Navigating the Trade-Offs: A Framework for effective conservation practices in the Upper Mississippi River Basin

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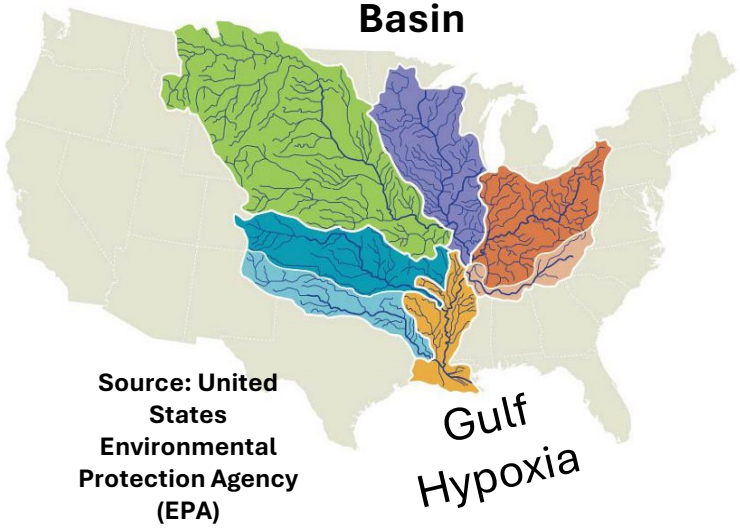
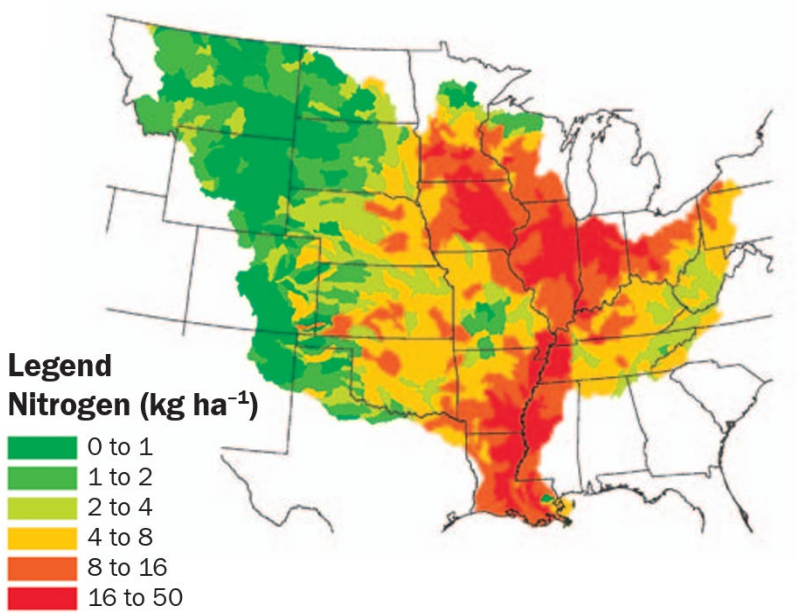
Background

Mississippi River Basin



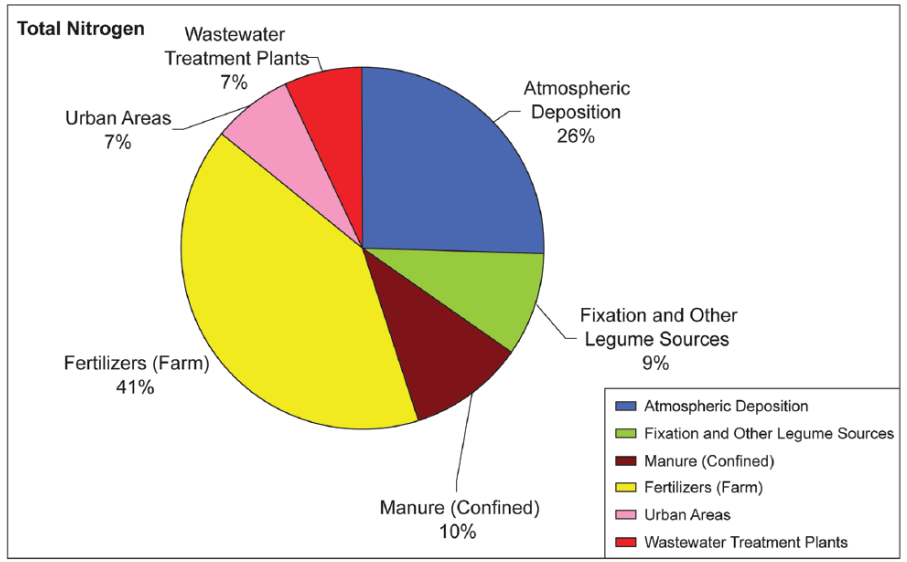
Source: United States Environmental Protection Agency (EPA)

Nitrogen Yield from the landscapes delivered to Gulf of Mexico



White et al., 2014
Journal of Soil and Water Conservation

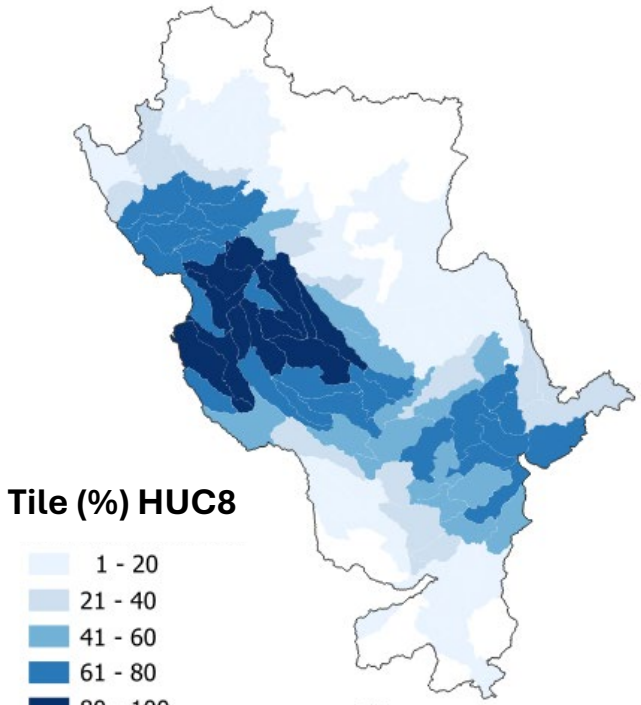
Nitrogen Sources of UMRB

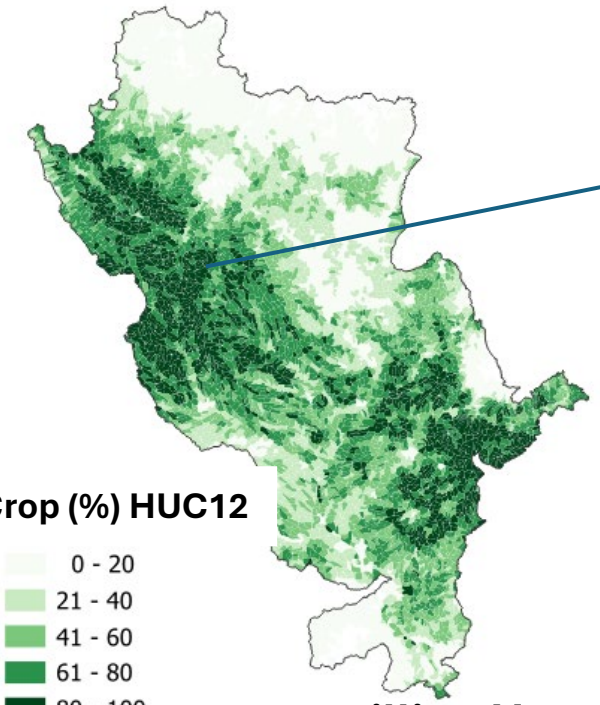


Robertson et al., 2014
Journal of environmental quality

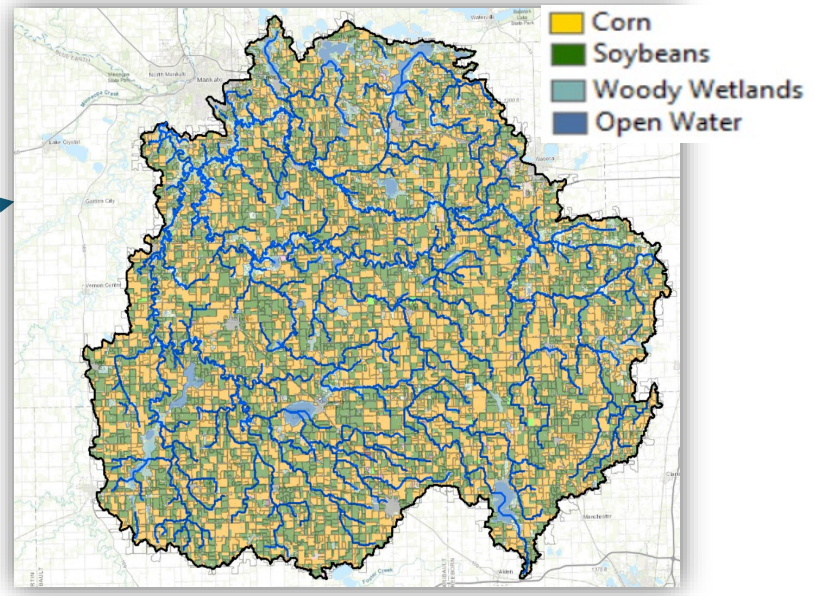
- Nearly half of the nitrogen discharged into the gulf originates from the Upper Mississippi River Basin.
- Non-point agricultural sources are the key factor.
- 45-60% reduction in nitrogen loading to reduce Hypoxic Zone (EPA , 2017)

Background





22 million Ha. of cropland



Corn and Soyabean fields

White et al., 2022, JAWRA

- Spatial Overlap Between Cropland and Tile Drainage.
- Implications for quick Nutrient Transport and Water Quality.
- Corn / soyabeans are main cultivated crops

HUC : Hydrologic Unit Code

Challenges in Realizing Conservation Benefits at Watershed Scale

Despite increasing adoption of agricultural conservation practices across croplands , water quality improvements in the UMRB and Gulf of Mexico remain limited. USDA-NRCS (2012), US EPA (2017)

Key questions:

- How do the timing, location , and type of practices influence watershed-scale water quality?
- Are conservation practices effectively targeted in critical source areas?
- Do stacked conservation practices interact, creating trade-offs that offset potential benefits?
- Is the current scale of implementation sufficient to show regional water quality changes?

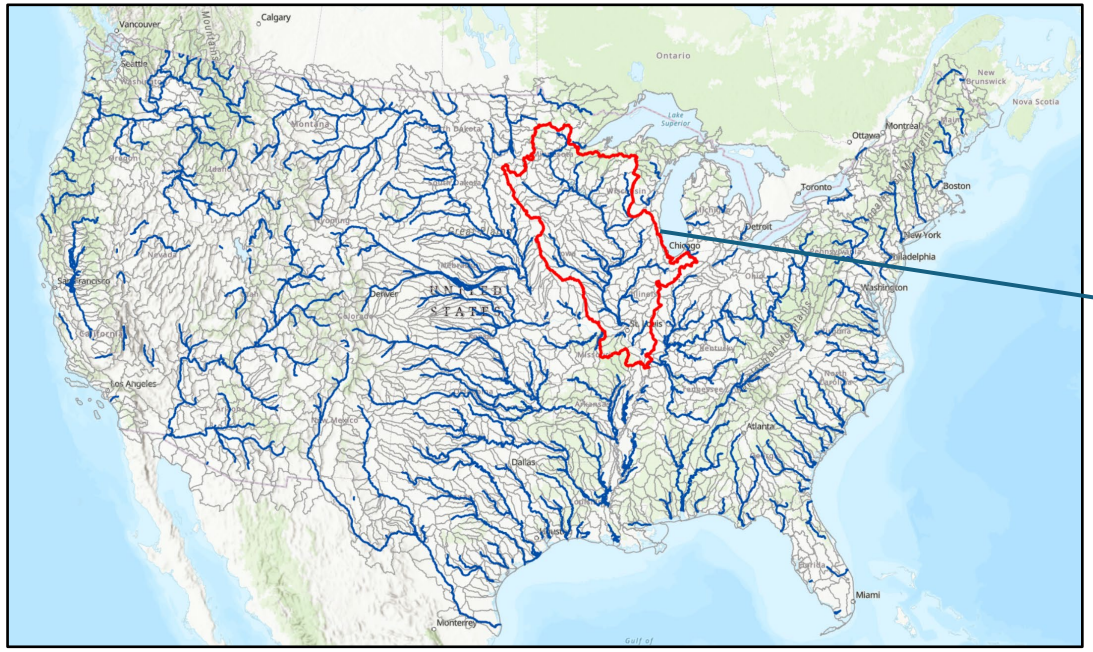
Objectives

1)Explore the impacts of current conservation practices on nitrogen loads.

2) Investigate how trade-offs between conservation practices, water quality benefits, and crop production vary across space and time.

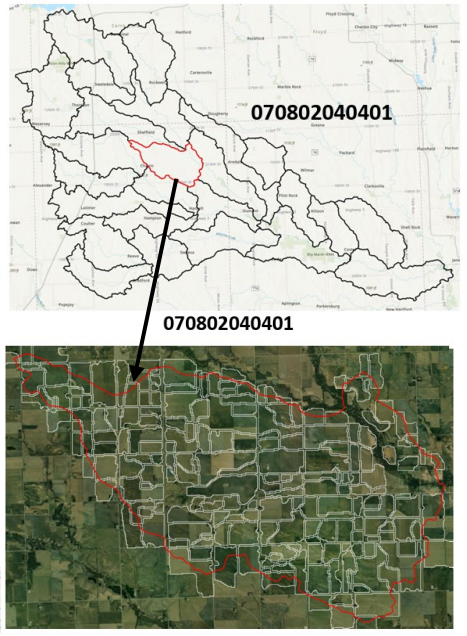
3) Identify key drivers and mechanisms underlying these trade-offs.

SWAT+ Model Setup



National Agroecosystems Model (NAM), **USDA-ARS**

HUC12s



132 HUC8s, 6731 HUC12s watersheds in UMRB

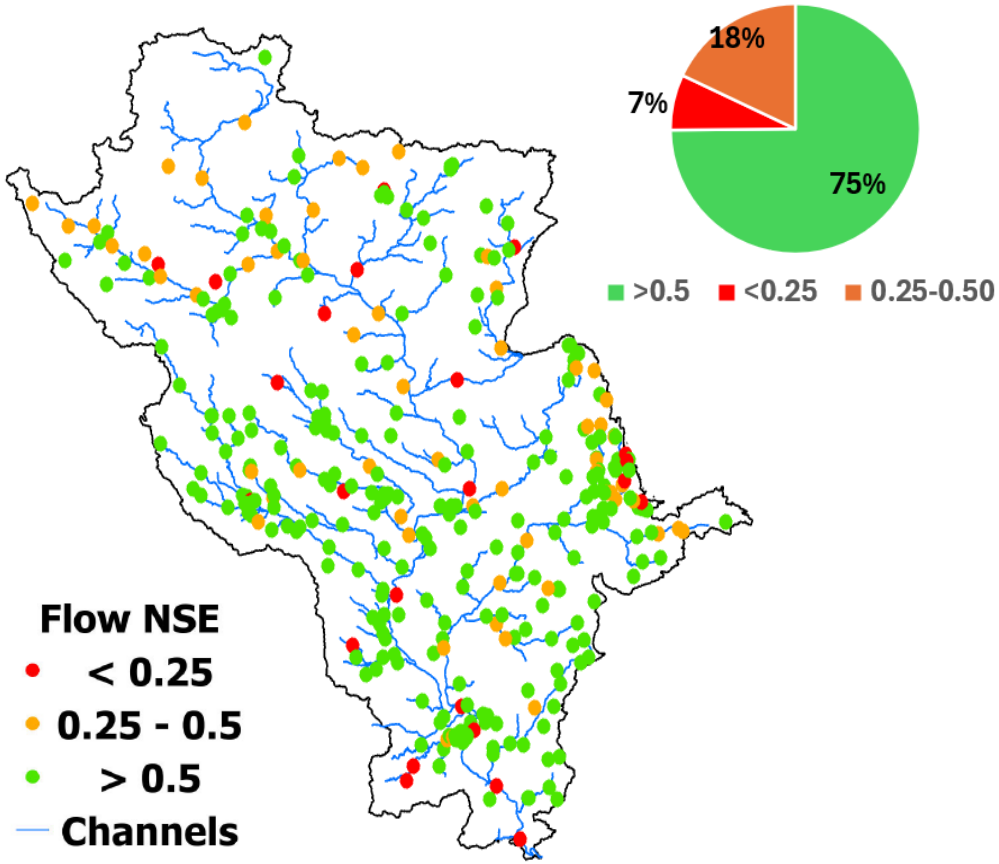
The NAM is a field-based, national scale hydrologic model to aid in conservation planning and policy.

The management practices follow the NRCS crop management Template and US Agricultural Census data.

White et al., 2022, JAWRA

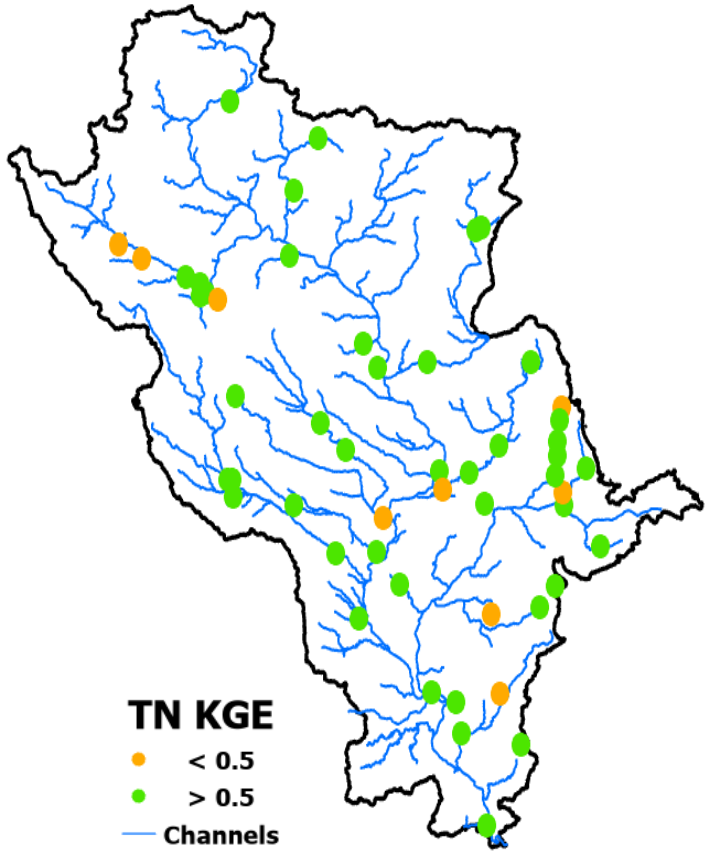
NRCS: Natural Resources Conservation Service

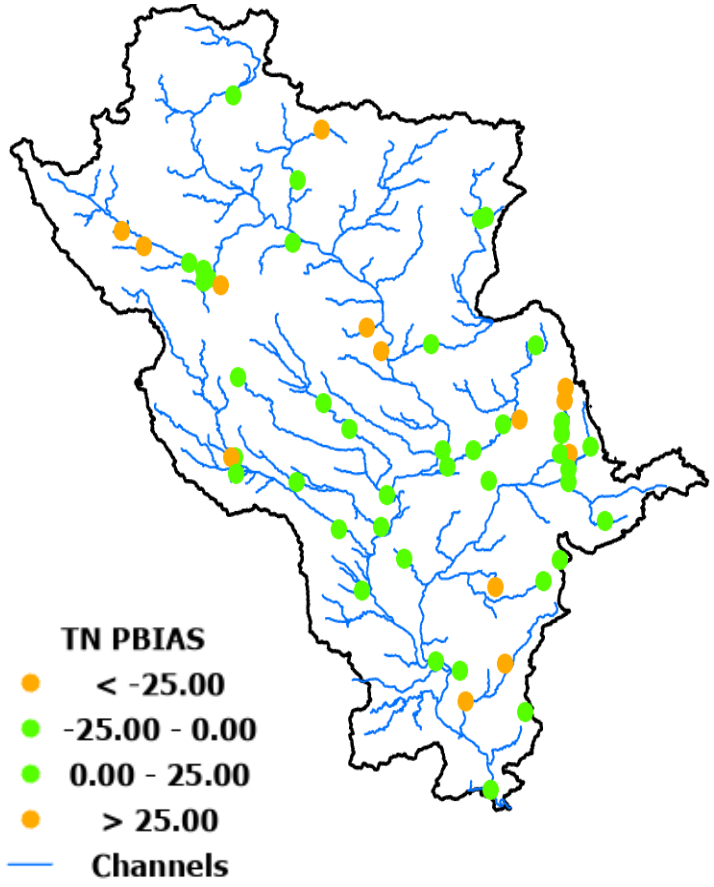
Calibration



Monthly Flow Calibration (2000-2018)

Monthly Total Nitrogen Load Calibration(2000-2018)

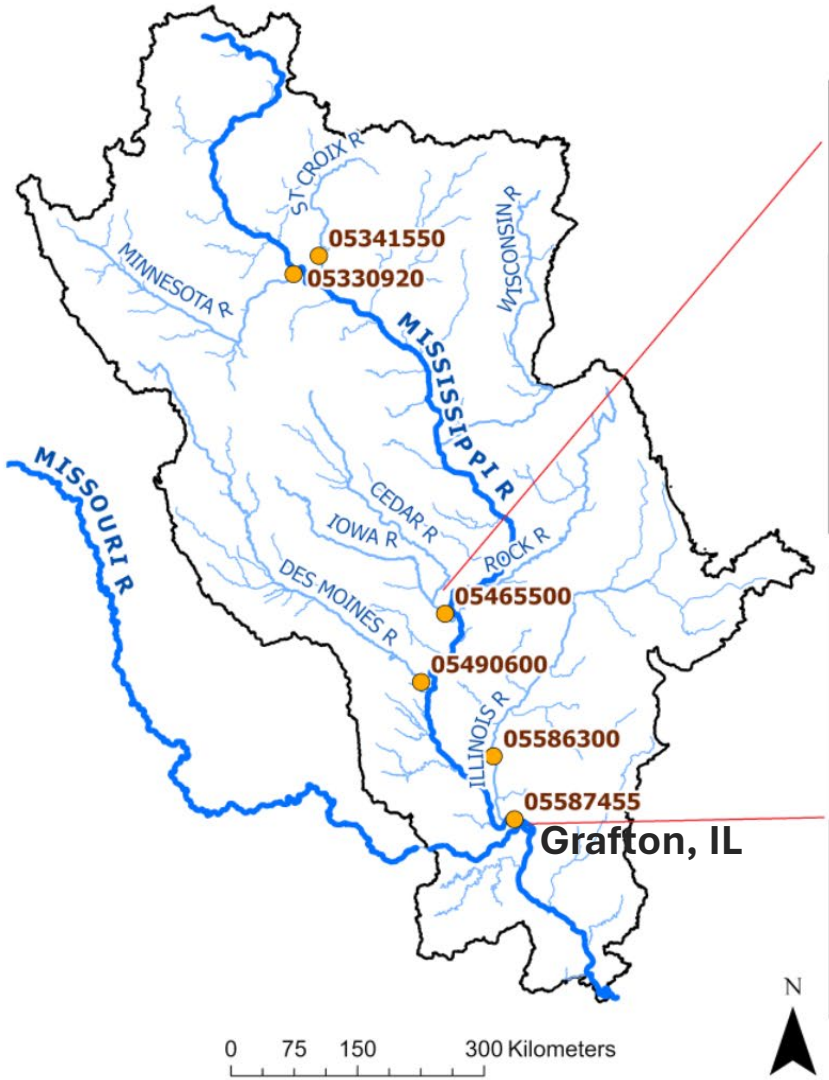


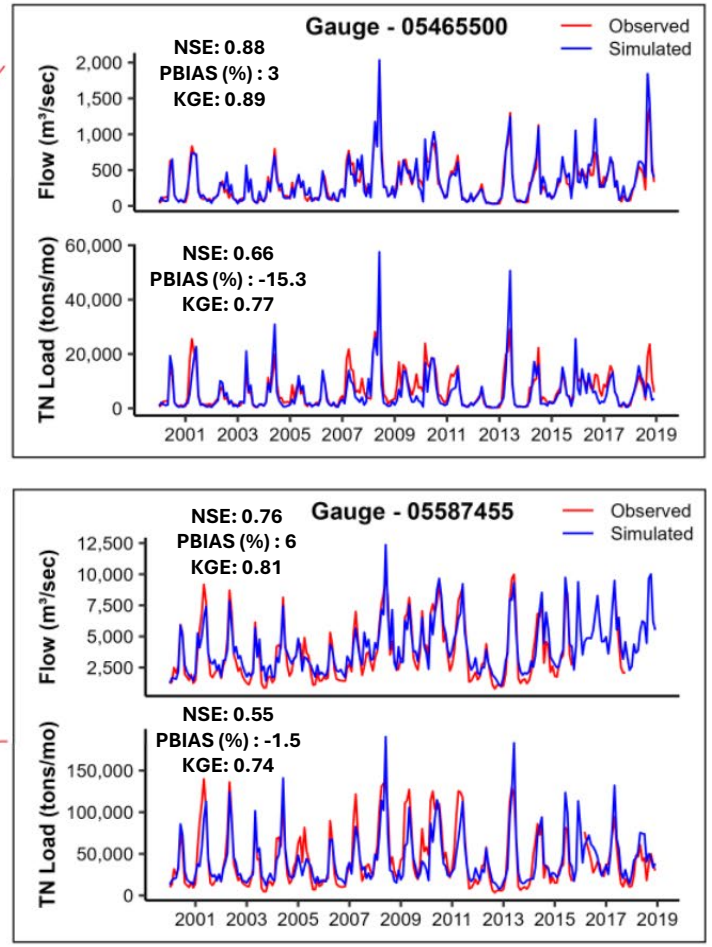


Soft Calibration: White et al., 2022
PDDS: Parallel computing Dynamically Dimensioned Search Gao et al ., 2025

Gao et al., 2025 https://doi.org/10.1016/j.envsoft.2025.106708

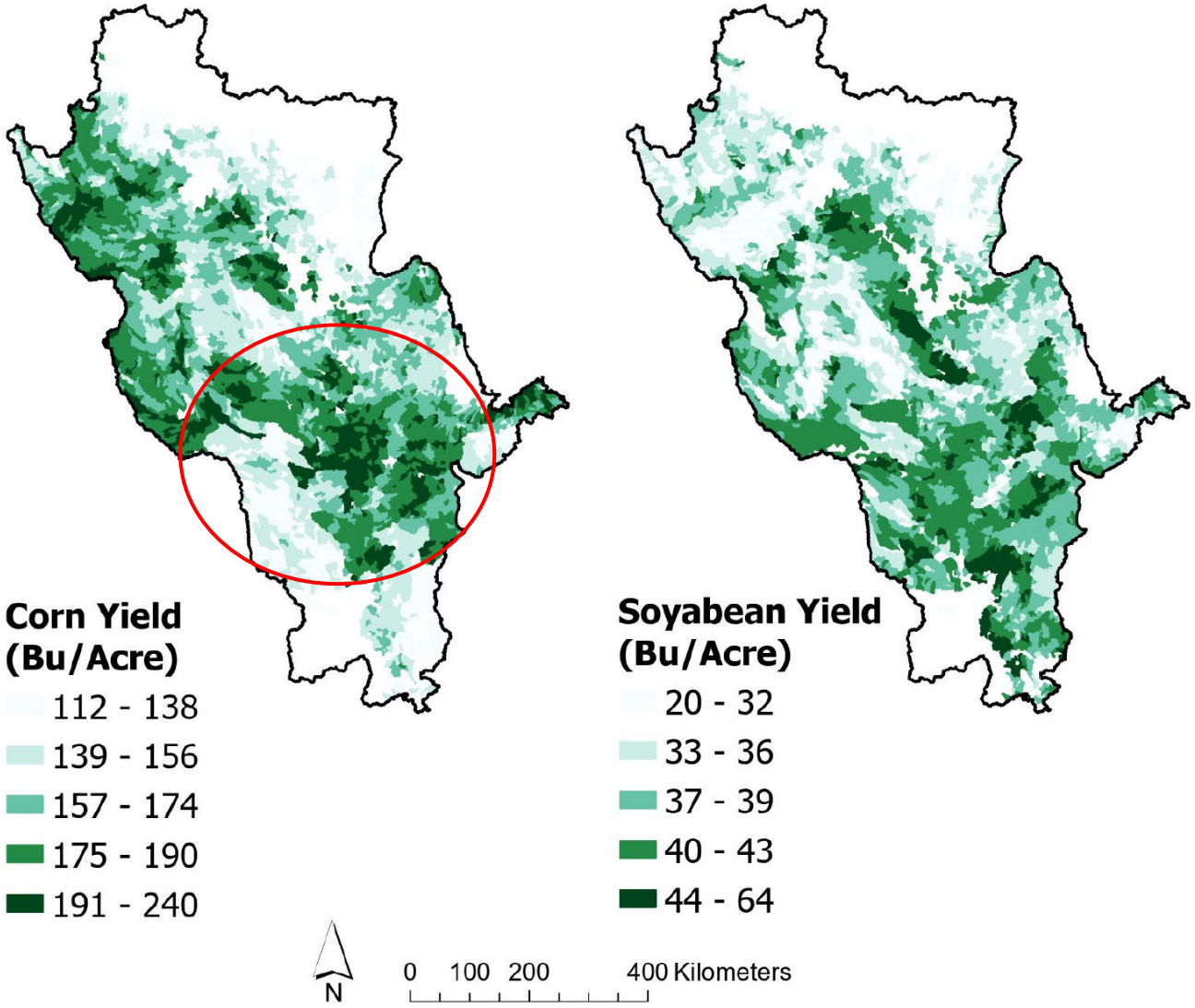
Calibration

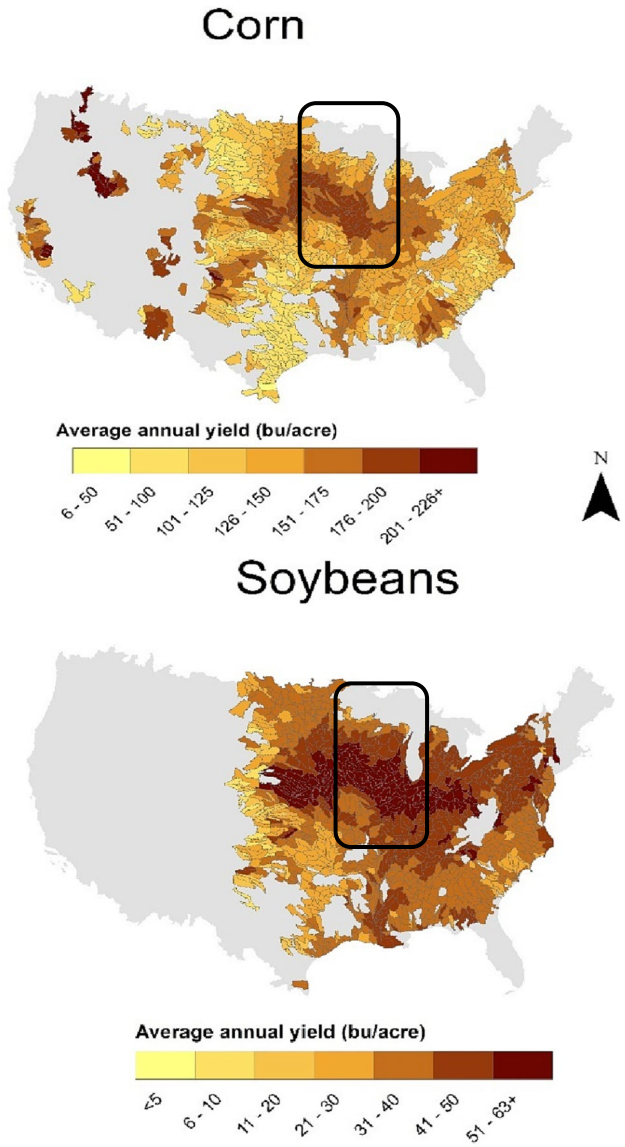




	Flow			TN		
	KGE	NSE	PBIAS	KGE	NSE	PBIAS
05586300	0.81	0.68	12.6	0.77	0.56	8.2
05490600	0.84	0.75	9.3	0.75	0.68	-15.5
05330920	0.35	0.28	-25.5	0.28	0.12	-35.3

Calibration (Corn & Soybean Yield)





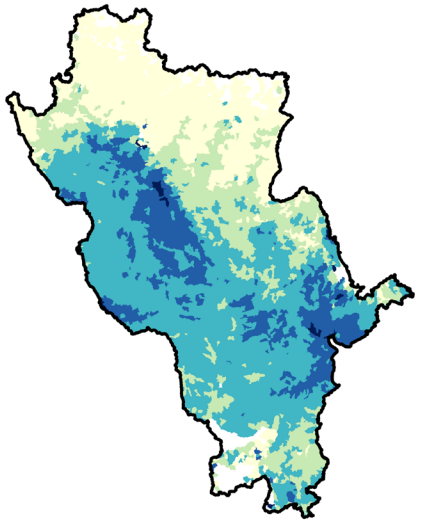
https://doi.org/10.1016/j.agsy.2023.103695

Cerkasova et al., 2023

Nutrient Loss Critical Areas

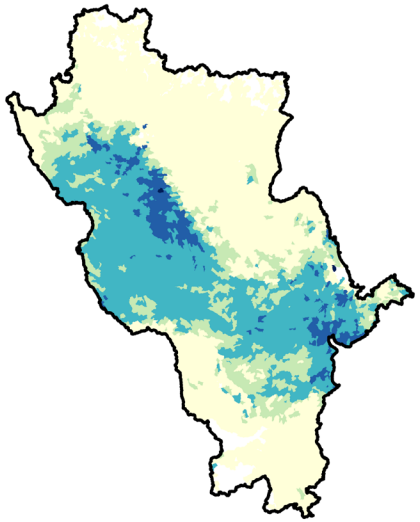
Baseline Calibrated Model

TN



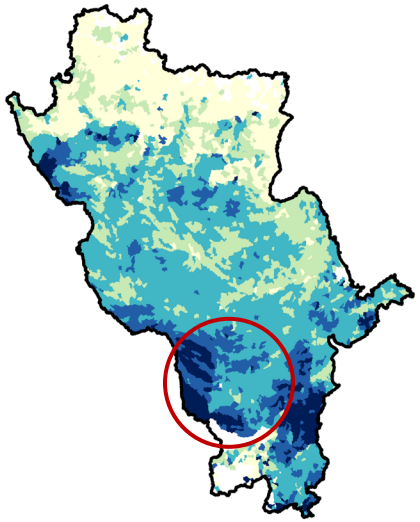
Kg/Ha/Yr
- 0 - 10
- 10 - 25
- 25 - 50
- 50 - 75
- > 75

Tile NO3



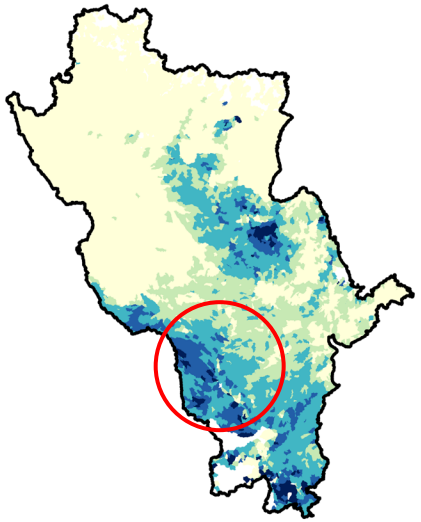
Kg/Ha/Yr
- 0 - 10
- 10 - 25
- 25 - 50
- 50 - 75
- > 75

SURQ NO3



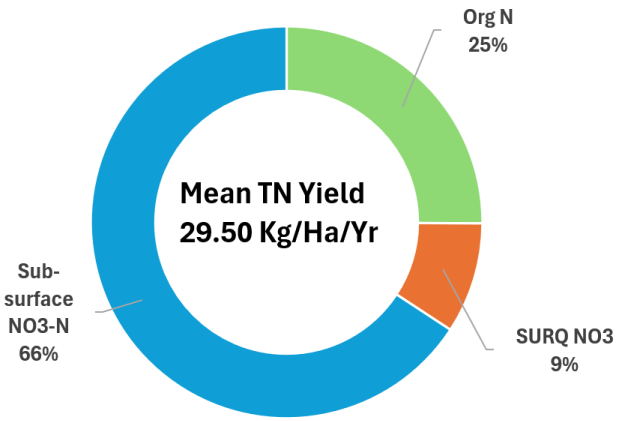
Kg/Ha/Yr
- 0 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- > 6

Organic N



Kg/Ha/Yr
- 0 - 5
- 5 - 10
- 10 - 20
- 20 - 30
- > 30

Partition of TN yield



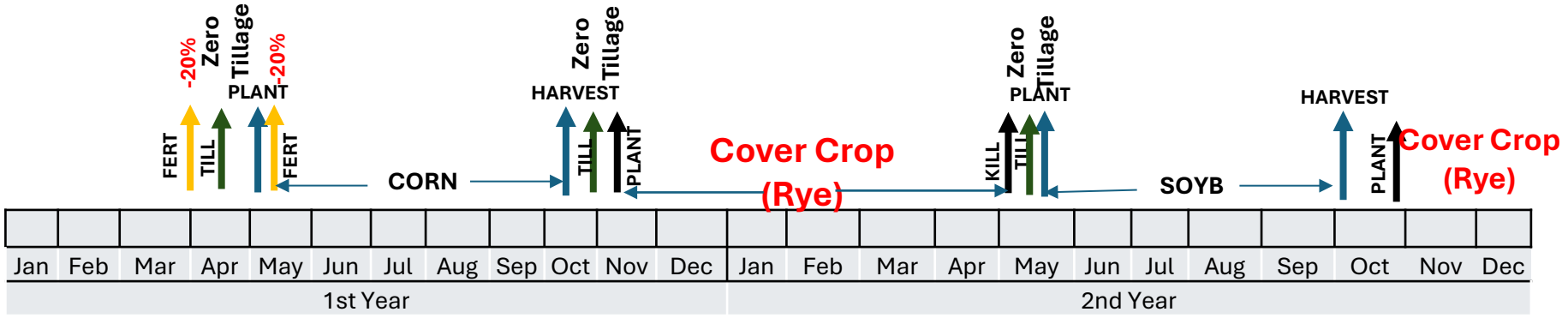
*Nitrogen Yield from Crop fields aggregated at HUC12 scale

Subsurface tile pathways dominate nitrogen loss, ~ 66% of total nitrogen yield originates from subsurface nitrate pathways, underscoring the dominant role of leaching and tile drainage in nutrient export.

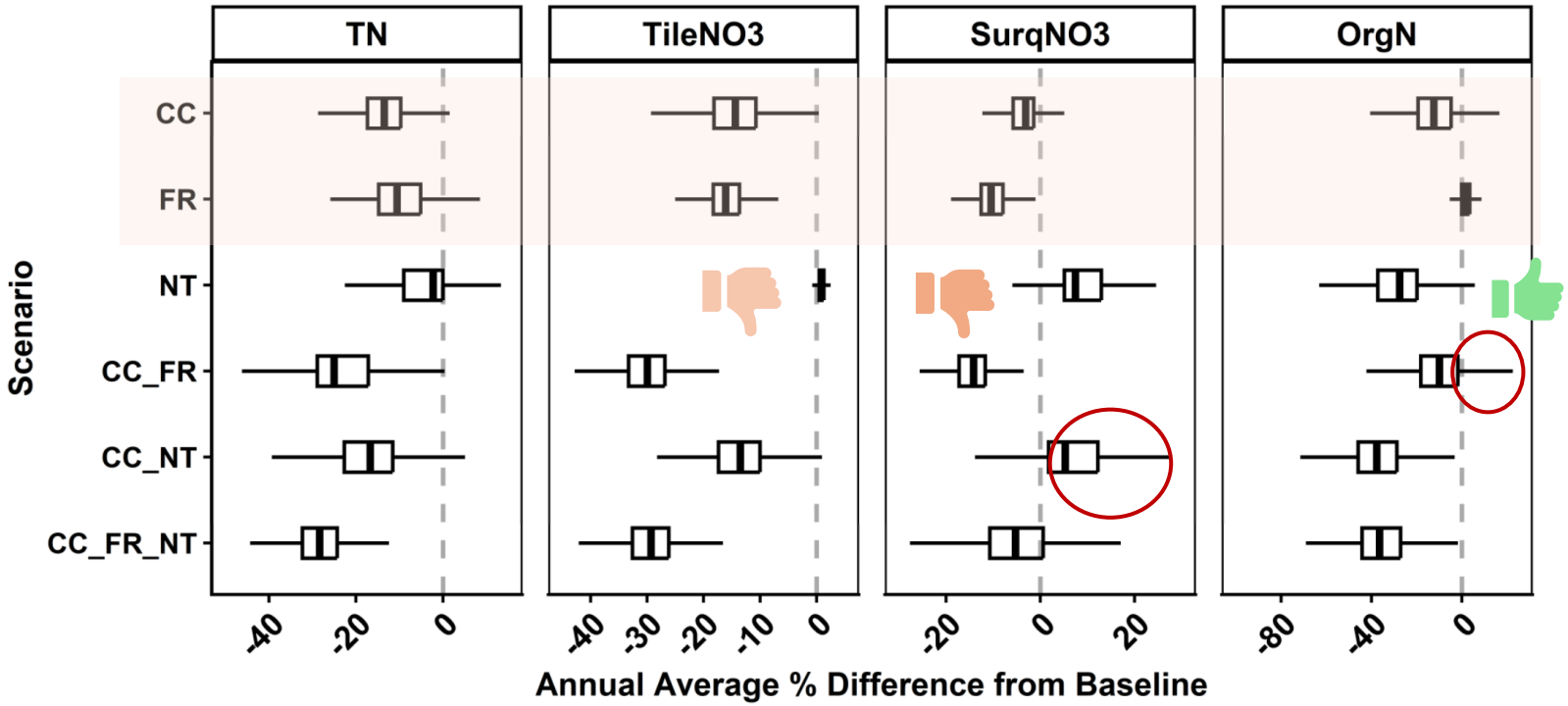
Tested Scenario

Conservation Practices	Implementation Details
Cover Crop (CC)	• Winter Rye applied to crop lands • **Timing:** Planted immediately after harvest, terminated (killed) before next crop planting.
No-Till (NT)	• Applied to croplands • Zero tillage: Minimum disturbance of the upper soil layer.
Fertilizer Reduction (FR)	• Applied to crop lands • 20% Reduction in applied N (McLellan et al., 2015, JAWRA)

Stacked practices
CC-FR
CC-NT
CC-FR-NT



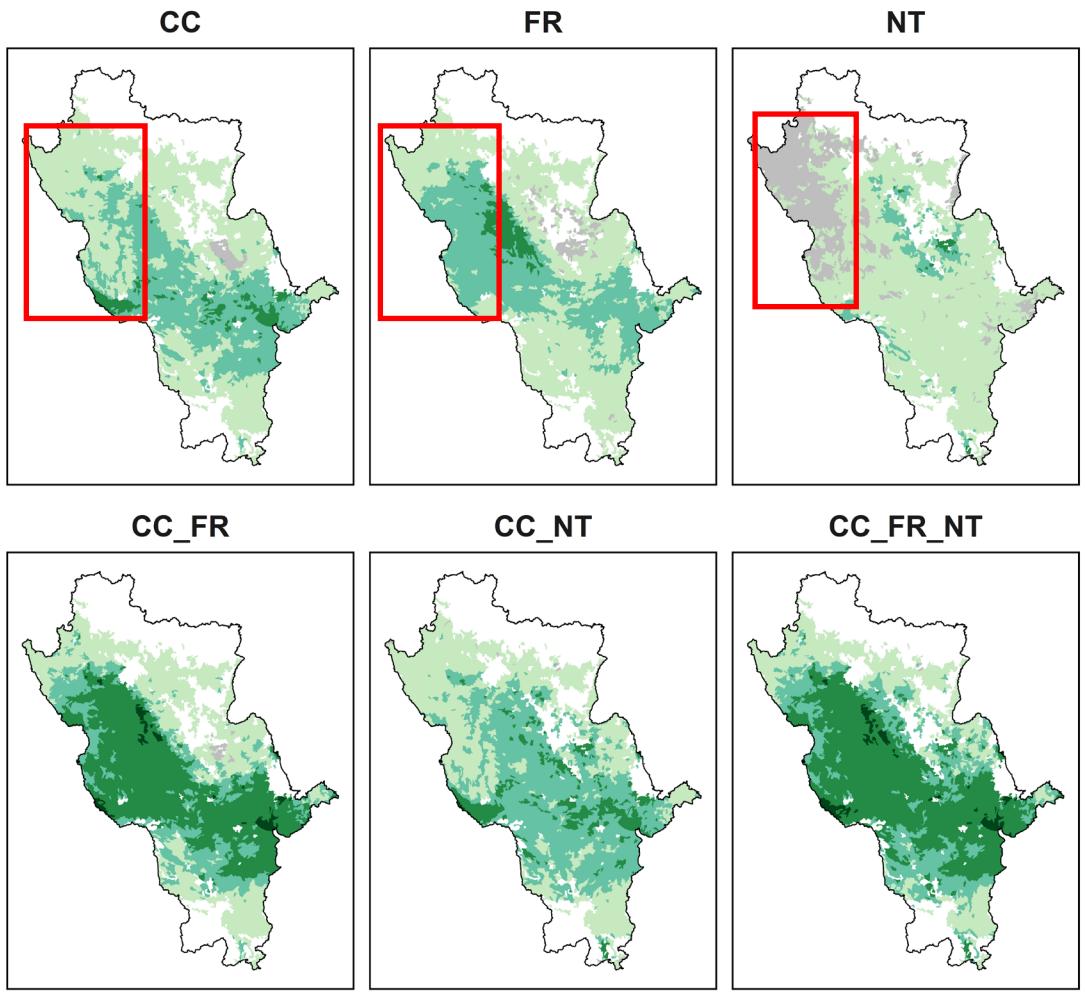
Results

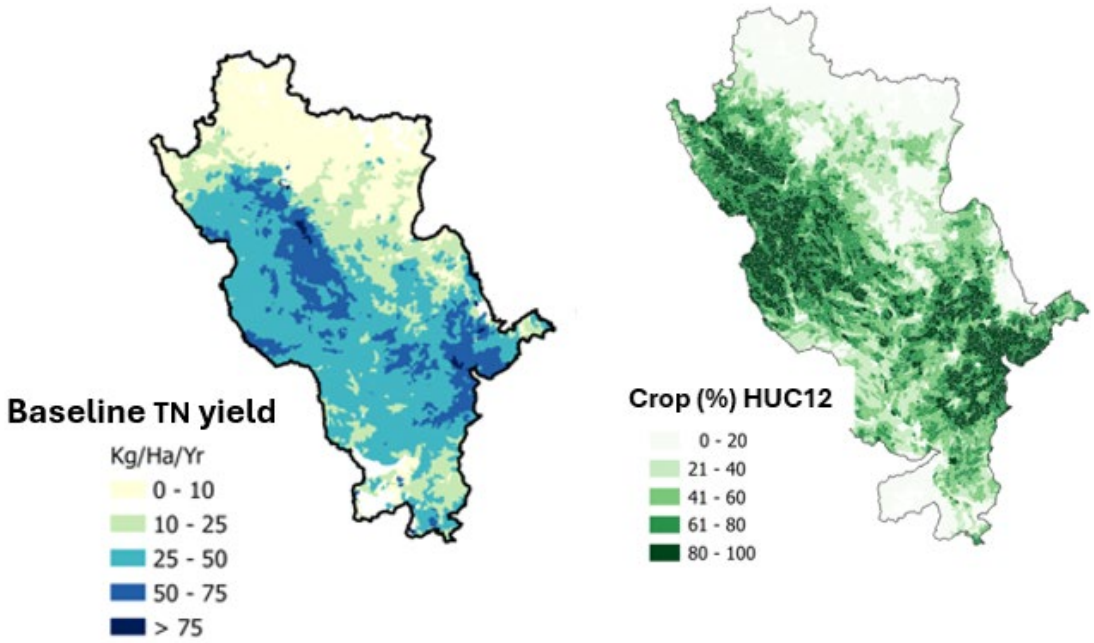


*Nitrogen Yield from Crop fields aggregated at HUC12 scale

- CC and FR are effective for TN reduction(median 10%), and both the practices are effective to reduce the losses though tile and surface runoff.
- FR has almost no impact on losses through soil erosion.
- No-Till reduces organic nitrogen loss (from reduced soil erosion).
- No-till increases both surface and subsurface nitrate losses, resulting in minimal overall nitrogen reduction relative to other scenarios
- Stacked practices significantly greater reduction in TN yield (20 – 40%) compared to single practices (10%).

Results

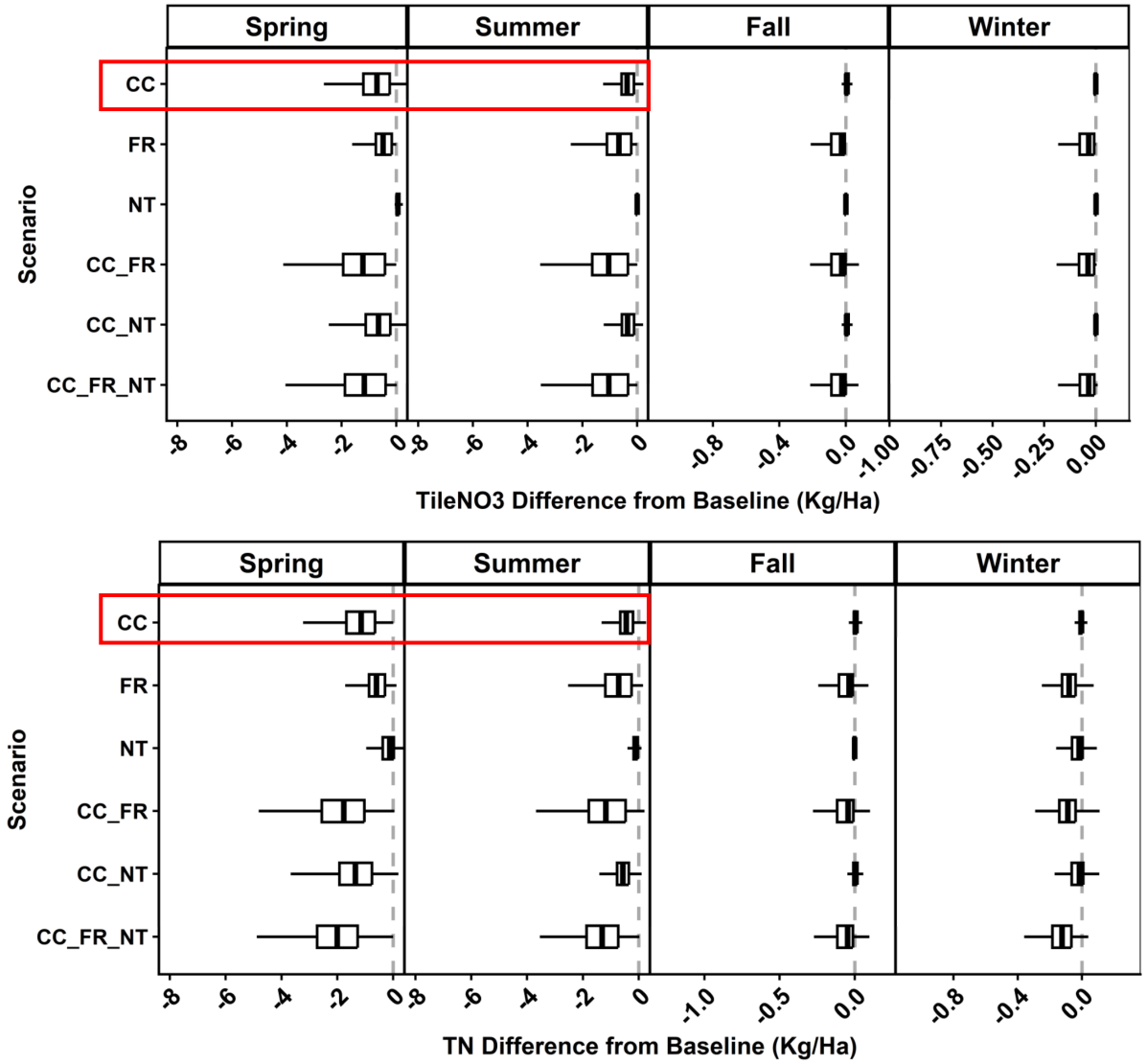




- CC and FR can lower the TN yield up to 10 kg/ha in most of the crop fields in tiled region.
- FR performs better than CC in northwestern tiled watersheds; NT increases TN yields. Stacked CC–FR practice most effective, reducing TN up to 20 kg/ha.

*TN Yield from Crop fields aggregated at HUC12 scale

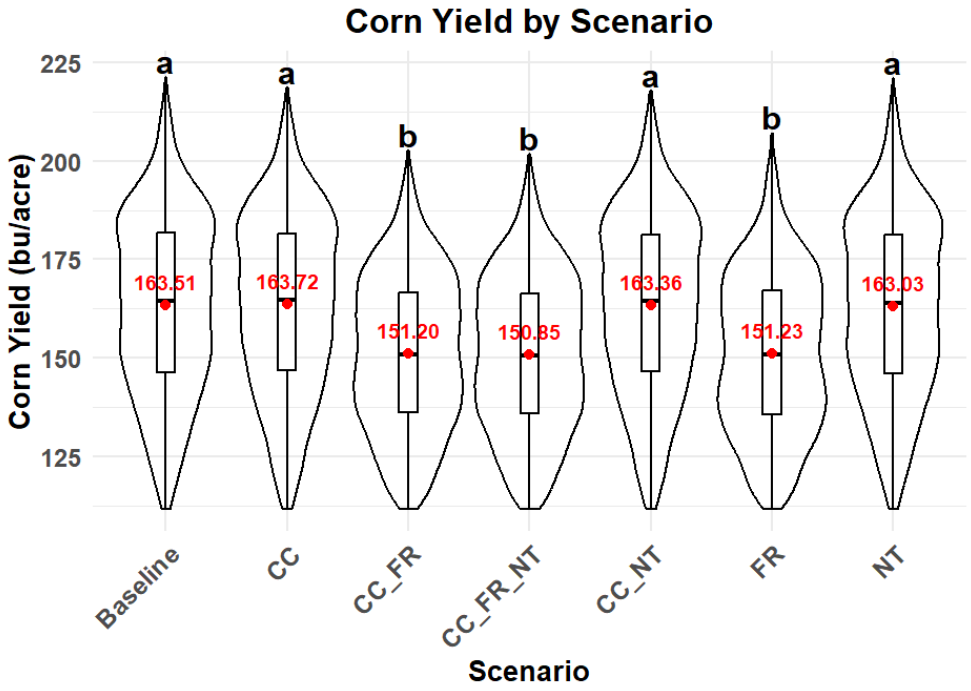
Seasonal analysis

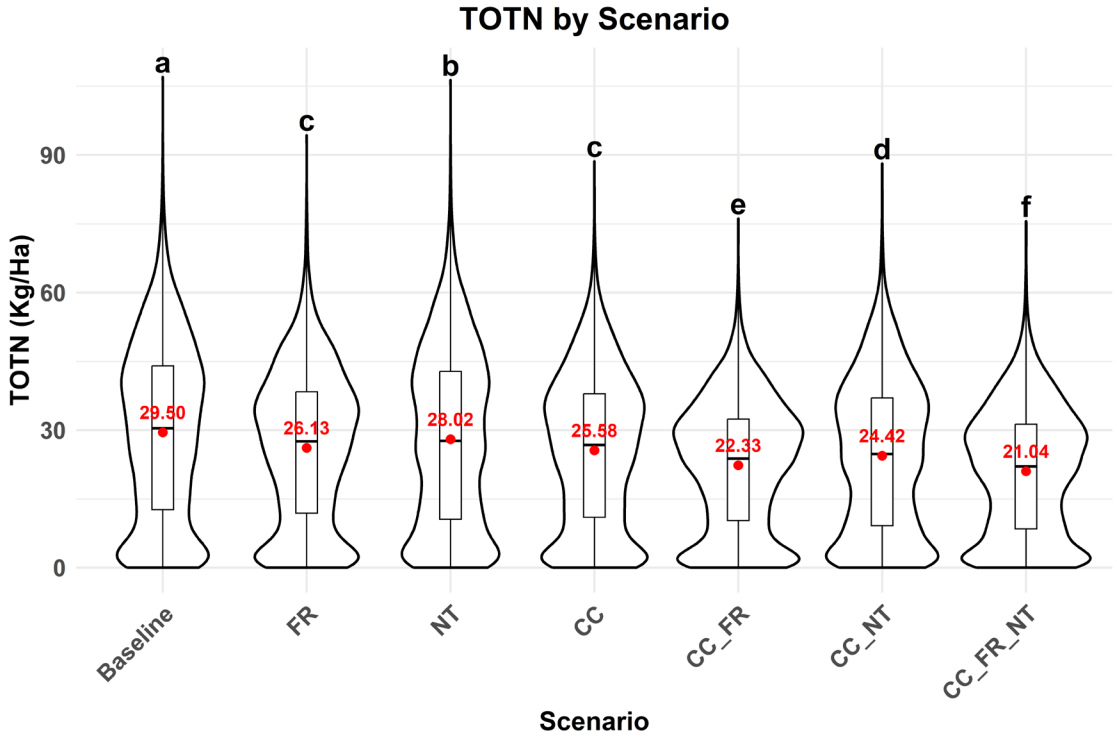


- The effectiveness of conservation practices is **highly seasonal.**
- The larger reduction are observed during the **Spring** and **Summer** seasons for both tile nitrate and TN yield and minimal Impact in Fall/Winter.
- Fall-planted cover crops are most effective in spring, when leaching and runoff occur from snowmelt and rainfall, but may need a companion practice to reduce nutrient loss during the dormant season.

Crop Yield vs Loss

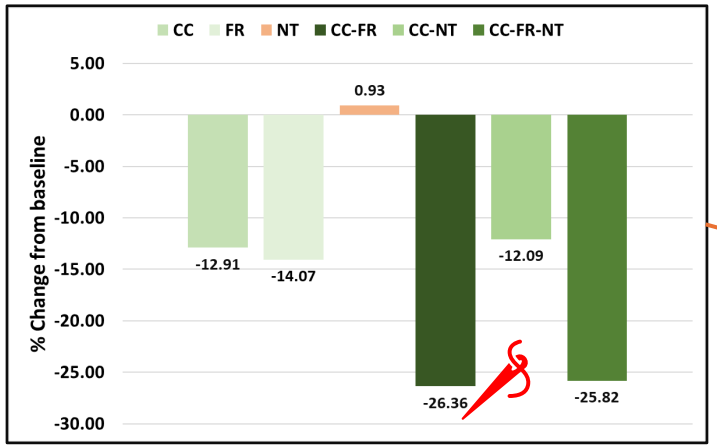
Different letters indicate significant difference at α = 0.05 level, Tukey's HSD test

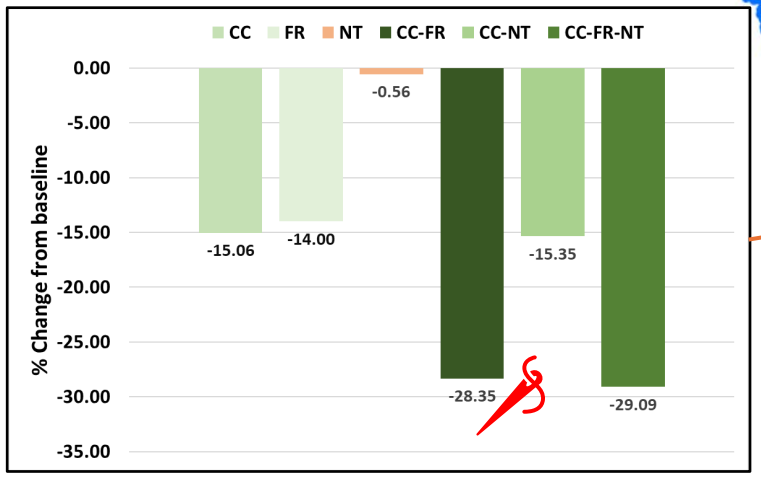


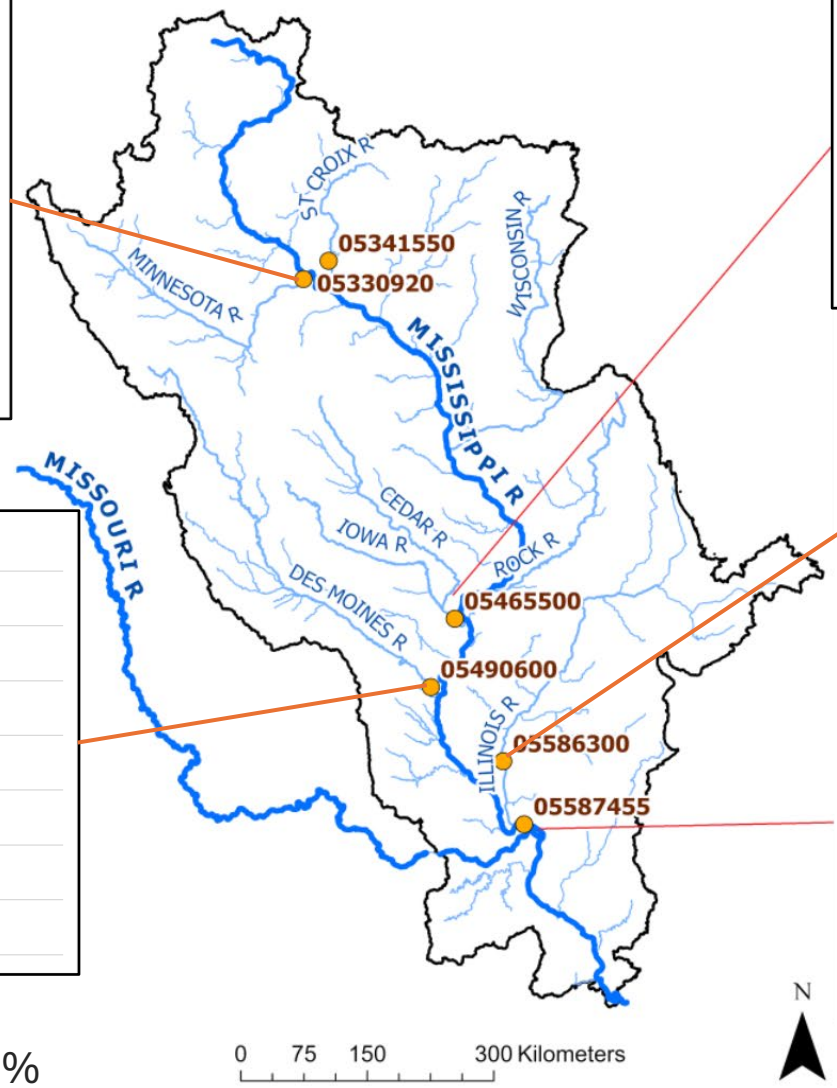


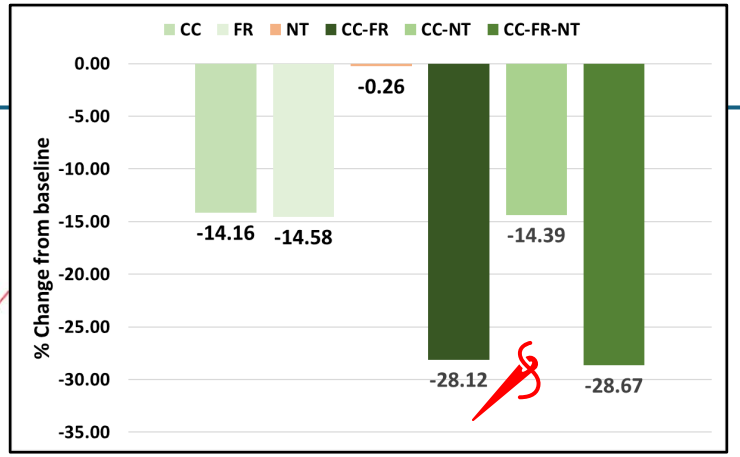
While fertilizer reduction and stacked practices substantially decrease nitrogen losses, they also result in moderate yield penalties (~10–15 bu/ac less). Conversely, practices like CC and NT maintain yields close to baseline but provide less TN reduction.

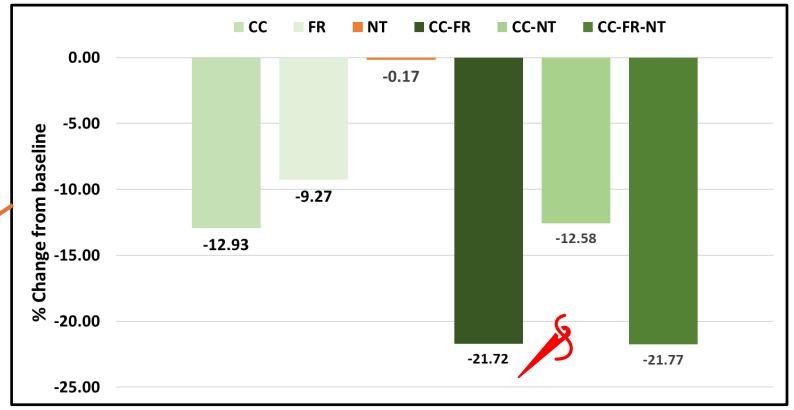
Channel load

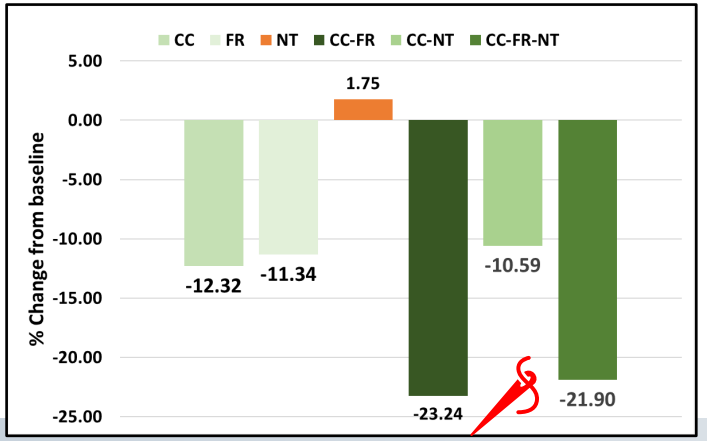












CC-FR reduces TN load by ~23%

Summary

- Cover crops and fertilizer reduction target subsurface and surface nitrogen pathways , while no-till helps conserve soil but can intensify nitrate leaching. Integrating CC and FR provides balanced nitrogen reduction.

- Understanding the seasonal dynamics of nutrient loss under different conservation practices can help refine and target management recommendations more effectively.

- Fertilizer rate reduction is effective for both surface and subsurface nutrient loss reduction , split and timely application may not affect the crop yield.

- Targeted conservation practices such as saturated buffer strips to reduce the nutrient loss through surface runoff and soil erosion need to be tested.