USDA Economic Research Service
U.S. DEPARTMENT OF AGRICULTURE

Estimating the Impact of Cover Crop Adoption on Ambient Water Quality in the Upper Mississippi River Drainage

Hsin Hsieh[1] and Ben Gramig[2,*]

[1]University of Illinois at Urbana-Champaign

[2]USDA Economic Research Service

* Presenter

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Disclaimer: The findings and conclusions in this presentation are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy. This work was partially supported by the U.S. Department of Agriculture, Economic Research Service.

Prior Research

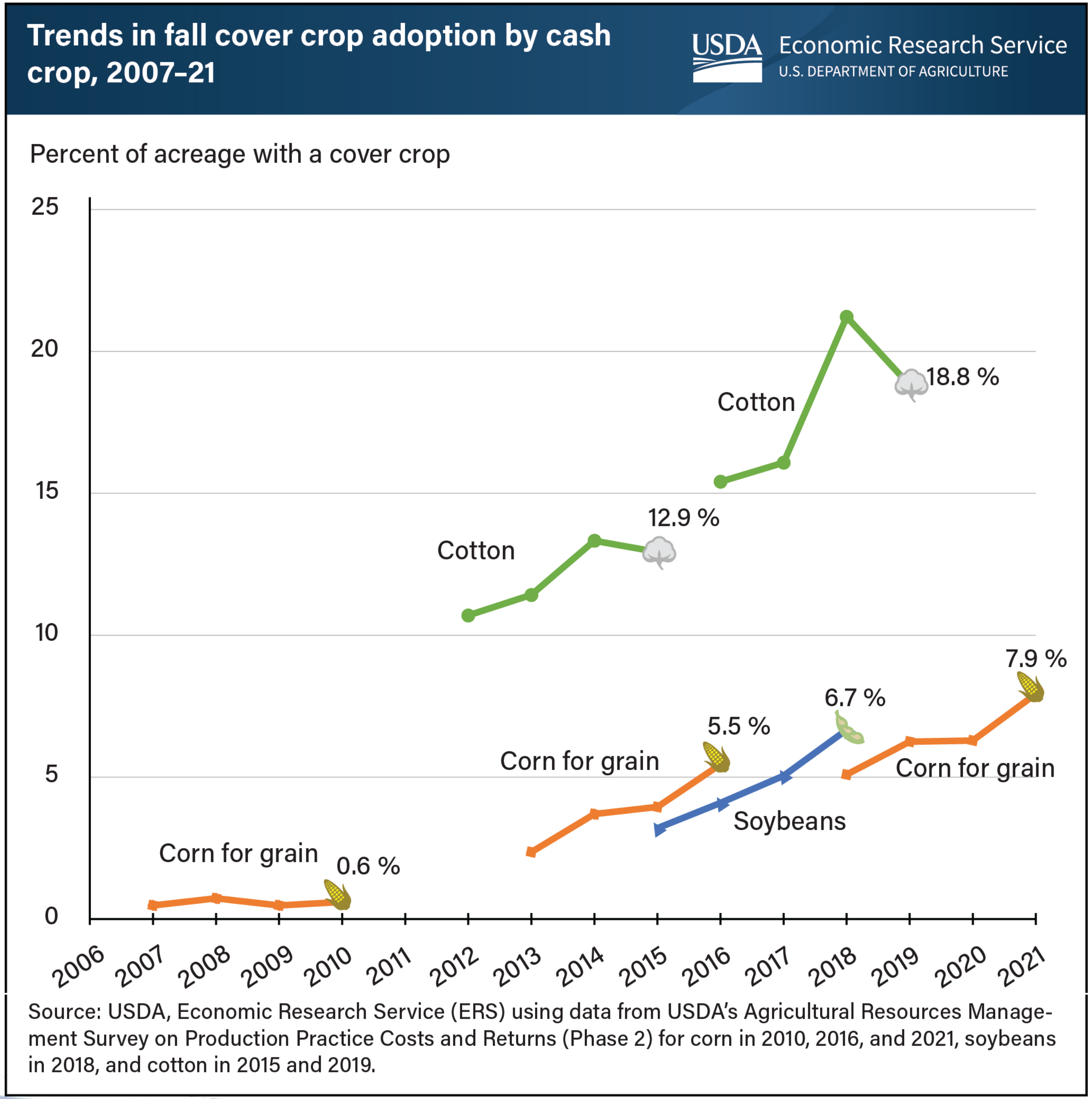
Same underlying hydrological network information and ambient pollution data sources have been used to investigate:

- Point source pollution (Keiser & Shapiro, 2019)
- A major conservation program (EQIP) that includes many different practices, in addition to cover crops (Liu et al., 2022)
- Fertilizer sales as a proxy for N fertilizer application (Paudel & Crago, 2020)

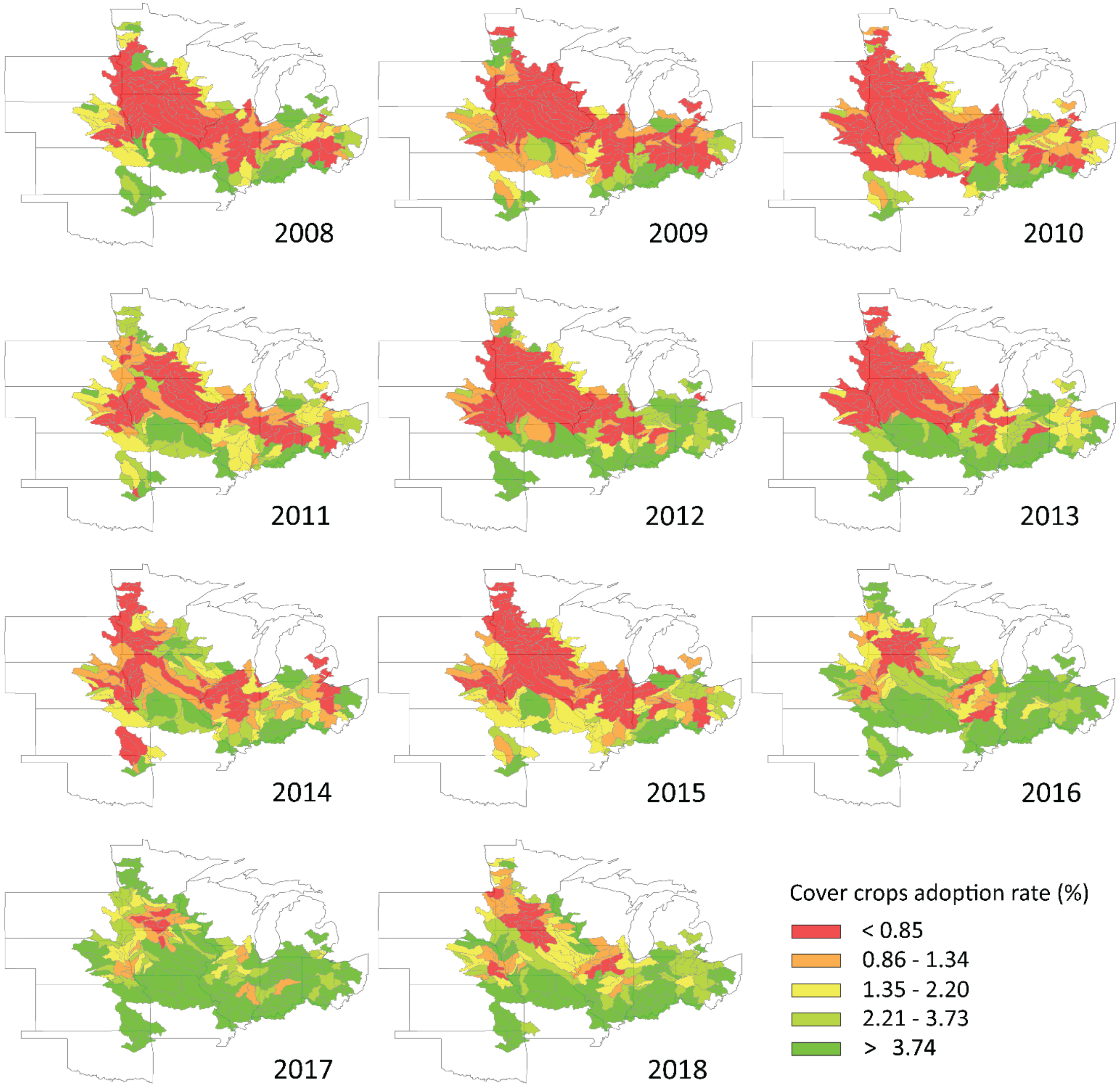
Contribution: first attempt the authors are aware of to estimate the effect of cover crop adoption on ambient N pollution levels using observed water quality and farm practice adoption data.

Motivation

- Cover crop adoption has increased nationally in recent years
- CC adoption has been prioritized:
  – For general soil health benefits
  – As part of state nutrient loss reduction strategies in the Mississippi River basin

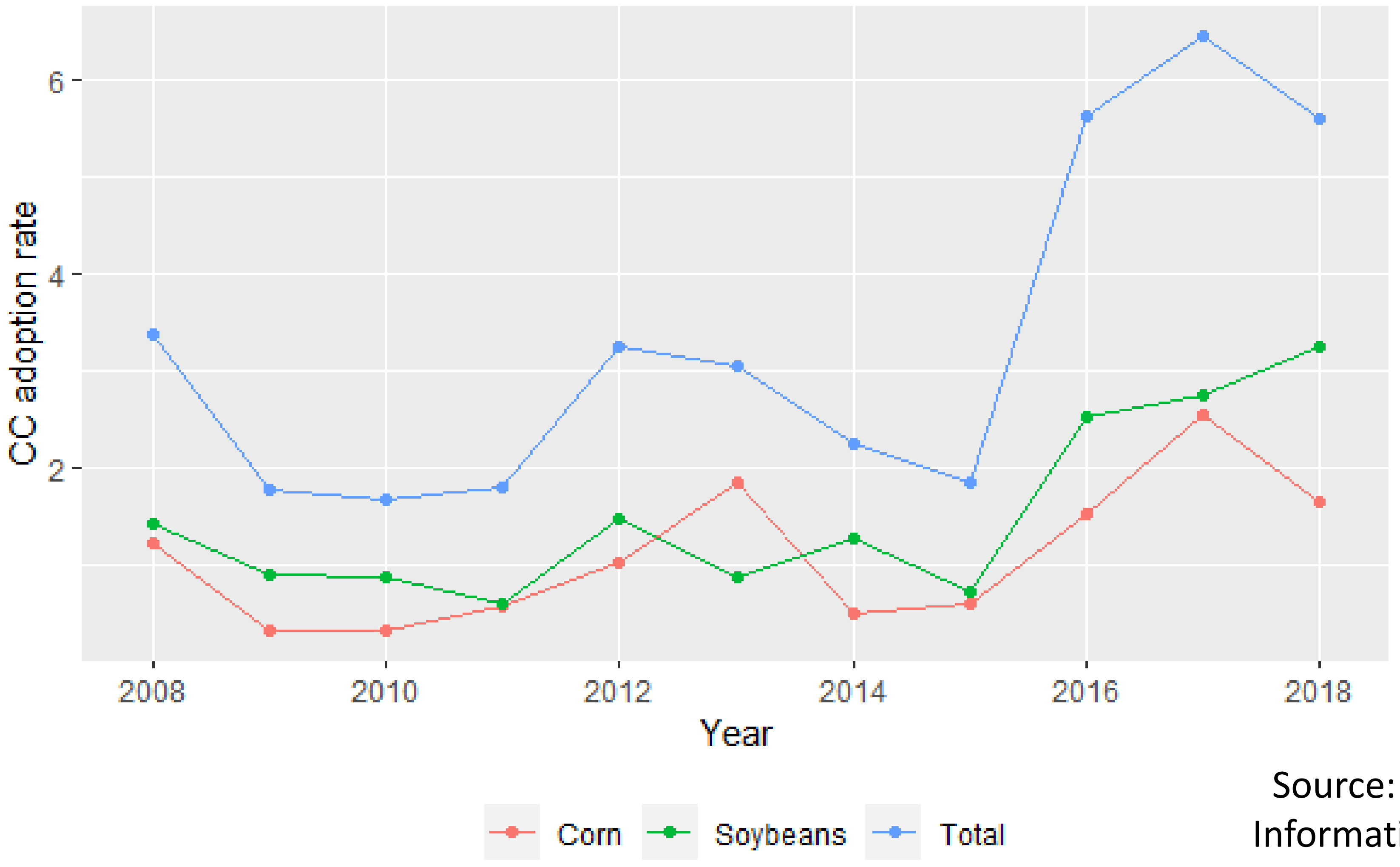


Cover Crop (CC) Adoption by water quality monitoring basins, 2008-2018



Source: Operational Tillage Information System (OpTIS), version 1

Annual mean adoption rate *following* corn & soybeans

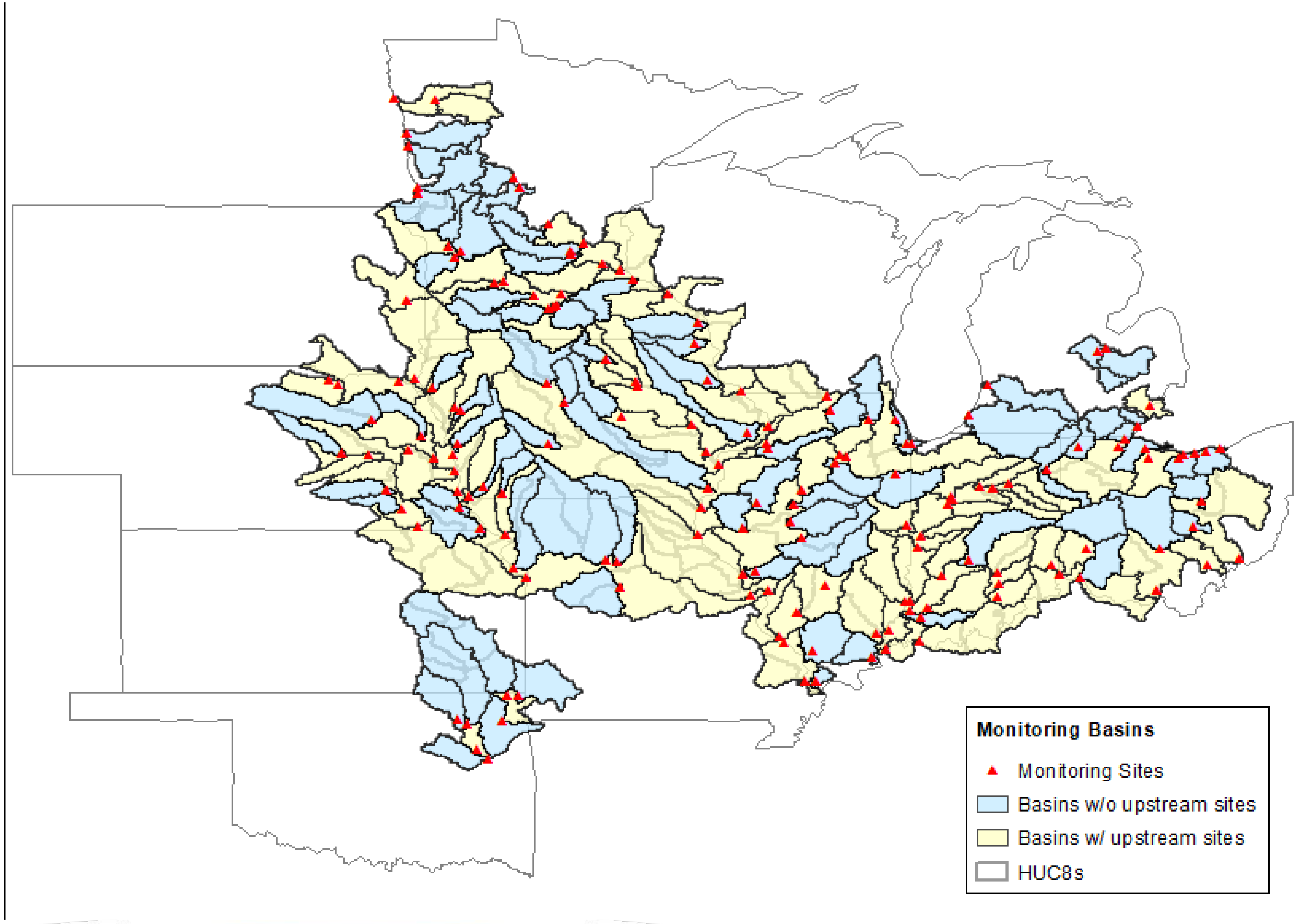


Source: Operational Tillage Information System (OpTIS), version 1

Watershed hydrology network

- Hydrologic Unit Code 8 (HUC8) is the spatial unit of analysis based the USGS National Hydrography Dataset

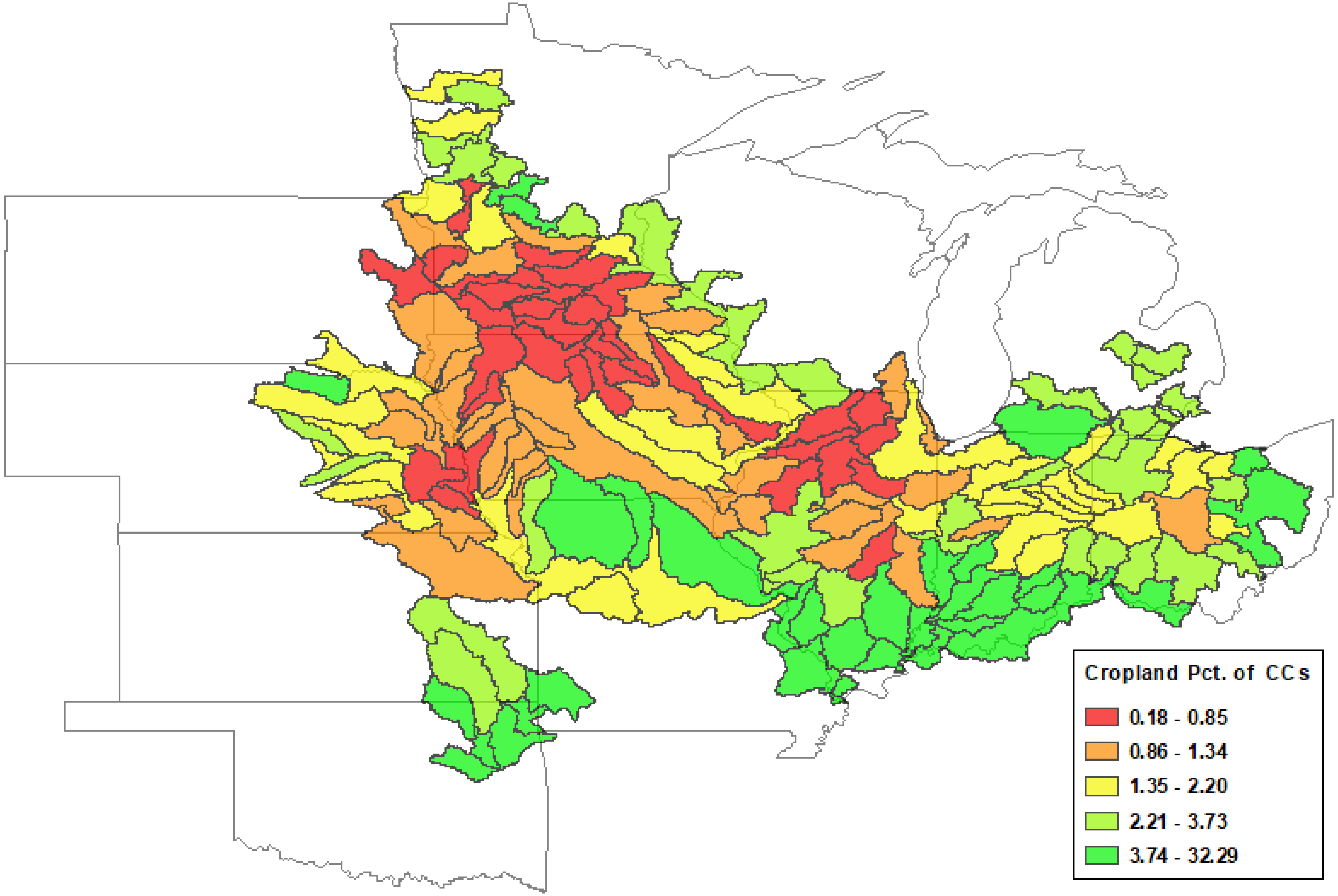
- **Monitoring basins** are formed by combining flow-connected HUC8s located between an upstream and downstream water quality monitoring site



Constructed monitoring basins aggregated by HUC8 sub-basins in the U.S. Corn Belt

Note: *headwater* basins are **blue**

Quantile map of the average cropland adoption rate of CCs from 2008 to 2018 by monitoring basin

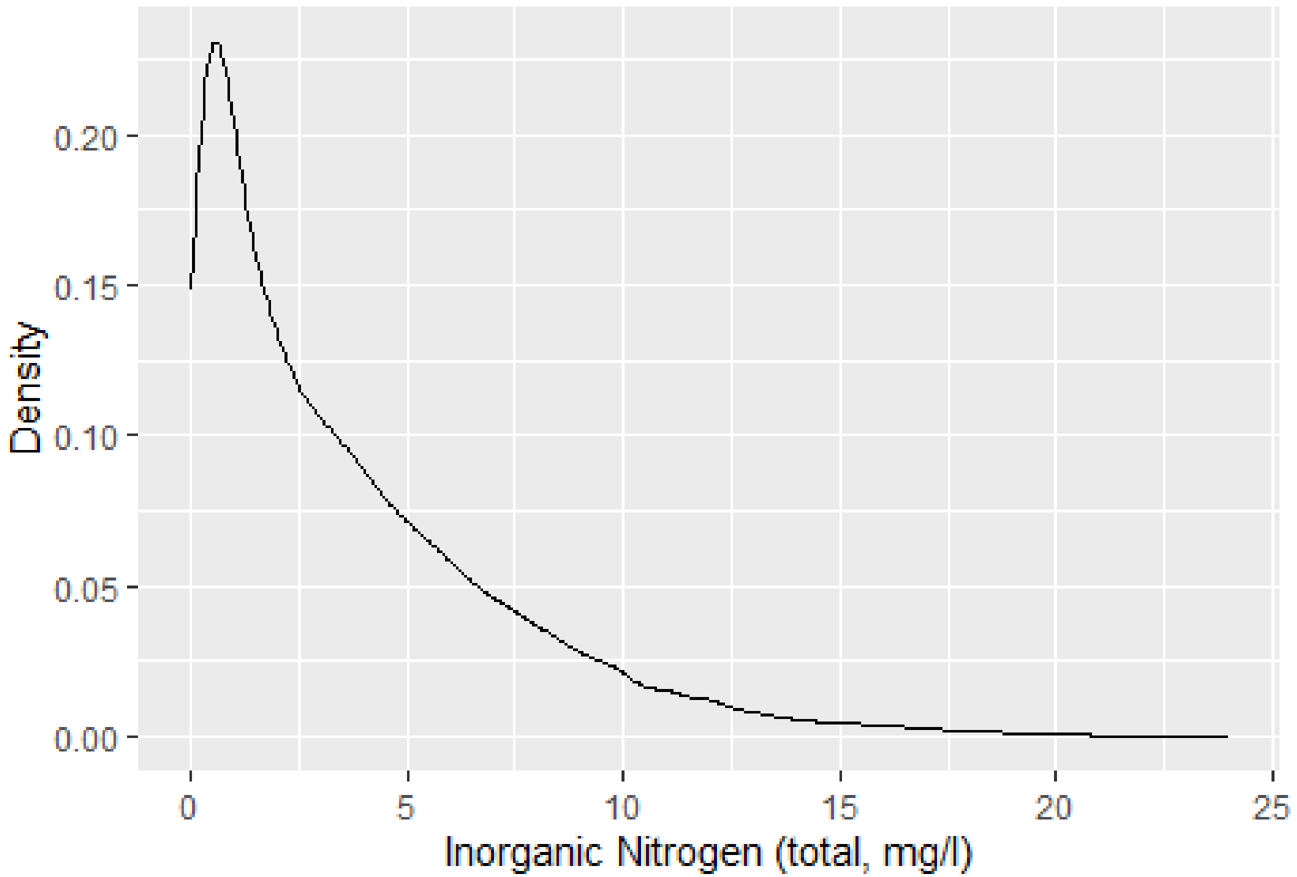


Water quality data

- Source: Water Quality Portal https://www.waterqualitydata.us/

- Ambient water quality measure:
  Total inorganic nitrogen (N) concentration (mg/l) (i.e., nitrite and nitrate)

Density plot of total inorganic nitrogen measurements at Corn Belt monitoring sites



Note: Higher N concentrations, which are less than 0.05% of the data, are excluded in the plot

Source: National Water Quality Monitoring Council

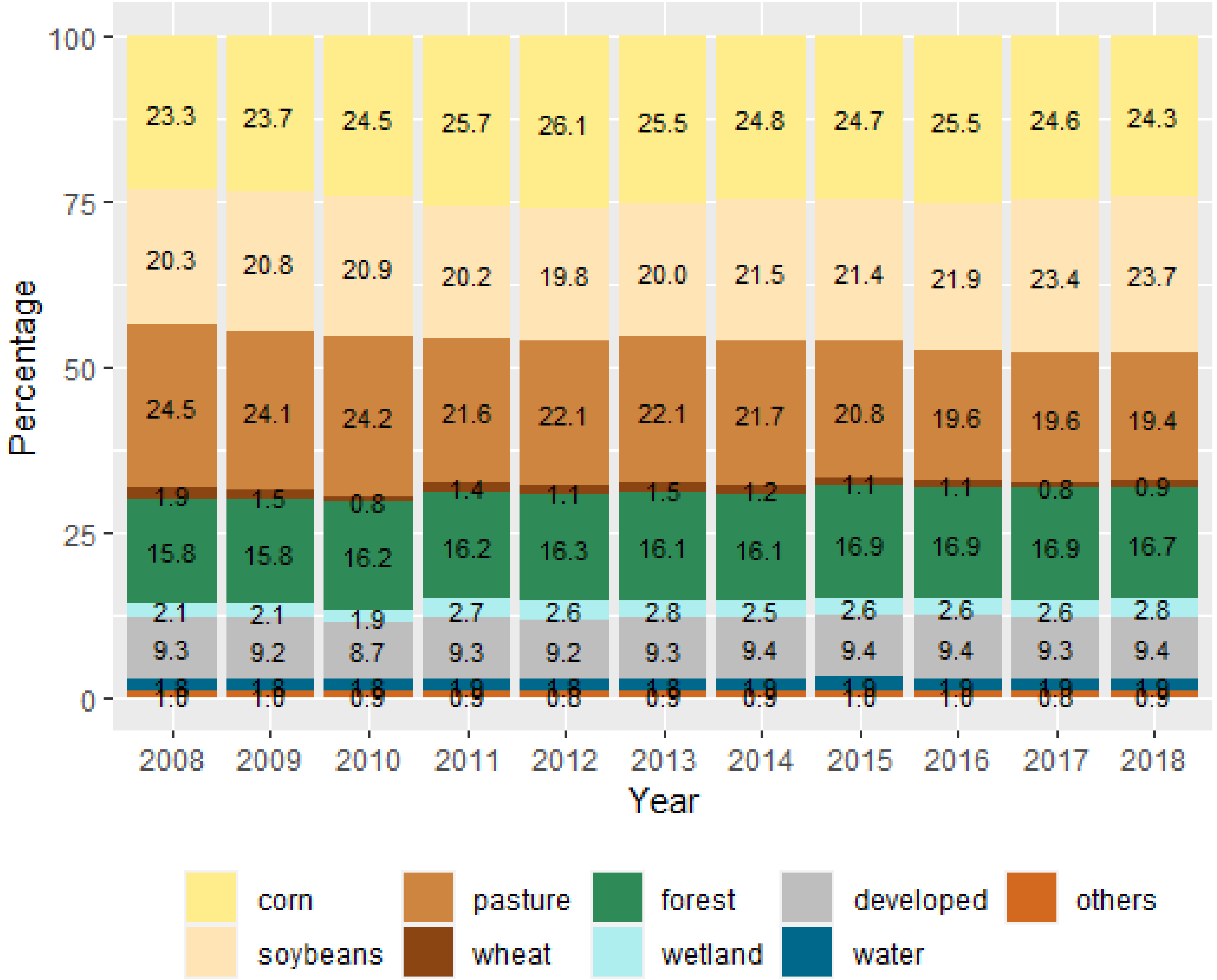
Weather, land use, and socioeconomic data

- Weather variables from PRISM Climate Group (OR State Univ)
  - Recent rainfall: 7-day cumulative precip prior to monitoring date
  - Palmer Drought Severity Index (PDSI) is calculated measure of hydrological drought based on monthly temp and precip
- Land Use and Land Cover data are from the USDA-NASS Cropland Data Layer (CDL) with annual data extracted using monitoring basin boundaries
- Control for crop yield (NASS) and gross farm income (BEA)

Land Use over Study Period

Note:

- Cropland occupies more than half of all Corn Belt land
- Slight overall increase…
    - Corn
    - Soybean
    - Forest
- Accompanying decline…
    - Pasture



Source: USDA National Ag Statistics Service, Copland Data Layer

Empirical strategy

- Panel fixed-effect (FE) approach using unbalanced annual panel data with separate models estimated based on hydrology
  - **Basins with inflow from upstream** control for spatial spillovers by including the nearest upstream pollution concentration measurement to isolate the effect of CC adoption in a given monitoring basins
    - Similar approach to Paudel and Crago (2020)
  - **Headwater basins** without inflow from upstream do not have this control variable
- Continuous treatment variable: share of cropland planted in CCs

Estimation equation

$$N_{it} = \alpha CC_{it} + \boldsymbol{X}'_{it}\beta + \gamma \sum_{k \in \Lambda_{i-1}} \psi_k N_{kt} + \theta_i + \eta_{rt} + \epsilon_{it}$$

- N_{it} = ambient N concentration (mg/l) in monitoring basin i and year t (annual mean of monthly measurements)
- CC_{it} = percentage of cropland with CCs

$\hat{\alpha}$ is coefficient of greatest interest = average treatment effect of CC adoption rate on N

$\sum_{k \in \Lambda_{i-1}} \psi_k N_{kt}$ = upstream pollution spillovers measured as weighted avg N over set of immediate upstream monitoring sites Λ_{i-1}

$\boldsymbol{X}'_{it}$ = vector of time-varying controls for weather, land use, crop yield, gross farm income

Table 1: Summary statistics

	Basins w/ upstream		Basins w/o upstream	
	Mean	St. Dev.	Mean	St. Dev.
Nitrogen concentration (mg/l) ***	3.059	2.176	3.617	2.830
Cropland percentage of cover crops **	3.196	5.832	2.453	5.294
7-day cumulative rain (mm)	20.843	9.644	21.311	9.224
Spring PDSI	-1.364	1.725	-1.253	1.843
Corn Yield (bu/acre)	153.982	41.239	156.063	41.016
Soybeans Yield (bu/acre)	46.224	10.628	45.526	11.466
Farm income (millions of dollars) ***	898.854	764.487	554.275	402.825
Percentage of corn land	27.970	13.186	28.269	14.841
Percentage of soybeans land	23.283	9.389	23.324	10.174
Percentage of developed land	10.072	7.927	9.444	10.222
Upstream N (mg/l)	3.567	2.383		

Notes: Asterisks denote p-value<0.1(*), <0.05(**), or <0.01(***). Figure 7 reports t-tests of differences in means for each variable between basin subgroups in Table 1.

Identification [1/3]

✓ Key assumption required for unbiased estimation of the treatment effect is that CC adoption rate is independent of the error term, conditional on observables: $E[CC_{it} \cdot \epsilon_{it} | \mathbf{X}'_{it}, N_{kt}, \theta_i, \eta_{rt}] = 0$

- Self-selection of individual farmers into CCs would be a potential threat to identification in our model only if individuals in each basin *systematically* made the <u>same</u> adoption decision
  - ➢ Our data are aggregate adoption data that are result of many individualized decisions such that no individual unobserved variable is systematically correlated with the CC adoption rate in an *entire* basin.

Identification [2/3]

- Economic factors may result in self-selection bias if these factors affect both N concentration and treatment distribution
  - ➢ Control for yield and farm income consistent with Prokopy et sl. (2019) finding that these are positively associated with individual adoption of ag conservation practices
  - ➢ Basin fixed effects may capture additional farm characteristics also found to positively affect individual adoption (Prokopy et al. 2019), to the extent that these factors are highly correlated within a monitoring basin

➢ Control for spring PDSI to limit endogeneity concern that expected drought conditions before growing season could influence CC adoption found to increase drought resilience (Myers et al. 2019)

Identification [3/3]

- If N concentration changes coincide directly with CC adoption rate ***but*** are the result of different conservation practices, this could bias estimated treatment effect
  - If additional mgt practices are installed simultaneously with CCs, this would lead to overestimating the effect of CCs in ambient N and provide an upper bound estimate of the treatment effect of interest

➢ No other practices are known to have changed over the same period on anywhere approaching the same level as CC adoption

Results

- Effect of CC adoption on ambient N is negative only in basins (1) where can control for upstream water quality
- Negative impact of spring drought conditions (measured by -1*PDSI) consistent with hydrology literature on streamflow effects of hydrological drought
  – Decrease in N measured in streams (Bowles et al., 2018; Mosley, 2015; van Vliet & Zwolsman, 2008)
- Increased rainfall accelerates drainage that increases N concentration in surface water (Bowles et al., 2018)

Table 2: Panel fixed-effect (FE) estimates for monitoring basins

	Dependent variable:		
	Nitrogen concentration (mg/l)		
	(1) Basins w/ upstream site	(2) Basins w/o upstream sites	(3) All basins
Treatment			
Cropland Pct. of Cover Crops	−0.015**	0.003	−0.006
	(0.007)	(0.006)	(0.005)
Weather			
7-D Cum. Rain	0.008	0.022*	0.016*
	(0.012)	(0.012)	(0.009)
7-D Cum. Rain (quadratic)	−0.0001	−0.0001	−0.0001
	(0.0002)	(0.0002)	(0.0002)
Spring PDSI	−0.098***	−0.152***	−0.132***
	(0.025)	(0.042)	(0.027)
Socioeconomic Char.			
Corn Yield (bu/acre)	−0.005**	0.001	−0.002
	(0.002)	(0.002)	(0.001)
Soybeans Yield (bu/acre)	0.029***	0.011	0.021***
	(0.009)	(0.010)	(0.006)
Farm Income (million of $)	0.0001	−0.002***	−0.0005
	(0.0003)	(0.001)	(0.0004)
Land use			
Corn	0.052**	0.045*	0.054***
	(0.023)	(0.026)	(0.019)
Soybean	−0.035	−0.094***	−0.057*
	(0.030)	(0.033)	(0.024)
Developed	0.160*	−0.139**	0.006
	(0.091)	(0.065)	(0.072)
Pollution Spillovers			
Upstream N (mg/l)	0.509***		0.374***
	(0.084)		(0.084)
Observations	590	725	1,315
R^2	0.594	0.344	0.371

Note: Each analysis includes monitoring basin and HUC2-by-year fixed effects. Standard errors are clustered by monitoring basin. Asterisks denote p-value<0.1(*), <0.05(**), or <0.01(***)

Key Findings

1) Estimated treatment effect of CC adoption: 10% *increase* in the share of cropland planted in CCs leads to a 0.15 mg/l *decrease* in average ambient N levels in non-headwater basins
   - ❖Estimated effect is equivalent to 5% of the average N concentration

2) Upstream pollution determines the largest amount of immediate downstream neighbors' ambient N measurements due to the connectivity and directional flow of streams and rivers
   - Controlling for these pollution spillovers, the model specification prevents the estimated effect of CCs from being confounded with N pollution and treatment in upstream basins

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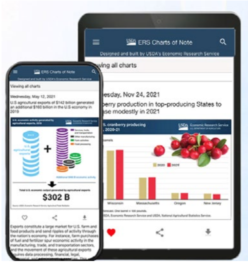

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