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Climate Prediction Applications Science Workshop (CPASW)
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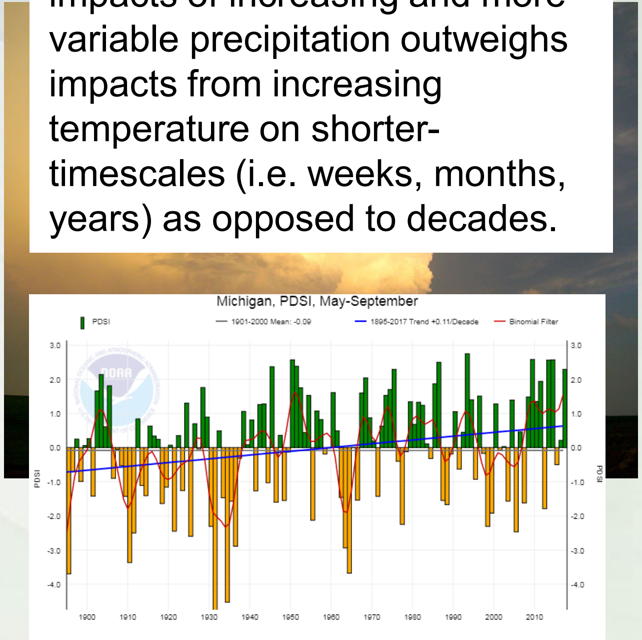
Changes in Precipitation Indicators Across the Midwestern and Great Lakes Regions of the United States: Implications for Corn-Soy Production from Field to Region

What’s Changing in Our Climate?

- Increasing annual precipitation
- Shifting seasonality of precipitation
- Increasing intensity of precipitation events
- Increasing air temperatures
- Increasing minimum temperatures more than maximum temperatures
- Longer growing seasons
- Increasing humidity (specific/absolute)

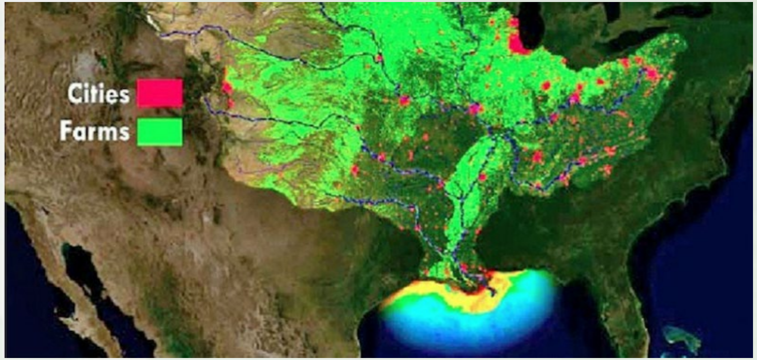
If we consider our end-user to be producers on working lands, the impacts of increasing and more variable precipitation outweighs impacts from increasing temperature on shorter-timescales (i.e. weeks, months, years) as opposed to decades.



Precipitation/Nitrogen

- Changes in precipitation amount and variability can have direct impacts on nitrogen cycling (Kalkhoff et al. 2016)
- Depending on crop requirements, application rate, & farm size, nitrogen losses can represent a significant financial loss to producers and a major environmental pollutant (Robertson et al. 2013)

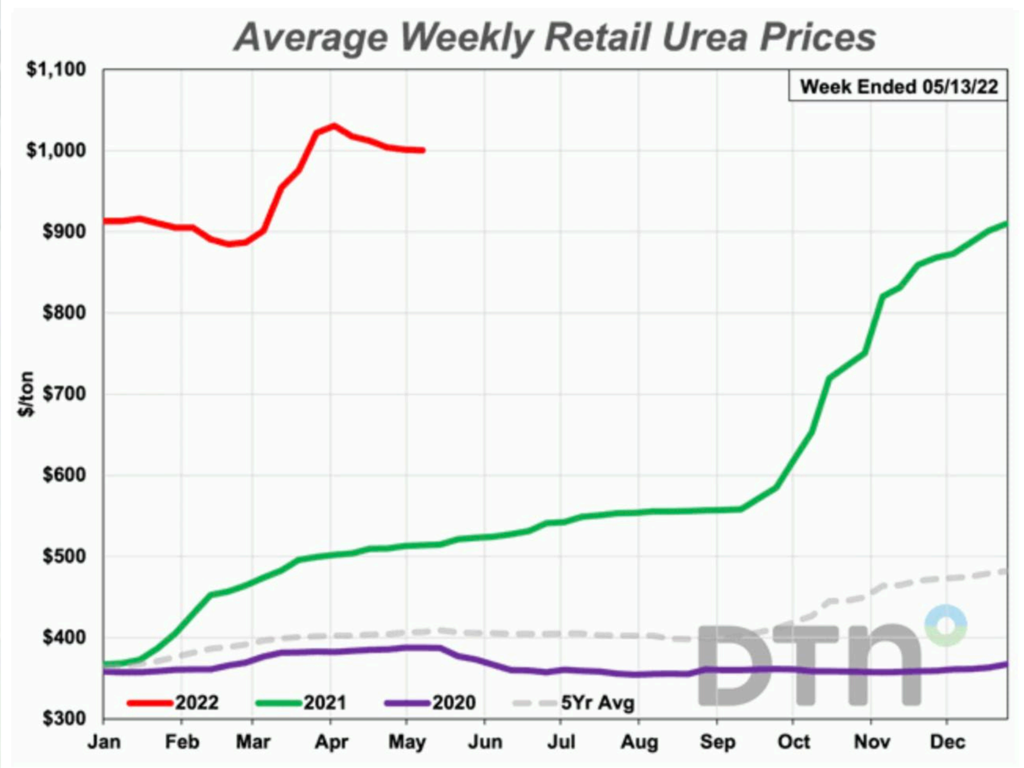
Source: Purdue University Extension



Source: NOAA

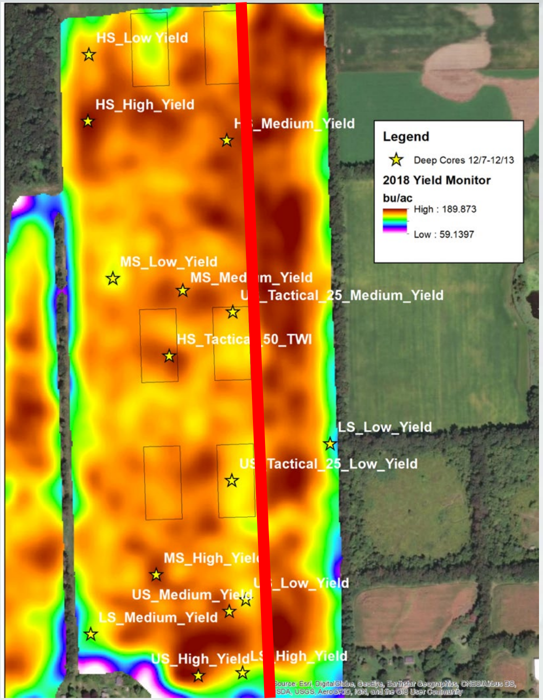
Nitrogen Efficiency

- Efficiency of nitrogen fertilizer applied has historically been poor.
  - ~50-75% not utilized
- Application of nitrogen in surplus of crop demand, results in lost nitrogen to the environment and lost money for the producer
- Nitrogen fertilization traditionally viewed as cheap insurance (Tei et al.

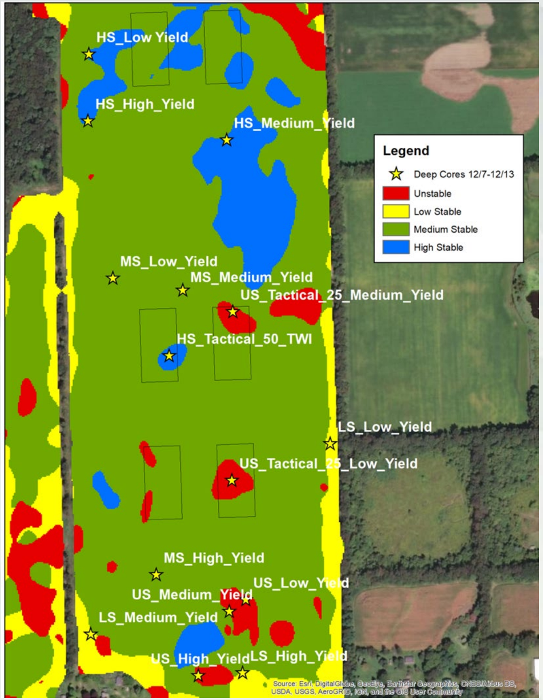


Source: DTN/Progressive Farmer, May 18 2022

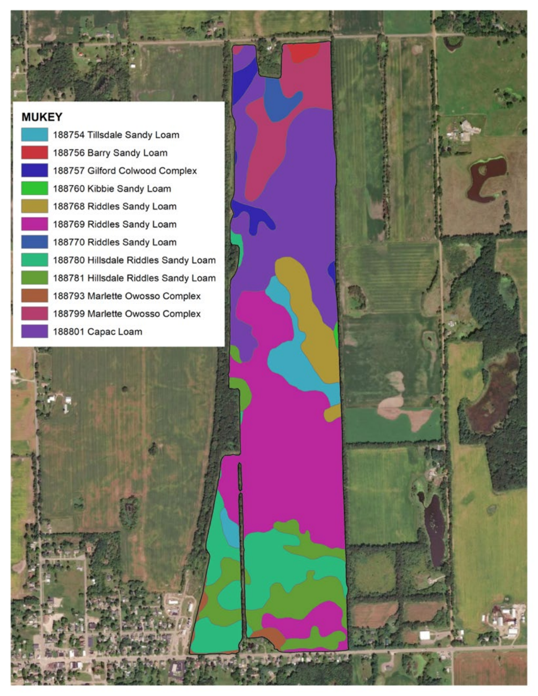
Background



2018 Corn Yield



Yield Stability Zones



Soil Types

Trends in Quality Controlled Precipitation Indicators

- Examined precipitation records from United States Historical Climatology Network across 14 states from 1951-2019.
- Focus on a suite of Indicators (modified from ETCCDI) that capture the character of precipitation at a given location
- Implemented a three-tiered quality control procedure that goes beyond the provided QC examining for incidences of 1. Data Completeness, 2. Observer Bias, 3. Abrupt Change in Observing Practice.
- Annual/Seasonal: Non-parametric trend analysis of precipitation indicators (3 CI levels). Correlation with atmospheric moisture
  - parametric/non-parametric methods

*Baule, W.J., J.A. Andresen, and J.A. Winkler, 2022: Trends in quality controlled precipitation indicators in the United States Midwest and Great Lakes Region. Frontiers in Water, **8**, 817342, doi:10.3389/frwa.2022.817342*

Tests for Observer Bias

Under-reporting check

$$R_L = \frac{C_{6-10}}{C_{1-5}},$$

If ratio exceeds 0.60, station fails

Five/Tens Bias
Carried out for values divisible by 5 and 10

$$R = 100*(P - O)$$

$$\gamma = \alpha\beta$$

$$\overline{R}_1 = \frac{\sum_{i=1}^{n_1} R_{1_i}}{n_1}; \ \overline{R}_5 = \frac{\sum_{i=1}^{n_5} R_5}{n_5}$$

Two-tailed t-test, alpha = 0.01, if different, station fails

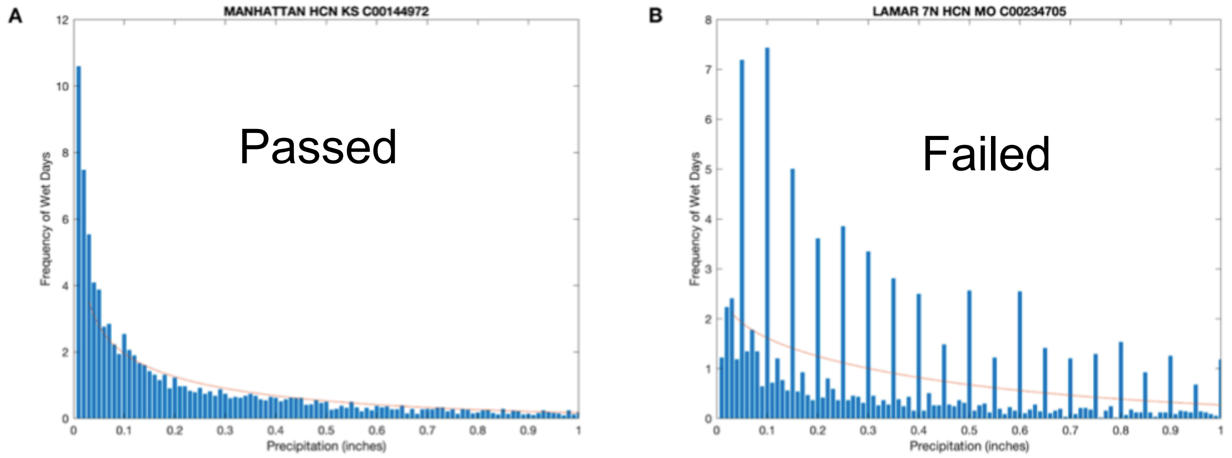


FIGURE 2 | Histograms from two example stations in the study region showing precipitation frequency (blue bars) over the period from 1951 to 2019 binned in 0.01 increments and a gamma distribution (red line) fit to the data following Daly et al. (2007). **(A)** Manhattan, KS HCN passes ($p \leq 0.01$) the tests for underreporting of daily precipitation amounts <0.05 in. (1.26 mm) and for over-reporting of daily precipitation amounts (in inches) evenly divisible by 5 or 10 despite showing a small divisible by 10 bias. (B) Lamar 7N, MO HCN fails all three tests ($p \leq 0.01$), showing a strong under reporting bias, a strong divisible by 5 bias, and a strong divisible by 10 bias.

Final Stations

- 317 stations met criteria for completeness
  - 90%, 1951-2019
- 114 passed observer bias checks
- Time series of annual and seasonal indicators were subject to additional check for breakpoints/discontinuities (Pettit Test).
  - If breakpoint detected, that time series is not considered

TABLE 2 | Number of stations exhibiting statistically significant trends (Mann Kendall, $p \leq 0.05$ two-tailed, $p \leq 0.10$ two-tailed, $p \leq 0.20$, two-tailed) from 1951 to 2019 in the annual precipitation indicators.

Precipitation indicator	Total number of stations after breakpoint analysis	Number of stations with significant positive trends ($p \leq 0.05$)	Number of stations with significant positive trends ($p \leq 0.10$)	Number of stations with significant positive trends ($p \leq 0.20$)	Number of stations with significant negative trends ($p \leq 0.05$)	Number of stations with significant negative trends ($p \leq 0.10$)	Number of stations with significant negative trends ($p \leq 0.20$)
PRCPTOT	100	47	**75**	**79**	1	1	1
R1.26mm	97	42	**53**	**61**	1	3	5
SDII	112	42	52	**62**	0	0	3
CWD	114	17	23	36	0	0	0
CDD	113	0	2	2	16	28	44
WW	105	27	44	51	5	7	9
DD	107	2	3	3	41	**61**	**65**
R10mm	104	42	**60**	**72**	0	1	1
R20mm	101	35	**58**	**59**	1	1	1
R95pTOT	104	38	**62**	**63**	0	0	0
R99pTOT	108	11	33	39	0	0	0
Rx1day	114	13	29	43	0	0	0
Rx5day	114	23	33	47	0	0	2

Indicators where more than 50% of stations analyzed showed a significant trend are shown in bold. See ***Table 1*** *for definition of the abbreviations for the precipitation indicators.*

Annual Results

- Annual precipitation has increased across the region in most indicators
- More variability in west and north when compared to east and south

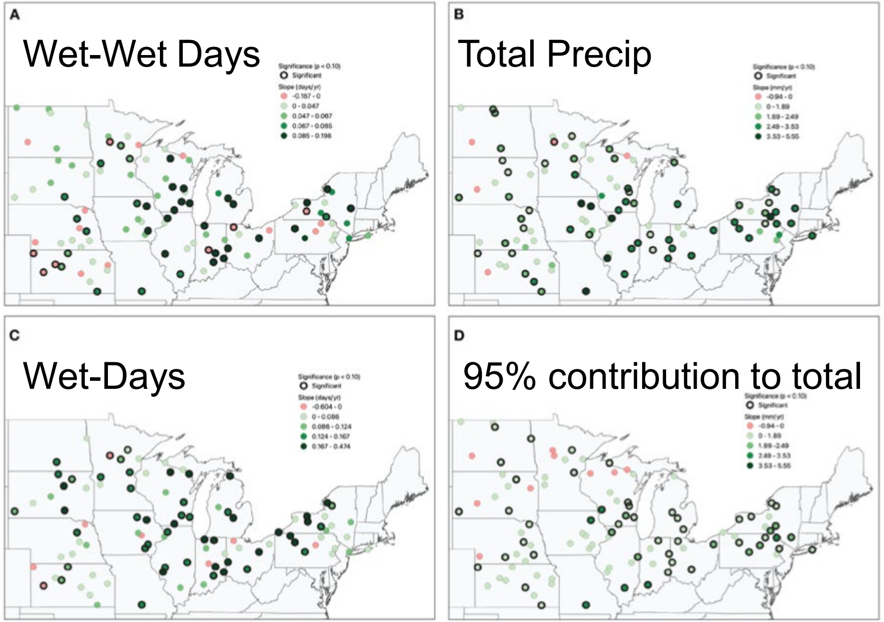


FIGURE 3 | Trends for 1951–2019 in representative annual indicators of precipitation characteristics at locations in the Midwest and Great Lakes region that passed the quality control checks described in the methods section: **(A)** annual counts of wet-wet day sequences (ANN WW; days; count year^{-1}; upper left), **(B)** annual total precipitation on wet days (PRCPTOT; mm year^{-1}; upper right), **(C)** number of days with precipitation ≥ 1.26 mm (R1.26mm; days year^{-1}; lower left), and **(D)** total precipitation on days when precipitation is ≥ 95th percentile (R95pTOT; mm year^{-1}; lower right).

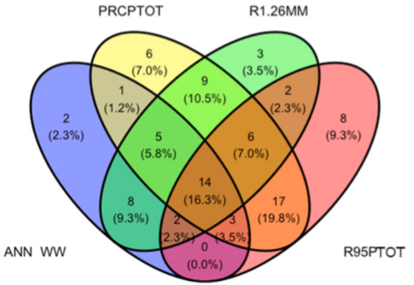


FIGURE 4 | Venn Diagram of the number of stations with significant positive trends for all possible combinations of four representative annual precipitation indicators: the probability of wet-wet days (WW), total annual precipitation (PRCPTOT), the number of wet days (R1.26mm), total precipitation on days with precipitation ≥ 95th percentile (R95pTOT). Percentages are relative to largest number of significant positive trends which was 86. Percentage of significant ($p \leq 0.10$) positive trends falling in each category is shown in parentheses.

Seasonal Results

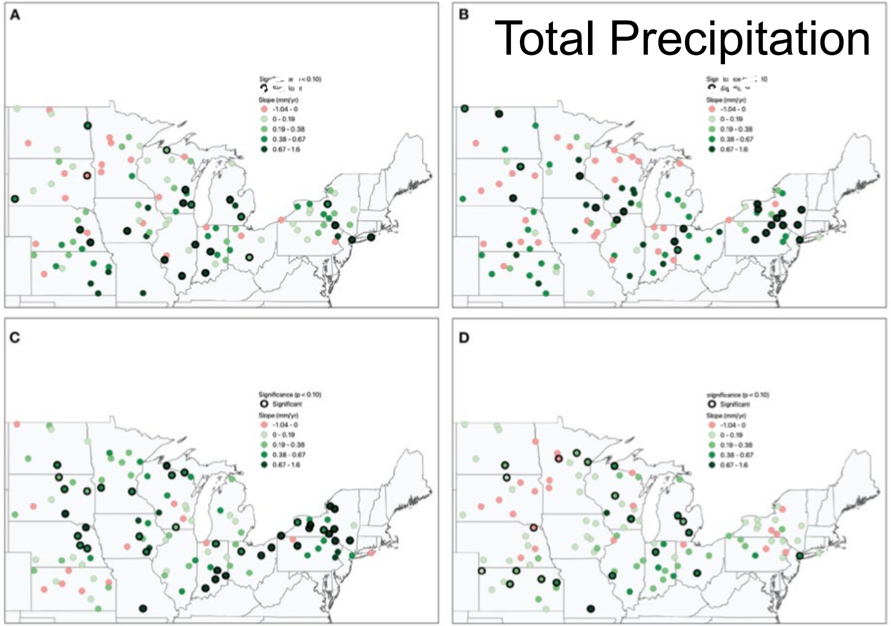
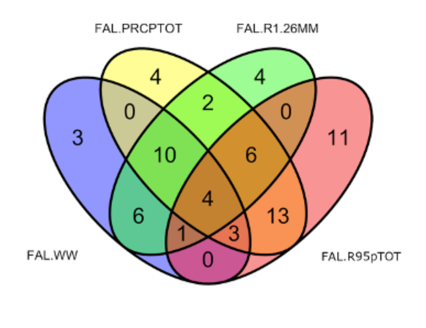


FIGURE 6 | Trends (mm year^{-1}) in the seasonal amount of total precipitation falling on days with precipitation ≥ 95th percentile (R95pTOT) for **(A)** spring, **(B)** summer, **(C)** fall, and **(D)** winter.

Seasonal Total Precipitation

- Seasonal indicators showed fewer significance trends than their annual counterparts
- The season with the most significant trends was fall; the fewest in spring.
- Fewer breakpoints were detected in seasonal time series

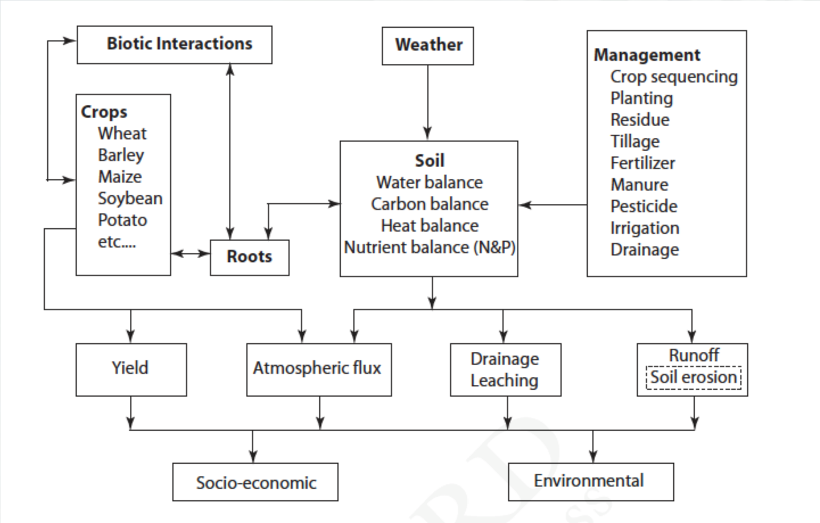


Take Aways from Precipitation Indicators

- Quality control procedures and methods implemented have a profound effect on the interpretation of trends.
  - i.e. Choose wisely and don't ignore light accumulation events
- Controlling for observer bias and change points in the data resulted in more spatially coherent patterns of statistical significance
  - Though not all indicators exhibited large positive/significant trends, the near absence of statistically significant negative trends is impressive.
  - Changes have occurred differently across space and time in the study region
    - More variation in the west, general wetting trend in the east

Process Based Crop Models

Components of the Systems Approach to Land Use Sustainability Model (SALUS)

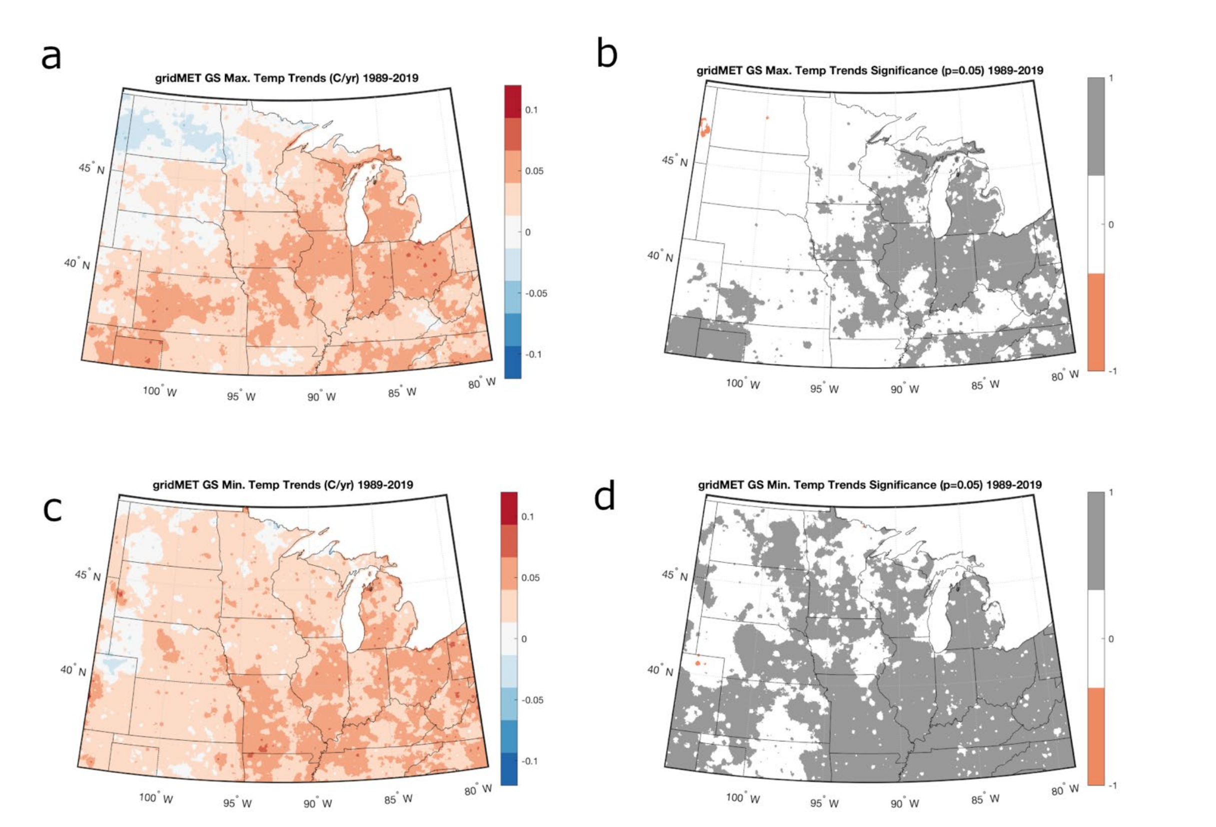


Source: Basso and Ritchie 2015

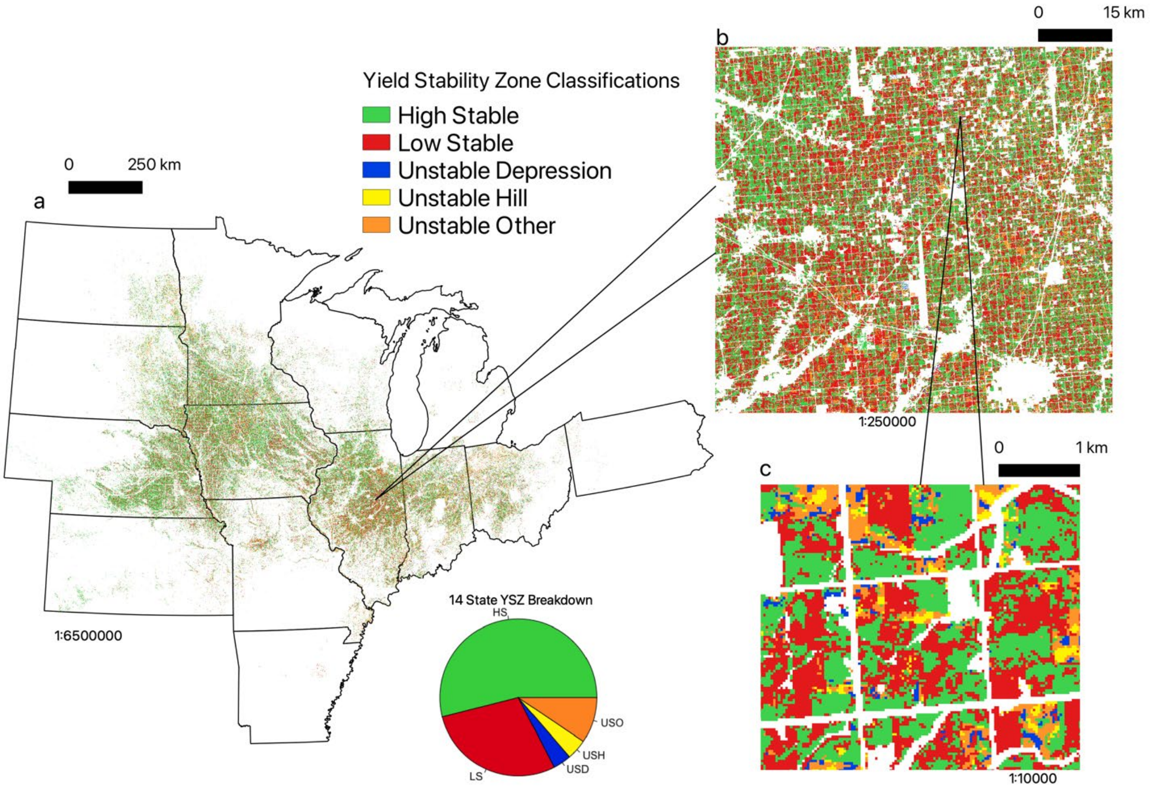
- Crop Models are a tool that can allow us to examine the linkages between components of the Soil-Plant-Atmosphere continuum
- Tie the different components together

Background Hydroclimatic Trends (1989-2019)

- gridMET (4-km)
- Precipitation and PET have generally increased
  - PET > PRCP
- GS Temperatures have increased
  - Exception ND/MN high temps.



Yield Stability Zones and Study Area



- Stability zones by FSA common land unit (CLU)/NDVI data (Basso et al. 2019). 30-meter resolution
- Modifications to soil and plant density necessary for each zone.
- Simulated corn-soy rotation from 1989-2019, alternate years.
  - Soy crops unfertilized
  - Start on corn
- Historical Management Practices
- Three tillage scenarios
  - No-Till, Minimum Tillage, Deep Tillage
- Approx. 22 million unique combinations of field, soil, stability zones (30-meter).

HS: Average NDVI always greater than field average, low temporal variation
LS: Average NDVI always less than field average, low temporal variation
US: Variable yields, year to year

Basso et al. 2019

$$\overline{NDVI}_{i,j} = \frac{\sum_1^n NDVI_{i,j,k}}{n}$$

$$\overline{snNDVI}_{j,k} = \frac{\sum_1^8 snNDVI_{i,j,k}}{8}$$

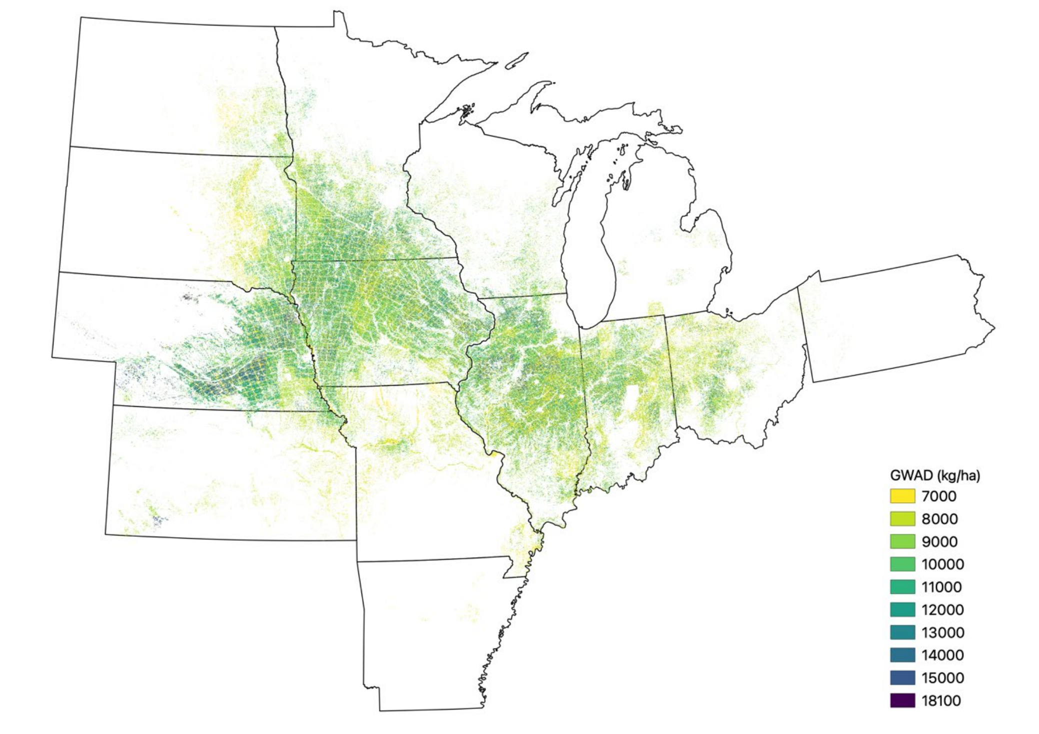
$$rNDVI_{i,j,k} = \frac{NDVI_{i,j,k} - \overline{NDVI}_{i,j}}{\overline{NDVI}_{i,j}}$$

$$tnNDVI_{j,k} = \sqrt{\frac{1}{8}\sum_1^8 (snNDVI_{i,j,k} - snNDVI_{j,k})^2}$$

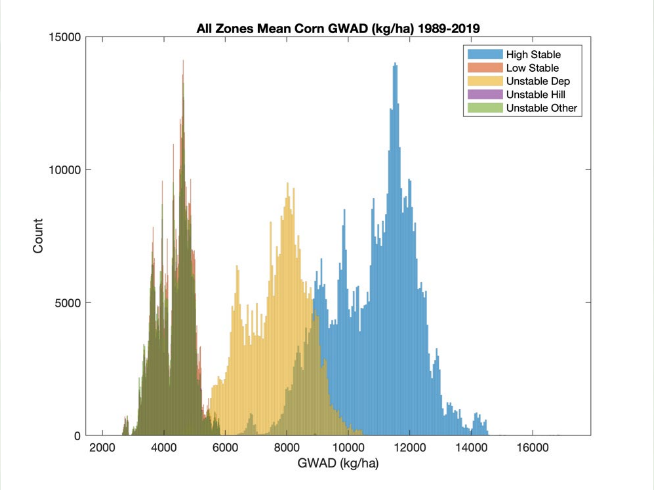
$$snNDVI_{i,j,k} = \begin{cases} High\ NDVI & if\ NDVI_{i,j,k} \geq \overline{NDVI}_{i,j} \\ Low\ NDVI & if\ NDVI_{i,j,k} < \overline{NDVI}_{i,j} \end{cases}$$

$$Stability_{j,k} = \begin{cases} SH\ \ if\ NDVI_{i,j,k} \geq \overline{NDVI}_{i,j}\ and\ tnNDVI_{j,k} < 0.15 \\ SL\ \ if\ NDVI_{i,j,k} \geq \overline{NDVI}_{i,j}\ and\ tnNDVI_{j,k} < 0.15 \\ U\ \ if\ tnNDVI_{j,k} \geq 0.15 \end{cases}$$

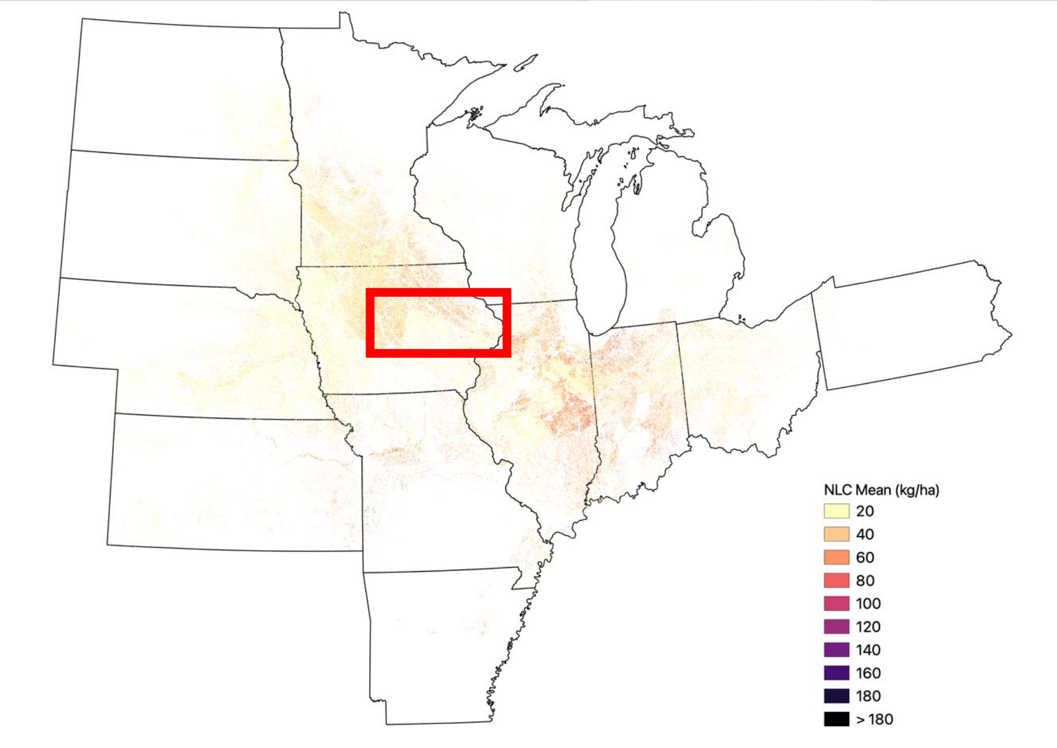
Yield Results



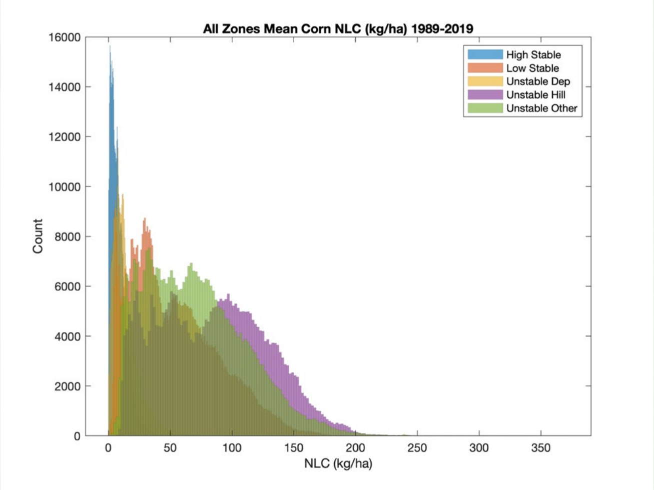
- High Stable/Unstable-Depression Zones are responsible for the majority of the yield.
- Low Stable, Unstable Hill & Other have similar yield response but different climatic sensitivities.



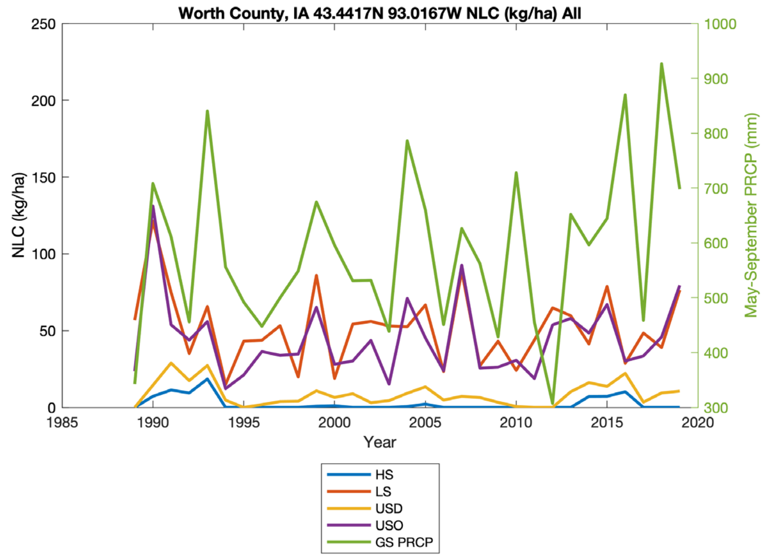
Leaching Results

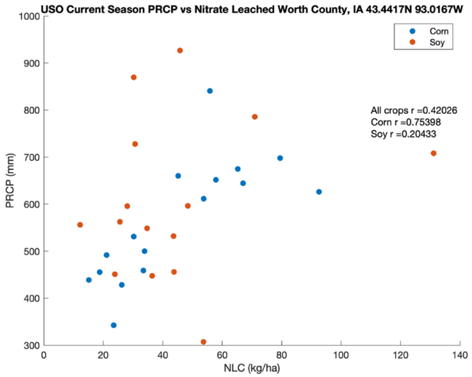


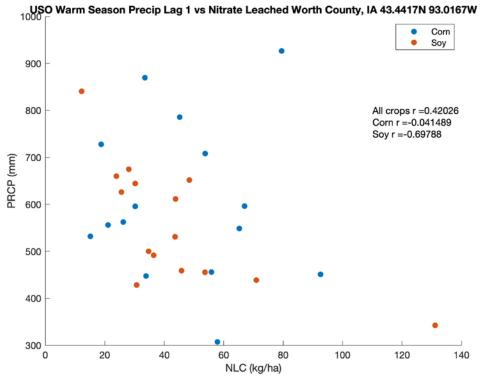
- Due to lower yields, N-Uptake, and *uniform management.* The Low Stable, Unstable Hill, and Unstable Other are responsible for the majority of leaching.
- Due to more favorable soil conditions and plant health, the high yielding zones leach little.



Sub-Field Leaching-Single Field

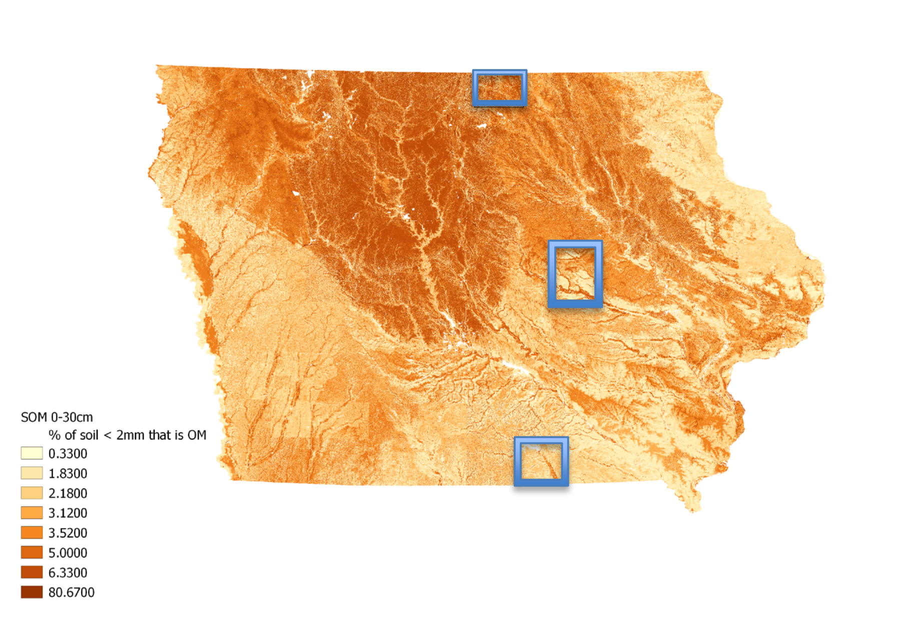


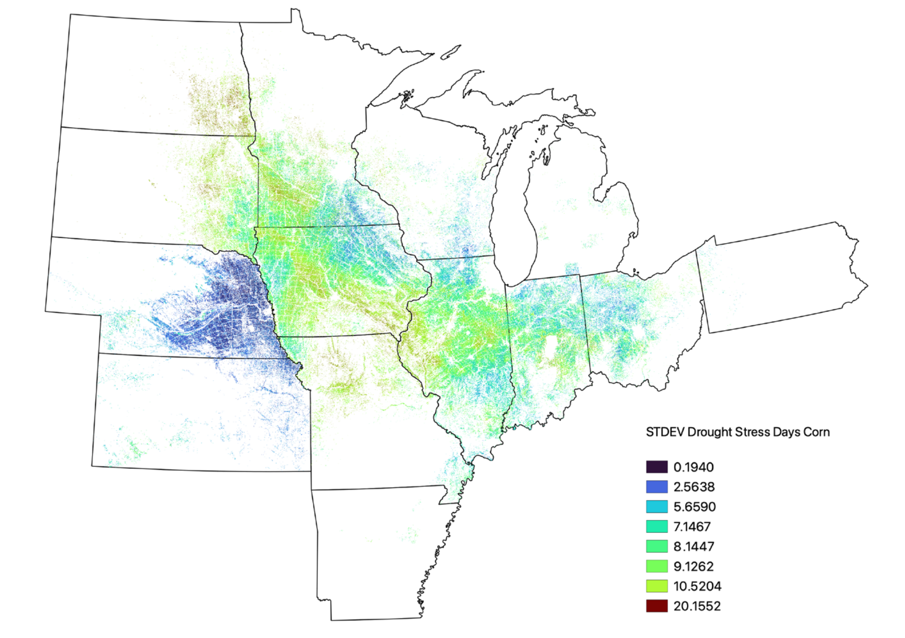




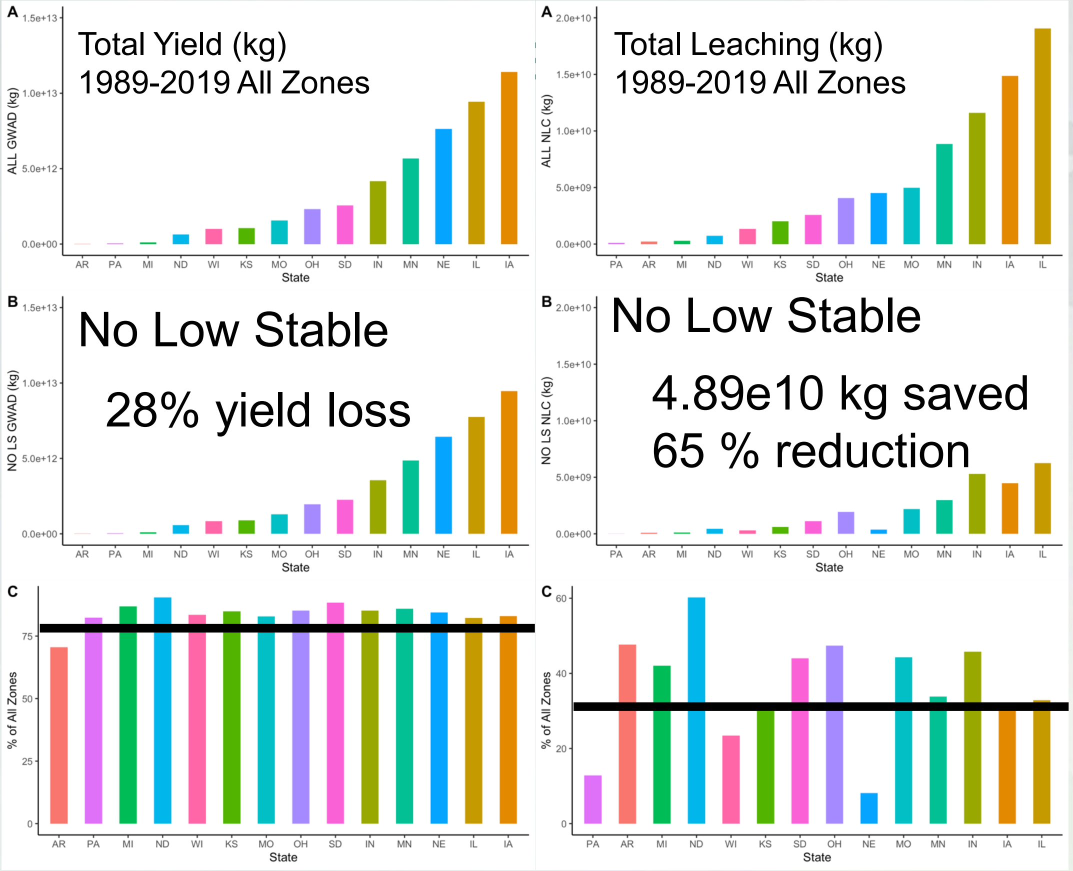
- Leaching is directly tied to precipitation/water stress
  - Crop and Management changes the result
- Corn years have highest leaching
  - Fertilization
  - Current Growing Season Precip
- Soy years have less leaching
  - No Fertilization
  - Prior Growing Season Precip.
- Highest leaching potential
  - Soy: following a drought
  - Corn: Wet year following a drought
- Unstable Other zones have highest correlations with hydroclimatic variables

Water Stress Variability/SOM





County	SOM% 0-30cm (%)	PRCP (mm)	PET (mm)	DIFF (mm)	HS Mean Drought Stress (days)	LS Mean Drought Stress (days)	HS Mean NLC (kg/ha)	LS Mean NLC (kg/ha)	HS Mean N Plant (kg/ha)	LS Mean N Plant (kg/ha)
Worth	6.09	899	964	-65	2.91	11.69	4.28	8.57	284.30	170.29
Tama	2.96	920	1015	-95	6.63	14.45	7.87	9.32	237.50	170.67
Appanoose	2.28	978	1112	-134	7.57	14.81	8.28	9.21	225.22	165.33



- Highest yields were simulated in Iowa, Nebraska (irrigated), and Illinois.
- Highest leaching contributions were simulated in Illinois, Iowa, and Indiana
- Higher climatic sensitivities in Unstable Zone: in-season precision management could reduce leaching from these areas.
- Low stable zones don't respond as strongly to weather/climate
  - Eliminating Low Stable Zones
    - Reduces total yield by ~ 25% across region
    - Reduces leaching by 40% (ND) to 85% (PA) (rainfed)
    - 90% Reduction NE (irrigated)

Thank You!

- Questions?
- Contact:
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Long-term Ecological Research

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Figure S1. Estimated yield using NDVI-stability class approach vs yield monitor data (right-hand bars).