Nitrogen Transformations in Flooded Agricultural Fields

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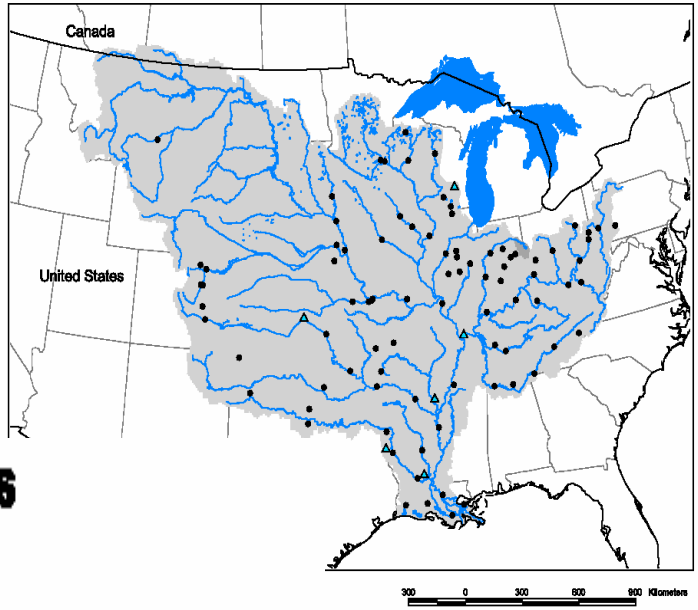
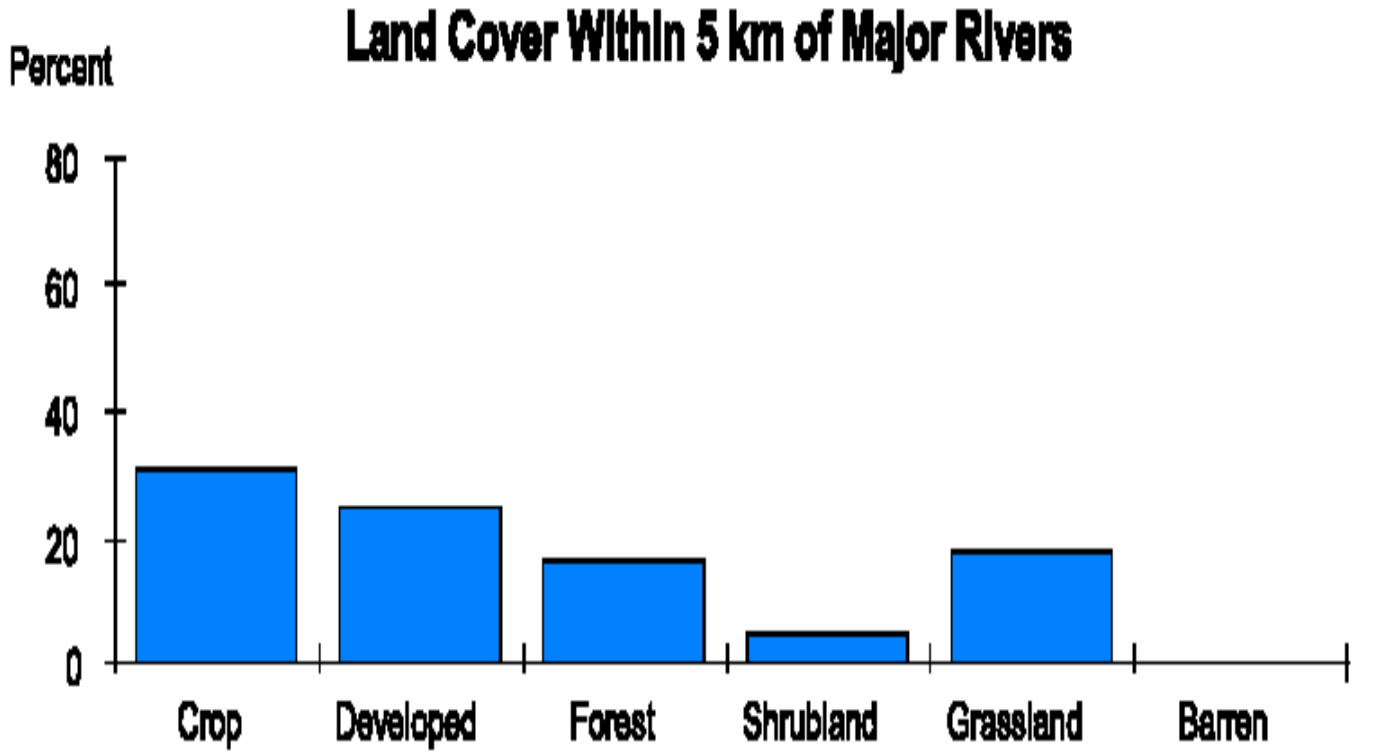
Outline of Talk

1. Fluxes of N in the Mississippi River Basin
2. Seasonally flooded fields and N transformations.
3. Research
4. Recommendations

The Mississippi River Basin is dominated by agriculture.

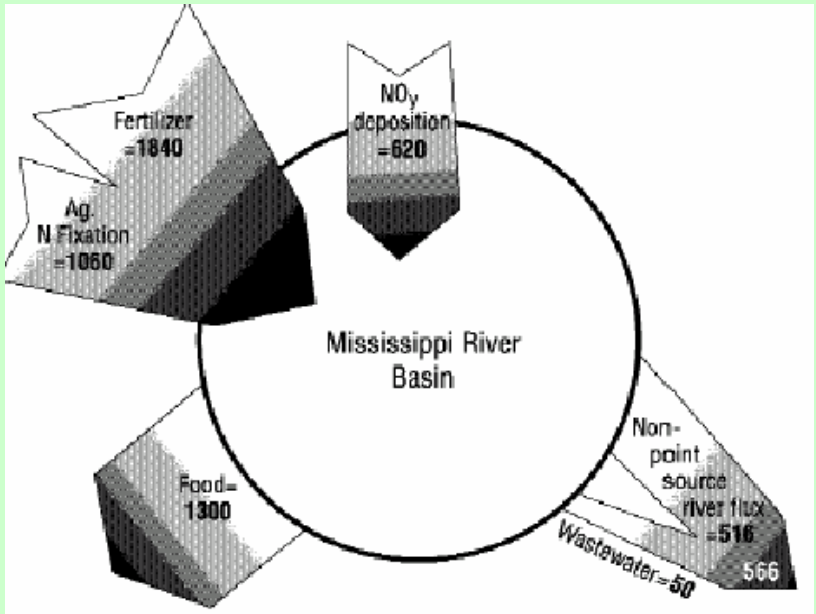




http://earthtrends.wri.org/maps_spatial/maps_detail_static.cfm?map_select=390&theme=2

Sources of new N to agricultural ecosystems in the Mississippi River Basin

1. Inorganic fertilizer (52% of new N input)
2. Legume fixation (30%)
3. Deposition of NO_x from fossil fuel use (18%)

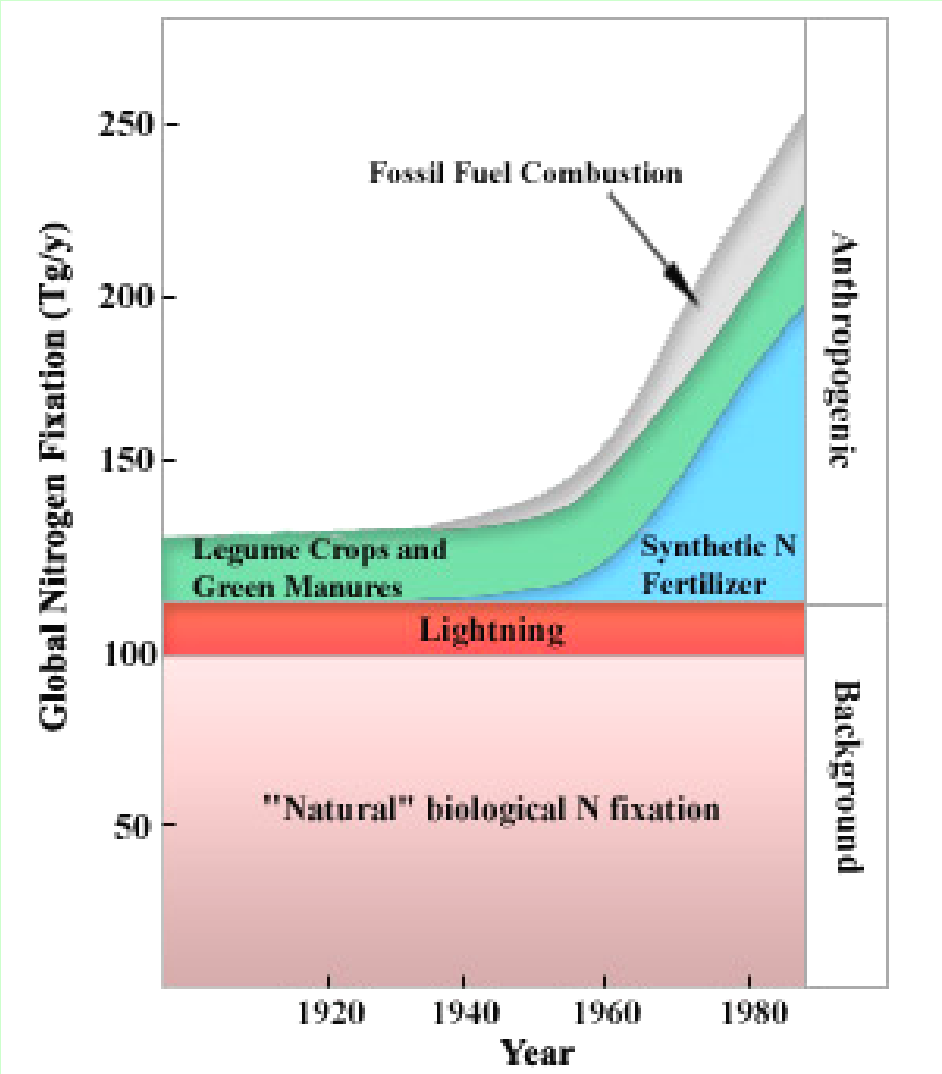


Values in figure are for 1997-1999.

Source: Howarth et al. 2002. Nitrogen use in the United States from 1961-2000 and potential future trends. Ambio 31: 88-96.

Agriculture is the dominant source of global change in the N cycle

Vitousek & Matson 1991



Modified from Vitousek, P. M. and P. A. Matson (1993). Agriculture, the global nitrogen cycle, and trace gas flux. The Biogeochemistry of Global Change: Radiative Trace Gases. R. S. Oremland. New York, Chapman and Hall: 193-208.

http://www.visionlearning.com/library/module_viewer.php?mid=98

N fertilizer use in sub-watersheds of the Mississippi Basin

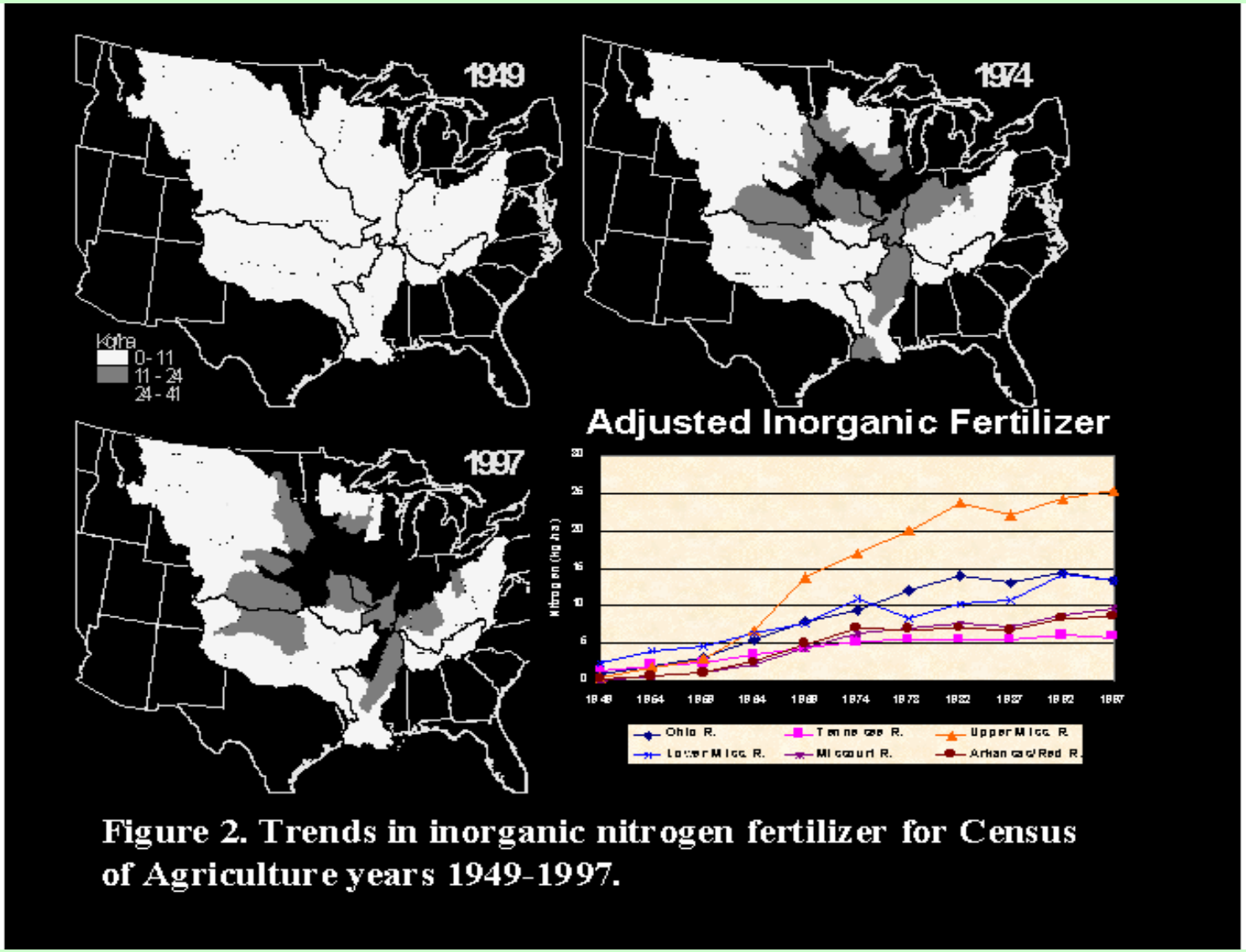
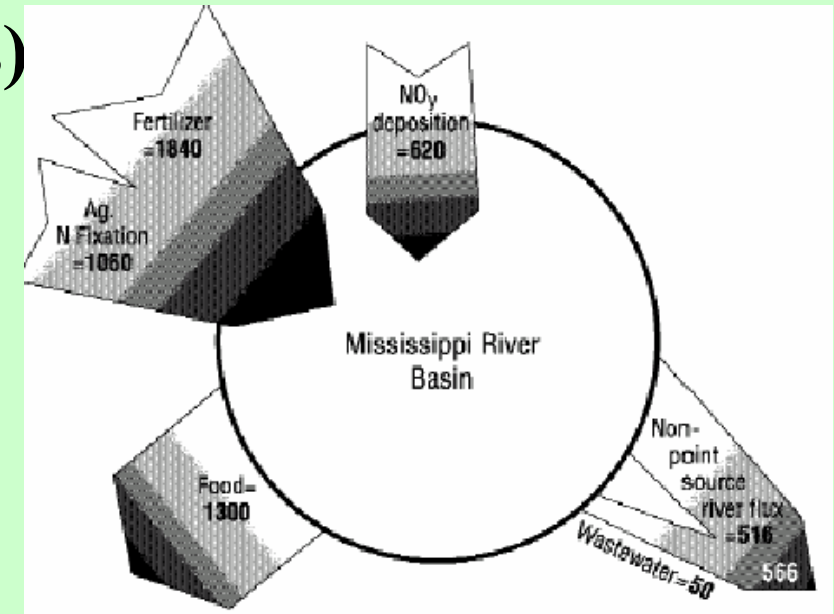


Figure 2. Trends in inorganic nitrogen fertilizer for Census of Agriculture years 1949-1997.

From: Burkart, M.R. and D.E. James. Agricultural Nitrogen Trends in the Mississippi Basin, 1949-1997. http://www.nstl.gov/pubs/burkart/trends/

Where does the N go?
Losses of N from agricultural ecosystems in the Mississippi River Basin

1. Crop harvest (56% of inputs)
2. Volatilization of NH_3 (1-2%)
3. Soil denitrification (23%)??
4. Runoff of N in surface or ground water (20%)



Values in figure are for 1997-1999.

Source: Howarth et al. 2002. Nitrogen use in the United States from 1961-2000 and potential future trends. Ambio 31: 88-96.

TABLE 3. Nitrogen and phosphorus discharges to surface waters (in 10^3 Mg/yr) from nonpoint and point sources in the United States.

Source	Nitrogen	Phosphorus
Nonpoint sources		
Croplands	3204	615
Pastures	292	95
Rangelands	778	242
Forests	1035	495
Other rural lands	659	170
Other nonpoint sources	695	68
Total	6663	1658
Total point sources	1495	330
Total discharge (nonpoint + point)	8158	2015
Nonpoint as percentage of total	82%	84%

Note: Data are modified from Havens and Steinman (1995) and Gianessi et al. (1986).

From: Carpenter et al. 1998. Nonpoint pollution of surface waters With nitrogen and phosphorus. Ecological Applications 8

N inputs vs Riverine N flux

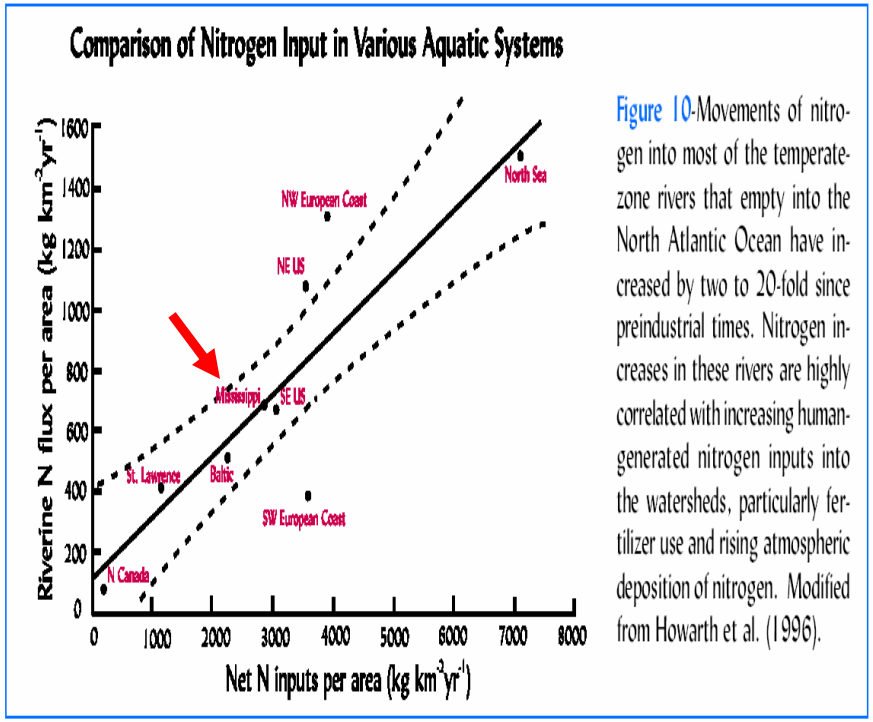
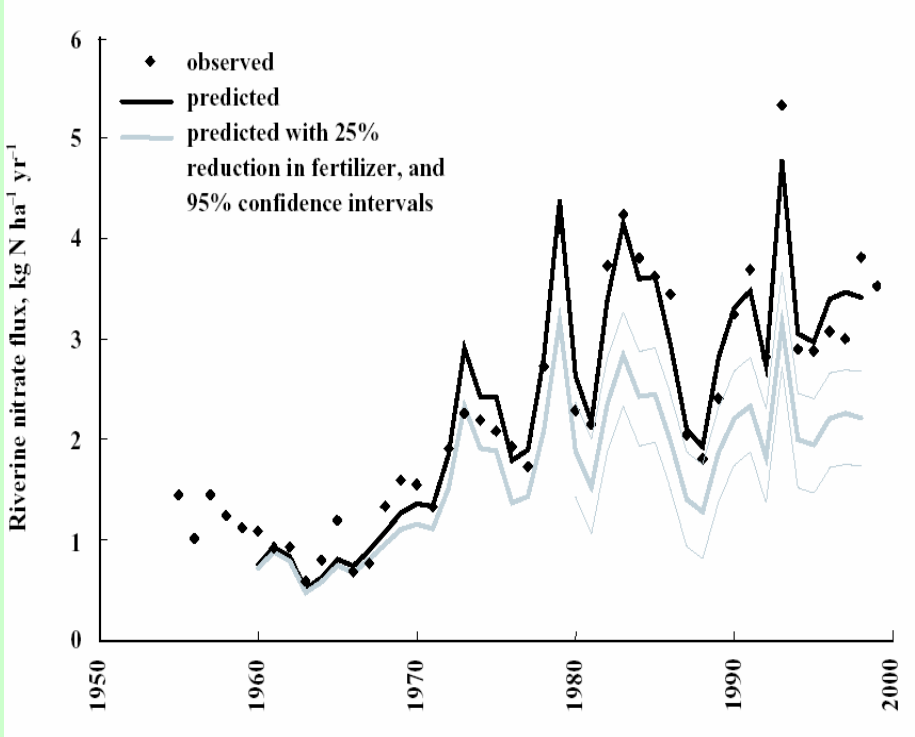


Figure 10-Movements of nitrogen into most of the temperate-zone rivers that empty into the North Atlantic Ocean have increased by two to 20-fold since preindustrial times. Nitrogen increases in these rivers are highly correlated with increasing human-generated nitrogen inputs into the watersheds, particularly fertilizer use and rising atmospheric deposition of nitrogen. Modified from Howarth et al. (1996).

From: Vitousek et al. 1997. Human Alteration of the Global Nitrogen Cycle: Causes and Consequences. Issues in Ecology 1.

NO_3 in the Mississippi River



From: McIssac et al. 2001. Eutrophication: Nitrate flux in the Mississippi River. Nature 414:166-167.

Could it get worse?

Projected trends in N fertilizer use

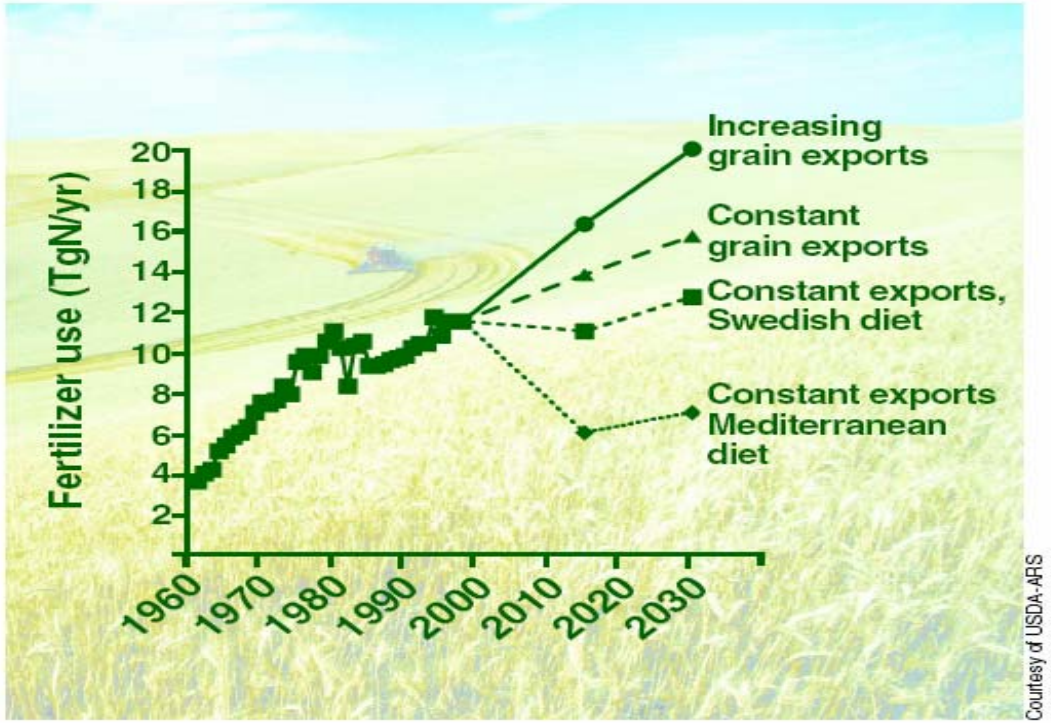
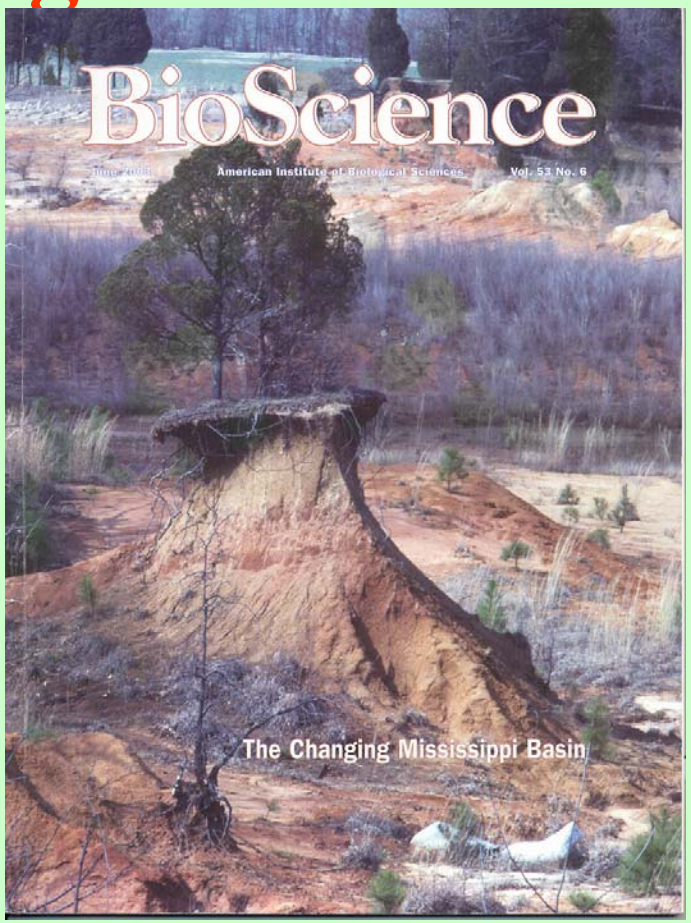


Figure 4. Use of inorganic N fertilizer in the US from 1961–1999 and projections on future use through 2030 based on a "business-as-usual" scenario of increasing grain exports (circles), constant grain exports (triangles), and two alternative diet scenarios with constant grain exports: Swedish diet (squares), and Mediterranean diet (diamonds). Reprinted from Howarth et al. (2002).

http://www.med.harvard.edu/chge/frontiers2003.pdf

Environmental problems associated with run-off from agricultural fields

- Translocation of agrochemicals
- Eutrophication of aquatic ecosystems
- Siltation of aquatic ecosystems
- Loss of soils with possible reduced soil fertility and crop yields



Turner, E. and N. Rabalais. 2003. Linking landscape and water quality in the Mississippi River Basin for 200 years. Bioscience 53: 563-572.

Table 2. Approaches for controlling nitrogen in the Mississippi River Basin.

- On-site control of agricultural drainage
  - Changing cropping systems
  - Reducing nitrogen fertilizer application rates
  - Managing manure spreading
  - Managing the timing of nitrogen application
  - Using nitrification inhibitors
  - Changing tillage methods
  - Increasing drainage tile spacing
- Off-site control of agricultural drainage
  - Wetlands
  - Riparian zones
- Urban and suburban nonpoint source control
- Point source control
  - Environmental technology
  - Ecotechnology
- Control of atmospheric NO_x
- Mississippi River diversions
- Upper Mississippi River flood control and restoration

The starting point for any improvement [in N-use efficiency] has to be a clear understanding of reactive N fluxes and balances at the farm level.

Galloway et al. 2002. Reactive nitrogen: Too much of a good thing?

From: Goolsby et al. 1999. Flux and sources of nutrients in the Mississippi-Atchafalaya Basin. NOAA Coastal Office. Decision Analysis Series no 17

What are seasonally flooded agricultural fields?

- Lands modified for agricultural use but flooded at specific times of year (eg winter).
- Located primarily in low lying areas including valley bottoms, floodplains and deltas of rivers and creeks.
- May flood by overflow from rivers or creeks, or by accumulation of precipitation.

Why are seasonally flooded agricultural field ecosystems considered ecologically important?

- Reduced winter-time erosion
- Reduced losses of nutrients and chemicals
- Increased pest/weed control
- Habitat for migrating waterfowl

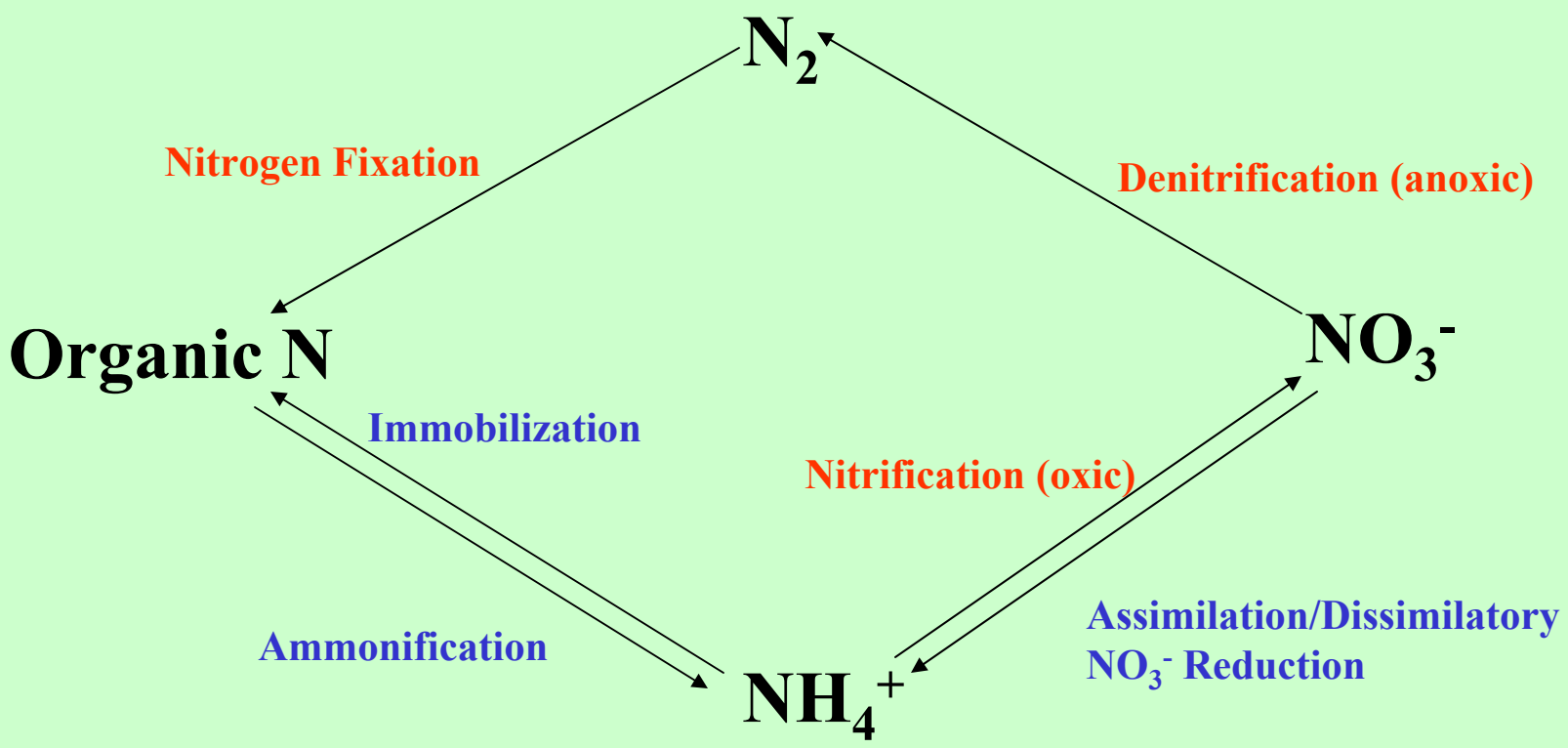
Our questions:

Will <u>wintertime</u> flooding of agricultural fields influence:

a. soil and/or surface runoff concentrations of N and P?

b. soil microbial metabolism related to N transformations?

N-transformations in wetlands



RED = prokaryotic metabolism

Types and rates of microbial N transformation in soils have different consequences for export and environmental quality

- **With mineralization – NH_4 is produced which may volatilize and/or (if O_2 is present) be converted to NO_3 by nitrification.**
- **With nitrification – NO_3 is produced which is soluble and will occur in runoff.**

  Result: offsite N pollution
- **With denitrification – N_2 released. Gaseous products do not occur in runoff.**

  Result: no problem

Research Field Sites and Mesocosms

Research Hypotheses

1 By producing an anoxic environment, wintertime flooding will decrease rates of nitrification leading to accumulation of NH_4-N in soils. Conversely, where flooding is prevented, NO_3-N will accumulate.

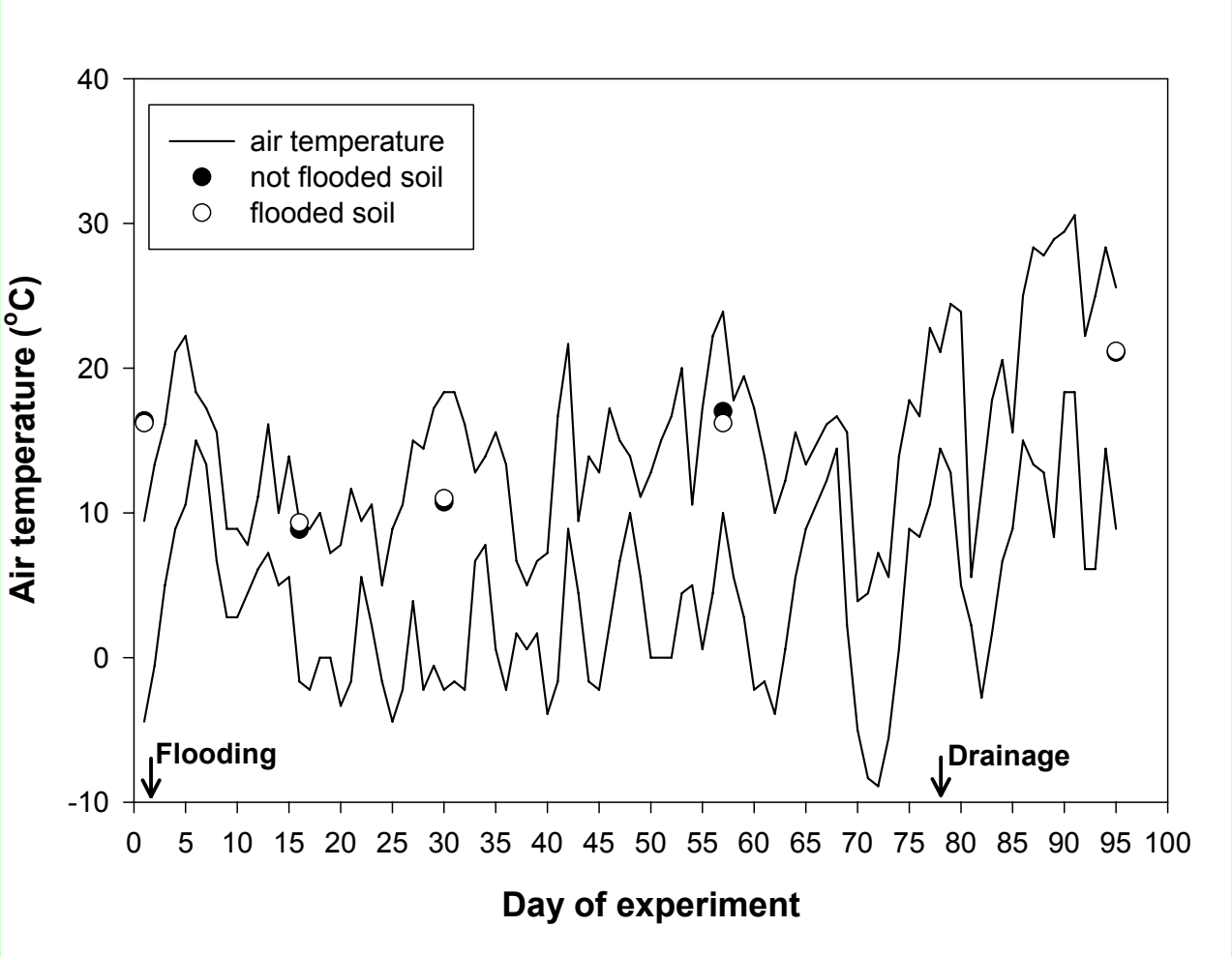
2 By providing an anoxic environment, winter-time flooding will enhance rates of denitrification.

3 By protecting bare soils from the impact of precipitation, flooding will reduce field losses of N and P in surface runoff.

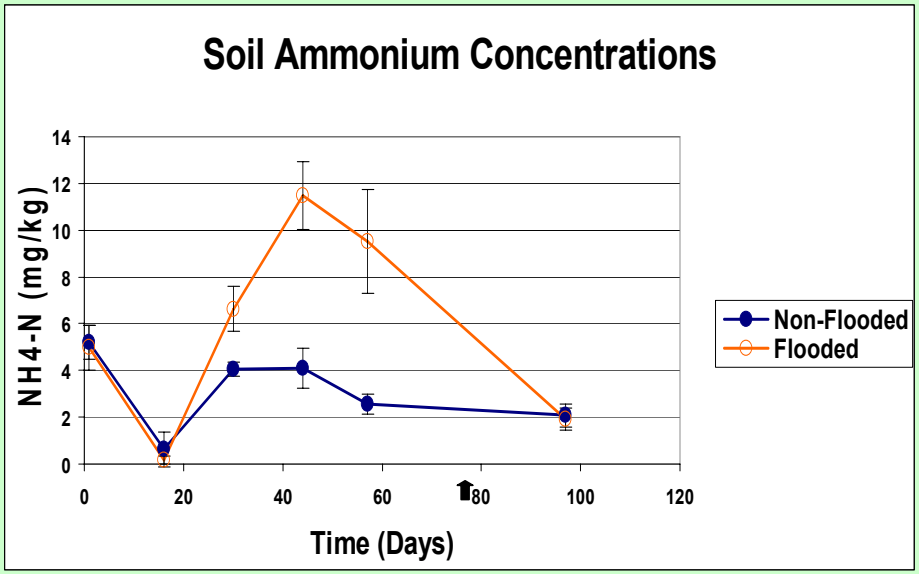
Analyses

- **Chemical parameters measured in soil:**
  - » **Ammonium, nitrate, total nitrogen, organic carbon, total phosphorus, and percent organic matter**
- **Chemical parameters measured in overlying water layer:**
  - » **Ammonium, nitrate, and total phosphorus**
- **Microbial community parameters :**
  - » **Microbial biomass and abundance of denitrifying bacteria, denitrification and respiration rates.**
- **Research conducted between January and April 1998.**

Mesocosm Experiment using Soil Cores



Soil NH_4 in soil core mesocosms



- During flooding, flooded soils had higher and increasing NH_4.
- Following drainage, NH_4 concentrations decreased in previously flooded soils.

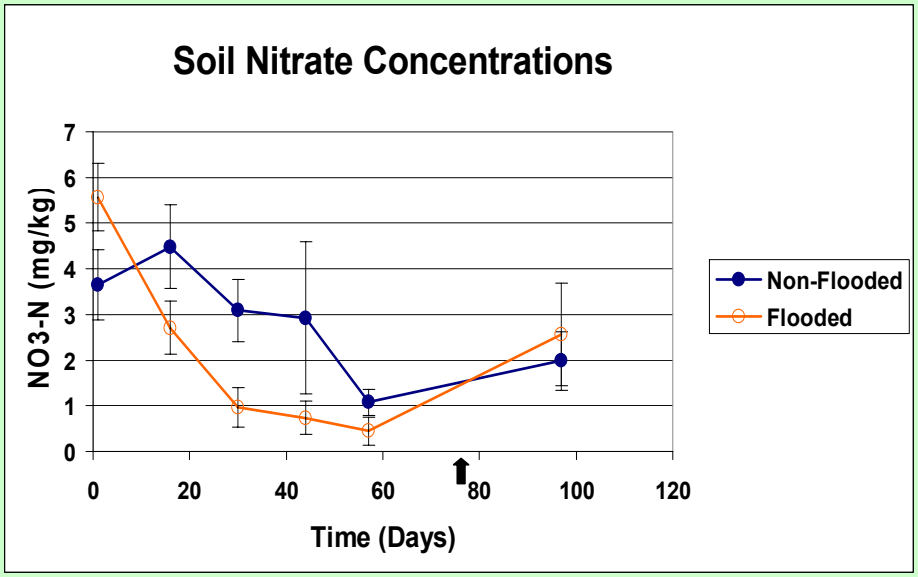
Explanations:

1. Mineralization produces NH_4 which accumulates in absence of nitrification in flooded, anoxic soils.

2. In non-flooded oxic soil, there are higher rates of NH_4 volatilization and perhaps of nitrification.

3. Following drainage, NH_4 is oxidized to NO_3 resulting in a decrease in NH_4

Soil NO_3 in soil core mesocosms



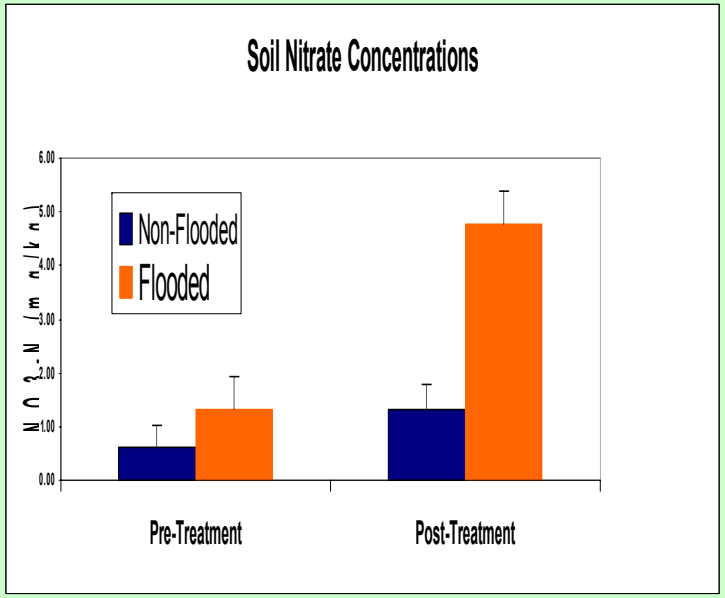
- During flooding, NO_3 was greater in non-flooded soils.
- NO_3 declined in both flooded and non-flooded soils.

Explanations:

1. Nitrification enhanced in non-flooded, oxic soils.

2. Some loss of nitrate is possible by denitrification, but measured denitrification rates do not explain magnitude of NO_3 declines.

Soil NO_3 in field experiment (*in situ*)



- **In the field experiment, NO_3 was much greater in previously flooded soils one week after drainage.**

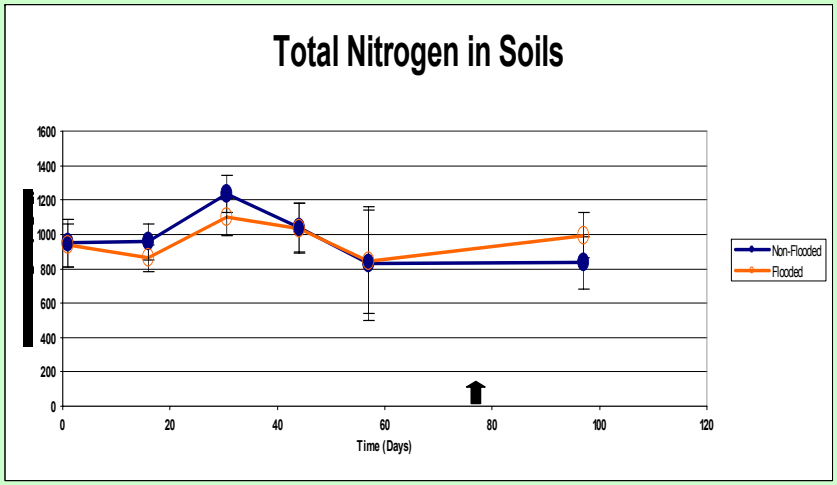
Explanations:

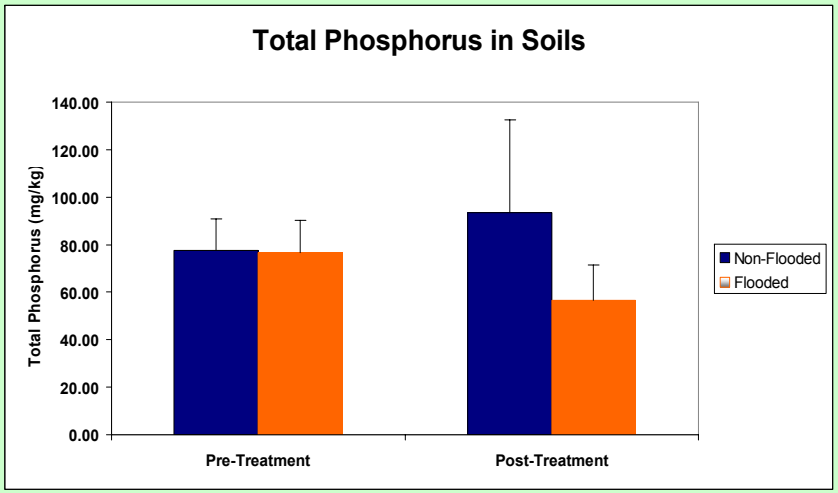
1. Following drainage there is a pulse of nitrification as the soils are re-oxygenated. This results in the large increase in NO_3 in previously flooded soils.

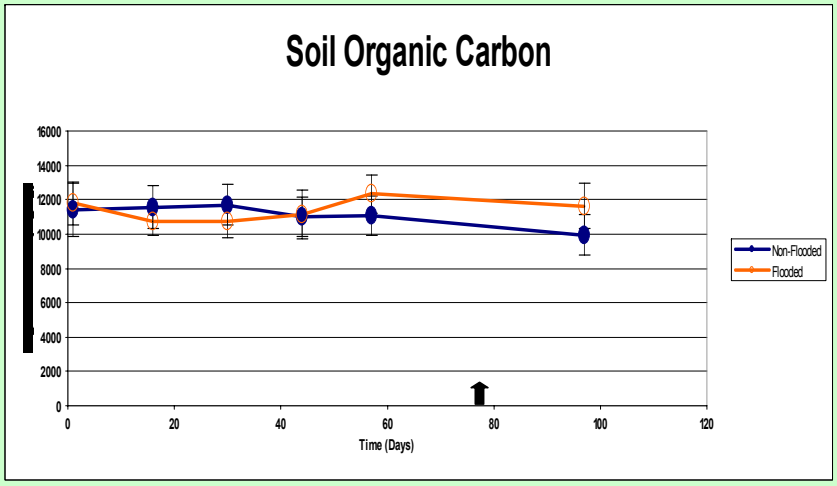
2. Unlike in mesocosm experiments, runoff was possible in non-flooded soils during the winter period. Nitrate produced during winter in non-flooded soils would be lost.

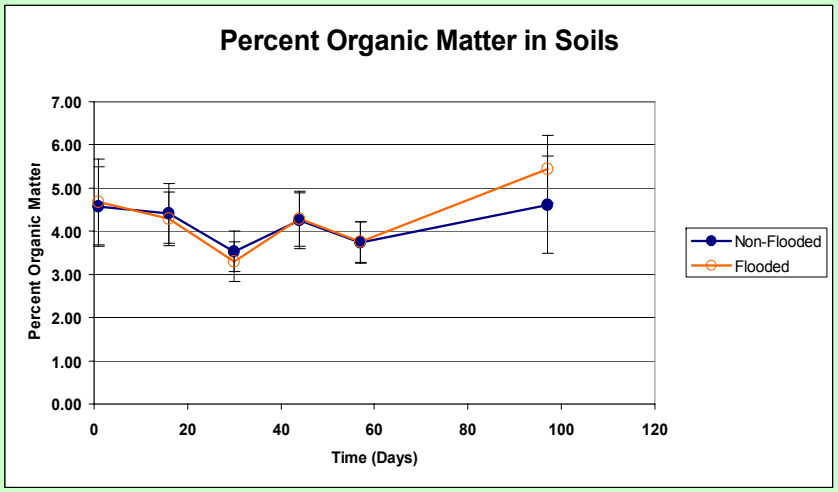
Mesocosm Experiment using Soil Cores

Other Soil Chemical Variables



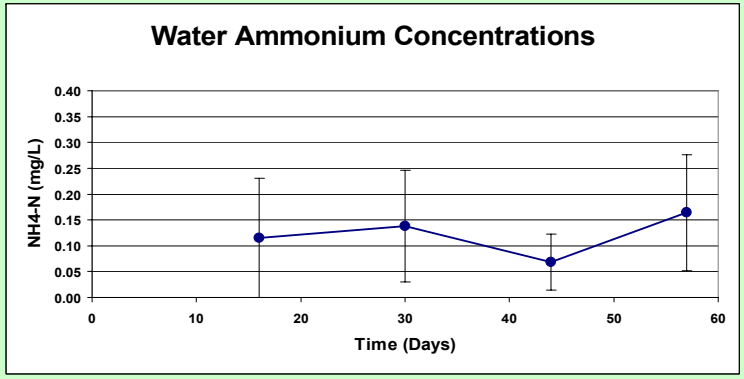


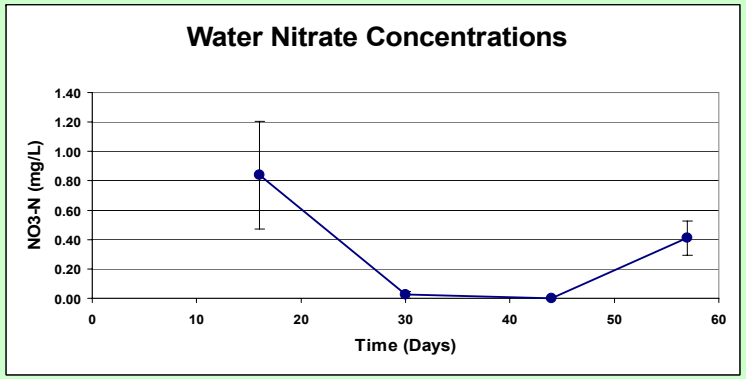


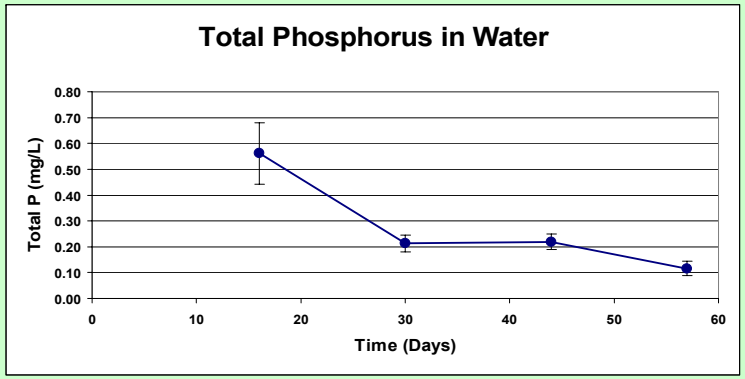


Chemical concentrations in overlying water

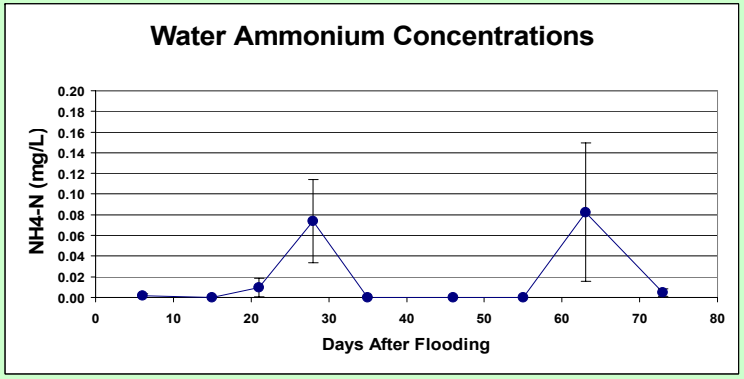
Mesocosms using Soil Cores

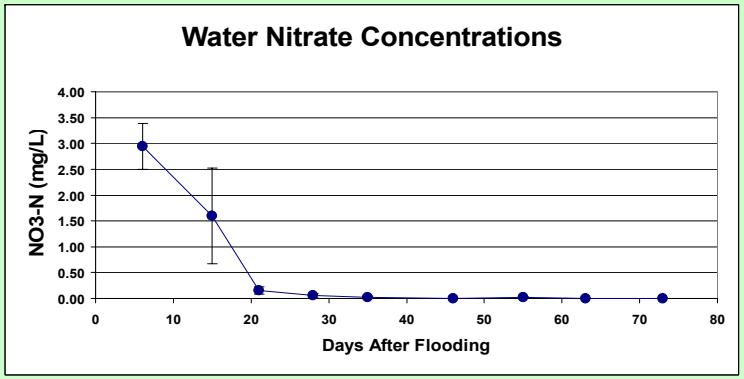


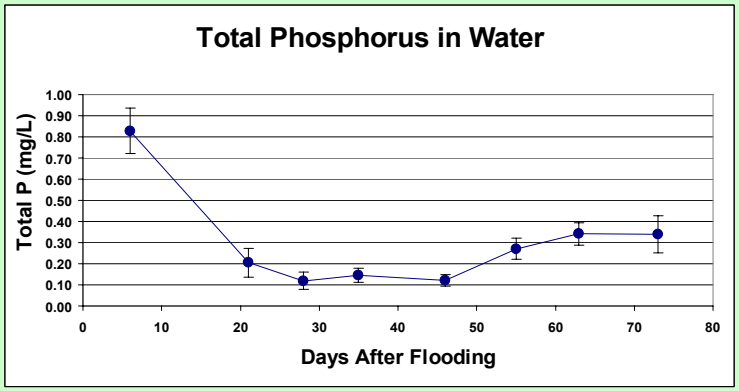




Mesocosms in Field (using flood water)

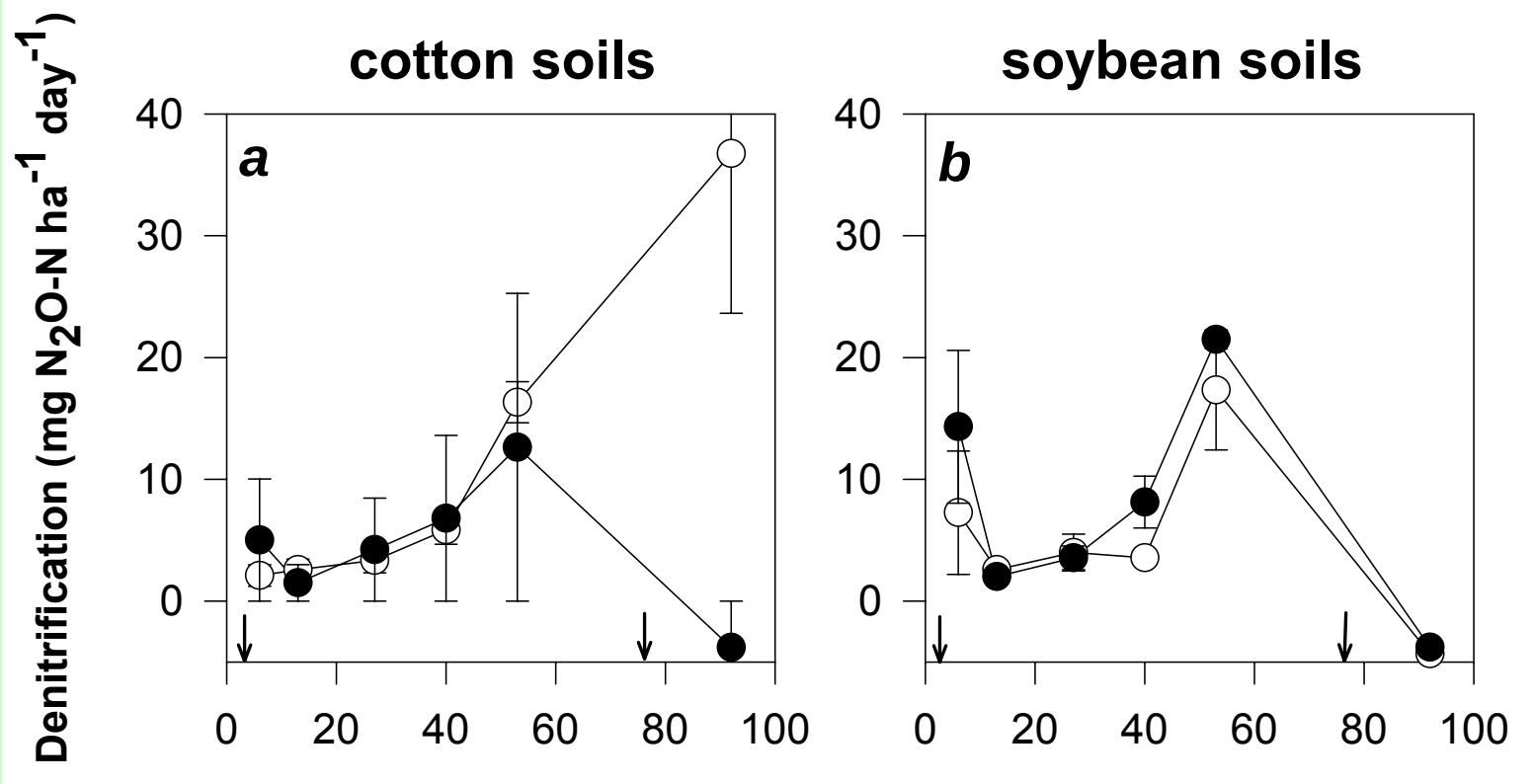




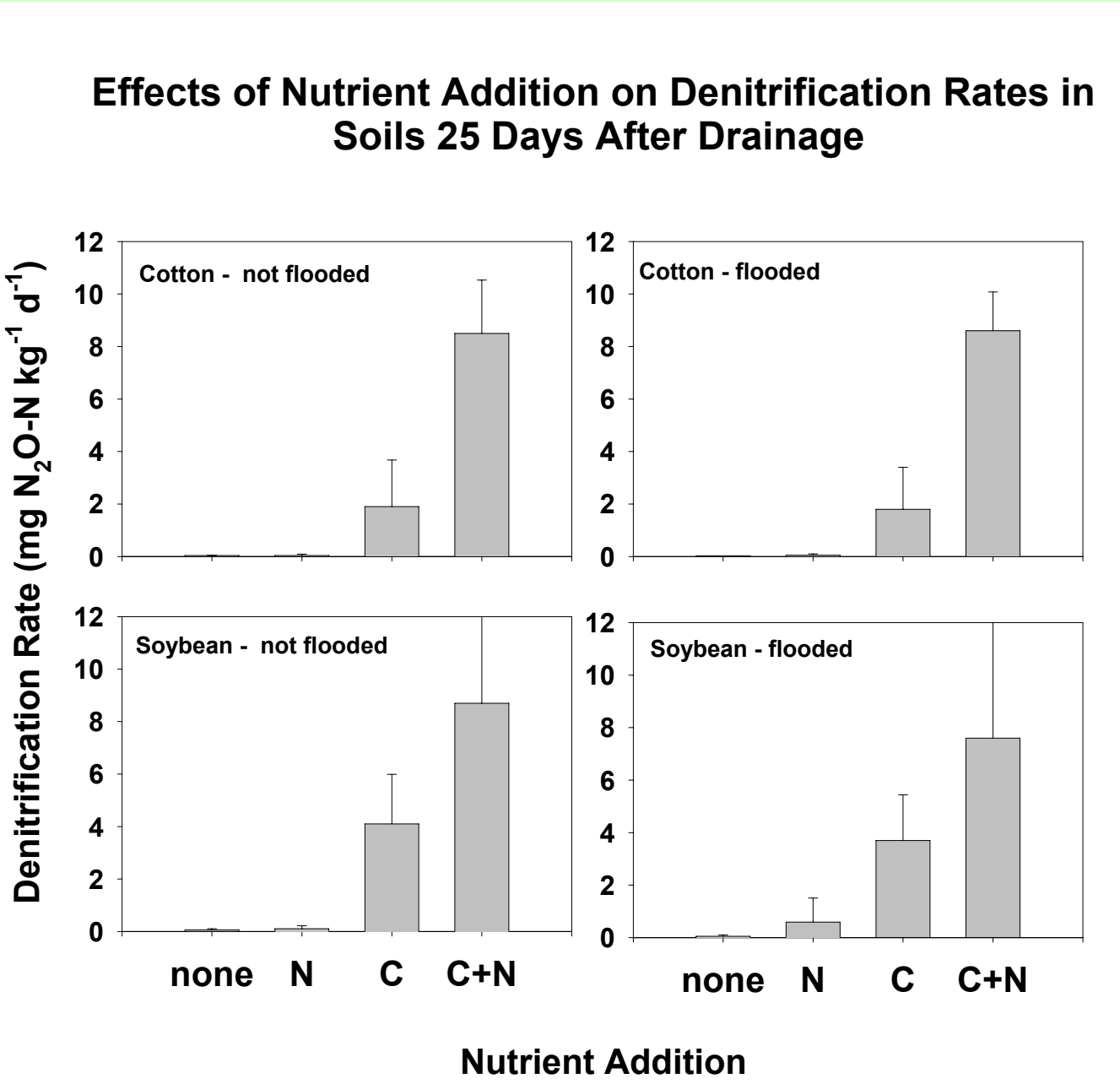


Mesocosm Experiment using Soil Cores

Denitrification rates



Mesocosm Experiment using Soil Cores



Concentrations of Dissolved Nutrients in Overlying Water After 55-57 days Flooding Compared to Average Concentrations in Runoff from LeFlore County Cotton Fields

Experiment	Chemical	Concentrations (mg/L)	n
Soil Cores	NH_4-N	0.00 – 0.17	4
	NO_3-N	0.00 - 0.31	
	Total P	0.10 – 0.71	
Field Mesocosms	NH_4-N	0.00	8
	NO_3-N	0.02 – 0.15	
	Total P	0.11 – 0.44	
Field Runoff	NH_4-N	0.68	14
	NO_3-N	0.13	
	Total P	3.5	

Conclusions

1. Flooding of soil cores for at least 57 days during winter had little or no detectable effect on soil nutrient concentrations in post-treatment cotton or soybean soils. During the period of flooding, nitrate-nitrogen was consistently lower and ammonium-nitrogen was higher in flooded soils.

2. Denitrification and soil respiration rates were not different between flooded and non-flooded soils during the period of flooding. Following drainage, denitrification in previously flooded cotton soils was higher than in previously non-flooded soils. In all soils, denitrification was limited principally by labile carbon.

3. Losses of N and P by denitrification and/or leaching during the period of flooding were insignificant relative to soil N concentrations.

4. Losses of N and P from flooded soils were less than losses by erosion from bare cotton-field soils.

Agricultural Extension Service
The University of Tennessee

SP597

Flooding Harvested Crop Fields in Winter: Effects on Crop Production and Opportunities for Waterfowl Management

William Minser, Instructor/Research Associate, Department of Forestry, Wildlife and Fisheries
Tim Pruitt, Wildlife Biologist, Tennessee Valley Authority
David Buehler, Associate Professor, Department of Forestry, Wildlife and Fisheries
Craig Harper, Assistant Professor, Department of Forestry, Wildlife and Fisheries
Ed Harsson, Wildlife Biologist, Tennessee Wildlife Resources Agency

Results of Study:

1. Winter flooding did not affect soybean production in following seasons.
2. No effect on soil fertility.
3. Fields flooded until April 1 had fewer weeds.
4. Bird use increased by 332% in 3 years of study.

http://www.utextension.utk.edu/publications/spfiles/SP597.pdf

Possible problems with winter-time flooding

1. **Excess guano deposition.**
2. **Negative effects on native soil fauna.**
3. **Possible mobilization of toxic compounds, eg methyl-mercury (CH_3-Hg).**

Recommendation:

Research over longer time scales, natural agricultural field conditions, various flooding conditions (eg duration), including subsurface drainage, and diverse soil types.

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