# Greenhouse gas emissions and Water quality from irrigated crop ecosystem


**M. Arlene Adviento-Borbe**

Research Agronomist, Lead Scientist USDA-ARS GRA PRRG-America Subgroup

Delta Water Management Research Unit, USDA-ARS Jonesboro, AR, USA, 72401

Email: arlene.advientoborbe@usda.gov

Phone: 1.870.253.3130



XIV International Conference of Rice for Latin America and the Caribbean

CONFERENCIA INTERNACIONAL DE ARROZ PARA AMÉRICA LATINA Y EL CARIBE

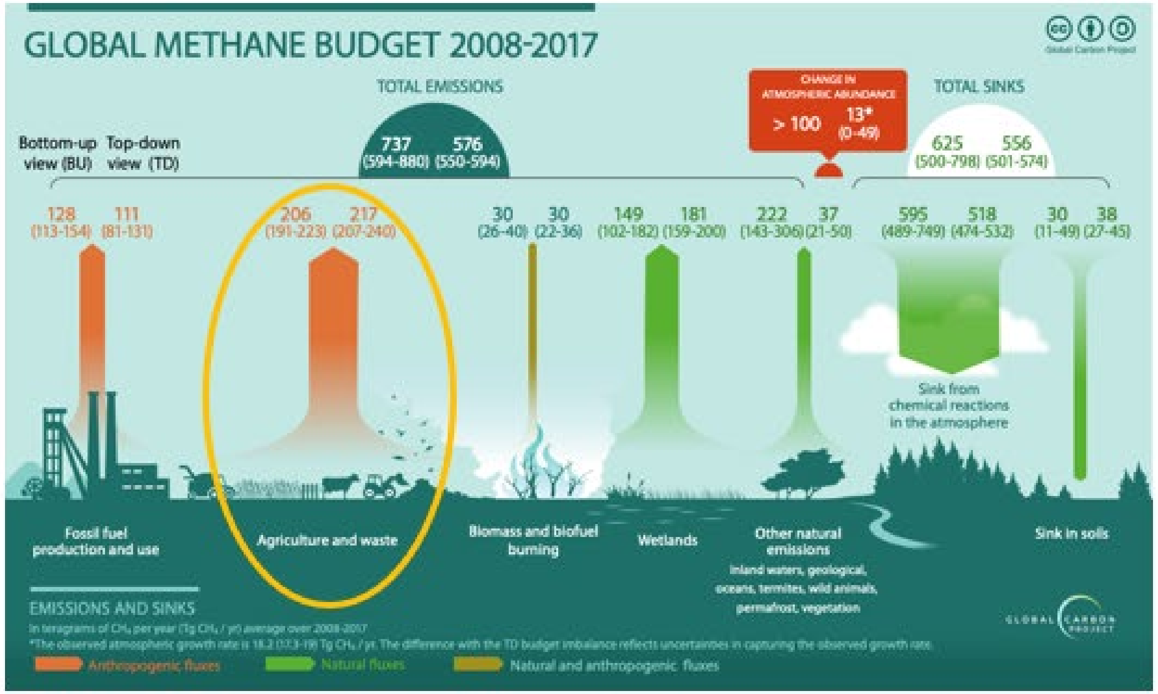
Innovación para alimentar al mundo

Panamá, 10 al 14 de junio de 2024

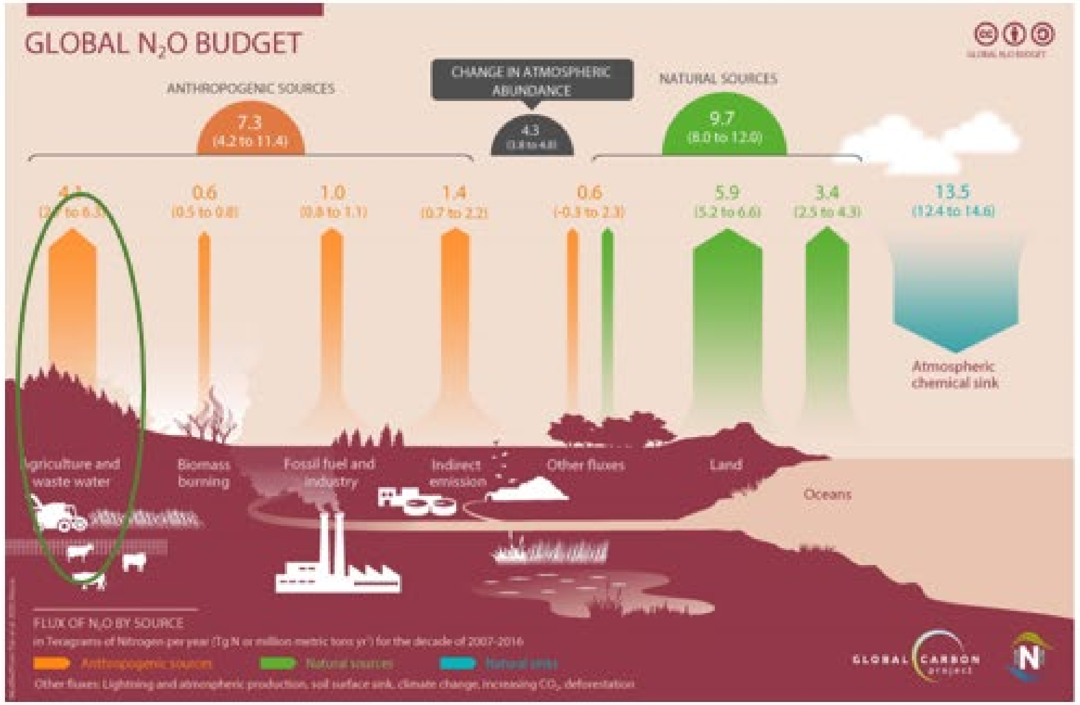

USDA ars United States Department of Agriculture Agricultural Research Service

DELTA WATER MANAGEMENT RESEARCH UNIT

# Global $CH_4$ and $N_2O$ budget




- **Agriculture and waste contributed 206 or 217 million ton $CH_4$**
- Rice cultivation contributed about 30 million ton $CH_4$ $yr^{-1}$; ca. 8% of total global anthropogenic emissions.

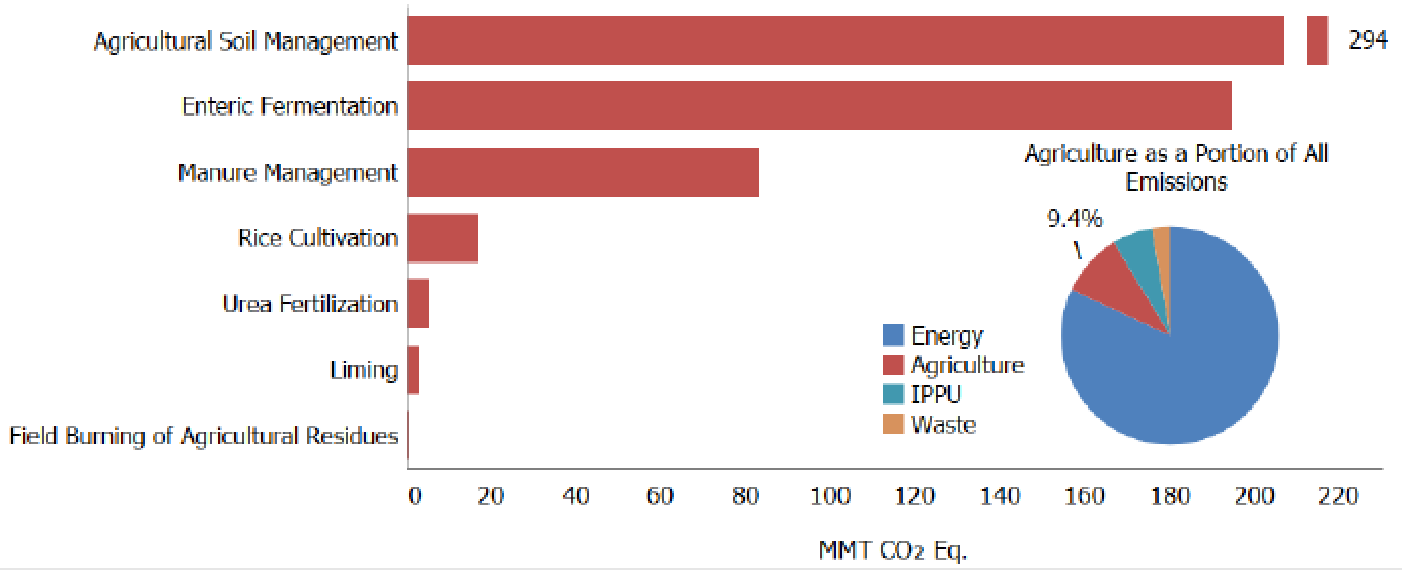



- $N_2O$ comes equally with natural (60%) and anthropogenic (40%) sources.
- Agriculture is the largest direct human source over half of total $N_2O$ emissions.
- 75% of total emissions come from synthetic fertilizers.

# Greenhouse gas emissions – U.S. emissions by source

In 2021, all US Agricultural GHG emissions represent 10% of US emissions (598 MMT $CO_2$ eq.)

- $CH_4$ emissions constitute 47% of total emissions
  - 70% from Enteric fermentation
  - ~6% from **rice cultivation** (estimates were based on surrogate data method)
- $N_2O$ emissions account for 7% of US GHG emissions
  - Agricultural soils account for 70% of US $N_2O$ emissions



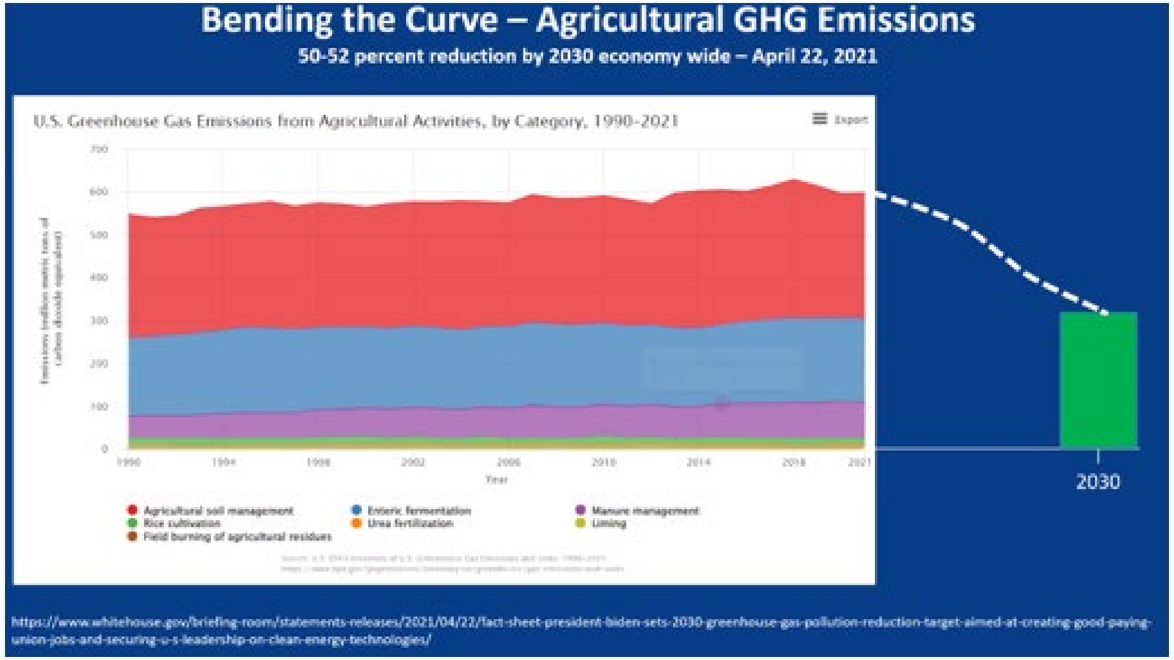

2021 US Agriculture Sector Greenhouse gas emission Sources.

***$CH_4$*** ➡ *is >80 times more potent than $CO_2$ over 20-yr lifetime,*

➡ *reducing $CH_4$ is likely the **biggest** and **fastest** way to address climate crisis over the next 20 years.*

*Source*: USEPA.gov

# U.S. Climate change goals




- **The United States has made a net-zero GHG economy wide commitment to be achieved by 2050** to avoid the worst effects of climate crisis.
- The US commits to economy-wide target of **reducing** its net GHG emissions by **50-52% relative to 2005 levels in 2030.**
- Achieving these climate goals will take ambitious activities in the next 6 years and require engagement and action among agencies.

# Changes within the US agricultural sector

**CROPLANDS**

- Adoption of conservation tillage to millions new acres and reduce field pass intensity
- Implementation of cover cropping, double cropping and reducing dry land fallow
- Smart fertilizers: enhanced efficiency fertilizers, N inhibitors and variable rate application
- New vegetative buffers, wind breaks and grassland conservation
- Reduce the frequency and duration of flooding of rice paddies

**ANIMAL AGRICULTURE**

- Implementation of anaerobic digesters
- Covers on anaerobic lagoons
- Improved and rotational grazing in millions of acres
- Commercially available and wide adoption of improved feed management and effective feed additives

Source: 2023 IRA Workshop

# Opportunities: crop management strategies to reduce GHG emissions



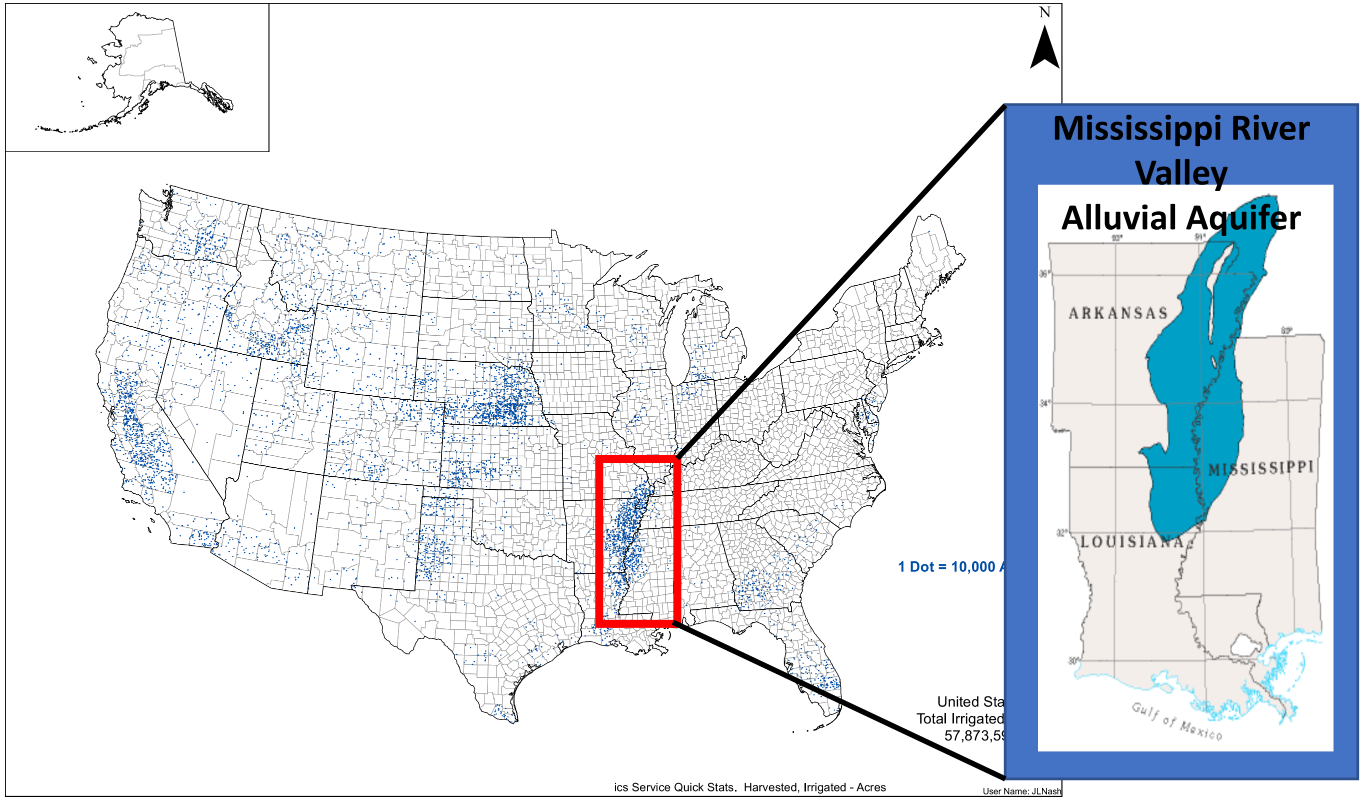


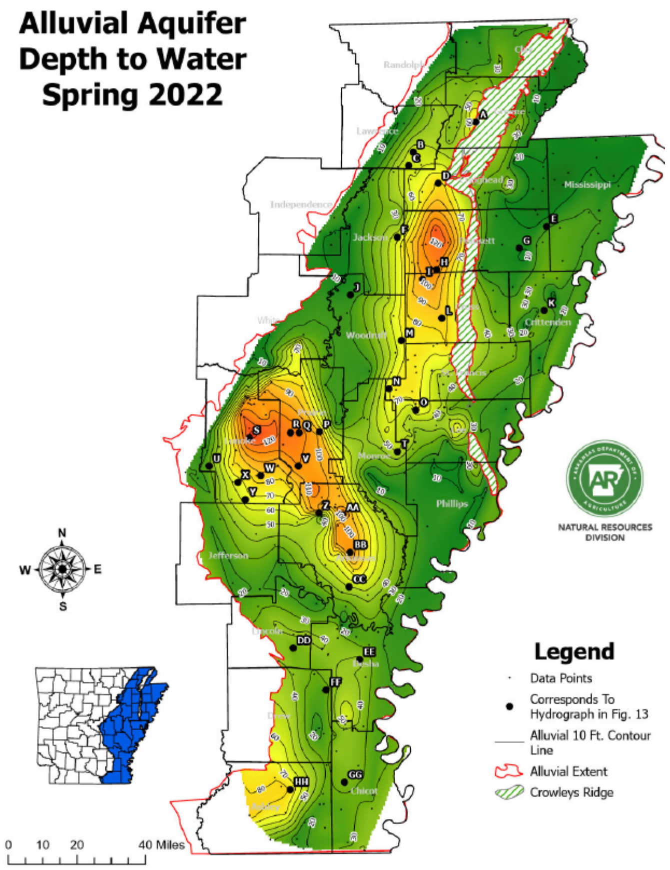
| Agronomic practices | Impact on GHG emission | Remarks |
|---|---|---|
| | - | |
| **Low inorganic N fertilizer rates (~79 kg N ha$^{-1}$)** | ↑18% $CH_4$ | Relative to 0 kg N ha$^{-1}$ |
| **High inorganic N fertilizer rates (~249 kg N ha$^{-1}$)** | ↓15% $CH_4$ | Relative to 0 kg N ha$^{-1}$ |
| **Ammonium sulfate** | ↓40% $CH_4$<br>↑ $N_2O$ | Replacing Urea at same N rate |
| **Dicyandiamide, (DCD)**<br>***Nitrification inhibitor*** | ↓18% $CH_4$<br>↓25% $N_2O$ | |
| **Deep placement of N fertilizer** | ↓$CH_4$<br>↑ $N_2O$ | |
| **Farmyard manure** | ↑26% $CH_4$ | Compared to same inorganic N rate |
| **Green manure**<br>***Sesbania*** | ↑192% $CH_4$ | Compared to same inorganic N rate |
| **Sulfate fertilizers (208 kg S ha$^{-1}$)** | ↓28% $CH_4$ | |
| **Sulfate fertilizers (992 kg S ha$^{-1}$)** | ↓53% $CH_4$ | |
| **Water saving irrigation practice AWD** | ↓48-93% $CH_4$<br>↑ $N_2O$ | Variable % water content threshold for re-flooding |
| **Rice varieties**<br>**Hybrids vs Inbreeds** | ??? | Depends on environmental conditions |

# Crop management strategies to reduce GHG emissions

| Agronomic practices | Impact on GHG emission | Remarks |
|---|---|---|
| | - | |
| **Low inorganic N fertilizer rates (~79 kg N ha$^{-1}$)** | ↑18% $CH_4$ | Relative to 0 kg N ha$^{-1}$ |
| **High inorganic N fertilizer rates (~249 kg N ha$^{-1}$)** | ↓15% $CH_4$ | Relative to 0 kg N ha$^{-1}$ |
| **Ammonium sulfate** | ↓40% $CH_4$<br>↑ $N_2O$ | Replacing Urea at same N rate |
| **Dicyandiamide, (DCD)**<br>***Nitrification inhibitor*** | ↓18% $CH_4$<br>↓25% $N_2O$ | |
| **Deep placement of N fertilizer** | ↓$CH_4$<br>↑ $N_2O$ | |
| **Farmyard manure** | ↑26% $CH_4$ | Compared to same inorganic N rate |
| **Green manure**<br>***Sesbania*** | ↑192% $CH_4$ | Compared to same inorganic N rate |
| **Sulfate fertilizers (208 kg S ha$^{-1}$)** | ↓28% $CH_4$ | |
| **Sulfate fertilizers (992 kg S ha$^{-1}$)** | ↓53% $CH_4$ | |
| **Water saving irrigation practice AWD** | ↓48-93% $CH_4$<br>↑ $N_2O$ | Variable % water content threshold for re-flooding |
| **Rice varieties**<br>**Hybrids vs Inbreeds** | ??? | Depends on environmental conditions |

# Declining groundwater in the Mississippi River Delta region

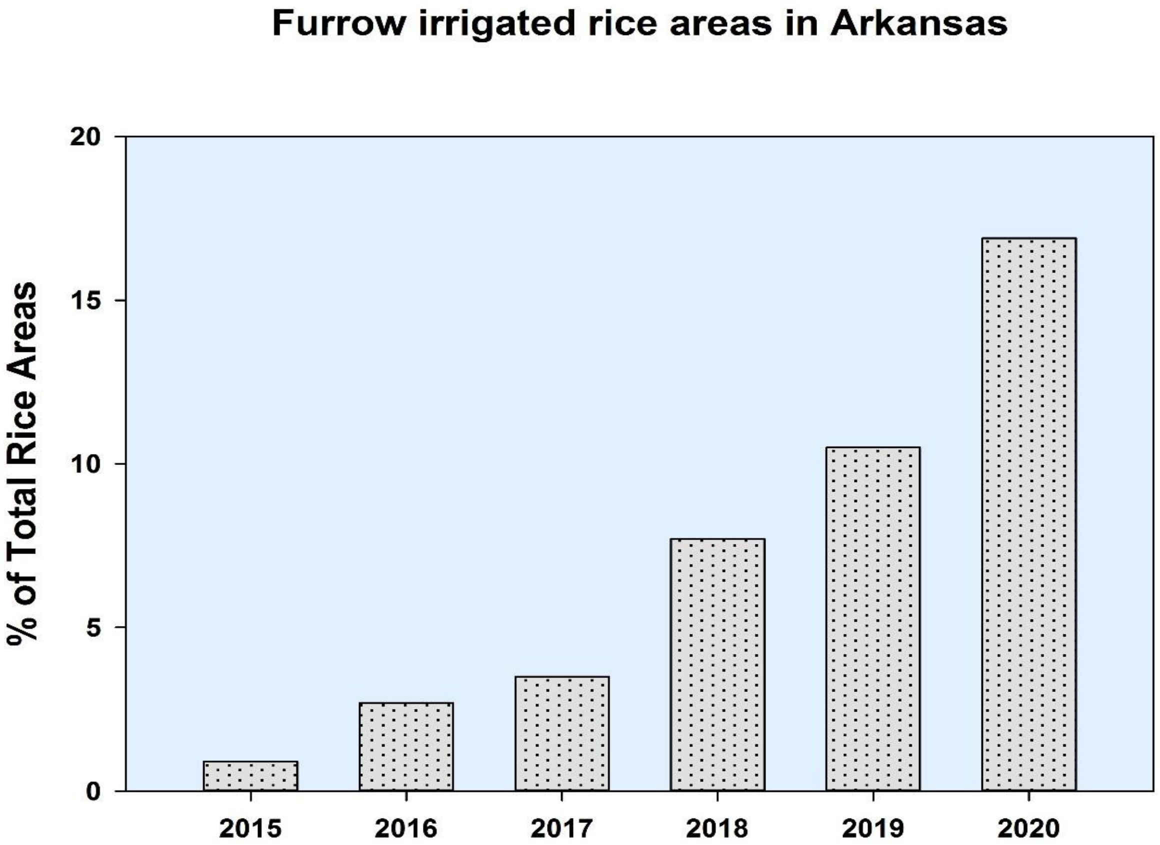



- Arkansas is third in the US for irrigated areas.
- Mississippi River Valley Alluvial Aquifer (MRVAA) is the primary source of irrigation water (≥80%)
- In 2018, aquifer sustainable recharge was 3,374 Mgal day$^{-1}$ but pumping during same year was 2 times than the recharge rate, thus created declined in groundwater.
- Rice accounts for about half groundwater use and received about 3 times the irrigation that is applied to maize and soybean.

- Two cones of depression in Grand Prairie and Cache regions
- 30-36 m (100-120 ft) alluvial aquifer depth to water

# AWD & Furrow Irrigated Rice/ Row rice




Hardke 2020, 2021

- Rapidly gaining popularity in Mid- South
  - due to reduced labor cost, time and efforts for land preparation
  - increased flexibility in responding to changing market and weather conditions

- Reduction in irrigation water use
  - 13-54 % of water savings

## Average seasonal GHG emissions and yields in Arkansas and California rice fields under different irrigation systems:

| State | Irrigation practice | Methane, $CH_4$ | Nitrous oxide, $N_2O$ | Global warming potential, GWP | | Grain yield | % $CH_4$ reduction relative to Flooded irrigation | % $N_2O$ increase relative to Flooded irrigation |
|---|---|---|---|---|---|---|---|---|
| | | kg $CH_4$-C $ha^{-1}$ $season^{-1}$ | kg $N_2O$-N $ha^{-1}$ $season^{-1}$ | kg $CO_2$eq $ha^{-1}$ $season^{-1}$ | kg $CO_2$eq $ton^{-1}$ $season^{-1}$ | Ton $ha^{-1}$ (bu $ac^{-1}$) | | |
| | | | | *Area-scaled* | *Yield-scaled* | | | |
| | | | | | | | | |
| **Arkansas** | Continuously Flooded | 70.7 | 0.04 | 2,472 | 248 | 9.7 (192) | | |
| | AWD | 21 | 0.16 | 802 | 81 | 9.8 (195) | ↓71% | ↑4x |
| | | | | | | | | |
| | Continuously Flooded | 55.9 | 0.15 | 2,116 | 179 | 11.9 (235) | | |
| | Furrow irrigation | 11 | 2.90 | 1,638 | 161 | 10.4 (205) | ↓81% | ↑20x |
| | | | | | | | | |
| **California** | Continuously Flooded | 205 | -0.05 | 7,622 | 694 | 11.0 (218) | | |
| | AWD | 78 | -0.06 | 2,876 | 266 | 11.0 (217) | ↓62% | - |

**Yield-scaled GWP** : kg $CO_2$ equivalent of $CH_4$ and $N_2O$ emissions per ton of yield

$$GWP_{N_2O,CH_4} = \left(\frac{kg\ N_2O}{ha \cdot season} \times 273\right) + \left(\frac{kg\ CH_4}{ha \cdot season} \times 27.2\right)$$

# Seasonal GHG emissions and yields between inbred and hybrid cultivars under intermittent irrigation

| Irrigation practice | Cultivar | Methane, $CH_4$ | Nitrous oxide, $N_2O$ | Global warming potential, GWP | | Grain yield | % $CH_4$ reduction relative to *Inbred |
|---|---|---|---|---|---|---|---|
| | | kg $CH_4$-C $ha^{-1}$ $season^{-1}$ | kg $N_2O$-N $ha^{-1}$ $season^{-1}$ | kg $CO_2$eq $ha^{-1}$ $season^{-1}$ | kg $CO_2$eq $ton^{-1}$ $season^{-1}$ | Ton $ha^{-1}$ (bu $ac^{-1}$) | |
| | | | | *Area-scaled* | *Yield-scaled* | | |
| | | | | | | | |
| **AWD** | CL151* | 39 | 0.50 | 1,682 | 191 | 8.0 (158) | |
| | XP753 | 37 | 0.15 | 1,434 | 156 | 10 (198) | |
| | XP760 | 38 | 0.10 | 1,454 | 156 | 11 (218) | |
| | CLXL745 | 21 | 0.17 | 872 | 101 | 9.0 (178) | ↓46% |
| | | | | | | | |
| **Furrow irrigation** | CLL15* | 14 | 1.11 | 979 | 117 | 8.5 (178) | |
| | RT7321 | 12 | 0.88 | 791 | 69 | 12 (234) | |
| | RT7521 FP | 6 | 0.72 | 513 | 44 | 12 (234) | ↓59% |
| | | | | | | | |

**Inbred cultivars*

- ***52%** average reduction of $CH_4$ emissions in **high-yielding hybrids** compared to inbred $CH_4$ emissions*

# Average seasonal $CH_4$ and $N_2O$ emissions for rice region for growing and non-growing seasons.

| Region | Studies | Growing season $CH_4$ emissions | | Non-growing season $CH_4$ emissions | | Studies | Growing season $N_2O$ emissions | | Non-growing season $N_2O$ emissions | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Weighted Average | Range | Weighted Average | Range | | Weighted Average | Range | Weighted Average | Range |
| | | -----------kg $CH_4$ $ha^{-1}$ $season^{-1}$---------- | | | | | -----------kg $N_2O$ $ha^{-1}$ $season^{-1}$----------- | | | |
| **California** | 7/5 | 218 | 67 – 446 | 79 | 10 – 215 | 3/3 | 0.15 | -0.17 – 0.66 | 0.65 | 0.20 – 2.24 |
| **Mid-South (Main Crop)** | 17/1 | 194 | 9 – 510 | 0.63 | 0.24 – 1.08 | 3/1 | 0.13 | 0.06 – 0.17 | 1.96 | 1.47 – 2.41 |
| **Mid-South (Ratoon)** | 1/na | 540 | 468 – 629 | - | - | na | na | na | na | na |

na = no available data

*SOURCE: Linquist, B.A., Marcos, M., Adviento-Borbe, M.A.A., Anders, M., Harrell, D. Linscombe, S., Reba, M., Runkle, B., Tarpley, L., Thompson, A. 2018. Greenhouse gas emissions and management practices that affect emissions in US rice systems. J Environ. Qual. 47:395-409.*

Actual GHG emissions in Arkansas:
$CH_4$: 70 (6 – 141)
$N_2O$: 0.32 (0.0 – 1.3)

# Water quality in US agricultural systems: The Mississippi River Watershed


- 4th largest watershed in the world, and drains over about half of the US total area (31 states and 2 Canadian provinces)
- Provides $50 billion in agricultural products and 25% of America's total hydropower
- 100 million people live in the basin
- Water quality is degraded due to nonpoint source pollution
    - *Excessive nutrients (N and P loading)* – synthetic fertilizer, manure, legume crops, human sewage & atmospheric deposition
    - *Sediment load into river* – erosion from agricultural lands, natural erosion, riverbank erosion




# Water quality in US agricultural systems: The Mississippi River Watershed

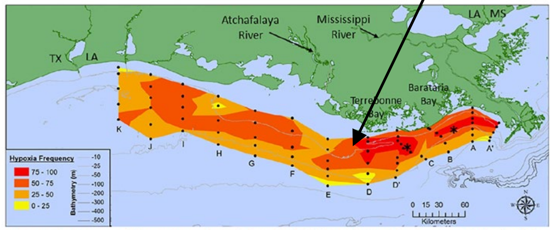



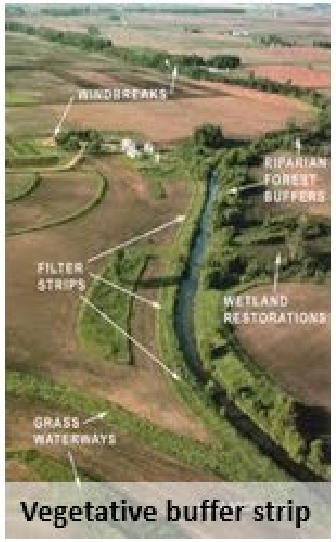

FIG. 1. The frequency of bottom-water hypoxia from shelf-wide hypoxia mapping (1985–2014) (updated from Rabalais et al. (2007b); frequency is determined from stations for which there are data for at least half of all cruises. Asterisks (*) indicate locations of near-bottom oxygen meters; transects C and F identified. Data source: N. N. Rabalais and R. E. Turner.

- Main outcome is **Hypoxia or Dead zone in Northern Gulf of Mexico** (11,259 $km^2$)
  - – oxygen level if <2 mg/L caused by eutrophication from excess N and P nutrients loads from agriculture, N fixation and atmospheric deposition

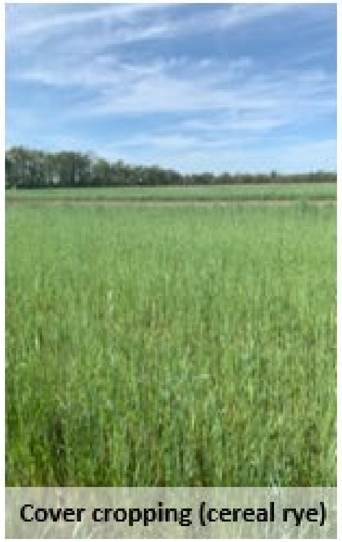
- **Contemporary strategies to improve water quality:**
  - Best management practices – i.e. Reduced/No till, vegetative cover, riparian zone

# Contemporary management strategies to improve water quality


Minimum tillage



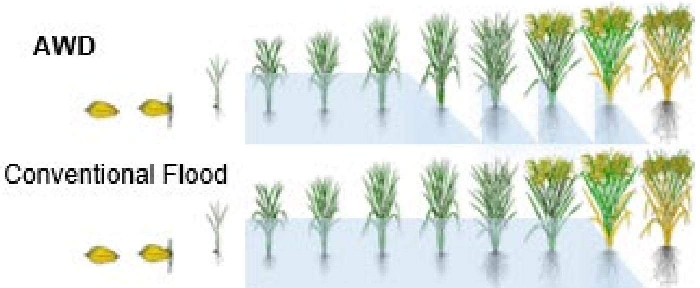
Vegetative buffer strip


Cover cropping (cereal rye)


Non-irrigated cropping


Furrow rice irrigation


Multiple inlet irrigation



Alternate wetting and drying practice


Smart fertilization *i.e.* inhibitors, EEFs


Hybrid cultivars

Efficient nutrient management

# Water quality in US agricultural systems: The Mississippi River Watershed

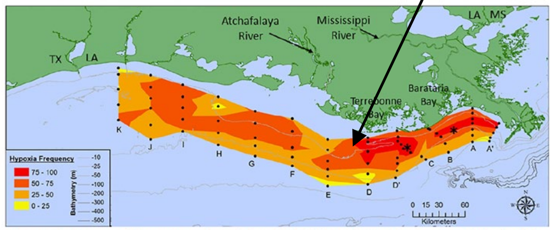
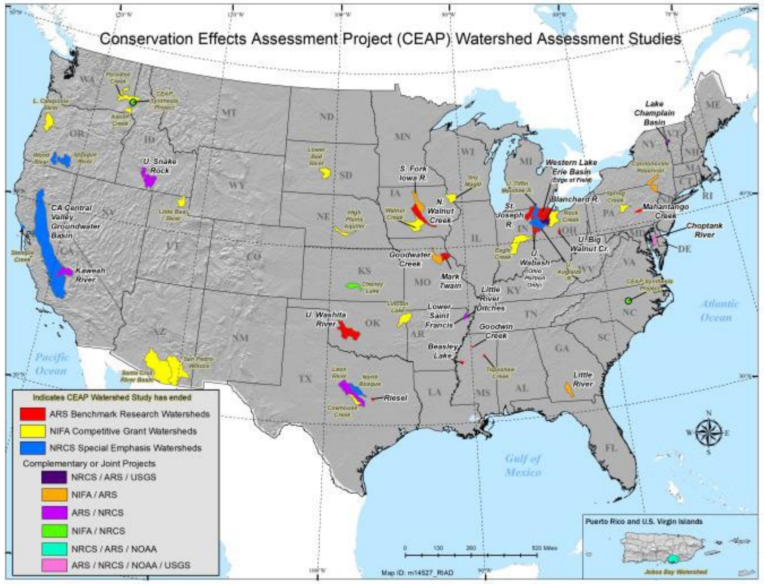




FIG. 1. The frequency of bottom-water hypoxia from shelf-wide hypoxia mapping (1985–2014) (updated from Rabalais et al. (2007b); frequency is determined from stations for which there are data for at least half of all cruises. Asterisks (*) indicate locations of near-bottom oxygen meters; transects C and F identified. Data source: N. N. Rabalais and R. E. Turner.

- Main outcome is **Hypoxia or Dead zone in Northern Gulf of Mexico** (11,259 km$^2$)
  – oxygen level if <2 mg/L caused by eutrophication from excess N and P nutrients loads from agriculture, N fixation and atmospheric deposition

- Contemporary strategies to improve water quality:
  - Best management practices – i.e. Reduced/No till, vegetative cover, riparian zone
  - Incorporation of social component – stakeholders involvement, adoption
  - Field- and watershed-scale monitoring and evaluation – water quality index, models
    - Conservation Effects Assessment Program, CEAP – US NRCS
    - Long-Term Agroecosystem Research, LTAR – USDA-ARS
    - Mississippi River Basin Healthy Watershed Initiative, MRBI – US NRCS

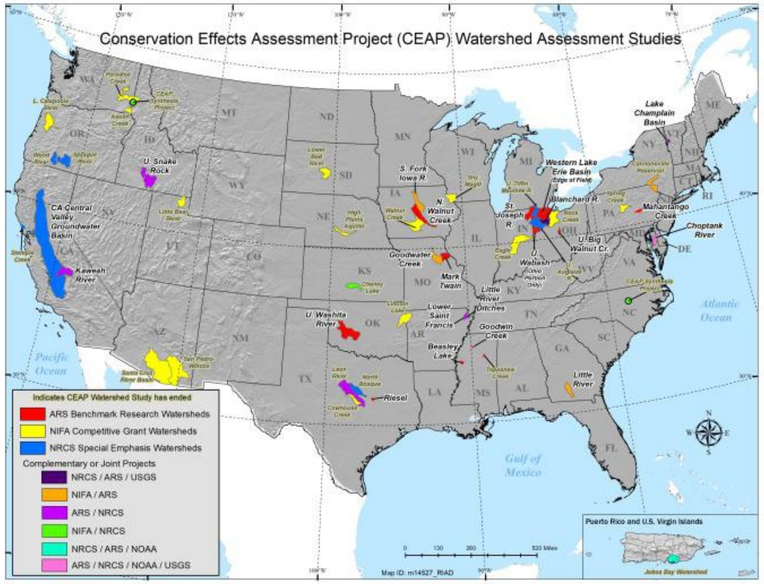
# Water quality in US agricultural systems: Field- and watershed-scaled monitoring and evaluation

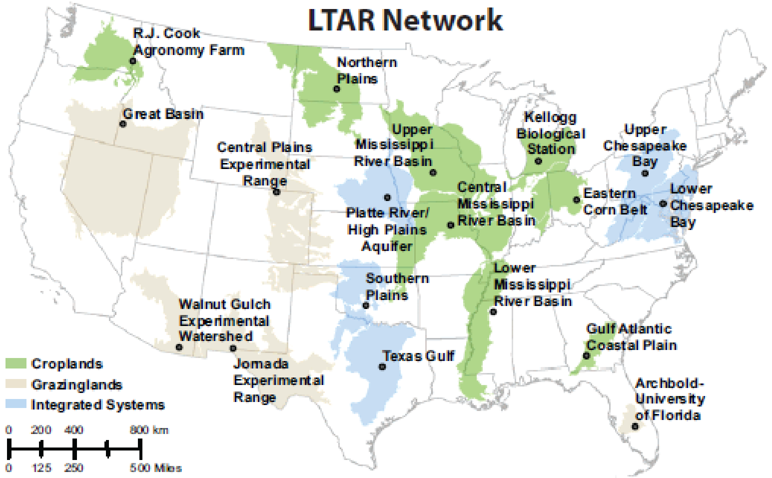



1. Conservation Effects Assessment Program, CEAP – NRCS

- Established in 2003 (2002 Farm Bill fund)
- Multi agency effort led by Natural Resources Conservation Service (NRCS)
- National/Regional Assessment: cropland, grazing lands, wetlands, wildlife, watersheds
- Goal is to improve efficacy of conservation programs thru science and education
- https://www.nrcs.usda.gov/ceap

# Water quality in US agricultural systems: Field- and watershed-scaled monitoring and evaluation



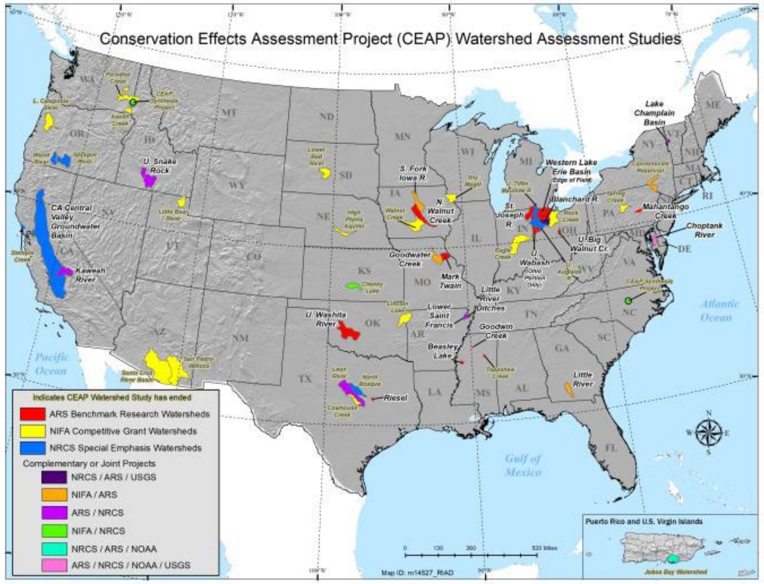

1. Conservation Effects Assessment Program, CEAP – NRCS

- Established in 2003 (2002 Farm Bill fund)
- Multi agency effort led by Natural Resources Conservation Service (NRCS)
- National/Regional Assessment: cropland, grazing lands, wetlands, wildlife, watersheds
- Goal is to improve efficacy of conservation programs thru science and education
- https://www.nrcs.usda.gov/ceap

2. Long-Term Agroecosystem Research, LTAR – USDA

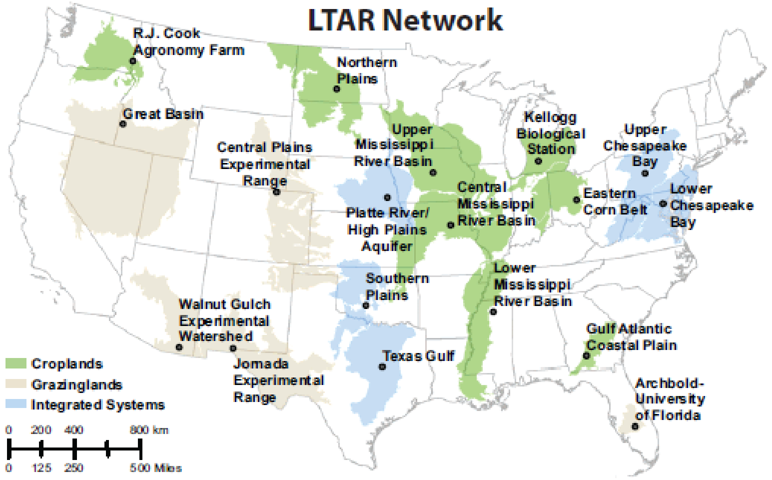
- 18 research sites, conducted in 1910
- Represents a range of major US agroecosystems i.e. cereal, forage, livestock production
- Goal is to develop and to share science-based findings to producers and stakeholders
- https://ltar.ars.usda.gov/network/

# Water quality in US agricultural systems: Field- and watershed-scaled monitoring and evaluation



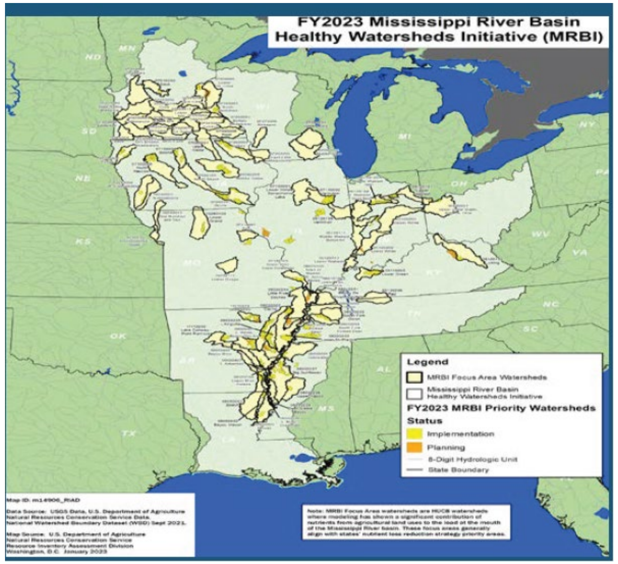

1. Conservation Effects Assessment Program, CEAP – NRCS

- Established in 2003 (2002 Farm Bill fund)
- Multi agency effort led by Natural Resources Conservation Service (NRCS)
- National/Regional Assessment: cropland, grazing lands, wetlands, wildlife, watersheds
- Goal is to improve efficacy of conservation programs thru science and education
- https://www.nrcs.usda.gov/ceap




2. Long-Term Agroecosystem Research, LTAR – USDA

- 18 research sites, conducted in 1910
- Represents a range of major US agroecosystems i.e. cereal, forage, livestock production
- Goal is to develop and to share science-based findings to producers and stakeholders
- https://ltar.ars.usda.gov/network/




3. Mississippi River Basin Healthy Watershed Initiative, MRBI – NRCS

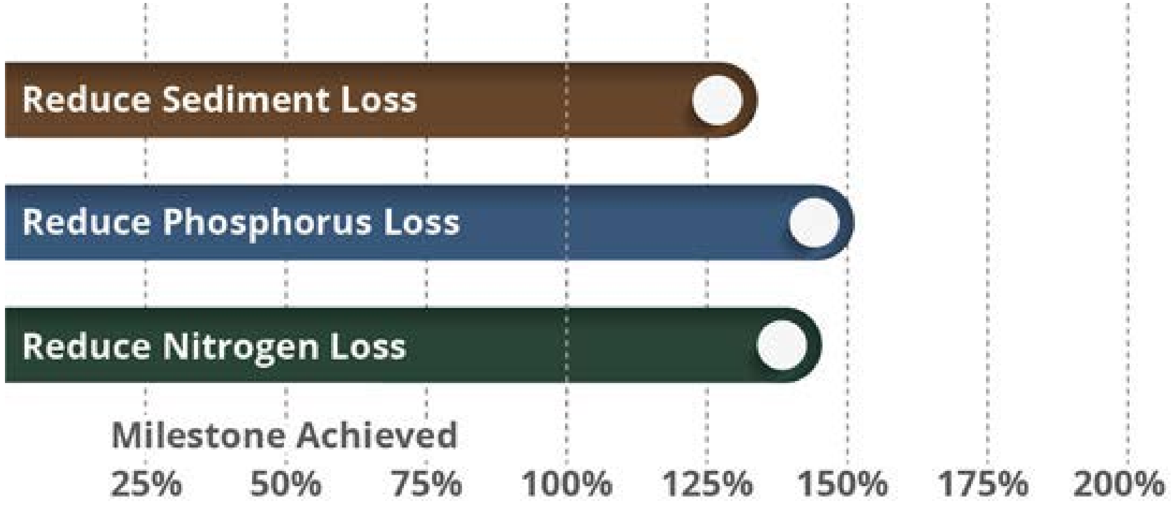
- 12 states, established in 2009
- Focus on agricultural farms
- Goal is to improve water quality and ensure viability of agricultural lands
- https://www.nrcs.usda.gov/programs-initiatives/mississippi-river-basin-healthy-watersheds-initiative

# Mississippi River Basi Healthy Watershed Initiatives: Outcomes

## 2023 Milestones

| Reduce Sediment Loss (tons) | | |
|---|---|---|
| Milestone | Achieved | Percentage Toward Milestone |
| 2,410,200 | 3,129,839 | 130% |
| *2,751,836 tons reduced in FY 2010–2022; 378,003 tons in FY 2023 | | |
| **Reduce Phosphorus Loss (lbs)** | | |
| Milestone | Achieved | Percentage Toward Milestone |
| 4,849,300 | 7,337,759 | 151% |
| *6,455,965 lbs reduced in FY 2010–2022; 881,794 lbs in FY 2023 | | |
| **Reduce Nitrogen Loss (lbs)** | | |
| Milestone | Achieved | Percentage Toward Milestone |
| 18,596,100 | 26,410,036 | 142% |
| *23,159,273 lbs reduced in FY 2010–2022; 3,250,763 lbs in FY 2023 | | |

Data source: FPAC Economics and Policy Analysis Division, January 2024




- Critical source of area for treatment: CEAP Soil Vulnerability Index (SVI)
- ID soils vulnerable to runoff loss of sediment and nutrients on cropland.
- Tracking conservation implementation on critical areas is one way to meet water quality objectives
- Highest SVI treated = 43%

# Concluding thoughts

- Multiple benefits can be achieved in integrated practices when implemented properly.

**GHG emissions**

- Rice: greatest reduction of $CH_4$ emissions occurred in non-continuous flooding practice
- Tradeoff between $CH_4$ and $N_2O$ emissions can be observed, thus need to manage irrigation and N fertilization effectively.
- Integrated mitigation approach that further reduce GHG emissions without yield penalty is a win-win strategy for growers

**Water quality**

- Soluble N/P and soil sediments are main pollutants in runoff water from agriculture.
- Current strategies to improve water quality in the US are underway.
  - Best management practices (BMP) for maximum pollution reduction
  - Long-term assessment and research on conservation practices to develop national roadmap for sustainable intensification of agricultural production.

- Challenges involved under a climate crisis
  - Complexity of system - variability in climate, soil, farming system, available resources, cultural practices, farmer's adoption
  - Limited long-term BMPs performance over time thru monitoring and evaluation
  - Climate change and growing human population

# AIM for Climate

Launched at COP26, the **Agriculture Innovation Mission for Climate** is an initiative co-led by the United Arab Emirates and the United States that seeks to enable global partnerships and solutions at the intersection of agriculture and climate change. The UAE, AIM for Climate co-lead and the incoming COP28 Presidency, has identified AIM for Climate as a leading platform to advance food and agriculture's contributions to COP28.

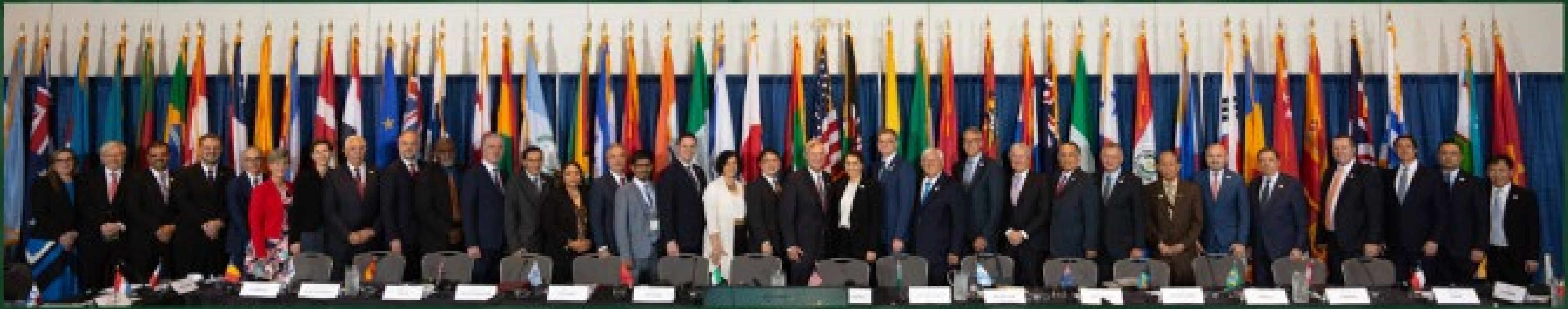
***Impact:***

**$13 billion**

Increased investment in climate-smart agriculture and food systems innovation by public and private-sector partners. Responsibility, control, and oversight of investments remains with participants.

**Over 500 partners – Join Us!**

Includes 50 government and over 450 non- government **partners**. AIM for Climate amplifies partners investments and acts as convening and networking platform.



*Pictured: 42 government partner delegations attended the AIM for Climate Summit in Washington, D.C., May 8-10, 2023*

**Website:** www.AIMforClimate.org
**Twitter:** @AIMforClimate

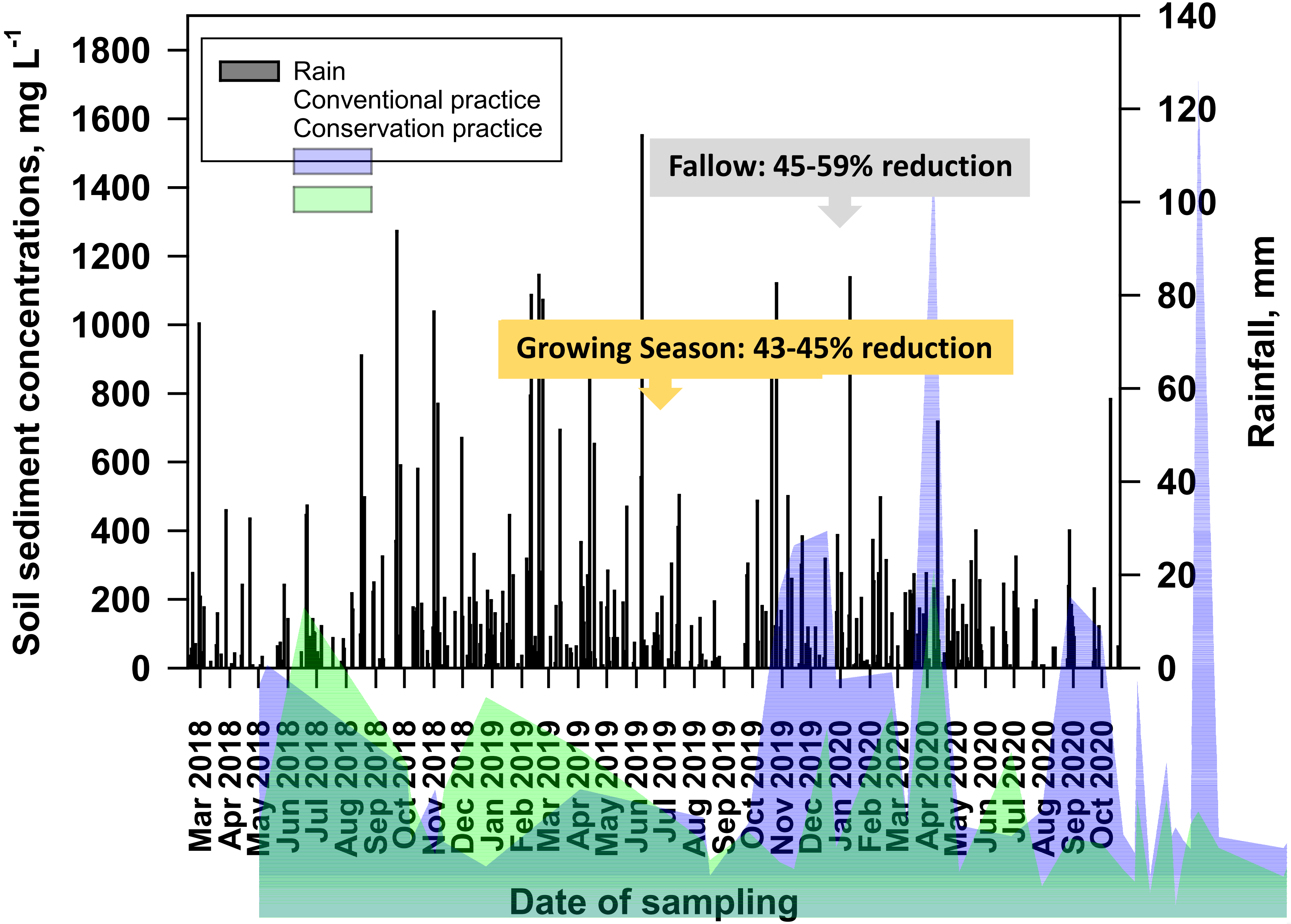
AIM FOR CLIMATE

# Thank you!


**“Climate change is one of the biggest challenges humanity has ever faced – but with human ingenuity and innovation we can avoid a climate disaster.”**

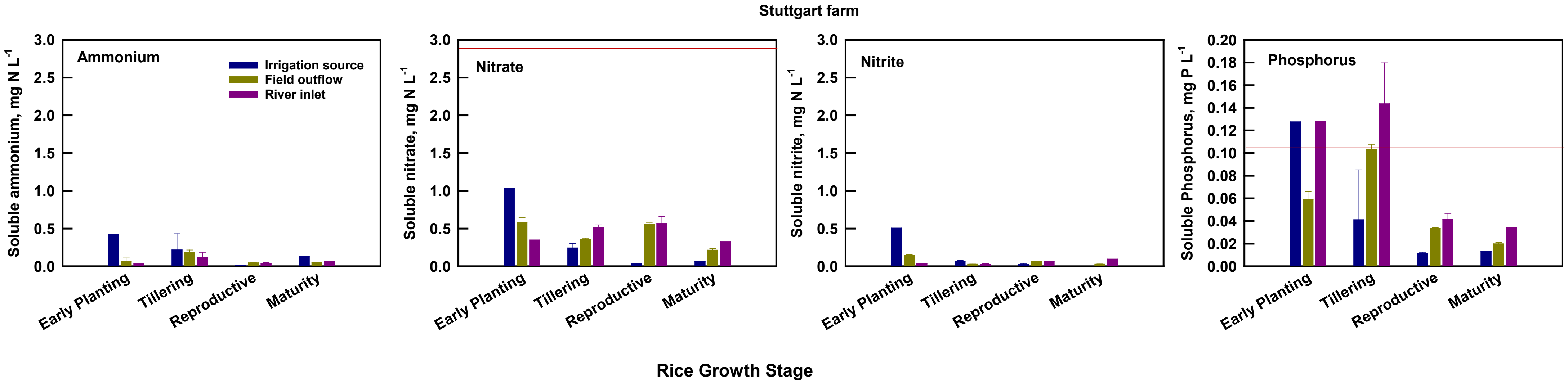
***– Bill Gates***

Integrated conservation practices in cotton: Soil sediment losses in runoff water





# Average concentrations of soluble N and P in runoff water at various growth stage of irrigated paddy rice




- Soluble nitrate mainly comprised the most losses in runoff water among nutrients.
- Large runoff losses occurred during early to tillering growth stage of rice
- Background P nutrient limit set by USEPA for the Delta region showed less likely to impair rivers and lakes.