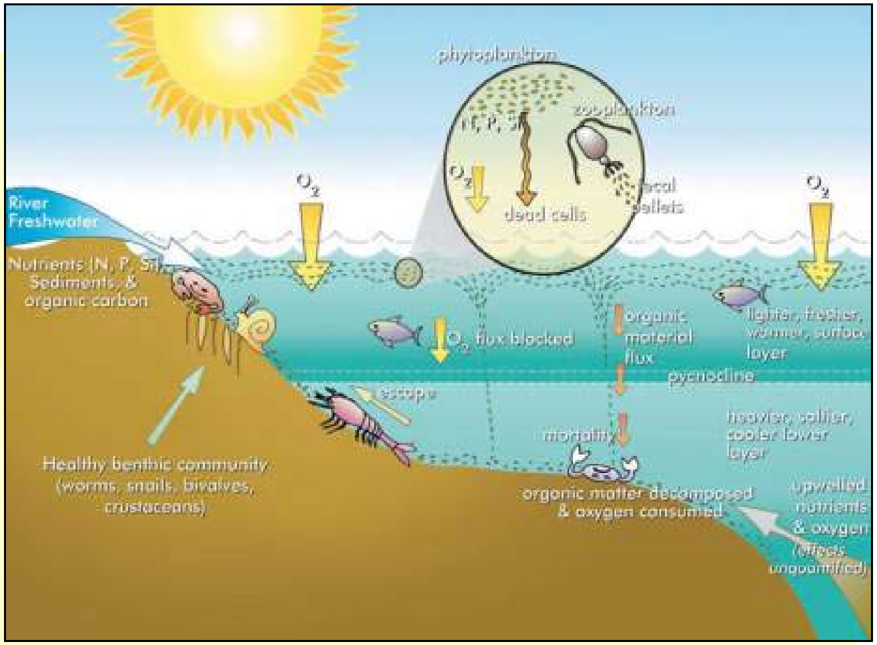
IPNI
INTERNATIONAL
PLANT NUTRITION
INSTITUTE

Corn Acreage, Fertilizer Use, & Spring Nutrient Discharge in the Mississippi River Basin: Relationships & Impact on Hypoxia

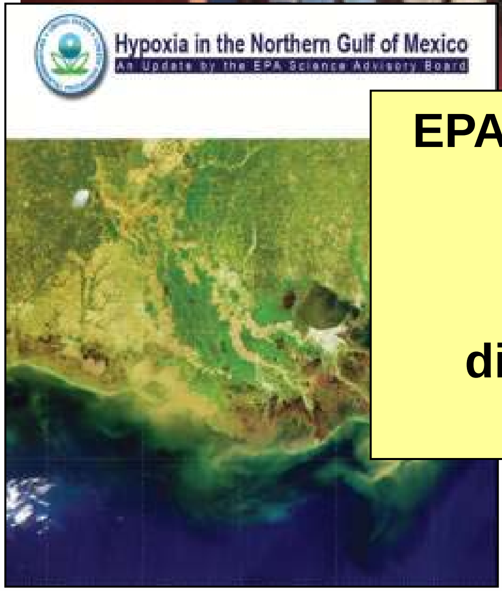
C.S. Snyder, PhD, CCA

Nitrogen Program Director

Northern Gulf of Mexico Hypoxia: Complex Causal Factors



- Natural event
  - <2 mg dissolved O_2/L
  - increased area and frequency in last half century
- Climate, weather
- Freshwater inflows
  - stratification of freshwater over saltwater
- Coastal water circulation patterns, water retention time
- Nutrient loadings (N, P, Si)
- Loss of processing marsh along Louisiana coast



Hypoxia in the Northern Gulf of Mexico

An Update by the EPA Science Advisory Board

EPA Hypoxia SAB report suggested

45% less total N

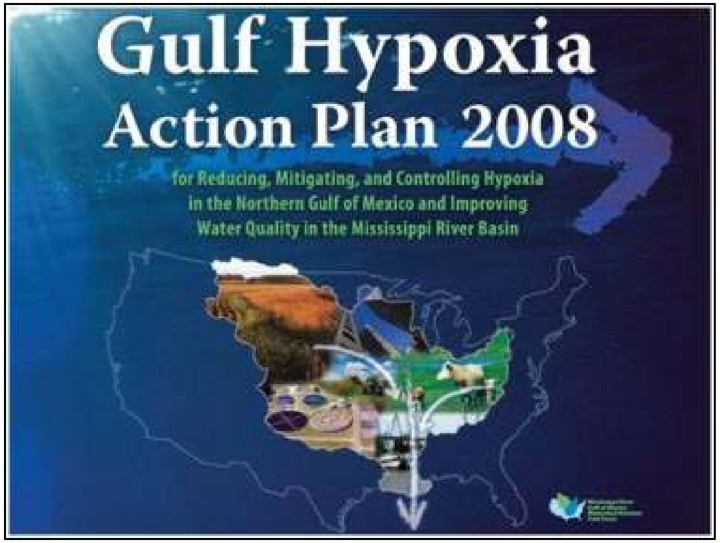
AND

45% less total P

discharge to the Gulf to reduce hypoxia

BETTER CROPS

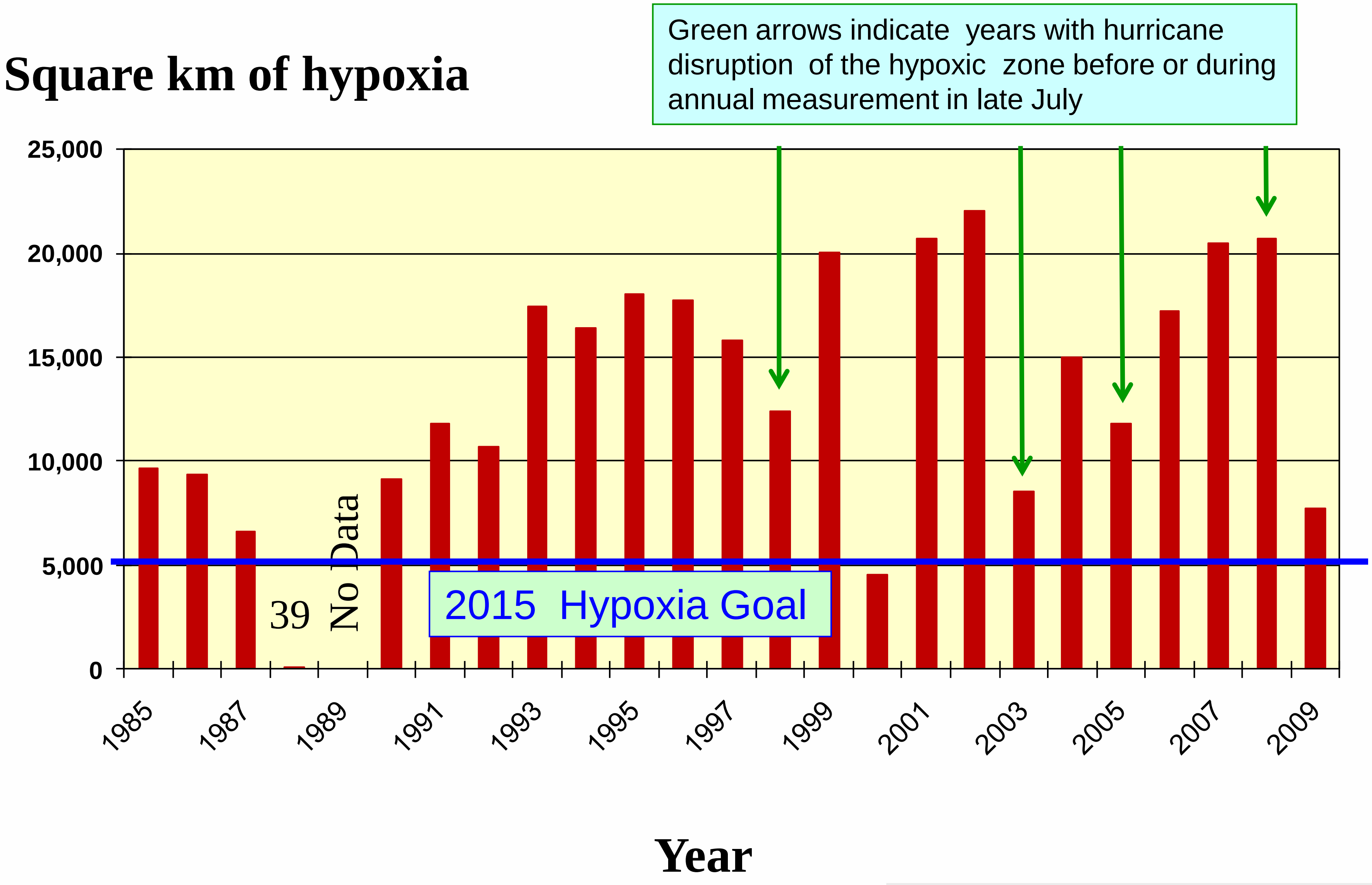
Nutrients and Hypoxia in the Gulf of Mexico — An Update on Progress, 2008



Gulf Hypoxia Action Plan 2008

for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico and Improving Water Quality in the Mississippi River Basin

Gulf of Mexico Hypoxia Area

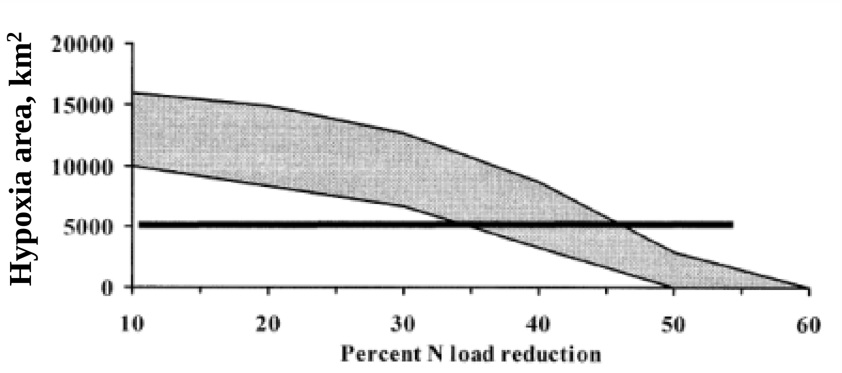


Green arrows indicate years with hurricane disruption of the hypoxic zone before or during annual measurement in late July

Hypoxia data from N. Rabalais, LUMCON

Predicting Hypoxia

- **Scavia et al. 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Miss. River N load.** Limnol. Oceanogr. 48(3), 2003, 951–956
  - May-June total N loads, to predict hypoxia, 1985-2002
  - *Also hindcast to 1972*



- **Turner et al. 2006. Predicting summer hypoxia in the northern Gulf of Mexico…** Marine Pollution Bull. 52:139-148 .
  - 1985 to 2004, *also hindcast to 1978*
  - R^2 for nutrient flux 2 months (May) before hypoxia measured

$NO_3^- + NO_2^-$ N	**0.50**
Total N	**0.27**
Ortho-P	**0.54**
Total P	**0.60**

- 1978-2004 error residual increased with years (system “memory”)
- **Best R^2 = 0.82: May $NO_3^- + NO_2^-$ N flux and “Year”**

Campbell & Booth. 2007. Spring Nitrate Flux in the Miss. River Basin: A Landscape Model with Conservation Applications. Environ. Sci. Technol., 41(15): 5410-5418

- "N derived from fertilizer runoff in the Mississippi River Basin (MRB) is acknowledged as a primary cause of hypoxia in the Gulf of Mexico."
- Regressions for 1990-2002, using SPARROW
  - relationship between springtime (March-June) nitrate loading to Gulf and
    - "fertilizer N" runoff - 59%, atmospheric nitrate deposition -17%, animal waste- 13%, municipal waste- 11%
  - **R^2 = 0.65** for March-June modeled delivery; **R^2 = 0.86** for April-July measured delivery

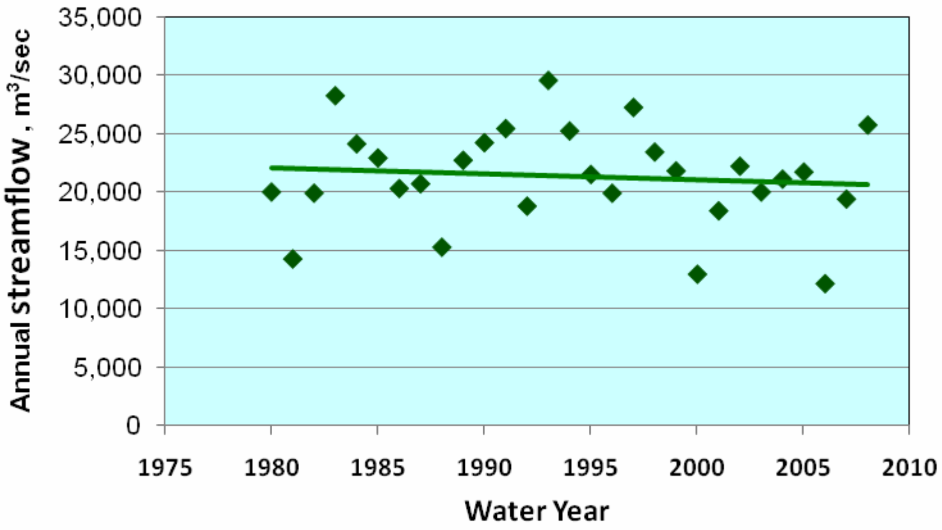
Greene et al. 2009. Multiple regression models for hindcasting and forecasting midsummer hypoxia in the Gulf of Mexico. Ecol. Applic.19(5):1161–1175

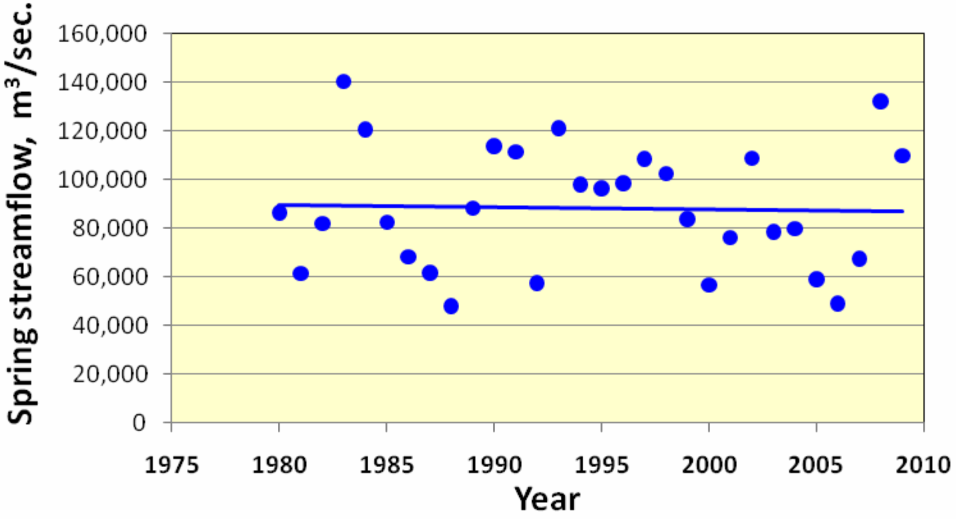
- Model input variables derived from two load estimation methods:
  - the adjusted maximum likelihood estimation (AMLE) and the composite (COMP) method, developed by USGS
  - **Hypoxia predicted 1955-2007**
    - May NO_{3+2} load **$R^2 = 0.42$** P = 0.001
    - May streamflow + (May NO_{3+2} conc. COMP) + (Feb. TP conc. COMP) **$R^2 = 0.60$** P = 0.003
    - May streamflow + (May NO_{3+2} conc.) + (Feb. TP conc.) + Epoch **$R^2 = 0.80$** $P < 0.0001$
  - Predicted that five years after instantaneous 50% NO_3 reduction or dual 45% NO_3 and TP reduction, … possible to achieve significant reduction in hypoxic area
  - If nutrient reduction targets achieved gradually (e.g., over 10 years), > 10 years required before significant downward trend in nutrient concentrations and hypoxic area

OBJECTIVES

- For 1985-2009, evaluate relationships between
  - – Measured annual Gulf hypoxia and
    - nutrient flux (annual, spring (April-June), and May)
  - – Spring and annual nutrient flux to Gulf and
    - fertilizer N and P consumption in MARB
    - harvested corn and soybean area in MARB
  - – **Data/information sources**
    - Hypoxic area – N. Rabalais
    - Nutrient flux – USGS, B. Aulenbach et al. (LOADEST AMLE)
    - Corn and soybean harvested area – USDA NASS
    - Fertilizer consumption - AAPFCO & TFI
    - MARB nutrient balance – EPA hypoxia SAB report
- Discuss more recent nutrient flux trends and balances

Annual and Spring Combined Miss. & Atchafalaya River Streamflow

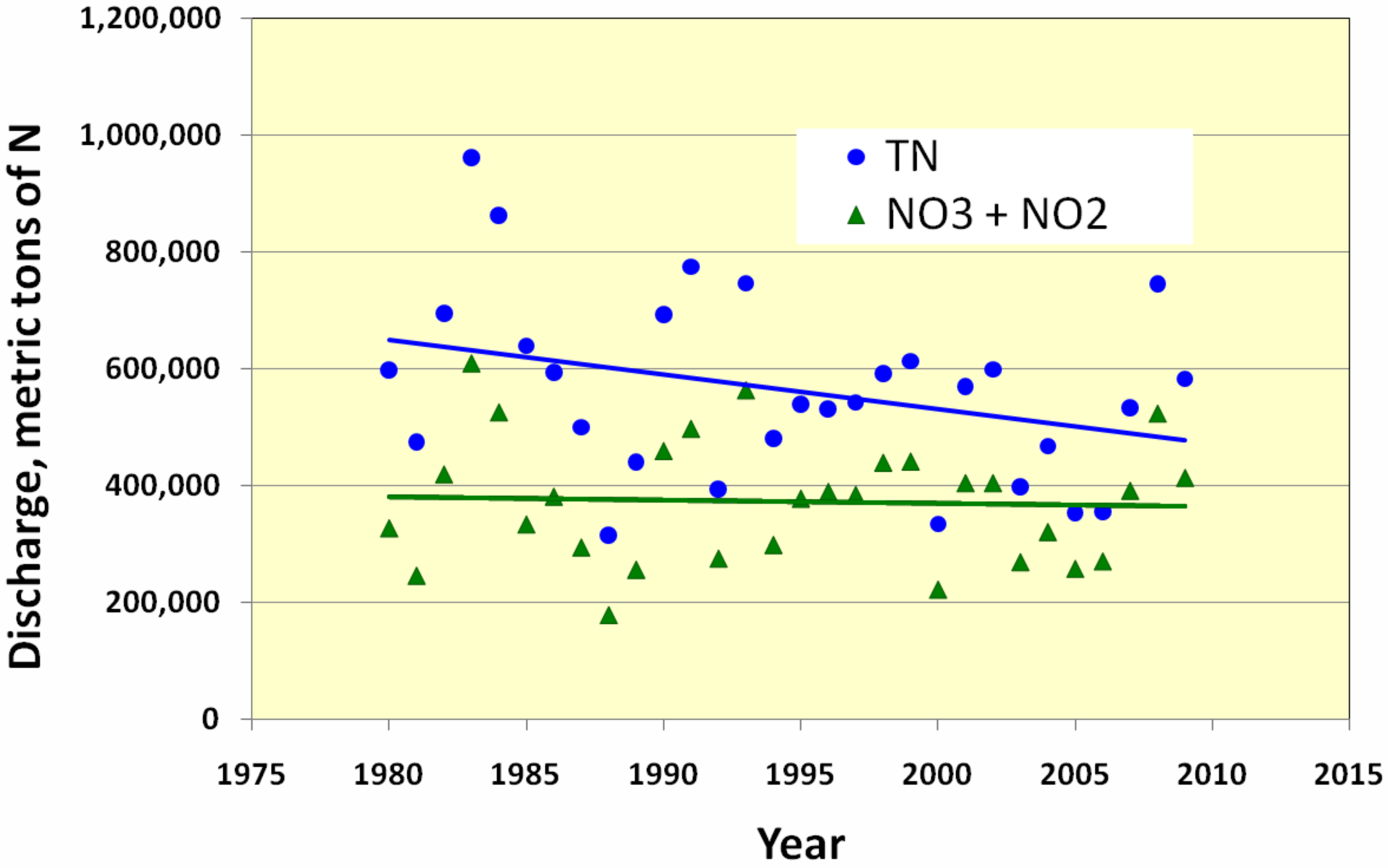




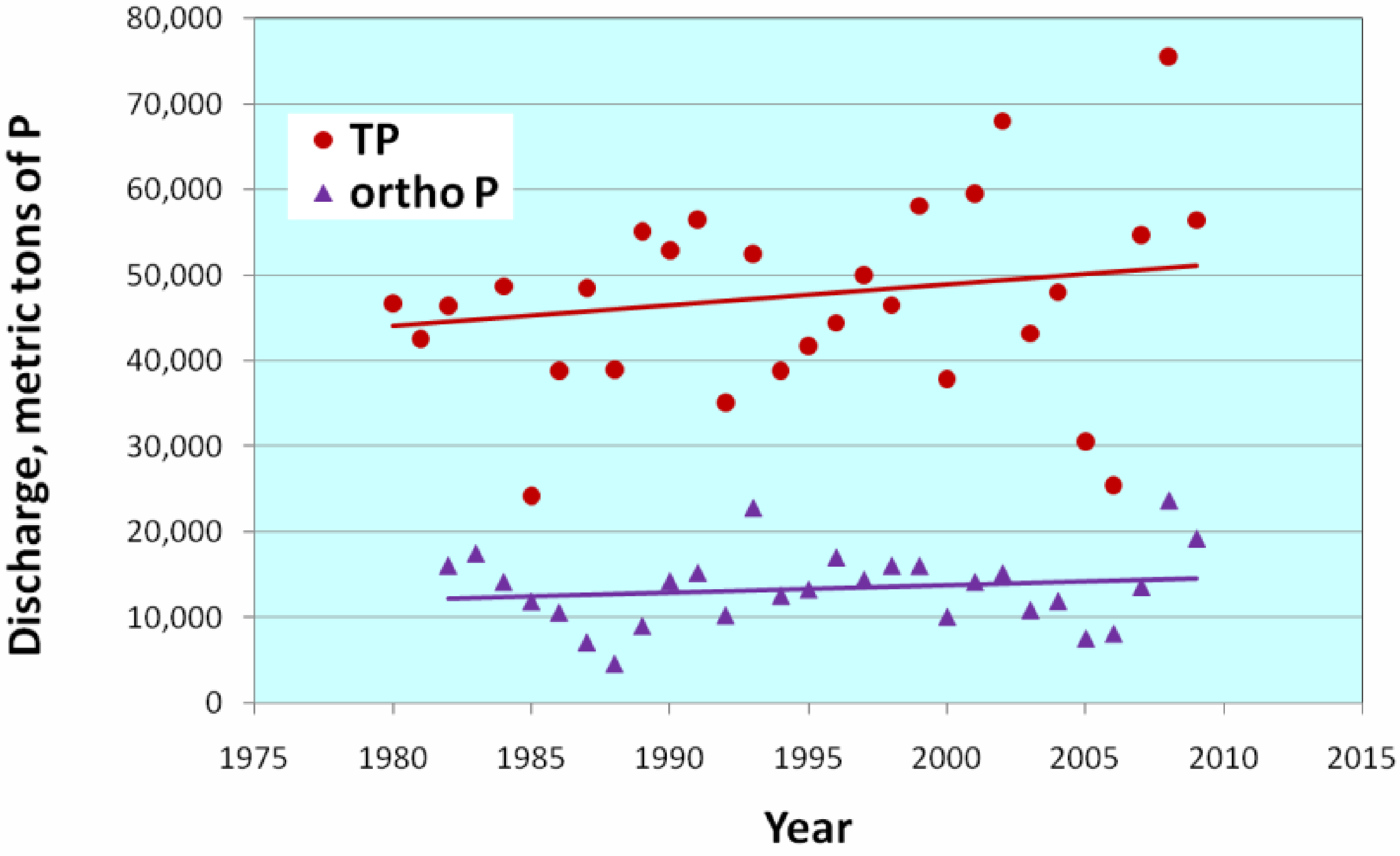
See Greene et al. (2009) and http://toxics.usgs.gov/hypoxia/mississippi/nutrient_flux_yield_est.html

for more detail and historical records

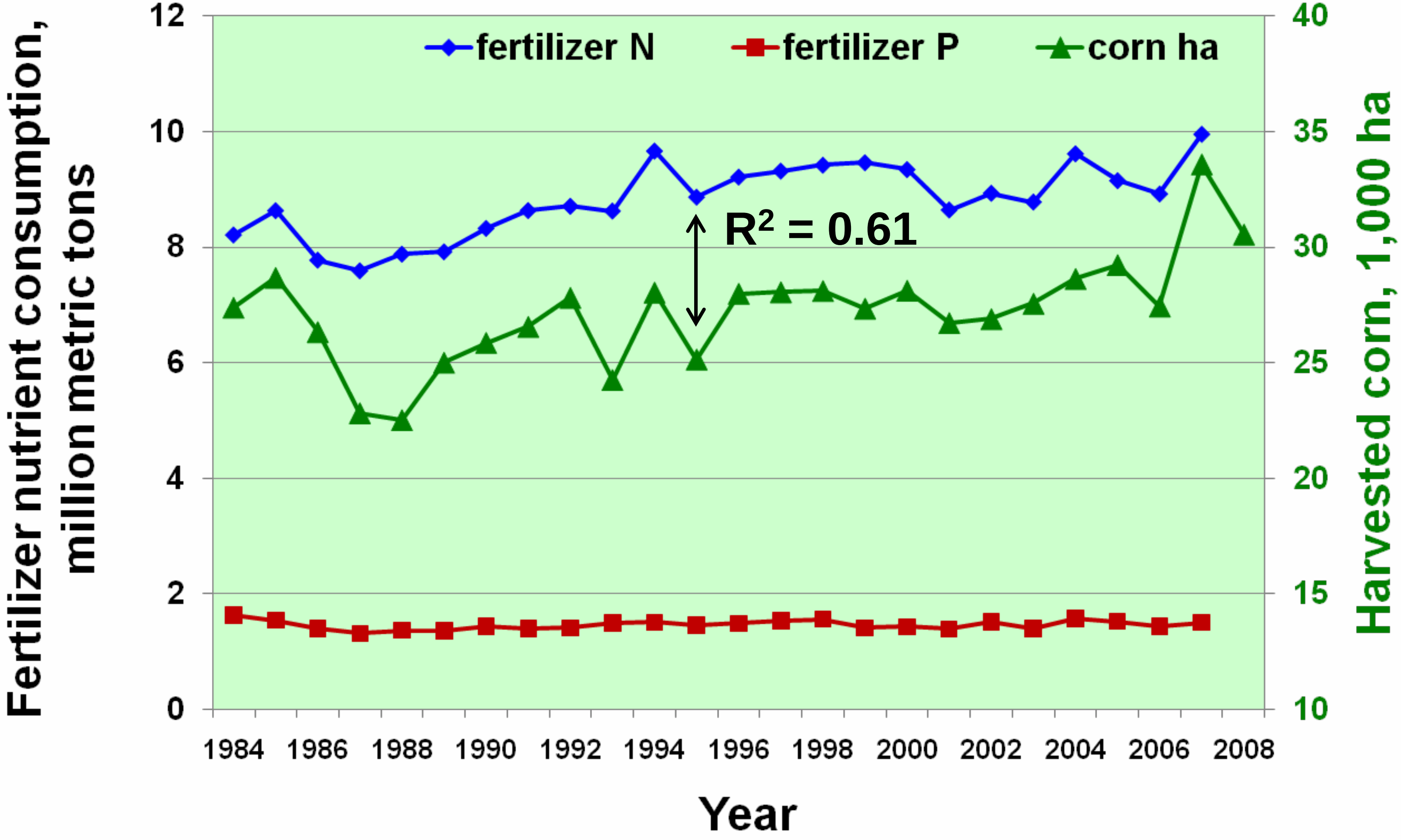
Combined Mississippi and Atchafalaya River (MAR) Spring Discharge of N to the Gulf of Mexico



Combined Mississippi and Atchafalaya River (MAR) Spring Discharge of P to the Gulf of Mexico, 1980-2009

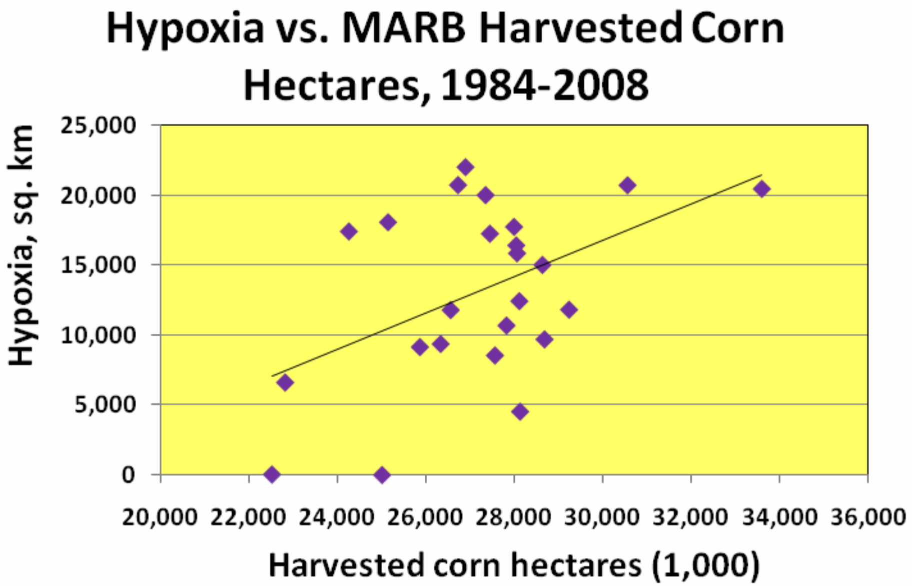


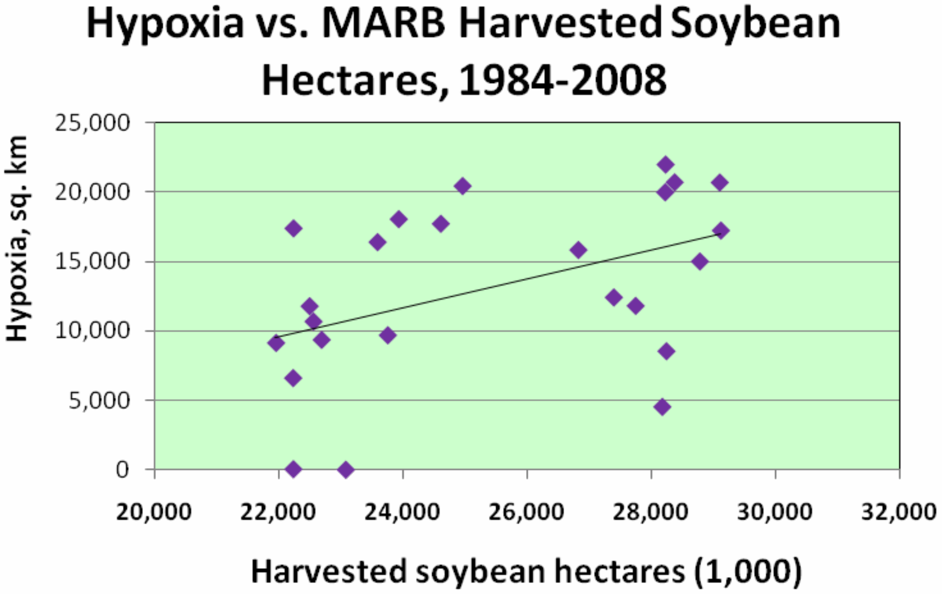
Fertilizer N and P Consumption and Harvested Corn Hectares in MARB, 1984-2008



Variability in Hypoxia Size 1985-2008 Explained by Corn & Soybean Hectares

Factor(s)	Adj. R^2	F significance
MARB Harvested corn ha	0.16	0.03
MARB Harvested soybean ha	0.13	0.05
MARB harvested corn + soybean ha	0.21	0.02





Variability in Hypoxia Size 1985-2009 Explained by Nutrient Flux to Gulf

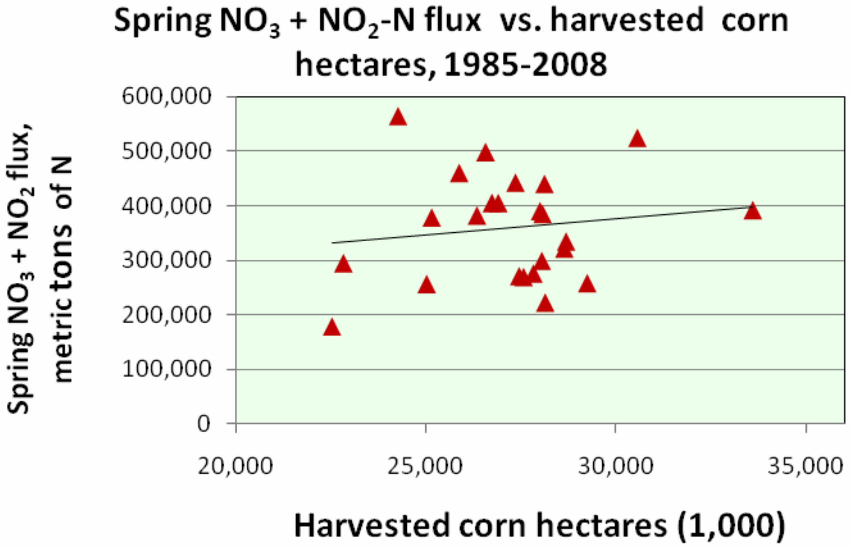
Factor(s)	Adj. R^2	F signif.	Adj. R^2	F signif.
Spring NO_3-N	**0.26**	0.006	**0.36**	0.001
Spring TN	0.12	0.06	0.24	0.009
Annual NO_3-N	0.11	0.06		
Annual TN	-0.02	0.44		
Spring orthophosphate-P	**0.27**	0.005	**0.28**	0.004
Spring TP	0.18	0.02	0.27	0.005
Annual orthophosphate-P	0.23	0.01		
Annual TP	0.08	0.10		
Spring NO_3-N and ortho-P [a]	0.25	0.02	0.33	0.006

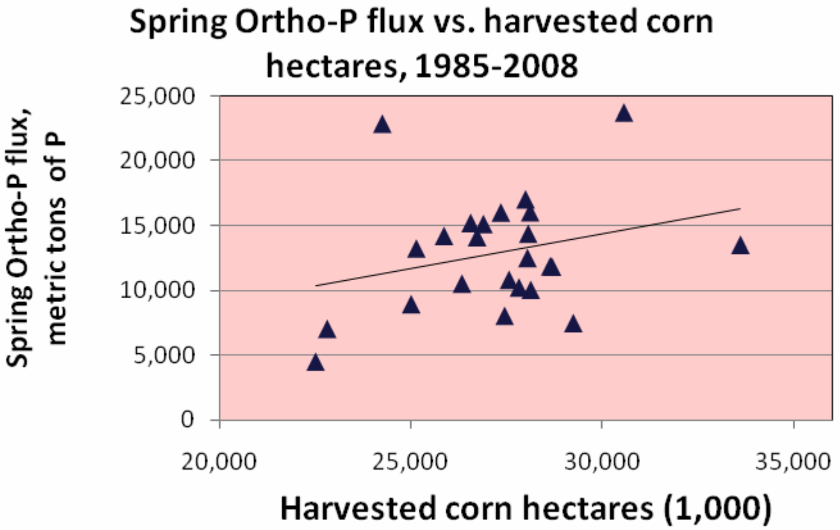
May flux

[a] Spring NO_3-N and ortho-P highly correlated: R^2=0.78, F signif.=8.1 x 10^{-9}

Variability in Spring NO_3-N and Ortho-P Flux Explained by Harvested Corn & Soybean Hectares, 1985-2008

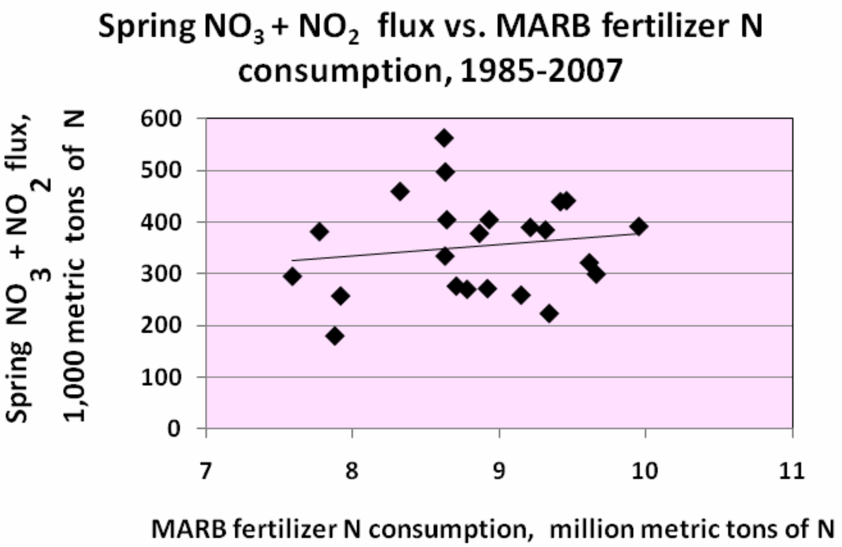
Relationships	Adj. R^2	F signif.
Spring NO_3-N flux vs. corn ha	-0.03	0.52
Spring NO_3-N flux vs. soybean ha	-0.04	0.91
Spring NO_3-N flux vs. corn + soybean ha	-0.04	0.78
Spring ortho-P flux vs. corn ha	0.04	0.18
Spring ortho-P flux vs. soybean ha	-0.02	0.48
Spring ortho-P flux vs. corn + soybean ha	0.02	0.25

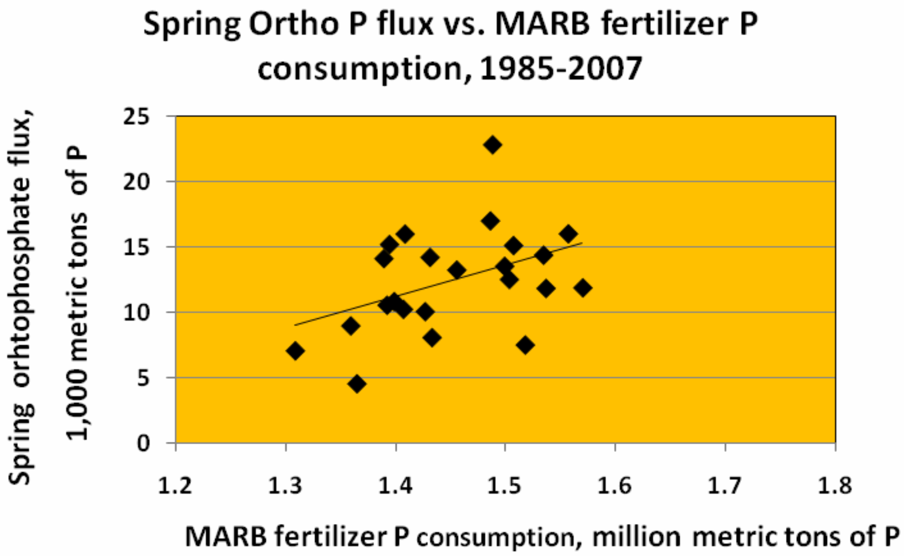

Spring $NO_3 + NO_2$-N flux vs. harvested corn hectares, 1985-2008


Spring Ortho-P flux vs. harvested corn hectares, 1985-2008

Variability in Spring NO_3-N, TN, Ortho-P and TP Flux Explained by MARB Fertilizer N and P Consumption, 1985-2007

Relationships	**Adj. R^2**	**F signif.**
Spring NO_3-N flux vs. fertilizer N	-0.03	0.51
Spring TN flux vs. fertilizer N	-0.05	0.84
Spring ortho-P flux vs. fertilizer P	0.12	**0.06**
Spring TP flux vs. fertilizer P	-0.04	0.62


Spring $NO_3 + NO_2$ flux vs. MARB fertilizer N consumption, 1985-2007


Spring Ortho P flux vs. MARB fertilizer P consumption, 1985-2007

Has nutrient discharge increased ?

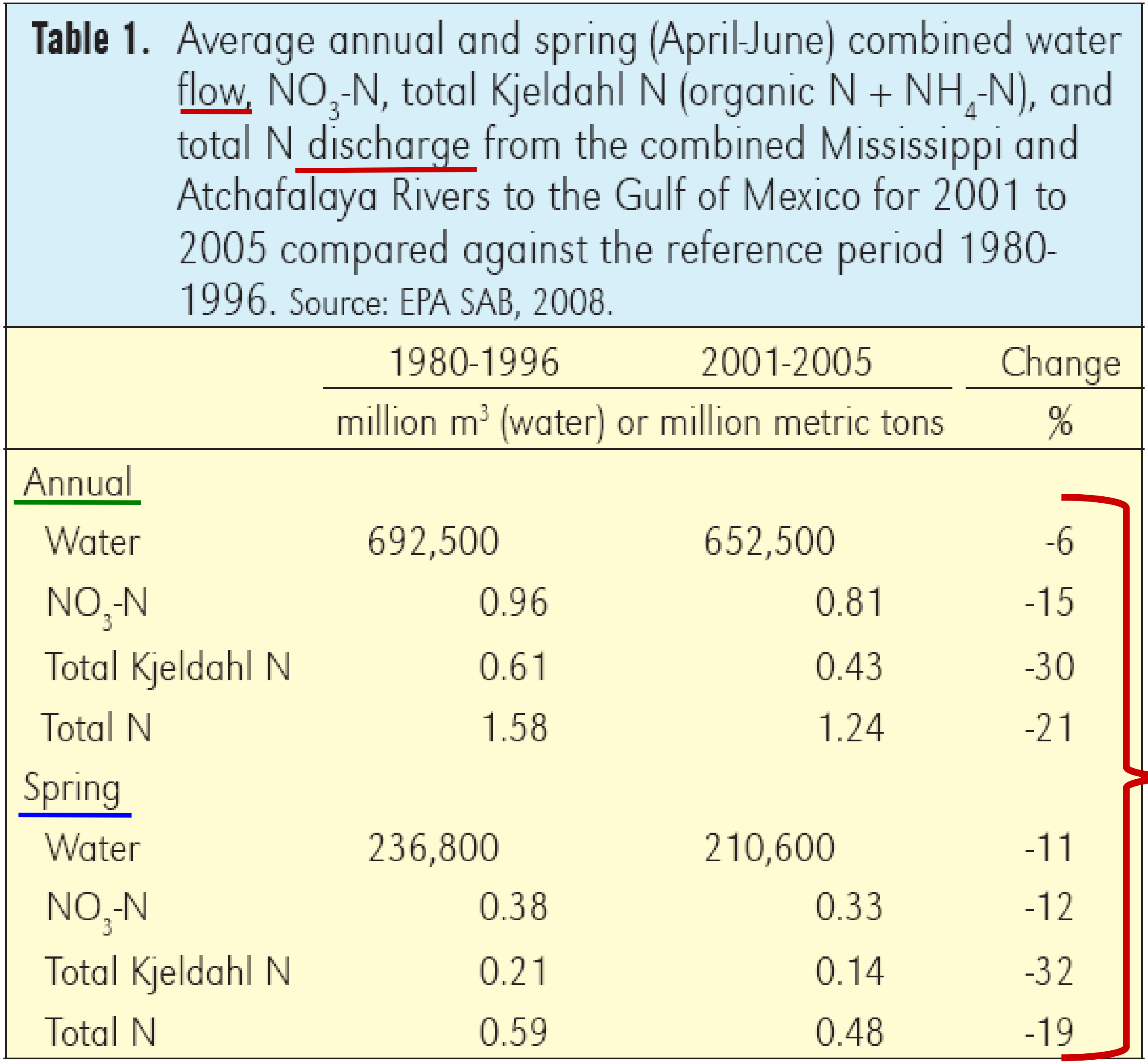


Table 1. Average annual and spring (April-June) combined water flow, NO$_3$-N, total Kjeldahl N (organic N + NH$_4$-N), and total N discharge from the combined Mississippi and Atchafalaya Rivers to the Gulf of Mexico for 2001 to 2005 compared against the reference period 1980-1996. Source: EPA SAB, 2008.

	1980-1996	2001-2005	Change
	million m^3 (water) or million metric tons		%
Annual			
Water	692,500	652,500	-6
NO$_3$-N	0.96	0.81	-15
Total Kjeldahl N	0.61	0.43	-30
Total N	1.58	1.24	-21
Spring			
Water	236,800	210,600	-11
NO$_3$-N	0.38	0.33	-12
Total Kjeldahl N	0.21	0.14	-32
Total N	0.59	0.48	-19

Notable Declines

Discharge by 5 Major Sub-basins

Where is it coming from?

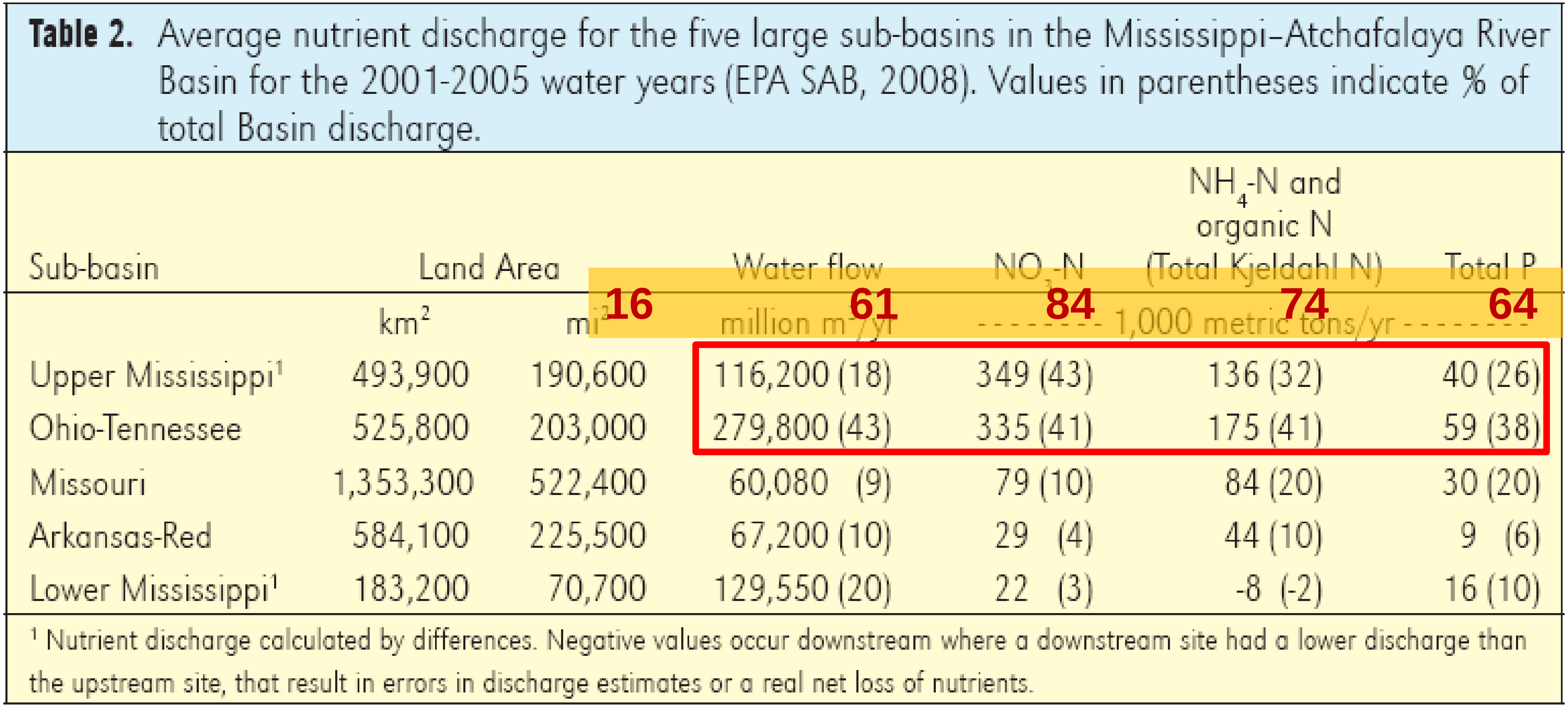


Table 2. Average nutrient discharge for the five large sub-basins in the Mississippi–Atchafalaya River Basin for the 2001-2005 water years (EPA SAB, 2008). Values in parentheses indicate % of total Basin discharge.

Sub-basin	Land Area		Water flow	NO_3-N	NH_4-N and organic N (Total Kjeldahl N)	Total P
	km^2	mi^2	million m^3/yr	- - - - - - - -	1,000 metric tons/yr	- - - - - - - -
Upper Mississippi[1]	493,900	190,600	116,200 (18)	349 (43)	136 (32)	40 (26)
Ohio-Tennessee	525,800	203,000	279,800 (43)	335 (41)	175 (41)	59 (38)
Missouri	1,353,300	522,400	60,080 (9)	79 (10)	84 (20)	30 (20)
Arkansas-Red	584,100	225,500	67,200 (10)	29 (4)	44 (10)	9 (6)
Lower Mississippi[1]	183,200	70,700	129,550 (20)	22 (3)	-8 (-2)	16 (10)

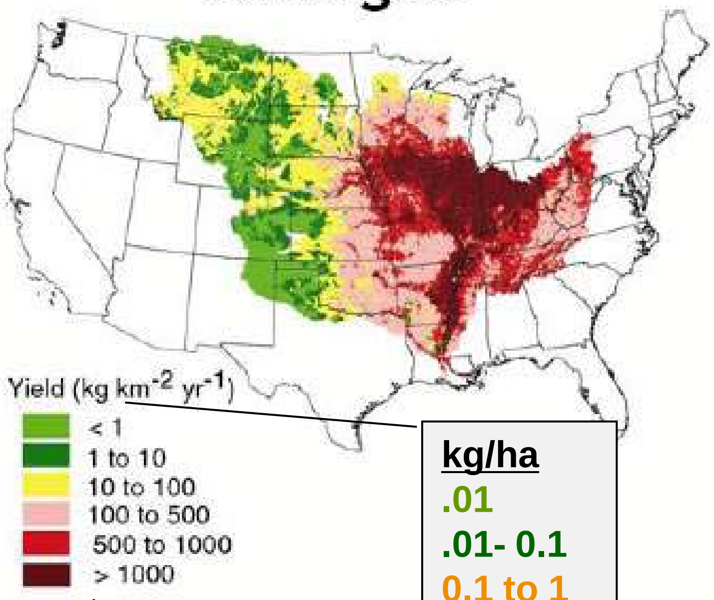
[1] Nutrient discharge calculated by differences. Negative values occur downstream where a downstream site had a lower discharge than the upstream site, that result in errors in discharge estimates or a real net loss of nutrients.

16 **61** **84** **74** **64**

USGS Estimates of Loss and Delivery of N and P to the Gulf

SPARROW - Modeled Estimate of N and P Discharge in Watersheds of the Mississippi R. Basin

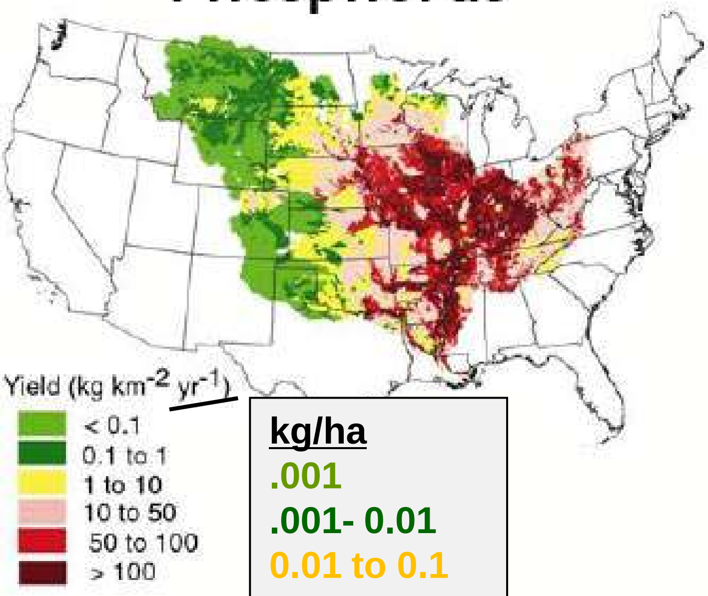
Nitrogen



kg/ha

- .01
- .01- 0.1
- 0.1 to 1
- 1 to 5
- 5 to 10
- >10

Phosphorus



kg/ha

- .001
- .001- 0.01
- 0.01 to 0.1
- 0.1 to 0.5
- 0.5-1.0
- >1

Alexander et al. *Environ. Sci. Technol. 2008, 42, 822–830*

Sub-basin Contributions of N & P

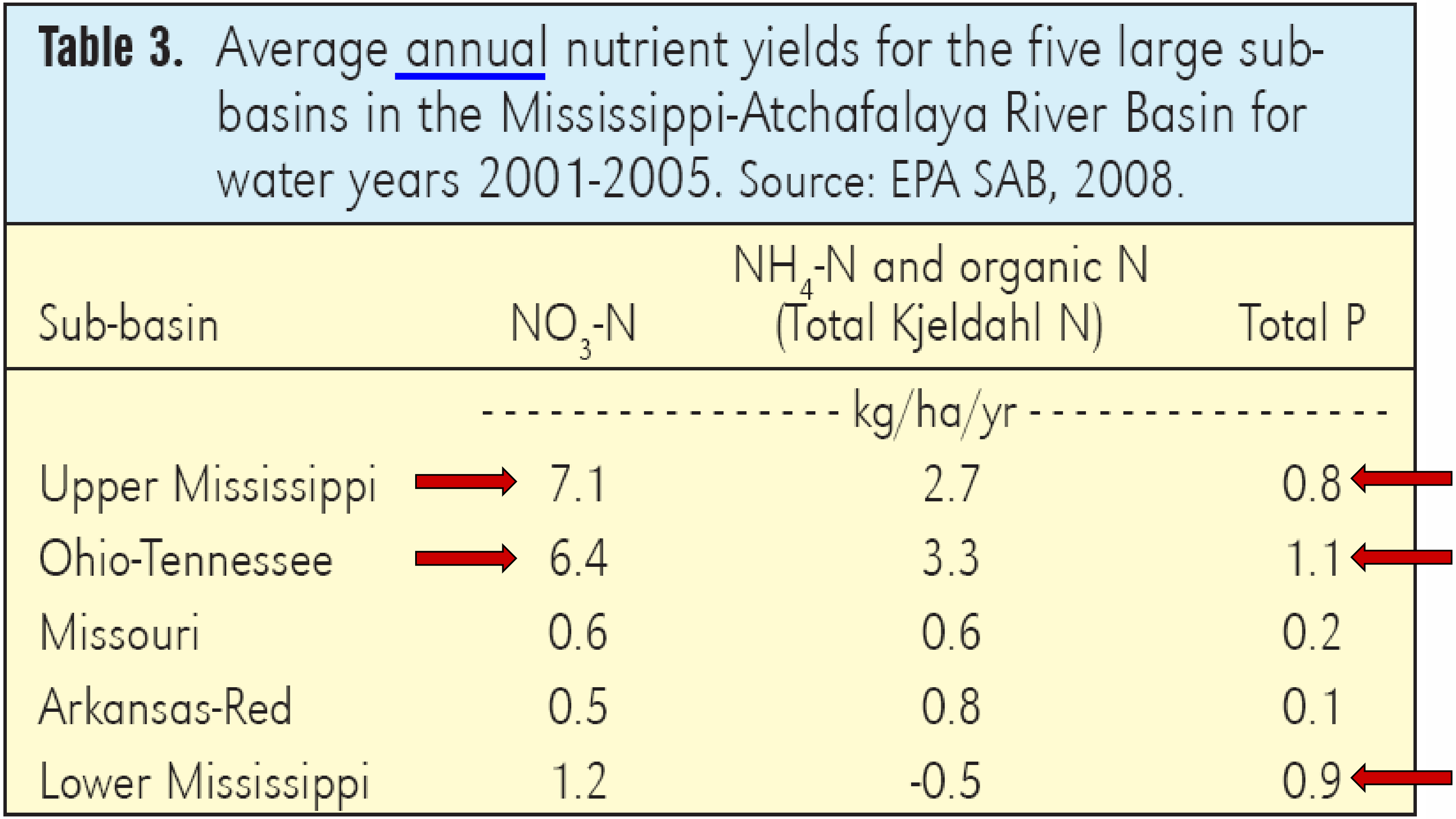


Table 3. Average annual nutrient yields for the five large sub-basins in the Mississippi-Atchafalaya River Basin for water years 2001-2005. Source: EPA SAB, 2008.

Sub-basin	NO_3-N	NH_4-N and organic N (Total Kjeldahl N)	Total P
	----------------	kg/ha/yr	----------------
Upper Mississippi	7.1	2.7	0.8
Ohio-Tennessee	6.4	3.3	1.1
Missouri	0.6	0.6	0.2
Arkansas-Red	0.5	0.8	0.1
Lower Mississippi	1.2	-0.5	0.9

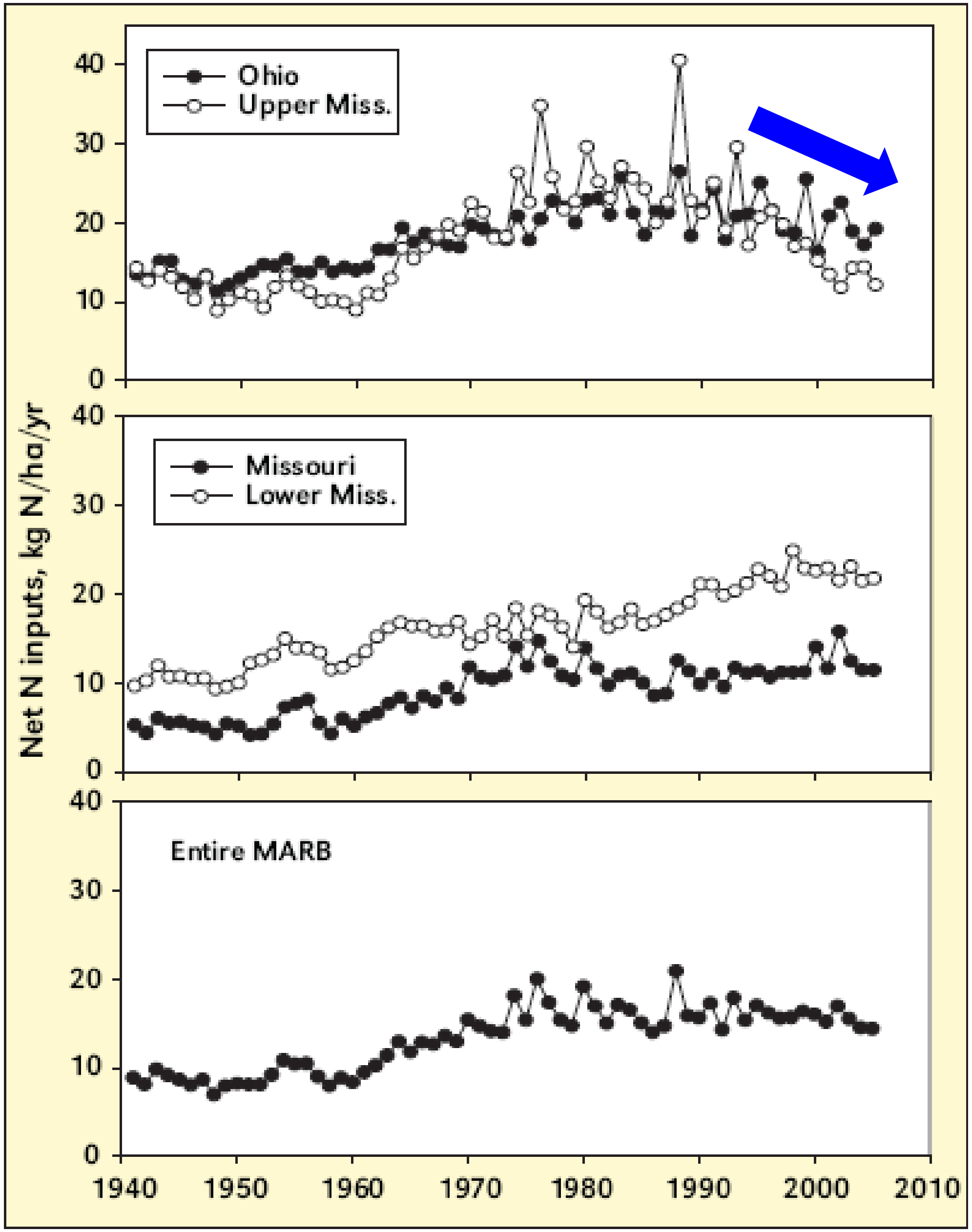


Figure 8. Nitrogen mass balance and net inputs for major regions of the Mississippi-Atchafalaya River Basin through 2005. Source: EPA SAB, 2008.

IPNI

Net N inputs

fertilizer + atm. dep.+ N_2 fixed

minus

net food and feed imports

- assumed SON in steady state
- manure is part of feed imports

after Goolsby et al. 1999; McIsaac et al. 2001, 2002

Voluntary actions are reducing the “net” Nitrogen (N) balance in the Mississippi River Basin; especially in two key upper sub-basins.

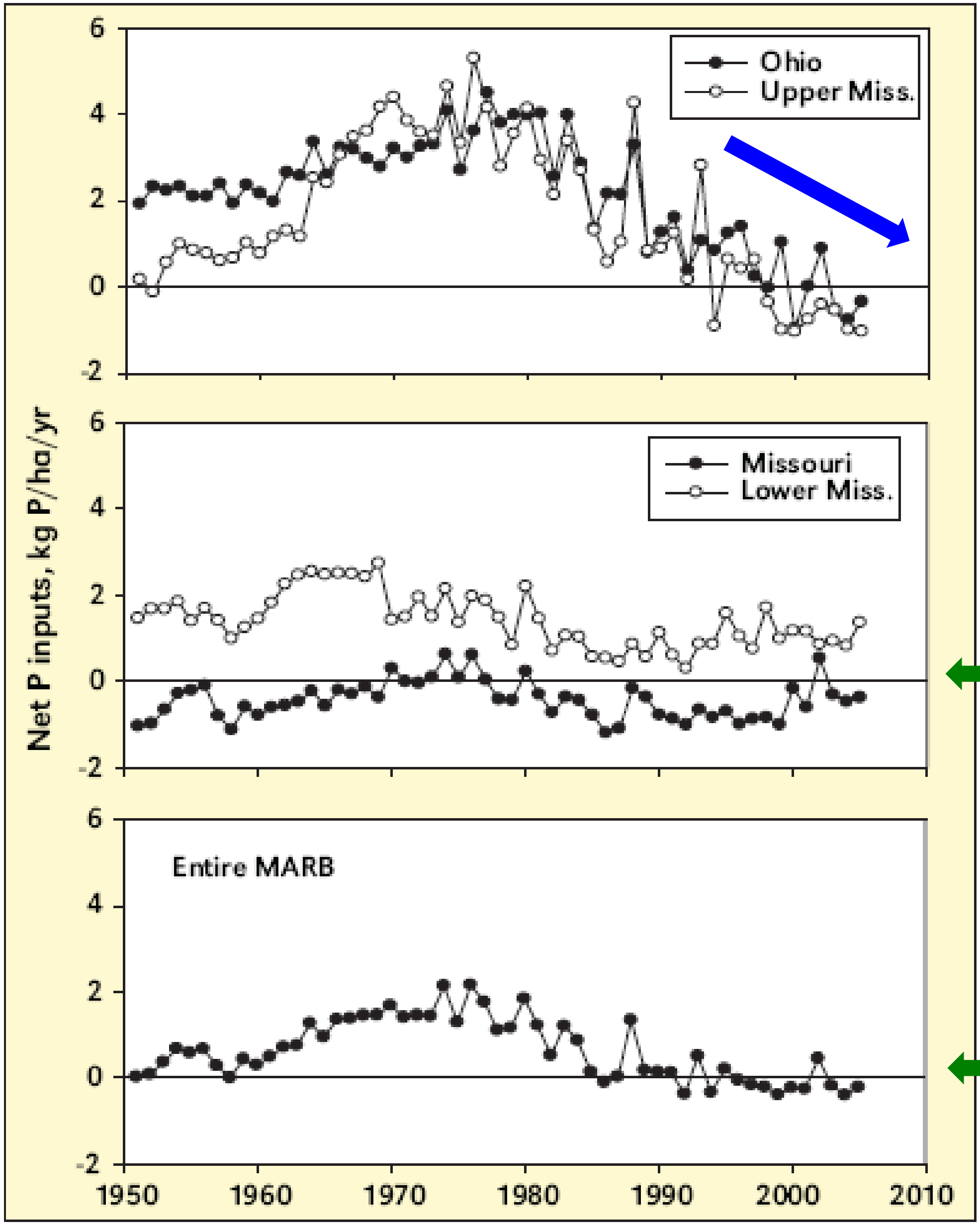


Figure 9. Phosphorus mass balance and net inputs for major regions of the Mississippi-Atchafalaya River Basin through 2005. Source: EPA SAB, 2008.

Voluntary actions are also reducing the "net" phosphorus (P) balance in the Mississippi River Basin; especially in two key upper sub-basins.

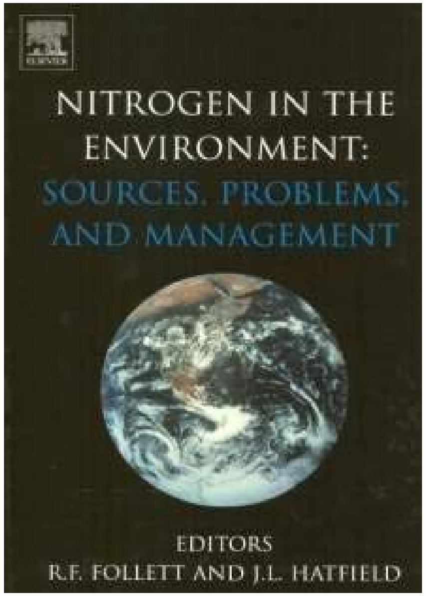
This is a concern, however, because soil P may be "mined", and may lead to yield reductions and lower N use efficiency

Summary for 1985 to 2009

- Harvested corn and soybean
  - weakly related to hypoxia ($R^2 < 0.22$)
  - no significant relationship to N and P flux to Gulf
- Hypoxia most related to spring (April-June) & May NO_3-N & ortho-P flux ($R^2 = 0.26$ to 0.36; $P \leq 0.006$)
- 2001-2005 compared to 1980-1996
  - annual NO_3-N and TN flux declined 15 and 21%
  - annual NO_3-N and TN flux declined 12 and 19%
  - Spring and annual ortho-P and TP tended to increase slightly
- MARB fertilizer N and P consumption
  - spring ortho-P flux weakly related ($R^2 = 0.12$) with fertilizer P, but no other significant relationships with nutrient flux

Kitchen and Goulding (2001) *in* Nitrogen in the Environment: Sources, Problems and Management

- **“ nitrogen use efficiency …rarely exceeds 70% ……. often ranges from 30-60%”**
- **“conversion of N inputs to products for arable crops can be 60-70% or even more”**



NITROGEN IN THE ENVIRONMENT:
SOURCES, PROBLEMS, AND MANAGEMENT

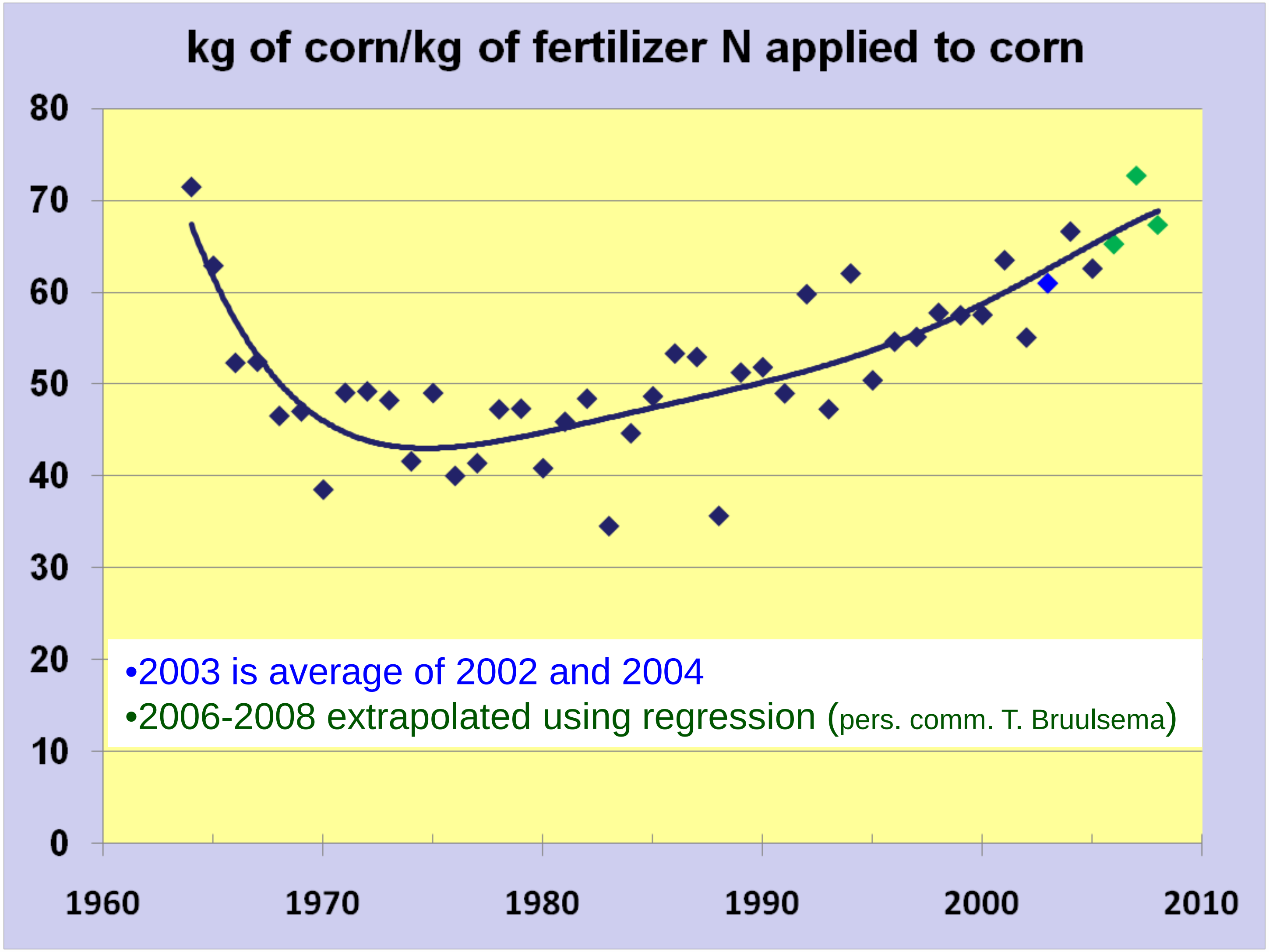
EDITORS
R.F. FOLLETT AND J.L. HATFIELD

N Use Efficiency (NUE) Terms

(after Snyder and Bruulsema 2007)

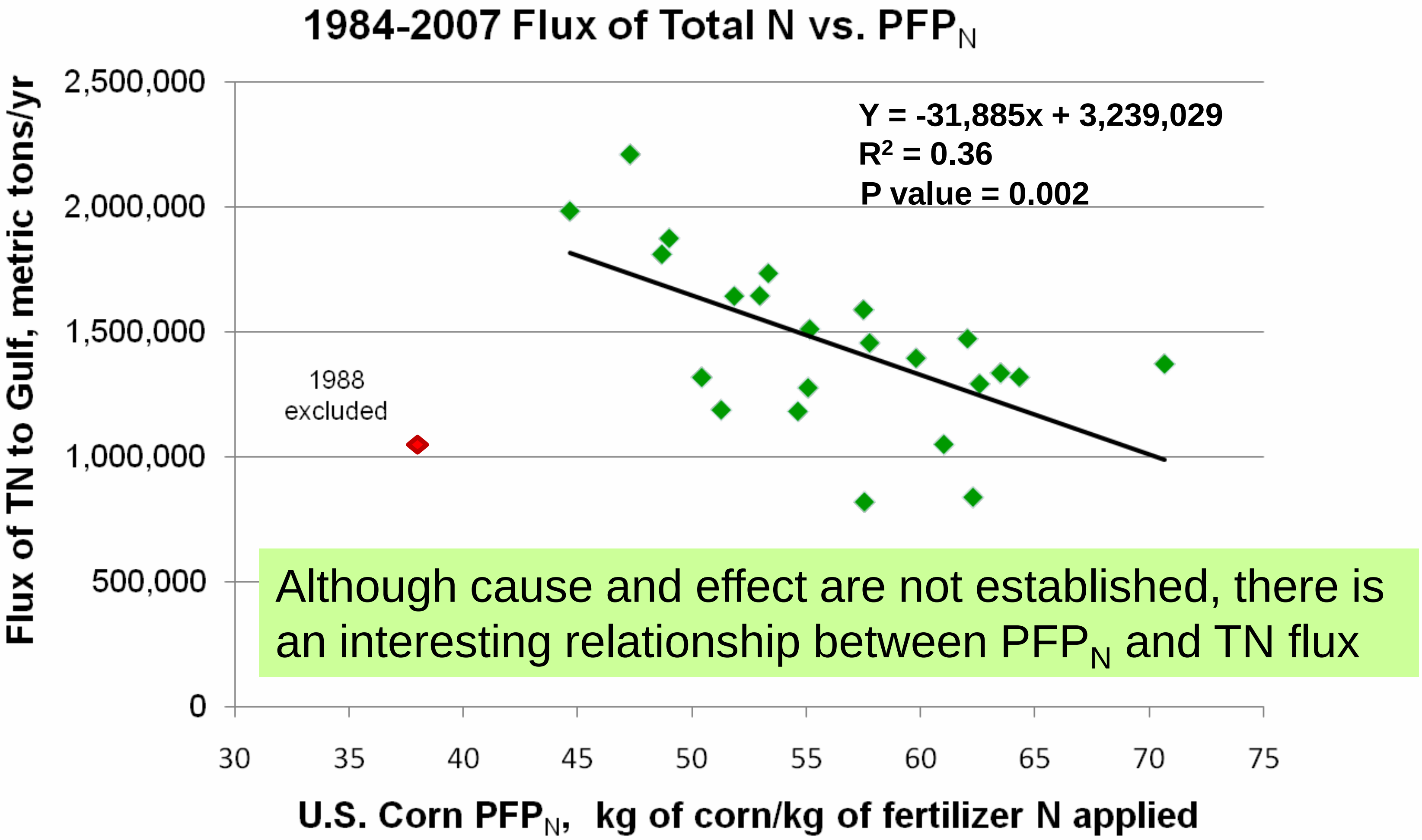
NUE term	Calculation	Reported Examples
PFP Partial factor productivity	Y/F	40 to 80 units of cereal grain per unit of N
AE Agronomic efficiency of applied N	$(Y-Y_0)/F$	10 to 30 units of cereal grain per unit of N
PNB Partial N balance (removal to use ratio)	U_H/F	0 to greater than 1.0- depends on native soil fertility and fertility maintenance objectives <1 in nutrient deficient systems (fertility improvement) >1 in nutrient surplus systems (under-replacement) Slightly less than 1 to 1 (system sustainability)
RE Apparent crop N recovery efficiency	$(U-U_0)/F$	0.3 to 0.5 – N recovery in cereals – typical 0.5 to 0.8 – N recovery in cereals – best management

Nitrogen Partial Factor Productivity for Corn in the U.S.



- •2003 is average of 2002 and 2004
- •2006-2008 extrapolated using regression (pers. comm. T. Bruulsema)

PFP$_N$ for U.S. Corn vs. Annual Total N Flux to Gulf of Mexico



1984-2007 Flux of Total N vs. PFP$_N$

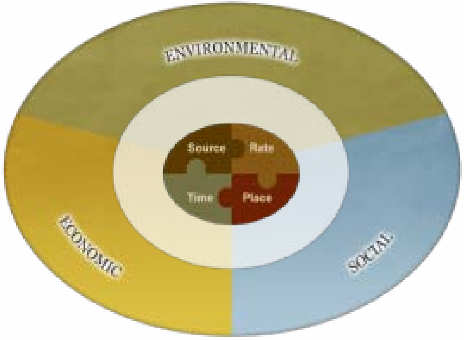
Although cause and effect are not established, there is an interesting relationship between PFP$_N$ and TN flux

Improving N Use Efficiency through 4R Nutrient Stewardship

Know your fertilizer rights

By Tom Bruulsema, International Plant Nutrition Institute, Guelph, ON, Canada; **Jerry Lemunyon**, USDA-NRCS, Fort Worth, TX; and **Bill Herz**, The Fertilizer Institute, Washington, DC

Crops & Soils 42(2): Mar-Apr 2009



The four fertilizer rights: Selecting the right source

By Robert Mikkelsen, International Plant Nutrition Institute, Merced, CA; **Greg Schwab**, University of Kentucky, Lexington; and **Gyles Randall**, University of Minnesota, Waseca

Crops & Soils 42(3): May-Jun 2009

The four fertilizer rights: placement

Scott Murrell (IPNI),Tony Vyn (Purdue), Guy Lafond (AAFC), Dave Finlayson (CFI),

Crops & Soils 42(6): Nov-Dec 2009 (in process)

Selecting the right fertilizer rate: A component of 4R nutrient stewardship

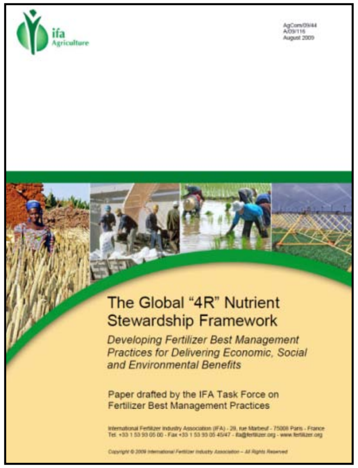
By S.B. Phillips, International Plant Nutrition Institute, Owens Cross Roads, AL; **J.J. Camberato**, Purdue University, West Lafayette, IN; and **D. Leikam**, Fluid Fertilizer Foundation, Manhattan, KS

Crops & Soils 42(4): Jul-Aug 2009

The four fertilizer rights: timing

By W.M. Stewart, International Plant Nutrition Institute, Norcross, GA; **J.E. Sawyer**, Iowa State University, Ames, IA; and **M.M. Alley**, Virginia Tech, Blacksburg, VA

Crops & Soils 42(5): Sep-Oct 2009



ifa
Agriculture

AgCom/09/44
A/09/116
August 2009

The Global "4R" Nutrient Stewardship Framework

Developing Fertilizer Best Management Practices for Delivering Economic, Social and Environmental Benefits

Paper drafted by the IFA Task Force on Fertilizer Best Management Practices

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Improving N Use Efficiency

- **Implementation of fertilizer best management practices (BMPs)**

Fertilizer BMPs — Best Management for Fertilizers on Northeastern Dairy Farms

Fertilizer BMPs — Suggested Practices for Semiarid North Dakota

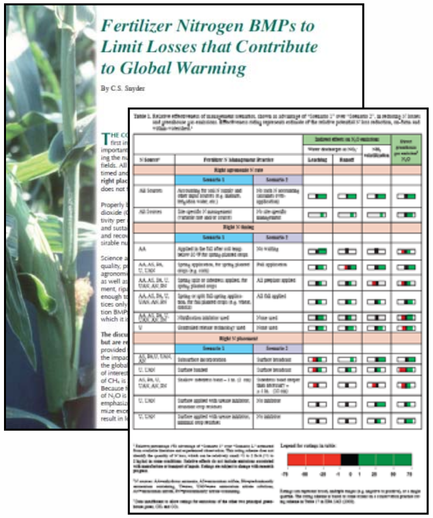
Fertilizer BMPs — Apply the "Four Rights" for Cotton Production in the Midsouth and Southeast

Fertilizing for Irrigated Corn

Guide to Best Management Practices

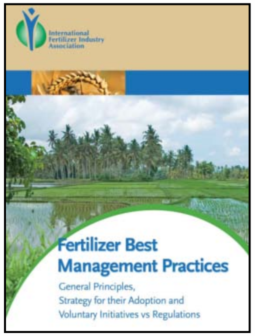
Edited by W.M. Stewart and W.B. Gordon

Fertilizer Best Management Practices



Fertilizer Nitrogen BMPs to Limit Losses that Contribute to Global Warming

By C.S. Snyder

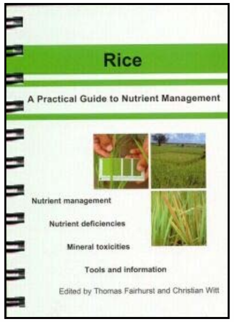


International Fertilizer Industry Association

Fertilizer Best Management Practices

General Principles, Strategy for their Adoption and Voluntary Initiatives vs Regulations

- **Site-Specific Nutrient Management (SSNM) - to help achieve improved economic results and environmental objectives**



Rice

A Practical Guide to Nutrient Management

Nutrient management

Nutrient deficiencies

Mineral toxicities

Tools and information

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Thank You

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