On-farm tile monitoring for conservation practice evaluations: lessons from Illinois

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Professor

https://margenot.cropsciences.illinois.edu/

Indiana Farm Bureau

Drainage School

August 26, 2026

Nutrient management for agricultural productivity, profitability, and environmental quality

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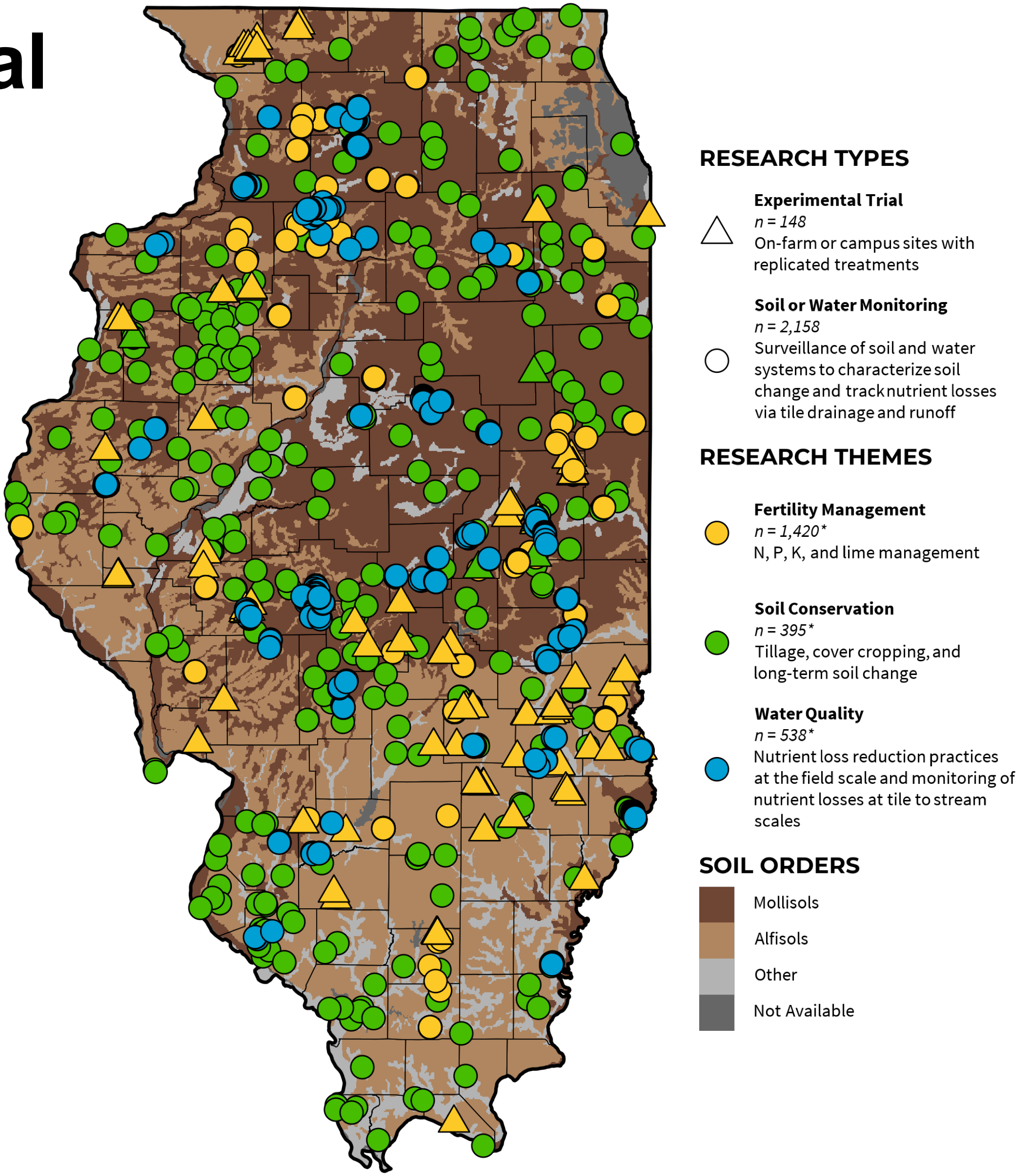

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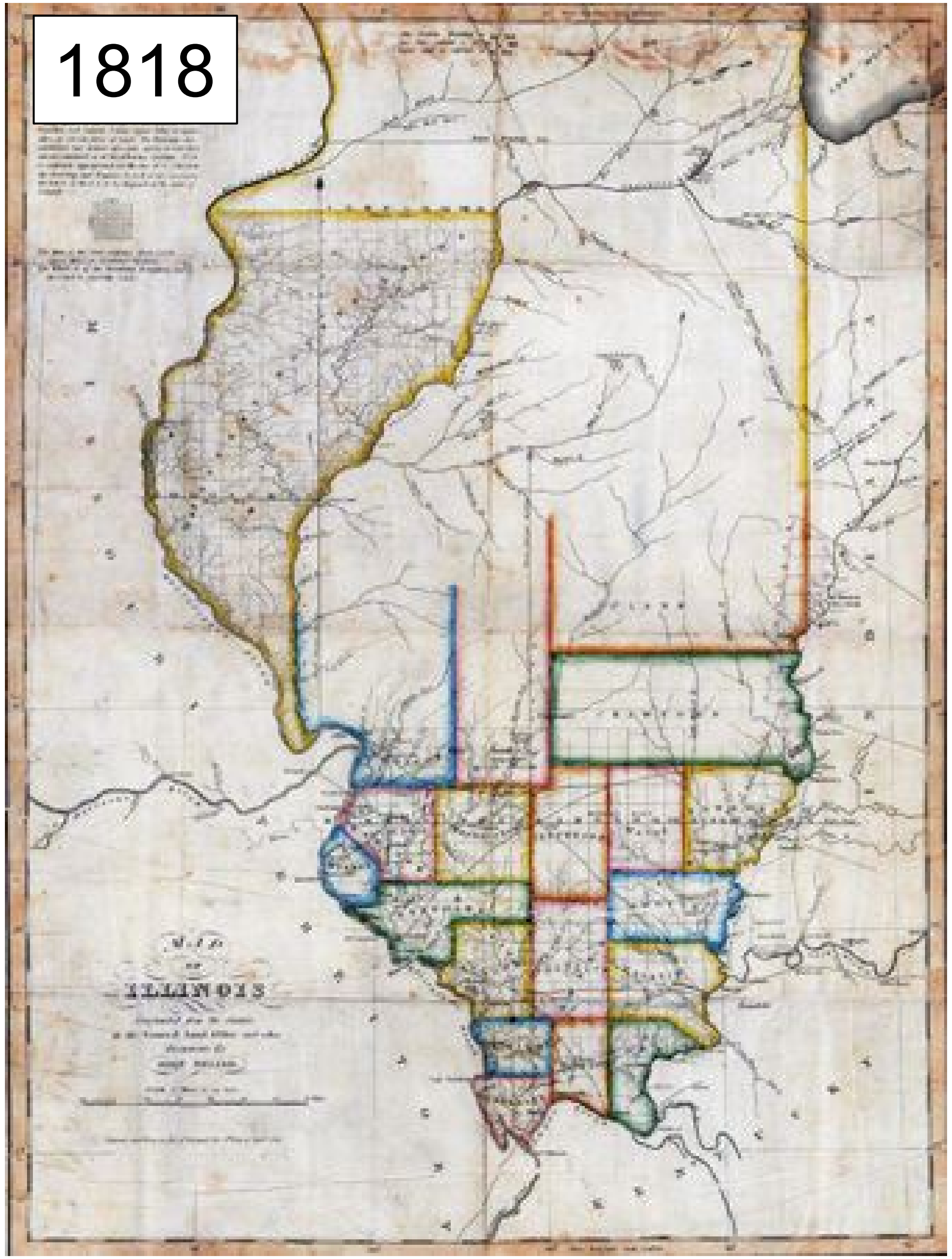
Tile drainage and agriculture in the US Midwest

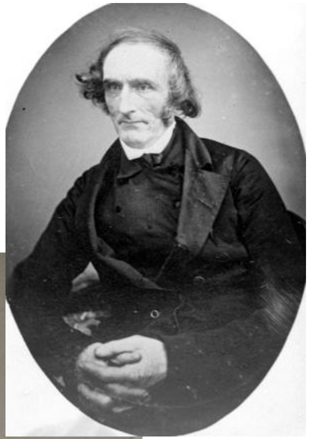


"The climate of the Illinois is more agreeable than that of England. The sky is brighter, the air more transparent, but at present, less healthy. The country is intersected with innumerable streams whose overflowings produce swamps, which partially dry up in the summer, filling the air with mosquitoes and noxious effluvia."

- *Elias Pym Fordham, 1818*

“Burying crockery in the ground”

John Johnston: the father of tile drainage in America, emigrated to NY from Scotland in 1821



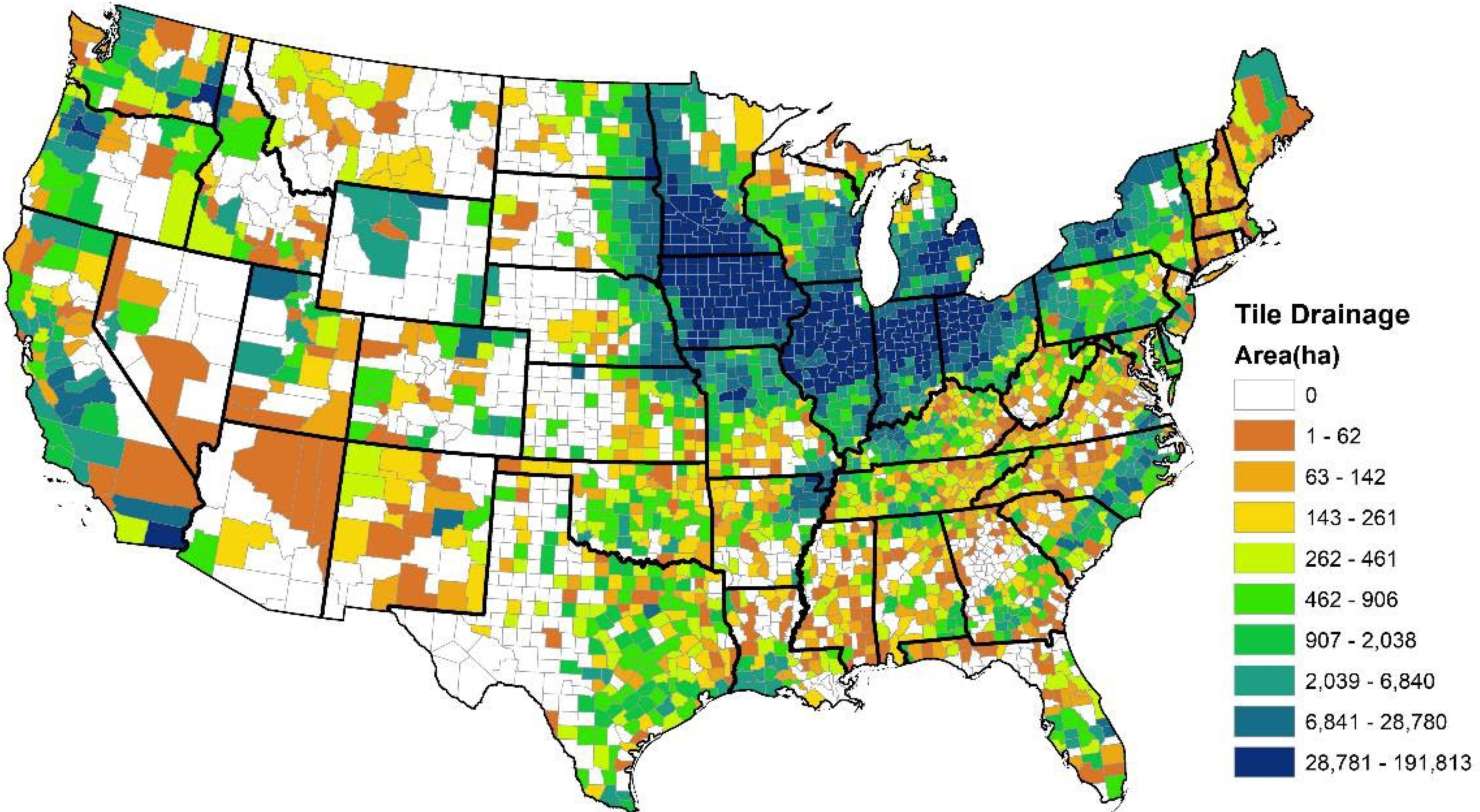
"We the men who started the tile work did so with a motive to benefit the town and country."

Signed T.P. LaRue of Scranton, Iowa

Photo Credit: Greene County Historical Society's museum in Jefferson, IA

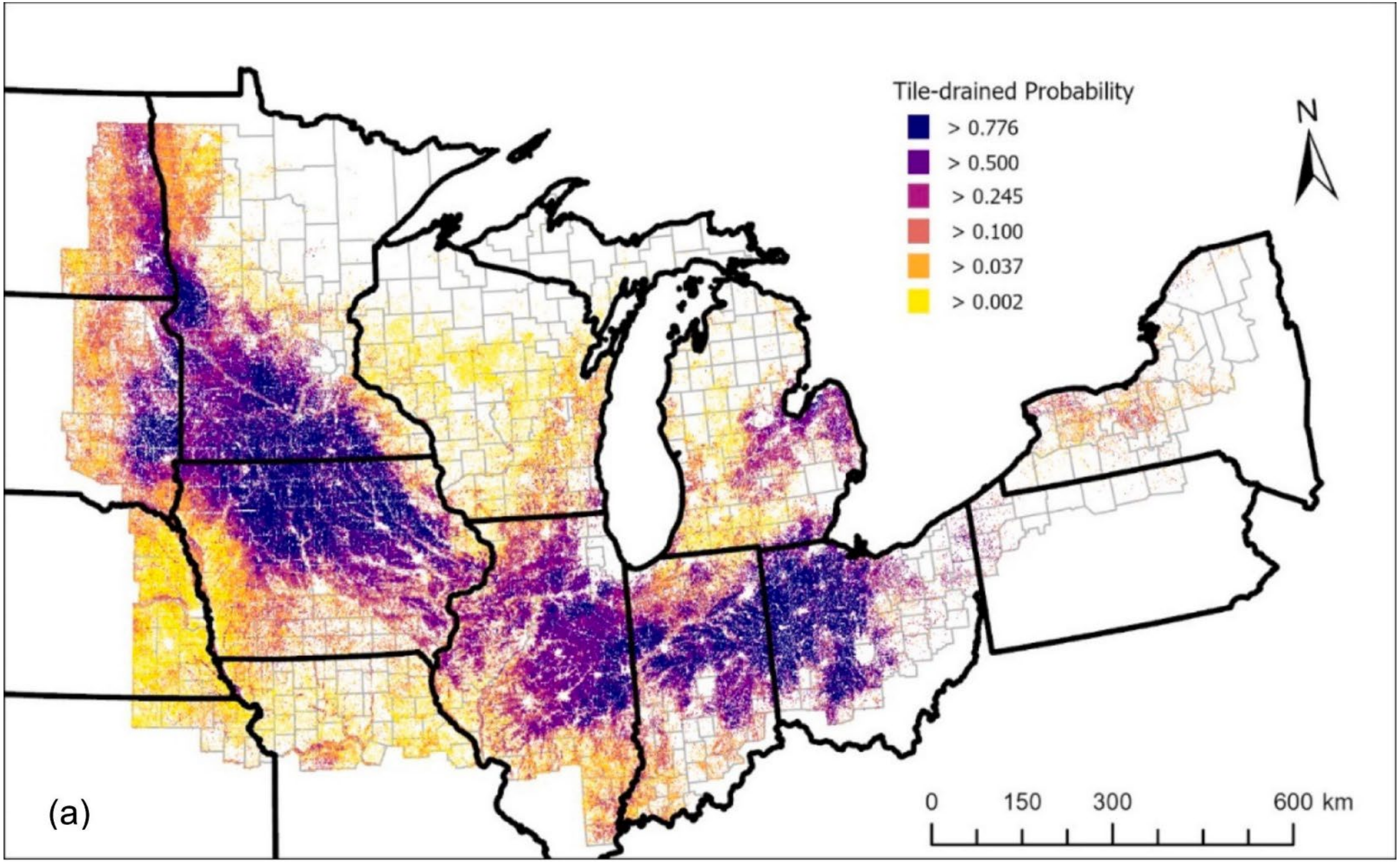
Tiling today

Subsurface tile drainage is concentrated in the Midwest



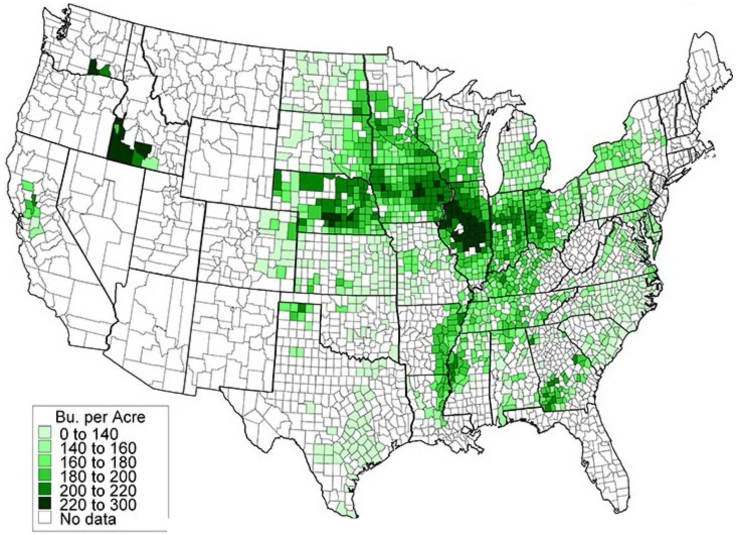
Valayamkunnath et al 2020 *Scientific Data* 7:257

…and in the Corn Belt

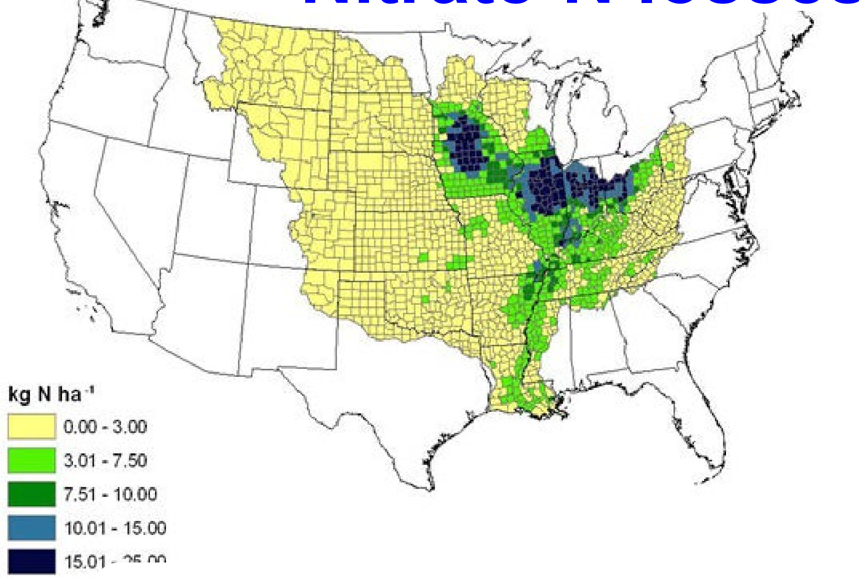


Tiling necessary for productive agriculture, but has trade-offs

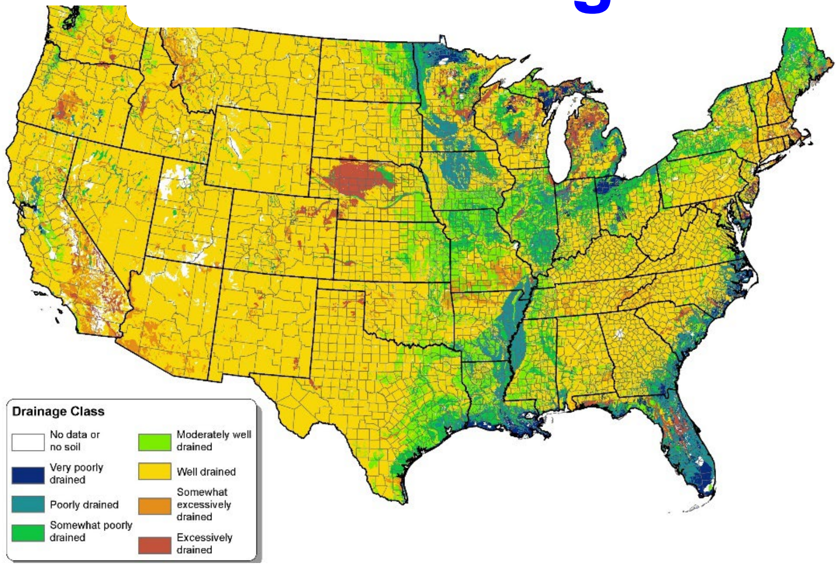
Yields



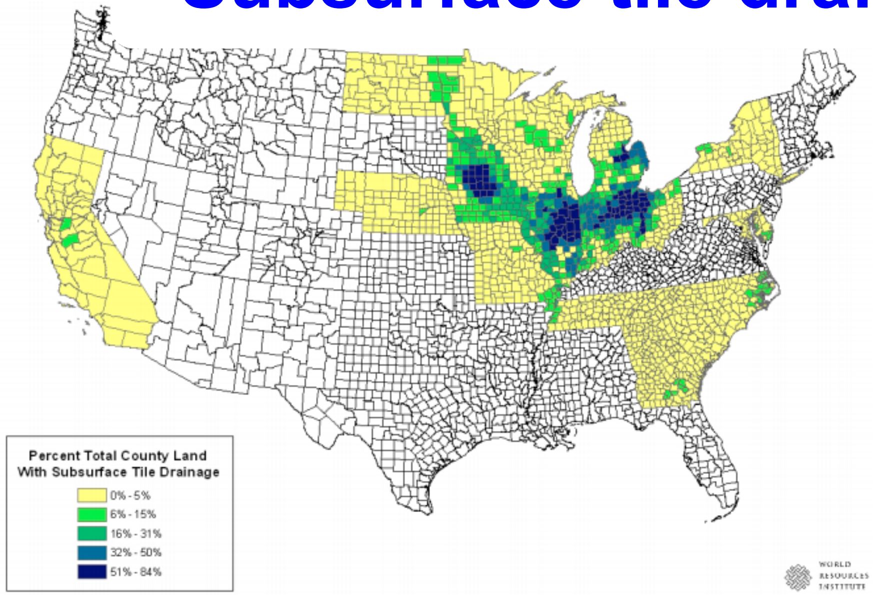
Nitrate-N losses



Soil drainage class



Subsurface tile drainage



Tile export of nutrients: a long history, but different emphasis

- By the mid-1800s, that nutrients were being exported from fields via subsurface drainage tiles was understood – and even being measured

- Motivation was *agronomic*: are we losing "**plant food**"?

- Water quality interests, focused on N and P, came later (1970s and onward)

Kentucky
Agricultural Experiment Station
UNIVERSITY OF KENTUCKY
Lexington, Ky.

BULLETIN NO. 237
(RESEARCH BULLETIN)

THE REMOVAL OF MINERAL PLANT-FOOD
BY NATURAL DRAINAGE WATERS.

By
J. S. McHARGUE and A. M. PETER

Lexington, Kentucky
November, 1921

Fertilizer and manure are not the only sources of nutrient losses

Peroxide of iron
Lime
Magnesia
Potash
Soda
Chlorine
Sulphuric acid
Phosphoric acid
Soluble silica
Ammonia
Nitric acid
Loss by ignition carbonic acid and difference

Farmyard-manure contains no nitrates, but the drainage-water of the field manured with farmyard-manure contained 5·28 grs. of nitric acid.

In the adjoining unmanured plot the drainage-water, collected on the same day, contained only 1¾ grs. of nitric acid, and the second unmanured plot 2·43 grs. of nitric acid.

It is worthy of observation that the drainage-water of the land to which nitrate of soda was applied in spring, contained no more nitric acid than the water from the unmanured plot, showing that soils have not the power of retaining nitrates.

Although some of the experimental plots were dressed with considerable quantities of ammoniacal salts, the drainage-waters contained only minute quantities of ammonia.

Practically the ammoniacal salts were gradually and completely oxidized and converted into nitrates, which passed away by degrees as nitrates in the drainage-water.

Rothamsted Experiment: England, 1844

Other nutrients besides N can be lost by tiles

2C. REMOVAL OF PLANT NUTRIENTS IN DRAINAGE WATERS[1]

J. A. Bizzell[2]

The removal of certain of the plant nutrients from the soil by drainage waters is of considerable economic importance. A large amount of information bearing on this subject has been published, but unfortunately a strict interpretation of the reported data does not lead to many definite conclusions. Satisfactory equipment for the quantitative determination of losses in drainage and the analytical work involved are expensive. The result has been that the number of strict and conclusive comparisons under a given set of soil and climatic conditions has been small. Again, there is some reasonable doubt as to the adequacy of the methods employed.

Two general methods have been followed. The first consists of the chemical analysis of waters from rivers, small streams, and tile drains. Since there seems to be no satisfactory way of measuring the total amount of drainage water, this method does not show us the total losses of plant nutrients by leaching. Reported data also indicate that generally river water contains much less soluble matter than does water issuing from tile drains or from drain guages.

In the second method use is made of lysimeters or drain guages—water tight vessels, containing soil so arranged that the water percolating through the soil can be collected, measured, and analyzed.

The drain guages at Rothamsted, England, and Aberdeen, Scotland, were built around a block of soil *in situ*. In other cases the lysimeters appear to have been filled after the soil was thoroughly

[1]Paper read by title as a part of the symposium on "Soil Deterioration" at th meeting of the Society held in Chicago, Ill., November 16, 1925.

[2]Professor of Soil Technology, Cornell University, Ithaca, N. Y.

REMOVAL OF CALCIUM

REMOVAL OF MAGNESIUM AND POTASSIUM

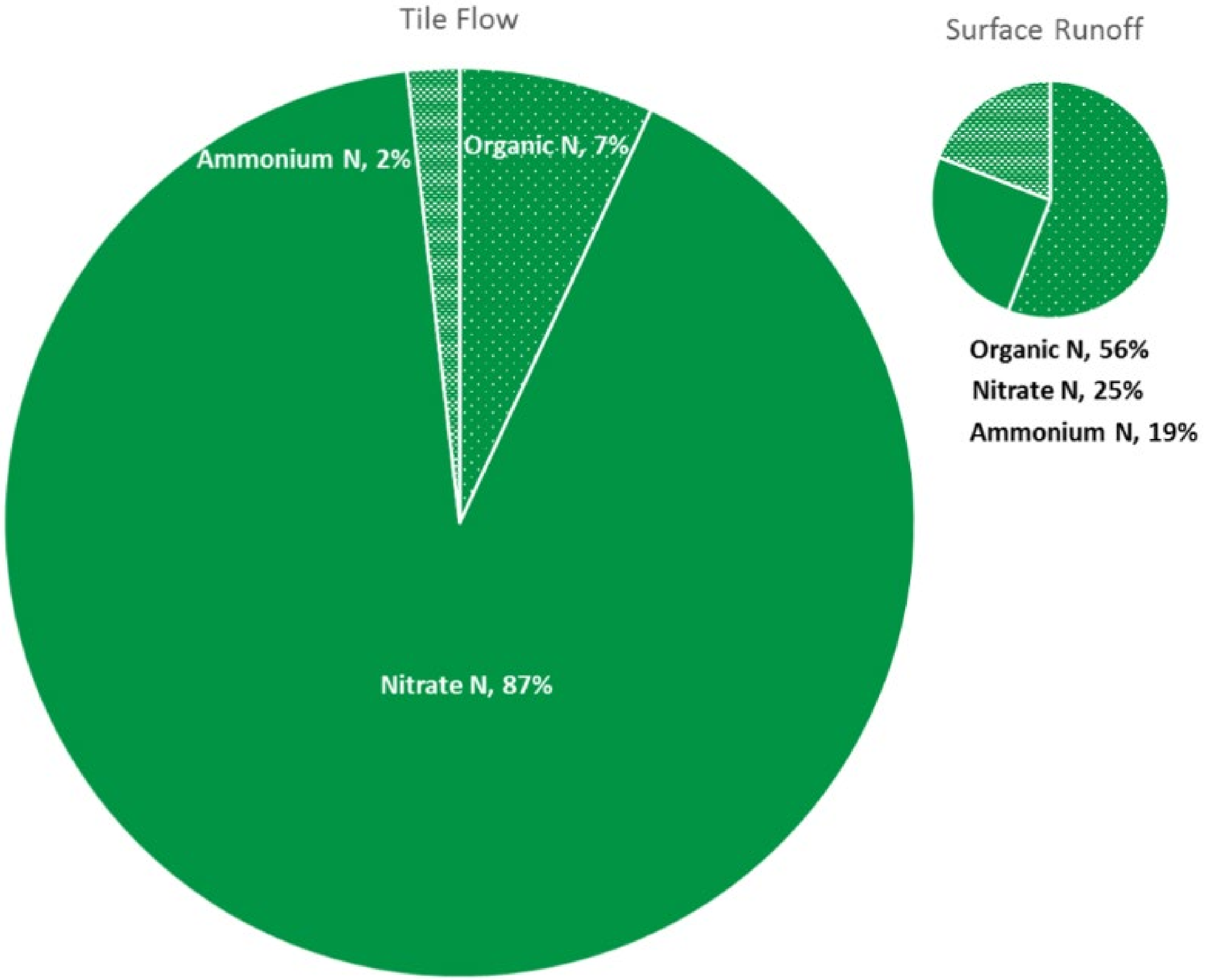
REMOVAL OF NITROGEN

REMOVAL OF SULFUR

REMOVAL OF PHOSPHORUS

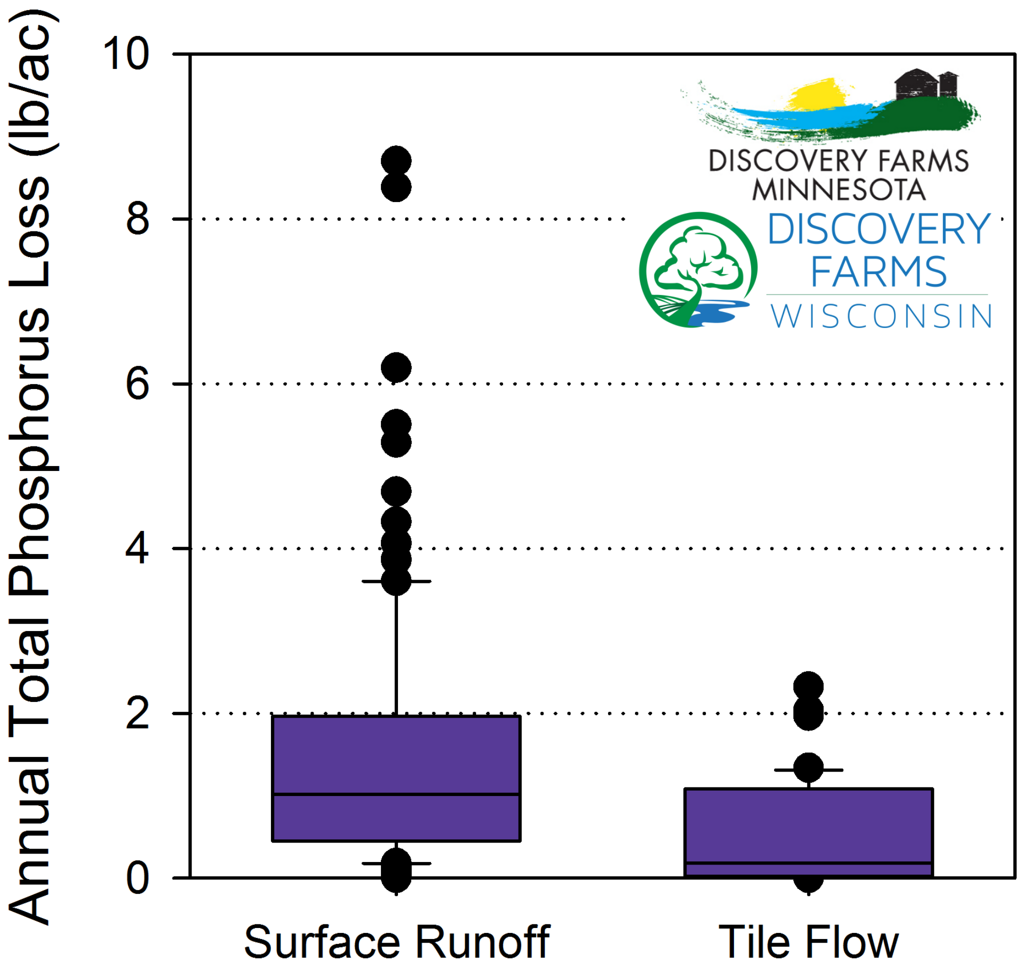
NY, 1925

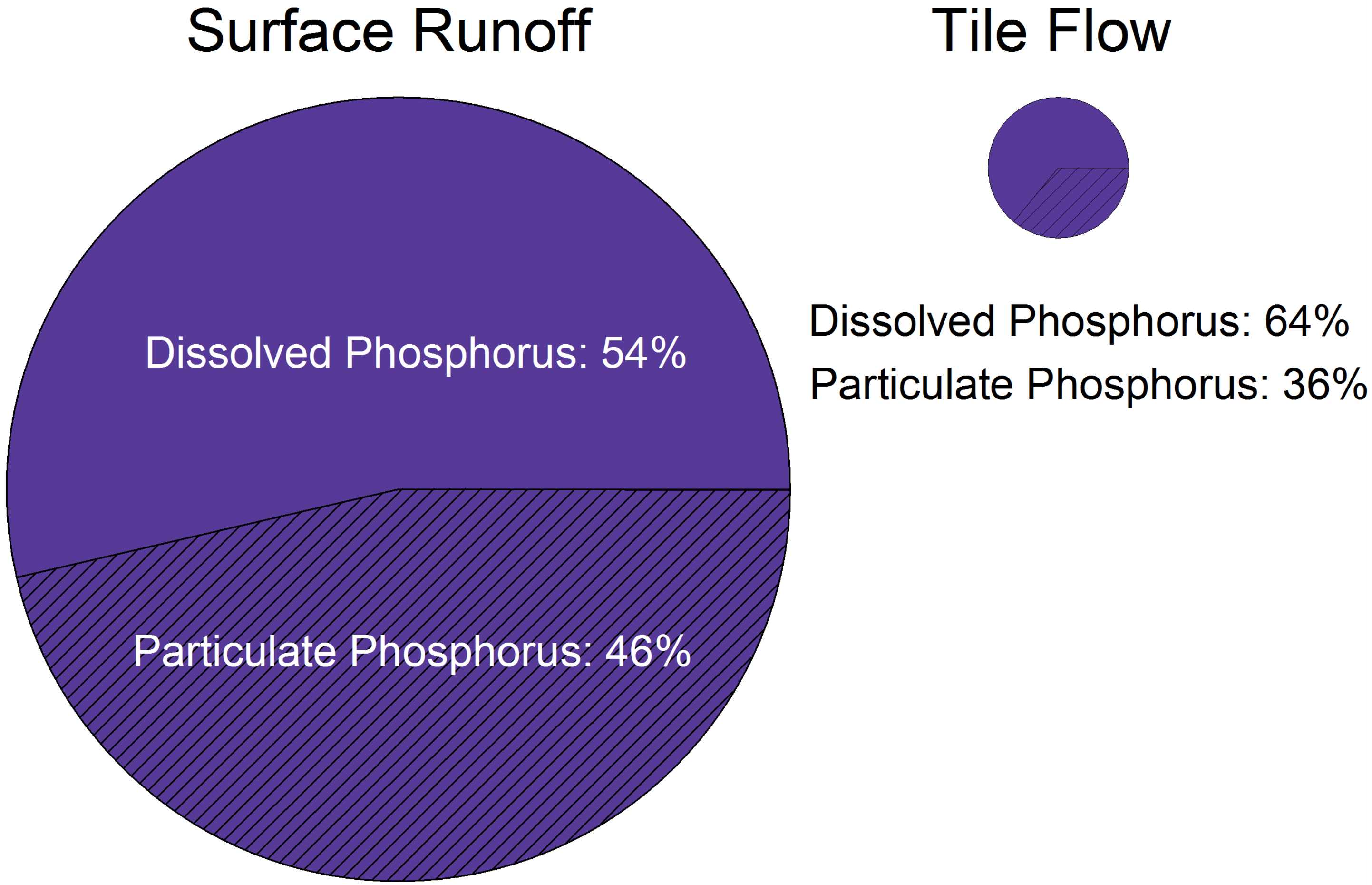
What are magnitudes and proportions of nitrogen export?



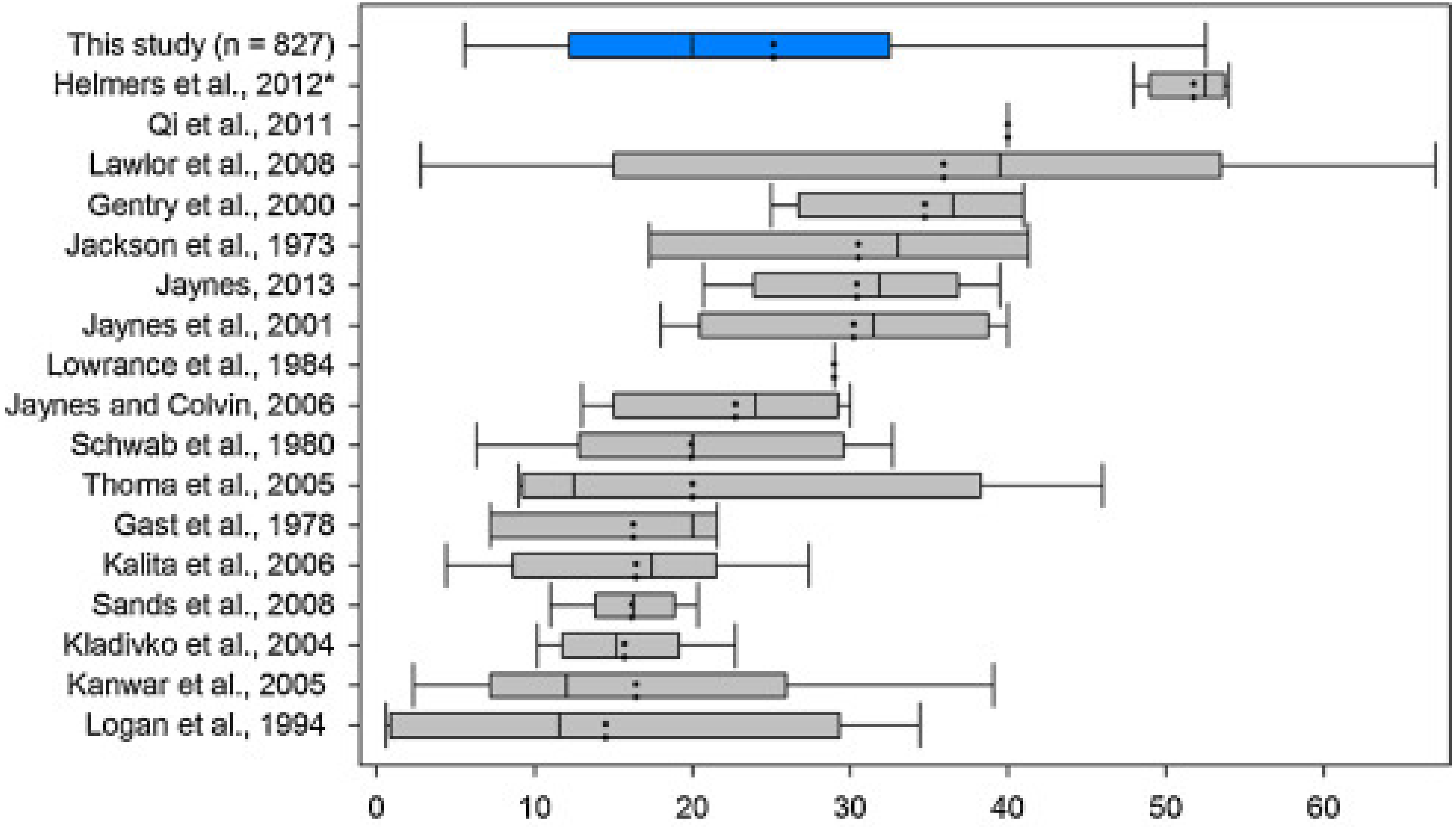
- In general, most tile N is nitrate-N
- Ammonium-N is both less mobile and oxidizes (“nitrifies”) to nitrate-N
- More organic N than ammonium-N
- More N loss via tile than surface run-off *in general*

What are magnitudes and proportions of phosphorus export?





How much water is discharged?
Drainage coefficient varies from 5-40%



% in magnitude of precipitation

MANAGE Drain Load database; Christianson et al., 2016

Not just nutrients: greenhouse gas emissions

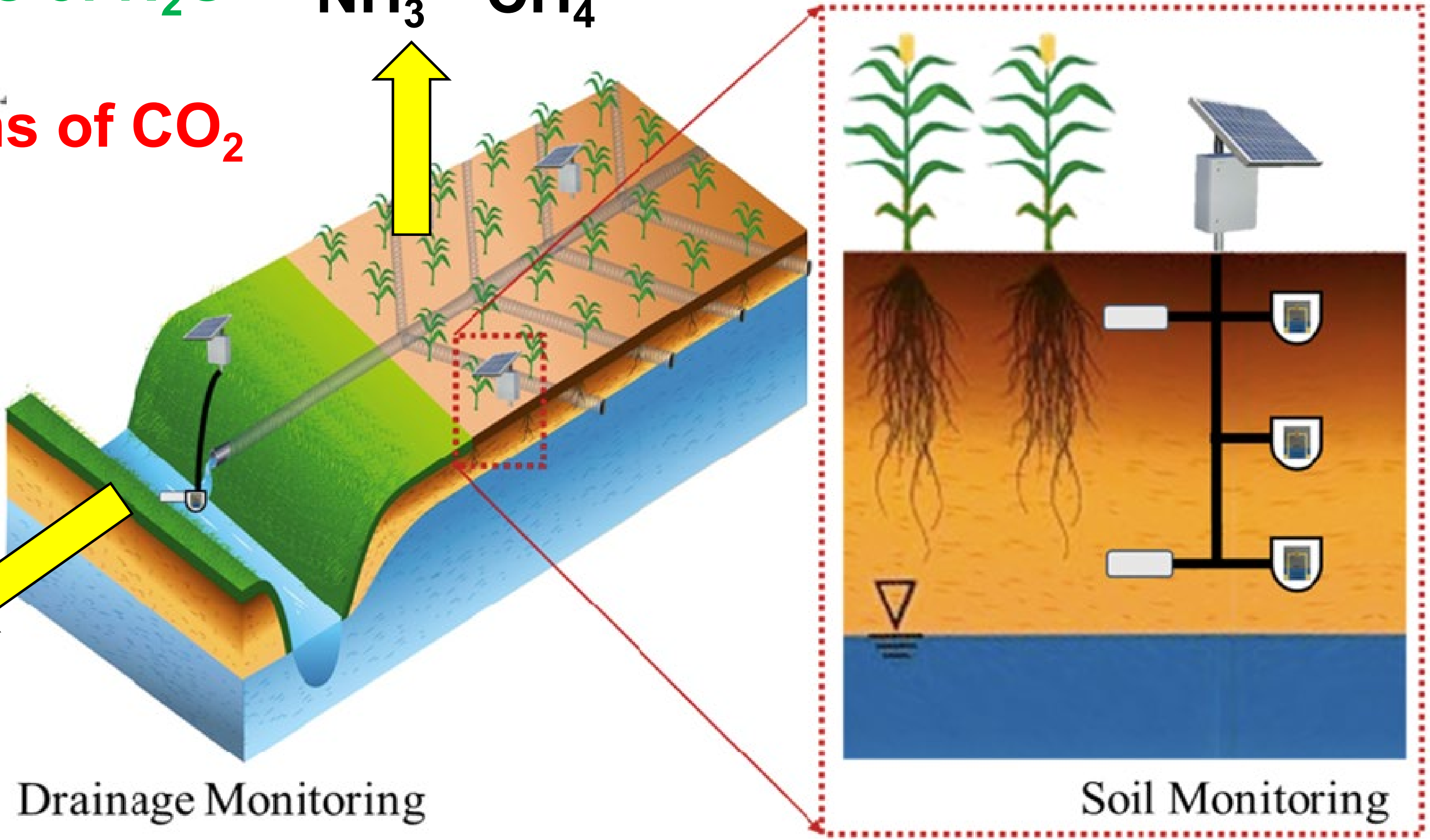
Greenhouse gases:
Lower emissions of N_2O and CH_4
Higher emissions of CO_2

N_2O CO_2
NH_3 CH_4

Tile export:
More losses of nitrate and phosphate

NO_3^-

PO_4^{3-}



Tile drainage has been used "passively": untapped potential to design and manage more actively for greater sustainability

PERSPECTIVE
https://doi.org/10.1038/s41893-019-0393-0
nature sustainability

Sustainable intensification of agricultural drainage

Michael J. Castellano[1,2]*, Sotirios V. Archontoulis[1], Matthew J. Helmers[3], Hanna J. Poffenbarger[4] and Johan Six[2]

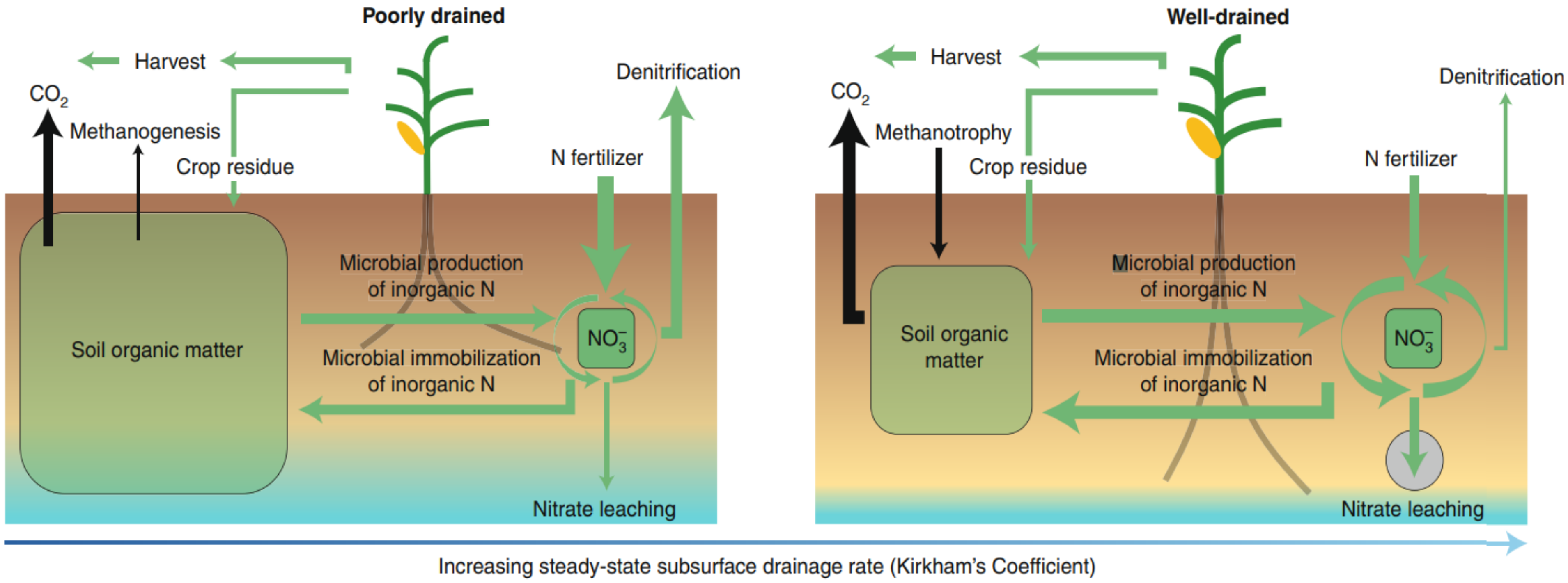
Artificial drainage is among the most widespread land improvements for agriculture. Drainage benefits crop production, but also promotes nutrient losses to water resources. Here, we outline how a systems perspective for sustainable intensification of drainage can mitigate nutrient losses, increase fertilizer nitrogen-use efficiency and reduce greenhouse-gas emissions. There is an immediate opportunity to realize these benefits because agricultural intensification and climate change are increasing the extent and intensity of drainage systems. If a systems-based approach to drainage can consistently increase nitrogen-use efficiency, while maintaining or increasing crop production, farmers and the environment will benefit.

Tiles *facilitate* intensification

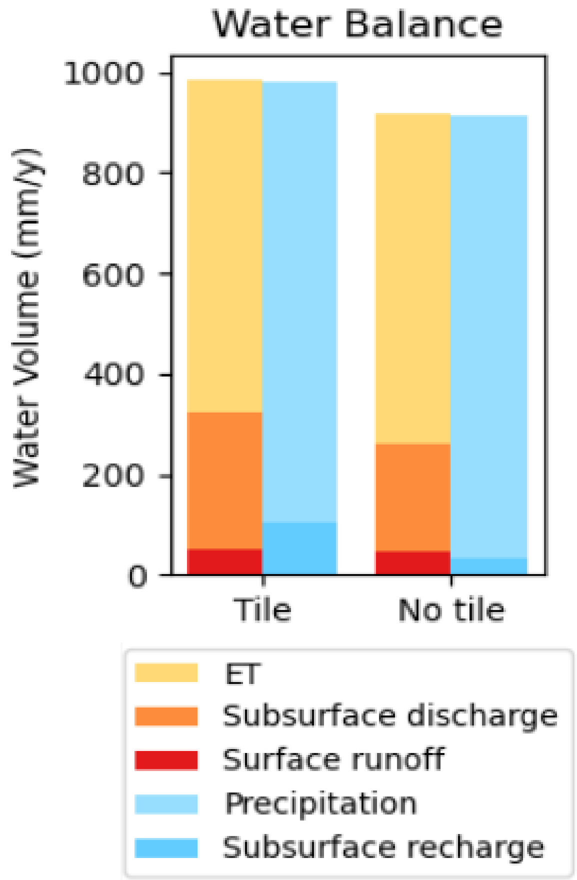
Greater utilization of **soil profile**

Greater utilization of added and native **nitrogen**

Greater **water** input-output (balance)



Castellano et al 2019 *Nature Sustainability* 2:914



Ma et al 2024. *EGU* Preprint

Tile drainage in the crosshairs

- Tile drainage: good or bad?

s 2°F

The Minnesota Star Tribune

eEdition

The Latest

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Britain's Princess of Wales says her cancer is in remission

7 MINUTES AGO
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Brooks: Catholic church flashes anti-drag queen message, hastily backpedals

AGRICULTURE

Minnesota's fertile farm fields have a cost, as this summer's floods showed

Replumbing fields, or "tiling" them, have made southern Minnesota a vital part of the nation's corn belt.

By Christopher Vondracek
The Minnesota Star Tribune

NOVEMBER 23, 2024 AT 7:00AM

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'We should have a sense of urgency' as farm drainage tile drives nutrient pollution

Agricultural drainage tile, a system used by farmers to increase crop yields, is a main contributor to excess nutrients in wa

by **Joy Mazur, Columbia Missourian** June 19, 2024

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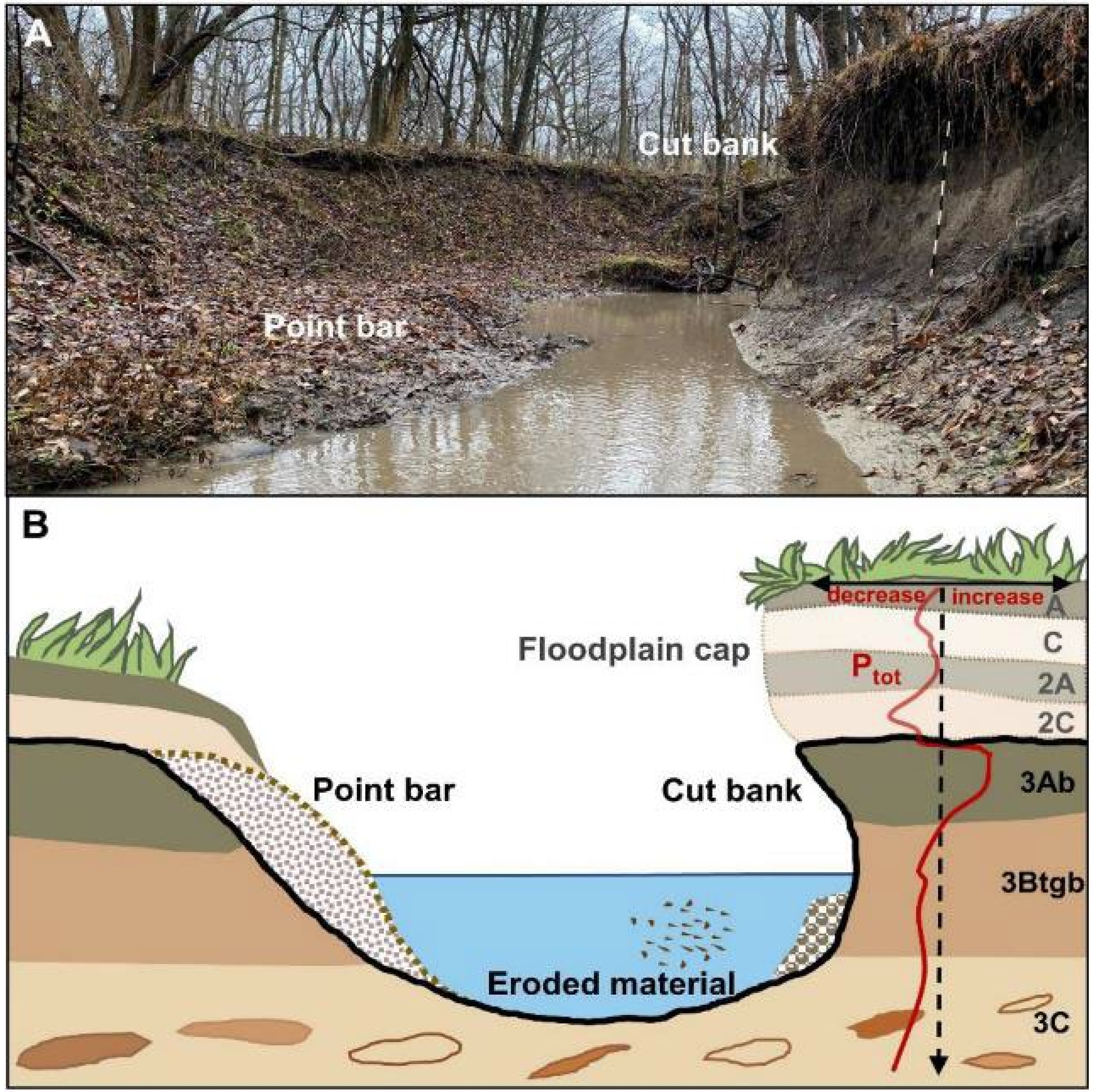
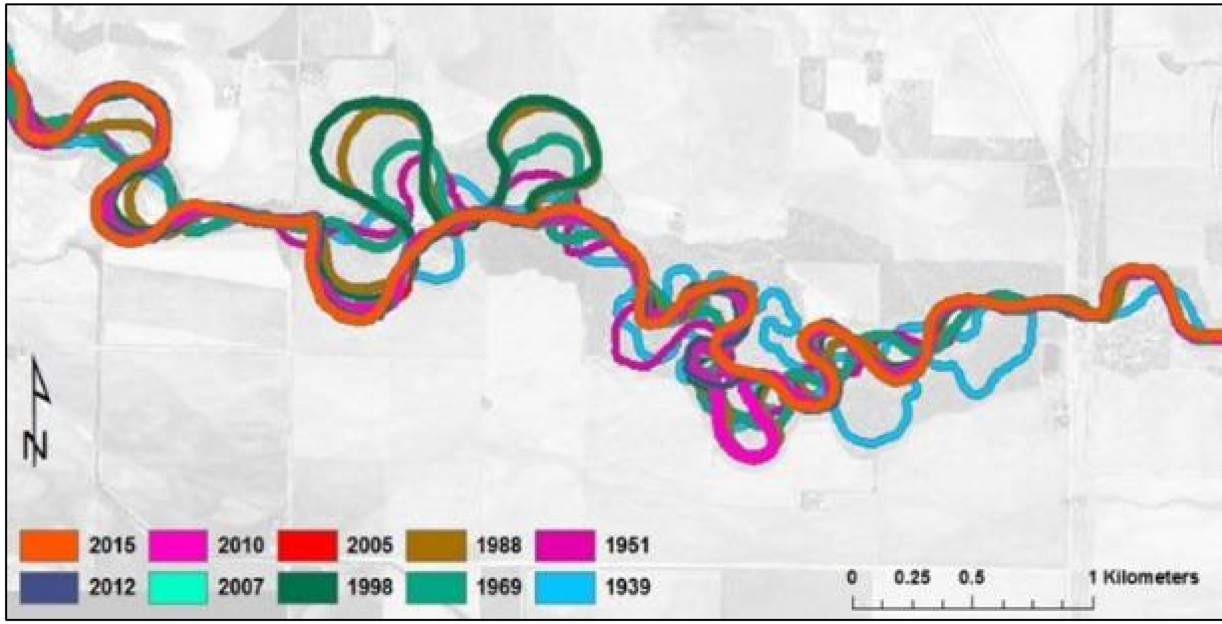
Why you can trust Investigate Midwest

Streambank erosion: P transfers from land to water





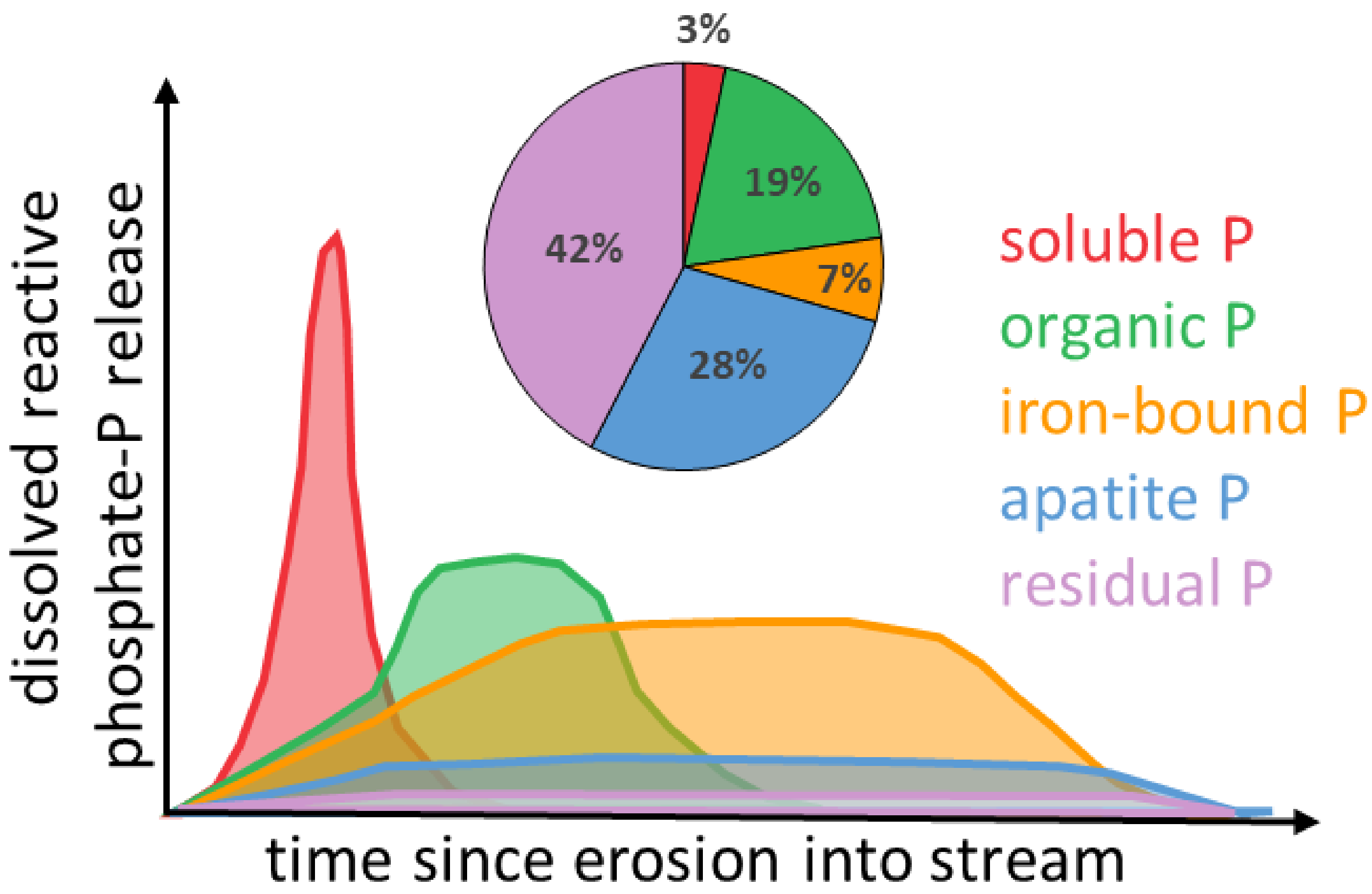
Mackinaw River (Illinois) migration from 1939-2015 identified by rectifying aerial imagery

- Meandering streams in flat topography especially prone to erosion
- Loads sediment as streambank soil
- Soils eroded into the stream contain P – most of it is native, from parent material (i.e., *not* fertilizer)

Zhou, Li & Margenot. *Geoderma* 2022. 424: 115989

The form of P is overlooked but entails lag times

Example of P forms in streambank soils and theoretical release rates

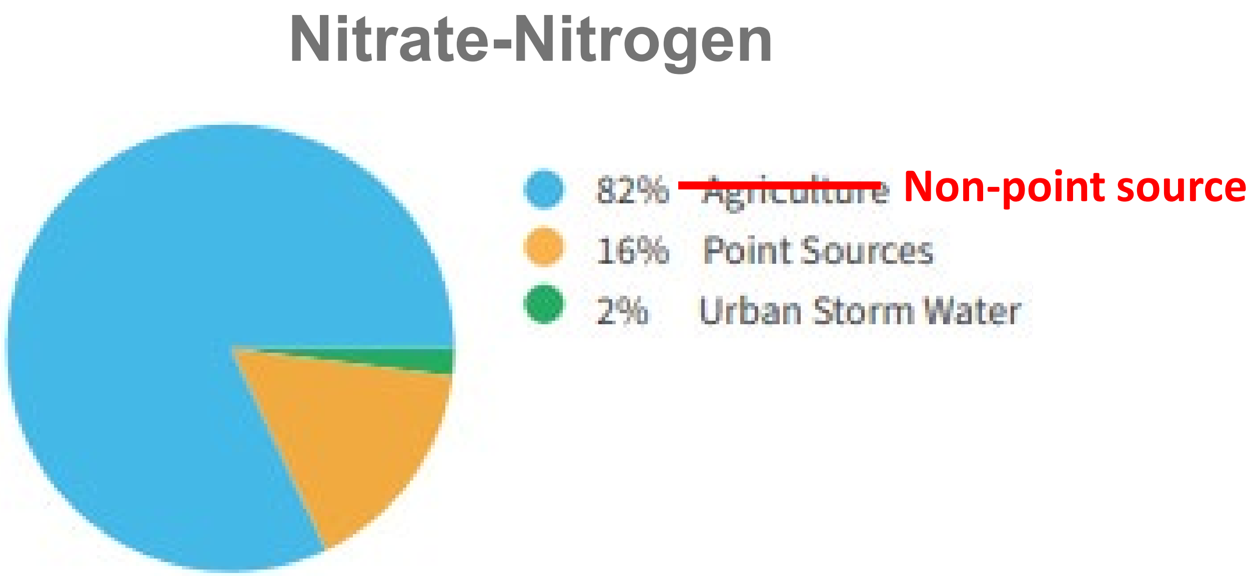


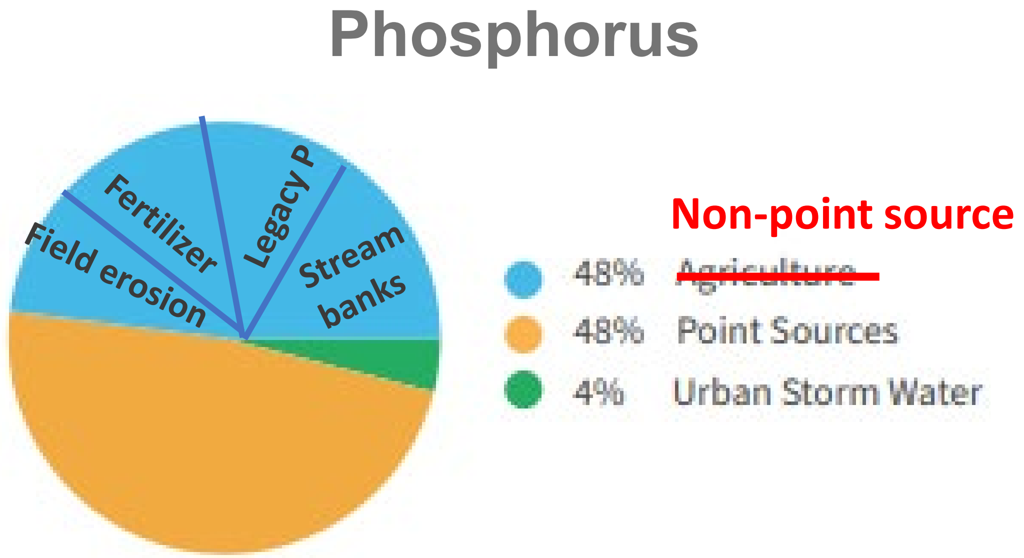
- Only a small % of the P eroded with streambanks will dissolve upon entering the stream
- Majority of P will likely take years to decades to centuries to dissolve
- Allows for DRP losses even with iterative sediment deposition-remobilization down the channel

Zhou, S. & Margenot, A.J. 2023, *CATENA* 231: 107305

Source apportionment:
"where" are the nutrients coming from?

- Illinois NLRS assigns point vs non-point vs urban stormwater as 3 loss sources





- Two issues:
  (1) Incorrectly equates non-point source with agriculture
  Total – point source = non-point source
  Thus, **non-point source ≠ agriculture**
  (2) Needs to account for *different types* non-point sources

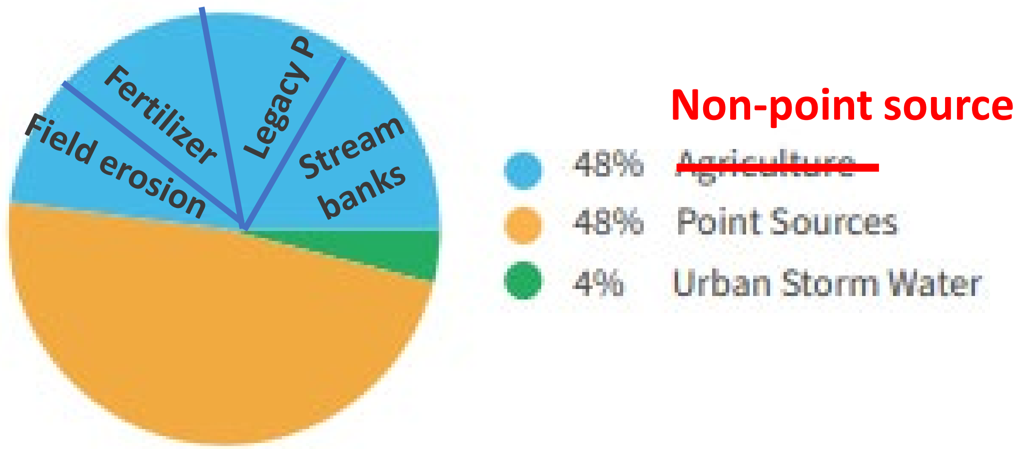
Source apportionment:
“where” are the nutrients coming from?

- Illinois NLRS assigns point vs non-point vs urban stormwater as 3 loss sources

Nitrate-Nitrogen

What are streambank erosion contributions to state P losses?

Phosphorus



- Two issues:

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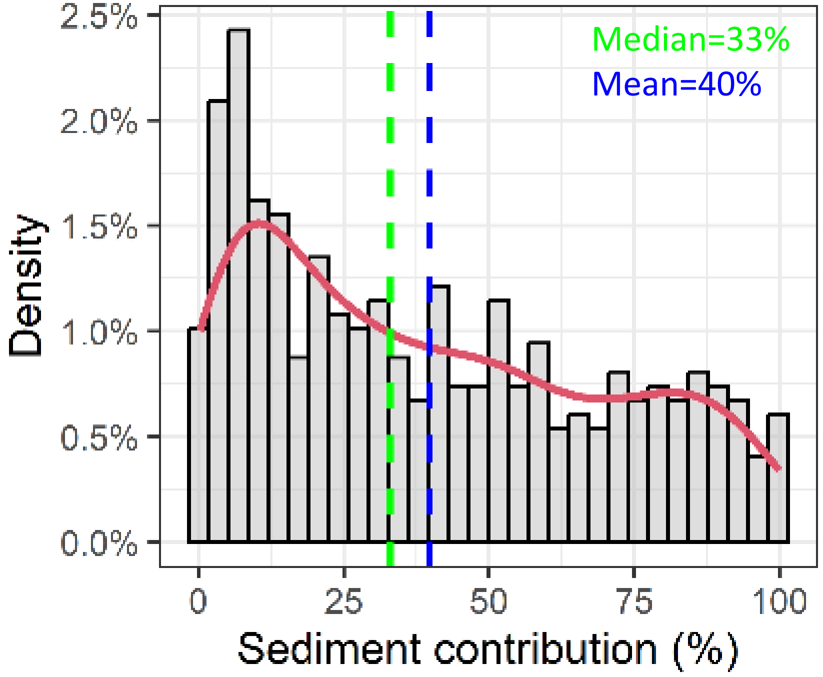
Total – point source = non-point source

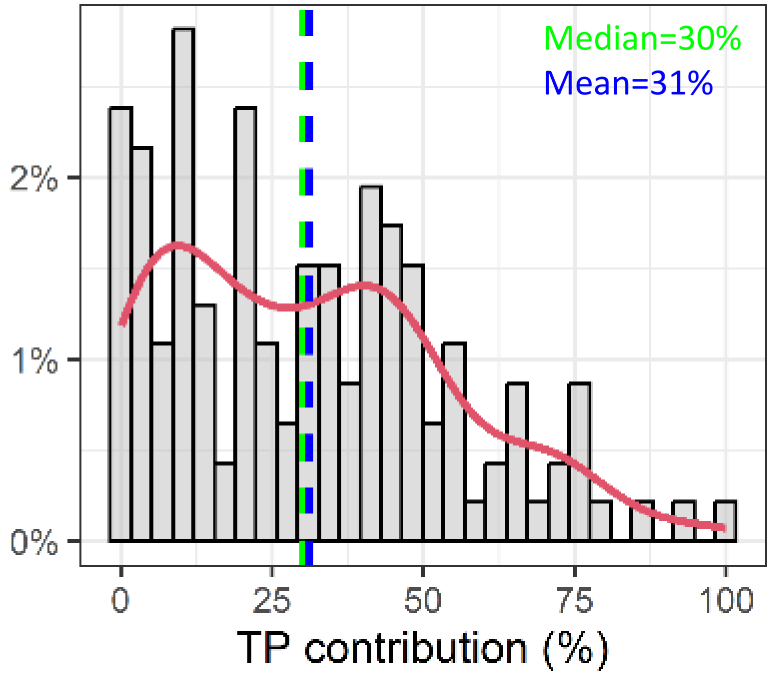
Thus, **non-point source ≠ agriculture**

(2) Needs to account for *different types* non-point sources

Streambank erosion contributes substantial riverine sediment and TP export

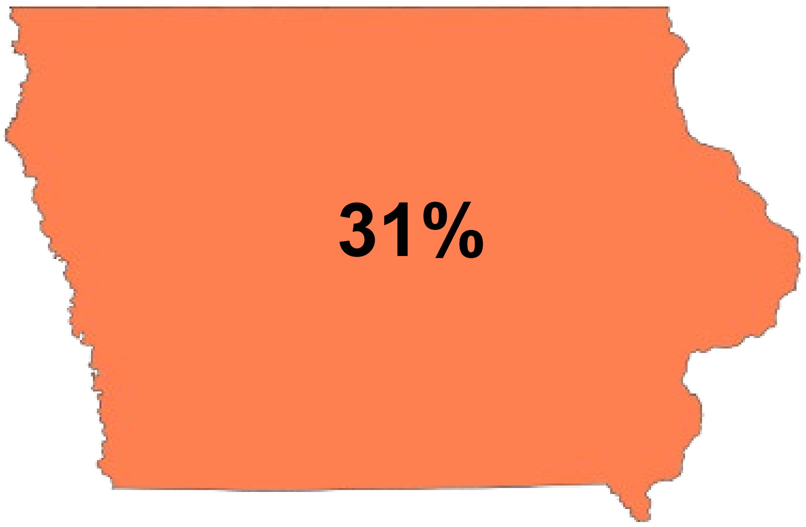
- Globally, bank erosion accounts for an average of
  - 40% riverine suspended sediment export
  - 31% riverine TP export





Zhou, S. & Margenot, A.J. In review

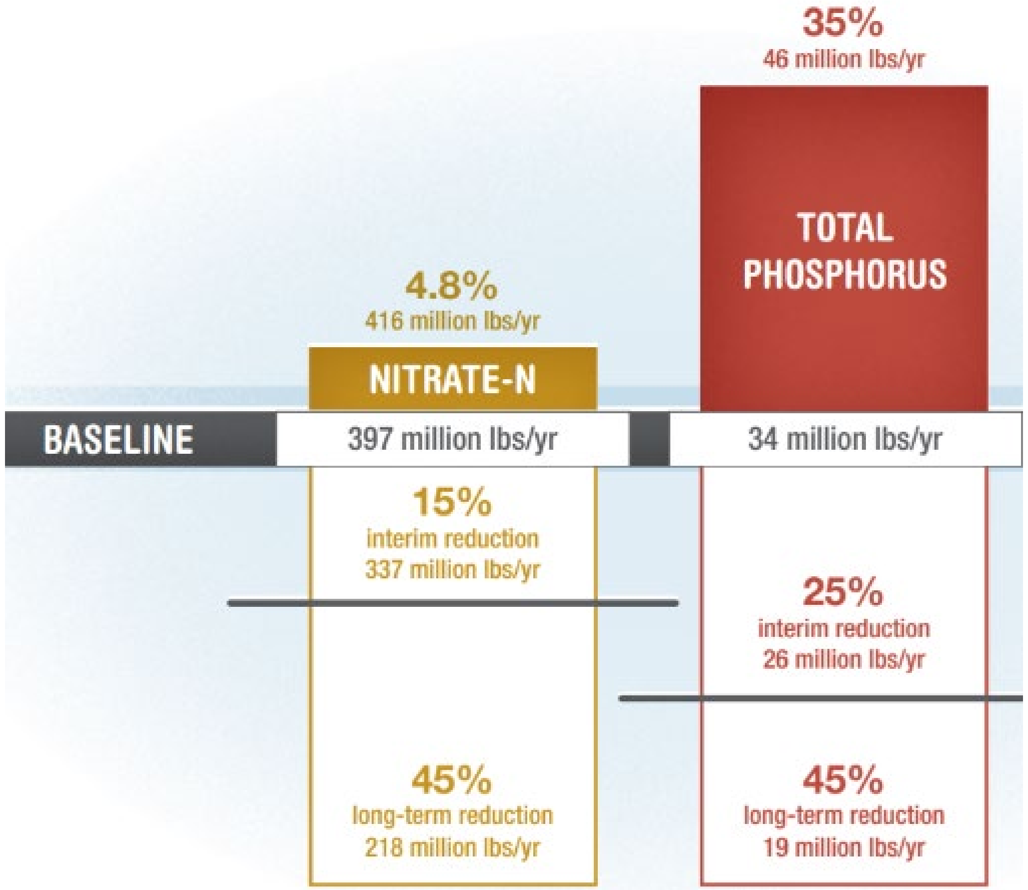
- Iowa (18 year average): 31% of TP export in magnitude, conservatively



Schilling et al. 2022. *JSWC* 77 (2) 103

Discrepancies between P losses vs P balances: legacy P?

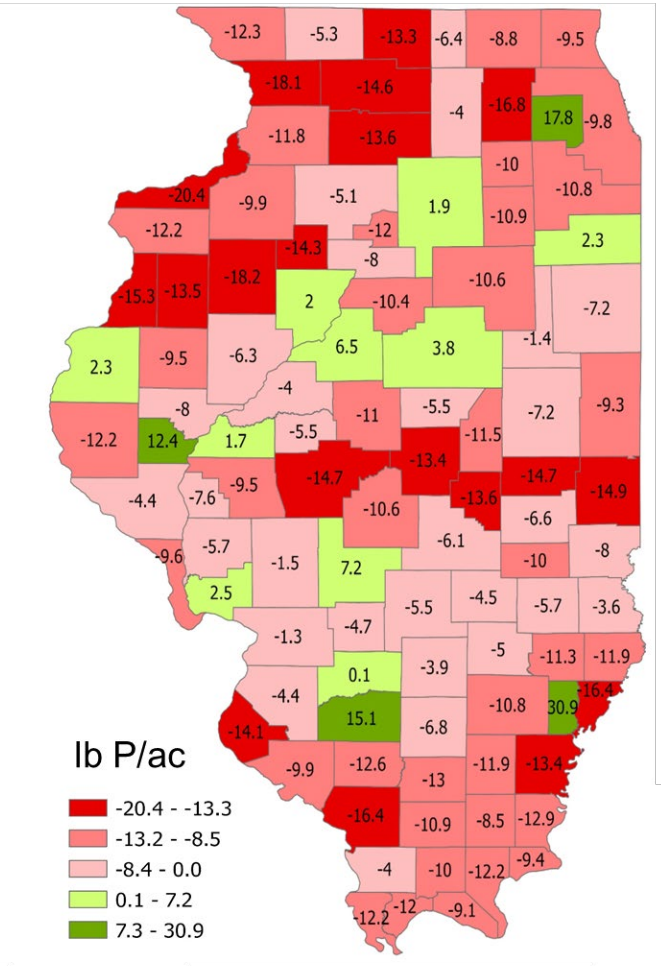
- +35% P riverine export as a 5-year average (2017-2021) for IL



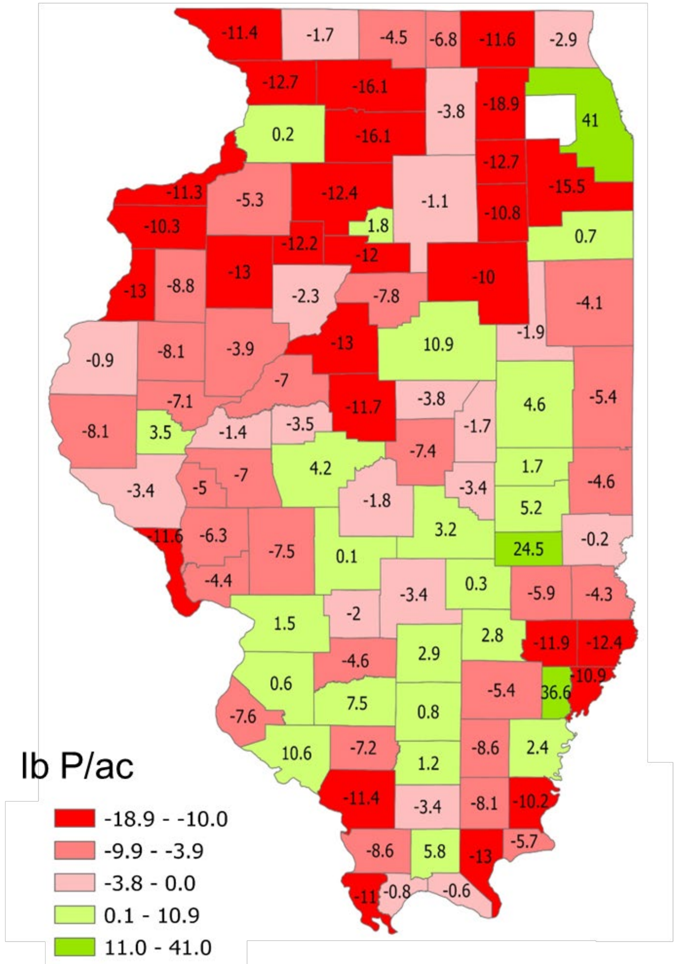
2023 Illinois NLRS Biennial Report Summary

- Yet: Illinois is estimated to be in a net negative P balance for croplands since 1990

2017 balance: -7.4 lb P/ac

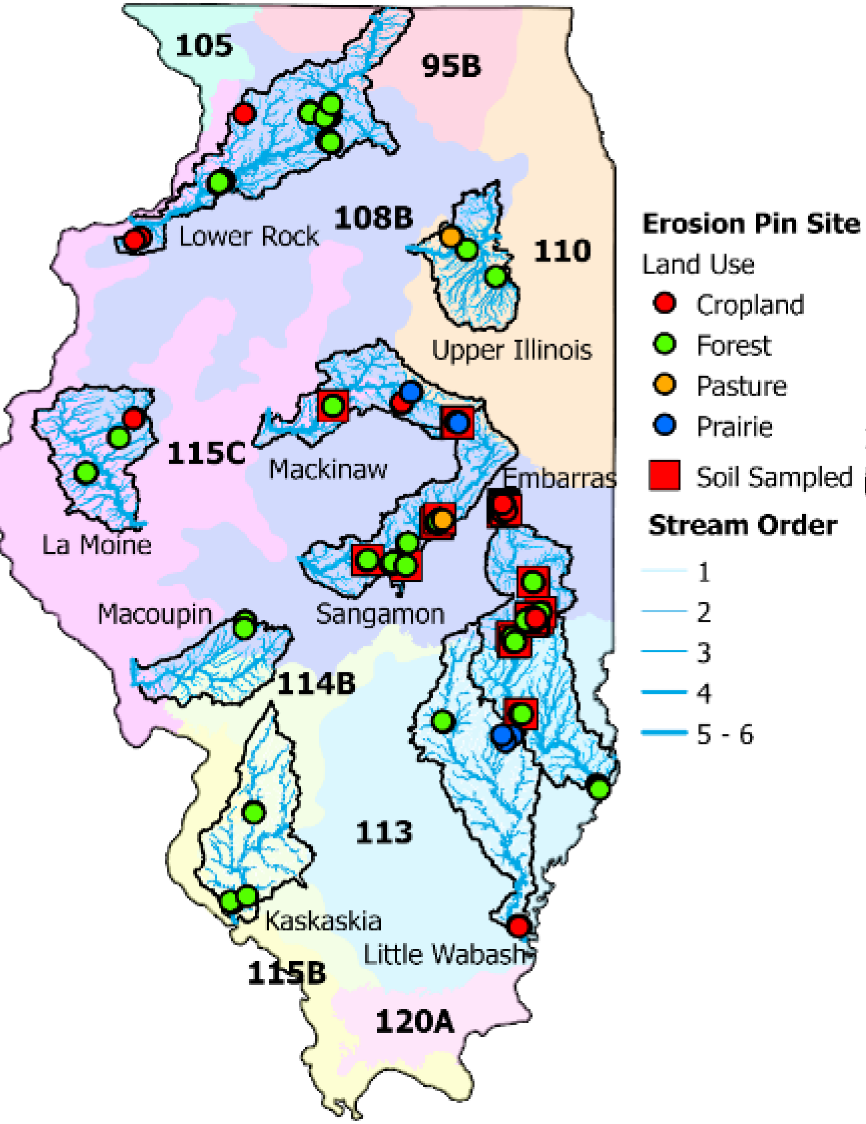


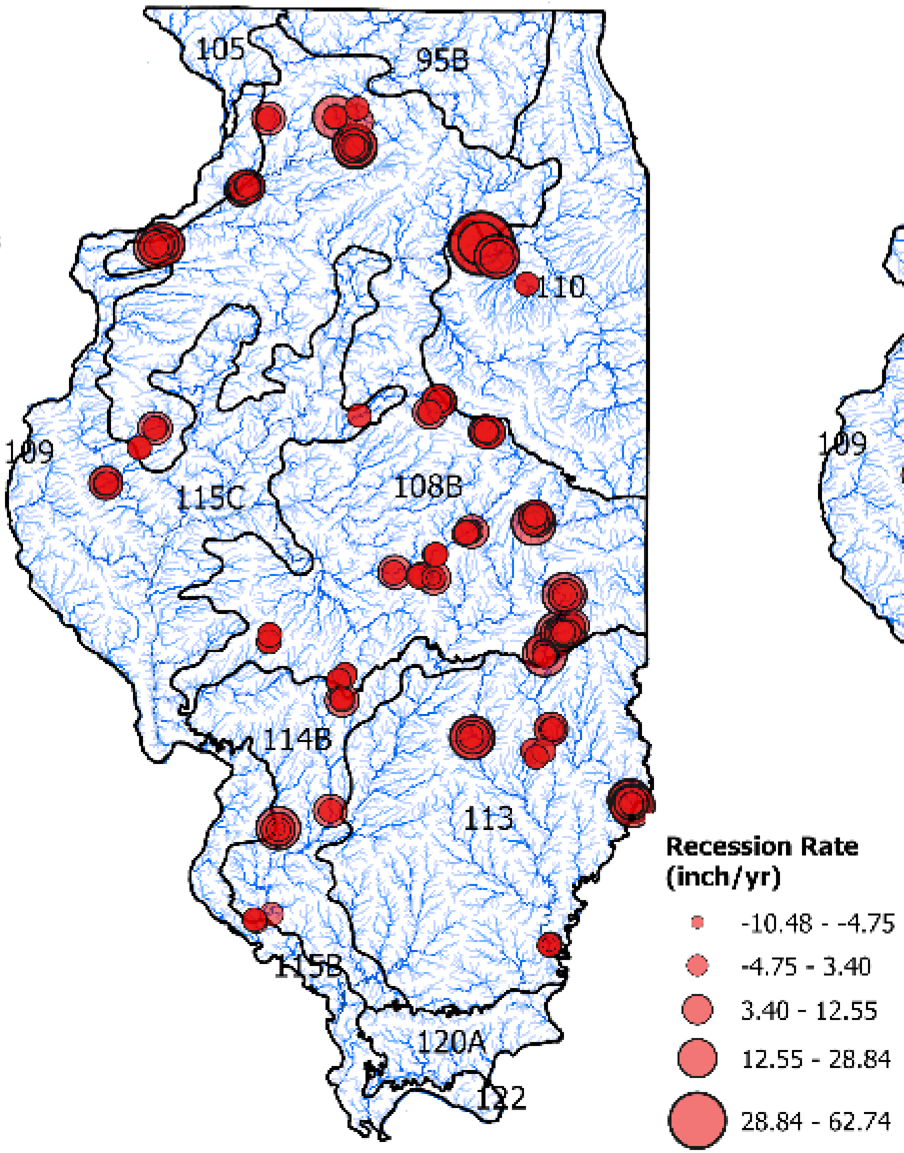
2022 balance: -3.9 lb P/ac

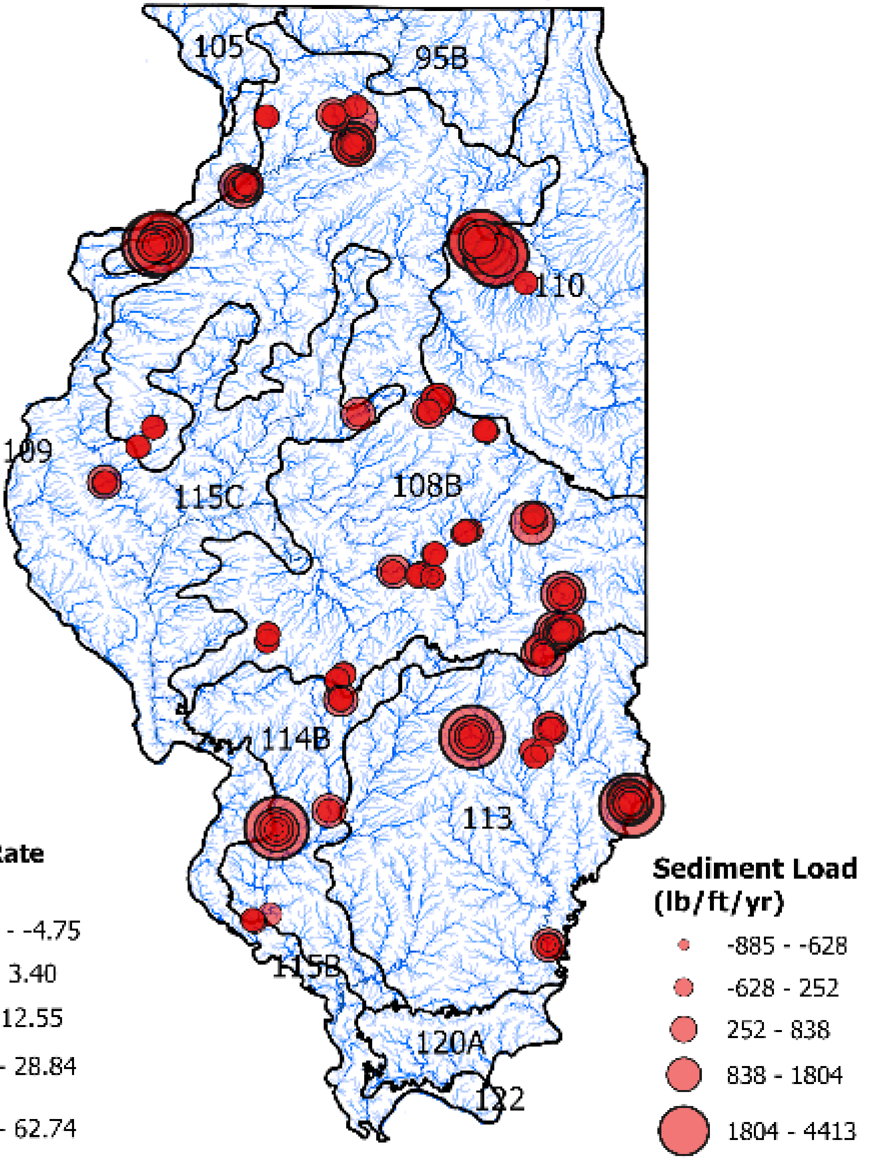


State-wide streambank erosion: contemporary (and future)

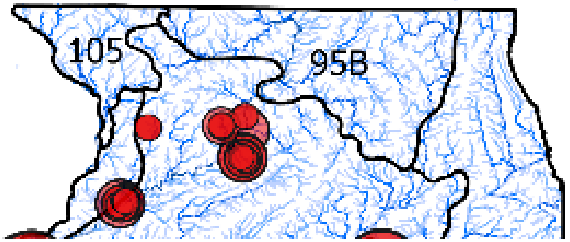
2375 pins over **475 stream sections** on 77 streams and rivers







A *preliminary estimate* of state-wide streambank loading of P



- Average of 373 mg/kg (ppm) total P (0.0373%)
- 86,110 miles of streams in Illinois
- Average of 229 lb sediment per foot of *eroding** streams

Assume for 50% of streams

87,100 miles × 0.5 × (5,280 ft/mile) × (229 lb/ft) × (0.0373%)

= 19.6 million lb P *entering* streams

= 57% of the 34 million lb baseline

Assume for 25% of streams

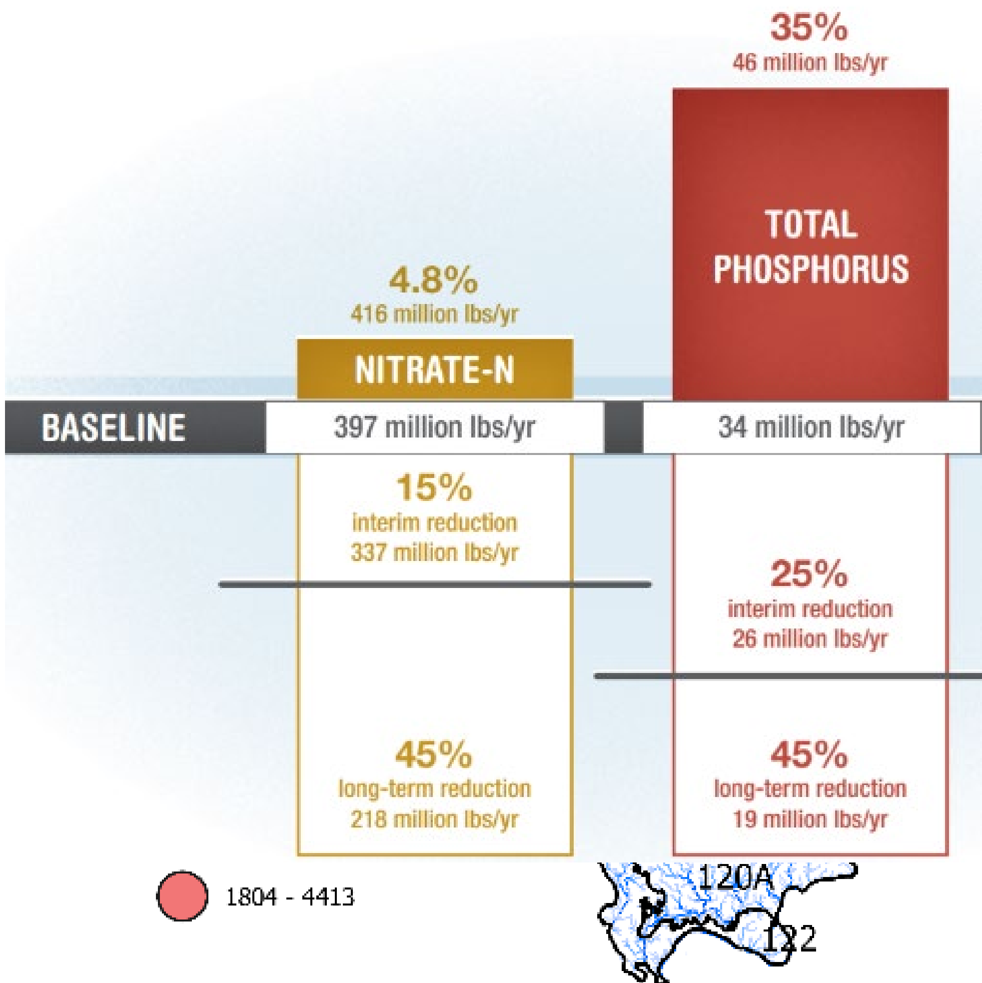
= 9.8 million lb P *entering* streams

= 29% of the 34 million lb baseline

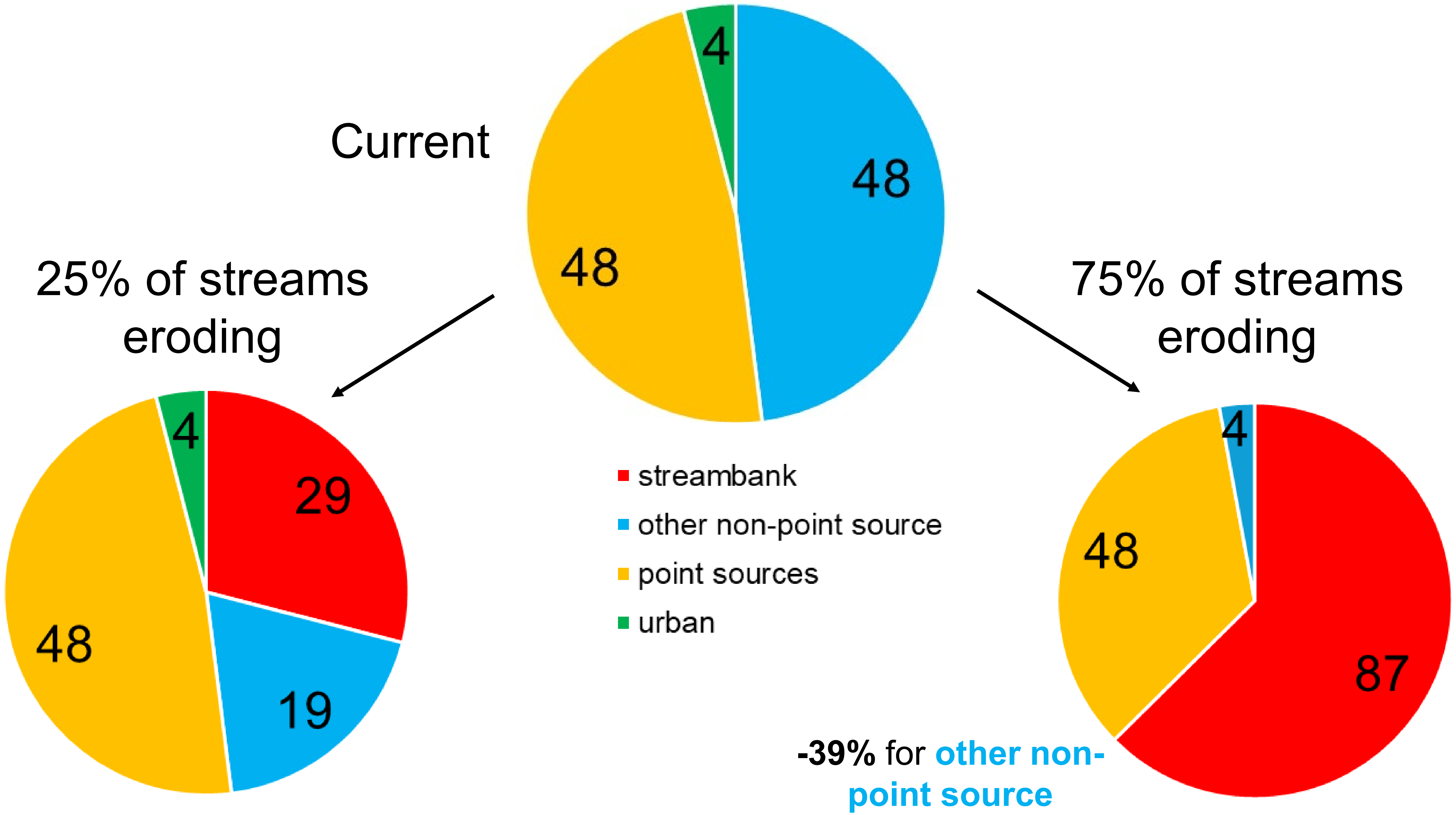
Assume for 75% of streams

= 29.5 million lb P *entering* streams

= 86.8% of the 34 million lb baseline



Implications for apportionment



Could agriculture influence streambank erosion *indirectly* via hydrological effects?

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DOI: 10.1002/hyp.15021

RESEARCH ARTICLE

WILEY

Tile drainage as a driver of streamflow flashiness in agricultural areas of the Midwest, USA

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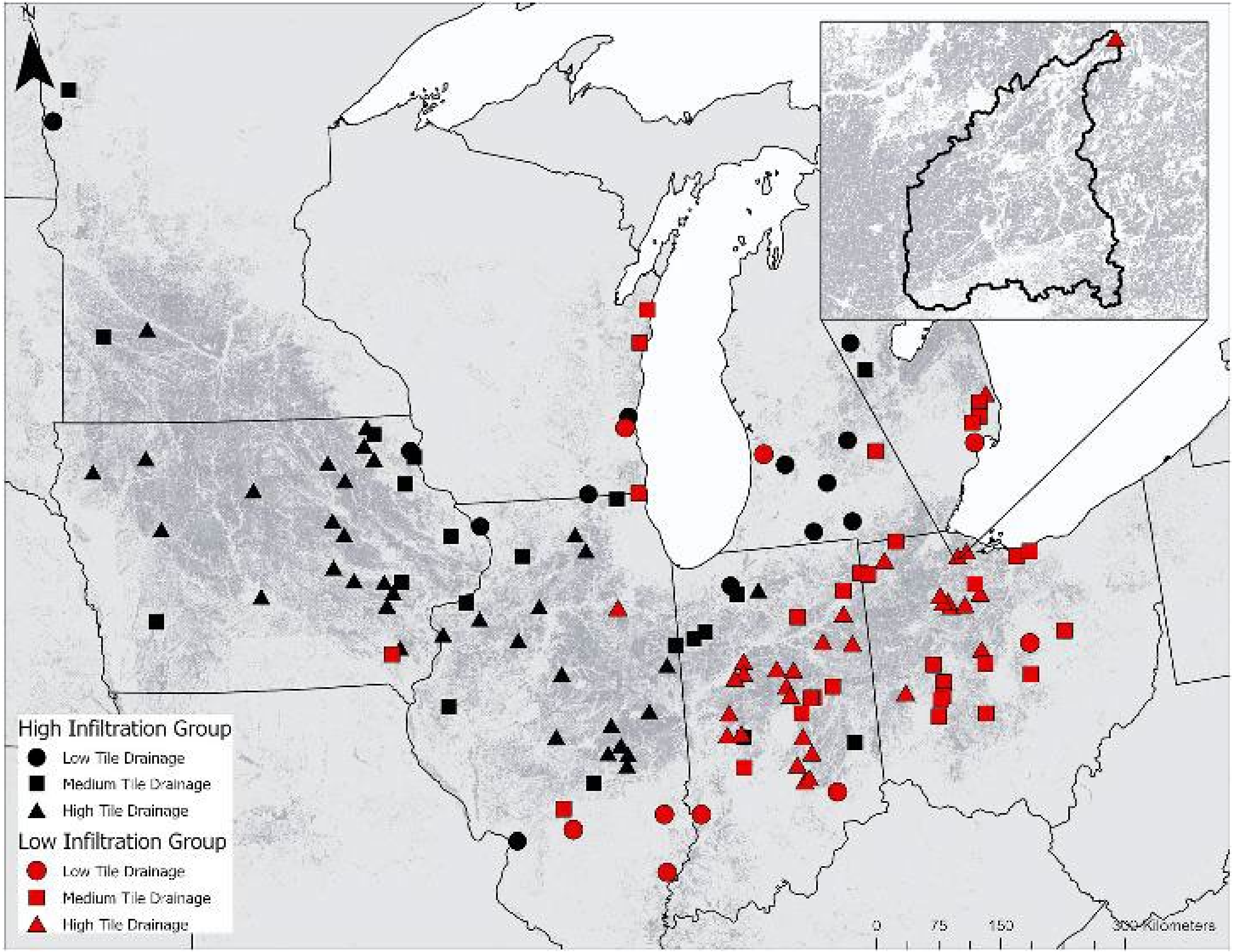
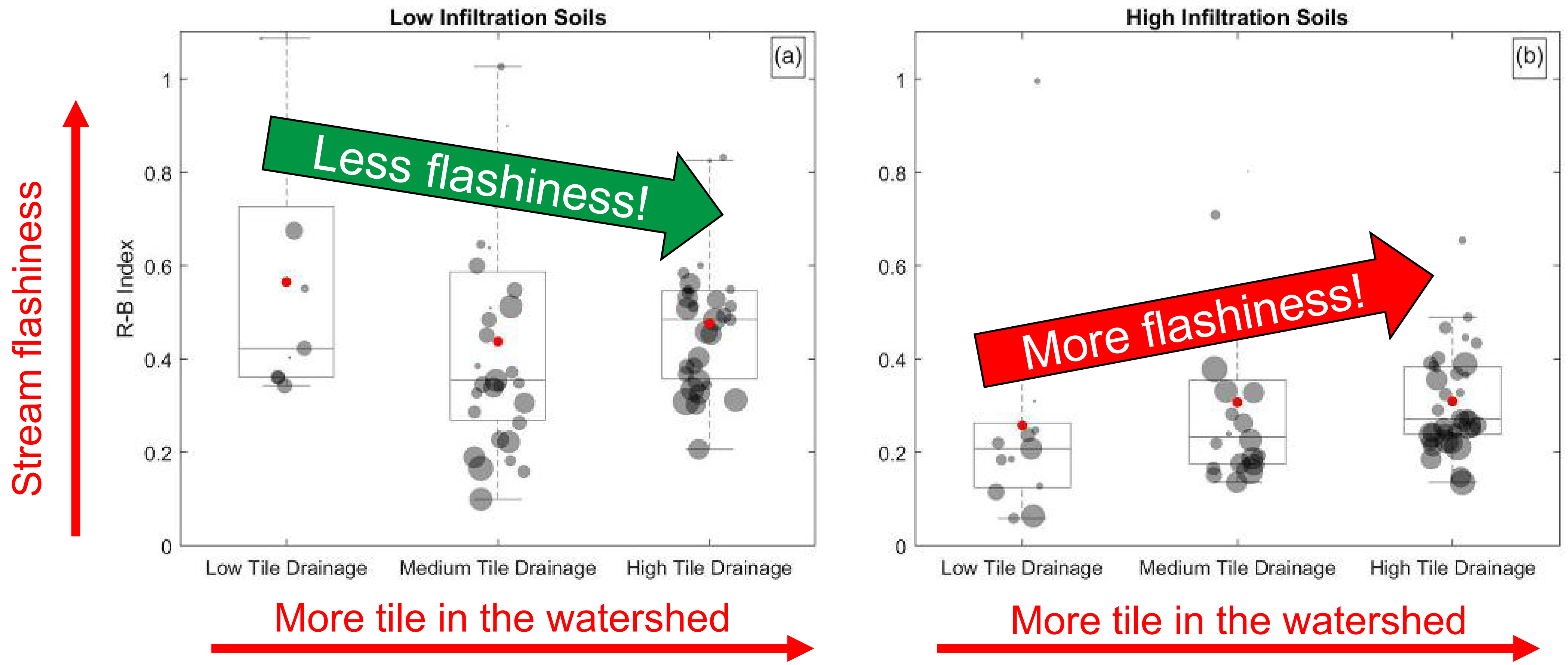
Abstract

The Midwest of the USA is a highly productive agricultural region, in part due to the installation of perforated subsurface pipes, known as tile drains that remove excess water from wet soils. Tile drains rapidly move water to nearby streams, influencing how quickly streamflow rises and falls (i.e., streamflow "flashiness"). Currently, there are no comprehensive studies that compare the extent to which tile drainage influences flashiness across large and diverse agricultural regions. We address this knowledge gap by examining growing-season (April–October) flashiness using the Richards-Baker Index (RBI) in 139 watersheds located throughout the Midwest. Using a spatial tile-drainage dataset, watersheds were split into low, medium, and high tile-drainage classes. We found no significant differences between the flashiness of these three classes using a one-way Kruskal–Wallis test. When watersheds were separated into infiltration groups to help control for different soil types, the high tile-drainage class RBI was significantly higher than the low tile-drainage class RBI in the high infiltration group. To further understand the causes of flashiness, additional environmental variables and their relationship to flashiness were examined using multivariate regression. In the low infiltration group, tile drainage significantly reduced flashiness, with watershed area and average depth to water table being the largest influences on flashiness. Tile drainage produced a larger reduction in flashiness in the high infiltration watersheds, with the largest influences being percent clay in the watershed and watershed area. These results indicate that the influence of tile drainage on flashiness emerges only after other watershed variables are accounted for. Given that tile drainage may increase in the future as precipitation patterns and extremes change, flashiness will likely continue to be modified. These results lead to an improved understanding of flood-generating and nutrient transport mechanisms that are relevant to stakeholders across a wide range of sectors.



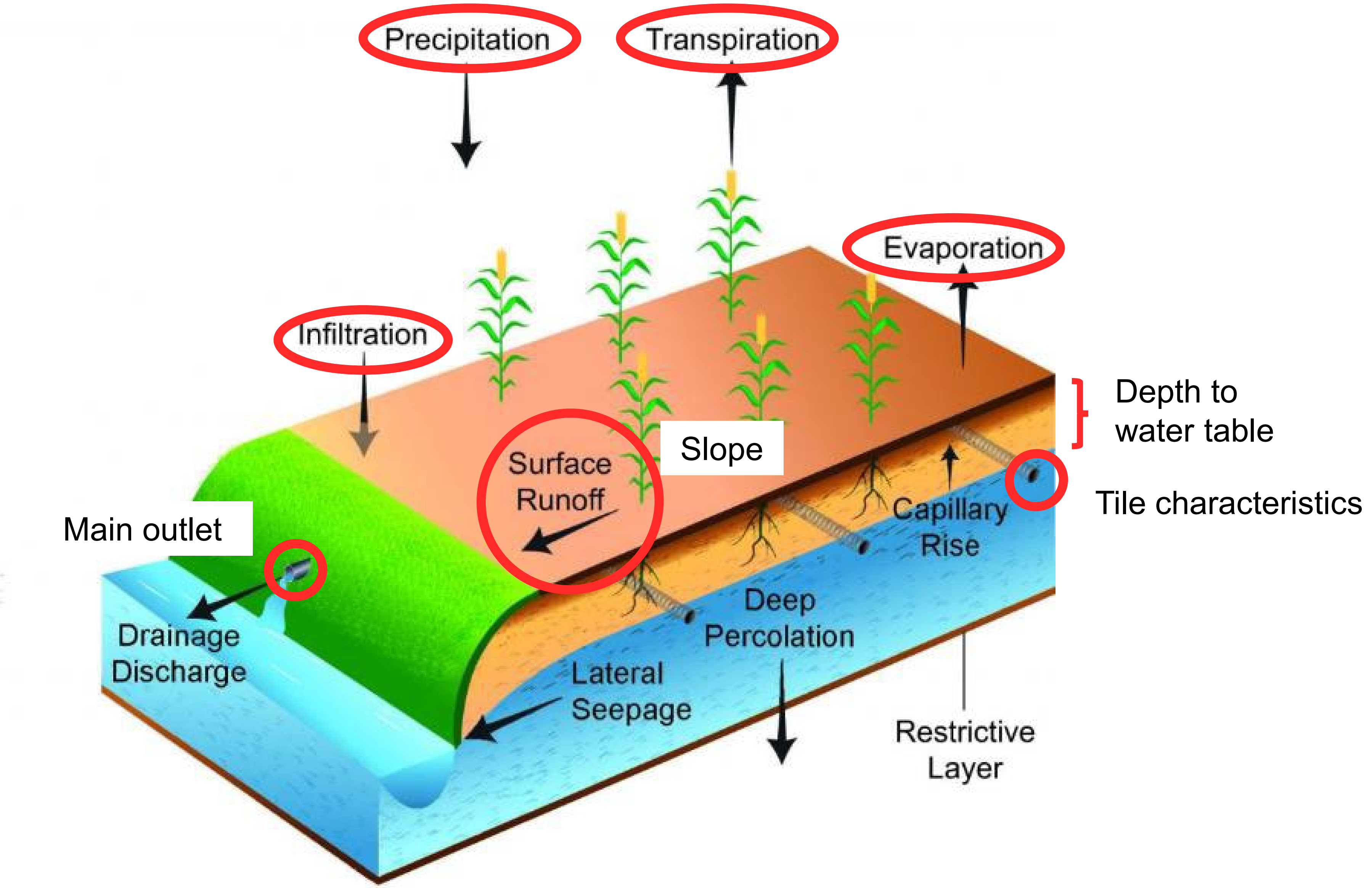
Could agriculture influence streambank erosion *indirectly* via hydrological effects?

At the watershed scale, the effect of subsurface tile drainage on stream flashiness (**RBI**) may depend on soil infiltration



Adelsperger et al 2023 Hydrological Processes 37:e15021

Net effect of tile drainage on stream flashiness, and thus potentially on streambank erosion, depends on several factors



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The double-edged sword of agricultural tile drainage effects on stream flashiness: A *meta*-analysis

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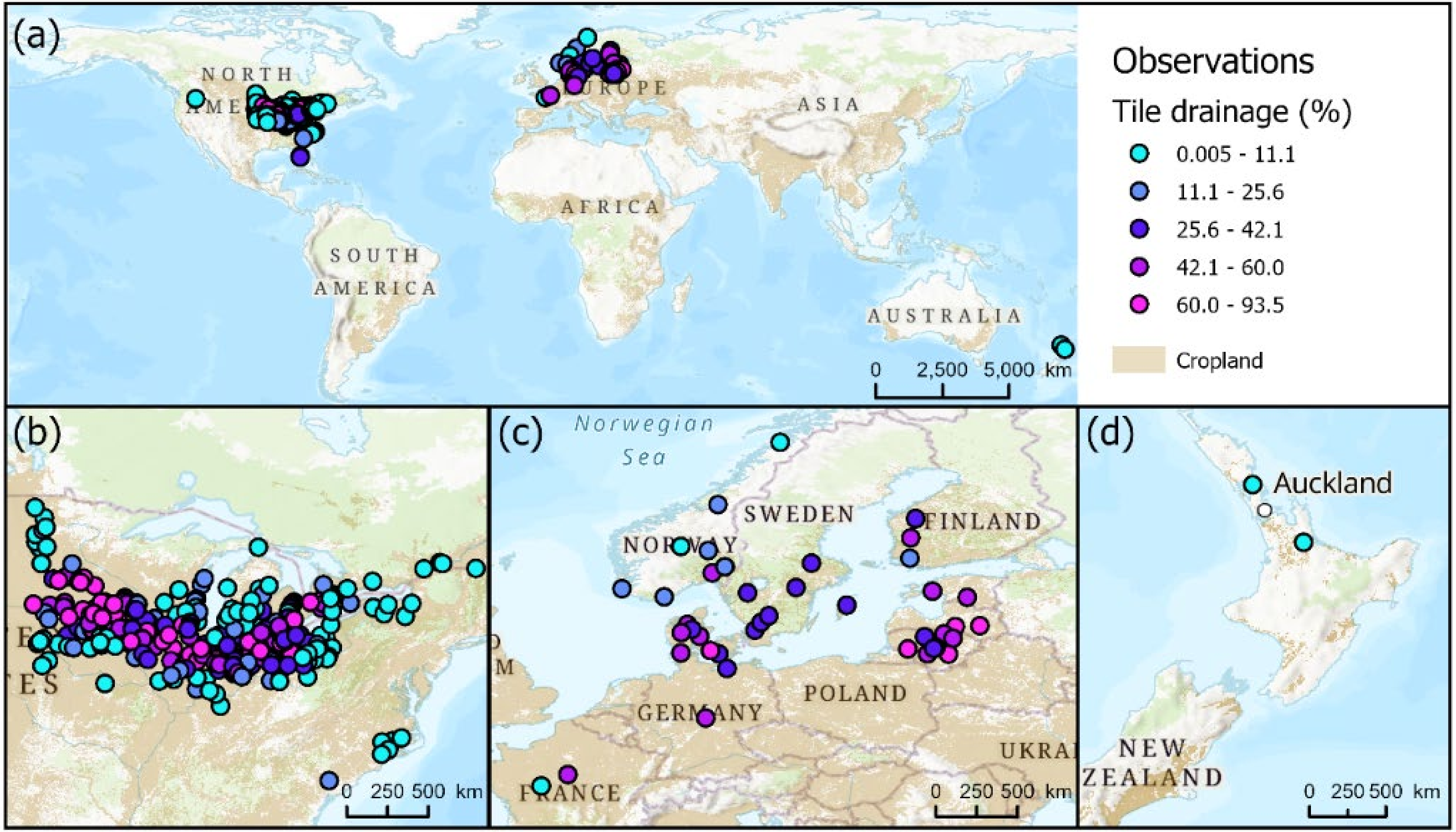
A R T I C L E I N F O

Keywords:
tile drainage
agriculture
flashiness
baseflow
watershed characteristics
meta-analysis

A B S T R A C T

Tile drainage increases agricultural productivity and can significantly alter downstream hydrology. A comprehensive understanding of tile drainage impacts on stream flashiness can inform tile drainage design and management at the watershed scale to balance agronomic benefits and potential impacts on watershed hydrology. We evaluated by *meta*-analysis the impact of tile drainage on downstream flashiness (Richards-Baker Index, RBI) for 464 rain-fed watersheds worldwide encompassing highly variable tile drainage extent and watershed characteristics, identified by systematic literature review and from USGS datasets. Watersheds were largely concentrated in North America (89.9 %), particularly the US Upper Midwest (77.4 %), and northern Europe (9.7 %). Stream flashiness was similar regardless of tile drainage extent. However, stream flashiness was higher in relatively flat (<2% slope) watersheds with medium (RBI 0.44) and high (RBI 0.37) tile drainage extent relative to low tile drainage extent (RBI 0.33) watersheds. For watersheds with slopes averaging >2 %, flashiness was greater for low tile drainage (RBI 0.49) than medium (RBI 0.25) or high (RBI 0.35) tile drainage. Watersheds with low infiltration soils exhibited 24 % greater flashiness for low (RBI 0.51) tile drainage extent than for high (RBI 0.41) tile drainage extent. In watersheds with soils of high infiltration rate, stream flashiness was similar across the low (RBI 0.28), medium (RBI 0.30), and high (RBI 0.29) tile drainage extents. By accounting for watershed characteristics of slope and soil infiltration, this work points to complex drivers of tile drainage outcomes for stream flashiness that can lead to opposite impacts of tile drainage on stream flashiness and thus preclude blanket conclusions of tiling effects on watershed hydrology. Additionally, we identify salient data gaps in tile system design and management (e.g., tile diameter, installation depth, and spacing) that must be resolved to enable more accurate assessments of context-specific tile drainage impacts on stream flashiness.

Distribution of studies reflects tiling distribution in EU and N. America



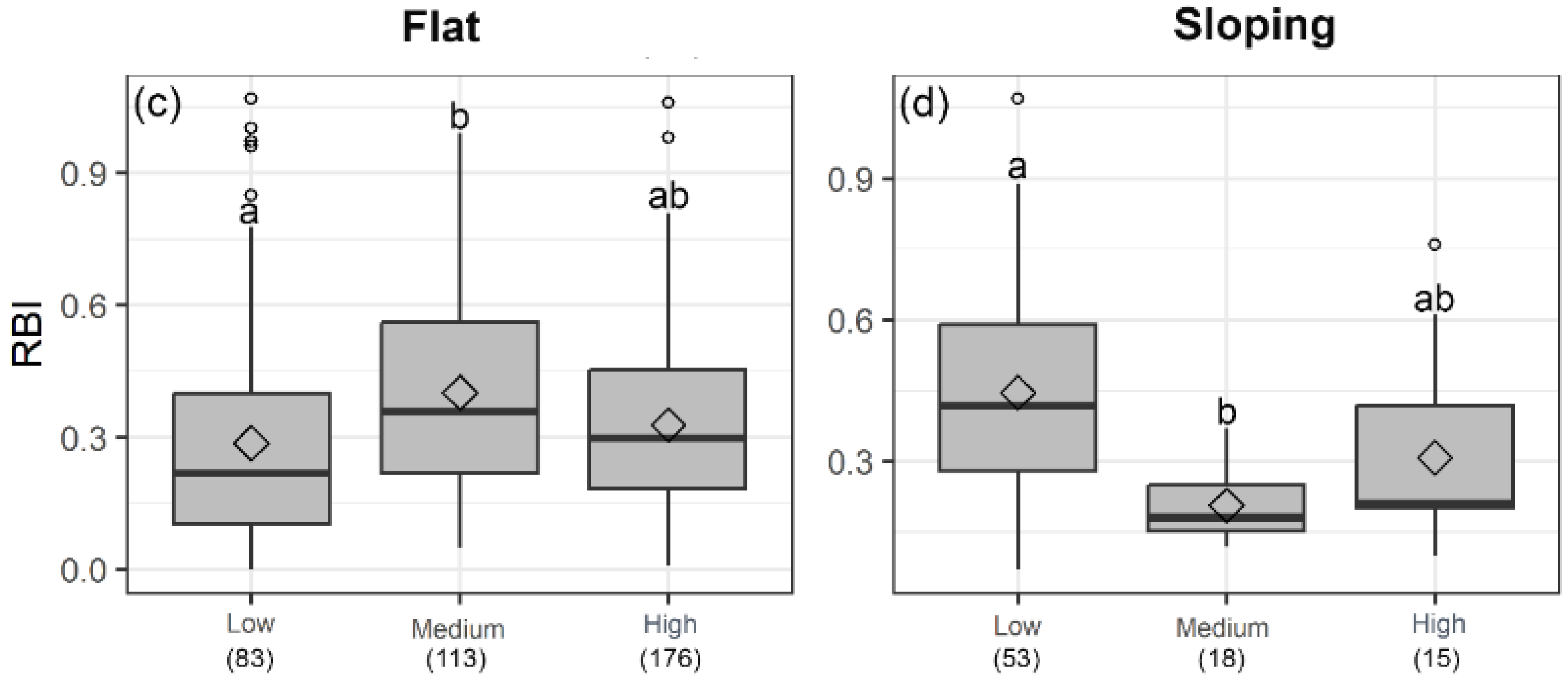
Location and density (% of area) of tile drainage across 472 agricultural watersheds

Stream flashiness poorly related one-on-one with watershed properties

Tile drainage

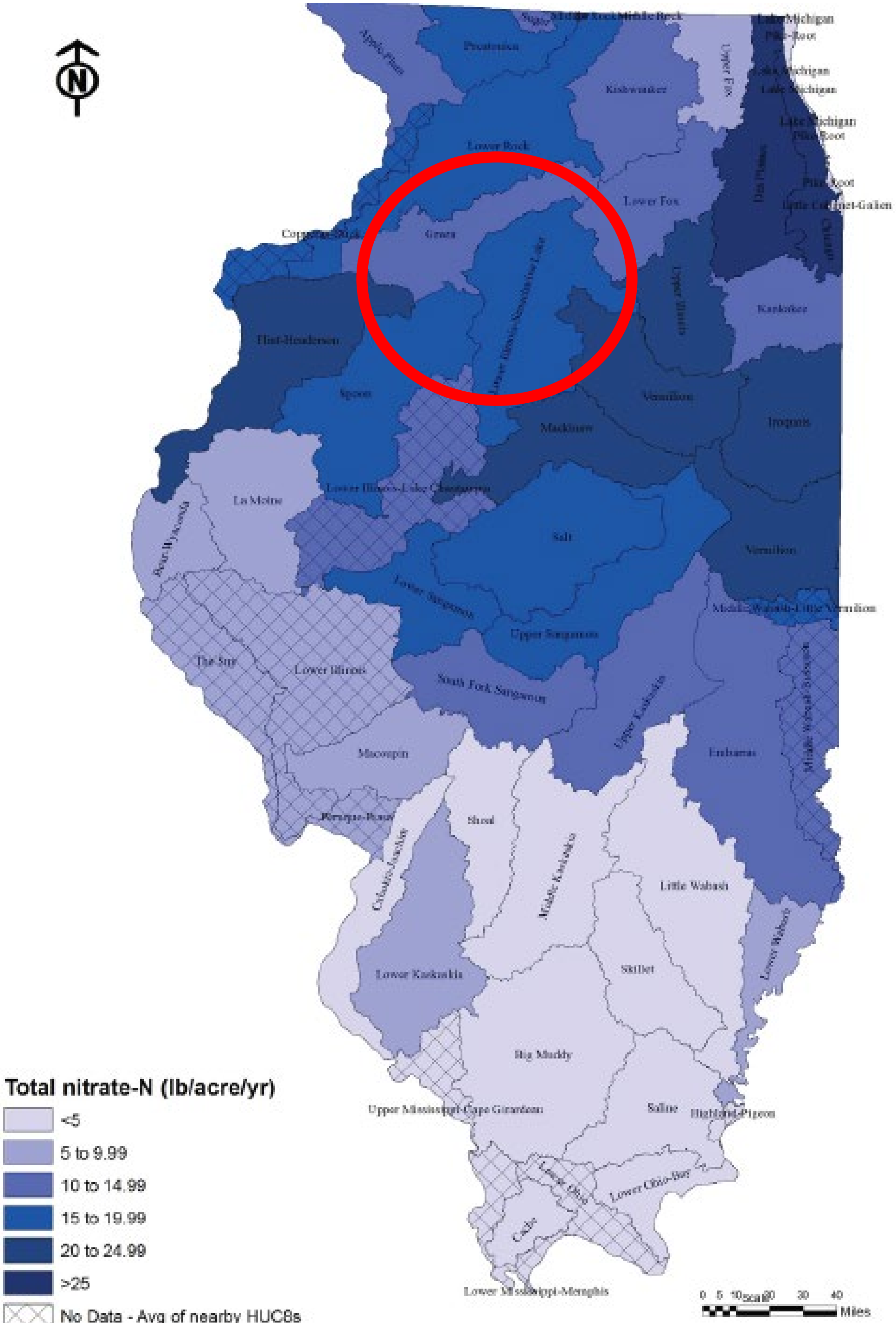
- High
- Medium
- Low

- Topography modulates **streambank flashiness** response to tile drainage extent



Summary

- Tiling enables public health and crop production
- Trade-offs (never solutions) offered by tiling point to positive, including unrealized positives on N and water use efficiency *if managed properly*
- For nearly 200 years, export of nutrients from subsurface drainage tiles has been studied
  - N and P, but also K, S, Ca, Mg etc
  - *How* much *depends*; consider lb/ac loss versus total soil reserve vs $
- Tiles generally have….
  - Greater absolute (lb/ac) losses of N than P
  - Greater proportion of N loss as nitrate-N than other forms
  - Greater portion of P loss as dissolved reactive P (than particulate P (PP)
- Stream flashiness is not necessarily due to increased tiling: it's complicated
- Streambank erosion: related to tile, and a key driver of P losses



High nitrate-N loss *watersheds*

- Illinois Nutrient Loss Reduction Strategy (INLRS) identifies as high priority
    1. Green River HUC-8
    2. Lower Illinois/Senachwine Lake HUC-8

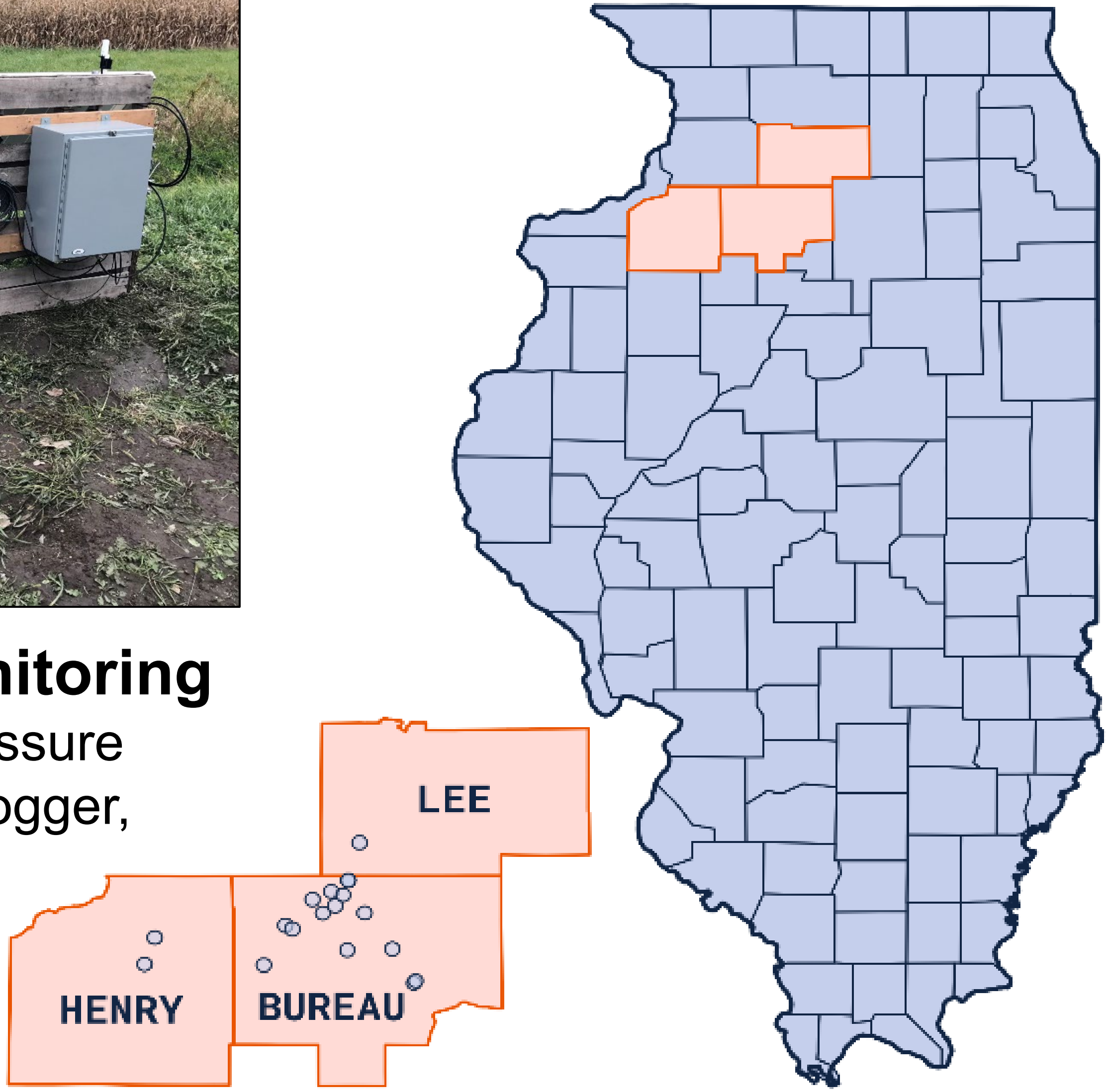
- ~60-75% of crop area drained with subsurface tiles
- Nitrate-N losses: 20-25 lb N/a total yield of watershed

What are losses – and loss reductions – on actual working farms?

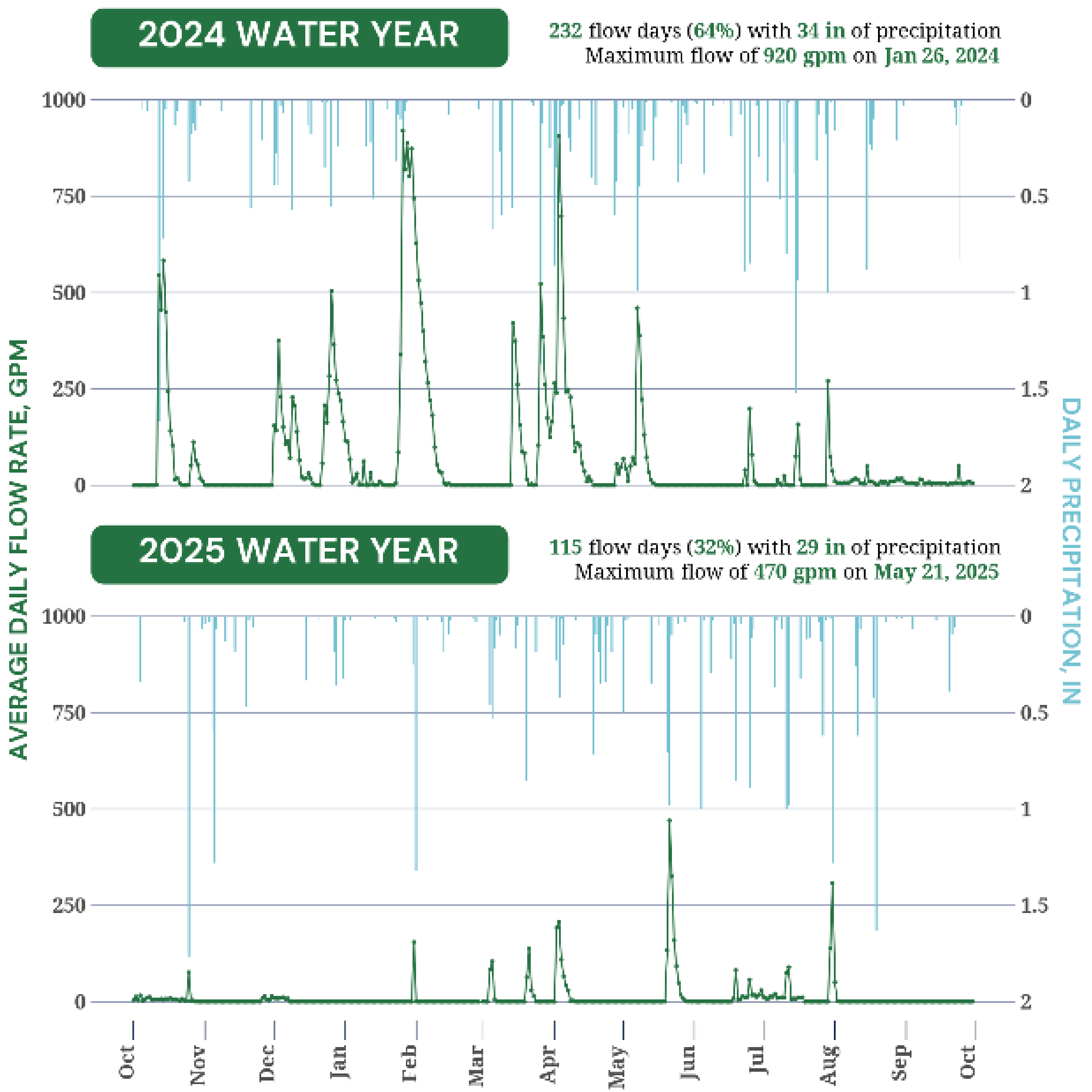
An on-farm network: origins and evolution of monitoring

"Bucket method":
time to fill 5 gallon bucket +
office nitrate-N sensor

Continuous monitoring
V-notch weir, pressure
transducer, datalogger,
ISCO



How much water is discharged? Depends on water year



14% less precipitation *but*

45% less tile discharge

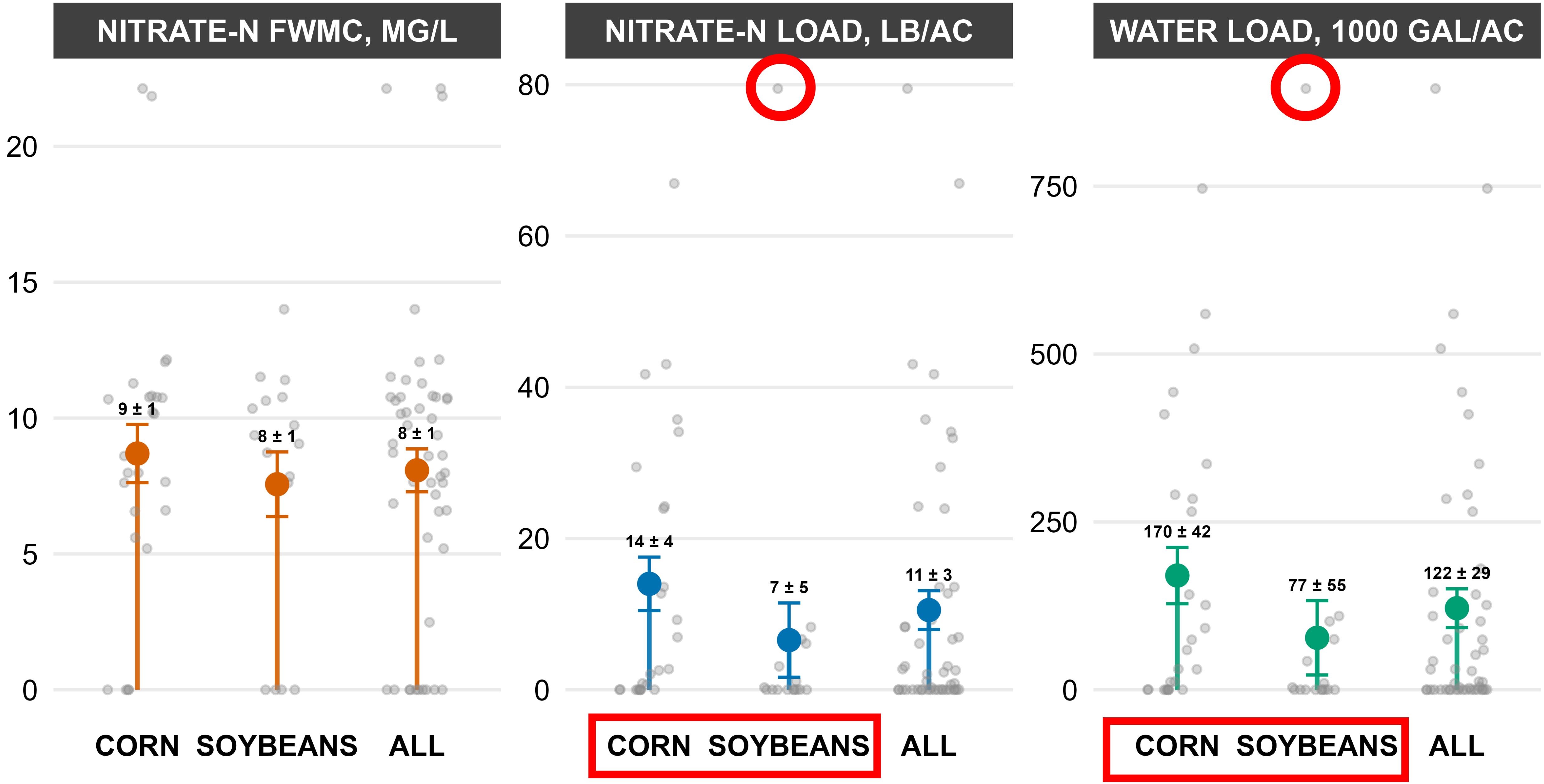
2024: 34”

0.32 drainage coefficient

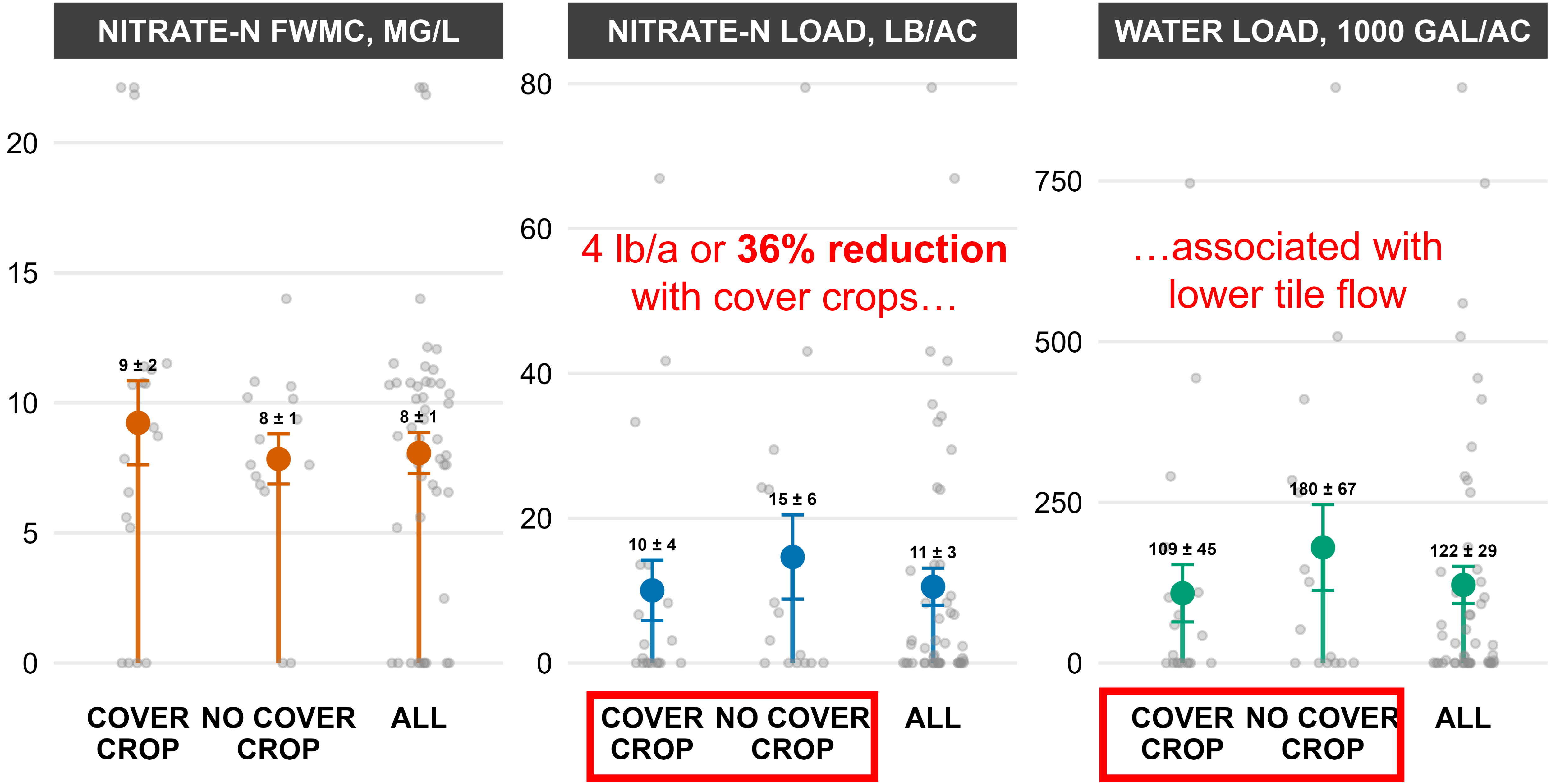
2025: 29”

0.20 drainage coefficient

Nitrate-N losses by corn vs soybean phase (49 site-years)

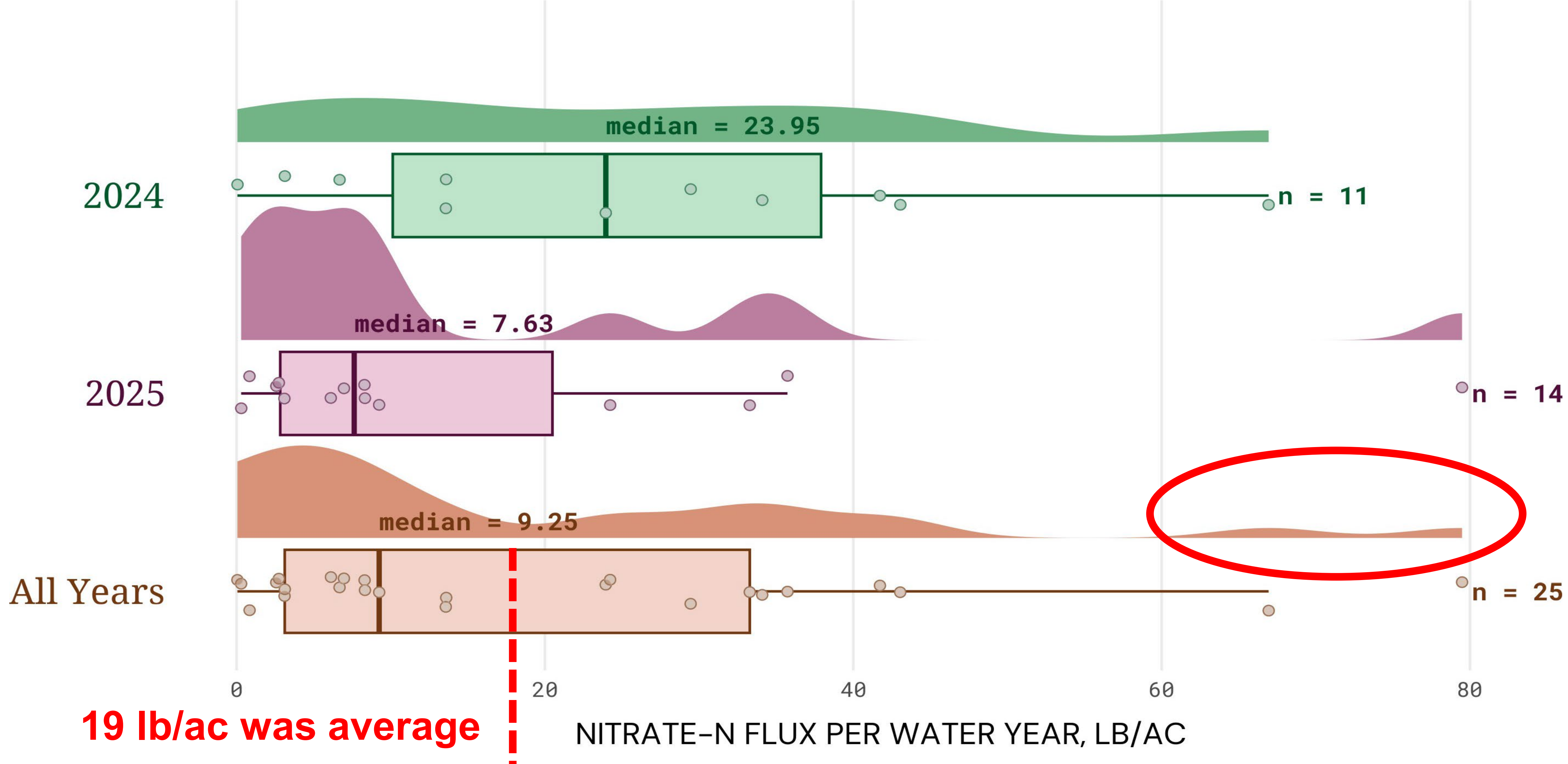


Nitrate-N losses by cover cropping (49 site-years)



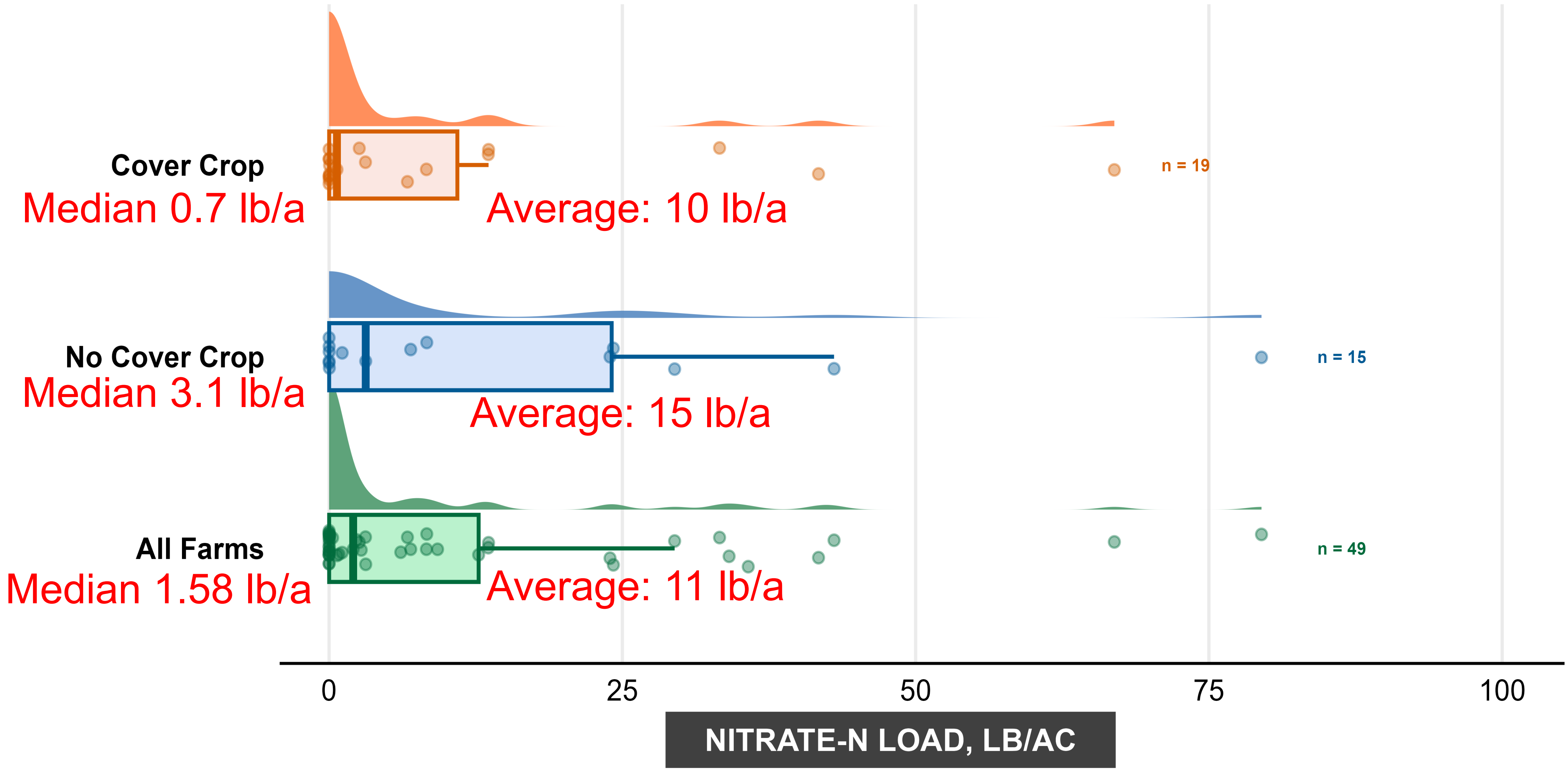
Average nitrate-N loss much higher than median

Why? "high loss fields" – which are often ***high flow*** fields



19 lb/ac was average

Because a few lose a lot, greater median than mean reductions of nitrate-N loss by cover crops: 77% reduction



Little relationship of field N balances and tile N loads