What does pre-planting soil moisture tell us about final corn yields?

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Risk and Profit Conference
August 21 & 22, 2025

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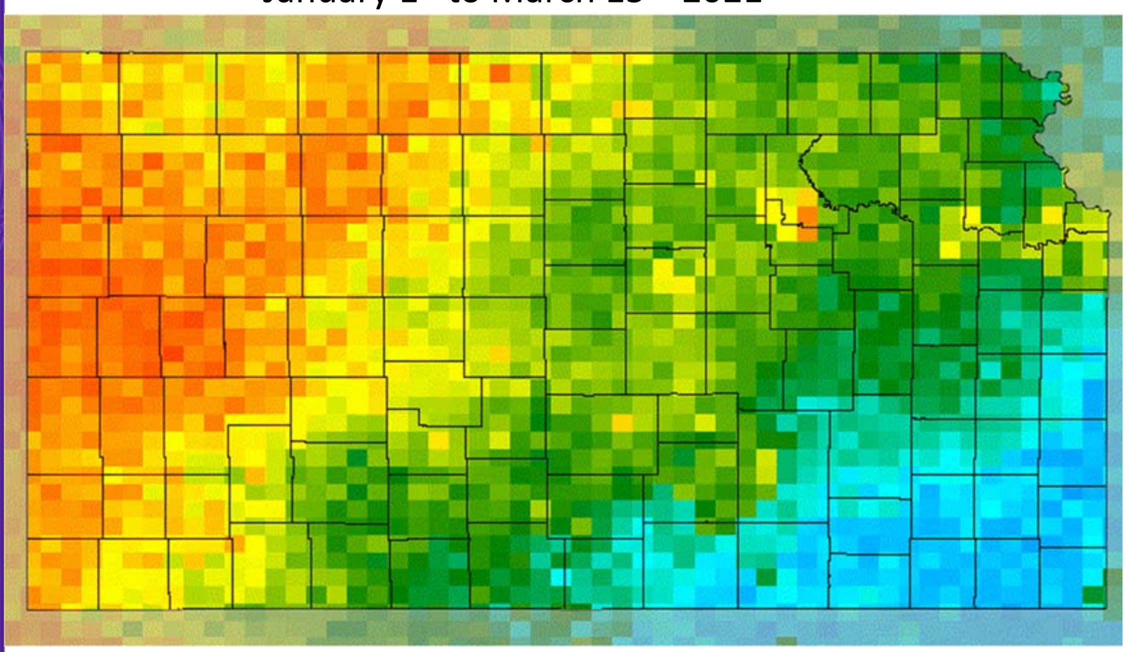
Daily Soil Moisture

January 1st to March 15th, 2021



Data source: NASA-USDA Enhanced SMAP

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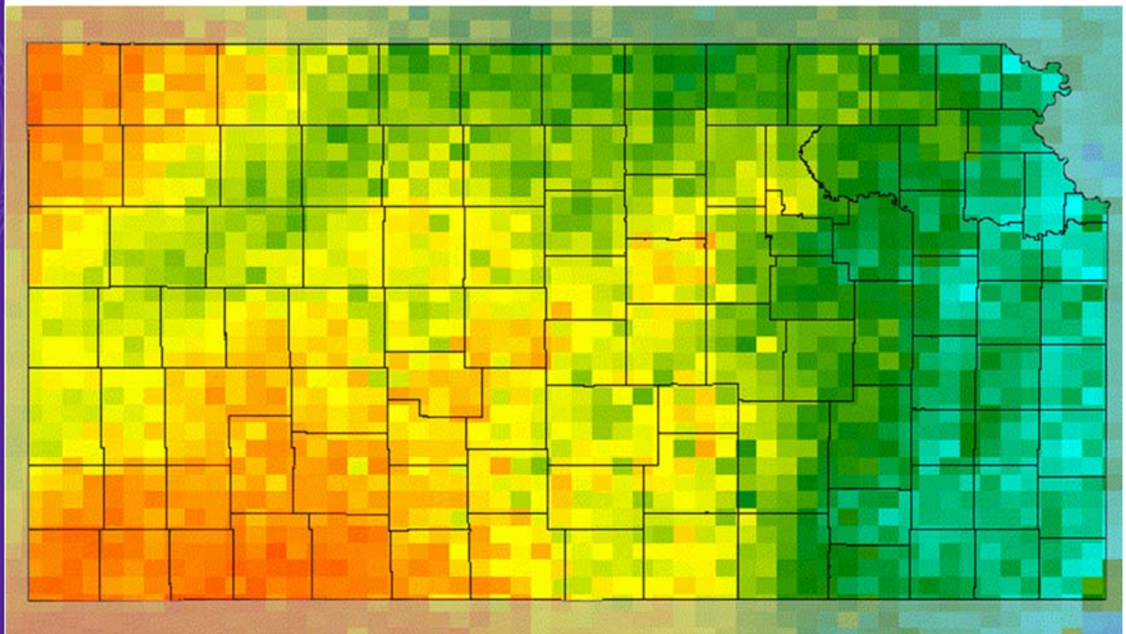
Daily Soil Moisture

January 1st to March 15th, 2022



Data source: NASA-USDA Enhanced SMAP

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Are decisions made based on early season soil moisture information supported by measurable impacts on corn yields?

Data Sources

Yield Data: USDA Risk Management Agency (1990-2022)

- Precise county yield records
- Ability to control for irrigation status

Soil Moisture Data: NASA SPoRT-LIS (1km^2 daily measurements)

- High-resolution standardized moisture data
- Longer time series than alternatives

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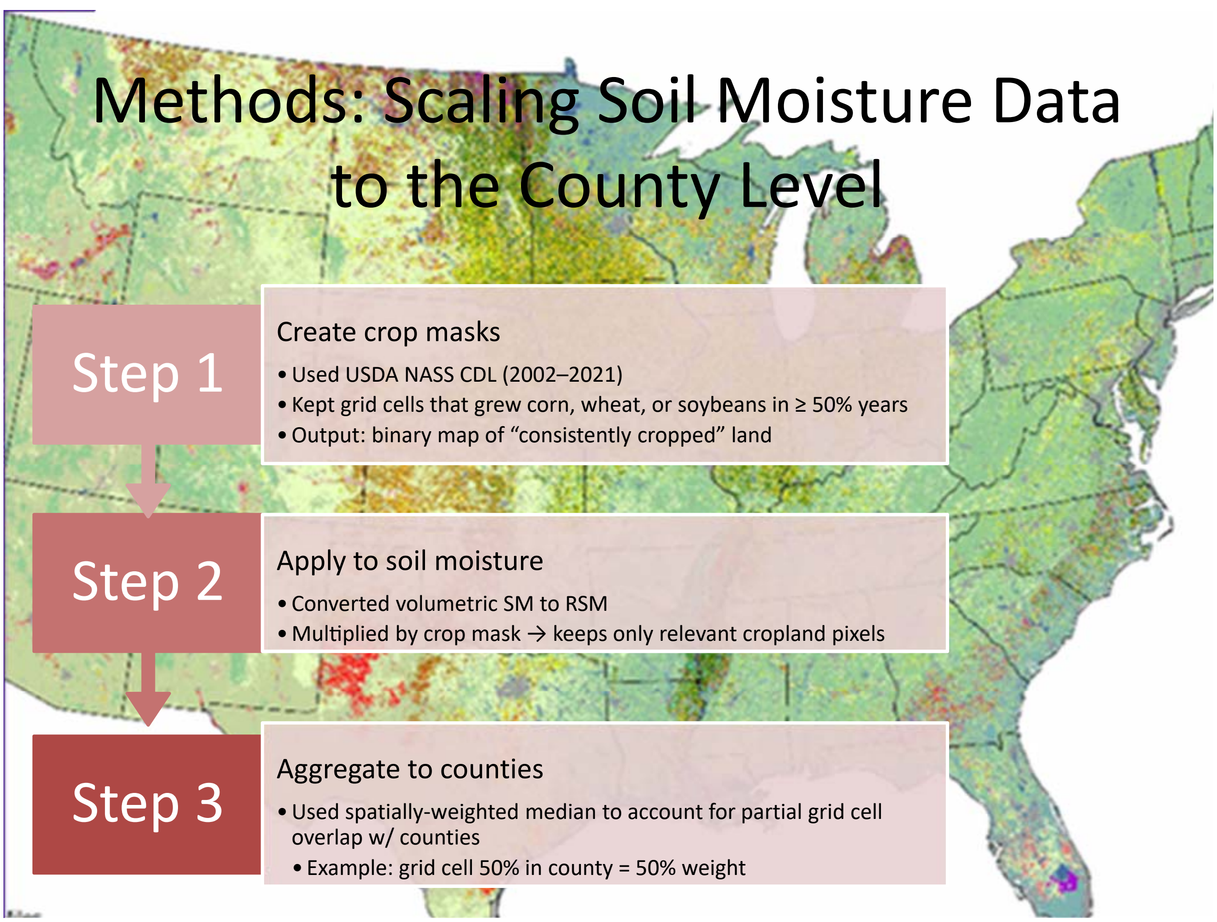
Methods: Scaling Soil Moisture Data to the County Level



Step 1 — Create crop masks

- Used USDA NASS CDL (2002–2021)
- Kept grid cells that grew corn, wheat, or soybeans in ≥ 50% years
- Output: binary map of "consistently cropped" land

Step 2 — Apply to soil moisture

- Converted volumetric SM to RSM
- Multiplied by crop mask → keeps only relevant cropland pixels

Step 3 — Aggregate to counties

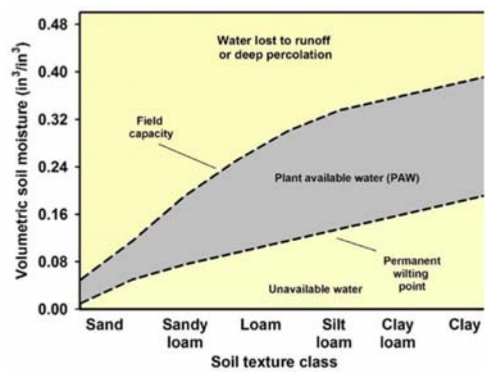
- Used spatially-weighted median to account for partial grid cell overlap w/ counties
  - Example: grid cell 50% in county = 50% weight

Relative Soil Moisture (RSM) Data

- Soil moisture influence depends on soil hydrological properties (Kisekka, et al. 2017, Archontoulis 2021):

$$Relative\ soil\ moisture = \frac{Volumetric\ soil\ moisture\ -\ wilting\ point}{Saturation\ -\ wilting\ point}$$

- Interpretation:
  - 0 = wilting point (no plant available moisture)
  - 1 = saturation (maximum water capacity)
- Optimal range around 0.54
- Stress thresholds:
  - Below 0.2: drought conditions
  - Above 0.8: excess moisture stress



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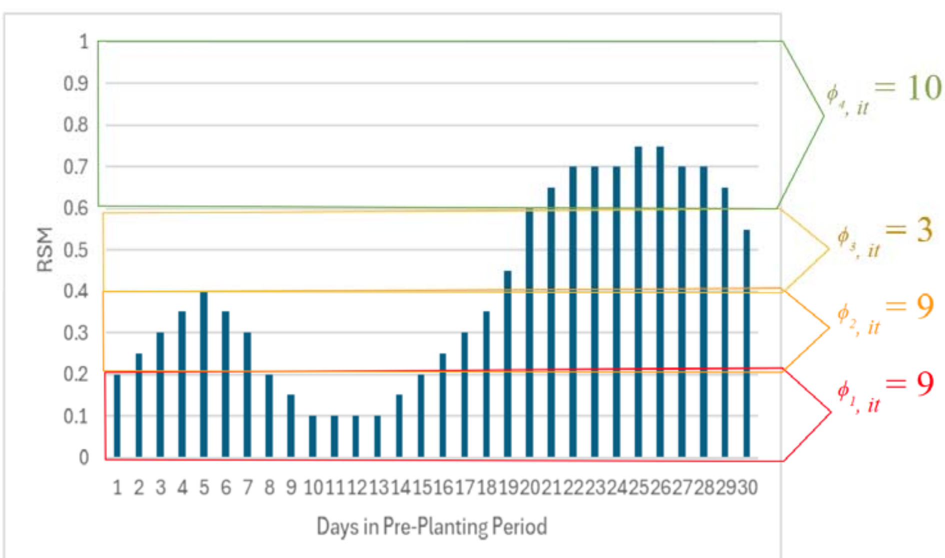
Methodology: Non-Parametric Soil Moisture Exposure Model



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Specifying Exposure Bins

Why Bin Selection Matters:

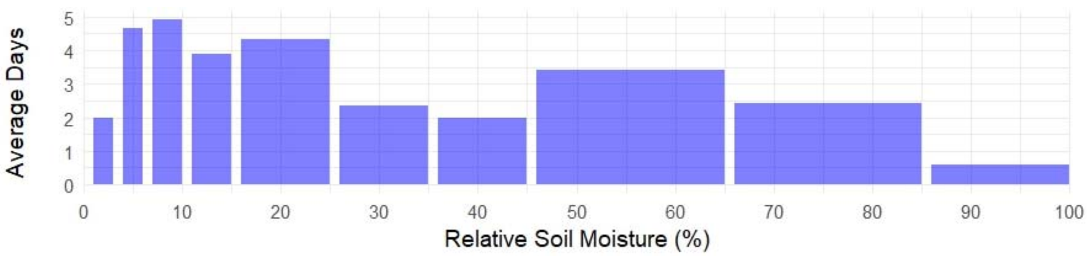
- Too many bins/regressors may cause **overfitting** (Schwarz, 1978).
- Too few bins may overlook important **nonlinear effects**.

Bin Definition and Calculation:

- Grouped into **100 bins**, each representing a 1% increment of Relative Soil Moisture (RSM).

Data-Driven Bin Selection Process:

- K-fold cross validation procedure.



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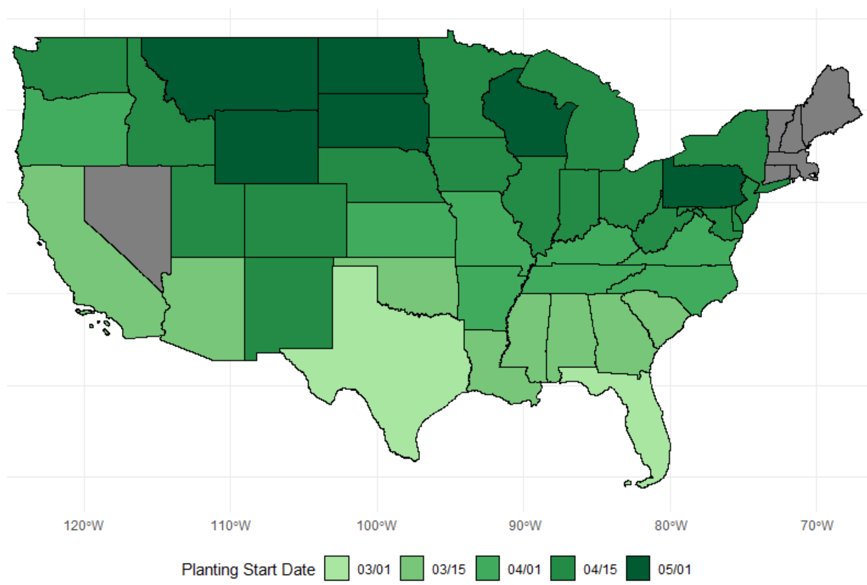
"Early Season" Definition

- **Use dates from Deines et al. (2023)**
- **Examine the 30 days prior to the date when 10% of the corn crop is planted.**



Regression Model Specification

$$\ln y_{it} = \sum_k \beta_k \phi_{k,it} + z_{it}\delta + c_i + \varepsilon_{it}$$

Where:

$\boldsymbol{ln\, y_{it}}$: natural logarithm of yield for county *i* in year *t*

$\boldsymbol{\phi_{k,it}}$: number of days county *i* in year *t* was exposed to relative soil moisture within bin *k*

$\boldsymbol{(\beta_k)}$: marginal impact of one additional day of exposure to relative soil moisture in bin *k*

$\boldsymbol{z_{it}}$ *:* control variables, such as a quadratic time trend (t and t^2) to account for technological change.

$\boldsymbol{(c_i)}$: county fixed-effects to control for unobserved heterogeneity

Finally, we expect moisture conditions to be correlated in adjacent counties, so we allow the error terms (ε_{it}) to be spatially correlated using Conley standard errors (Conley 1999).

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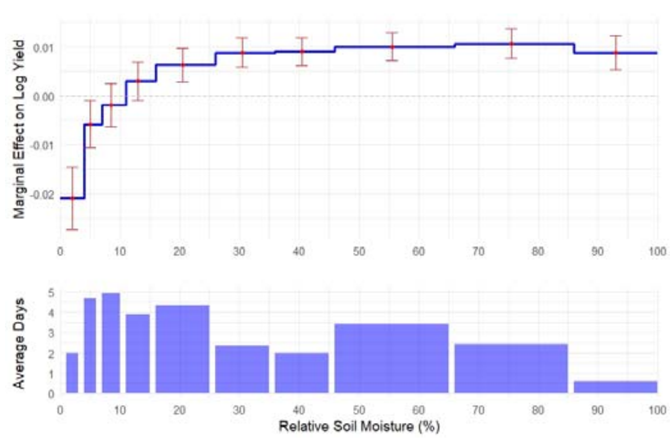
Results: National Model



What Do the Coefficients Mean?

- Each coefficient represents the effect of one additional day spent within a specific soil moisture bin. There are 30 days total. Adding a day to one bin means taking it away from another.

Overall Insight:

- Exposure to very low soil moisture (1–3% RSM) is associated with the strongest yield reduction
  - Coefficient: –0.0209
- Typical day falls in 45–65% RSM bin
  - coefficient: 0.01
- Estimated impact: Shifting one average day to driest bin→ ~3% yield decrease
  - 0.01 + 0.0209

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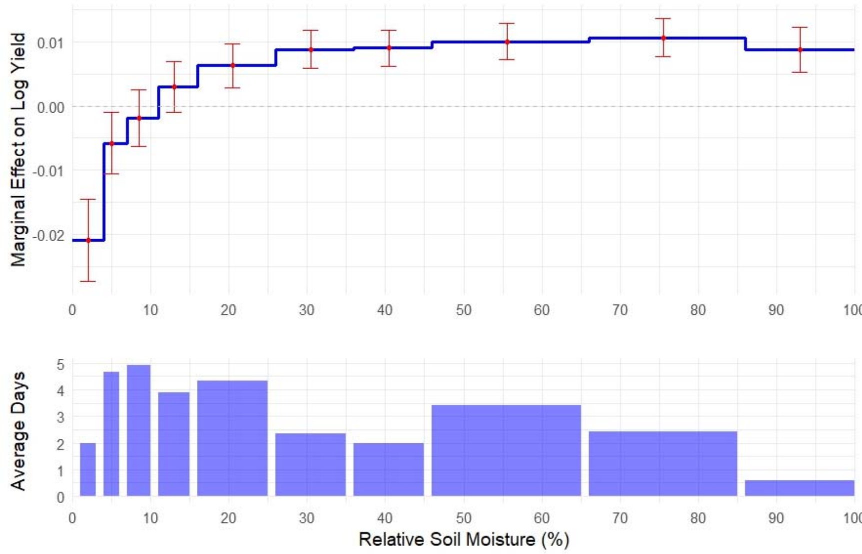
Dependent variable (ln)	National
1 - 3%	-0.0209 ***
	(0.0033)
4 - 6%	-0.0058 *
	(0.0025)
7 - 10%	-0.0018
	(0.0022)
11 - 15%	0.0030
	(0.0020)
16 - 25%	0.0063 ***
	(0.0018)
26 - 35%	0.0088 ***
	(0.0015)
36 - 45%	0.0090 ***
	(0.0014)
46 - 65%	0.0100 ***
	(0.0014)
66 - 85%	0.0106 ***
	(0.0015)
86 - 100%	0.0087 ***
	(0.0018)
Time	0.0013
	(0.0018)
Time^2	0.0005 ***
	(0.0001)
Observations	59846
County FE	Yes
Adj. R^2	0.5092
RMSE	0.3798

Results: National Model



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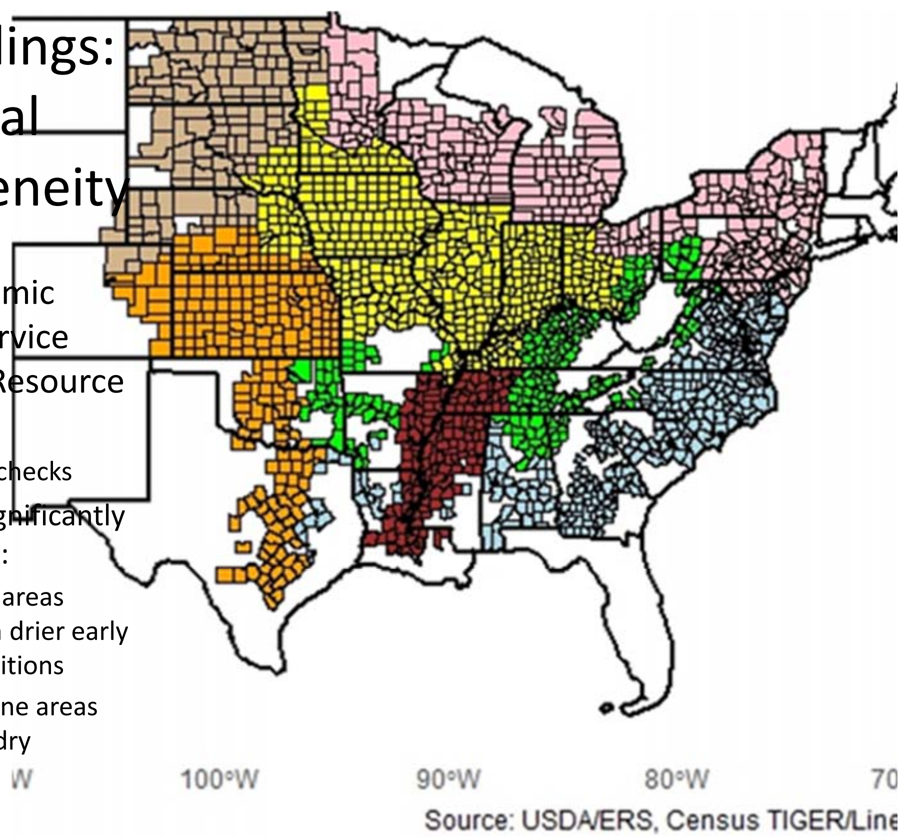
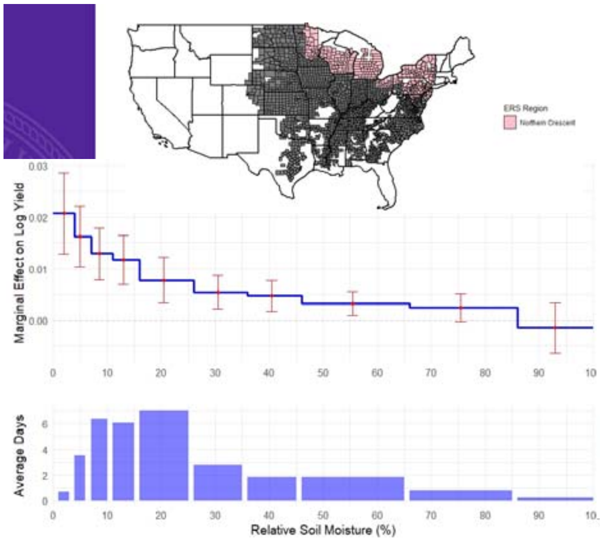
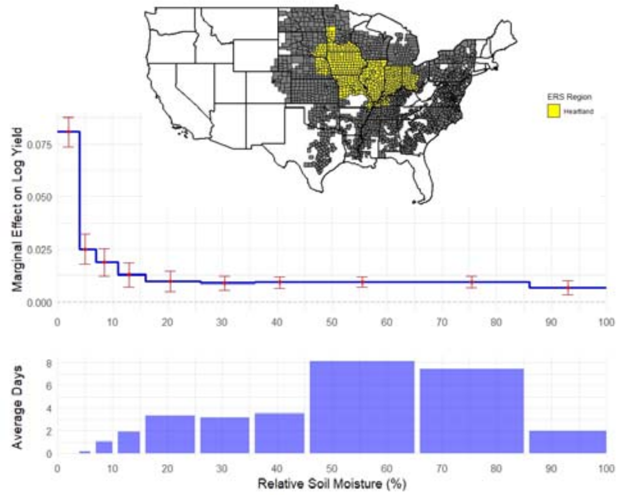
Key Findings: Spatial Heterogeneity



- USDA Economic Research Service (ERS) Farm Resource Regions
  - Robustness checks
- Effects vary significantly across regions:
  - High rainfall areas benefit from drier early season conditions
  - Drought-prone areas suffer from dry conditions

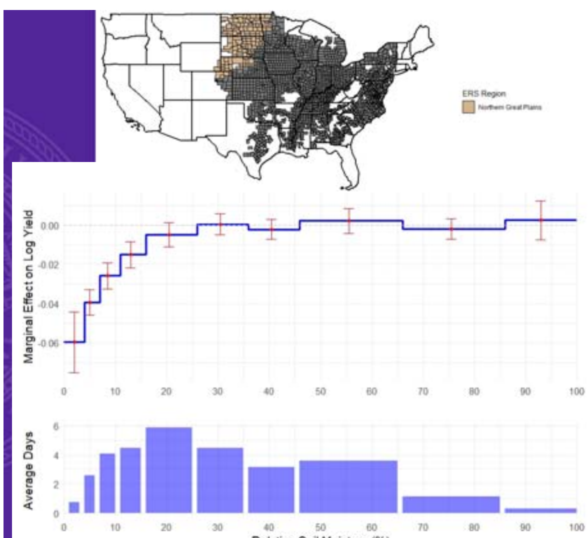


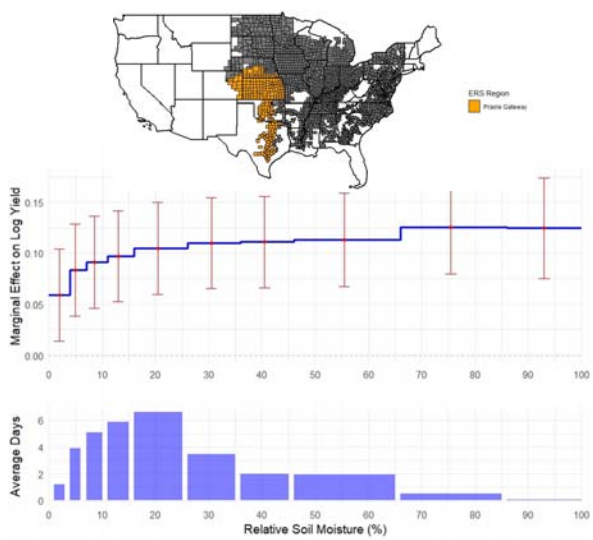


Key Findings: Spatial Heterogeneity

In **high-productivity regions** (e.g., Heartland, Northern Crescent), **low early season soil moisture** is associated with **higher yields**

- Excess moisture is often more harmful than drought in these areas:
  - Delayed planting, Nutrient leaching, Waterlogging (Bille & Rogna 2021; Li 2022)
- **Heartland model result:**
  - 1–3% RSM bin → **coefficient: 0.0807** (**99% confidence**)
  - Avg. day = 0.0095 → → **>7% yield increase**





Key Findings: Spatial Heterogeneity

In **drier regions** like the **Northern Great Plains** and **Prairie Gateway**, **low RSM** is **negatively associated** with yield

- These regions have **deep, high-capacity soils**:
  - Crops rely on subsurface moisture early on
  - Once depleted, they become rainfall-dependent
- Northern Great Plains model result:
  - 1–3% RSM bin → coefficient: –0.0597
  - Avg. day = 26–35% RSM (coefficient = 0.0003) → → **~6% yield reduction**

Summary and Contributions

Key Findings:

- Strong evidence of a nonlinear relationship between early season soil moisture and yield outcomes.
- Clear indication of regional heterogeneity
- Demonstrated method's effectiveness in capturing critical moisture thresholds without imposing restrictive assumptions.

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Thank you!

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	National	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Eastern Uplands	Southern Seaboard	Mississippi Portal
1 - 3%	-0.0209 ***	0.0807 ***	0.0207 ***	-0.0597 ***	0.0588 *	0.0381	0.0128	0.0297 ***
	(0.0033)	(0.0036)	(0.0040)	(0.0079)	(0.0230)	(0.0319)	(0.0136)	(0.0083)
4 - 6%	-0.0058 *	0.0251 ***	0.0163 ***	-0.0394 ***	0.0832 ***	0.0389	0.0176	0.0301 ***
	(0.0025)	(0.0036)	(0.0030)	(0.0033)	(0.0231)	(0.0310)	(0.0137)	(0.0077)
7 - 10%	-0.0018	0.0188 ***	0.0129 ***	-0.0259 ***	0.0911 ***	0.0413	0.0188	0.0327 ***
	(0.0022)	(0.0034)	(0.0026)	(0.0034)	(0.0232)	(0.0312)	(0.0135)	(0.0080)
11 - 15%	0.0030	0.0128 ***	0.0117 ***	-0.0152 ***	0.0969 ***	0.0406	0.0224	0.0324 ***
	(0.0020)	(0.0028)	(0.0024)	(0.0034)	(0.0229)	(0.0307)	(0.0136)	(0.0073)
16 - 25%	0.0063 ***	0.0098 ***	0.0078 ***	-0.0051	0.1048 ***	0.0395	0.0215	0.0332 ***
	(0.0018)	(0.0025)	(0.0022)	(0.0031)	(0.0230)	(0.0303)	(0.0137)	(0.0074)
26 - 35%	0.0088 ***	0.0089 ***	0.0055 **	0.0003	0.1099 ***	0.0305	0.0236 .	0.0380 ***
	(0.0015)	(0.0018)	(0.0017)	(0.0027)	(0.0229)	(0.0303)	(0.0137)	(0.0077)
36 - 45%	0.0090 ***	0.0093 ***	0.0047 **	-0.0023	0.1112 ***	0.0389	0.0248 .	0.0395 ***
	(0.0014)	(0.0014)	(0.0016)	(0.0026)	(0.0230)	(0.0300)	(0.0137)	(0.0078)
46 - 65%	0.0100 ***	0.0095 ***	0.0032 **	0.0020	0.1135 ***	0.0327	0.0281 *	0.0415 ***
	(0.0014)	(0.0013)	(0.0012)	(0.0032)	(0.0234)	(0.0301)	(0.0137)	(0.0079)
66 - 85%	0.0106 ***	0.0095 ***	0.0024 .	-0.0020	0.1254 ***	-0.0096	0.1027 ***	0.0428 ***
	(0.0015)	(0.0015)	(0.0014)	(0.0027)	(0.0235)	(0.0316)	(0.0139)	(0.0082)
86 - 100%	0.0087 ***	0.0069 ***	-0.0015	0.0023	0.1247 ***			0.0496 ***
	(0.0018)	(0.0016)	(0.0025)	(0.0051)	(0.0253)			(0.0089)
Time	0.0013	0.0110 ***	0.0091 ***	0.0267 *	-0.0523 ***	0.0088 *	-0.0012	0.0061 *
	(0.0018)	(0.0017)	(0.0019)	(0.0105)	(0.0086)	(0.0039)	(0.0030)	(0.0028)
Time^2	0.0005 ***	0.0001 *	0.0002 **	0.0003	0.0020 ***	0.0002	0.0005 ***	0.0003 ***
	(0.0001)	(0.0000)	(0.0001)	(0.0003)	(0.0002)	(0.0001)	(0.0001)	(0.0001)
N	59846	16554	9081	4073	7324	7116	9827	4267
Adj. R-squared	0.5092	0.4300	0.4244	0.4647	0.2539	0.3189	0.3286	0.4228
RMSE	0.3798	0.2247	0.2465	0.5502	0.6438	0.3105	0.3593	0.2093

Figure 7.3 Marginal Effects by Region (January 1st - March 15th)

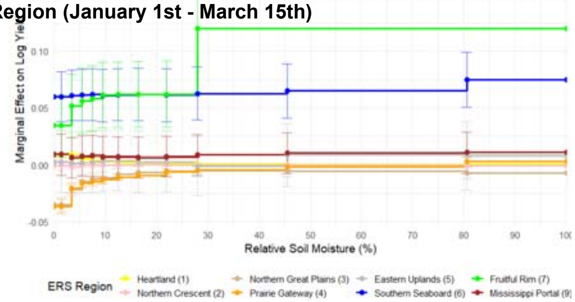

Figure 7.4 Marginal Effects by Region (February 1st -March 15th)

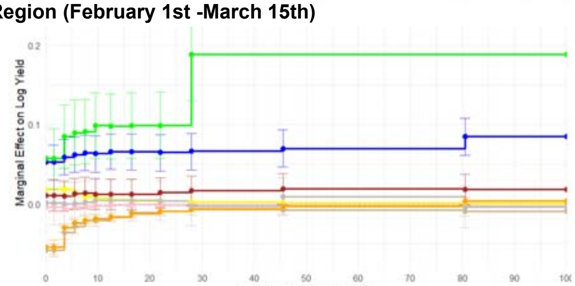

Figure 7.5 Marginal Effects by Region (March 1st - March 15th)

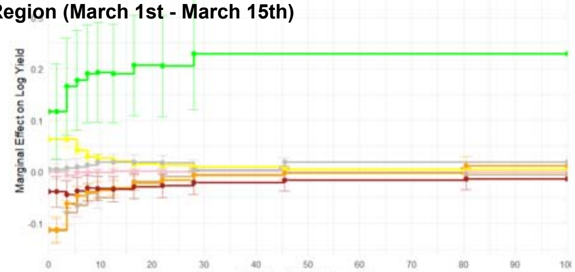

Figure 7.1 Distribution of Adjusted R2 Values Over All Breakpoint Specifications

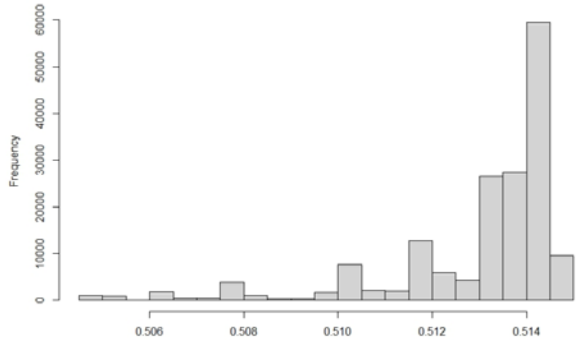

Figure 7.2 Distribution of BIC Values Over All Breakpoint Specifications

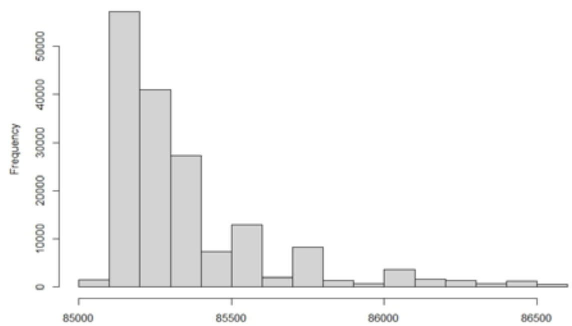

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Figure 7.6 AEZ 8

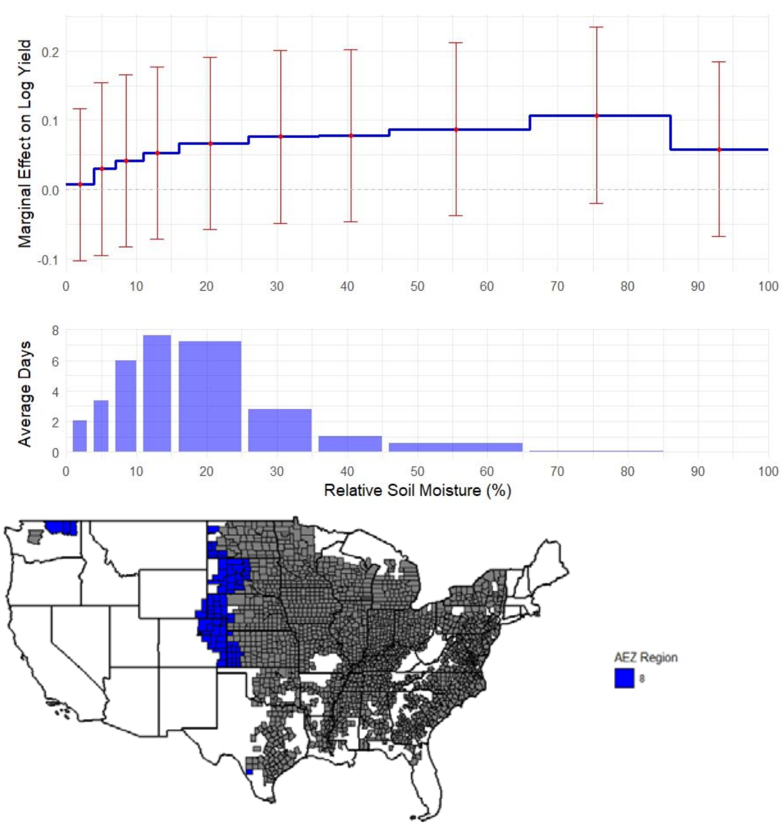

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Figure 7.7 AEZ 9

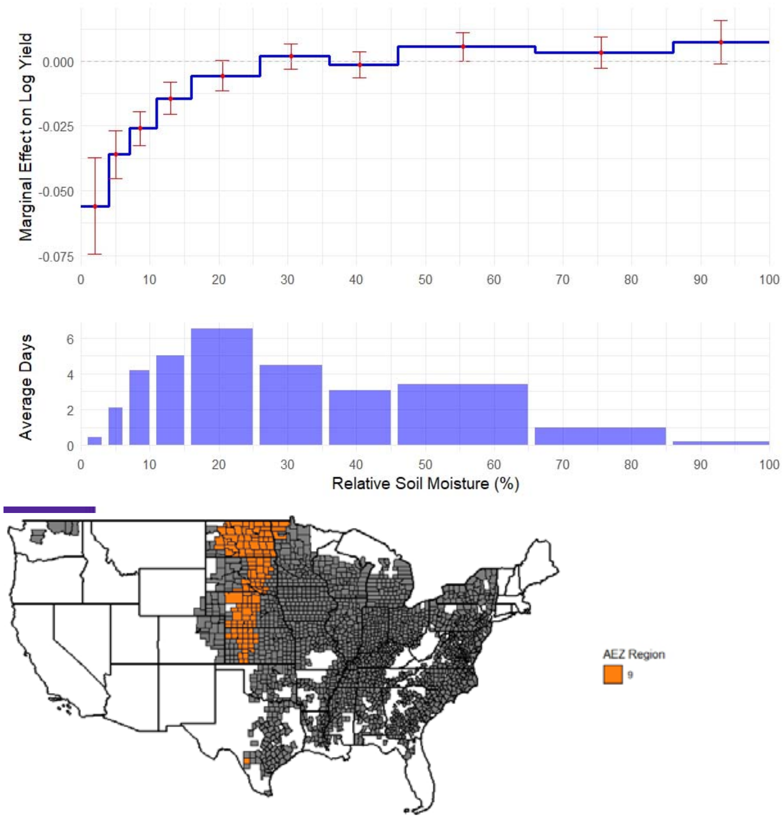

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Figure 7.8 AEZ 10

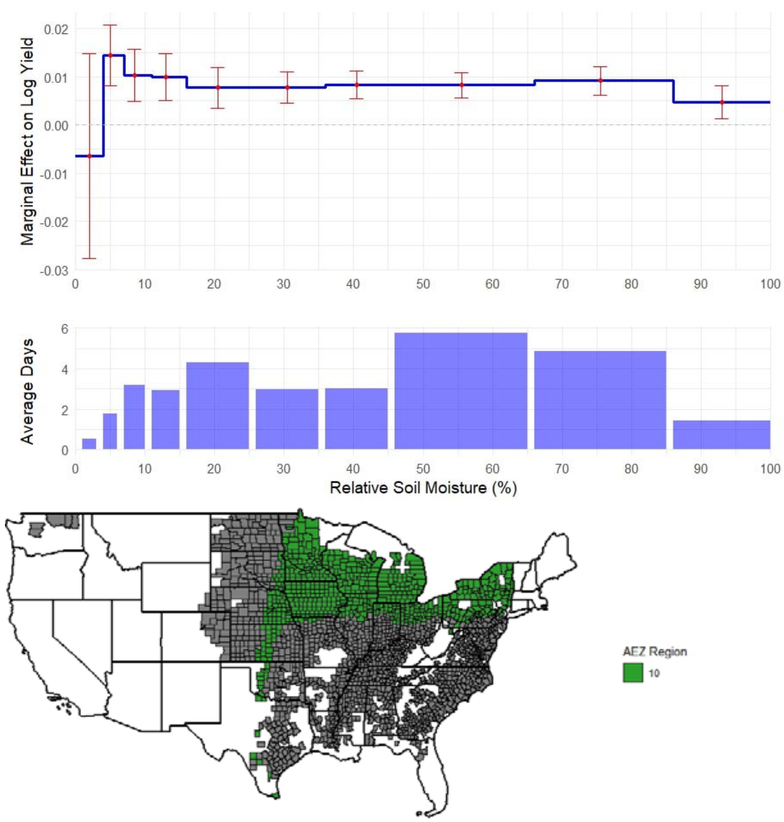

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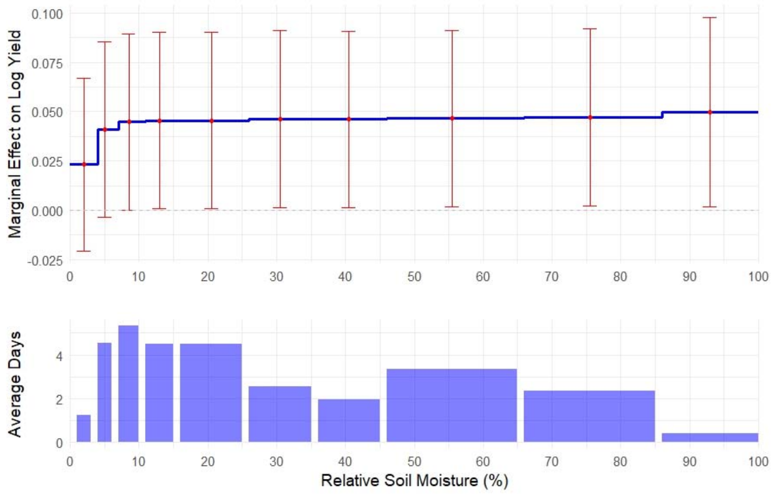
Figure 7.9 AEZ 11



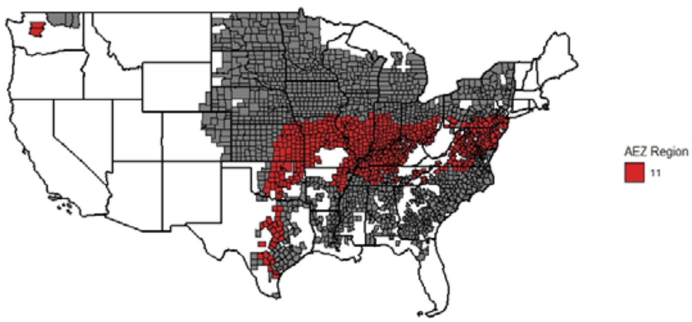
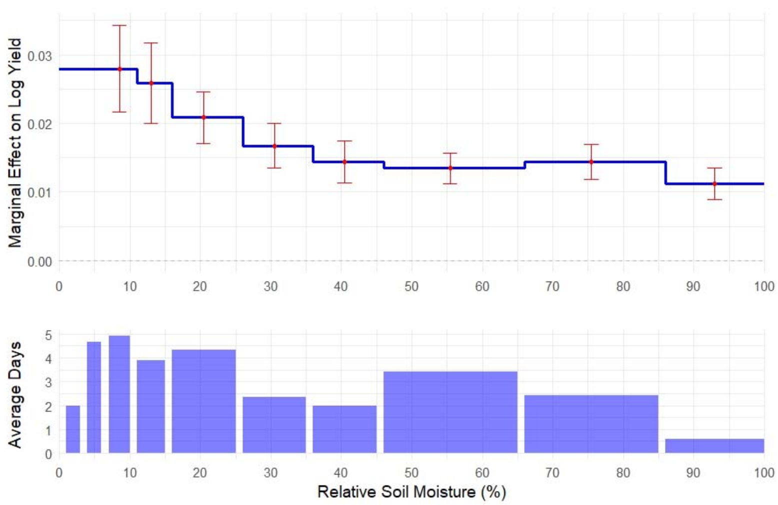


Figure 7.11 Iowa Model



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