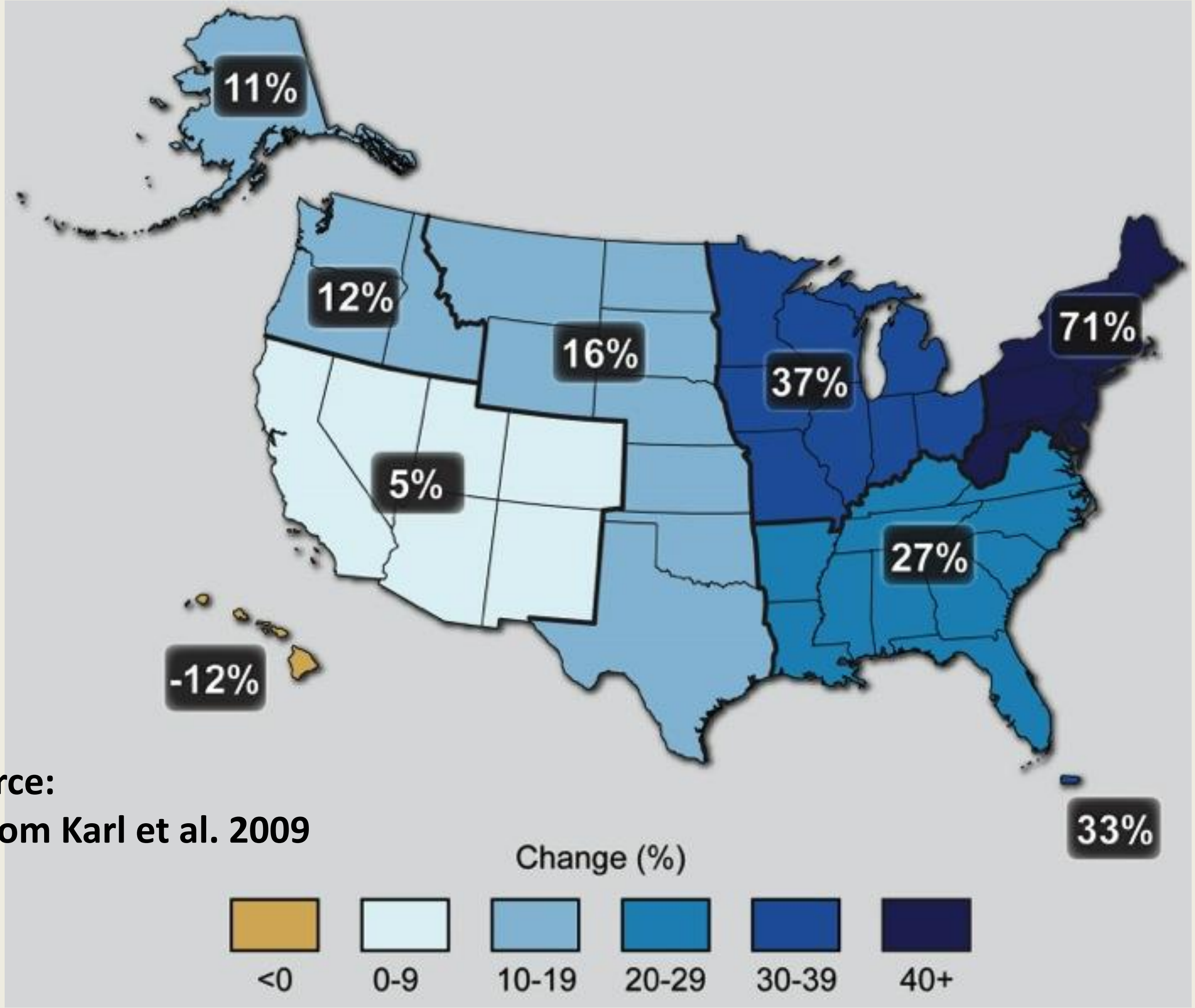
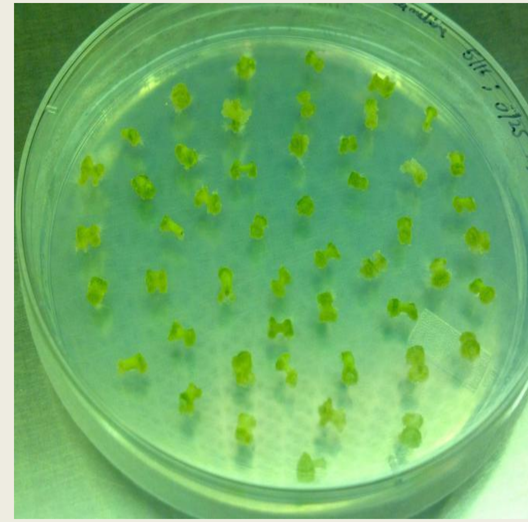



**Figure source:**
**updated from Karl et al. 2009**

# POTENTIAL EFFECTS ON SOIL EROSION AND RUNOFF FROM CROPLAND OF OBSERVED CHANGES IN PRECIPITATION (SWCS)

| | Increase in Mean Annual Precipitation | | | |
|---|---|---|---|---|
| | **5%** | **10%** | **20%** | **40%** |
| **Change in Erosion** | | | | |
| Increase only frequency of precipitation | 4% | 9% | 17% | 34% |
| **Increase only intensity of precipitation.** | **12%** | **24%** | **48%** | **95%** |
| Increase frequency and intensity equally | 8% | 17% | 33% | 66% |
| **Change in Runoff** | | | | |
| Increase only frequency of precipitation | 6% | 13% | 26% | 51% |
| **Increase only intensity of precipitation** | **13%** | **25%** | **50%** | **100%** |
| Increase frequency and intensity equally | 10% | 20% | 39% | 79% |

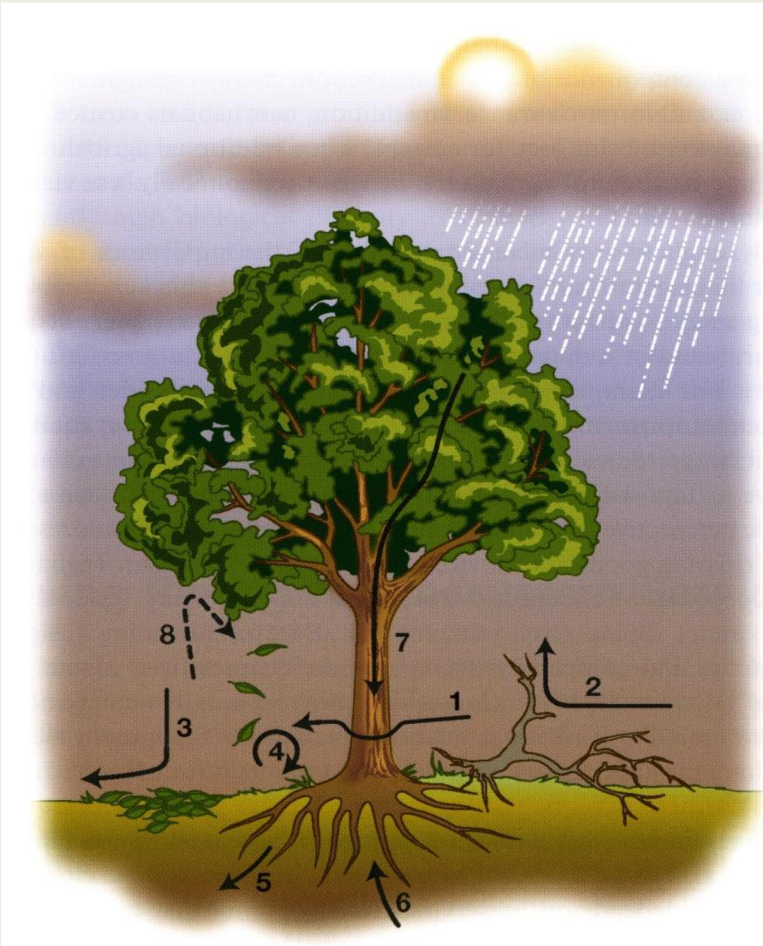
Source: Derived from Pruski and Nearing 2002.



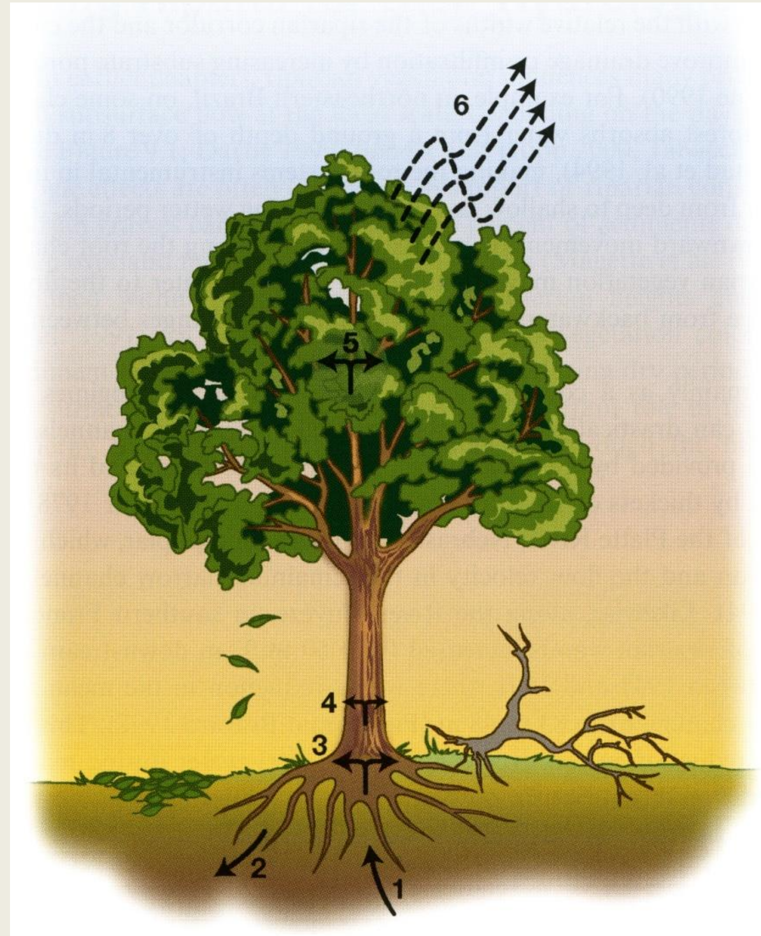

# Performance?

# The Role of Trees

## Physical Impact




## Physiological Impact




1. Flow resistance
2. Flow diversion
3. Infiltration
4. Turbulence
5. Porosity
6. Capillary fringe by root
7. Stem flow
8. Condensation

1. Hydraulic lift
2. hydraulic redistribution
3. Water storage (large roots)
4. Water storage (stem)
5. Water storage (branches leaves)
6. Evapotranspiration



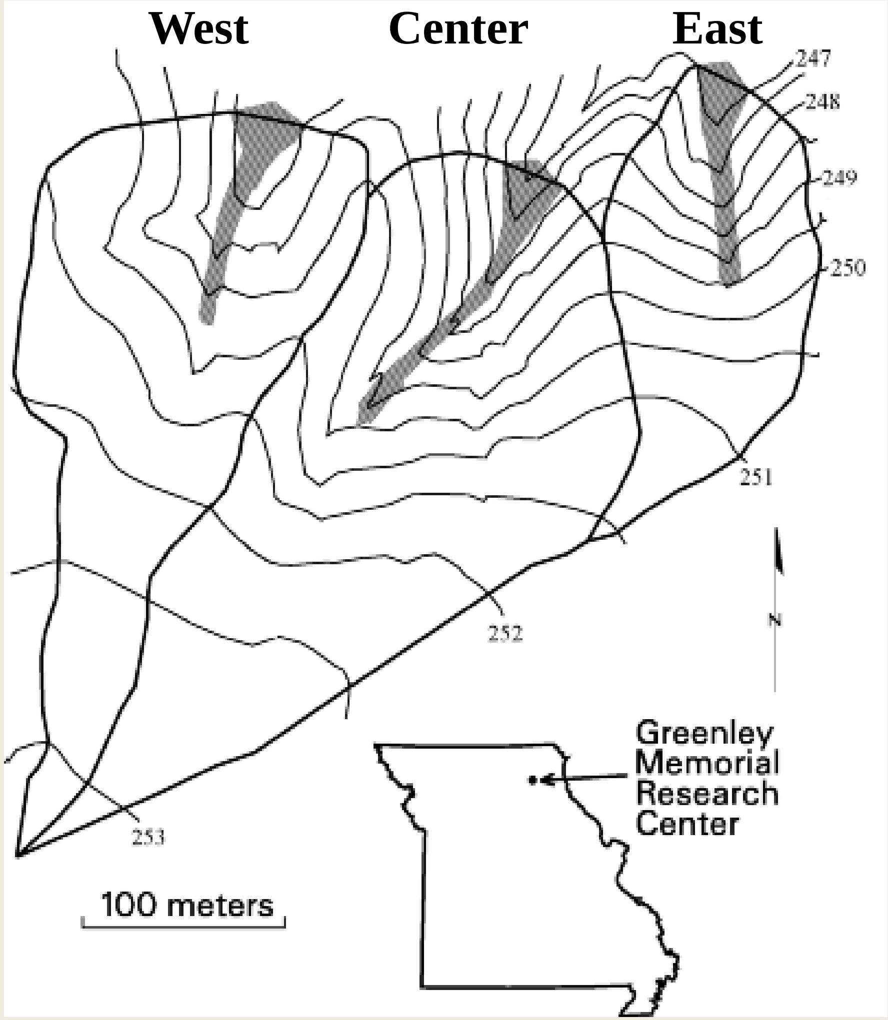
Naiman et al., 2005


Paired watershed at Greenley Center

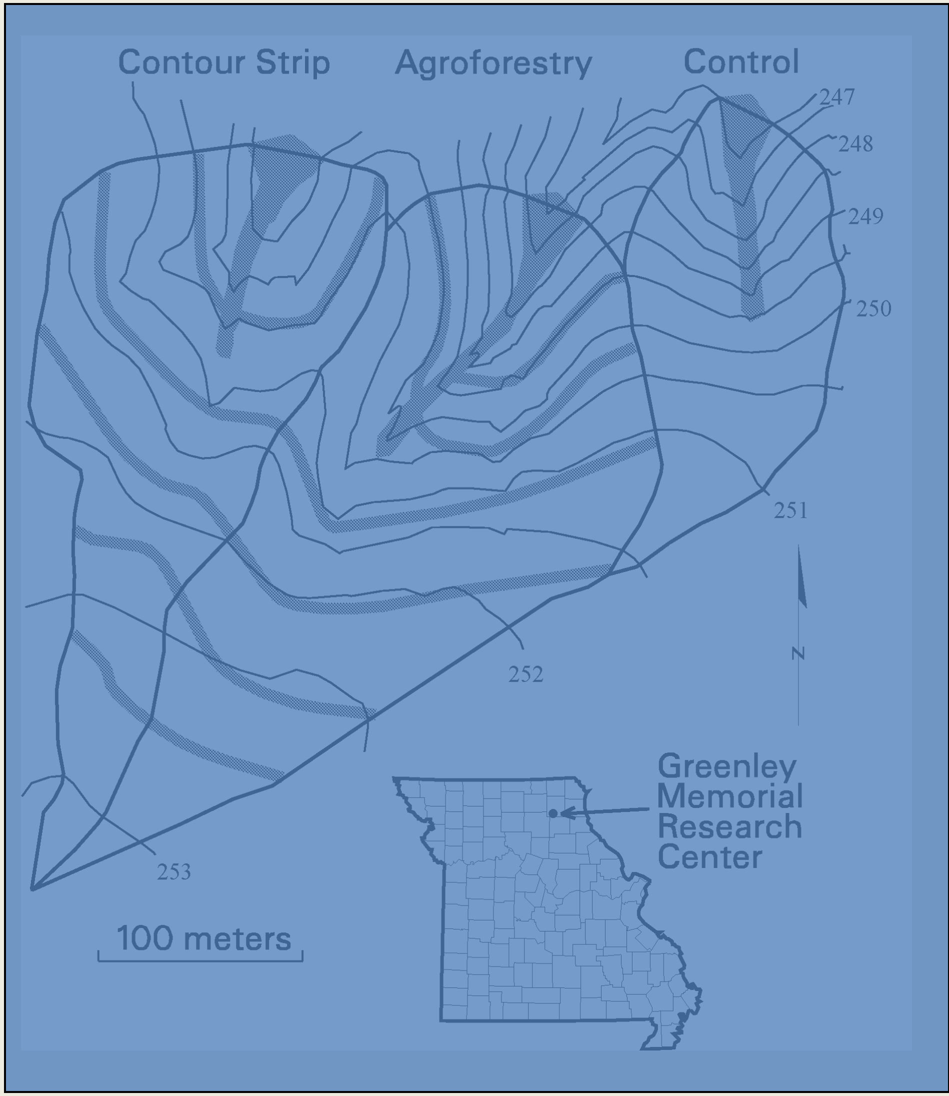

Maryville
Wildwood
St. Joseph
Chillicothe
Kirksville
Columbia
Sedalia
St. Louis
Clinton
Rolla
Lebanon
Salem
Cape Girardeau
Joplin
Springfield
Eminence
Ava
West Plains
Popular Bluff


Grazed Pasture watersheds at HARC

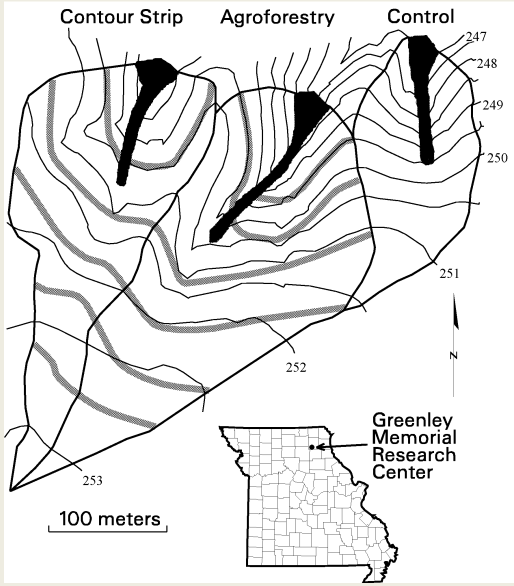

4230
4220




1991-1997




Approximate study site location in Missouri and 0.5 m interval contour lines on watersheds. Gray bands represent location of contour grass buffers on contour strip watershed, agroforestry buffers on agroforestry watershed and grass waterways on all three watersheds.


Contour Strip
Agroforestry
Control
247
248
249
250
251
252
253
N
Greenley Memorial Research Center
100 meters


2012


2007
AUG 1 2007


2005

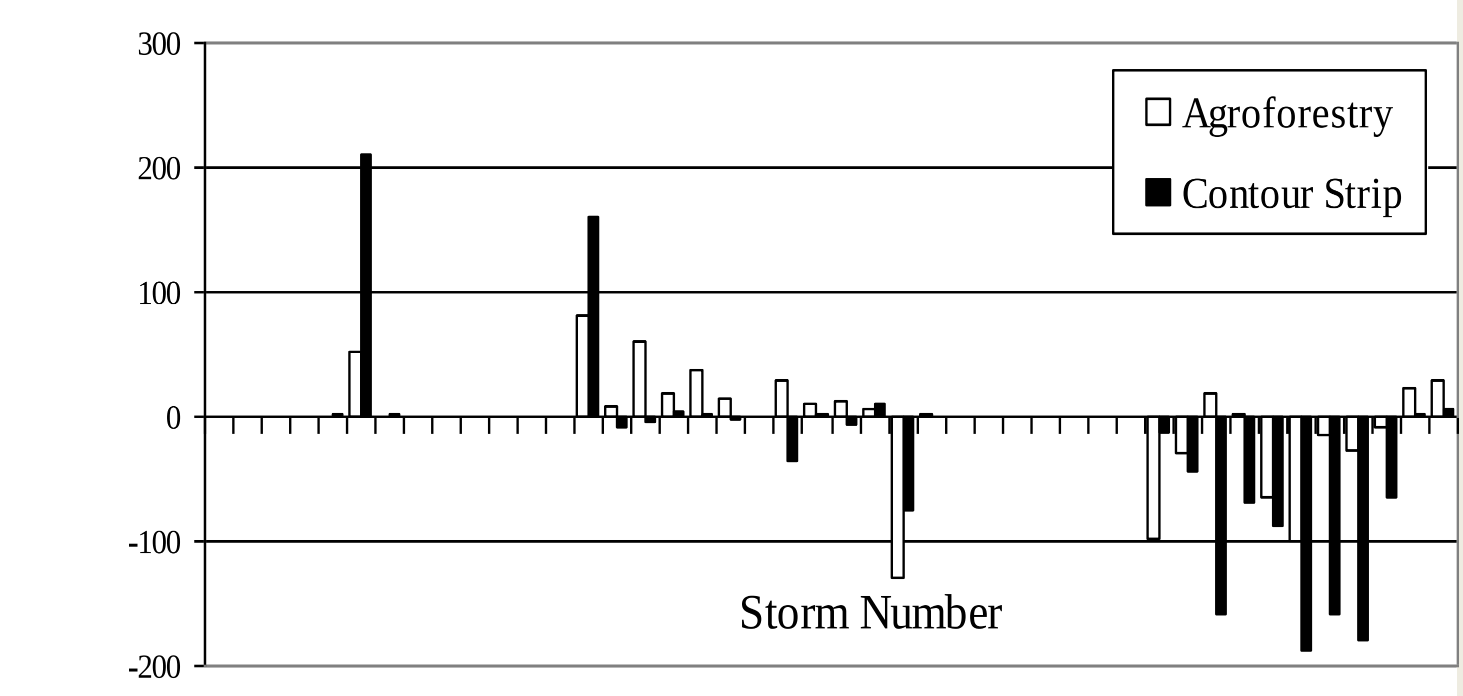

2002


1999

Observed Deviation from Predicted (observed minus predicted) Runoff on Agroforestry and Contour Strip Watersheds During the Treatment Period

Change in runoff

$m^3$/ha




Storm number and sampling year

# Riparian Systems: Runoff Control Sediment, N, and P losses

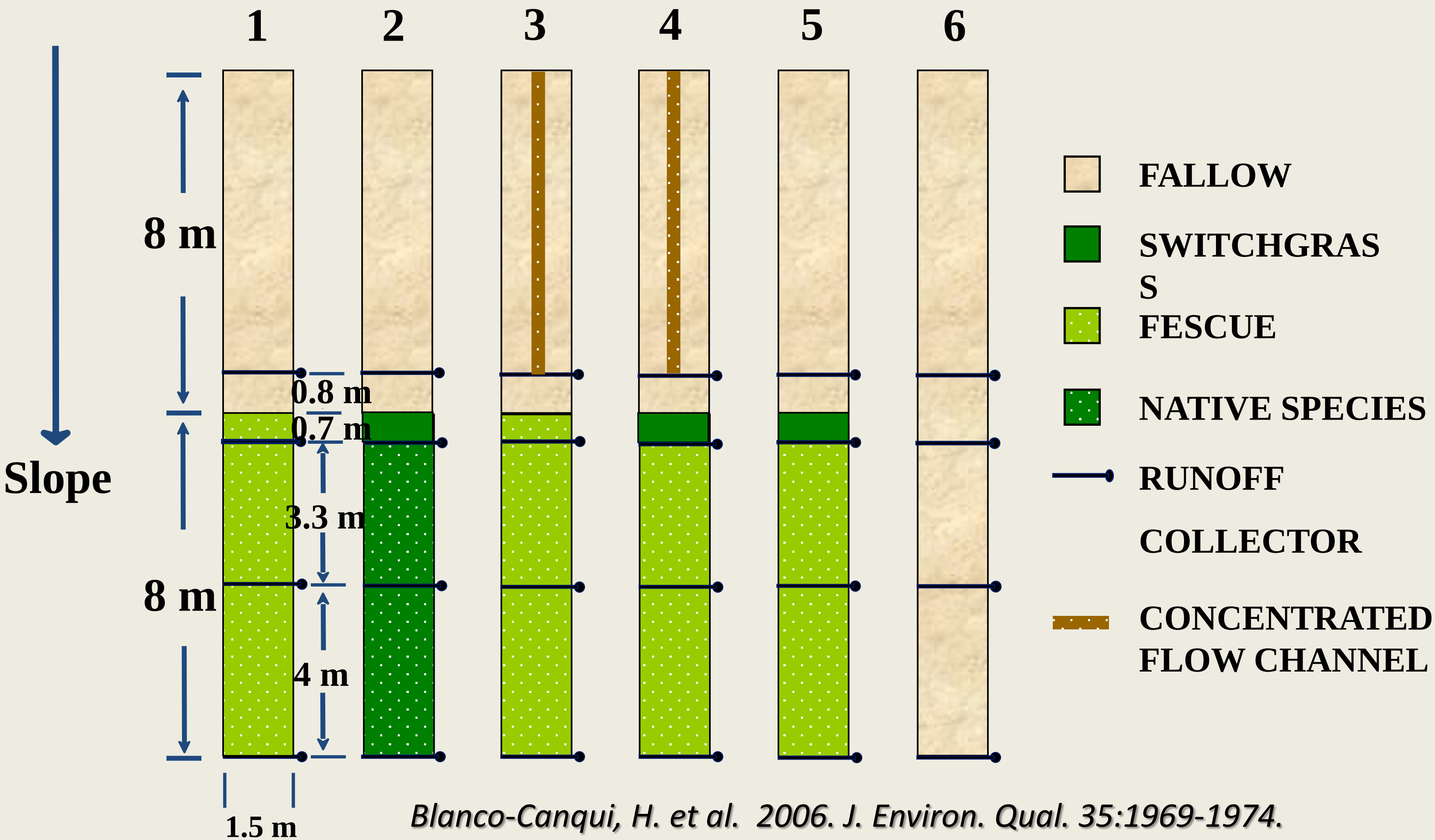
Nonpoint-source pollution reduction
Agroforestry buffers under grazing and row crop management.

**Table 1. Percent reduction of sediment, total N, and total P losses on grazing and row crop management practices with agroforestry and grass buffers compared with the respective control treatment.**

| Parameter | Managements and treatments | | | |
|---|---|---|---|---|
| | Grazing management | | Row crop management | |
| | Agroforestry | Grass buffer | Agroforestry | Contour grass |
| | % | | | |
| Sediment | 48 | 23 | 30 | 28 |
| Total N | 75 | 68 | 11 | 13 |
| Total P | 70 | 67 | 26 | 22 |

*Udawatta et al. 2011. J Environ. Qual. 40:800-806.*

# Cropland Zone: Grass Barriers and Filter Strips




*Blanco-Canqui, H. et al. 2006. J. Environ. Qual. 35:1969-1974.*

# Cropland Zone: Grass Barriers and Filter Strips


**Concentrated flow channel (0.20 wide by 0.15 m deep) in the fallow area of the plots.**

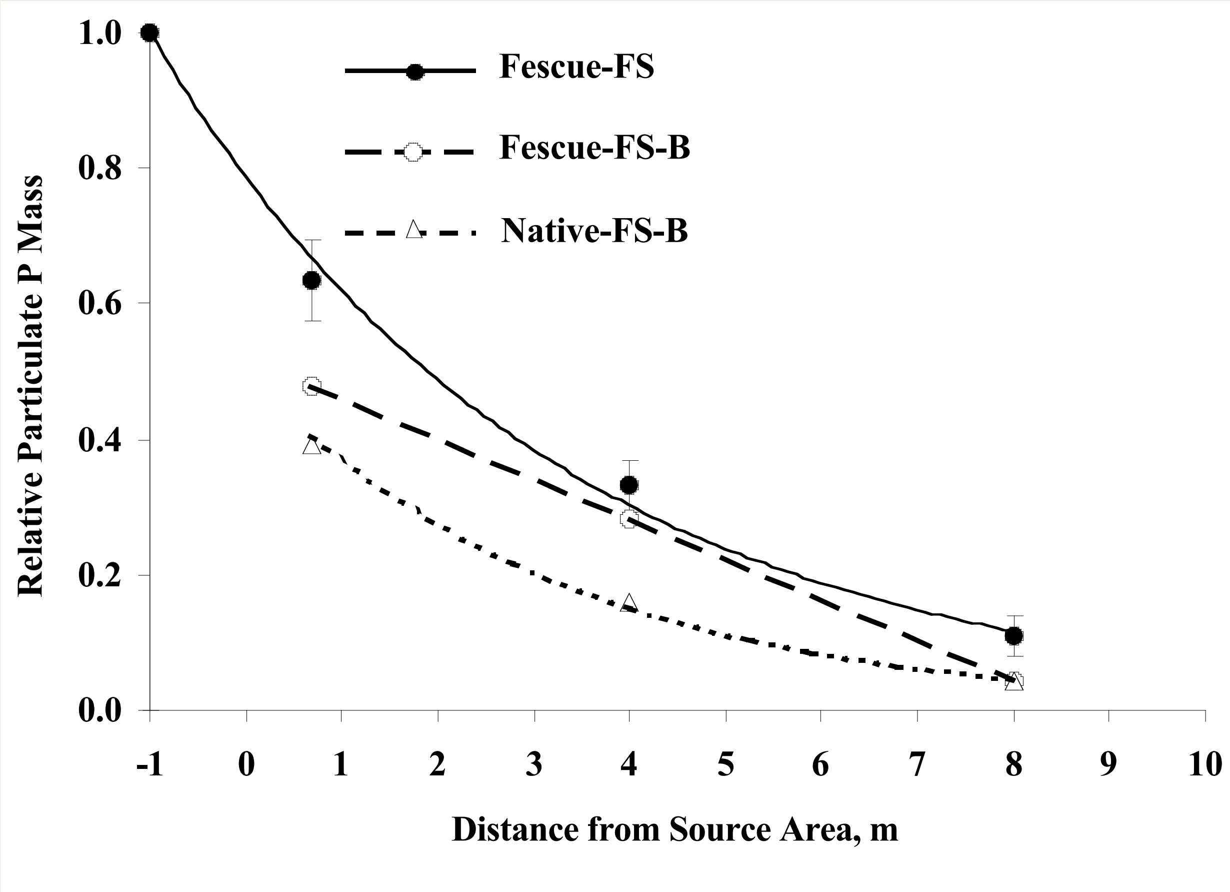
Blanco-Canqui, H. et al. 2006. J. Environ. Qual. 35:1969-1974.

# Cropland Zone: Grass Barriers and Filter Strips

**A rotating boom rainfall simulator** (Swanson, 1965) concentrated flow test.

Blanco-Canqui, H. et al. 2006. J. Environ. Qual. 35:1969-1974

# Cropland Zone: Grass Barriers and Filter Strips




**Nutrients in runoff decrease with distance**

Blanco-Canqui, H. et al.  2006. J. Environ. Qual. 35:1969-1974.

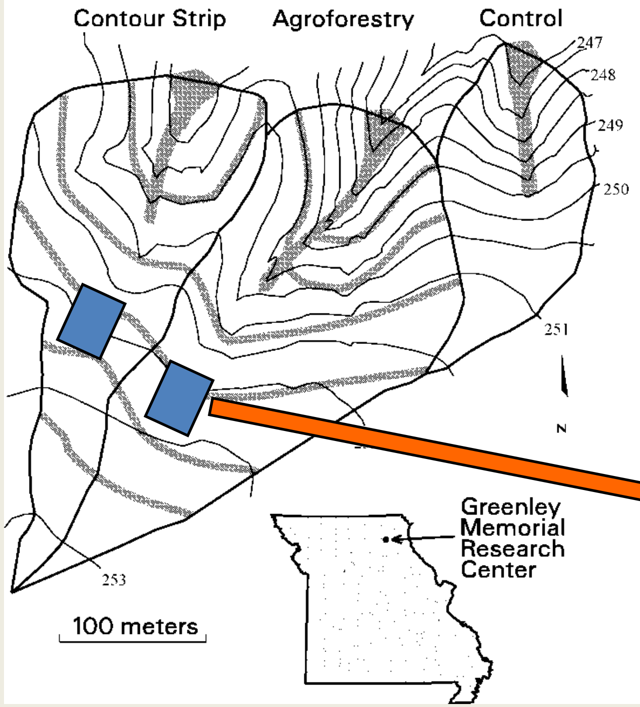
# Riparian Systems: Runoff Control

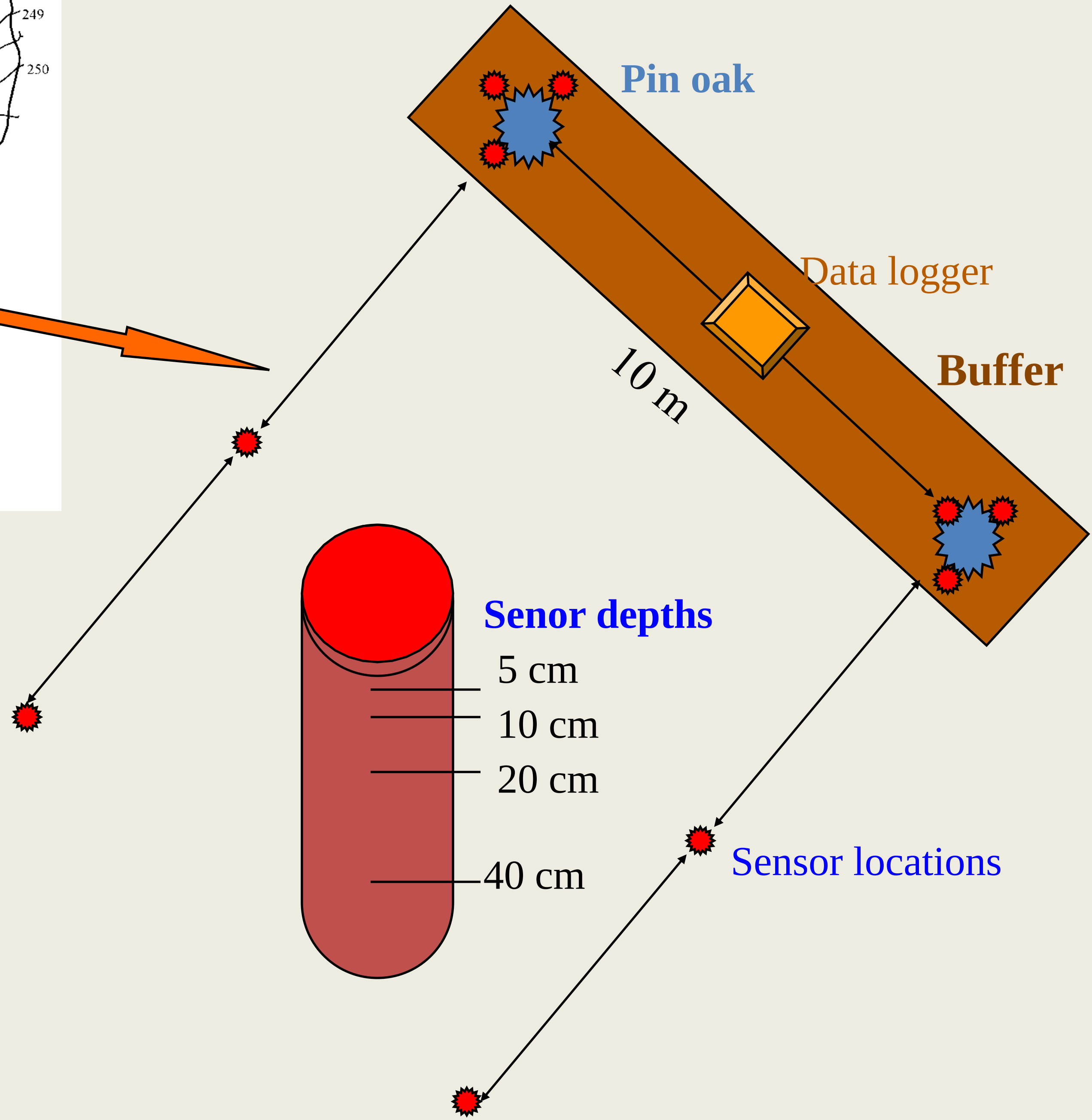
Reported Effectiveness of Buffer Zone Width for Sediment Reduction in the USA

**GRASS**

| Reduction | Width | Reported By |
|---|---|---|
| More than 80 percent | 4 to 9 m | Dillaha et al. (1989) |
| | 9 m | Ghaffarzadeh et al. (1992) |
| | 24 m | Chaubey et al. (1994) |
| | 25 m | Young et al. (1980) |
| | 61 m | Horner and Mar (1982) |
| Between 77 and 66 percent | 3 to 6 m | Lee et al. (1999) |
| Between 60 and 30 percent | 6 to 18 m | Daniels and Gilliam (1996) |
| Between 100 and 40 percent | 20 m | Arora et al. (1996) |
| Below 50 percent | 26 m | Schwer and Clausen (1989) |

After NRCS, 2002

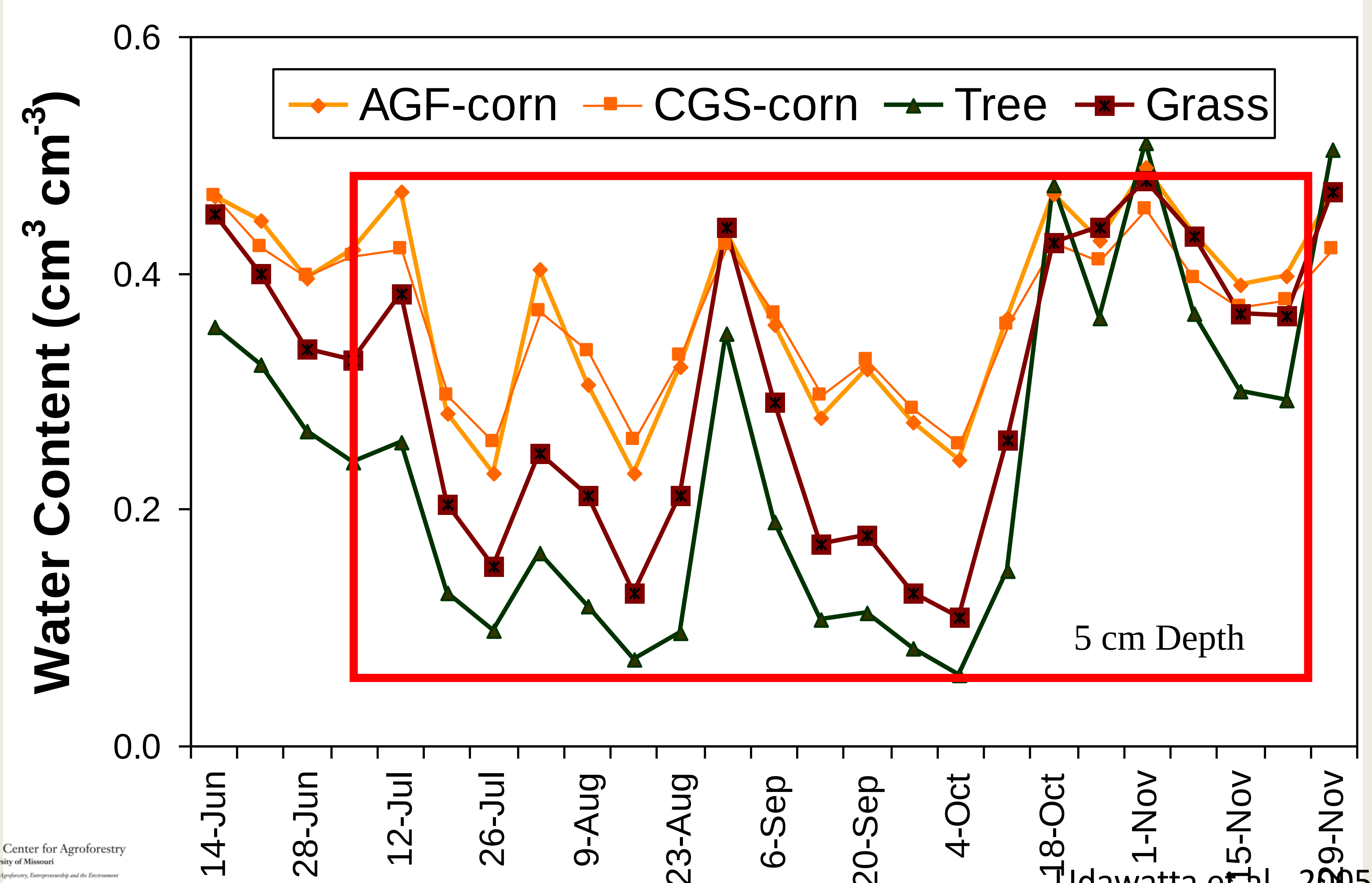



# Study Design

Campbell TDR soil moisture sensors were installed on two transects

# Soil Water Content for Tree, Grass, and Crop Areas from June 14 to November 30, 2004




Udawatta et al., 2005

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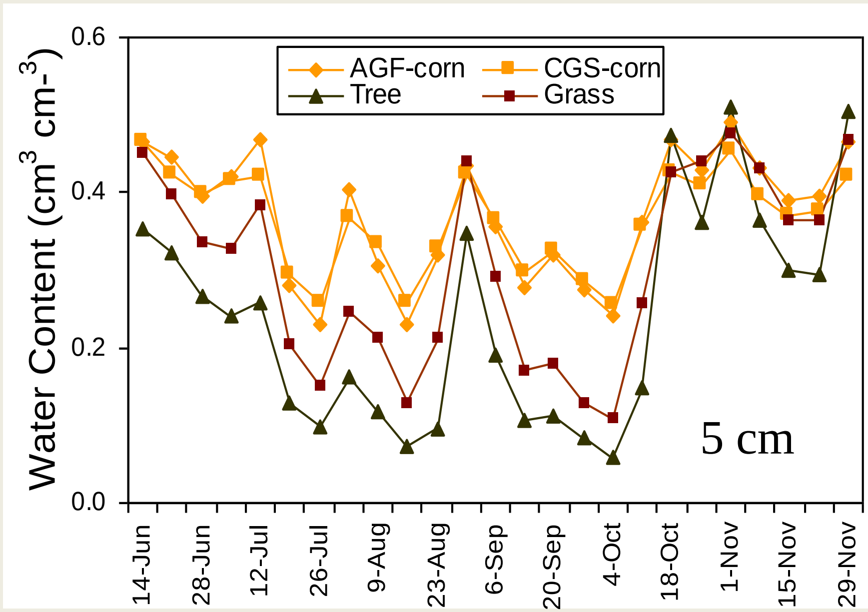
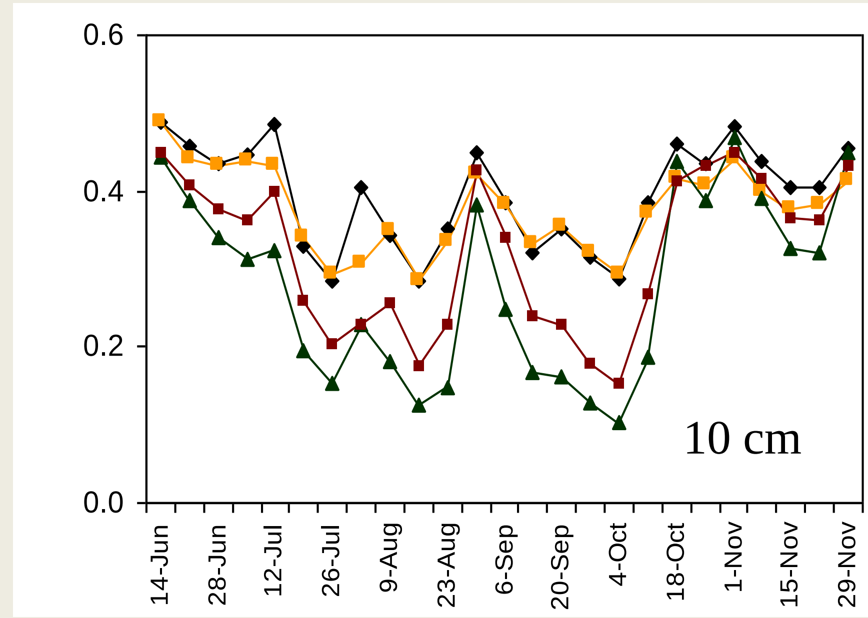
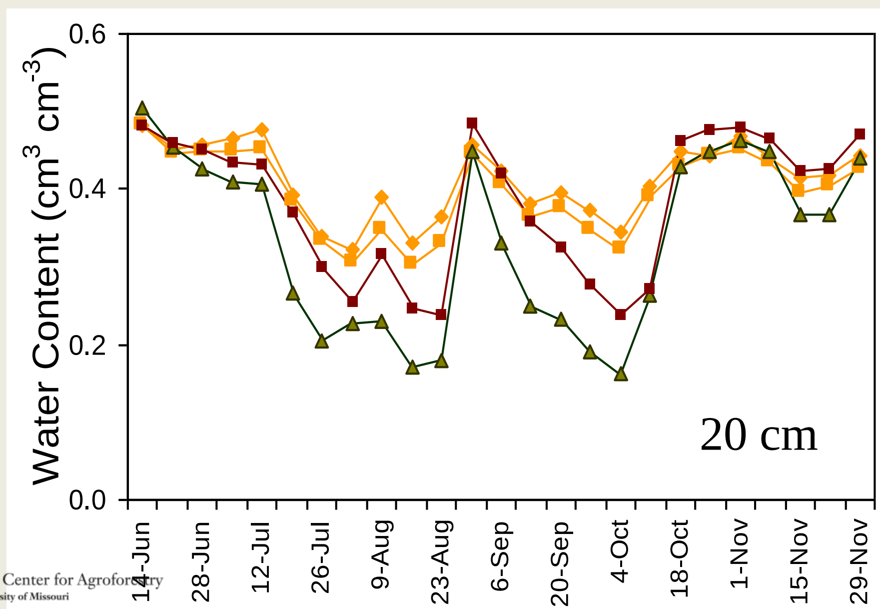
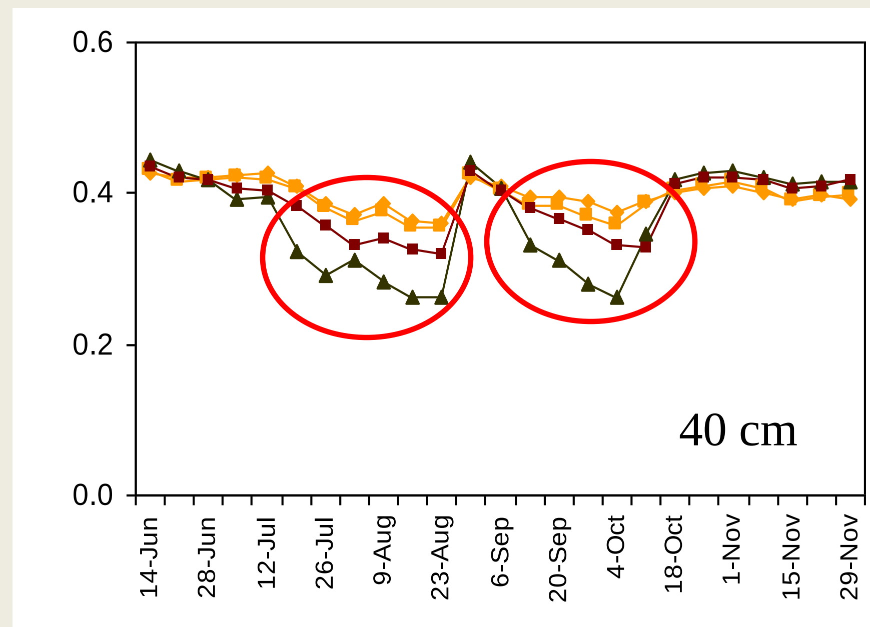
# Soil Water Content for Tree, Grass, and Crop Areas 6-14 to 11-30

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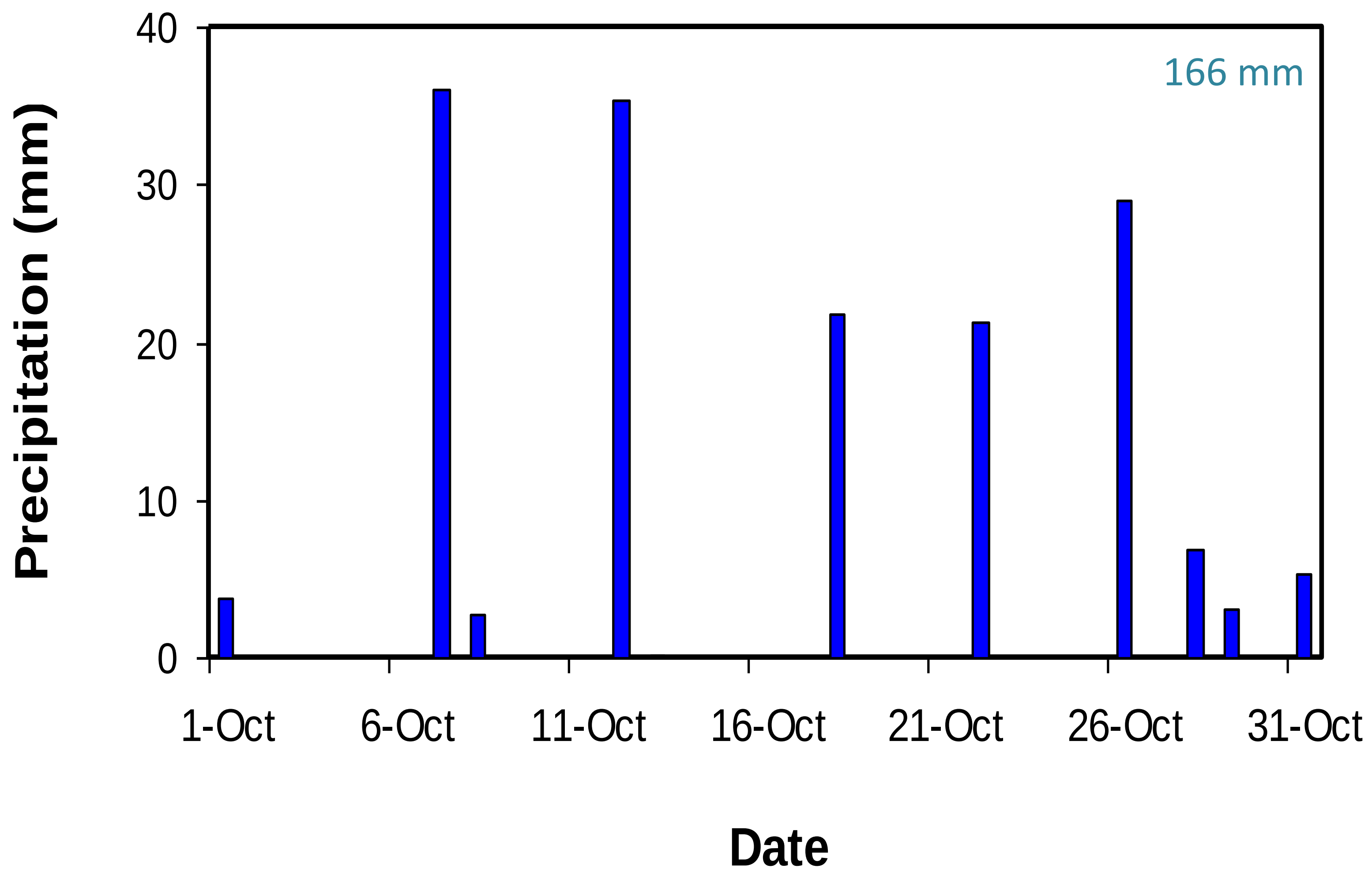
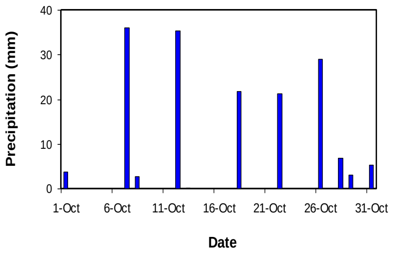
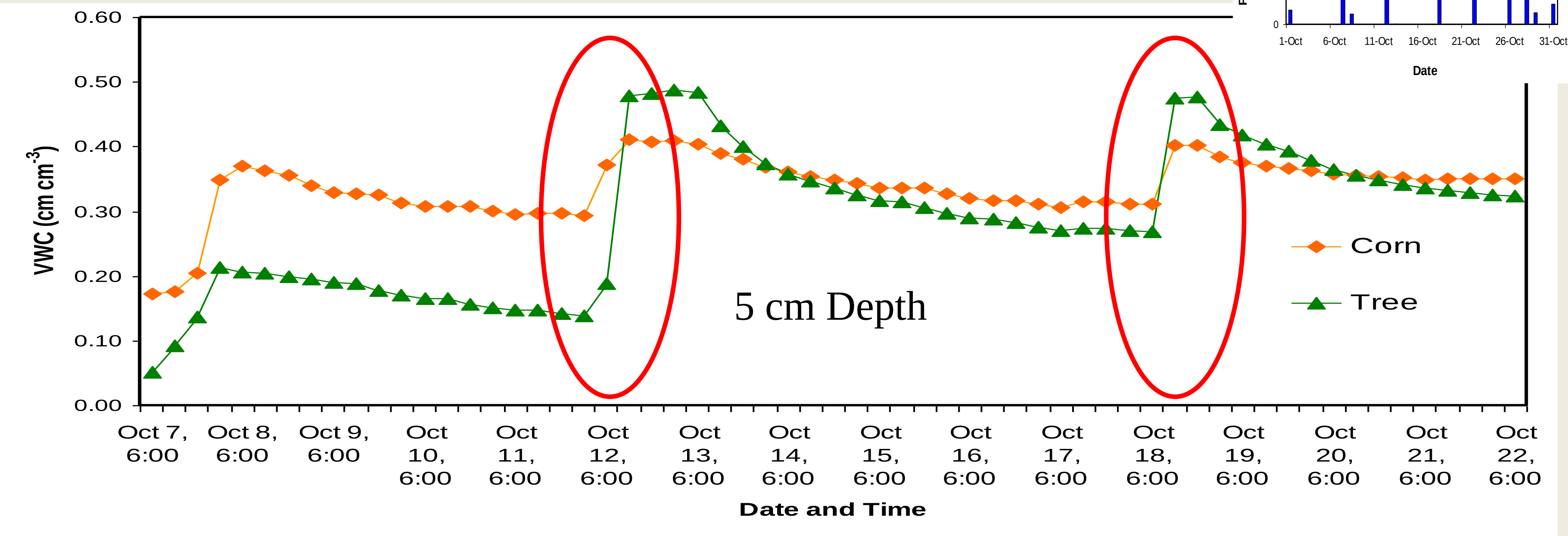
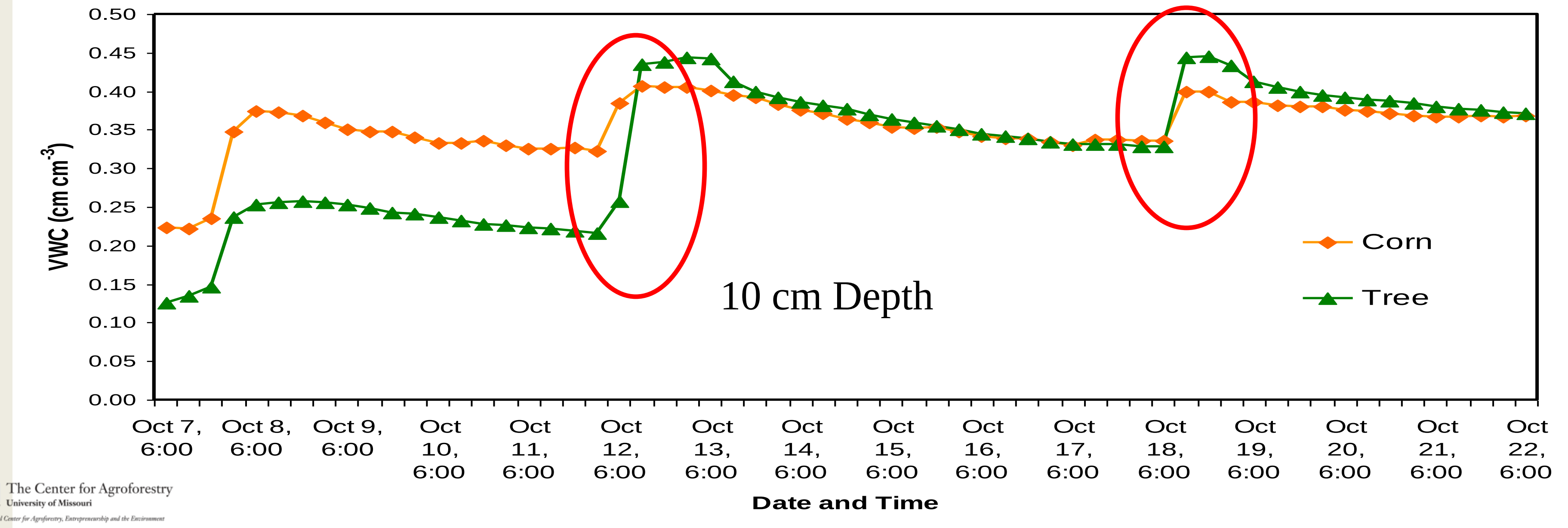
# Daily Precipitation During October 2004 Recharge Period



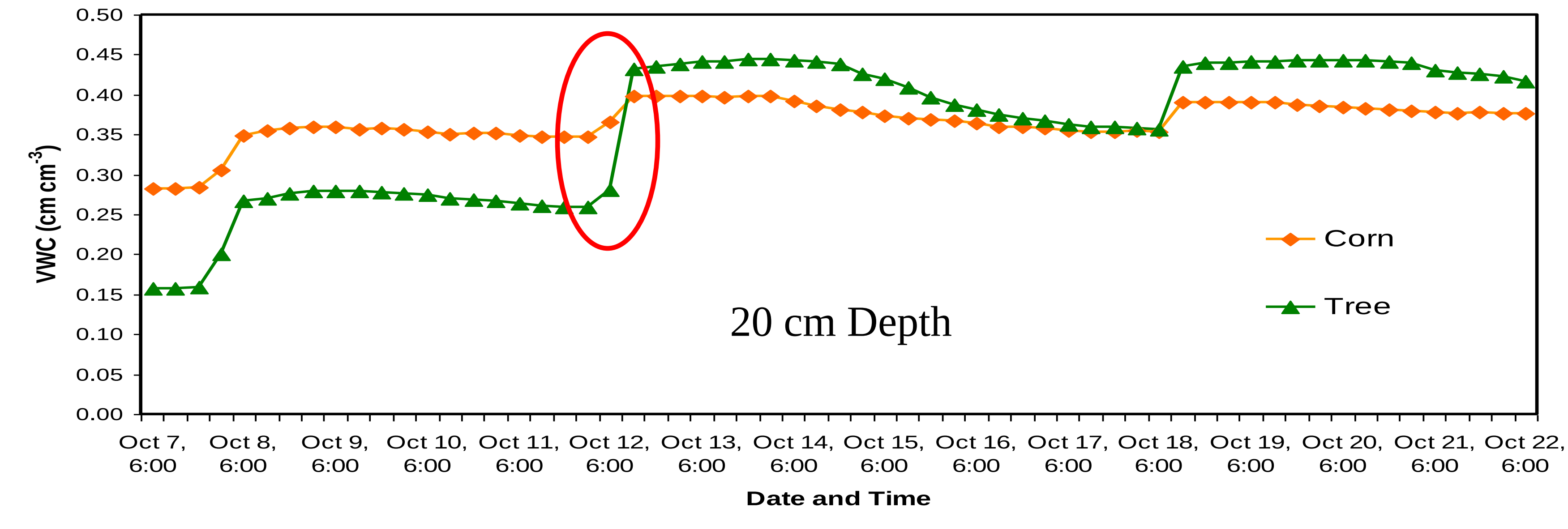
# Soil Water Recharge (5 and 10 cm depths)

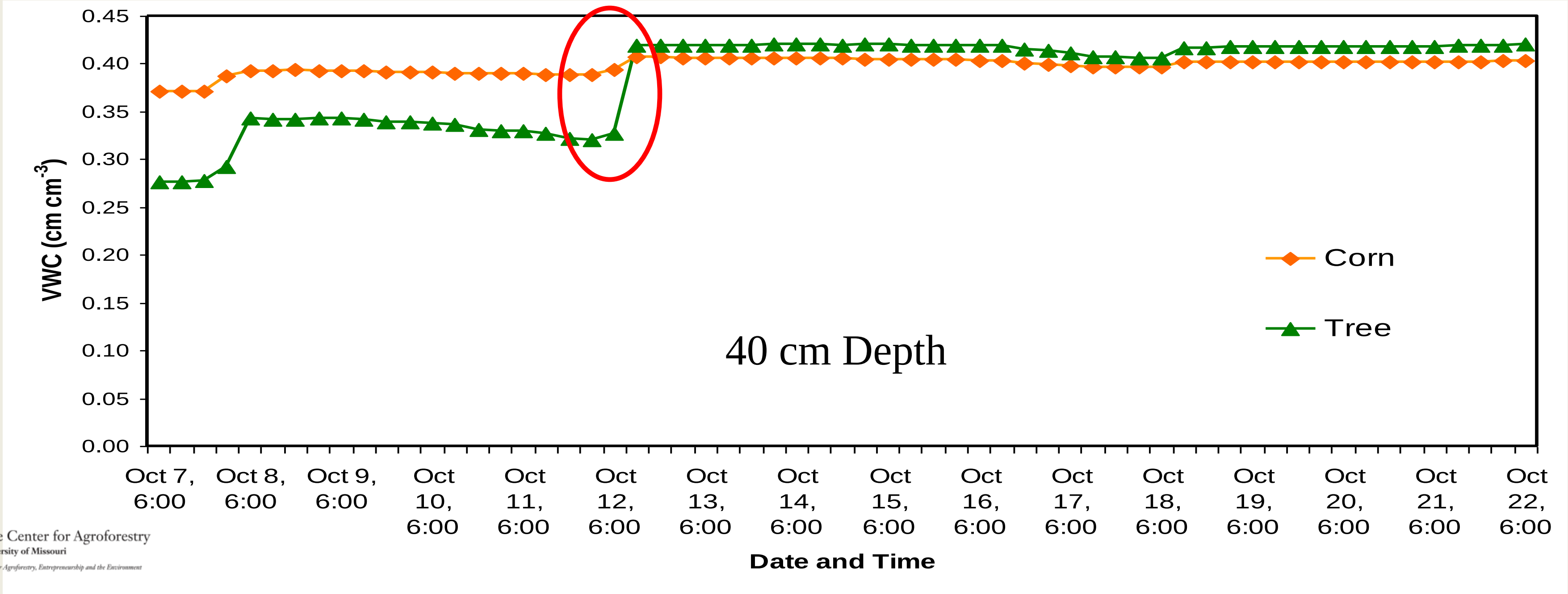


# Soil Water Recharge (20 and 40 cm depths)



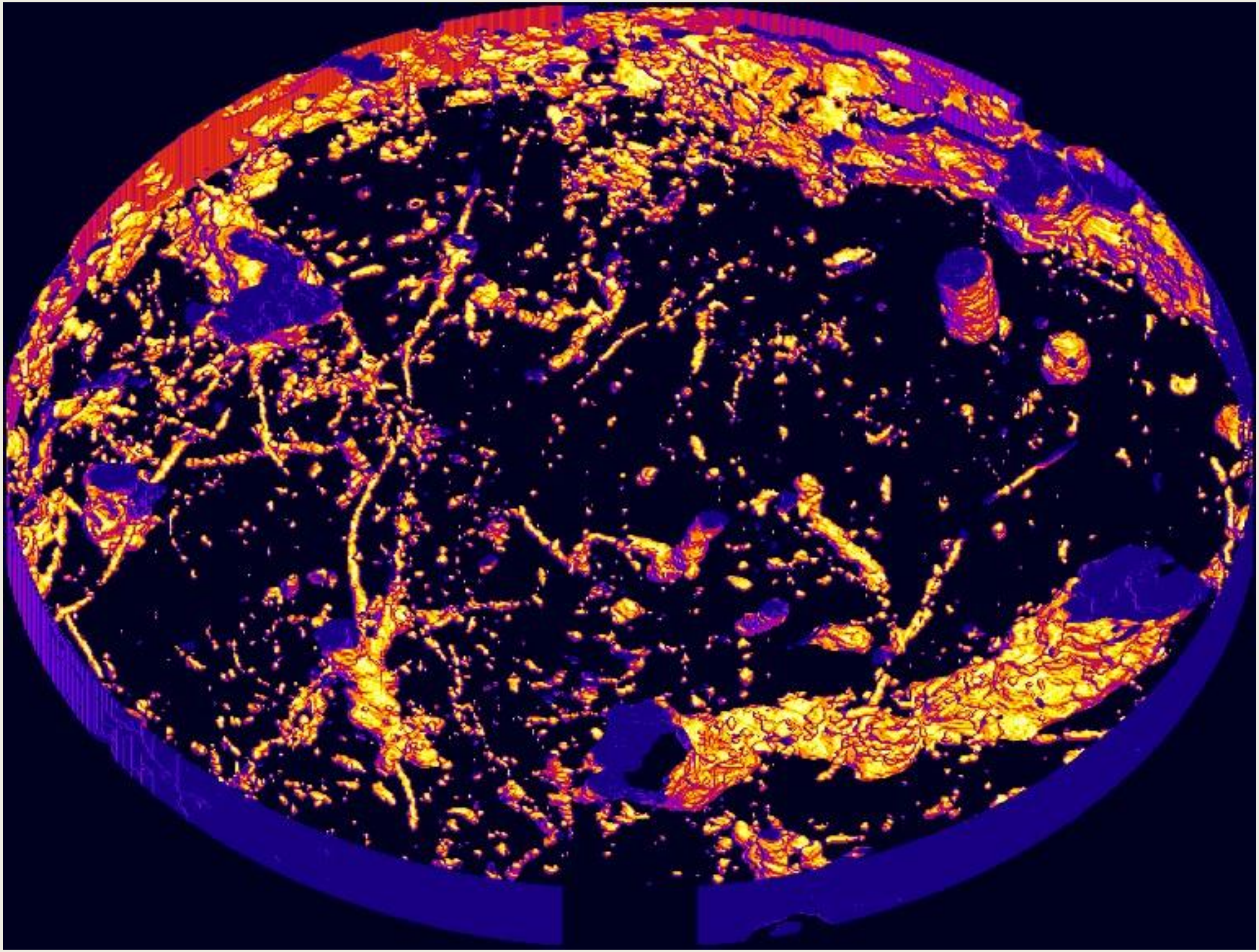



# Cores taken at 5 depths:

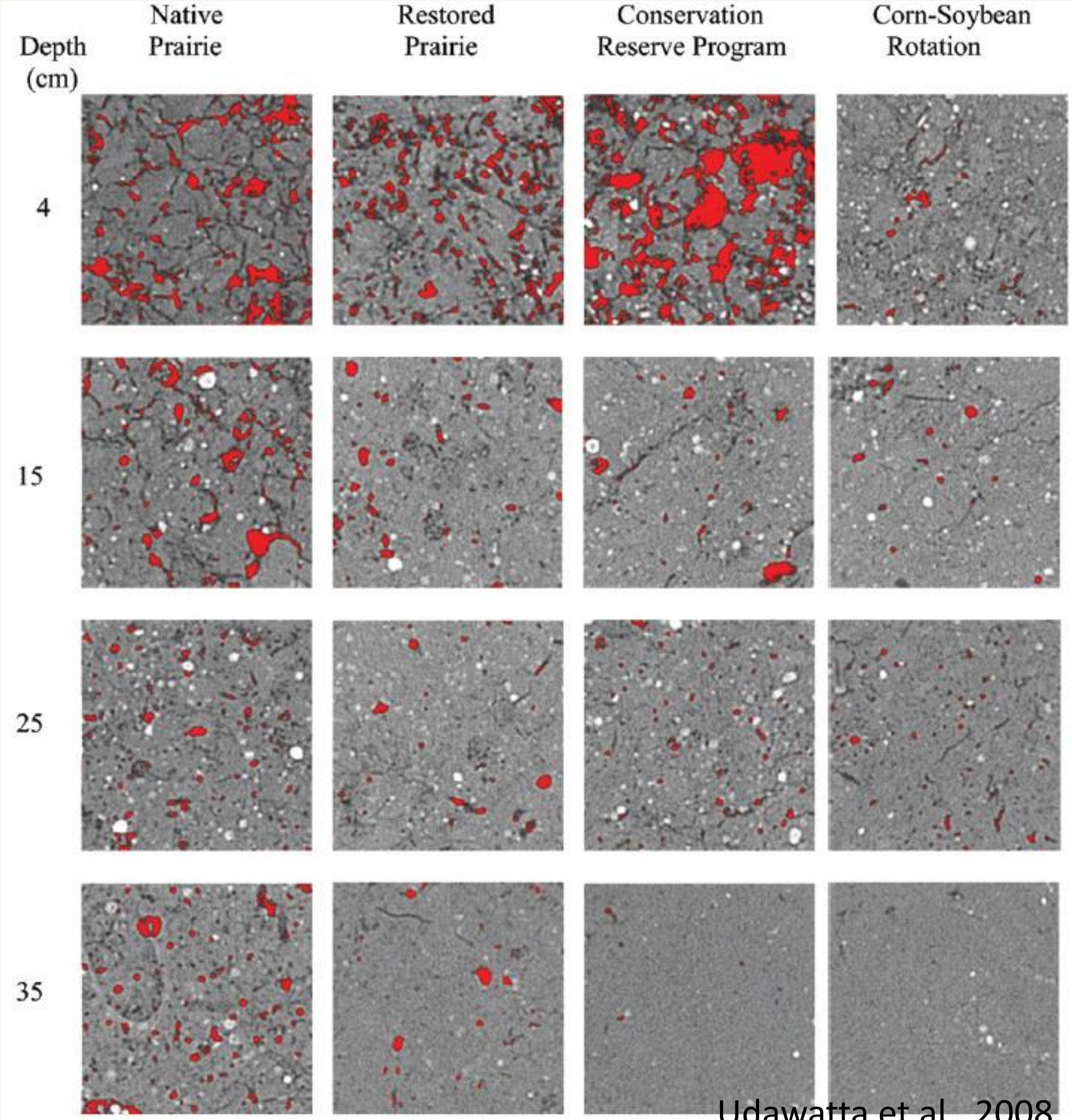
# 0-10, 10-20, 20-30, 30-40, and 40-50 cm depths


SIEMENS
APR 16 2006

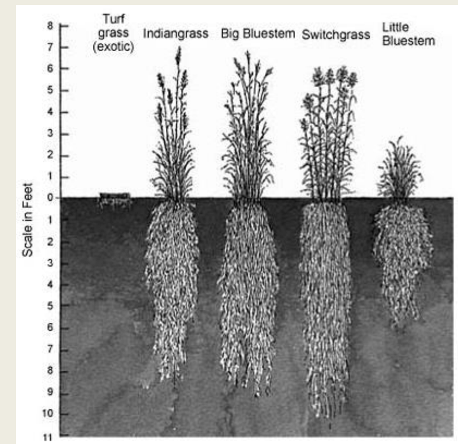
# Pore scale (x-ray CT, micro-computed tomography)



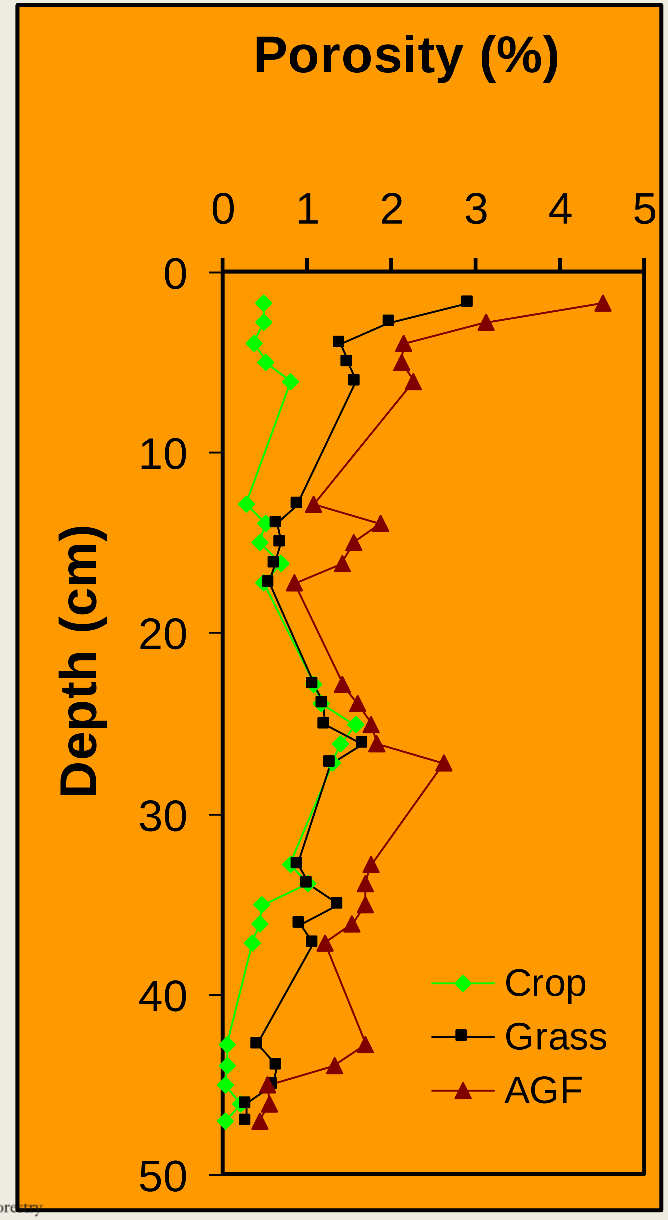
Gantzer and Anderson, 2006

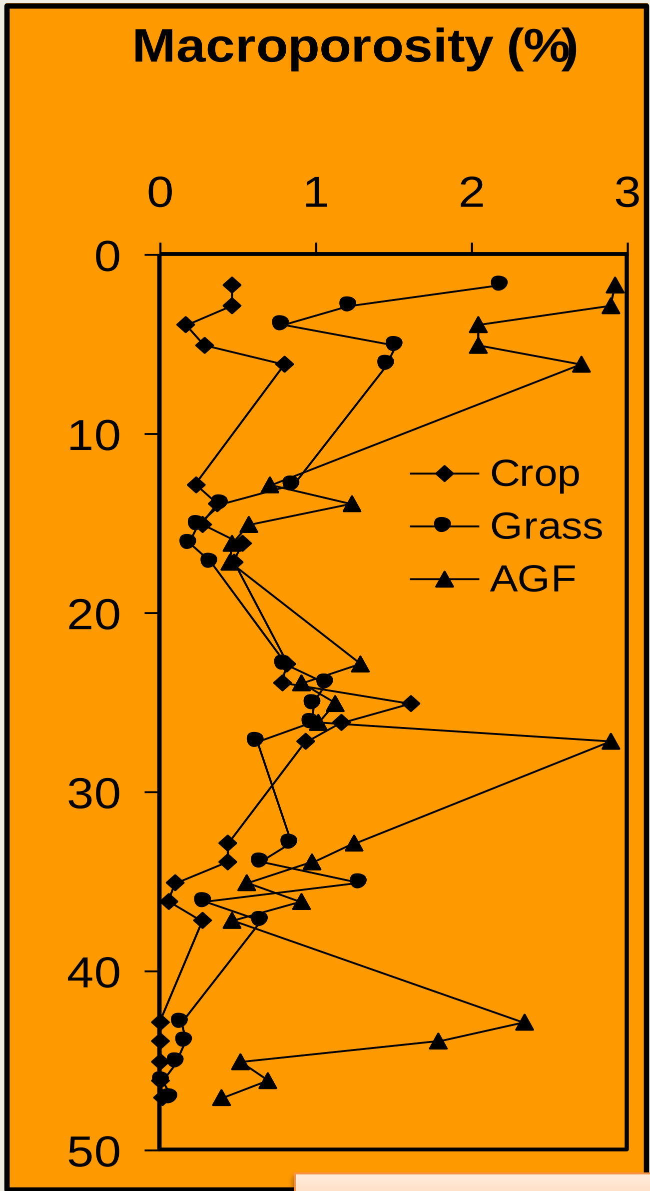



Udawatta et al., 2008




# CT-measured Porosity and Macroporosity




Udawatta and Anderson, 2009

The Center for Agroforestry
University of Missouri
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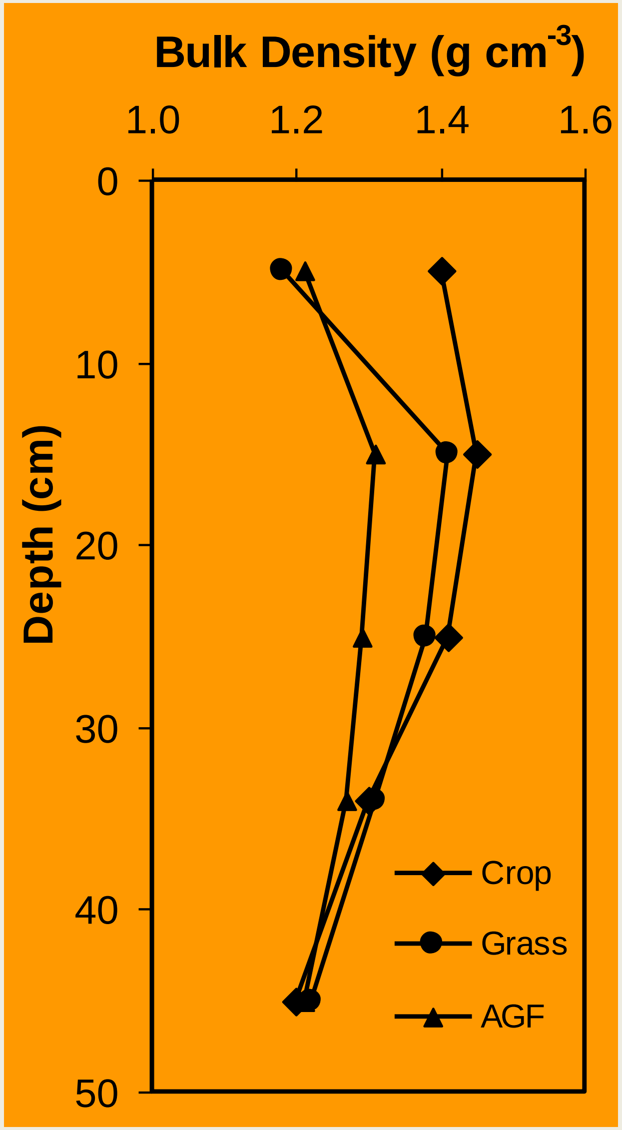
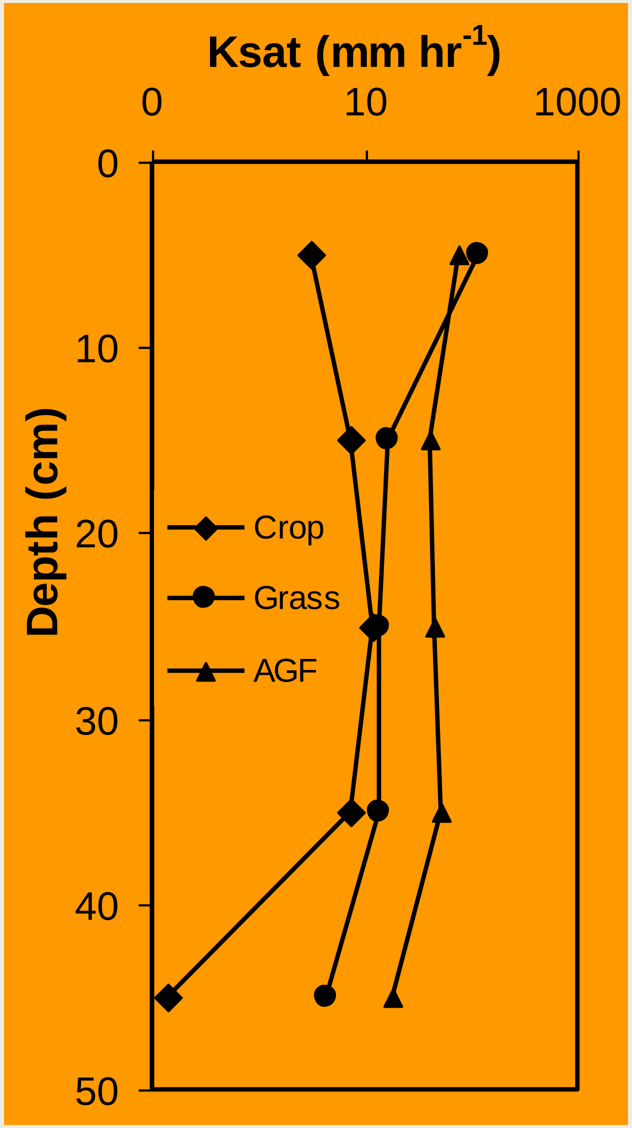
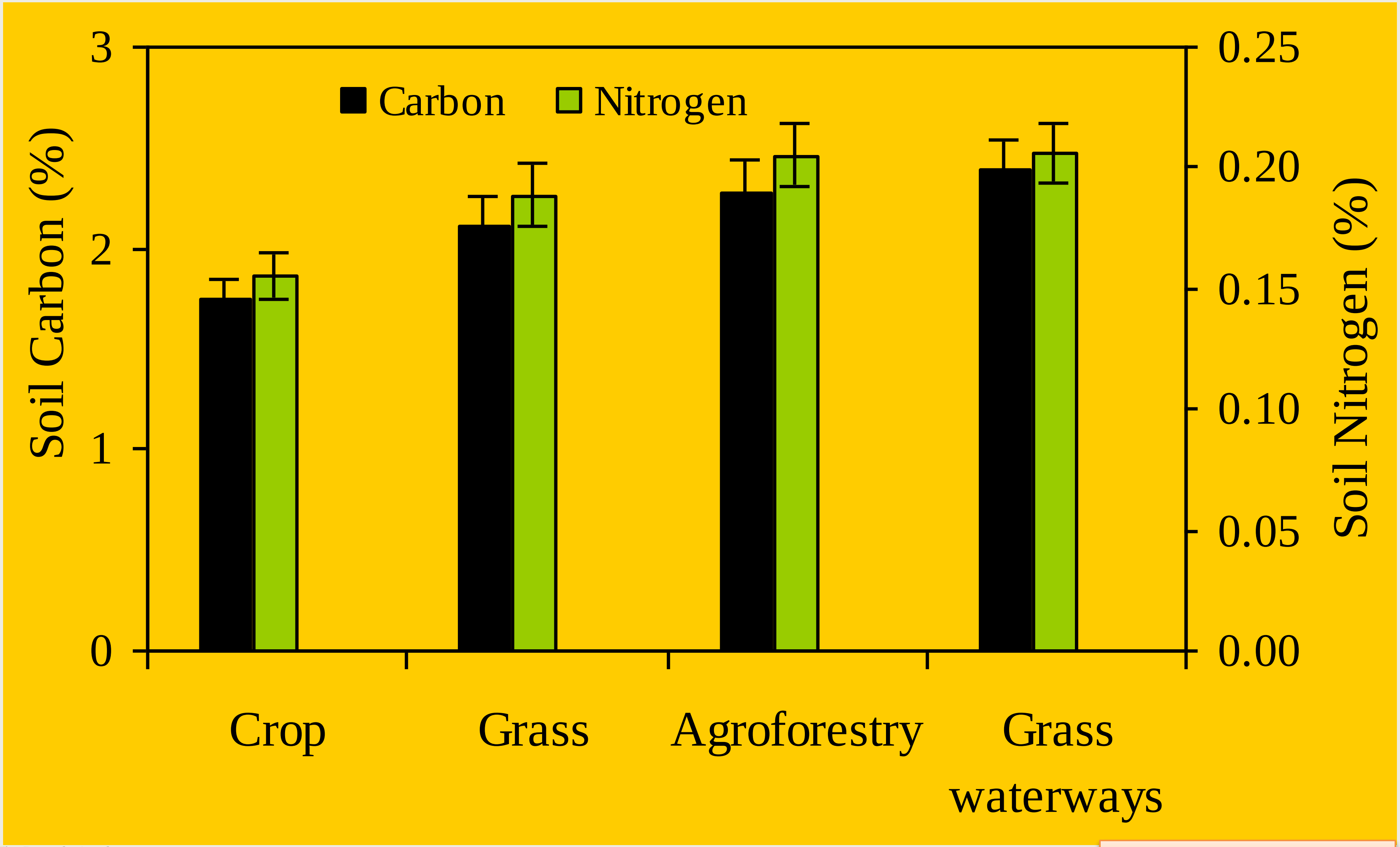
# Bulk density and saturated hydraulic conductivity (*K*sat) for row crop, grass buffer, and agroforestry buffer treatments by soil depth.



# Soil Carbon and Nitrogen as Influenced by Agroforestry Buffers

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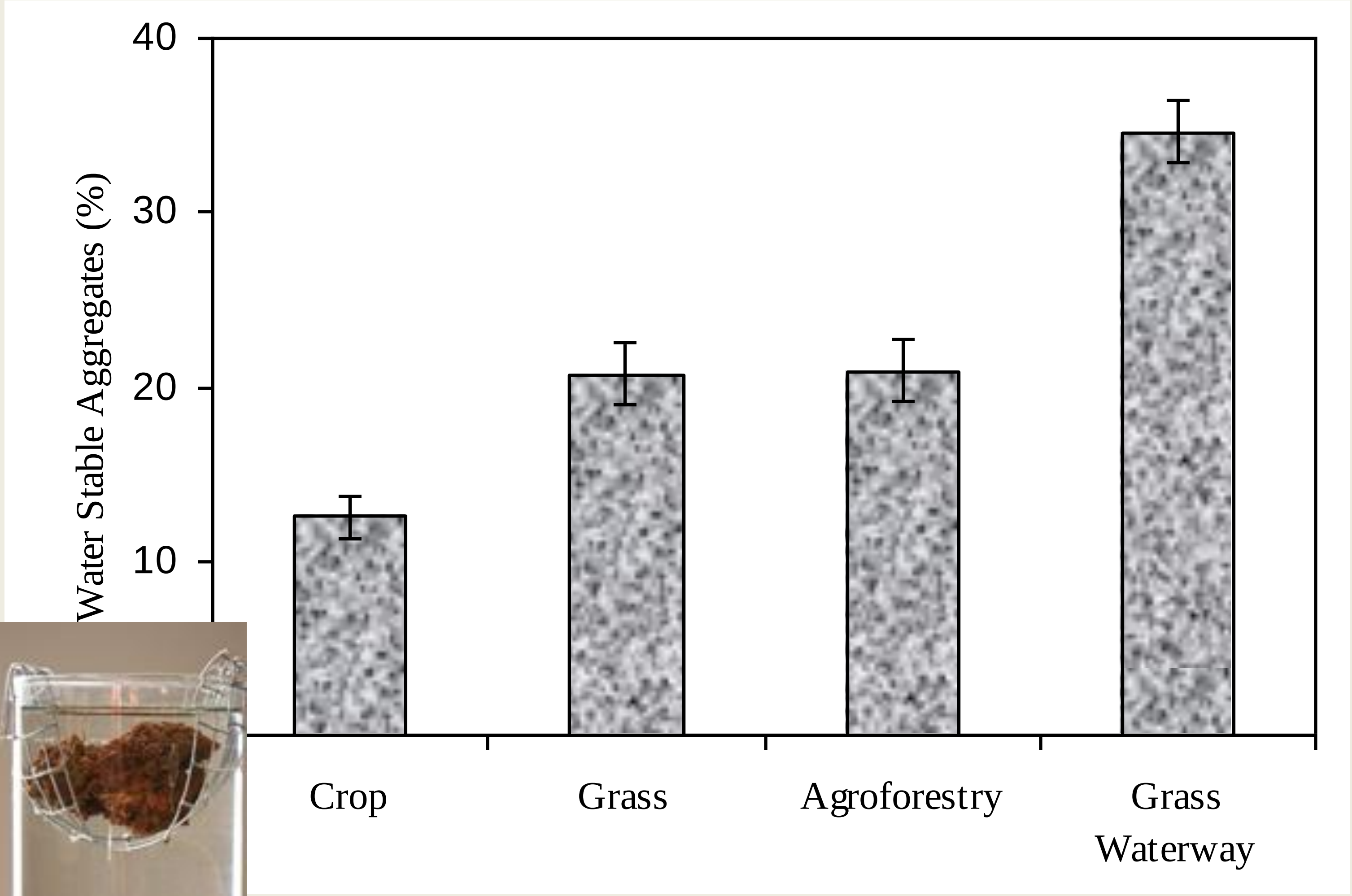
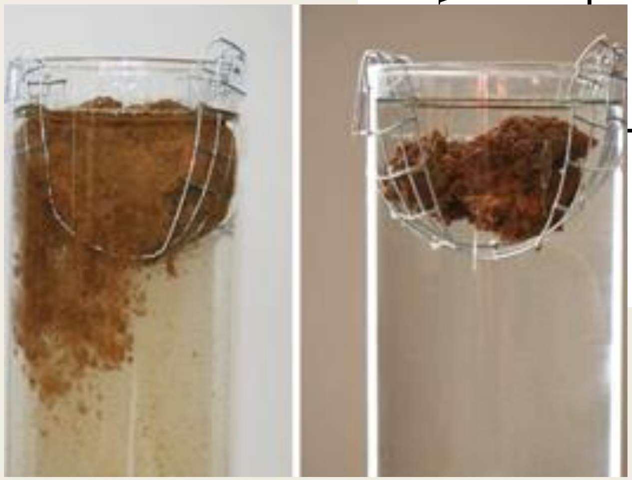
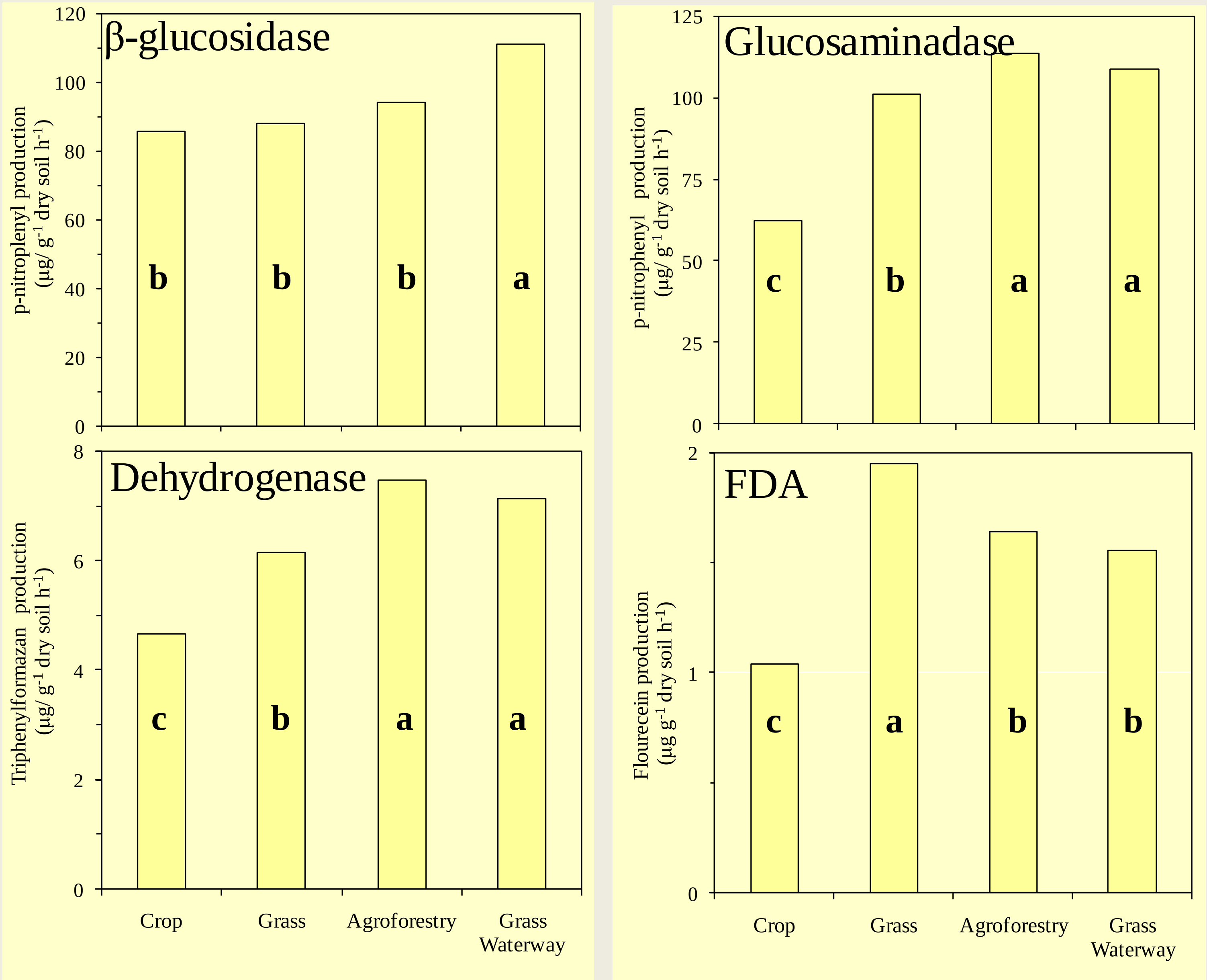
Udawatta et al., 2008

# Water Stable Aggregate Percentage as influenced by Management



# Soil Enzymes as Influenced by Perennial Vegetation




Perennial Vegetation buffers have been shown to have increased microbial diversity and enzyme activities.

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**Udawatta et al., 2008**

National Academy of Sciences – Natural Resources Committee

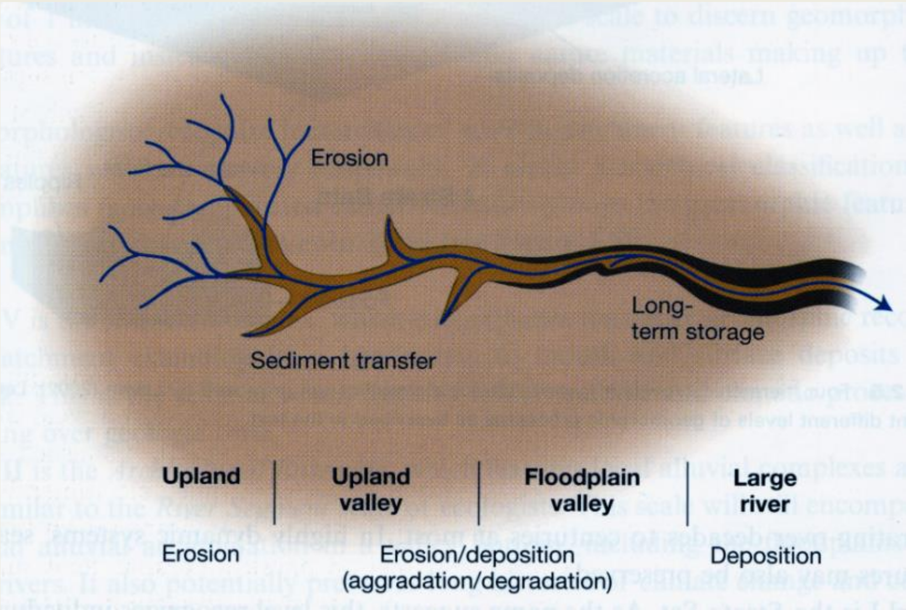
Riparian Areas: Functions & Strategies for Management (2002)

**Recommendation:**

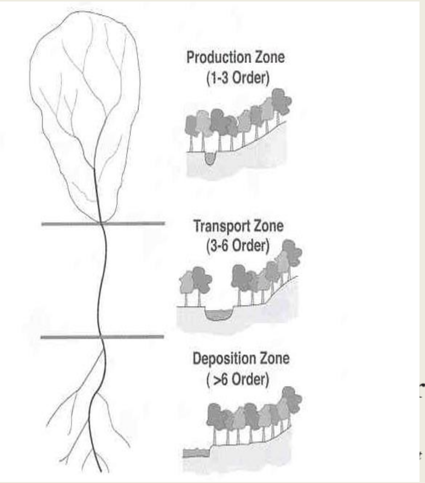
… ***"restoration of riparian functions along America's waterbodies should be a national goal."***

# Buffer Impacts: Stream Size - I

Buffers have greatest influence on <u>water quality</u> along
1st - 3rd order streams (smallest size) as
*over 90% of stream lengths in a watershed are 1st - 3rd order*




This is the <u>zone of erosion and sediment and solute production</u> and most of this production passes through the buffer (riparian) community

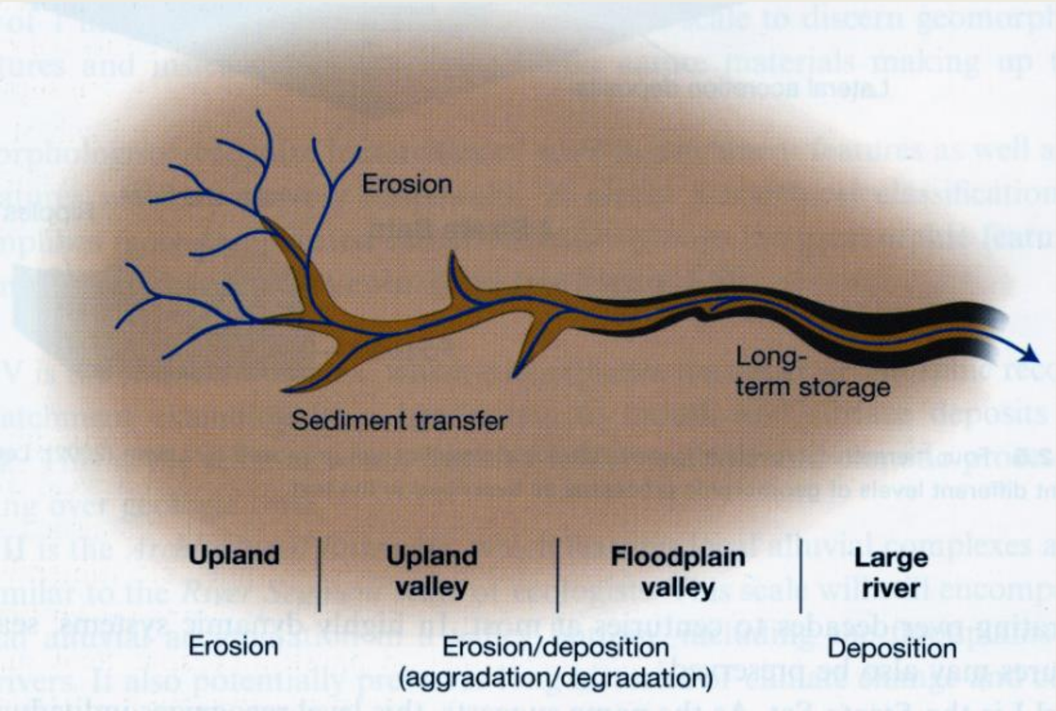


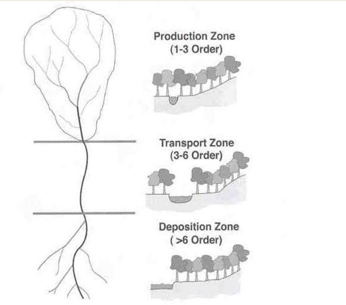
# Buffer Impacts: Stream Size - II

Buffers have greatest influence on <u>aquatic habitat</u> along mid-order streams (3-6) (moderate size)

This is a <u>zone of sediment storage and transport</u>

Channels have sufficient flow and woody debris to support an active aquatic community



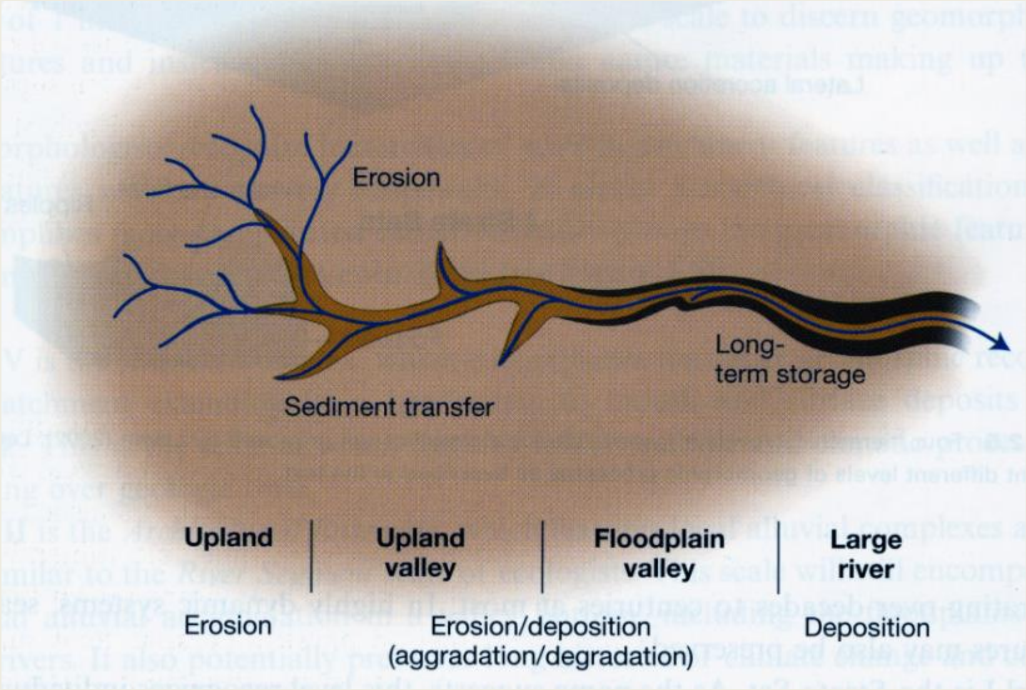



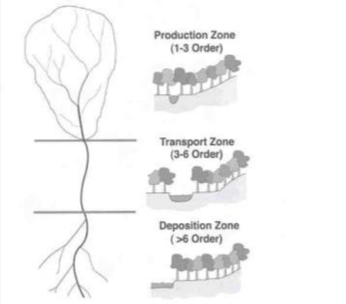
# Buffer Impacts: Stream Size - III

Buffers have greatest influence on flood moderation along highest order streams (6+)

This is a zone of sediment deposition

Major river flood plains with wide riparian forests and wetlands

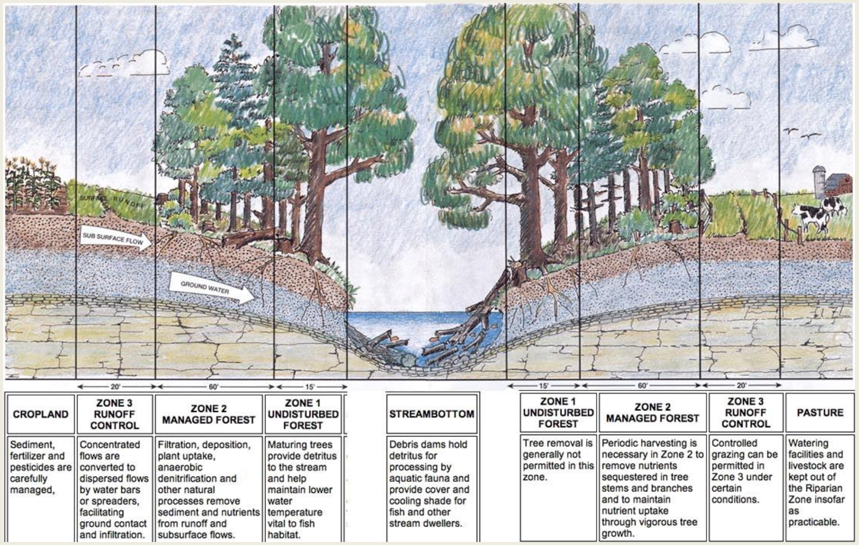


# Multi- Species Riparian Buffer Design

## *Species Selection Criteria*

1. Owner Objectives
2. Site Conditions
3. Surrounding Landuse
4. Cost-share program requirements



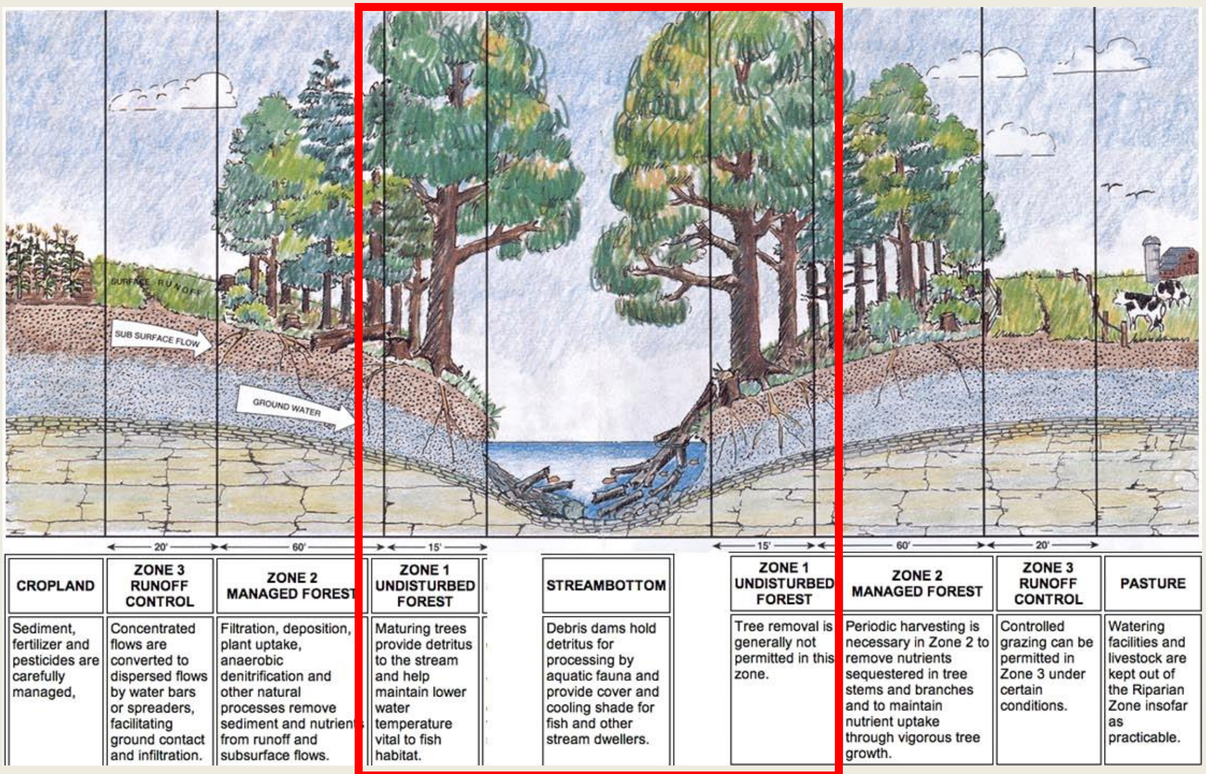
# Tree Zone – Adjacent to the Stream Undisturbed Forest

Trees selected for:

- early rapid growth
- deep rooting ability to increase bank stability

Best choices:

- bottom land species tolerant of wet conditions
  – Silver maple, cottonwood, green ash, willow



# Tree Zone – Further from the Stream

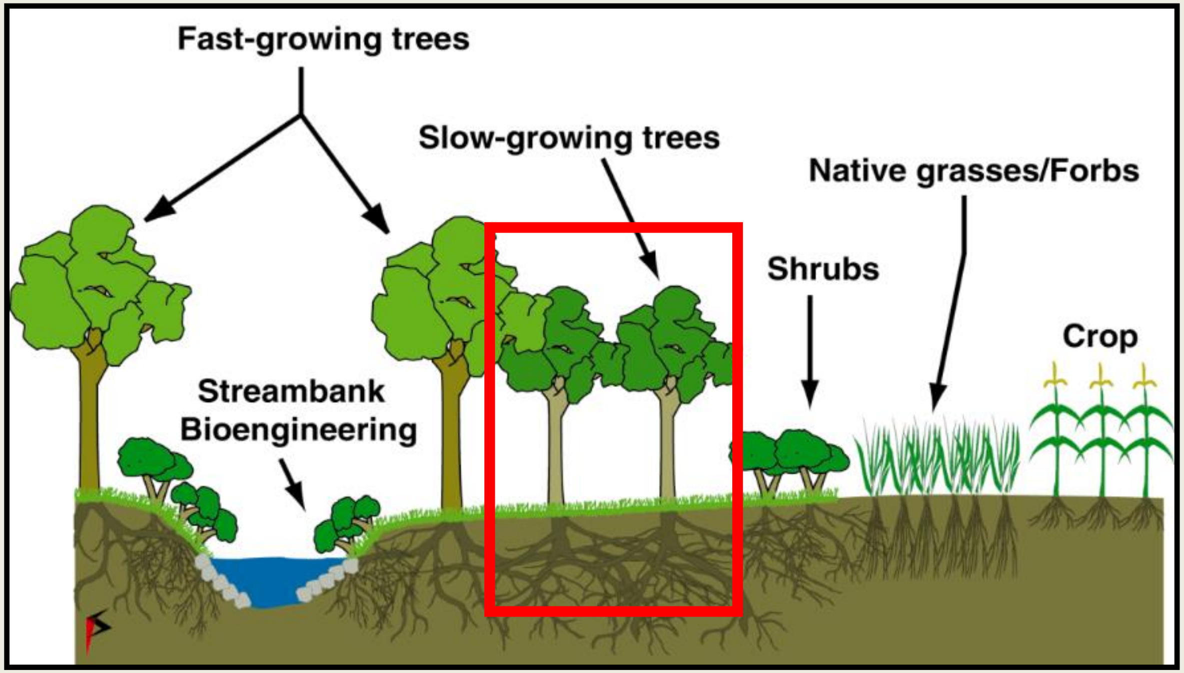
## Managed Forest

Trees selected for:

- higher timber values (long-term)

Best choices:

- more upland habitat species requiring well drained soils (intolerant of wet conditions)
  - white ash, walnut, red/white oak



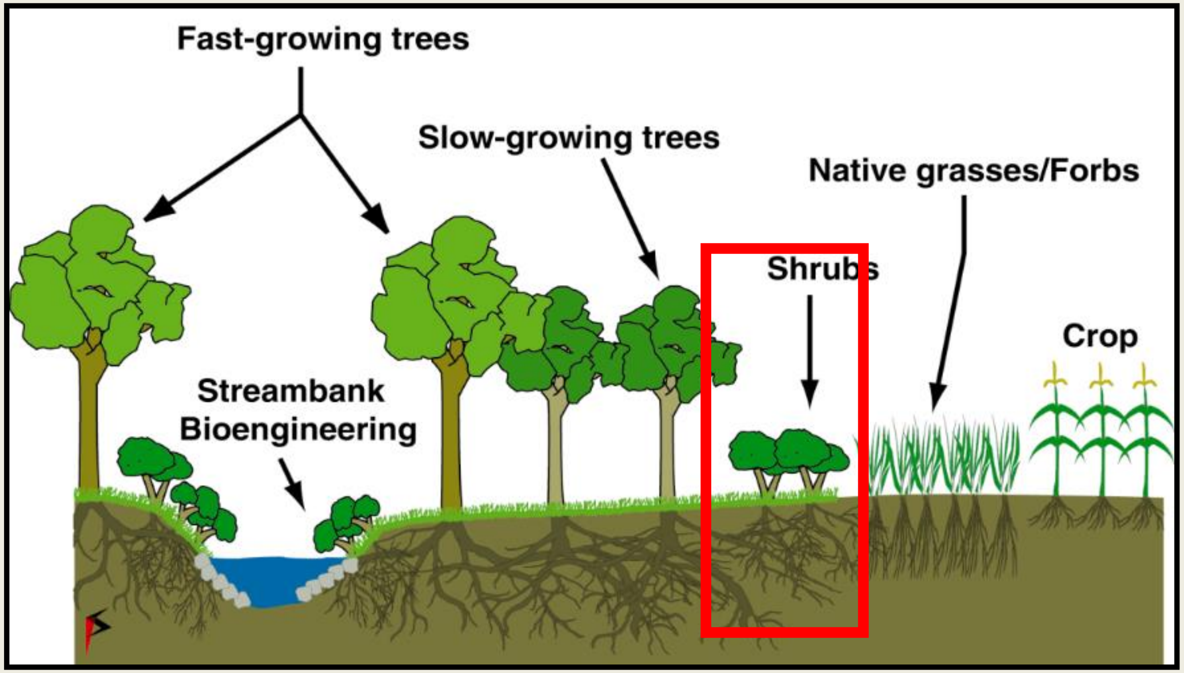
# Shrub Zone – Between trees and grasses

## Shrubs selected for:

- Perennial rooting
- Species diversity
- Slowing of floodwaters
- Wildlife habitat
- Economic value

## Best choices:

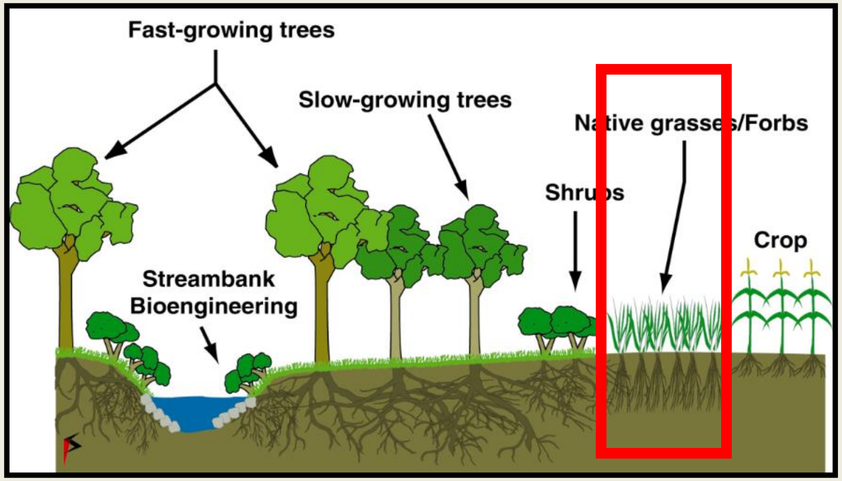
- Plant a mixture of shrubs (be aware of soil type as with the trees)
  - Ninebark, red osier dogwood, curly willow, alders, wild plums, hazelnut, …



# Grass Zone – Adjacent to crop field

## Warm season grasses selected

- Dense, stiff stems
- Extensive, deep root systems
- Organic matter accumulation, increased infiltration
- Runoff interception, sediment deposition
- Wildlife habitat

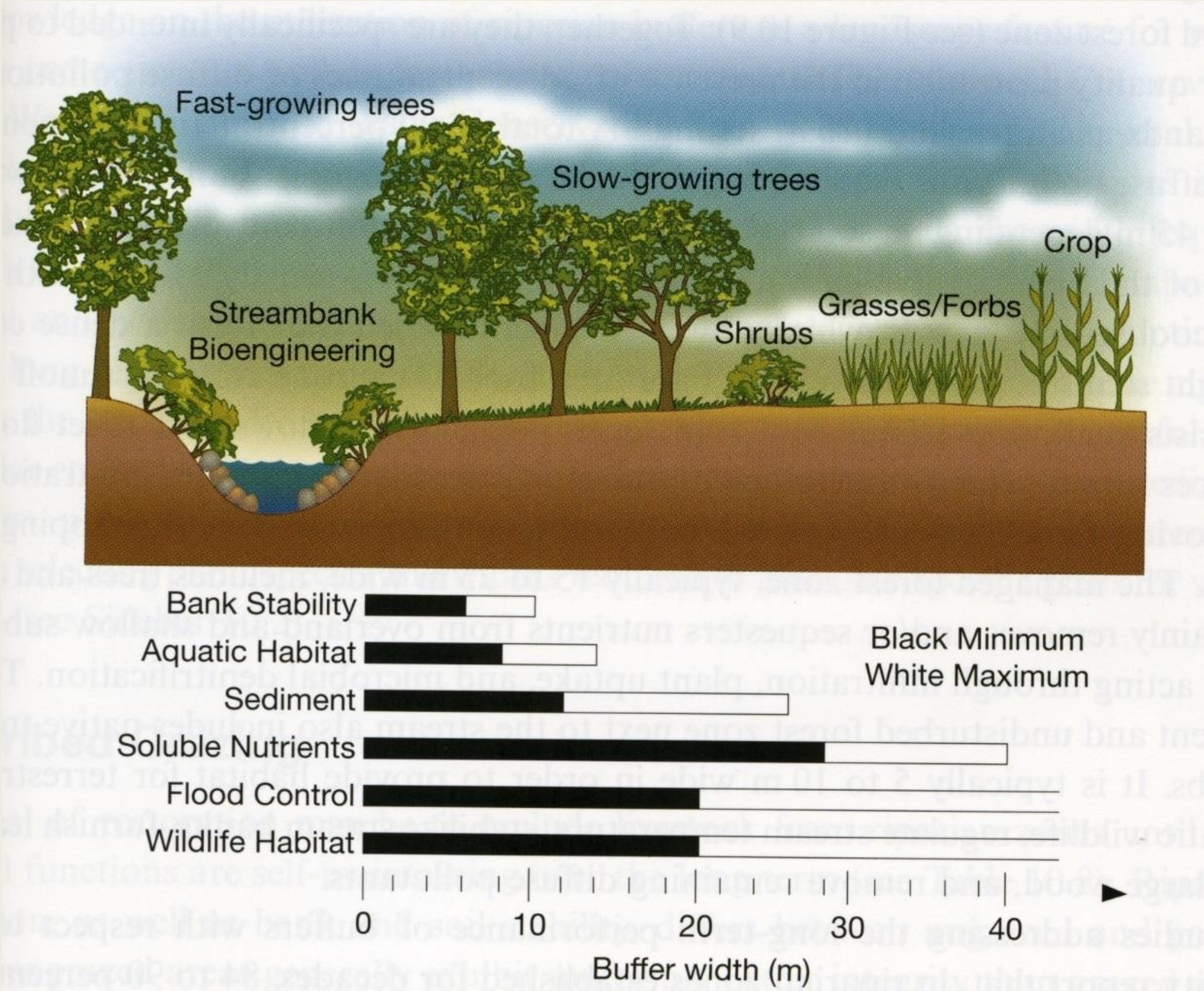



## Best choices:

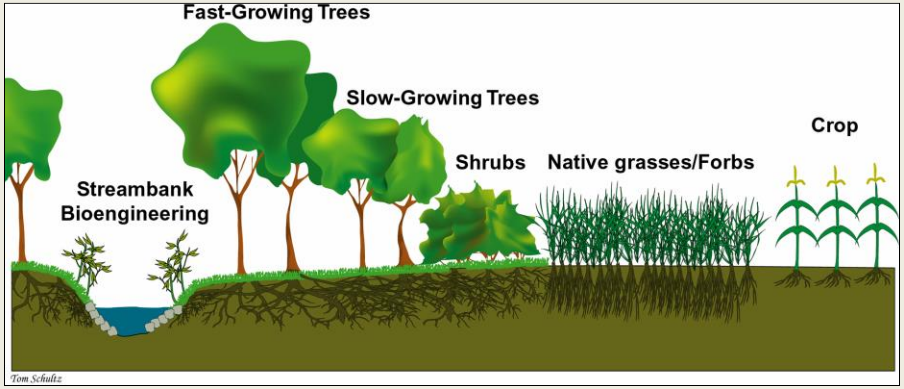
- Switchgrass (where runoff is a serious issue)
- Native warm season grasses, e.g., Indian grass, big/little bluestem (if little runoff problem) combined with switchgrass
- Native forbs
- Avoid cool season grasses (do not stand up to flow, produce less root mass)

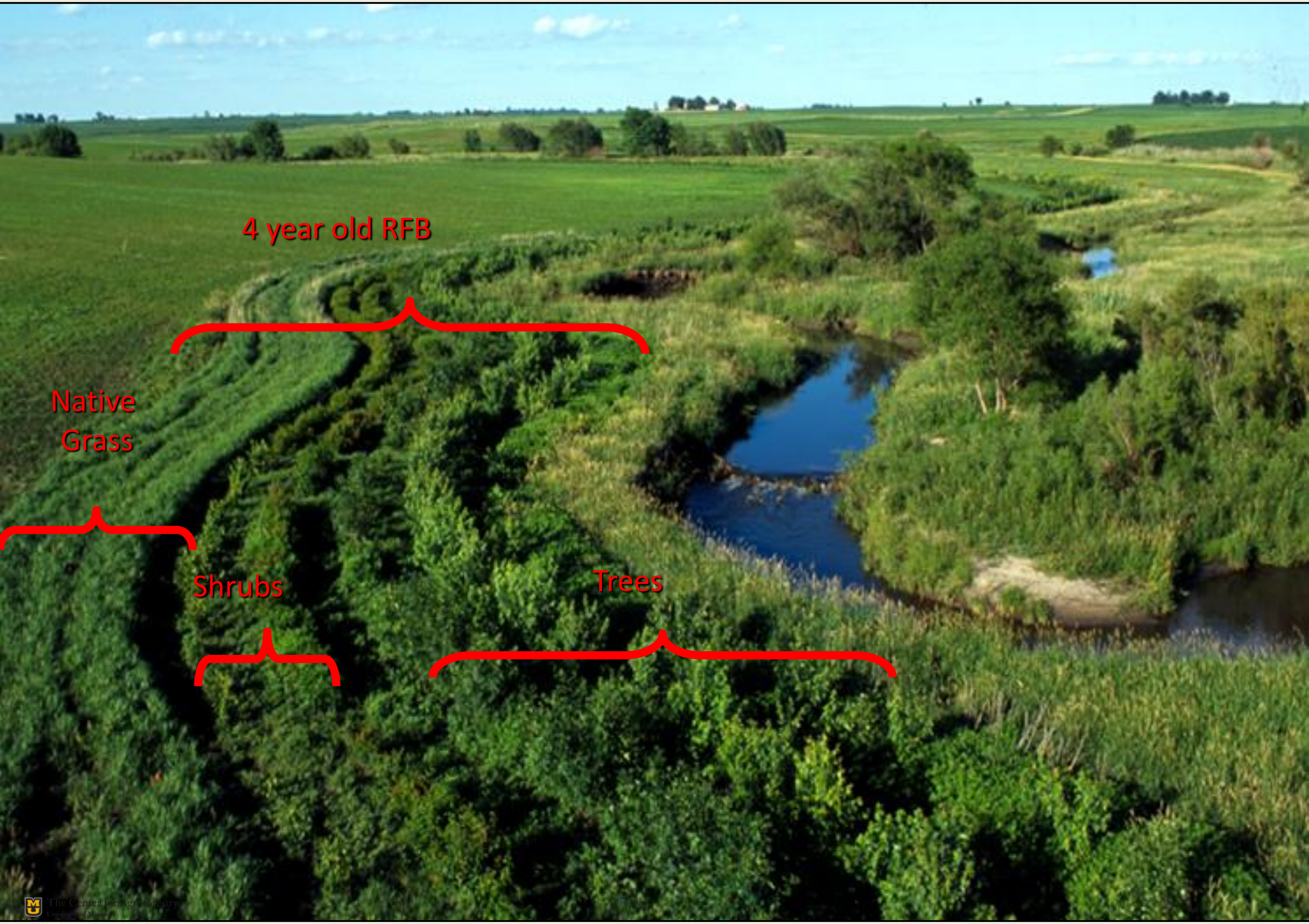
# Wider is better

- Land owner objectives
- Slope
- Soil type
- Farming practices
- Size of crop fields
- Problem(s) to be addressed



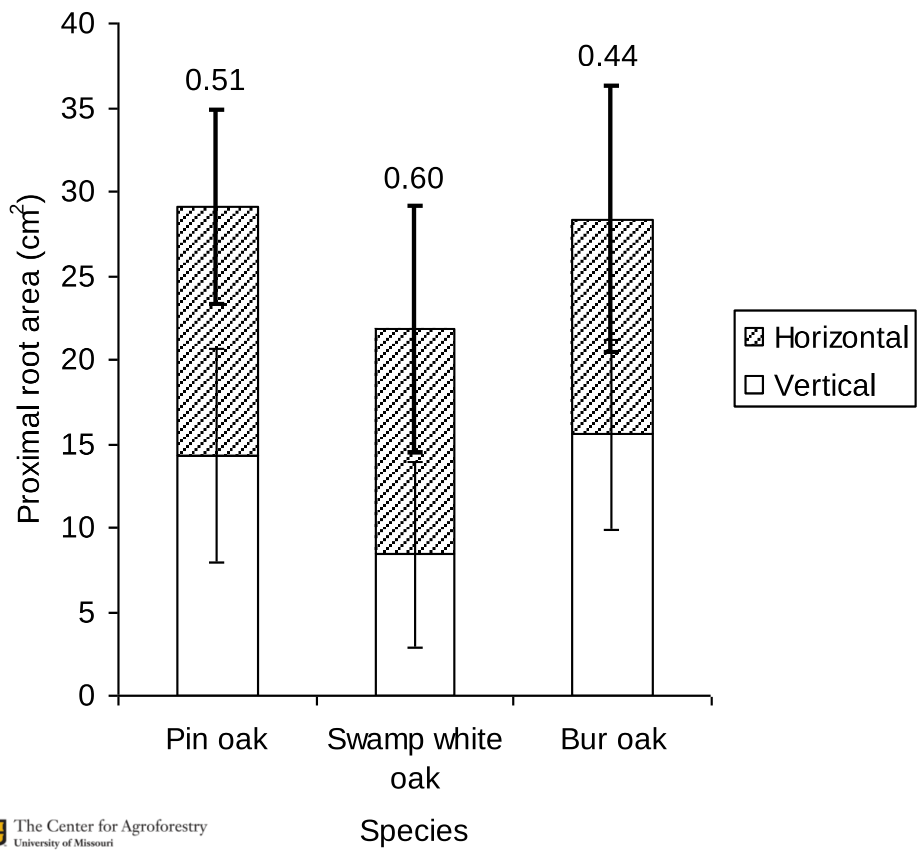
# A combinations of trees, shrubs, grasses, forbs & bioengineered structures have been shown to be effective in removing NPSP and improving soil quality

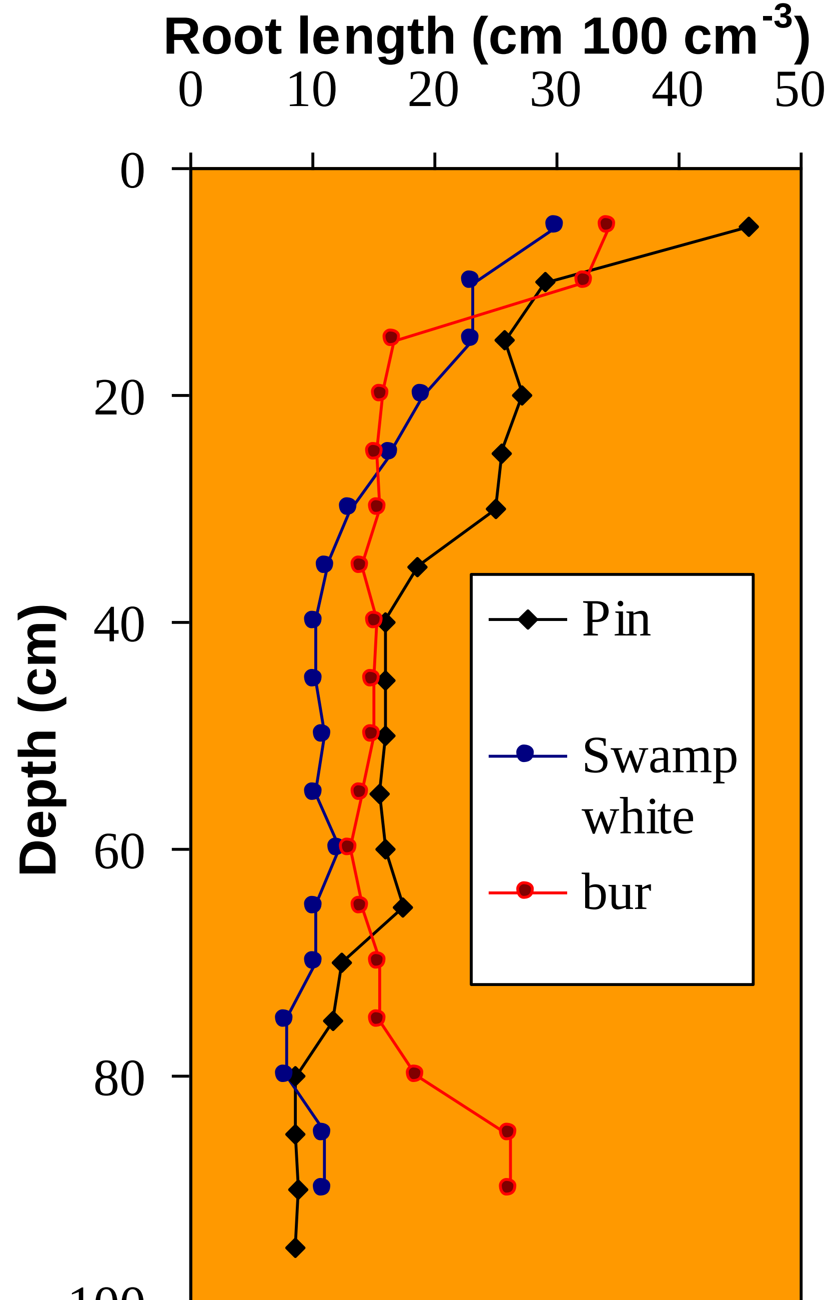



4 year old RFB
Native Grass
Shrubs
Trees

Thank you

# Vertical distribution of root length for pin oak, swamp white oak, and bur oak




Udawatta et al., 2005

# Soil cover Reduces Erosion




# **Cropland Zone:** Erosion Reduction with Cover Crops

Literature summary of percent reduction (57 to 96%) in erosion due to winter cover crops.

| Reference | Location | Cropping System | Cover crop | Reduction in Erosion |
|---|---|---|---|---|
| Beale et al., 1955 | South Carolina | Conv. Till corn | hairy vetch and rye | 57% |
| Wendt and Burwell, 1985 | Missouri | No-till corn silage | winter rye or wheat | 96% |
| Zhu et al. (1989) | Missouri | No-till soybean | chickweed | 87% |
| Zhu et al. (1989) | Missouri | No-till soybean | downy brome | 96% |
| Mutchler and McDowell 1990 | Mississippi | Conv. Till cotton | wheat or hairy vetch | 73% |
| Mutchler and McDowell 1990 | Mississippi | No-till cotton | wheat or hairy vetch | 88% |

**Bioengineering - Willow Cuttings/Posts**

-Woody vegetation slows velocity in vicinity of the bank

-Root systems strengthen the bank

-Shade, habitat, and aesthetic value improve

# *Ecosystem Resilience*

*Resilience* is
the capacity
of an *ecosystem*
to respond to a
perturbation or
disturbance by
**resisting damage**
and
**recovering quickly.**

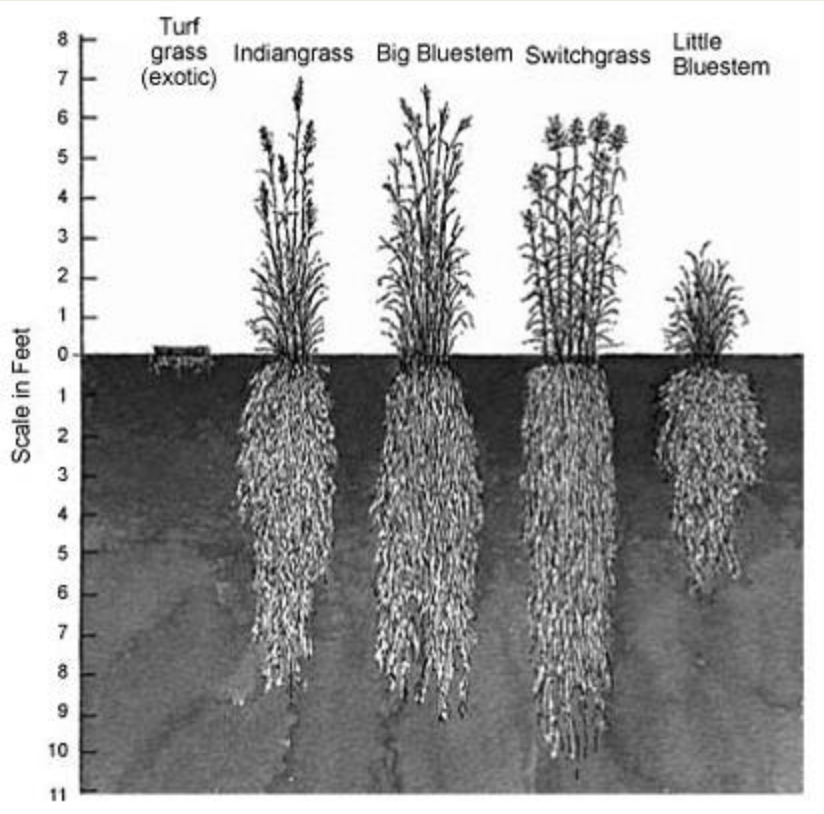

New Madrid, MO. Following the Birds Point Levee breach – Even a one-yr-old Poplar plantation survived and grew fine once water receded

# Significance of Vegetation

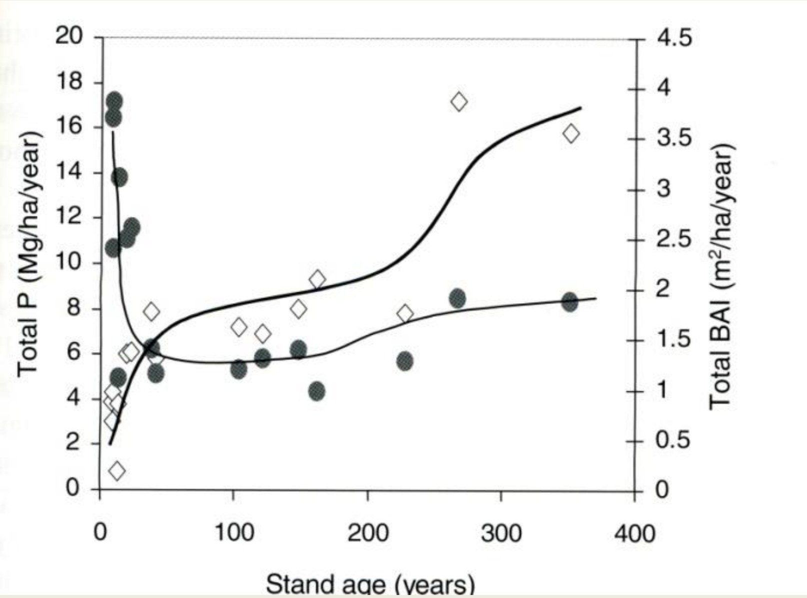
- **Vegetation strengthens streambanks**
  **(More than 50% of sediment loss is**
  **from streambank erosion (Lawler et al., 1999).**
- **Water quality**
- **Soil quality**
- **Carbon Sequestration**
- **Wildlife Habitat**
- **Biological diversity**
- **Economic benefits**

Photo Eric Epstein

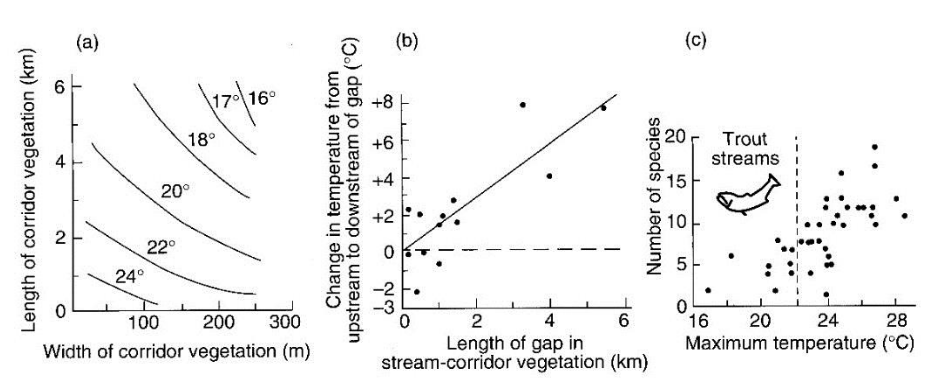
*Overtopped levee at Winfield Missouri, June 2008.*




2-year old cottonwood, River Partners



# Riparian Buffers
# Ecosystem Services


Effect of riparian vegetation width, length of gap on Stream temperature, fish species. Foramn 1995; Barton et al., 1985