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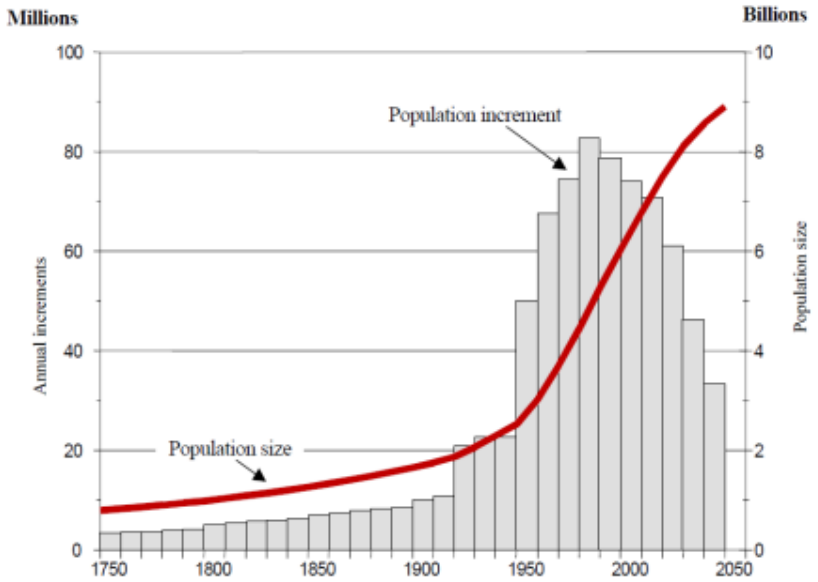
INSTITUTE

Environmental and Social Drivers of Improved Nitrogen Management Technology

SSSA Meetings S08 Symposium
Improving Adoption of Nitrogen Management Technologies
Long Beach, CA November 2010

C.S. Snyder, PhD, CCA
Nitrogen Program Director

A Growing World Population Requires an Increased Global Food, Fiber, and Fuel Supply



Source: United Nations Population Division

Hosted by Google Search News Back to Google News

UN report: 22 nations face protracted food crises

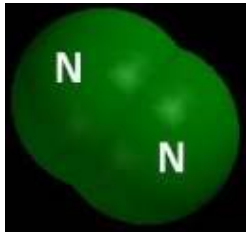
By ALESSANDRA RIZZO (AP) – Oct 6, 2010

Associated Press

"Stewart et al. (2005) reviewed data representing 362 seasons of crop production and reported **at least 30 to 50% of crop yield can be attributed to commercial fertilizer inputs**."

"…**food production will have to increase by 50% ….. to help solve the current food crisis**."

(Roberts. 2009. Better Crops 93(2):12-15)



Nitrogen Facts

- **N is essential to the survival of all life**
- **78% of Earth's atmosphere is N_2**
- **Half the synthetic N fertilizer ever used has been utilized since 1985** (Howarth, 2005).
- **"Human alterations of the N cycle have caused a variety of environmental and human health problems ranging from too little to too much reactive N in the environment."** (http://www.whrc.org/policy/global_nitrogen.htm)

Science 8 October 2010:
Vol. 330. no. 6001, pp. 192 - 196
DOI: 10.1126/science.1186120

REVIEW

The Evolution and Future of Earth's Nitrogen Cycle

Donald E. Canfield,[1,*] Alexander N. Glazer,[2] Paul G. Falkowski[3]

"Microbial processes will ultimately restore balance to the N cycle but the damage done by humans to the N economy of the planet will persist for decades, possibly centuries, if active intervention and careful management strategies are not initiated"

Food Security

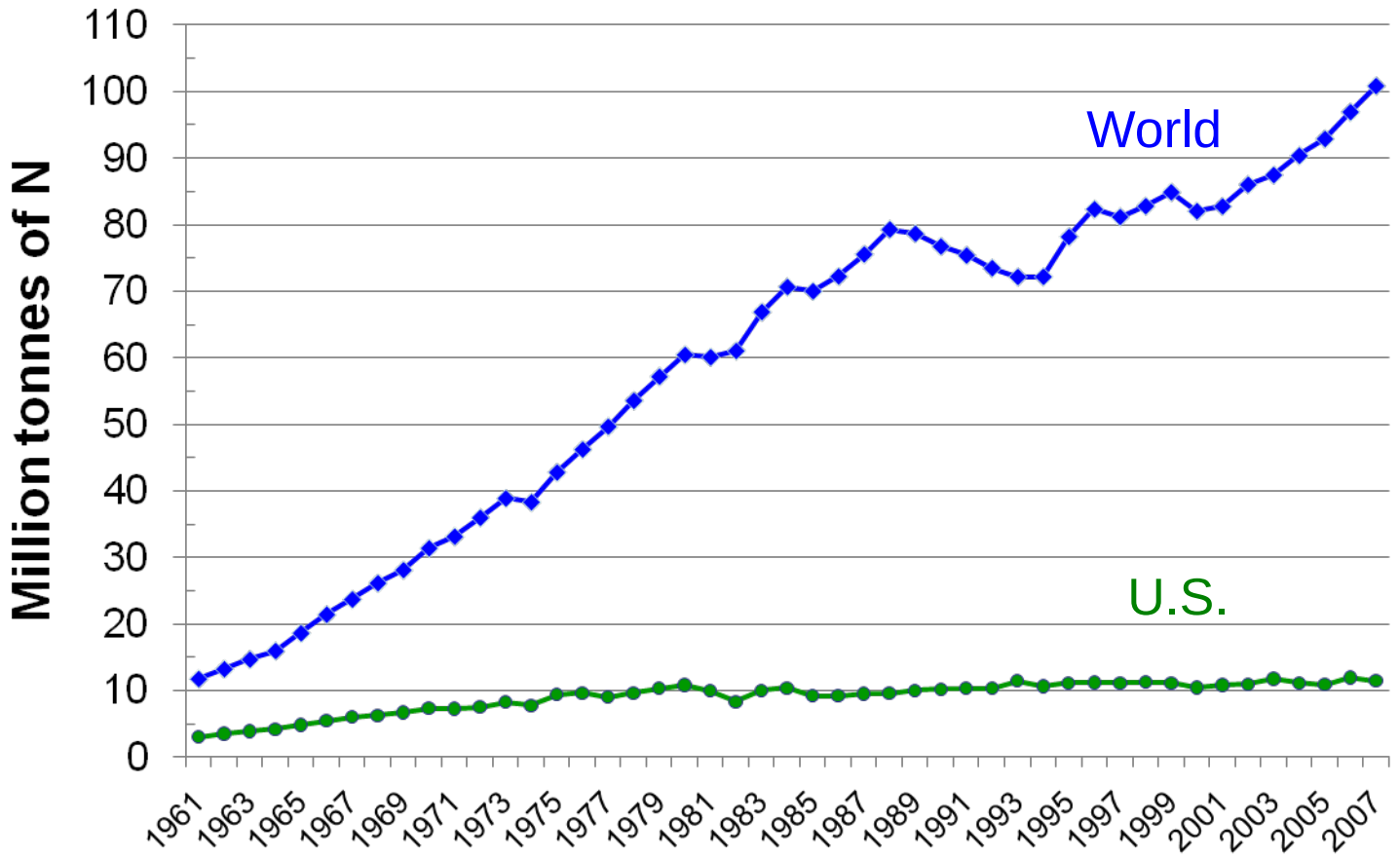
Human Health

Water Quality

Air Quality and Climate Change

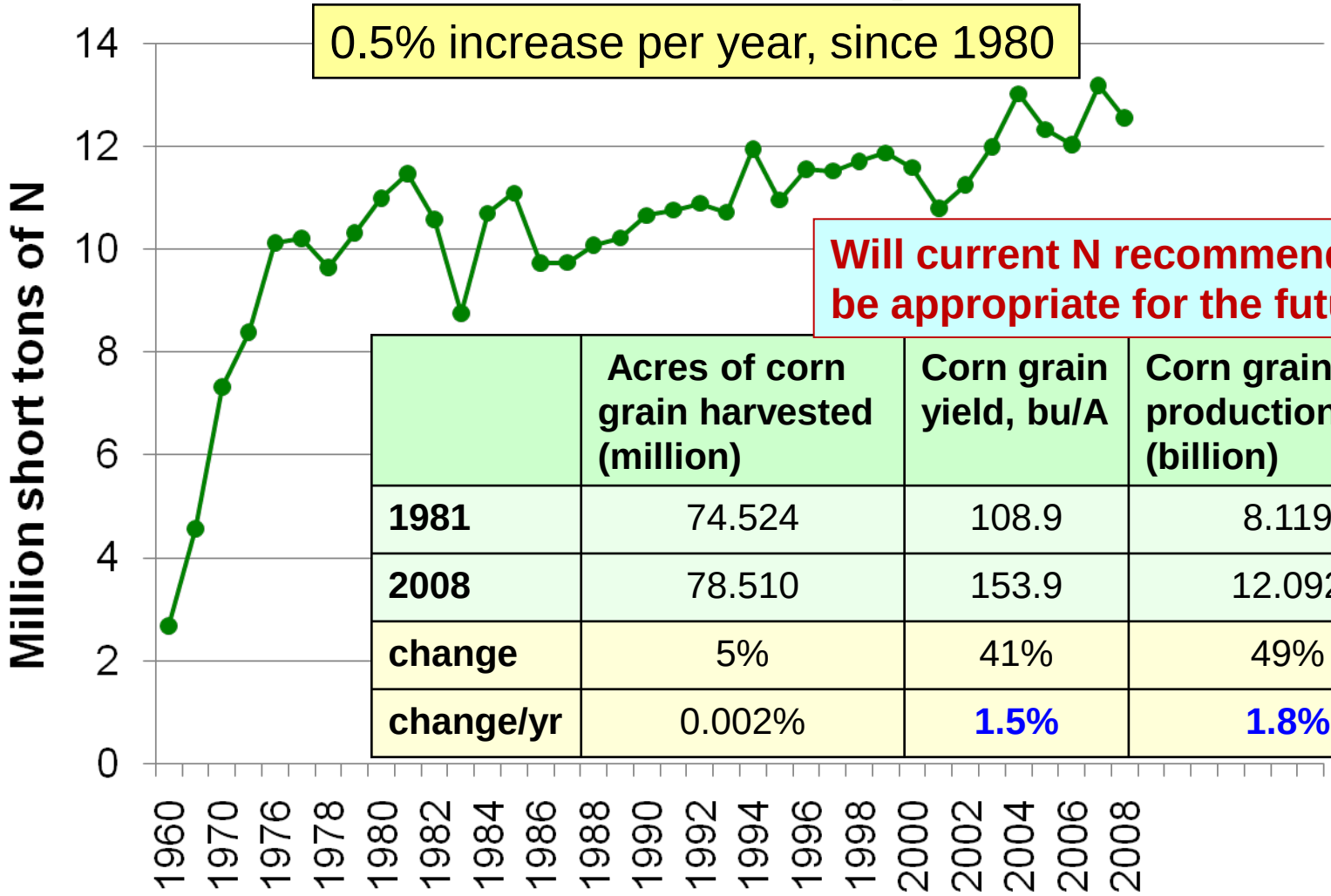
Ecosystem Health & Biodiversity

World and U.S. Fertilizer N Consumption



Source: IFA Statistics, 2010

U.S. Fertilizer N Consumption and Biofuel Use Perceptions

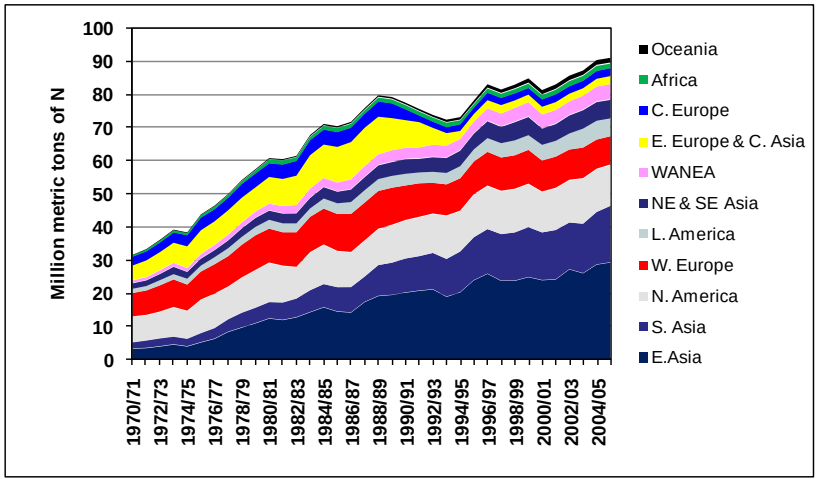


Will current N recommendations be appropriate for the future?

	Acres of corn grain harvested (million)	Corn grain yield, bu/A	Corn grain production, bu (billion)
1981	74.524	108.9	8.119
2008	78.510	153.9	12.092
change	5%	41%	49%
change/yr	0.002%	**1.5%**	**1.8%**

Source: AAPFCO and TFI, 2010

"Food production will have to increase by 70 percent to feed a population of nine billion people by 2050" (FAO, 2010)



- **Use, cost and access to fertilizer in Africa** (http://www.agra-alliance.org/section/work/soils):
  - African farmer uses: 8 kg fertilizer/ha
  - Global farmers use > 100 kg/ha
  - ***Africa Goal: ≥50 kg/ha by 2015***
  - Fertilizer cost 2-6 times the global average
  - Farmers often travel up to 50 km by foot/bicycle to reach a distributor--who may not have the quantities or combinations that make sense for a small farm.

Insufficient and Surplus Nitrogen Issues

POLICYFORUM

AGRICULTURE

Nutrient Imbalances in Agricultural Development

Nutrient additions to intensive agricultural systems range from inadequate to excessive—and both extremes have substantial human and environmental costs.

P. M. Vitousek,[1*] R. Naylor,[2] T. Crews,[3] M. B. David,[4] L. E. Drinkwater,[5] E. Holland,[6] P. J. Johnes,[7] J. Katzenberger,[8] L. A. Martinelli,[9] P. A. Matson,[10] G. Nziguheba,[11] D. Ojima,[12] C. A. Palm,[11] G. P. Robertson,[13] P. A. Sanchez,[11] A. R. Townsend,[14] F. S. Zhang[15]

Nutrient cycles link agricultural systems to their societies and surroundings; inputs of nitrogen and phosphorus in particular are essential for high crop yields, but downstream and downwind losses of these same nutrients diminish environmental quality and human well-being. Agricultural nutrient balances differ substantially with economic development, from inputs that are inadequate to maintain soil fertility in parts of many developing countries, particularly those of sub-Saharan Africa, to excessive and environmentally damaging surpluses in many developed and rapidly growing economies. National and/or regional poli-

	Nutrient balances by region (kg ha $^{-1}$ year $^{-1}$)					
Inputs and outputs	Western Kenya		North China		Midwest U.S.A	
	N	P	N	P	N	P
Fertilizer	7	8	588	92	93	14
Biological N fixation					62	
Total agronomic inputs	7	8	588	92	155	14
Removal in grain and/or beans	23	4	361	39	145	23
Removal in other harvested products	36	3				
Total agronomic outputs	59	7	361	39	145	23
Agronomic inputs minus harvest removals	-52	+1	+227	+53	+10	−9

Science. 2009. 324: 1519-1520

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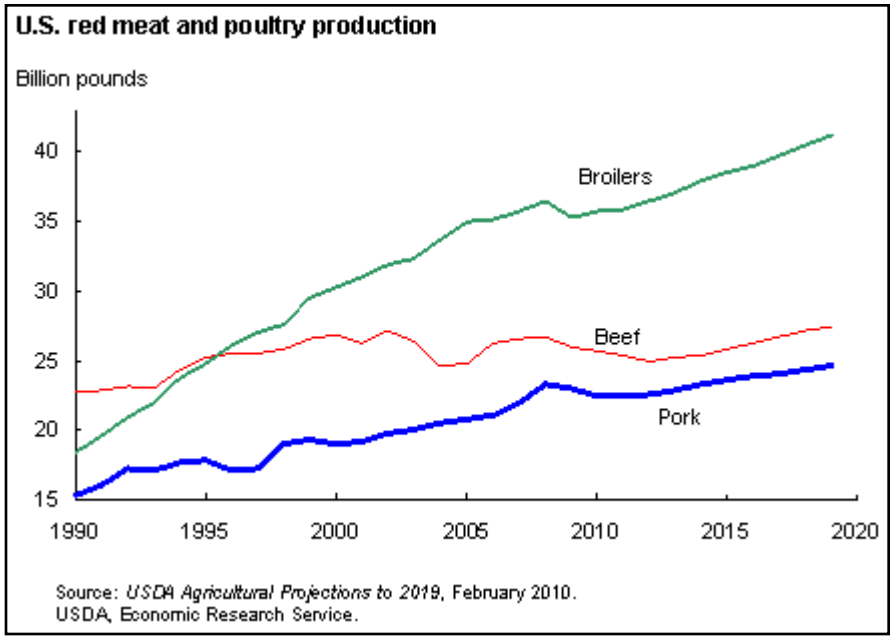
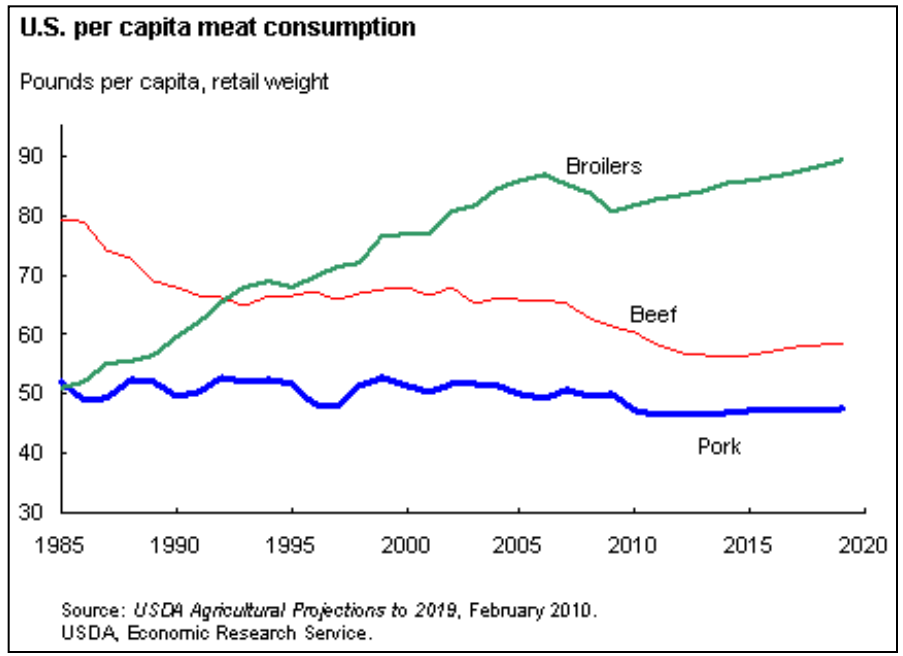




- **What are the consequences of increased development and personal income on global per capita meat and poultry consumption?**

Galloway and Cowling. 2002. Ambio 31(2): 64-71

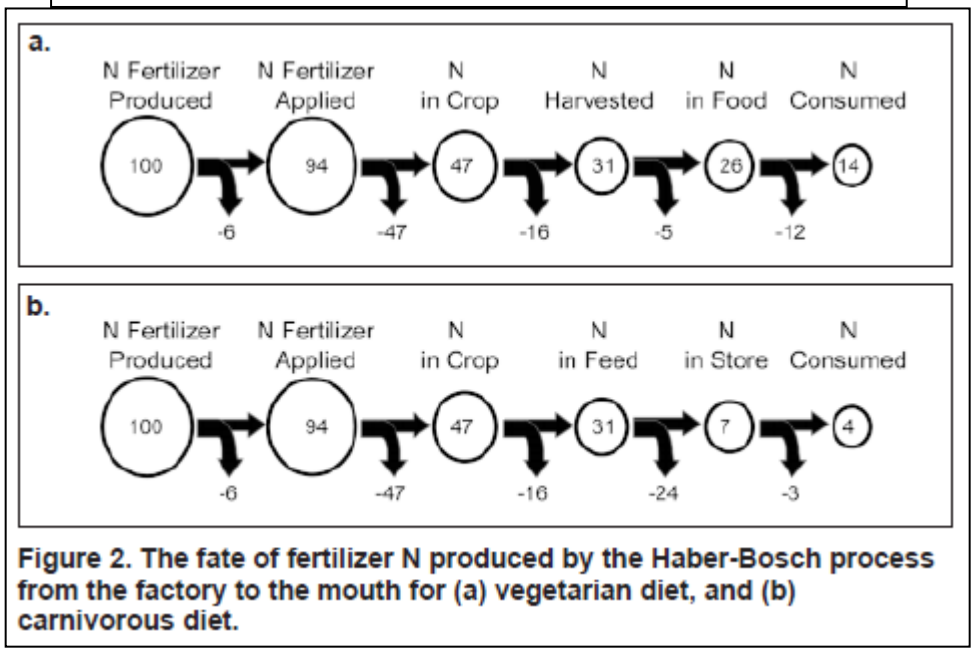
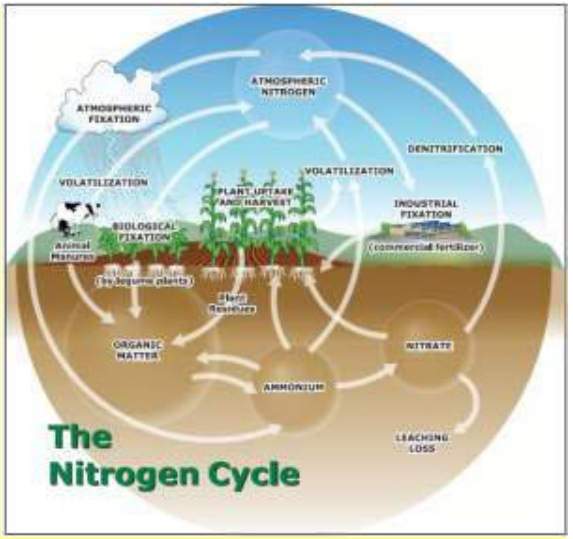


Figure 2. The fate of fertilizer N produced by the Haber-Bosch process from the factory to the mouth for (a) vegetarian diet, and (b) carnivorous diet.

Fertilizer N Use Efficiency is Affected by

- N supply from:
  - Soil
  - Fertilizer
  - Other inputs
- Crop N uptake
- N losses from the soil–plant system
  - Volatilization, leaching, runoff, denitrification (and nitrification)
- All are affected by cropping system management and environmental conditions

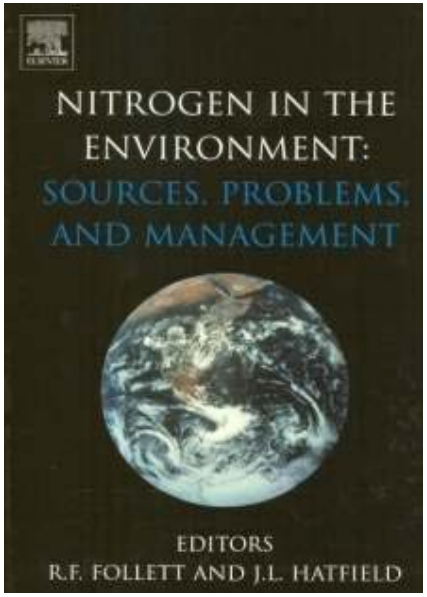


Global Nitrogen Use Efficiency, Expressed as Apparent N Recovery (RE_N)

- ≤50% N use efficiency globally by most crops (Balasubramanian et al., 2004; Ladha et al., 2005)
- typical on-farm RE_N (Dobermann and Cassman, 2002)
  - only 30% in rice and 37% in maize,
  - with good management RE_N could be 50 to 80%
- in cereal crop research
  - total RE_N from a one-time application of N averages 50 to 60%, and 40 to 50% under most on-farm conditions (Dobermann, 2007)

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"**



EPA SAB Integrated N Committee report on reactive N (May 28, 2010 DRAFT): "…suggests crop N-uptake efficiencies be increased by up to 25% over current practices through a combination of knowledge-based practices and advances in fertilizer technology (such as controlled release and inhibition of nitrification)."

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EPA Lays Out Five-Year Plan on Agency Priorities – Oct. 7, 2010

- **Five strategic goals to advance EPA's environmental and human-health mission:**
  - Taking action on climate change and improving air quality
  - Protecting America's waters
  - Cleaning up communities and advancing sustainable development
  - Ensuring the safety of chemicals and preventing pollution
  - Enforcing environmental laws

Increased N Loss to Water Resources with Increased N Consumption ?

- Global fertilizer N consumption
  - 31.8, 81.2, & 90.9 MMT in 1970,200 & 2005 (**148% increase**,1970 to 2005).
- Global delivery from rivers to coastal waters
  - DIN increased from 14 million metric tons (MMT) in 1970 to 18.9 MMT in 2000 (**35% increase**)
  - TN increased from 36.7 MMT in 1970 to 43.2 MMT in 2000 (**18% increase**)

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National Scope of U.S. Nutrient Problems in Surface Water Resources

- **14,000 Nutrient-related Impairment Listings in 49 States**
  - 2.5 Million Acres of Lakes and Reservoirs
  - 80,000 Miles of Rivers and Streams
  - And This is an Underestimate . . .
- **Over 47% of Streams Have Medium to High Levels of Phosphorus and Over 53% Have Medium to High Levels of Nitrogen**
- **168 Hypoxic Zones in U.S. Waters**
- **78% of Assessed Continental U.S. Coastal Area Exhibits Eutrophication Symptoms**

Source: Ephraim King, EPA OST
18th Hypoxia Task Force Meeting, Sep. 2009, Des Moines, IA

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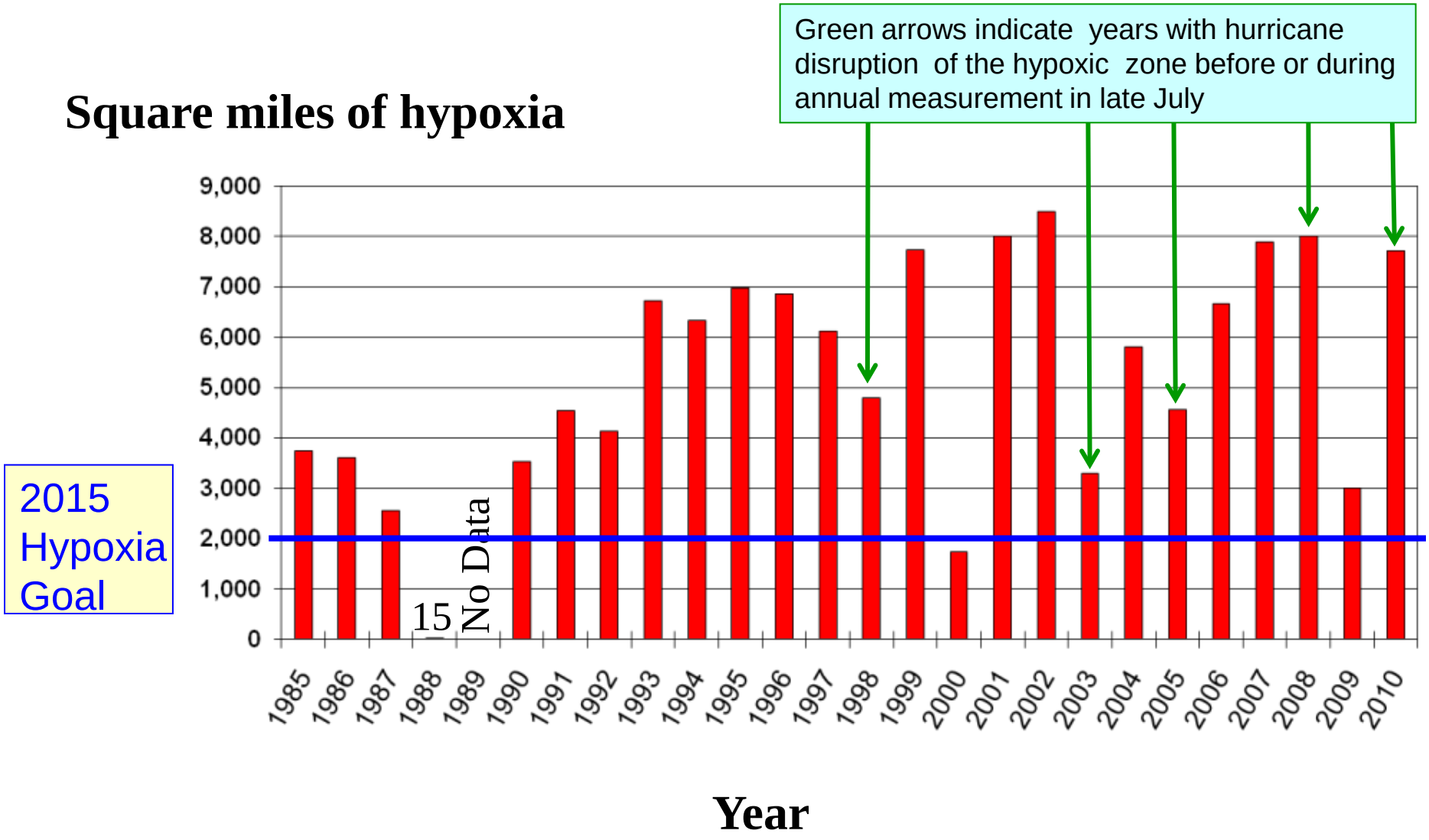
Gulf of Mexico Hypoxia Area



Hypoxia data from N. Rabalais, LUMCON

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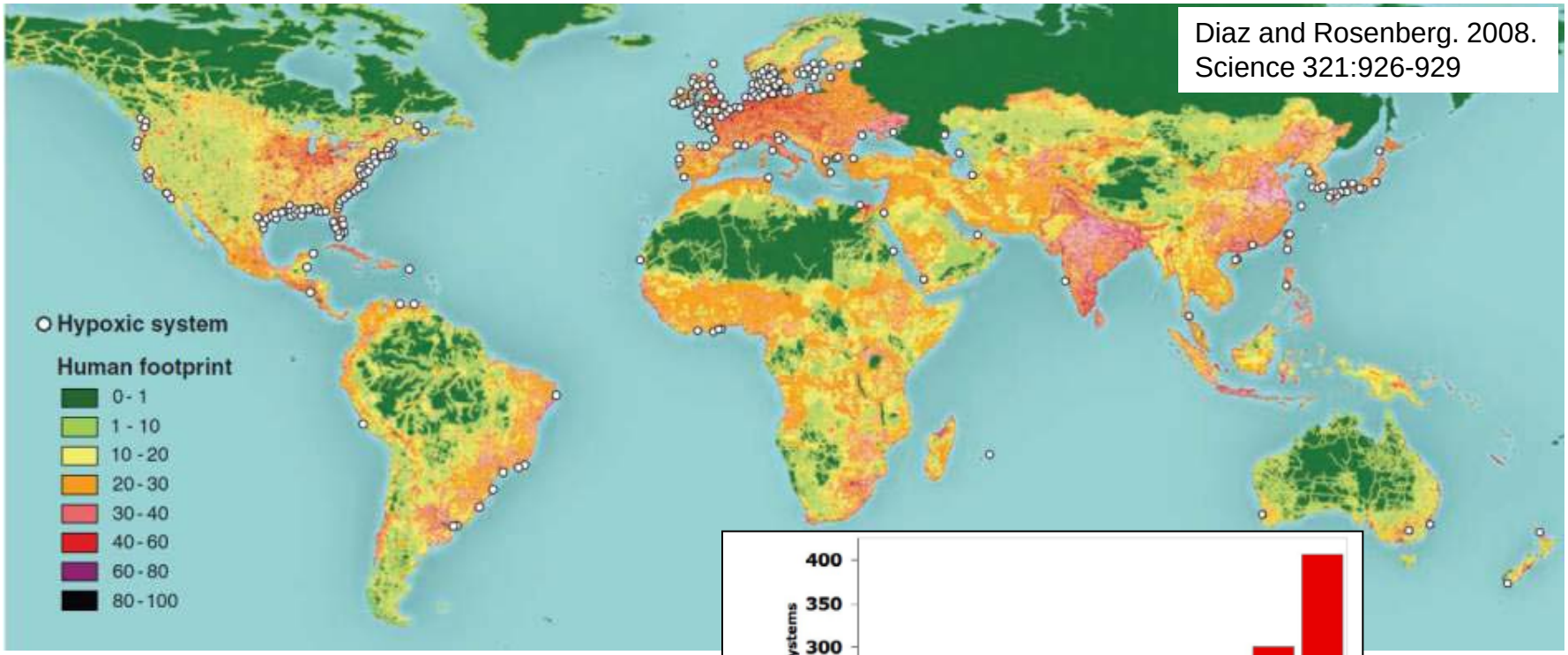
Hypoxic Zones Are Increasing Globally

Diaz and Rosenberg. 2008. Science 321:926-929



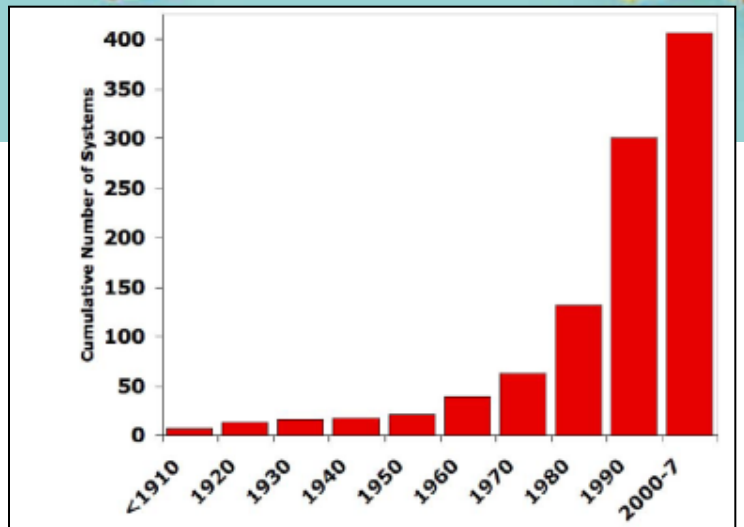
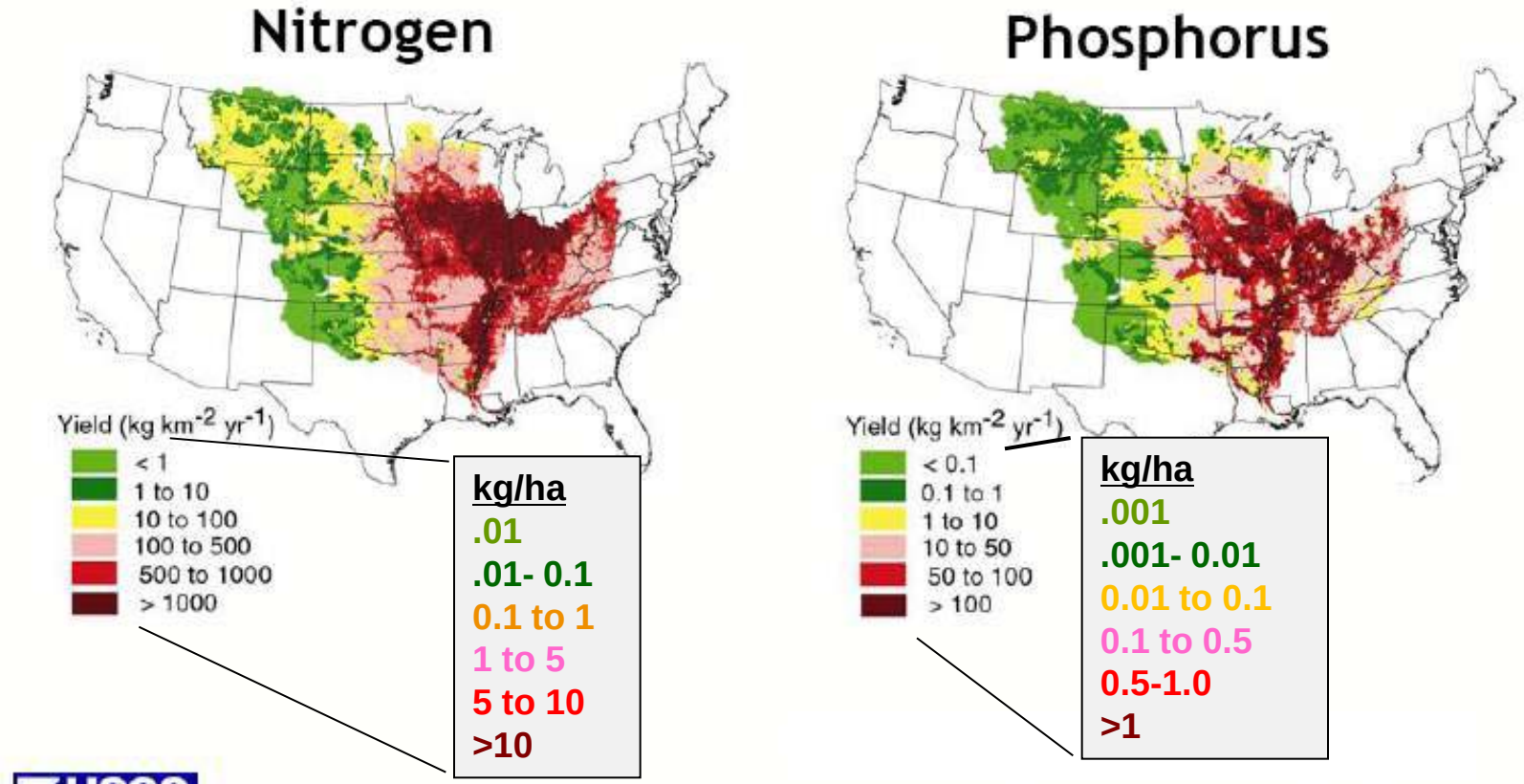


Figure S1. Cumulative increase in dead zones through time reported in the scientific literature. Systems are grouped by decade of first documented account (Table S1). The number of dead zones started to approximately double every ten years starting in the 1960s.

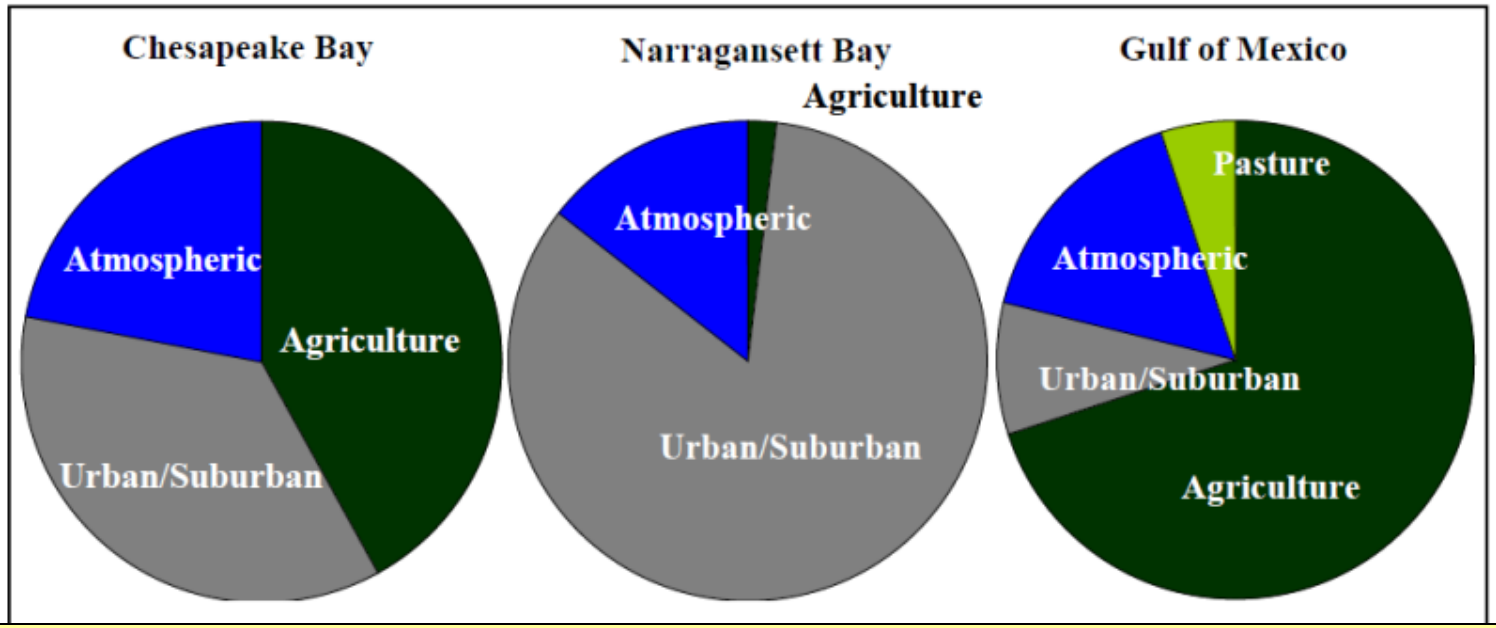
USGS Estimates of Loss and Delivery of N and P to the Gulf of Mexico

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

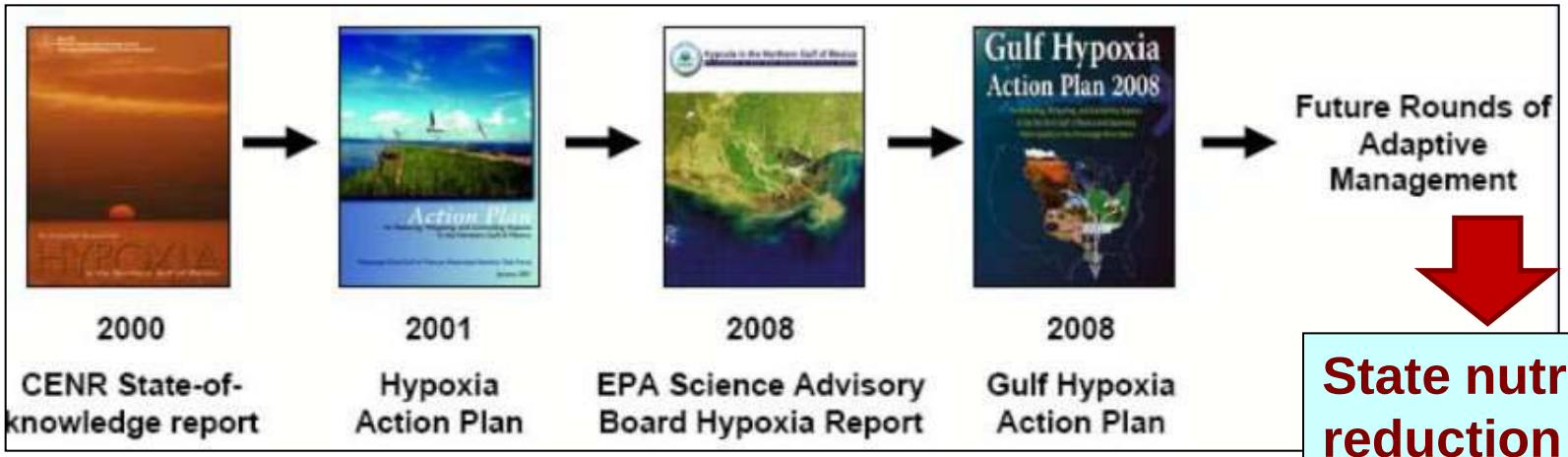


Alexander et al. *Environ. Sci. Technol. 2008, 42, 822–830*

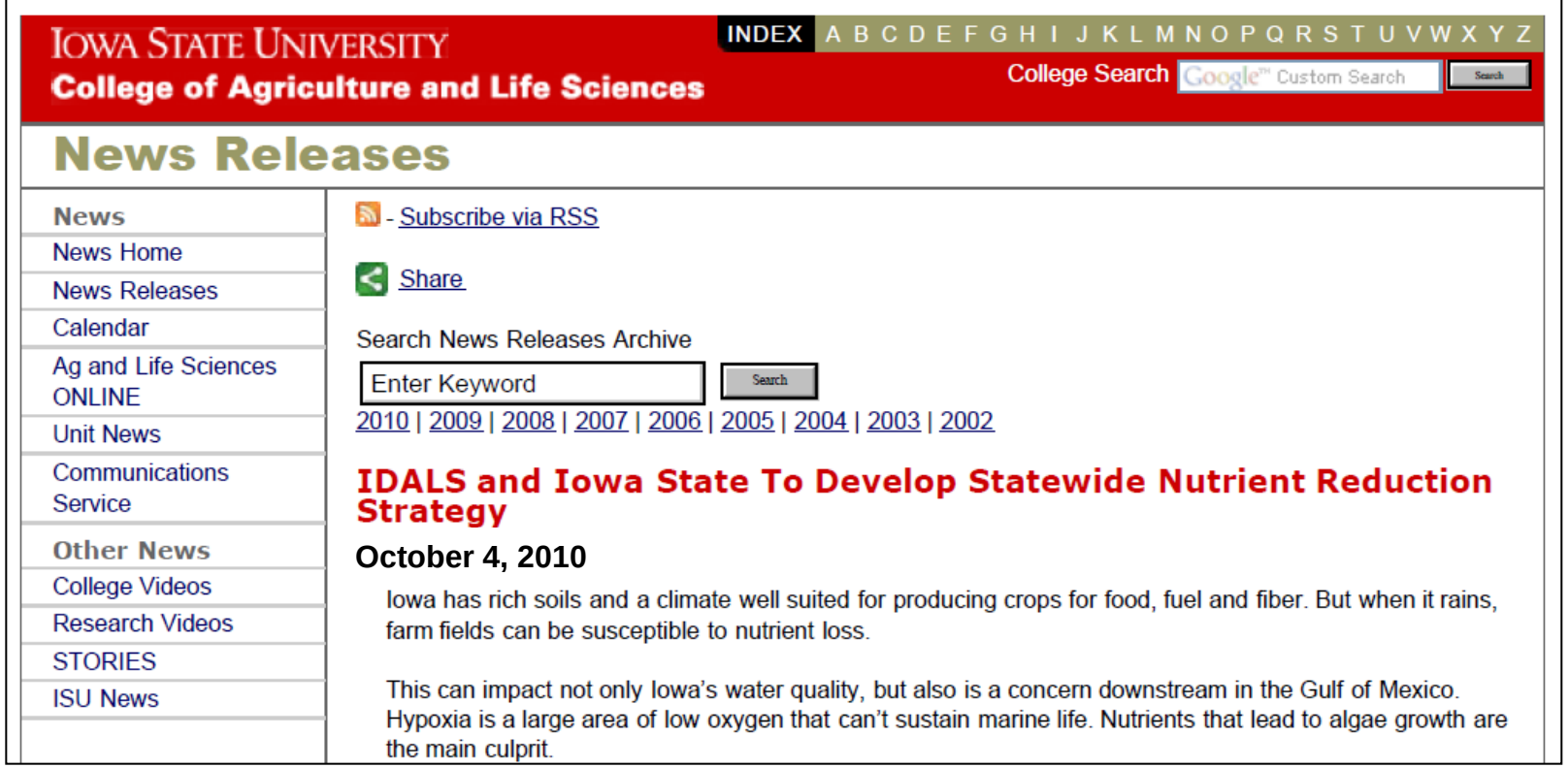
Sources of N Pollution to Coastal Waters



Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health, Sep. 2010



- **"voluntary compliance, if you will, is not working. The self-regulated approach isn't working;"**
- **"one option is to look at applications and how much we allow people to apply and when we allow them to apply it."**
- **"I am in agreement with this newspaper in terms of what we've done in the past isn't working;"**
- **"We all have to acknowledge the fact that the problem is getting worse not better."**



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College of Agriculture and Life Sciences

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IDALS and Iowa State To Develop Statewide Nutrient Reduction Strategy

October 4, 2010

Iowa has rich soils and a climate well suited for producing crops for food, fuel and fiber. But when it rains, farm fields can be susceptible to nutrient loss.

This can impact not only Iowa's water quality, but also is a concern downstream in the Gulf of Mexico. Hypoxia is a large area of low oxygen that can't sustain marine life. Nutrients that lead to algae growth are the main culprit.

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Chet Culver: Limit use of fertilizer by farmers

By PERRY BEEMAN • pbeeman@dmreg.com • October 12, 2010

Iowa should consider limiting how much commercial fertilizer farmers apply to crop fields, Gov. Chet Culver said Monday.

The DNR has been ordered by the U.S. EPA to come up with standards for nitrogen and phosphorus in waterways. (*Wayne Gieselman, Environmental Services Division Chief, Iowa DNR*). "…. commercial-fertilizer management plans would be a good idea."

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Does Watershed N Balance Relate to N Losses to Surface Waters ?

- Net N inputs
  - not a good predictor of riverine nitrate-N yields, nor were other N balances.
- Modeling to predict the expected nitrate-N yield from each county in the Mississippi River basin
  - greatest nitrate-N yields corresponded to the highly productive, tile-drained cornbelt from southwest MN, across IA,IL,IN, and OH

David, Drinkwater & McIsaac.2010.
Sources of Nitrate Yields in the Mississippi River Basin
J. Environ. Qual. 39:1657–1667
1997-2006 data

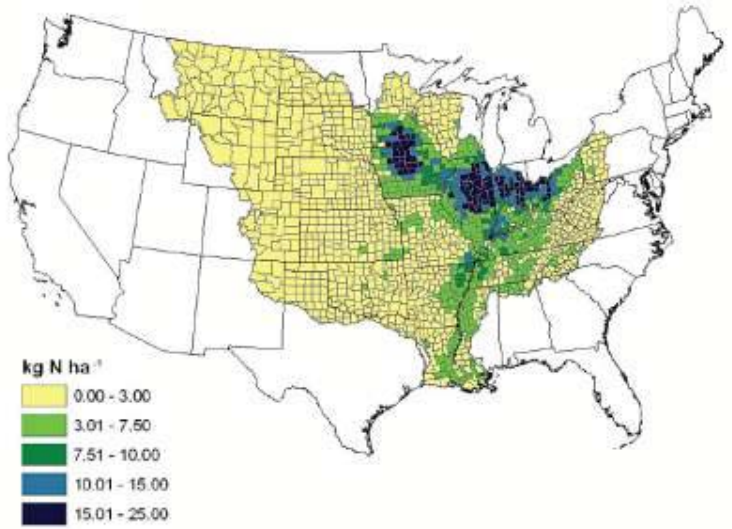
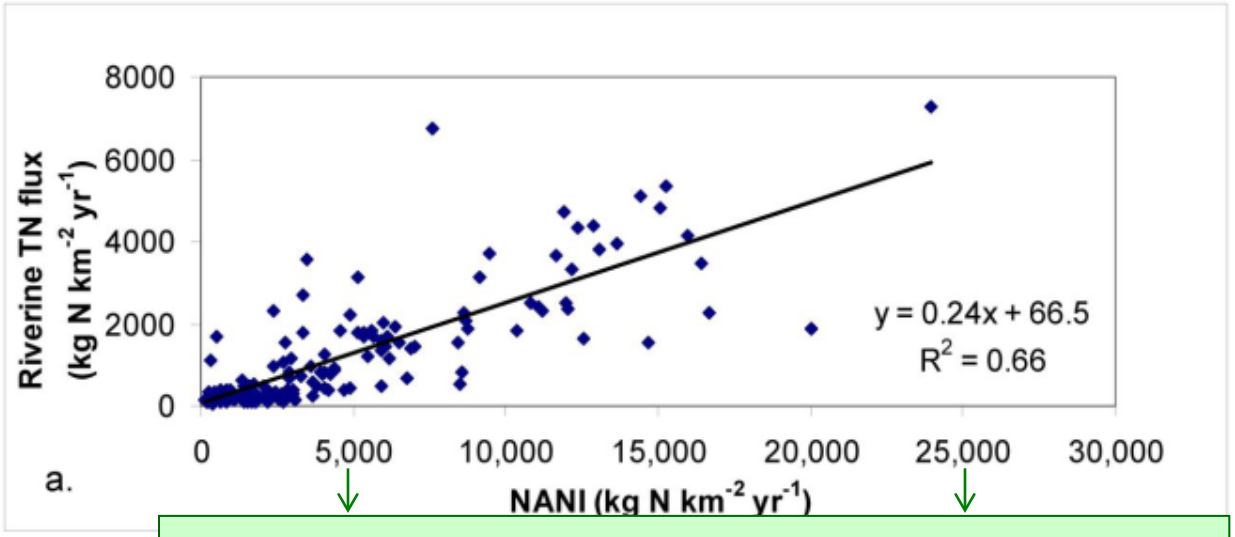


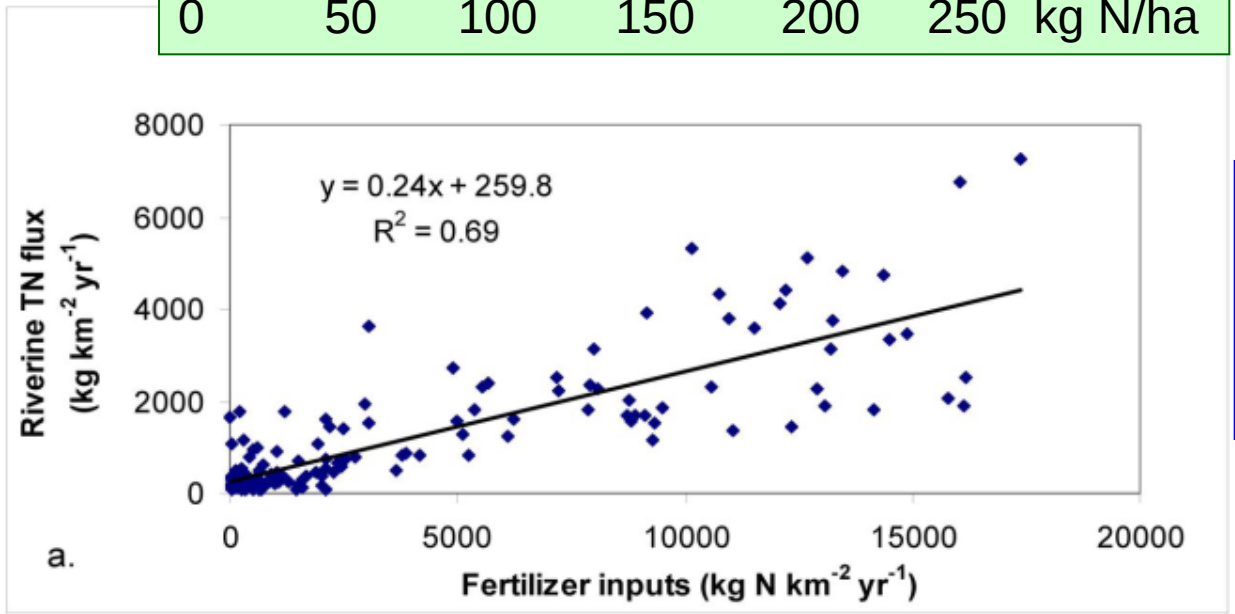
Fig. 8. Predicted average riverine nitrate N yield, January to June, for all counties in the Mississippi River basin for the period 1997 to 2006.

Net Anthropic N Input vs. River TN Flux

154 Rivers U.S. & Europe – R. Howarth, unpublished, 2010

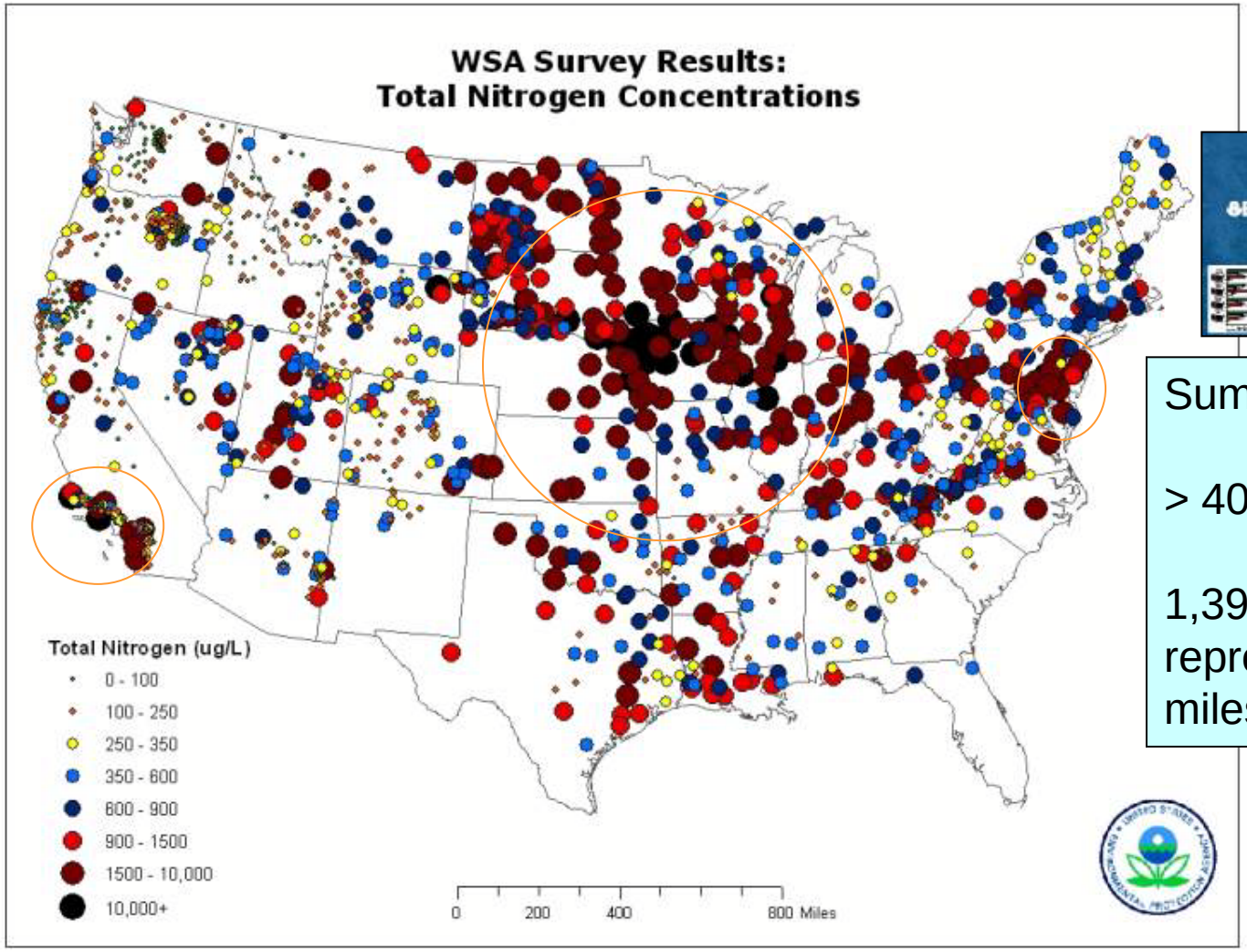


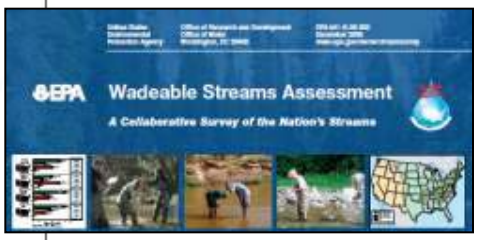
0 50 100 150 200 250 kg N/ha



Fertilizer N inputs explained a large portion of the variability in riverine TN flux

Wadeable Stream Assessment in the U.S.





Summers, 2000-2004

> 40 trained crews

1,392 stream sites, representing 671,051 miles

Source: EPA- OST, Ephraim King, Iowa Water Conf. 2009

FL Alarm Over Numeric Nutrient Criteria

FLORIDA GROWER

Home > News > Florida Grower

National Ag Groups Sound Alarm Over EPA's Florida Water Mandates

September 20, 2010

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Wheat farmers in Kansas, dairy farmers in Wisconsin, and corn farmers in Iowa, along with millions of employers and employees who rely on a strong agricultural industry for prosperity, all have reason to be deeply concerned by the EPA's implementation of draconian water mandates in Florida. That's the word from national agriculture leaders. In a letter sent to EPA administrator Lisa Jackson, 36 leading national agriculture groups expressed concern about the new EPA mandates for numeric nutrient criteria (NNC) in Florida's waters.

If enacted, these mandates would establish a template of how NNC could be structured nationwide and would result in economic harm for the regulated community, for the economy as a whole and for the public sector that must develop and administer the NNC.

- EPA urged to delay further NNC policymaking until it has engaged all relevant stakeholders in a thorough and transparent review of the strategic direction of NNC policies
- Florida Dept. of Agric. estimated
  - total initial cost for producers to comply: $855 million to $3.069 billion;
  - subsequent compliance cost $902 million to $1.605 billion per year
  - size of the Florida economy will be reduced by $1.148 billion a year and that 14,545 full and part-time jobs would be lost

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Turf Fertilizer Restrictions Increase

CourierPostOnline.com
FROM SOUTH JERSEY TO YOU

Fertilizer debate puts N.J. environmentalists against lawn care groups

IN TRENTON: Plan to limit runoff pits lawn care industry against environmental groups.

By KIRK MOORE • GANNETT NJ• October 7, 2010

The bill, if passed this fall, would prohibit N.J. lawn-care businesses from applying lawn fertilizer from Nov. 15 to March 1. Industry representatives say fall is a critical — and profitable — season as contractors nurse summer damaged turf and prepare new growth.

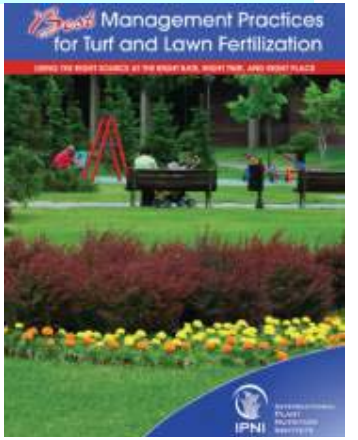
- **Suffolk County, VA** - law prohibits lawn fertilizer applications from Nov.1 to April 1 to prevent N runoff from frozen ground.
  - Violators, whether landscapers or homeowners, risk fines of $1,000.
- **N.Y. passes ban**
  - Law will ban use of P in lawn fertilizers starting in 2012, except where soil tests show
  - Law also bans fertilizer application Dec. 1 and April 1,

FDACS – Fact Sheet
Florida Department of Agriculture and Consumer Services
July 1, 2010

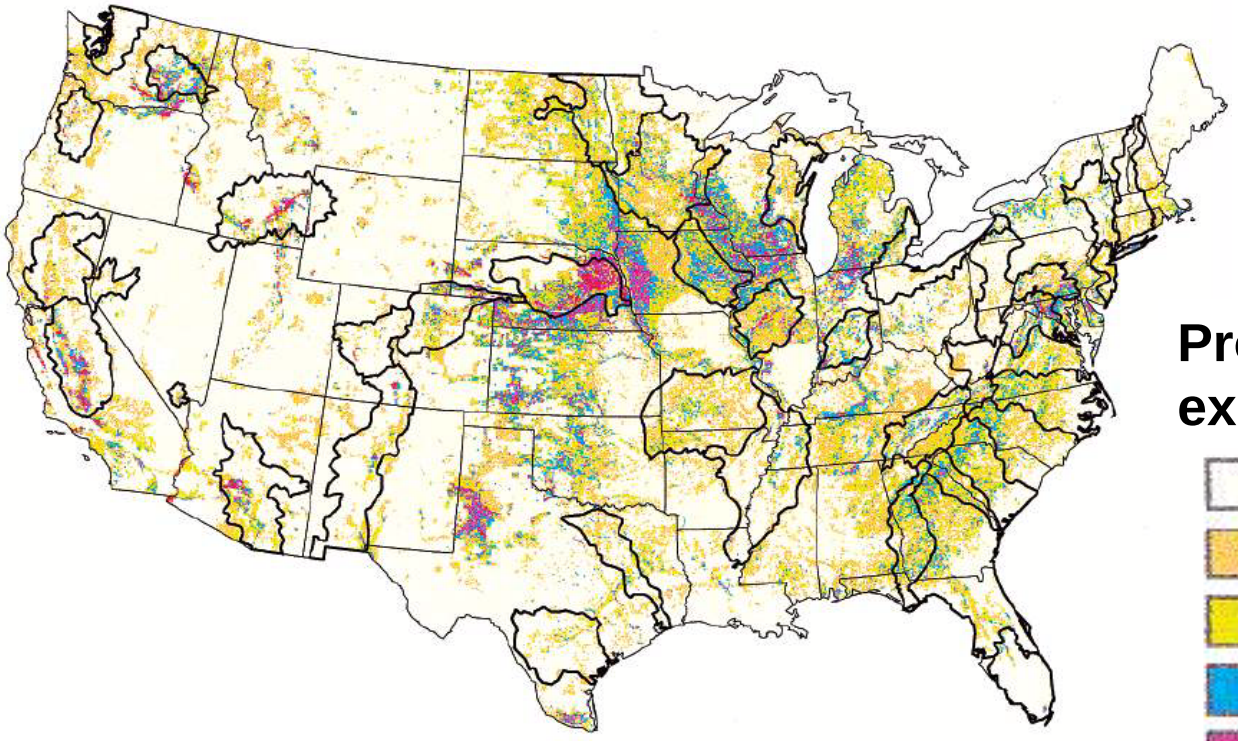
What You Should Know About Florida's Urban Turf Fertilizer Rule

•requires Specialty Fertilizer Products labeled for turf or lawns to limit the amount of N and P_2O_5

•N: A maximum of 0.7 lbs of readily available N per 1000 sq. ft. at any one time based on the soluble fraction of N formulated in the fertilizer. A maximum of 1 lb total (N) per 1000 sq. ft. to be applied at any one time, not exceeding the annual N recommendations in the Fertilizer Guidelines for Established Turf Grass Lawns in Three Regions of Florida.



Probability of Nitrate Contamination of Recently Recharged Shallow Ground Waters in the Conterminous U.S.



Probability that nitrate-N exceeds 4 mg/L

- 0 – .17
- >.17 – .33
- >.33 – .50
- >.50 – .67
- >.67 – .83
- >.83 – 1

Nolan et al. Environ. Sci. & Technol. 2002. 36(10):2138-2145 (USGS)

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

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

inadequate data in the heartland

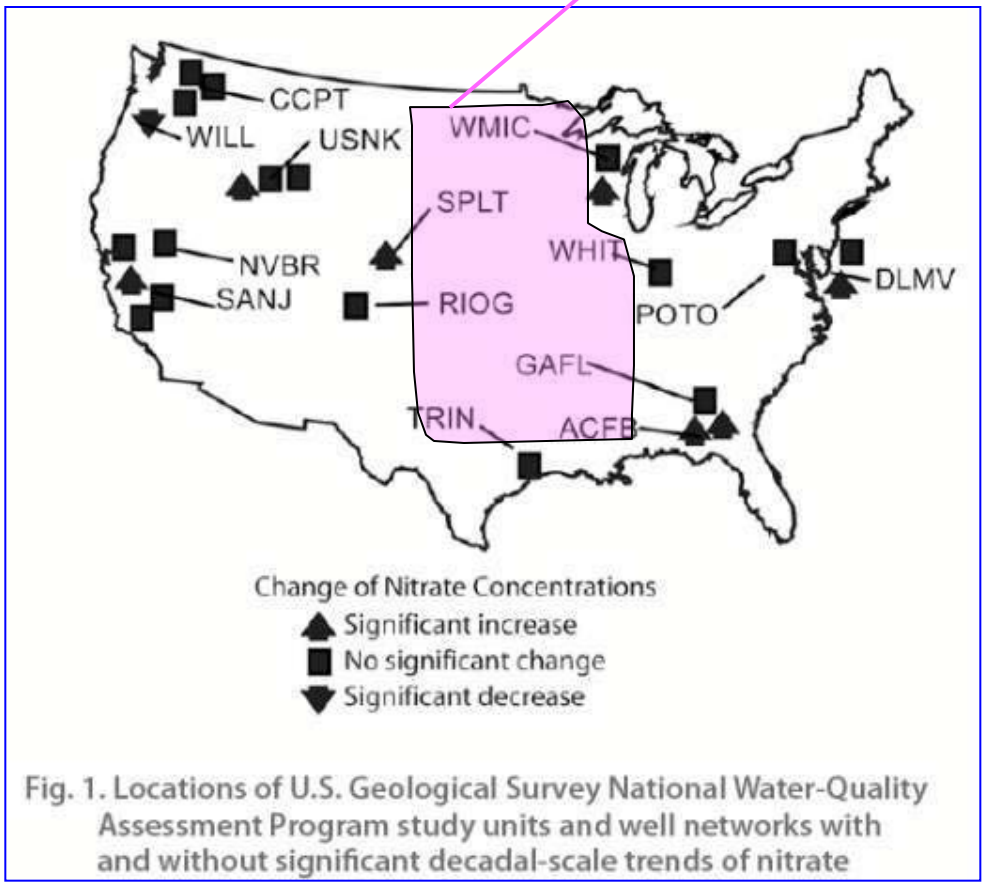
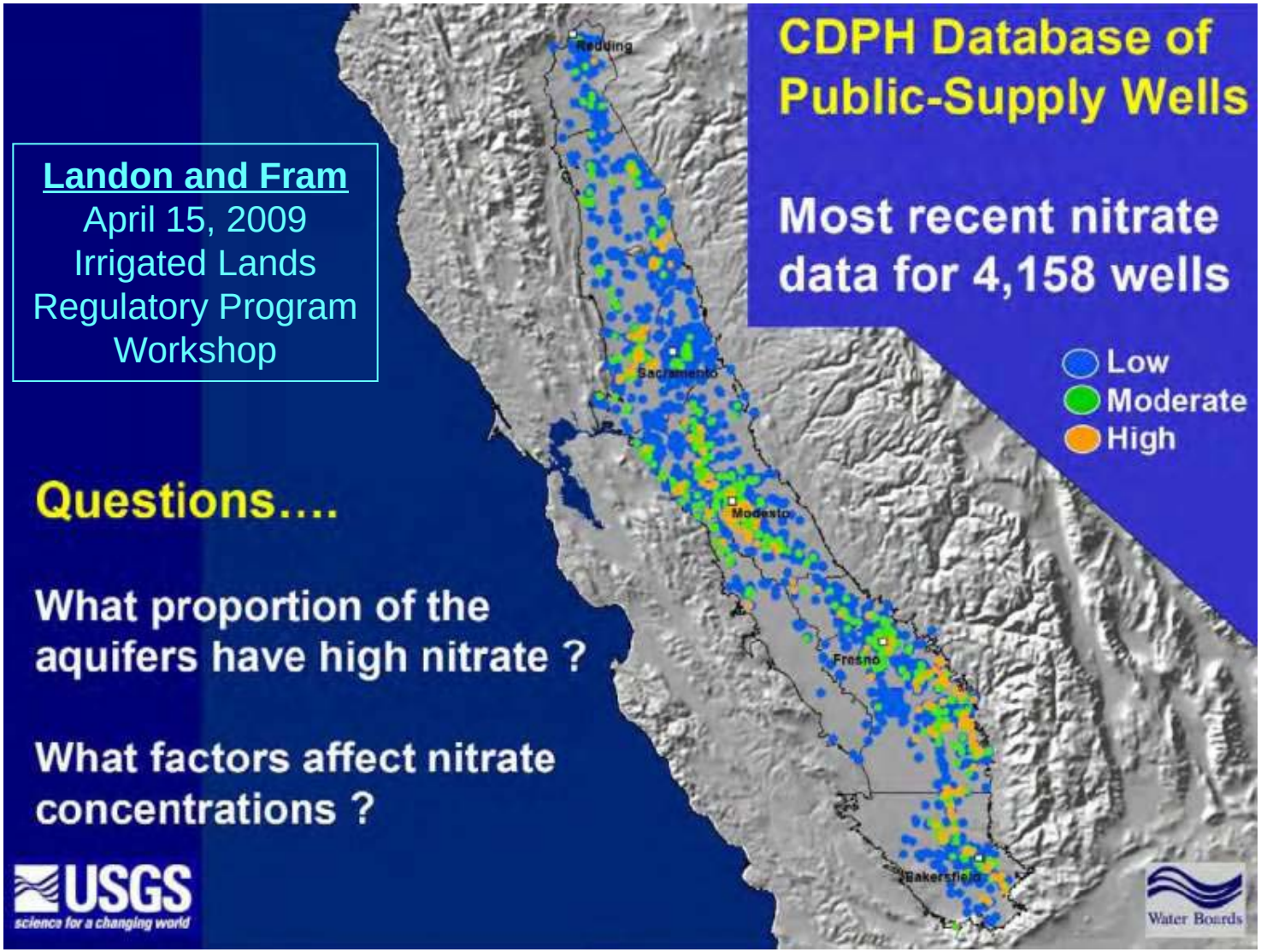


Fig. 1. Locations of U.S. Geological Survey National Water-Quality Assessment Program study units and well networks with and without significant decadal-scale trends of nitrate

- 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."

Groundwater Nitrate – CA Central Valley



Landon and Fram
April 15, 2009
Irrigated Lands Regulatory Program Workshop

Relative Conc.
Measured/MCL
<0.5
0.5 to 1
>1

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Rising Costs of Wastewater N Treatment

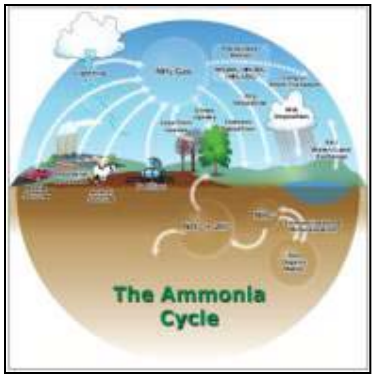
Societal Pressures on Other Economic Sectors ?

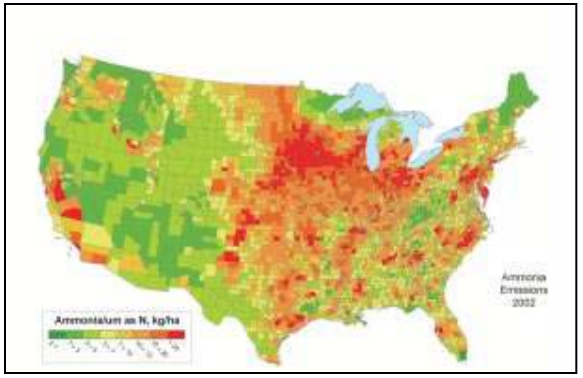
- Blue Plains WWTP serves metro Washington, D.C. area
  - *Metro DC has weekly work population =1,000,000*
  - 350 million gallons treated wastewater to Potomac River/day
  - Potomac flows into Chesapeake Bay, largest estuary in U.S.
  - single largest point source of N for the Bay, at 20 tons N/day
- Methanol denitrification
  - helped reduce discharge to 10 tons of N/day
  - cost $100 million less than closest alternative method
- **Result**: 30% drop in N levels in Chesapeake Bay, from just one treatment plant
- **Cost**: $0.50 to $0.60/lb of N removed, while average N removal costs in Chesapeake Basin are $4.00/lb of N

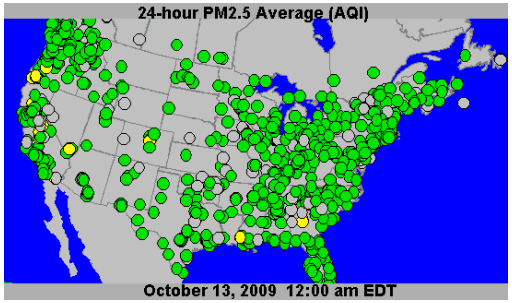
http://www.szennyviztudas.bme.hu/files/metanol%20denitrification%20-%20basics.pdf

Air Quality Challenges

- **N_2O emissions**
  - direct
  - indirect
- **Ammonia emissions**
  - $PM_{2.5}$
- **NOx emissions**
  - Smog
  - React with NH_3 and can result in acid rain

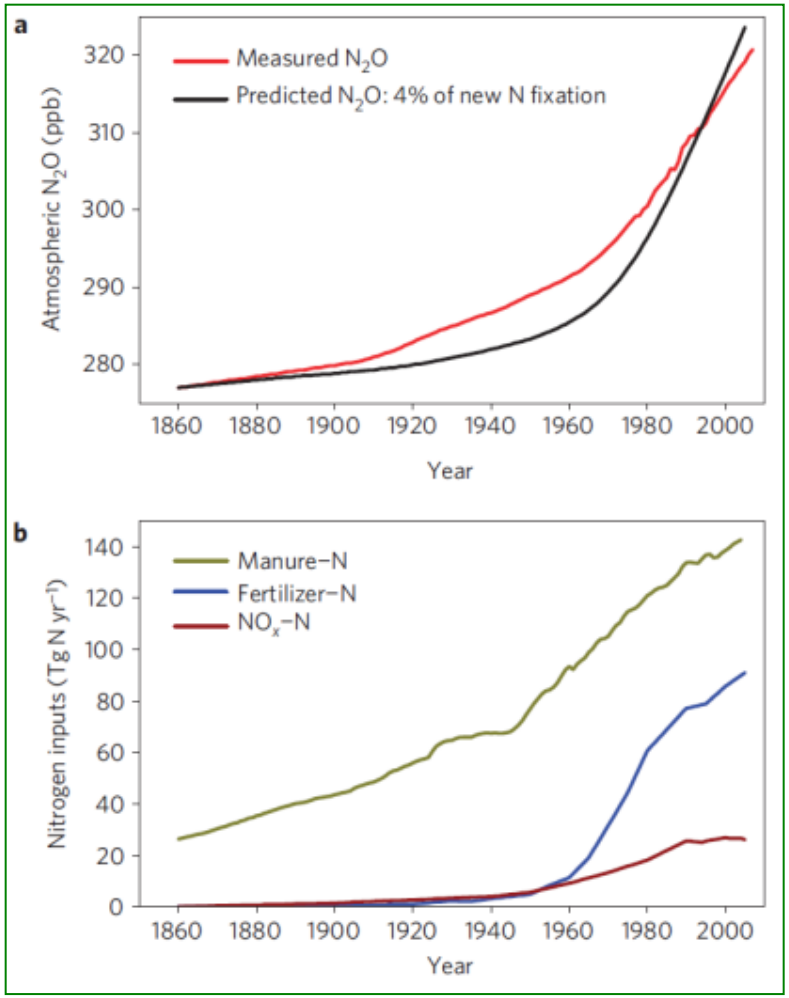






Increased N Loss to Atmosphere with Increased N Consumption ?

- Global fertilizer N consumption
  - 31.8, 81.2, & 90.9 MMT in 1970, 2000 & 2005 (**148% increase**,1970 to 2005).
- Global atmospheric N_2O concentration increased from 270 parts per billion (ppb) in pre-industrial times to 319 ppb (**18% increase**) by 2005



Davidson.2009. Nature Geoscience 2: 659-662

EPA - Endangerment and Cause or Contribute Findings for GHGs under Section 202(a) of the Clean Air Act

- Dec. 7, 2009, the EPA Administrator signed two findings:
  - **Endangerment Finding:** current and projected concentrations of the six key well-mixed GHGs — carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) — in the atmosphere threaten the public health and welfare of current and future generations.
  - **Cause or Contribute Finding:** combined emissions of these well-mixed GHGs from new motor vehicles and new motor vehicle engines contribute to GHG pollution which threatens public health and welfare.

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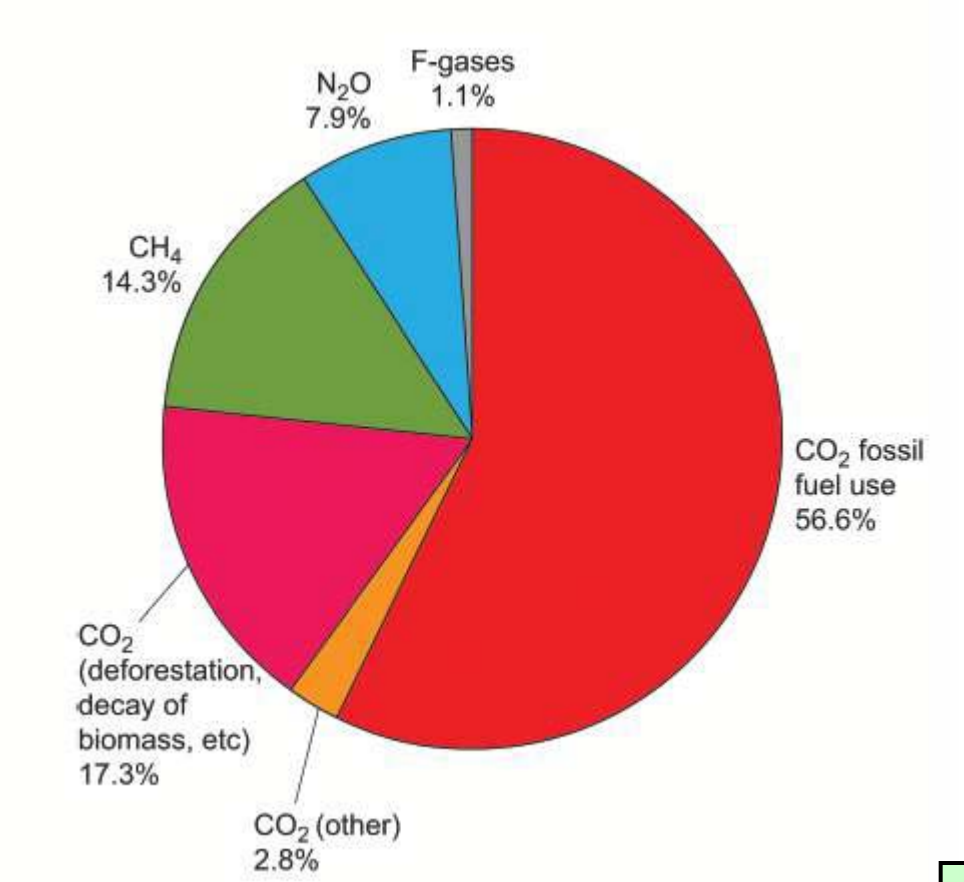
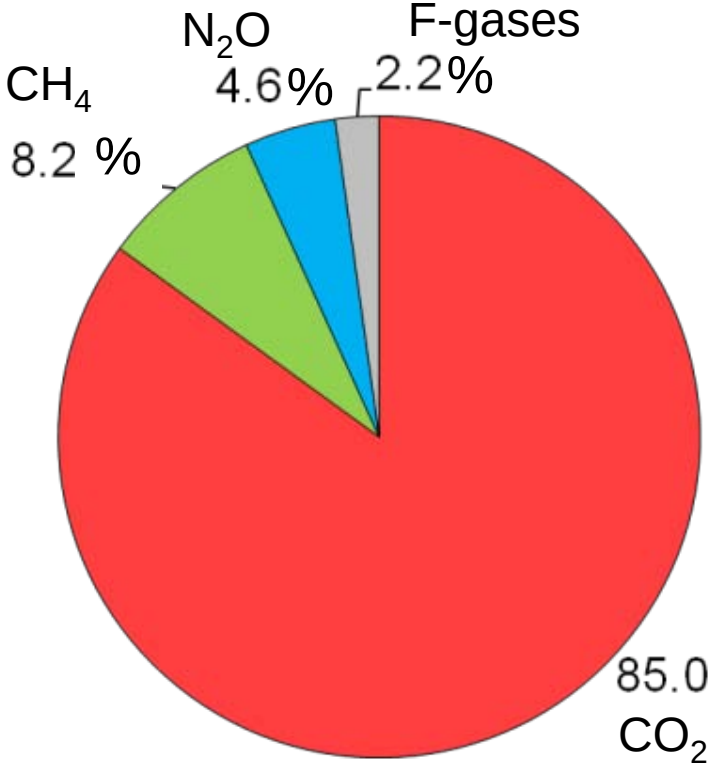
Global GHG Emissions

U.S. GHG Emissions

CO_2 equivalents





Verifying Greenhouse Gas Emissions: Methods to Support International Climate Agreements

Committee on Methods for Estimating Greenhouse Gas Emissions; National Research Council

ISBN: 978-0-309-15211-2, 124 pages, 8 1/2 x 11, paperback (2010)

Source: Figure 1.1b from IPCC (2007b),Cambridge Univ. Press

6% of all U.S. GHG emissions attributed to ag

3.6% ag soil management N_2O as portion of total U.S. GHG emissions in 2008, *and has not changed appreciably since 1990*

Source: U.S. EPA Inventory of GHG Emissions and Sinks,1990 – 2008 (2010)

Ag GHG Mitigation Protocol Scoping

Ranking Exercise: Outcomes

CLIMATE ACTION RESERVE

Category	Ranking
Cropland management	1
Nutrient management	2
Restoration of degraded lands	3(t)
Establishing aboveground woody biomass	3(t)
Rice management	5
Cropland/Grassland land use change – mineral soils	6
Cropland/Grassland land use change – histosol soils	7(t)
Livestock feed management	7(t)
Grazing land management	9
Productivity improvements	10

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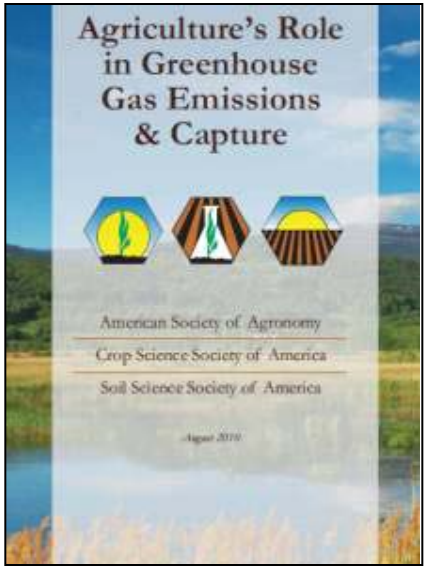
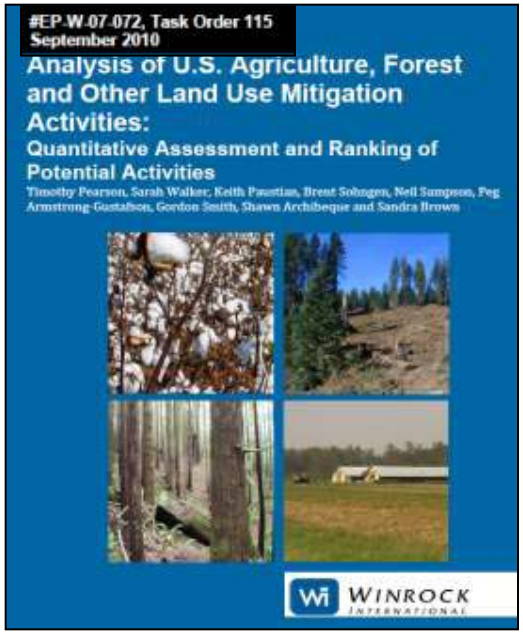
GHG Emissions – Ag Mitigation Protocol

- **N**itrous Oxide **E**mission **R**eduction **P**rotocol
  - Under development – Alberta, Canada (Oct. 2008)
- **C**limate **A**ction **R**eserve Scoping Meetings
  - Oct. 6 – Chicago, IL
  - Oct. 9 – Modesto, CA
  - Oct. 27 – Washington, DC





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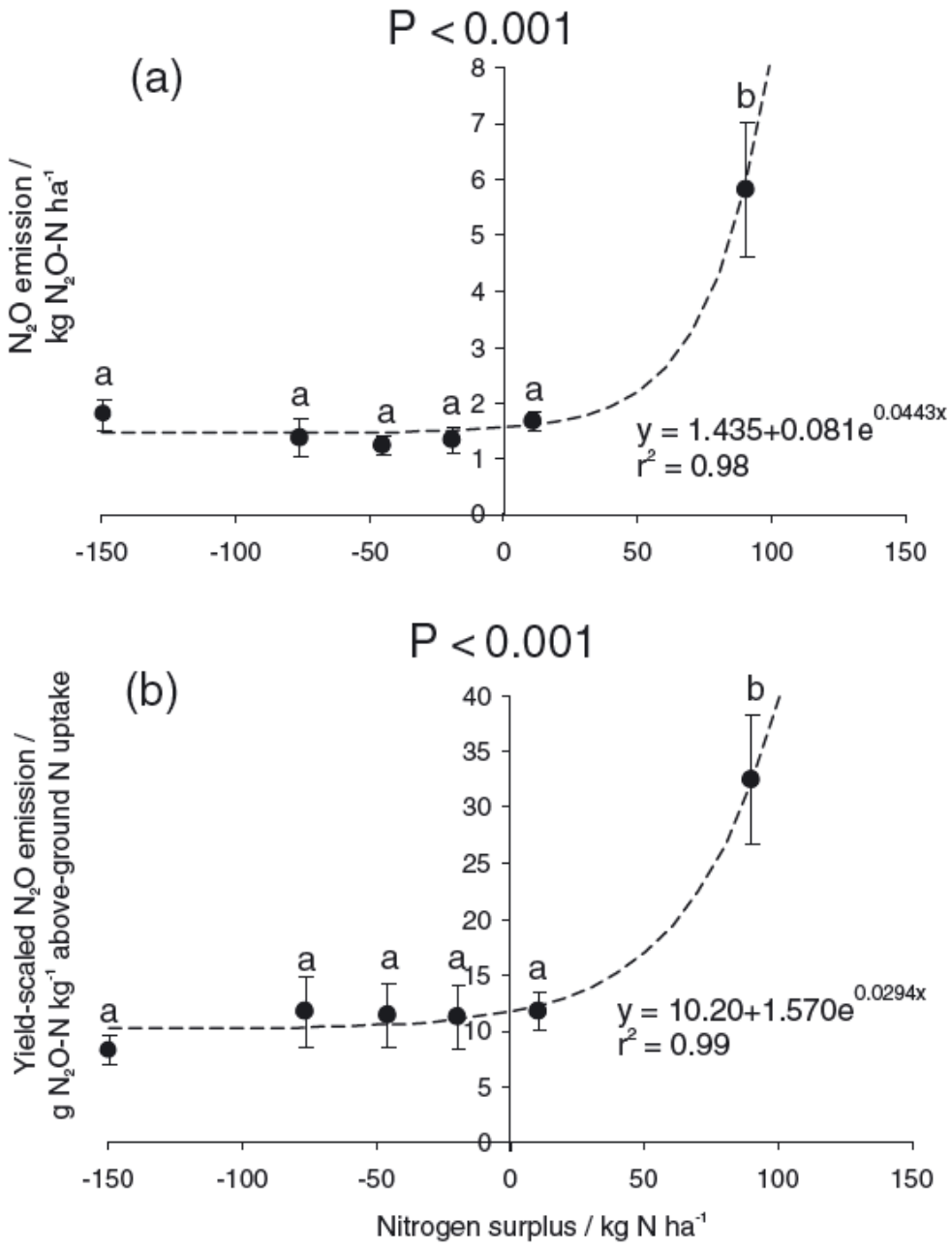


The Key is to Limit Potential "Surplus N"

" … agricultural management practices to reduce N_2O emissions should focus on optimizing fertilizer-N use efficiency under median rates of N input, rather than on minimizing N application rates."

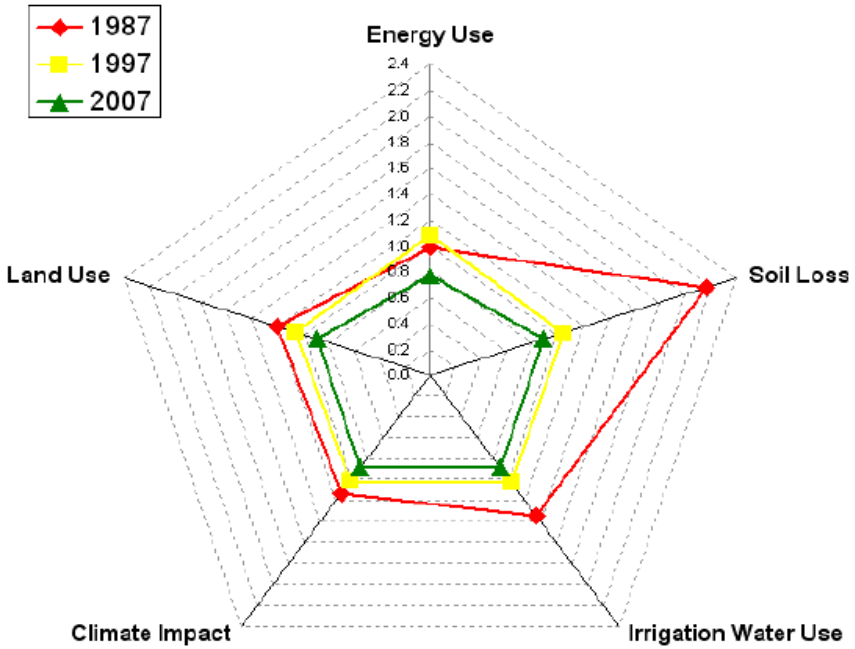
Van Groenigen et al. 2010. Europ. J. Soil Sci. doi: 10.1111/j.1365-2389.2009.01217.x

The Keystone Alliance for Sustainable Agriculture

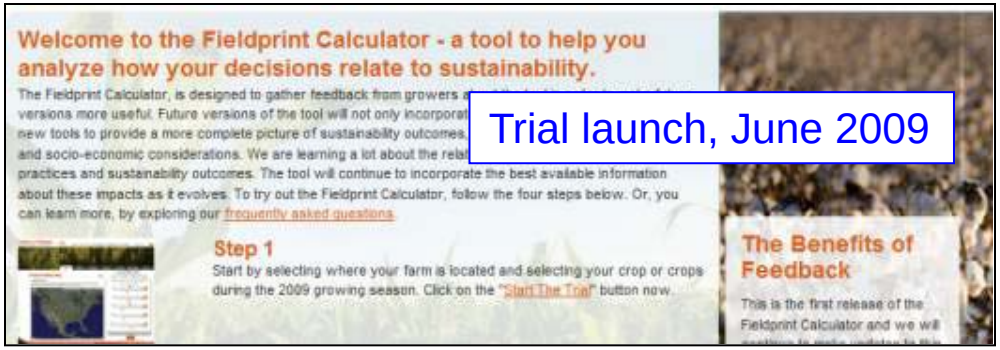
Industry, Conservation, & Nonprofit Groups Collaborating

Initial Environmental Indicator Report Jan. 2009
Corn, cotton, soybean, wheat

Example - Corn Efficiency Indicators (per unit of output), Index 2000 = 1



Year	2000	Unit
Energy Use	0.057	Million Btu/bushel
Soil Loss	28.7	Pounds soil/bushel
Irrigation Water Use	5.6	Thousand gallons/Incremental bushel due to irrigation
Net Carbon Emissions	3.0	Pounds Carbon/bushel
Land	0.013	Acres/bushel



Demand for More Sustainable, Less Chemically Dependent Agriculture

Wal-Mart sets out fresher-foods goals

Retailer aims

STEVE PAINTER
ARKANSAS DEMOCRAT-GAZE

Wal-Mart Stores Inc
nounced several new g
Thursday aimed at get
more fresh foods on its s
shelves while at the s
time reducing the envi
mental impact of grov
those products.

The announcement came as Wal-Mart executives and employees met with suppliers and representatives of environmental groups at the company's headquarters in Bentonville. About 700

of Wal-Mart's business. Yet only four of our 39 public sustainability goals address food," Mike Duke, president and chief executive officer, said in prepared remarks for the gathering.

medium farms.

■ Train a million farmers and farm workers in sustainable farming practices and crop selection.

■ Boost the income of small farmers supplying the retailer

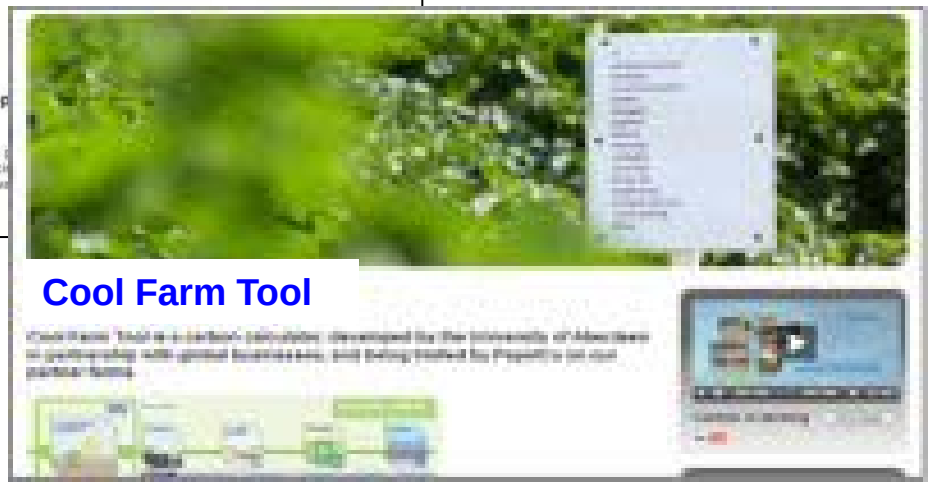
manager in Bentonville for the corporate partnerships program of the Environmental Defense Fund, said the initiative revealed Thursday began early in the summer of

See **WAL-MART**, Page 6D

"…..boost the incomes of small and medium-sized farmers….while reducing the use of pesticides and fertilizer"

Arkansas Democrat- Gazette, October 15, 2010

Food and Beverage Companies Tracking Water and Carbon Footprints



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AGRICULTURAL SUSTAINABILITY INSTITUTE AT UCDAVIS

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- Agriculture, Resources and the Environment
- California Nitrogen Assessment
  - N Science
  - N Stakeholders
  - Research
  - Learn about Nitrogen
  - Project Information
  - Upcoming Events
  - Contact
- UC SAREP Conferences and Symposia
- Food Systems

THE CALIFORNIA NITROGEN ASSESSMENT



Nitrogen plays a critical role in the global food supply, but the tradeoffs of excess nitrogen application involve increased costs for farmers and consequences for the environment and human health. Despite increasing awareness of the importance of these tradeoffs, there is still a lack of cohesive knowledge that gives a big-picture view of California's nitrogen system. The California Nitrogen Assessment (CNA) is designed to fill this void.

Our approach: The CNA comprehensively examines the existing knowledge on nitrogen science, policy, and practice in California. Our scientists collect and synthesize a large body of data, using this data to analyze patterns and trends. Our methodology is modeled on integrated ecosystem assessments like the Intergovernmental Panel on Climate Change and the Millennium Ecosystem Assessment.

What is unique about the CNA: Unlike conventional research projects, the CNA will not generate new primary data. Instead, the CNA looks at existing knowledge to distinguish between what is well-known about agricultural nitrogen, and that which is more speculative. A large amount of information already exists on agricultural-related nitrogen in California which has never been looked at as a whole – and the CNA adds value by sorting, summarizing, synthesizing, analyzing, translating, and communicating this information.

Stakeholder involvement: A primary goal of the assessment is to develop information and products that are relevant to stakeholders' needs. Because of this, stakeholder participation is a vital part of the assessment, and we are conducting outreach to

Nitrogen Science Symposium

Date: Oct. 27, 2010
For: UC researchers and UCCE academics.
Information: Click here

Stakeholders

We want your input on nitrogen. Contact us!

What's New

Watch California farmers talk about how they manage nitrogen.

Bruce Rominger, tomato grower

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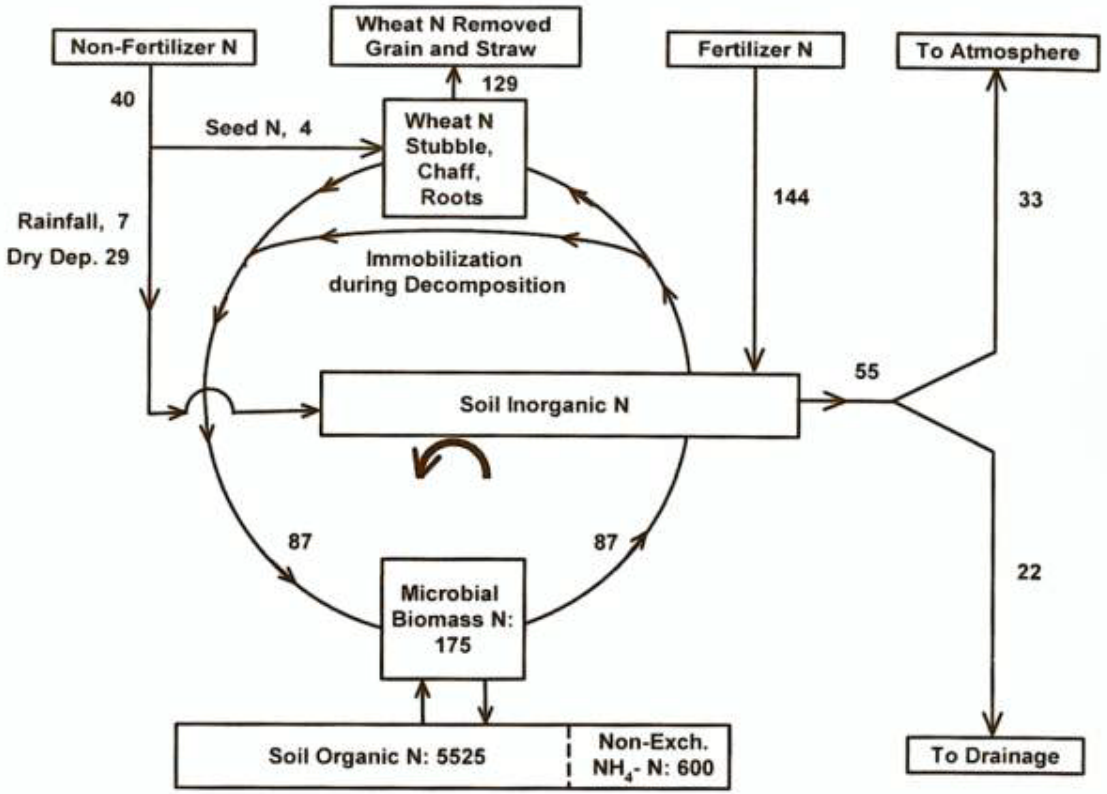
Society Increasingly Expects Accountability for N Use and Losses

Broadbalk Continuous Winter Wheat Experiment Plot 08



- **Do we know the magnitude of N losses via the different pathways in our major cropping systems in the U.S.?**
- **In the absence of this information, how can we effectively develop improved management, educate society, and inform environmental policy?**

Source: Meisinger, J.J., F.J. Calderon, and D. S. Jenkinson. 2008. Soil nitrogen budgets. Ch. 13, p. 505-562. *In* J.S. Schepers and W.R. Raun (ed.) Nitrogen in Agricultural Systems. Agronomy Monograph No. 49. ASA-CSSA-SSSA.

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We Can Improve Nitrogen Use Efficiency & Effectiveness

by implementing

nutrient BMPs …..

Right source @ Right rate, Right time & Right place

4R Nutrient Stewardship

Thank You

Better Crops, Better Environment … through Science

www.ipni.net