Managing Reactive N in the Environment

C.S. Snyder, PhD, CCA

Nitrogen Program Director

Presented to

EPA FRRCC 2009


Brazil's Lula: food riots are wake-up call
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Top thinktank issues stark warning of unrest over prices and says GM crops could offer a solution
Jamie Doward, home affairs editor
The Observer, Sunday 1 February 2009
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Britain faces a major food crisis unless urgent steps are taken to revive its flagging agricultural sector, warns one of the world's most influential thinktanks.
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EPA SAB Integrated Nitrogen Committee Report on Reactive N (Nr)

November 15, 2008

- **Improved practices** -impact lowered through better management practices
- **Product substitution** - a product is developed or promoted which has a lower dependency on, or releases less, reactive nitrogen)
- **Transformation** - one form of N converted to another form
- **Source limitation** - introduction of Nr in environment lowered through preventive measures (e.g. **precision fertilizer application, controls on NOx generation)**
- **Removal** - in which Nr is sequestered from impacting a particular resource
- **Improved use or reuse efficiency** - efficiency of production that is dependent on Nr is improved (e.g. increased grain yields for lower Nr applied), or Nr wasted from one source is reused in another (e.g. algal farming).

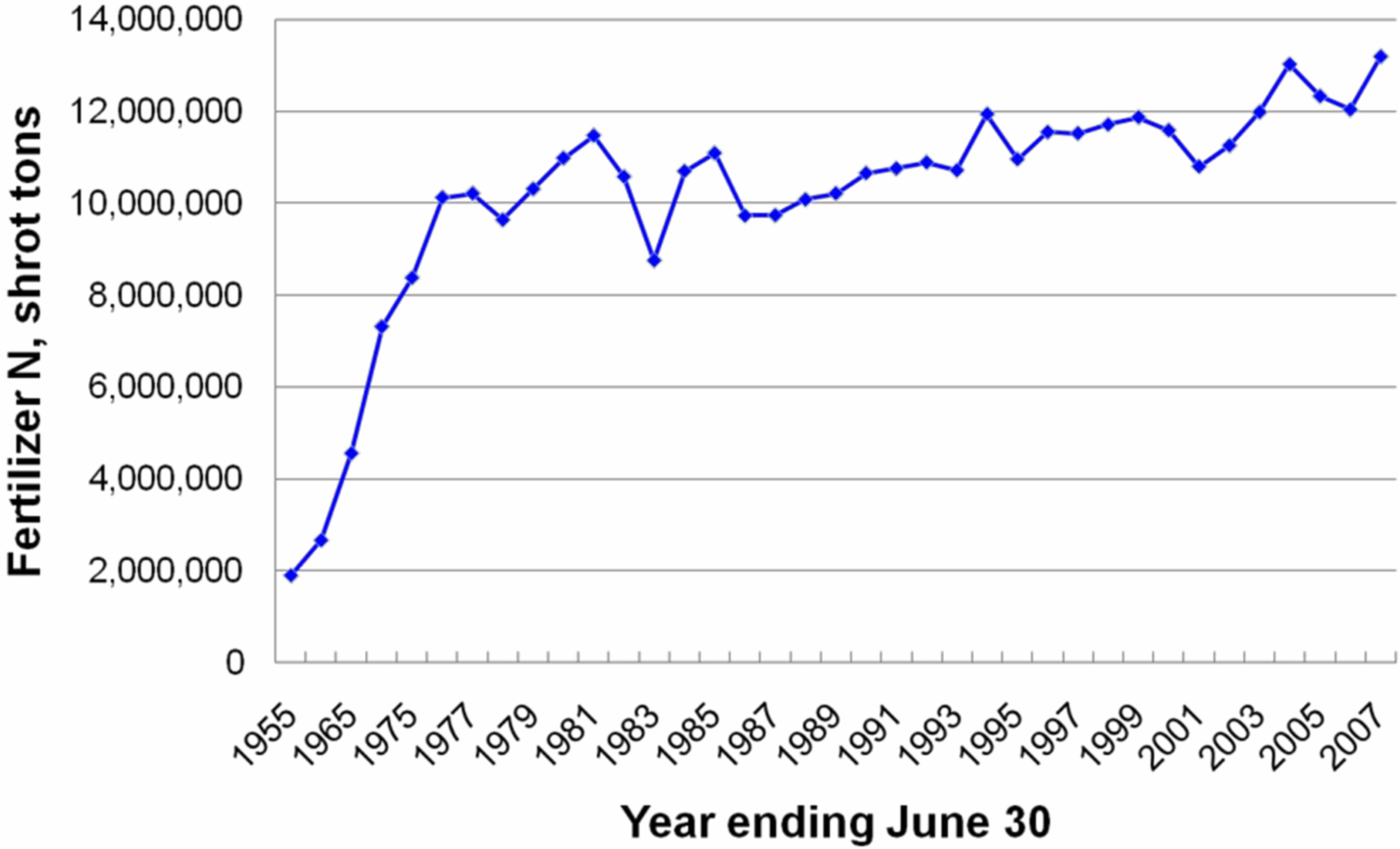
From DRAFT report Nov. 15, 2008

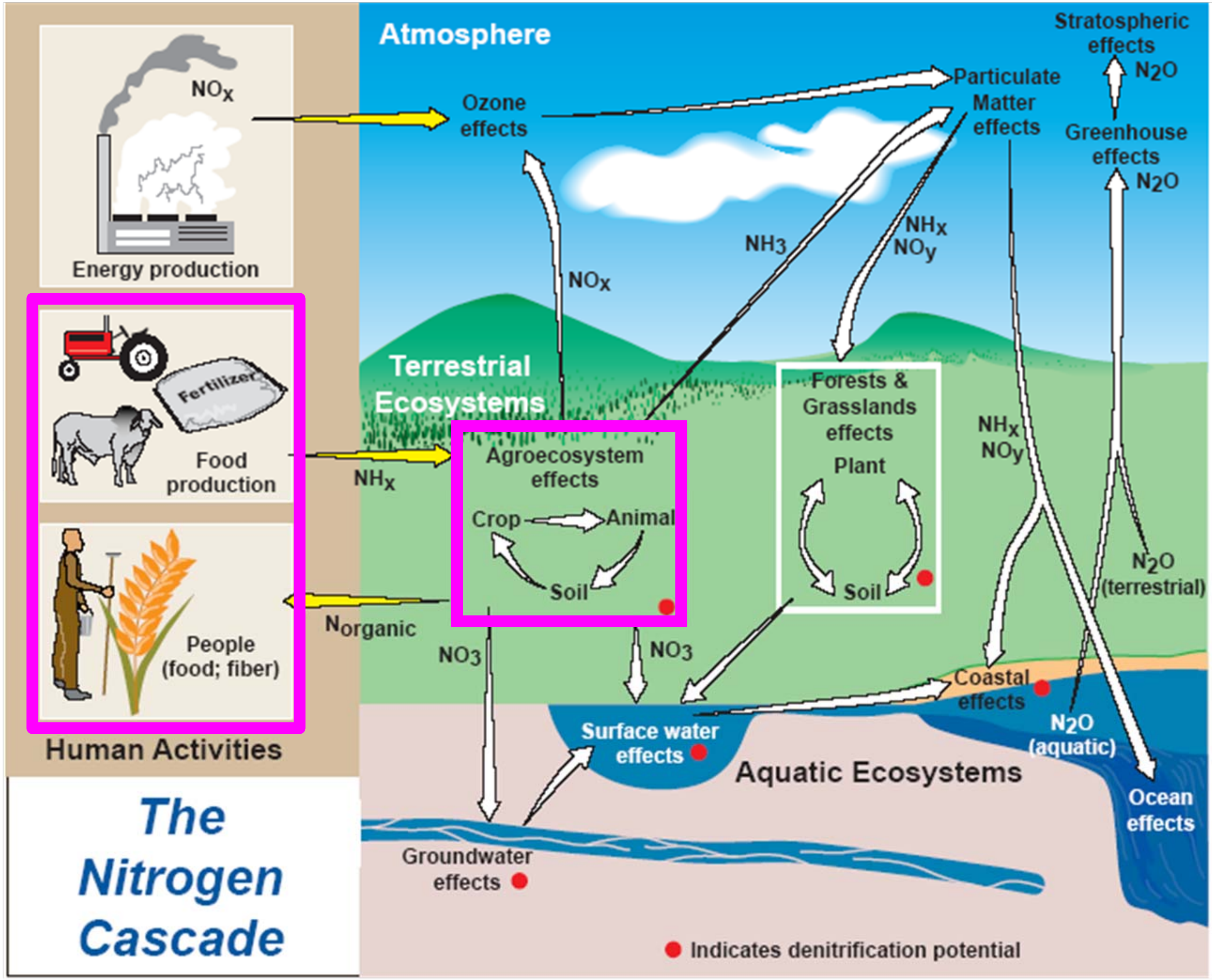
EPA INC Draft Recommends - Reduce Nr Loss to Environment by 25%

- Decrease livestock-derived ammonia emissions to approximately 80% of 1990
- Decrease excess flows of Nr into streams, rivers, and coastal systems by approx. 20%
- Increase crop output while reducing total Nr up to 20% of applied artificial Nr.
- High priority for a targeted construction grants program under the CWA (i.e wetlands)

From DRAFT report Nov. 15, 2008

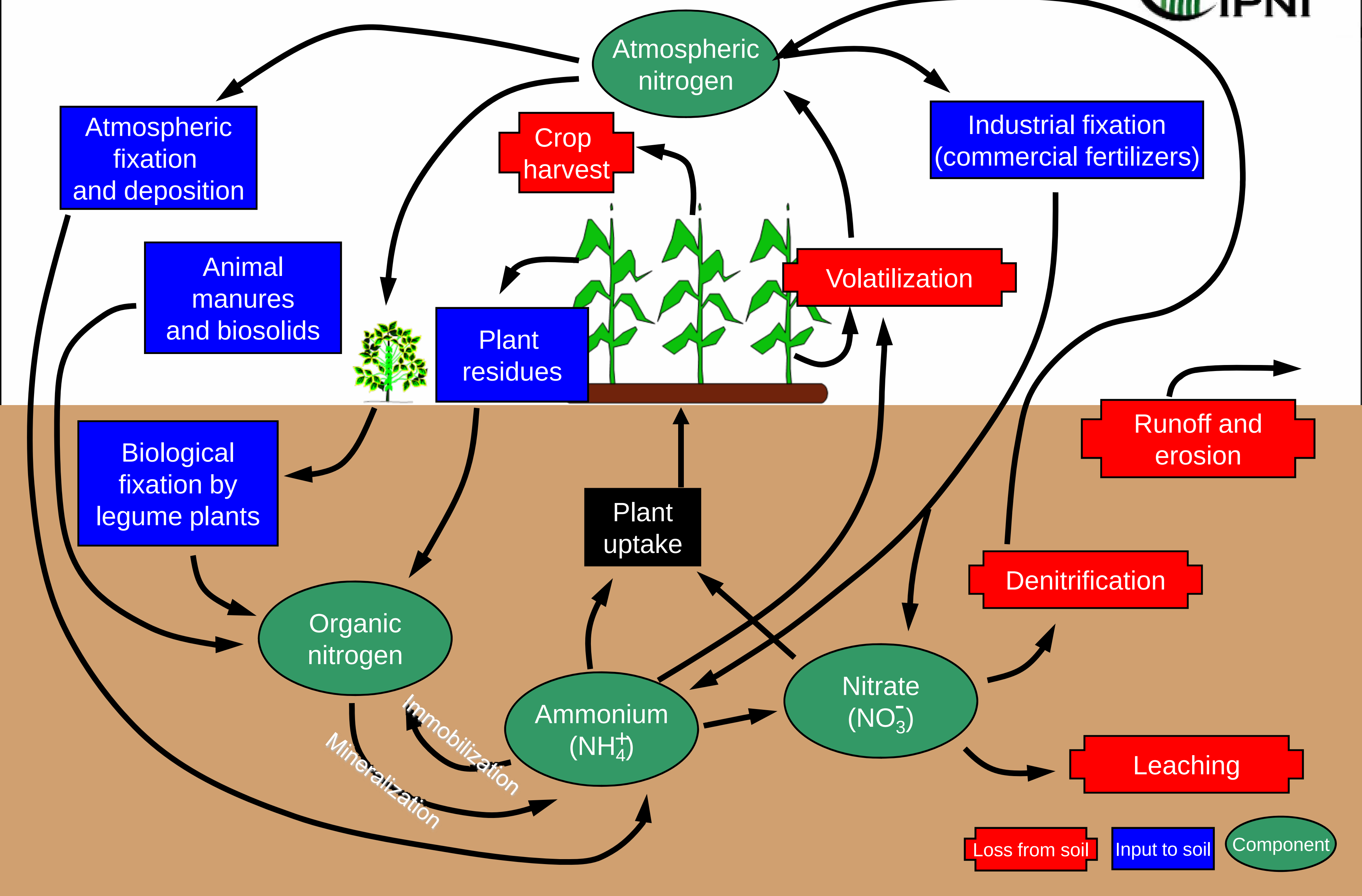
U.S. Fertilizer N Consumption

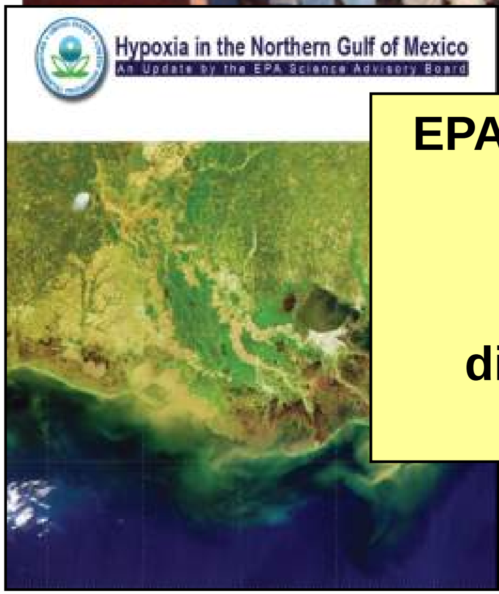




Galloway & Cowling, 2002; UNEP, 2003

The Nitrogen Cycle





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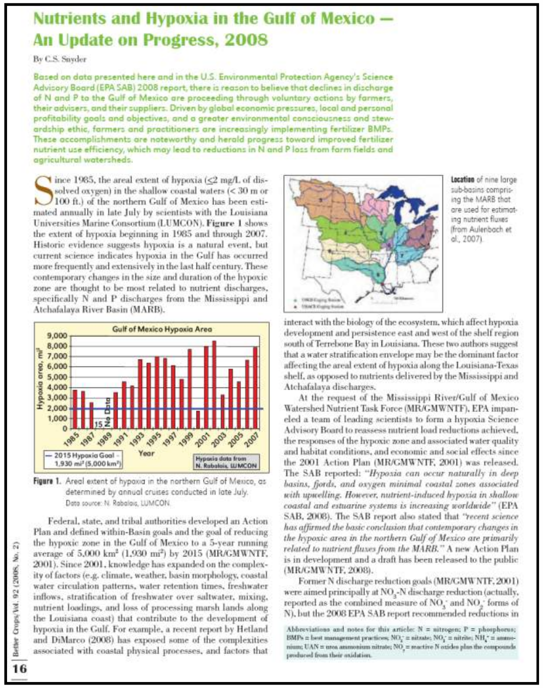
EPA Hypoxia SAB report suggested
45% less total N
AND
45% less total P
discharge to the Gulf to reduce hypoxia



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

By C.S. Snyder

Based on data presented here and in the U.S. Environmental Protection Agency's Science Advisory Board (EPA SAB) 2008 report, there is reason to believe that declines in discharge of N and P to the Gulf of Mexico are proceeding through voluntary actions by farmers, their advisers, and their suppliers. Driven by global economic pressures, local and personal profitability goals and objectives, and a greater environmental consciousness and stewardship ethic, farmers and practitioners are increasingly implementing fertilizer BMPs. These accomplishments are noteworthy and herald progress toward improved fertilizer nutrient use efficiency, which may lead to reductions in N and P loss from farm fields and agricultural watersheds.

Since 1985, the areal extent of hypoxia (≤2 mg/L of dissolved oxygen) in the shallow coastal waters (< 30 m or 100 ft.) of the northern Gulf of Mexico has been estimated annually in late July by scientists with the Louisiana Universities Marine Consortium (LUMCON). **Figure 1** shows the extent of hypoxia beginning in 1985 and through 2007. Historic evidence suggests hypoxia is a natural event, but current science indicates hypoxia in the Gulf has occurred more frequently and extensively in the last half century. These contemporary changes in the size and duration of the hypoxic zone are thought to be most related to nutrient discharges, specifically N and P discharges from the Mississippi and Atchafalaya River Basin (MARB).

Figure 1. Areal extent of hypoxia in the northern Gulf of Mexico, as determined by annual cruises conducted in late July. Data source: N. Rabalais, LUMCON.

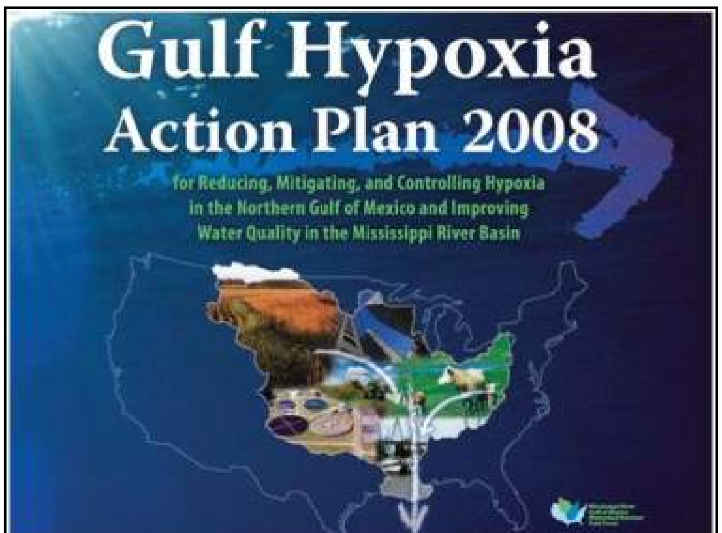
Location of nine large sub-basins comprising the MARB that are used for estimating nutrient fluxes (from Aulenbach et al., 2007).

Federal, state, and tribal authorities developed an Action Plan and defined within-Basin goals and the goal of reducing the hypoxic zone in the Gulf of Mexico to a 5-year running average of 5,000 km² (1,930 mi²) by 2015 (MR/GMWNTF, 2001). Since 2001, knowledge has expanded on the complexity of factors (e.g. climate, weather, basin morphology, coastal water circulation patterns, water retention times, freshwater inflows, stratification of freshwater over saltwater, mixing, nutrient loadings, and loss of processing marsh lands along the Louisiana coast) that contribute to the development of hypoxia in the Gulf. For example, a recent report by Hetland and DiMarco (2008) has exposed some of the complexities associated with coastal physical processes, and factors that interact with the biology of the ecosystem, which affect hypoxia development and persistence east and west of the shelf region south of Terrebone Bay in Louisiana. These two authors suggest that a water stratification envelope may be the dominant factor affecting the areal extent of hypoxia along the Louisiana-Texas shelf, as opposed to nutrients delivered by the Mississippi and Atchafalaya discharges.

At the request of the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (MR/GMWNTF), EPA impaneled a team of leading scientists to form a hypoxia Science Advisory Board to reassess nutrient load reductions achieved, the responses of the hypoxic zone and associated water quality and habitat conditions, and economic and social effects since the 2001 Action Plan (MR/GMWNTF, 2001) was released. The SAB reported: *"Hypoxia can occur naturally in deep basins, fjords, and oxygen minimal coastal zones associated with upwelling. However, nutrient-induced hypoxia in shallow coastal and estuarine systems is increasing worldwide"* (EPA SAB, 2008). The SAB report also stated that *"recent science has affirmed the basic conclusion that contemporary changes in the hypoxic area in the northern Gulf of Mexico are primarily related to nutrient fluxes from the MARB."* A new Action Plan is in development and a draft has been released to the public (MR/GMWNTF, 2008).

Former N discharge reduction goals (MR/GMWNTF, 2001) were aimed principally at NO_3-N discharge reduction (actually, reported as the combined measure of NO_3^- and NO_2^- forms of N), but the 2008 EPA SAB report recommended reductions in

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; BMPs = best management practices; NO_3^- = nitrate; NO_2^- = nitrite; NH_4^+ = ammonium; UAN = urea ammonium nitrate; NO_y = reactive N oxides plus the compounds produced from their oxidation.



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?

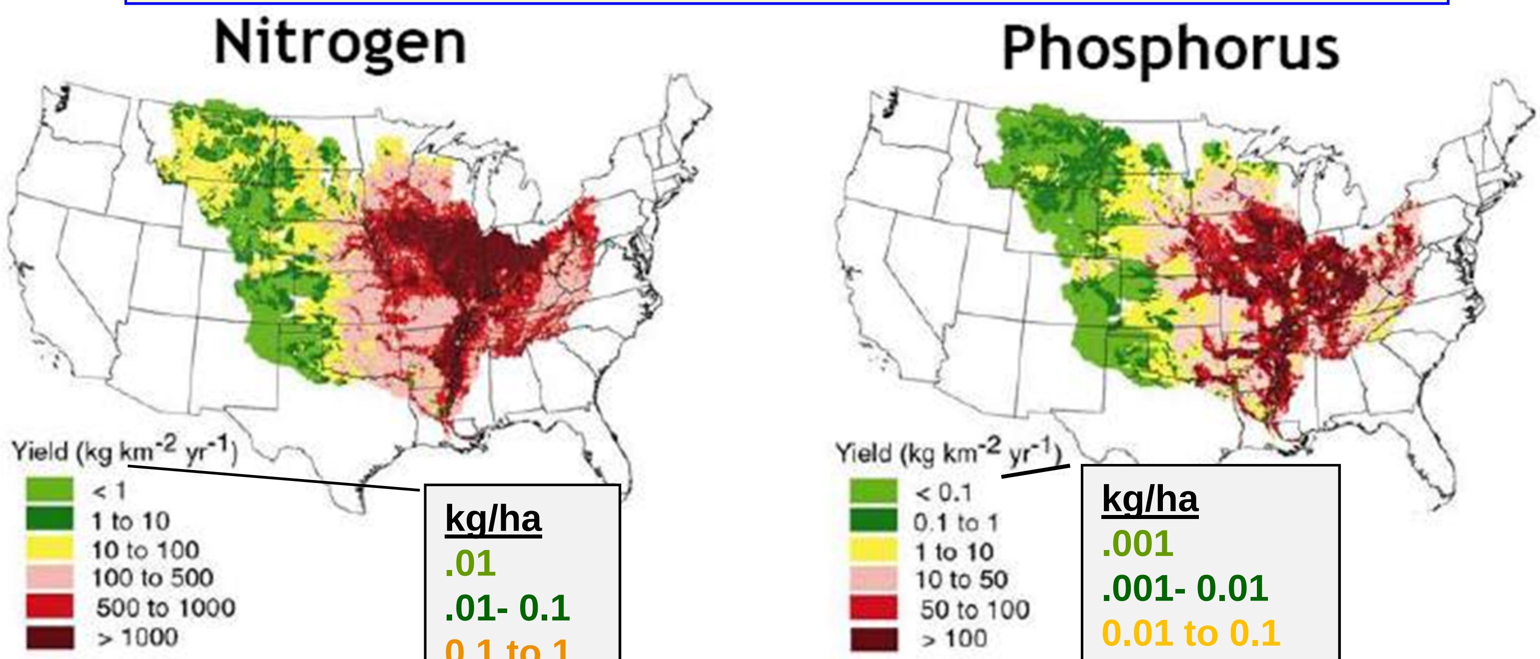
Table 2. Average nutrient discharge for the five large sub-basins in the Mississippi–Atchafalaya River Basin for the 2001-2005 water years (EPA SAB, 2008). Values in parentheses indicate % of total Basin discharge.

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	- - - - - - - -
		16	61	84	74	64
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.

USGS Estimates Loss of N and P to Water Resources in Different Areas

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



kg/ha
.01
.01- 0.1
0.1 to 1
1 to 5
5 to 10
>10

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

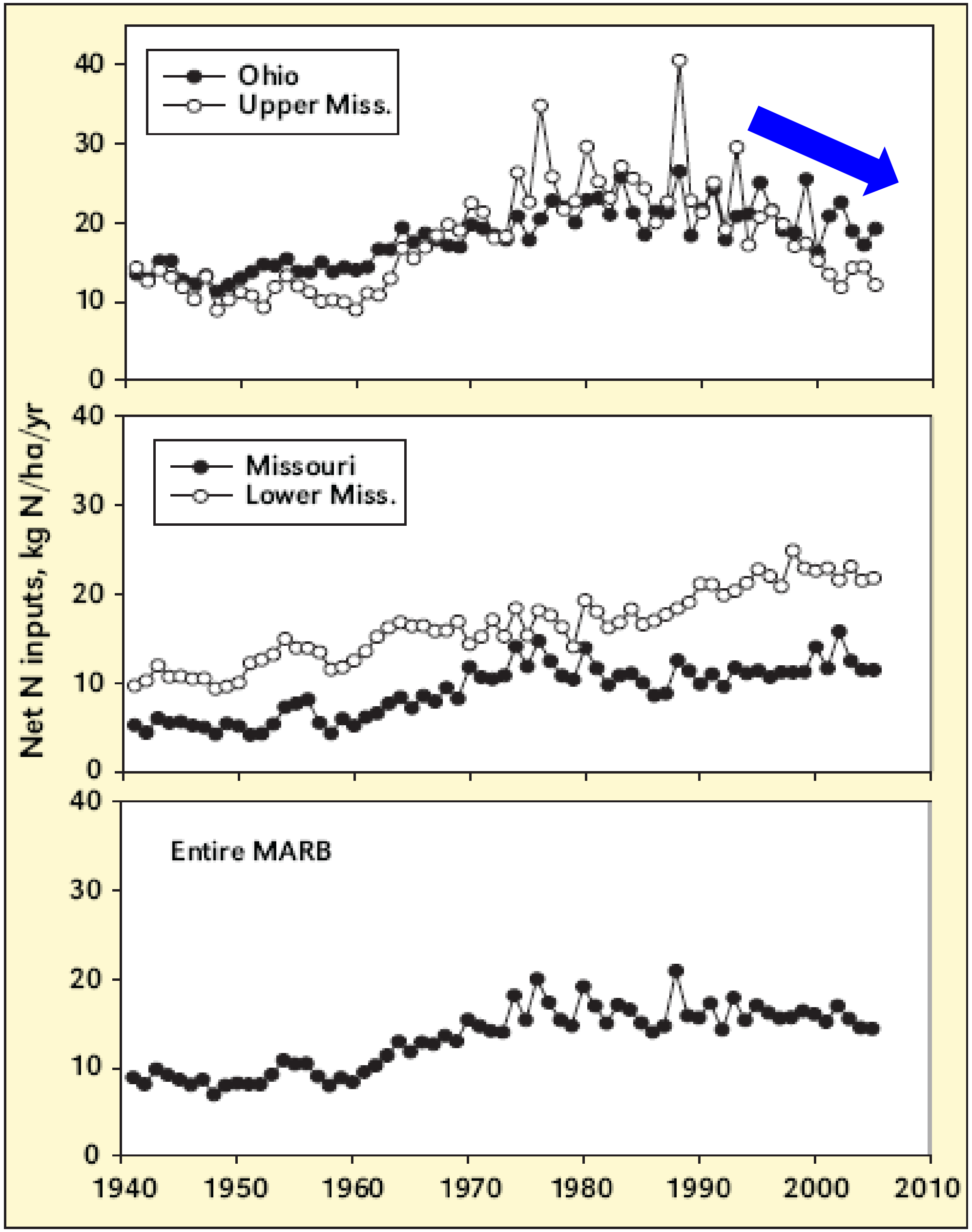


Figure 8. Nitrogen mass balance and net inputs for major regions of the Mississippi-Atchafalaya River Basin through 2005. Source: EPA SAB, 2008.

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

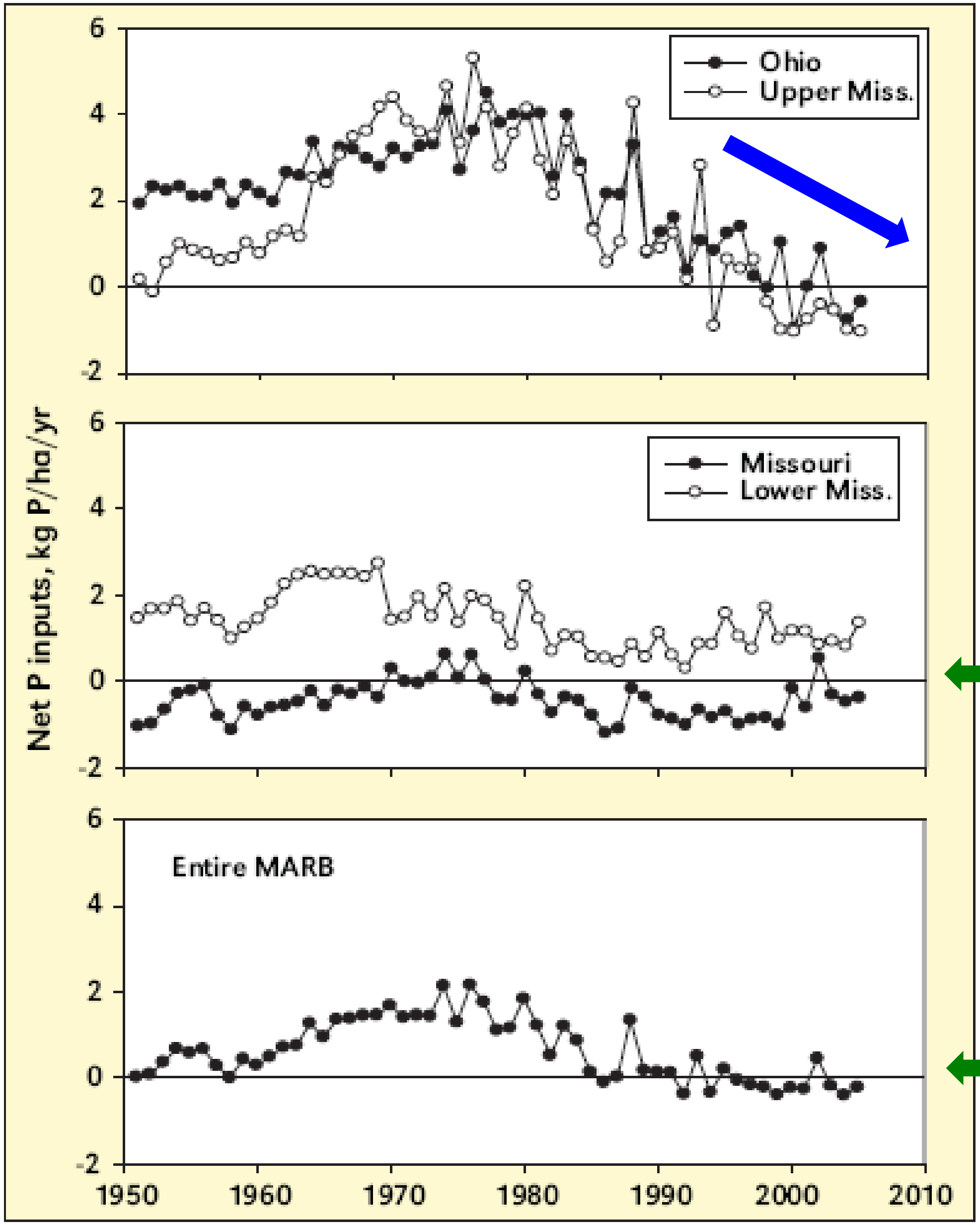
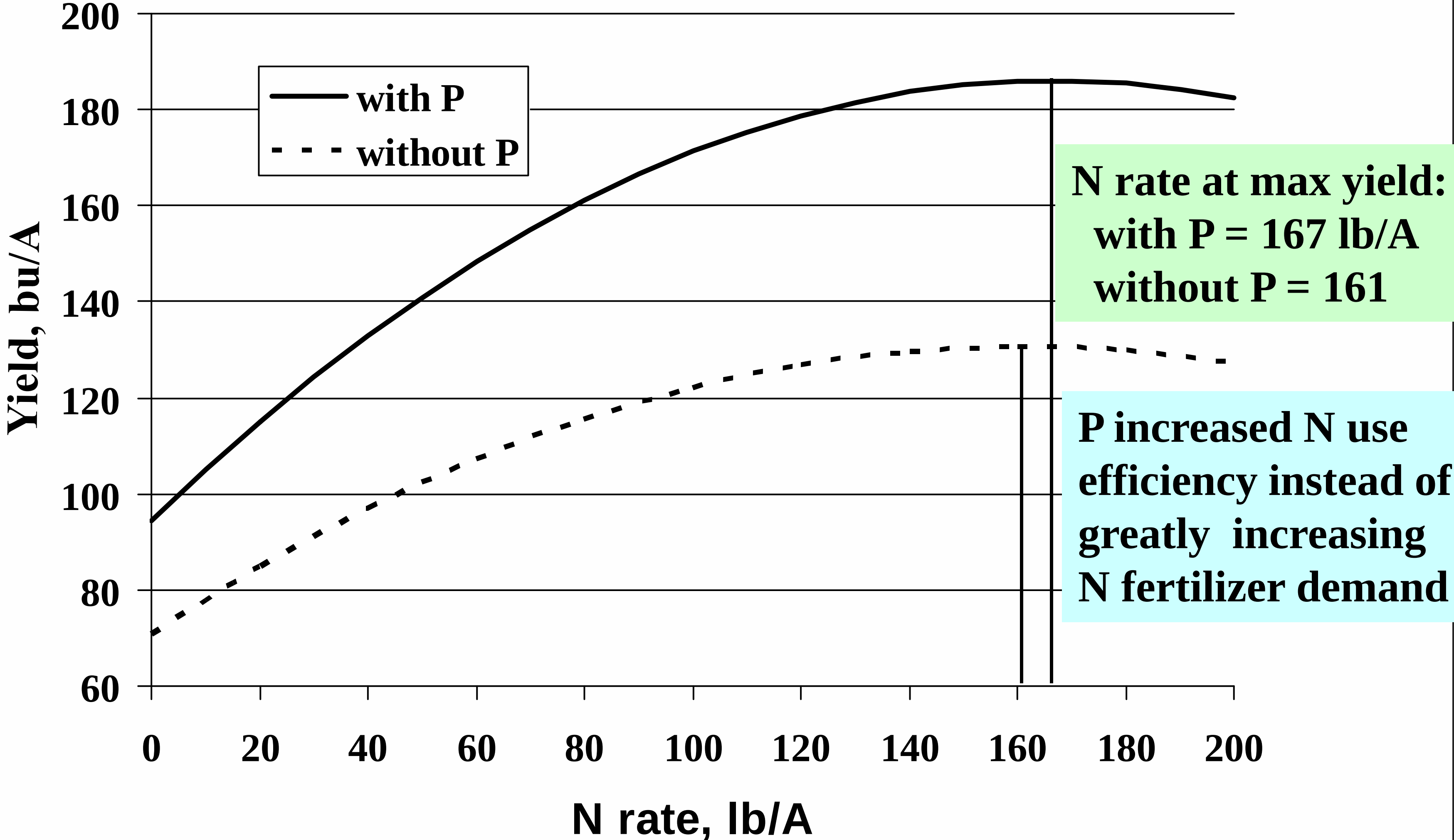


Figure 9. Phosphorus mass balance and net inputs for major regions of the Mississippi-Atchafalaya River Basin through 2005. Source: EPA SAB, 2008.

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

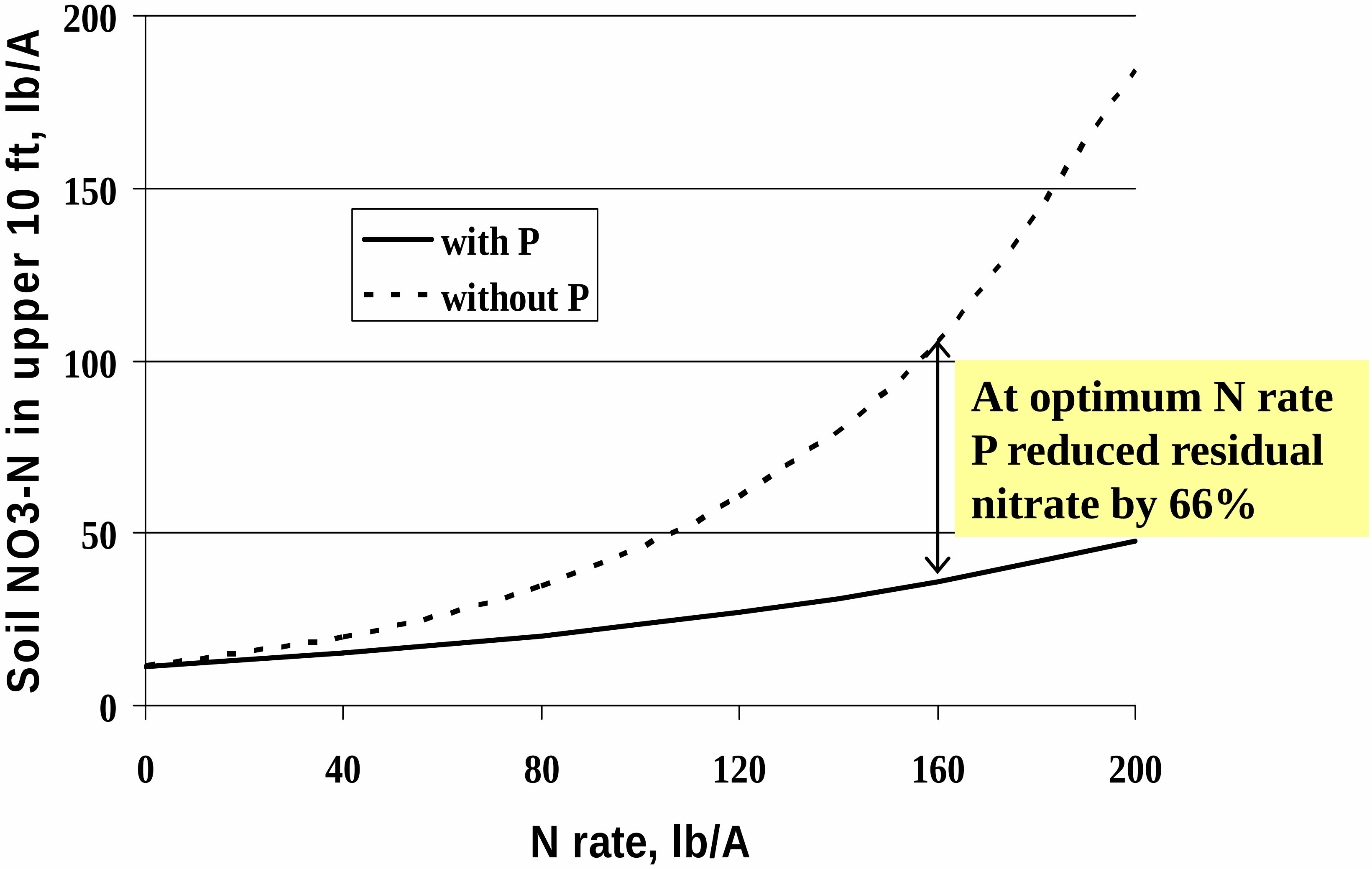
This is a concern, however, because soil P may be "mined", and may lead to yield reductions and lower N use efficiency

Effect of N and P on Corn Yield



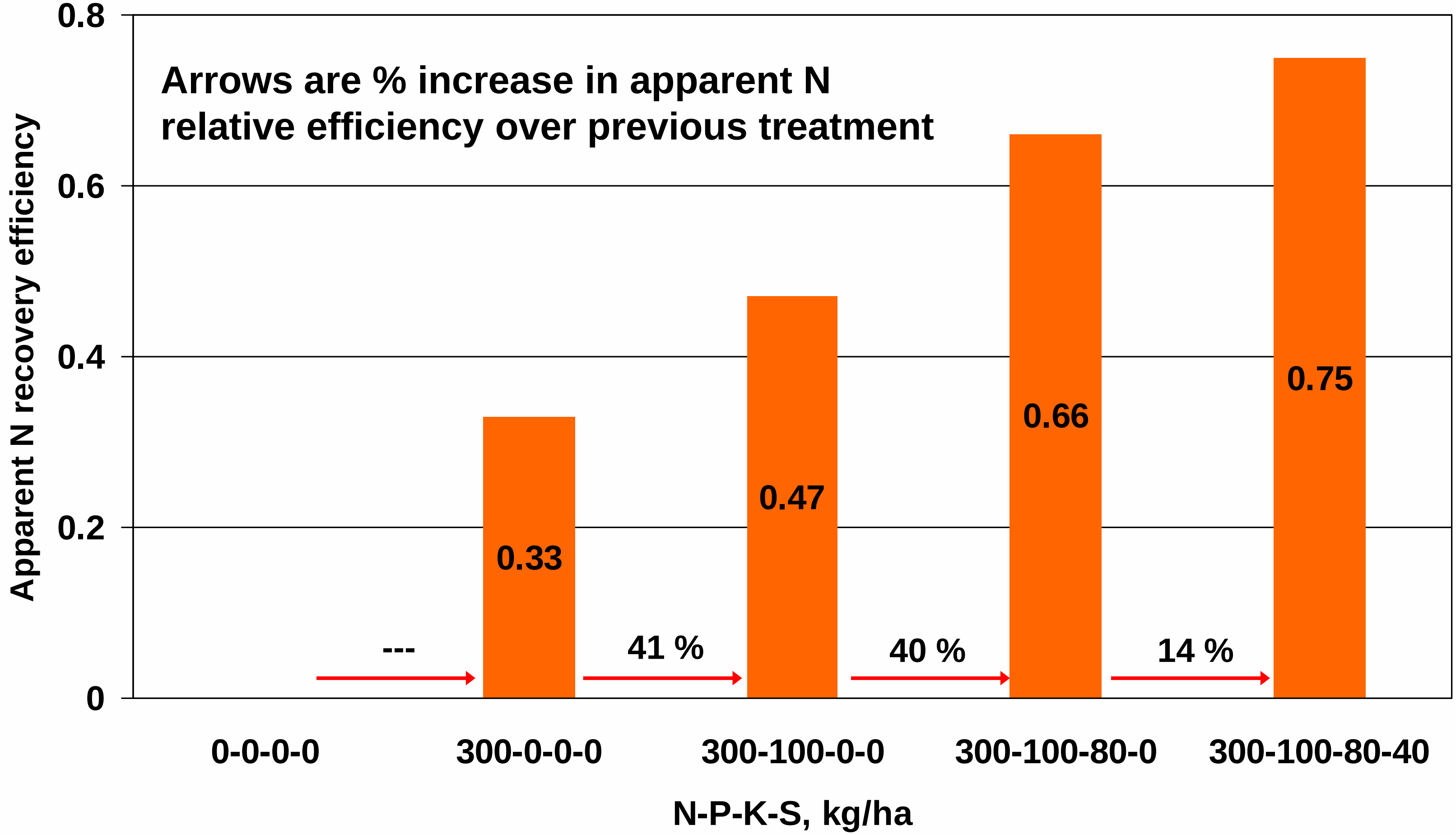
Schlegel, Dhuyvetter, and Havlin, 1996
J. Produc. Agric. 9:1
30 year average

P Reduces Residual Soil Nitrate and Potential for Nitrate Leaching



Schlegel, Dhuyvetter, and Havlin, 1996
J. Produc. Agric. 9:1
30 year average

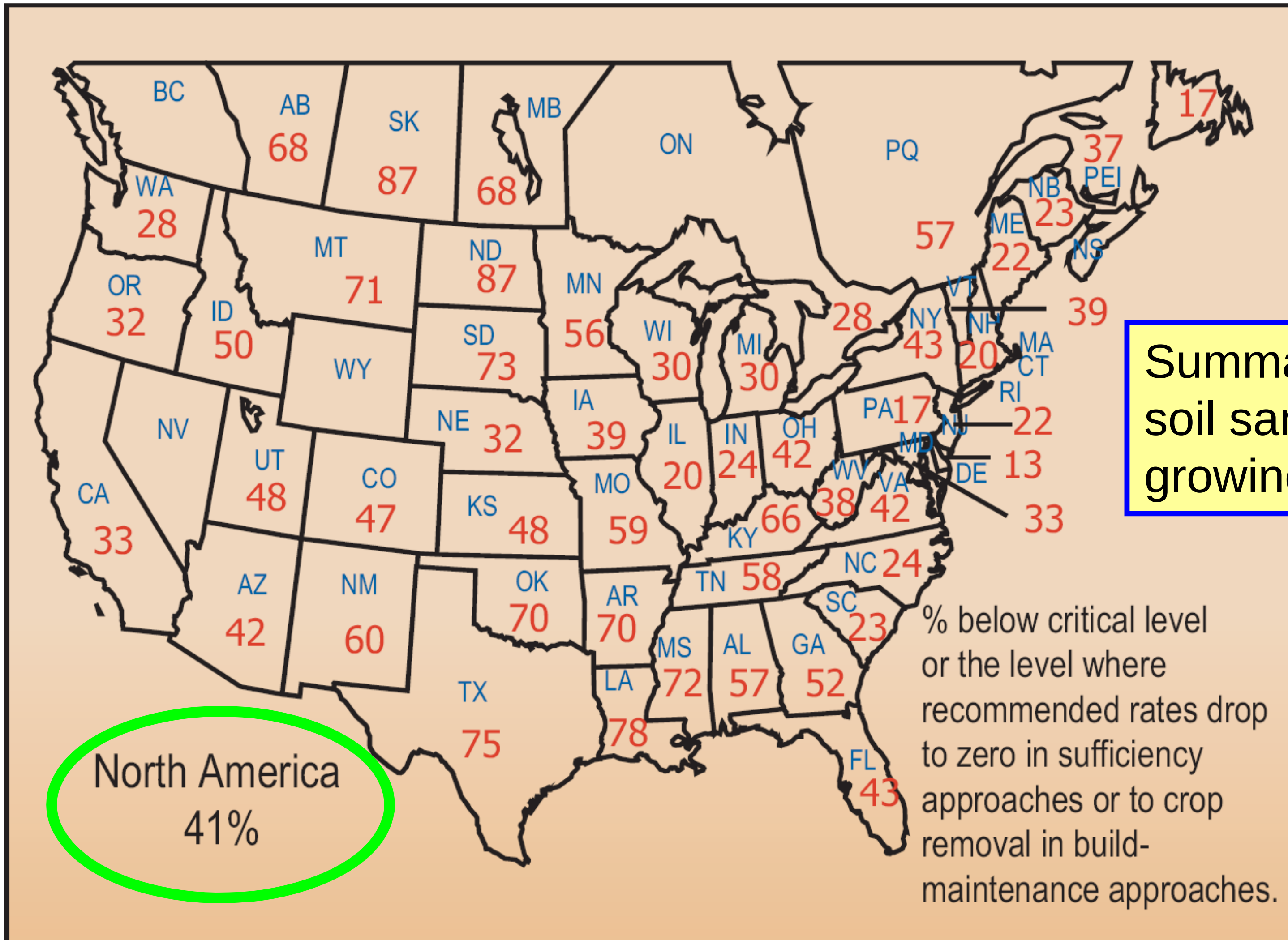
Balanced Fertilization Improves Crop N Recovery



Gordon. Better Crops. 2005 (KS, Car sandy loam)
2- year average (2001- 2002)

Assumes uptake 1.4 lb N/bu grain

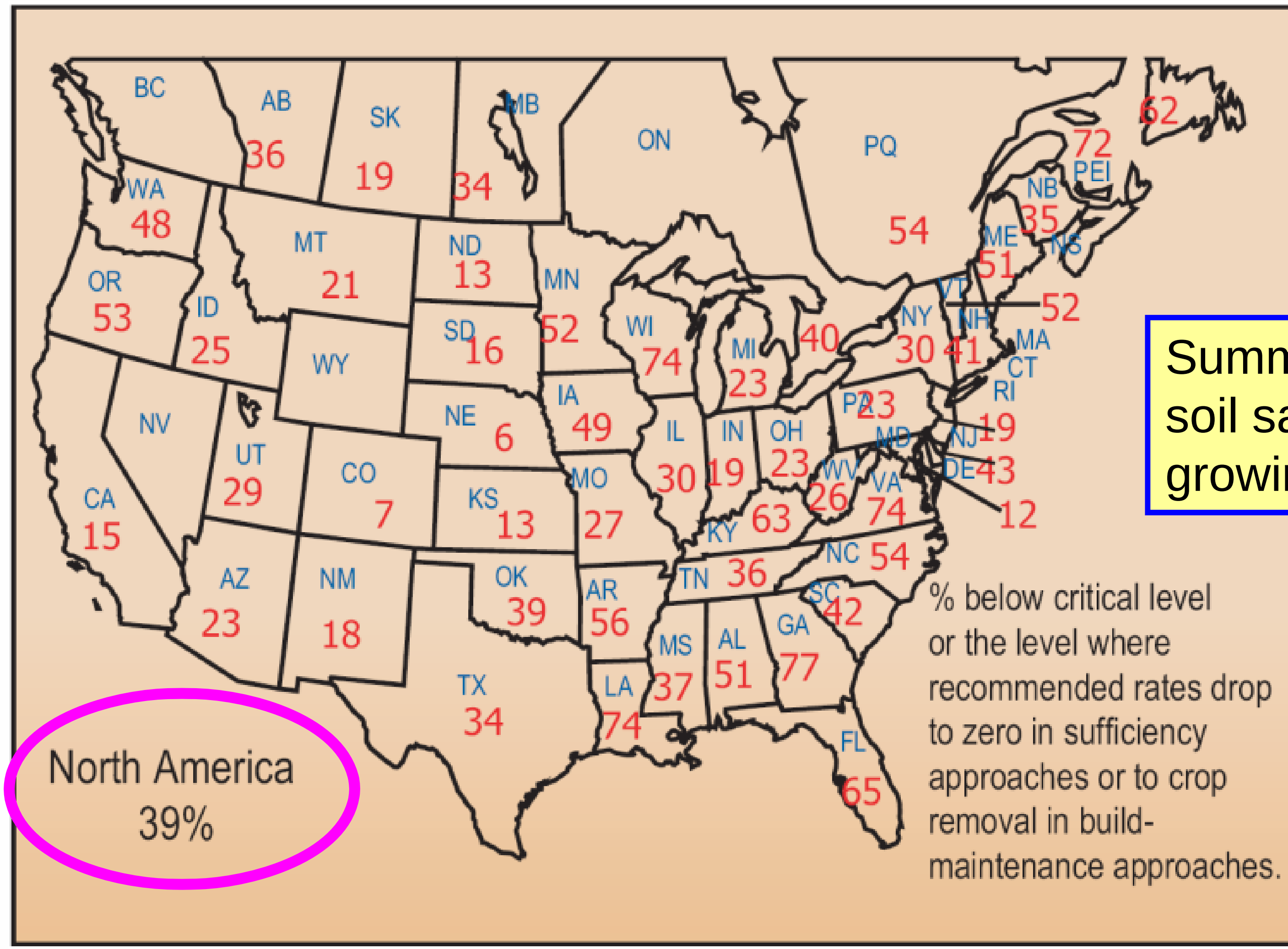
Percent of soil samples requiring annual P fertilization to avoid profit loss in most major crops in 2005



Summary of 3.4 million soil samples for 2005 growing season

Fixen et al. 2006

Percent of soil samples requiring annual K fertilization to avoid profit loss in most major crops in 2005



Summary of 3.4 million soil samples for 2005 growing season

Fixen et al. 2006

Decadal-Scale Changes of Nitrate in Ground Water of the United States, 1988–2004.

(Rupert. 2008. J. Environ. Qual. 37:S-240–S-248)

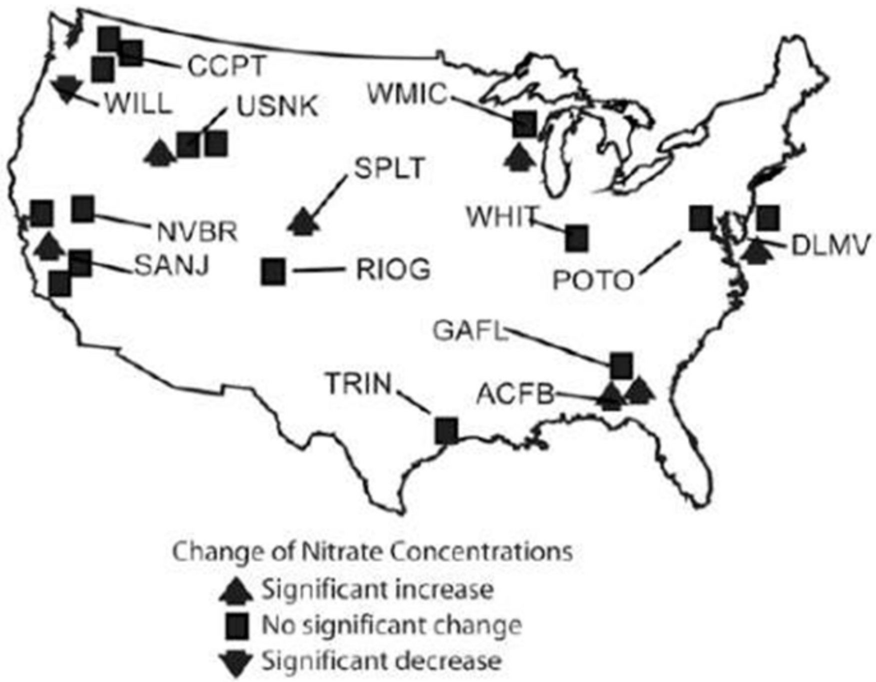


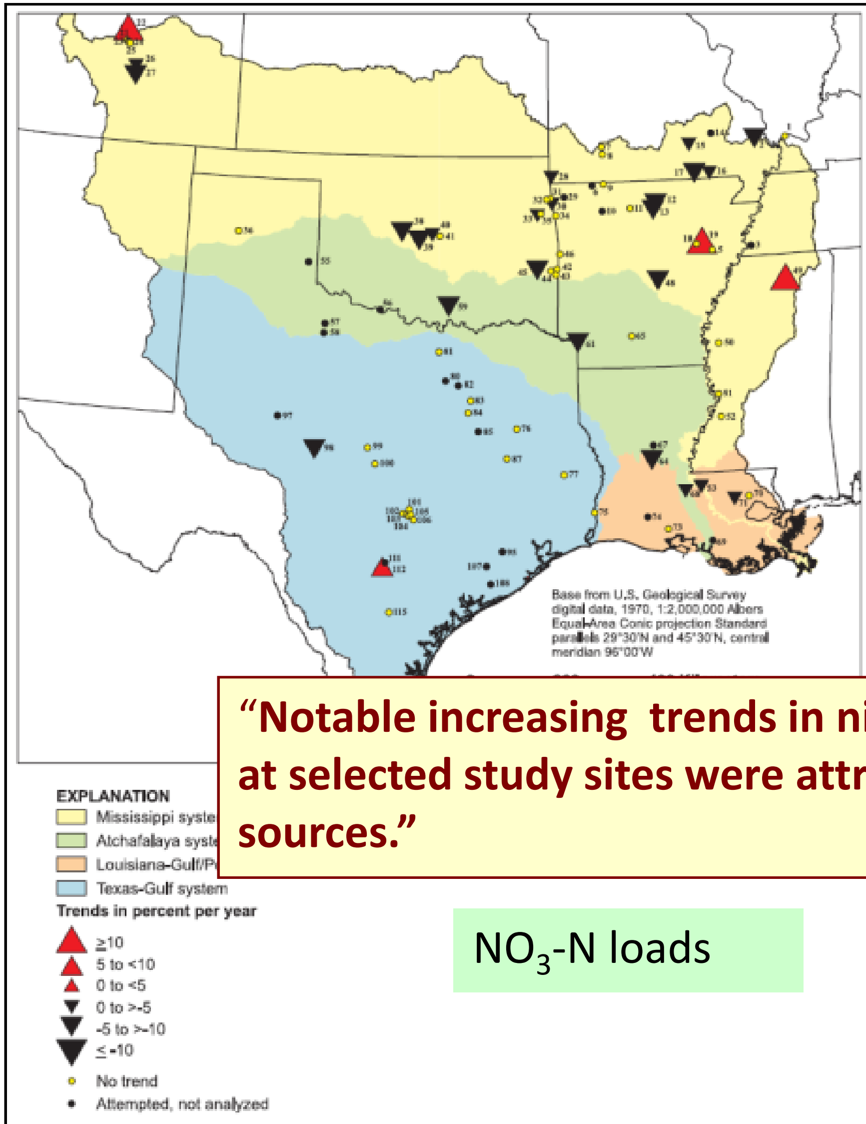
Fig. 1. Locations of U.S. Geological Survey National Water-Quality Assessment Program study units and well networks with and without significant decadal-scale trends of nitrate

- 67% of sites (16 out of 24) - had no significant change in NO_3 concentrations
  - All but 1 of the 8 others had increases in NO_3
- “A subset of wells had data on ground water recharge date; nitrate concentrations increased in response to the increase of N fertilizer use since about 1950.”

National Water-Quality Assessment Program

Trends In Nutrient and Sediment Concentrations and Loads In Major River Basins of the South-Central United States, 1993-2004

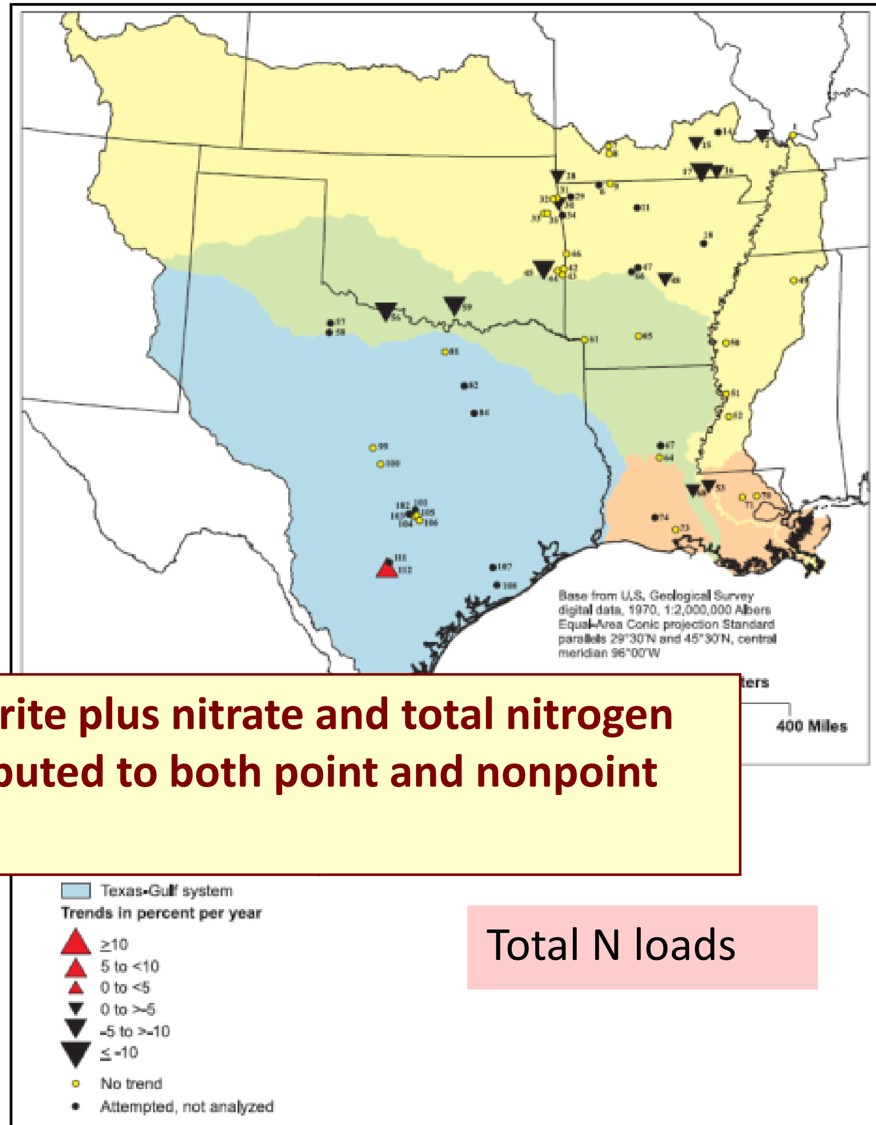
Scientific Investigations Report 2007–5090



NO_3-N loads

Figure 14. Trends in nitrite plus nitrate loads at study sites, 1993-2004.

"Notable increasing trends in nitrite plus nitrate and total nitrogen at selected study sites were attributed to both point and nonpoint sources."

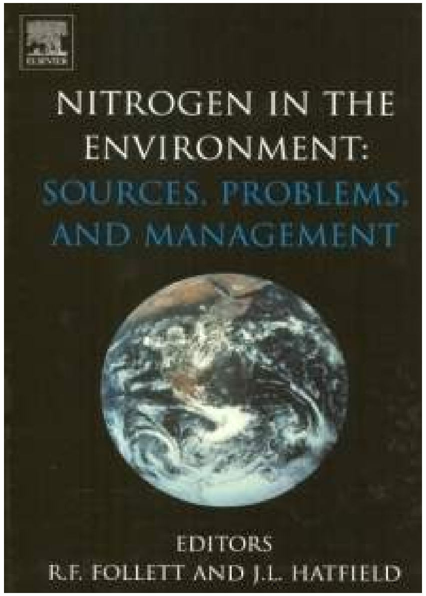


Total N loads

Figure 18. Trends in total nitrogen loads at study sites, 1993-2004

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"**



We can improve Nutrient Use Efficiency & Effectiveness

by implementing

Fertilizer BMPs …..

Right source @ Right rate, Right time & Right place

↓

4R Stewardship

Improving Fertilizer N Use Efficiency (NUE)

- **Proper rates and sources - best placement and proper timing**
- **Nitrification inhibitors** - slow the conversion of NH_4^+ to NO_3^-
- **Urease inhibitors** – slow conversion to NH_4^+ and reduce potential NH_3 volatilization
- **Slow release N fertilizers** - release N over the growing season, matching availability and crop needs
- **Site-specific applications**
  - Variable rate, and possibly variable source
  - In-season sensing and variable rate/place application

How Do You Define and Rate NUE?

Nutrient Use Efficiency and Effectiveness in North America:

Indices of Agronomic and Environmental Benefit

By C.S. Snyder and T.W. Bruulsema, International Plant Nutrition Institute

MINERAL FERTILIZERS have made it possible to sustain the world's growing population, sparing millions of acres of natural and ecologically-sensitive systems that otherwise would have been converted to agriculture[1]. Today, economic and environmental challenges are driving increased interest in nutrient use efficiency. Higher prices for both crops and fertilizers have heightened interest in efficiency-improving technologies and practices that also improve productivity. In addition, nutrient losses that harm air and water quality can be reduced by improving use efficiencies of nutrients, particularly for nitrogen (N) and phosphorus (P).

The world's population, growing in both numbers and purchasing power, is projected to consume more food, feed, fiber, and fuel—increasing global demand for fertilizer nutrients[2]. Since fertilizers are made from non-renewable resources, pressure to increase their use efficiencies will continue. At the same time, efforts should increase to enhance fertilizer use effectiveness for improved productivity and profitability of cropping systems.

System Efficiency

Efficiencies are generally calculated as ratios of outputs to inputs in a system. The "system" can be defined in many ways, depending on the interest of the observer.

Agricultural cropping systems contain complex combinations of components, including: soils, soil microbes, roots, plants, and crop rotations. Improvements in the efficiency of one component may or may not be effective in improving the efficiency of the cropping system. Efficiency gains in the short term may sometimes be at the expense of those in the long-term. Short-term reductions in application rates increase nutrient use efficiencies, even when yields decline. However, in the long-term, lower yields reduce production of crop residues, leading to increased erosion risks, decreased soil organic matter, and diminished soil productivity. Sustainable system efficiency demands attention to the long-term impacts.

Best management practices (BMPs) focus on the effectiveness of fertilizers and keeping them in the field for use by the intended crop in adapting cropping systems to the economic and environmental challenges noted above. Effectiveness is maximized when the most appropriate nutrient sources are applied at the right rate, time, and place in combination with conservation practices such as buffer strips, continuous no-till, cover crops, and riparian buffers within intensively managed cropping systems that achieve both increasing yields and diminishing nutrient losses[3]. This approach ensures that improvements to the nutrient use efficiency of the components contribute toward improving the efficiency of the entire system.

Many components contribute to the efficiency of a cropping system.

Because a cropping system includes multiple inputs and outputs, its overall efficiency depends on the science of economics. To maximize profit is to obtain the maximum value of outputs per unit value of all inputs. At the rate where the net return to the use of one input peaks, the input is making its maximum contribution to increasing the efficiency of all other inputs involved. Rates of nutrient application optimal for economic yields often minimize nutrient losses[4].

Component Efficiencies

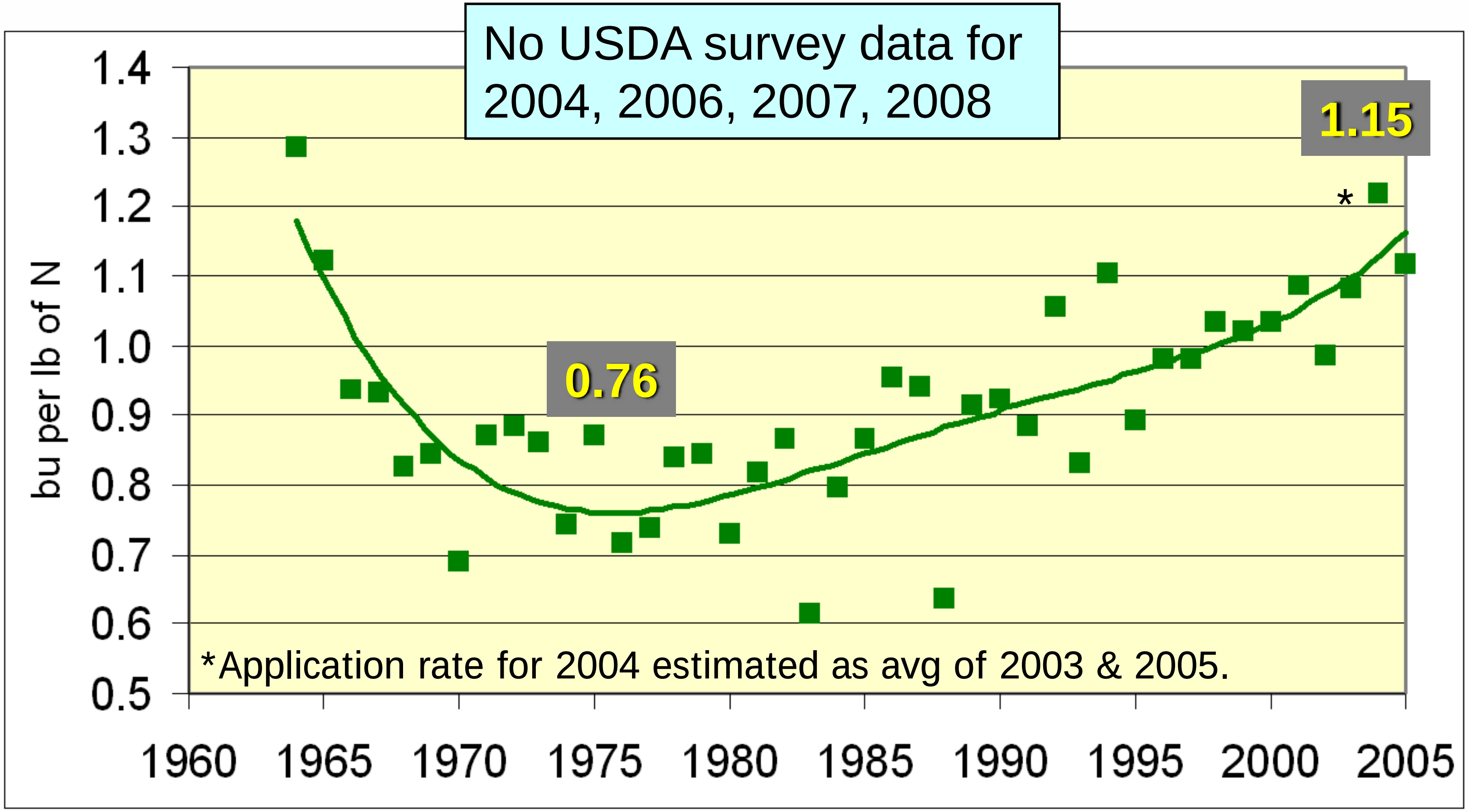
A recent review identified no fewer than 18 different definitions and calculations of nutrient use efficiency[5]. Even the most useful component efficiencies require careful interpretation if they are to contribute to effective nutrient use in cropping systems. In **Table 1**, we

http://www.ipni.net/ipniweb/portal.nsf/0/d58a3c2deca9d7378525731e006066d5/$FILE/Revised%20NUE%20update.pdf

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	$(Y-Y_0)/F$	**10 to 30** units of cereal grain per unit of N
PNB - Partial nutrient balance (removal to use ratio)	U_H/F	**0 to > 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 – Recovery efficiency of applied nutrient	$(U-U_0)/F$	**0.1 to 0.3** - proportion of P input recovered first year **0.5 to 0.9** - proportion of P input recovered by crops in long-term cropping systems **0.3 to 0.5** - N recovery in cereals-typical **0.5 to 0.8** - N recovery in cereals- best management

F-amt. nutrient applied, Y- yield of harvested portion with applied nutrient, Y_0- yield of harvested portion with no applied nutrient, U_H –nutrient content of harvested portion of crop, U –total nutrient uptake in aboveground biomass with nutrient applied, U_0 –total nutrient uptake in aboveground biomass with no nutrient applied

Corn grain produced in the U.S. per unit of fertilizer N used, 1964 to 2005.



Since 1975: **51 % increase in N efficiency**
12 % increase in N fertilizer use

Data sources: USDA Ag Chem Use Survey & Annual Crop Production.

U.S. ENVIRONMENTAL PROTECTION AGENCY

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Greenhouse Gases, Climate Change & Energy

Greenhouse Gases, Climate Change, and Energy

What Are Greenhouse Gases?

Many chemical compounds found in the Earth's atmosphere act as "greenhouse gases." These gases allow sunlight to enter the atmosphere freely. When sunlight strikes the Earth's surface, some of it is re-radiated back towards space as infrared radiation (heat). Greenhouse gases absorb this infrared radiation and trap the heat in the atmosphere. Many gases exhibit these "greenhouse" properties. Some of them occur in nature (water vapor, carbon dioxide, methane, and nitrous oxide), while others are exclusively human made (certain industrial gases). Over time, if atmospheric concentrations of greenhouse gases remain relatively stable, the amount of energy sent from the sun to the Earth's surface should be about the same as the amount of energy radiated back into space, leaving the temperature of the Earth's surface roughly constant.

Why Are Atmospheric Levels Increasing?

Levels of several important greenhouse gases have increased by about 25 percent since large-scale industrialization began around 150 years ago (Figure 1). During the past 20 years, about three-quarters of anthropogenic (human-caused) emissions came from the burning of fossil fuels. Concentrations of carbon

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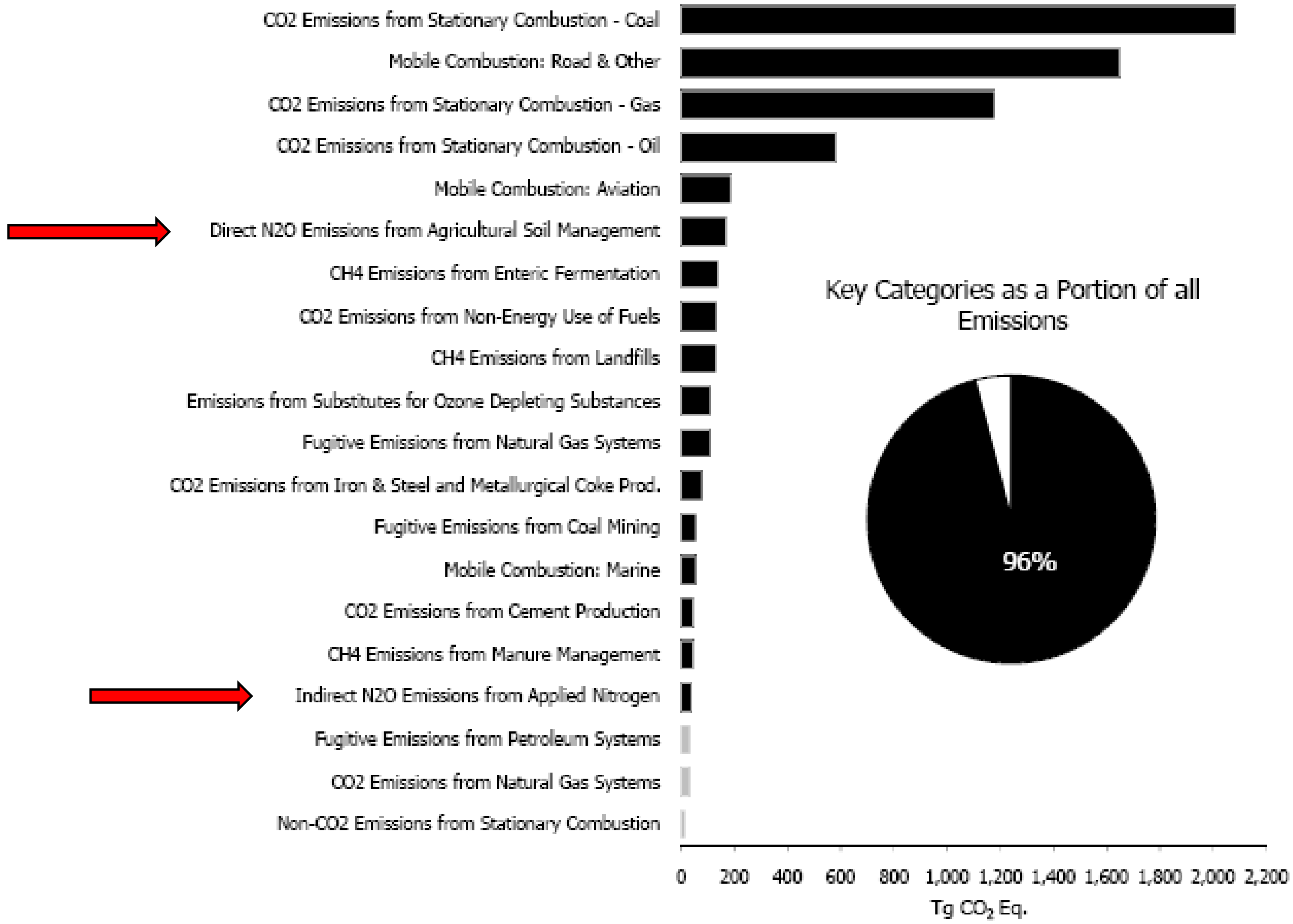


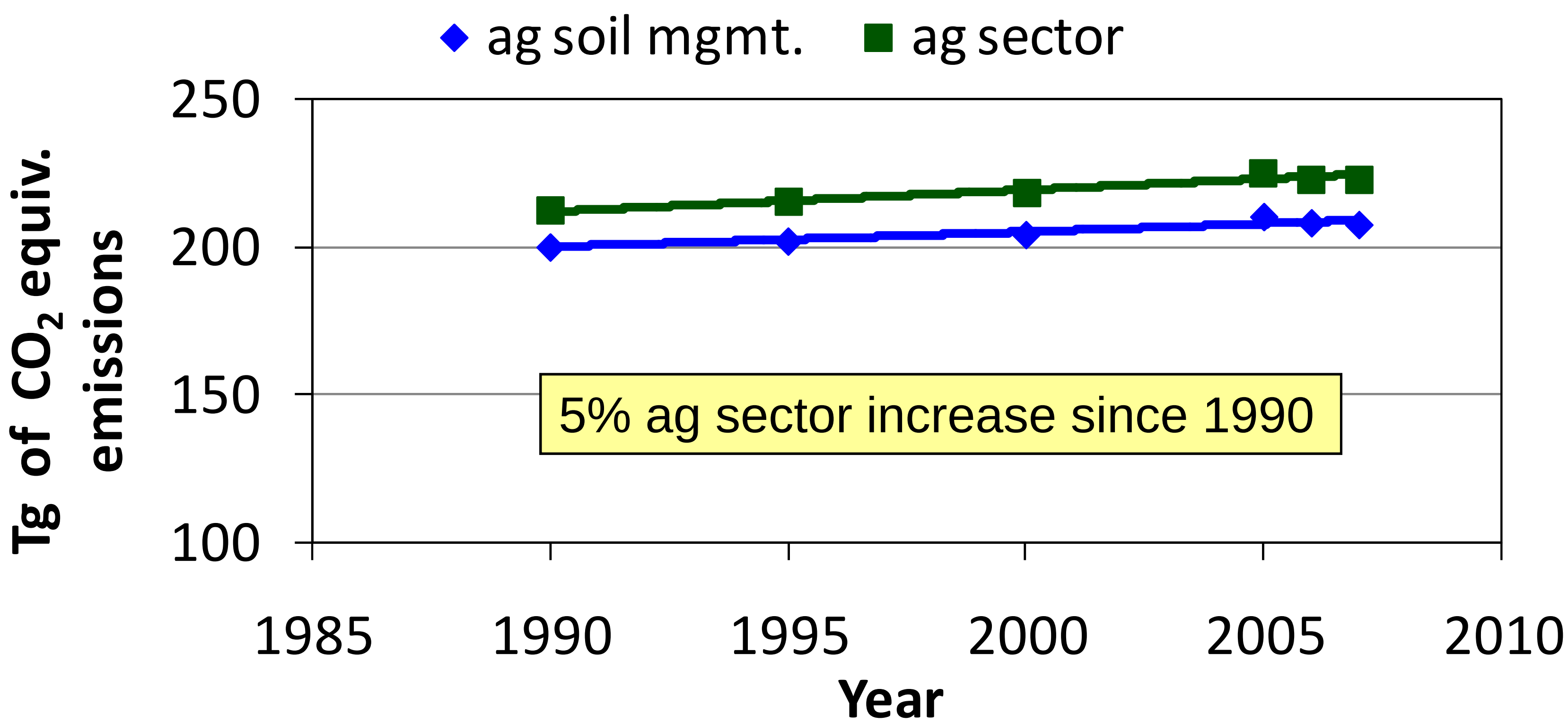
Figure ES-16: 2007 Key Categories
Notes: For a complete discussion of the key source analysis, see Annex 1.
Black bars indicate a Tier 1 level assessment key category.
Gray bars indicate a Tier 2 level assessment key category.

(EPA final April 15, 2009 U.S. GHG inventory, 1990-2007)

http://epa.gov/climatechange/emissions/usinventoryreport.html

N_2O Emissions Trends: Ag Soil Management and Ag Sector

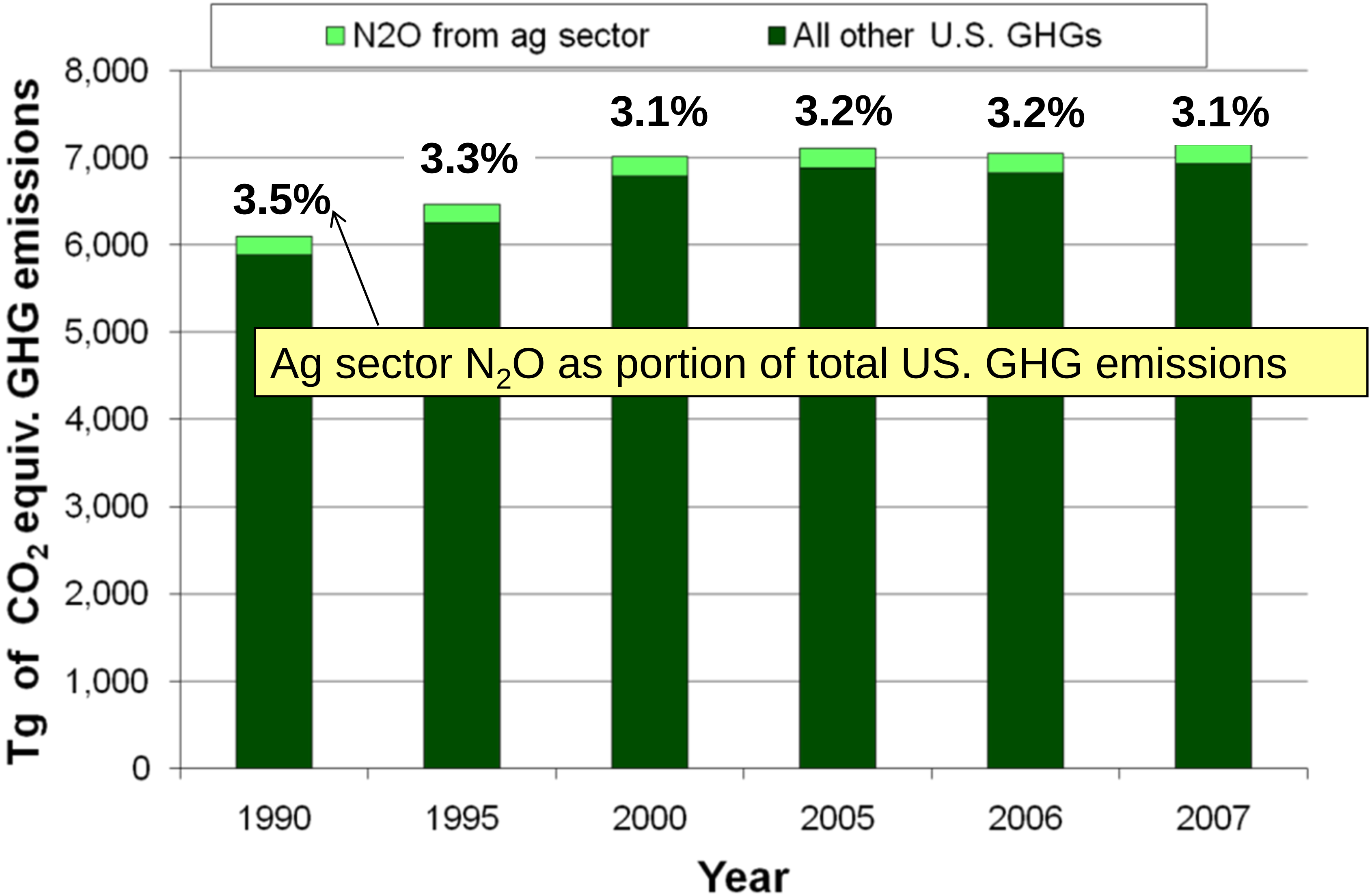
(EPA final April 15, 2009 U.S. GHG inventory, 1990-2007)



http://epa.gov/climatechange/emissions/usinventoryreport.html

Total U.S. GHG Emissions & N_2O from the Ag Sector – CO_2 Equiv.

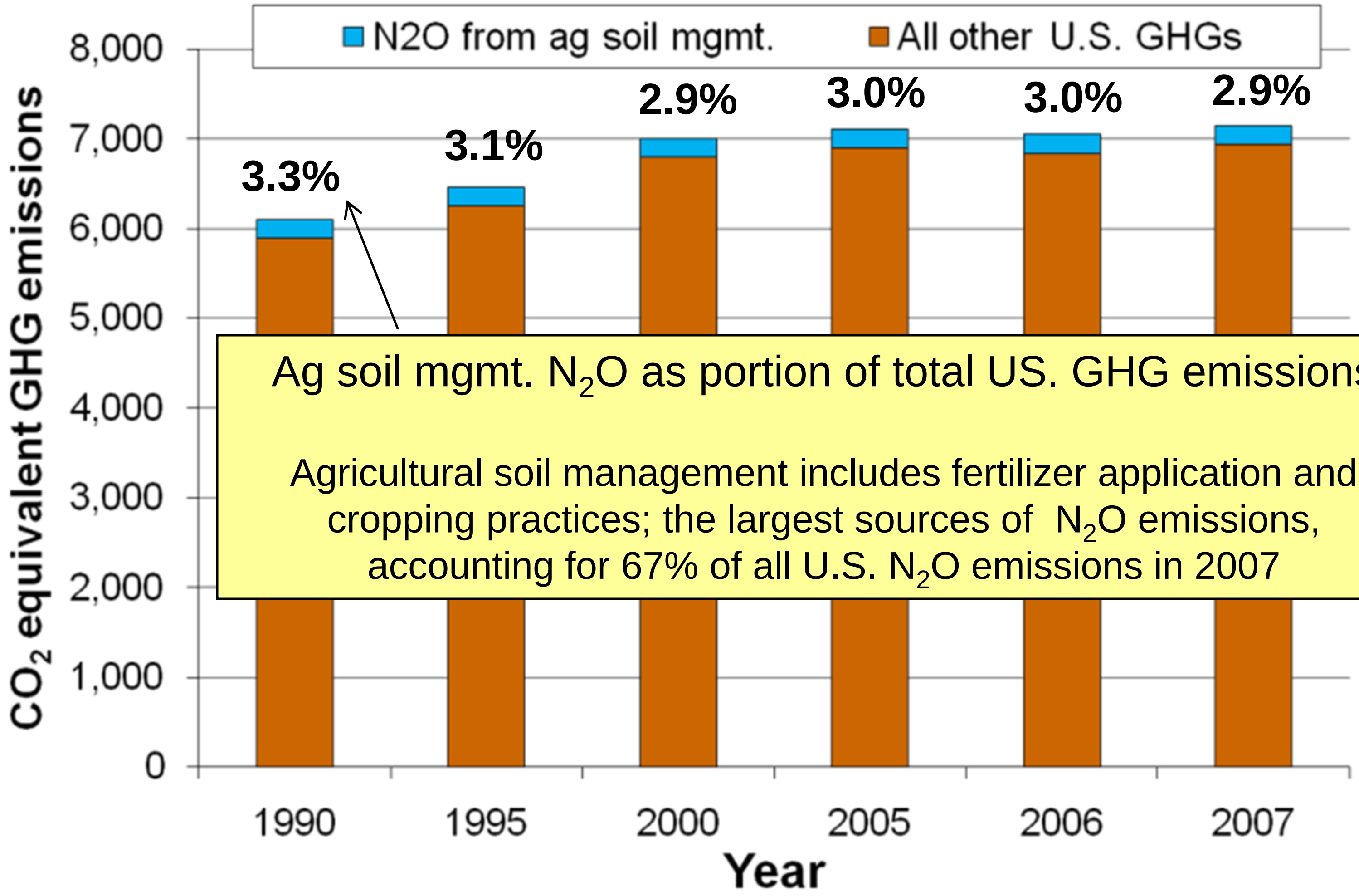
(EPA final April 15, 2009 U.S. GHG inventory, 1990-2007)



http://epa.gov/climatechange/emissions/usinventoryreport.html

U.S. GHG Emissions & N_2O from Ag Soil Management – CO_2 Equiv.

(EPA final April 15, 2009 U.S. GHG inventory, 1990-2007)



Ag soil mgmt. N_2O as portion of total US. GHG emissions

Agricultural soil management includes fertilizer application and cropping practices; the largest sources of N_2O emissions, accounting for 67% of all U.S. N_2O emissions in 2007

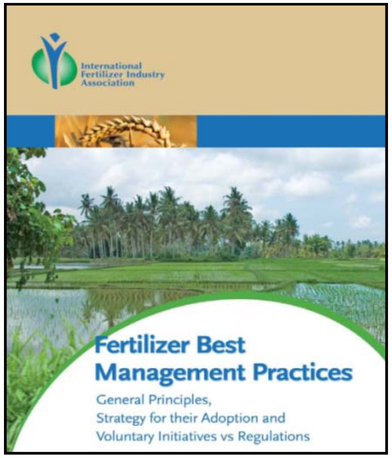
http://epa.gov/climatechange/emissions/usinventoryreport.html

Right Product, Right Rate, Right Time, and Right Place…the Foundation of BMPs for Fertilizer

By Terry L. Roberts

This article was originally presented as a paper at the International Fertilizer Industry Association (IFA) Workshop on Fertilizer Best Management Practices, March 7-9, 2007, in Brussels, Belgium. It is reprinted here with permission…see reference below[1].

http://www.ipni.net/bettercrops



http://www.fertilizer.org

New IPNI Practical Guide:

Fertilizer Nitrogen BMPs to Limit Losses that Contribute to Global Warming

Table 1. Relative effectiveness of management scenarios, shown as advantage of "Scenario 1" over "Scenario 2", in reducing N losses and greenhouse gas emissions. Effectiveness rating represents estimate of the relative potential N loss reduction, on-farm and within-watershed.[1]

			Indirect effects on N_2O emissions			Direct greenhouse gas emission[3] N_2O
			Water discharges as NO_3^-		NH_3 volatilization	
N Source[2]	Fertilizer N Management Practice		Leaching	Runoff		
	Right agronomic N rate					
	Scenario 1	Scenario 2				
All Sources	Accounting for soil N supply and other input sources (e.g. manure, irrigation water, etc.)	No such N accounting (assumes over-application)				
All Sources	Site-specific N management (variable rate and/or source)	No site-specific management				
	Right N timing					
	Scenario 1	Scenario 2				
AA	Applied in the fall after soil temp. below 50 °F for spring-planted crops	No waiting				
AA, AS, PA, U, UAN	Spring application, for spring planted crops (e.g. corn)	Fall application				
AA, AS, PA, U, UAN, AN, PN	Spring split or sidedress applied, for spring planted crops	All preplant applied				
AA, AS, PA, U, UAN, AN, PN	Spring or split fall-spring application, for fall planted crops (e.g. wheat, canola)	All fall applied				
AA, AS, PA, U, UAN, AN, PN	Nitrification inhibitor used	None used				
U	Controlled release technology used	None used				
	Right N placement					
	Scenario 1	Scenario 2				
AS, PA, U, UAN, AN	Subsurface incorporation	Surface broadcast				
U, UAN	Surface banded	Surface broadcast				
AS, PA, U, UAN, AN, PN	Shallow sidedress band – 1 in. (2 cm)	Sidedress band deeper than necessary – ≥ 4 in. (10 cm)				
U, UAN	Surface applied with urease inhibitor; abundant crop residues	No inhibitor				
U, UAN	Surface applied with urease inhibitor; minimal crop residues	No inhibitor				

[1] Relative percentage (%) advantage of "Scenario 1" over "Scenario 2," estimated from available literature and experienced observation. This rating scheme does not identify the quantity of N loss, which can be relatively small <1 to 2 lb/A (<1 to 2 kg/ha) in some conditions. Relative effects do not include emissions associated with manufacture or transport of inputs. Ratings are subject to change with research progress.

[2] N sources: AA=anhydrous ammonia, AS=ammonium sulfate, PA=predominantly ammonium containing, U=urea, UAN=urea ammonium nitrate solutions, AN=ammonium nitrate, PN=predominantly nitrate-containing.

[3] Data insufficient to allow ratings for emissions of the other two principal greenhouse gases, CH_4 and CO_2.

Legend for ratings in table:

Ratings can represent broad, multiple ranges (e.g. negative to positive), or a single quartile. The rating scheme is based to some extent on a conservation practice rating scheme in Table 17 in EPA SAB (2008).

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N Source[2]	Fertilizer N Management Practice		Indirect effects on N_2O emissions: Water discharges as NO_3^- – Leaching	Indirect effects on N_2O emissions: Water discharges as NO_3^- – Runoff	Indirect effects on N_2O emissions: NH_3 volatilization	Direct greenhouse gas emission[3] N_2O
	Right N timing					
	Scenario 1	**Scenario 2**				
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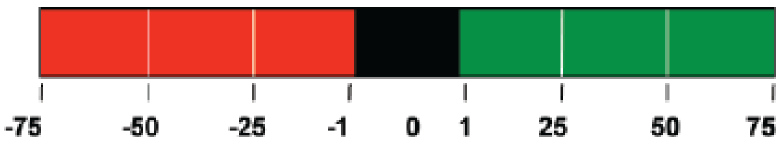

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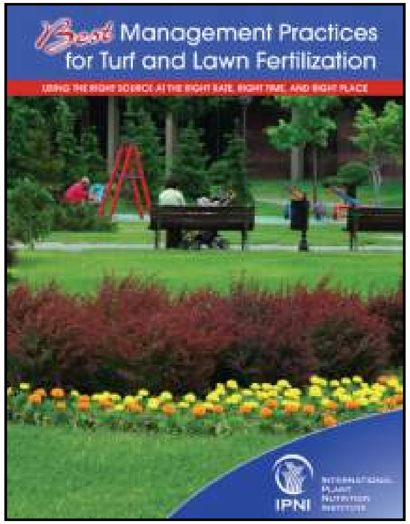
- **Fertilizer N BMPs can help minimize the potential for residual NO_3-N accumulation & losses**

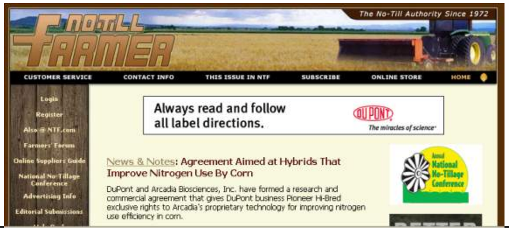
- **N source, rate, timing, and placement …. which may include**
  - **Urease inhibitors**
  - **Nitrification inhibitors**
  - **Slow-release materials**
  - **Controlled-release materials**
- **In combination with appropriate, site-specific cropping system and conservation practices**
  - **(e.g. conservation tillage, cover crops, vegetative buffers, managed drainage, wetlands, bioreactors, etc.)**

Intensified Fertilizer BMP Education & Outreach



New Tools, Technologies, Opportunities ??

- John Deere - hi-speed (10 mph) anhydrous ammonia applicator
- Agrotain & Lange-Stegmann - $20 million Urea and Stabilized Nitrogen Center in St. Louis, MO
- Corn hybrids with improved N uptake/redistribution characteristics ???



Thank You

Better Crops, Better Environment … through Science

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