

The background of the slide is a faded, semi-transparent image of the University of Florida campus. It features the prominent white clock tower of the Old Union Hall on the right side, and other historic buildings with red roofs and white columns on the left. The sky is a pale blue, and there are green trees in the foreground and middle ground.

# How Drought Shocks Alfalfa Production and Export Markets? Evidence from U.S. Alfalfa Spatial Diagnostics and Panel Analysis

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## Context

- ▶ Drought alters nutrient, water cycles and threatens forage-based livestock systems.
- ▶ Around 1/3 of U.S. alfalfa acreage was in drought-affected areas in 2025 (NOAA–NIDIS).
- ▶ Western alfalfa is irrigation-intensive and export-oriented; Midwest alfalfa is mostly rain-fed and used locally.
- ▶ Alfalfa's biological characters (land rotation, anti-drought, deeper roots, land intensive) and strategic importance on dairy and meat lead it became 3rd. valuable field crop in U.S.

Table: U.S. agriculture affected by drought (2025)

Commodity	% Area Affected
Alfalfa hay acreage	32
Hay inventory	33
Milk cow inventory	39
Cattle inventory	25

## Motivation

- ▶ Environment/water policy scientists argue alfalfa delivers relatively low water-use efficiency returns per unit of water (dollars/jobs per drop). When this hay is exported, the region is essentially exporting its scarce water.
- ▶ Agronomists argue that alfalfa can survive "deficit irrigation" (reducing ET without killing the plant), it is a flexible, water-saving tool during droughts.
- ▶ But irrigation is necessary for export alfalfa, and complex water rights make alfalfa arguments and rigid in Western States.

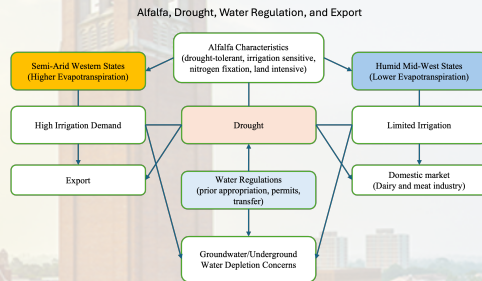


Figure 1: Alfalfa, Drought, Water Regulation, and Export

*Note:* These institutional features can make alfalfa production more rigid in practice, intensifying debates over its role in water-scarce western states.

## Alfalfa systems: West vs Midwest

- ▶ **Western states** (CA, AZ, WA, ID, NV)
  - ▶ High irrigation dependence (often > 50% irrigated alfalfa area).
  - ▶ About 20% of hay output exported; strong link to global markets.
  - ▶ Highly exposed to multi-year drought and water allocation cuts.
- ▶ **Upper Midwest** (WI, MN, SD, NE, KS)
  - ▶ Largely rain-fed alfalfa.
  - ▶ Integrated into local dairy systems; minimal exports.

Average Acres by State

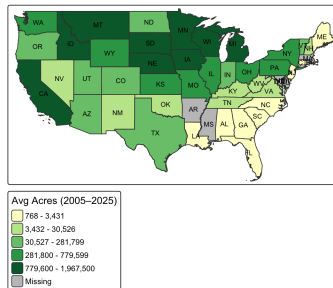


Figure 2: Average annual alfalfa acreage by state

# Research questions and contribution

## Research questions

- ▶ How does drought, measured by SPEI, affect state-level alfalfa:
  - ▶ yields (tons/acre),
  - ▶ export value (thousand USD)?
- ▶ How strongly are drought and export activity coupled in space?
- ▶ Do drought impacts differ between irrigation-intensive western states and rain-fed Midwest states, do irrigation buffer drought impacts?

## Contribution

- ▶ Combine geospatial analysis, time-series modeling, variogram-based spatial diagnostics, fixed effects, and GAM.
- ▶ Provide a spatially explicit assessment of biophysical and economic drought impacts in the U.S. alfalfa sector.

## Data overview

- ▶ **Drought:** Standardized Precipitation–Evapotranspiration Index (SPEI), 12-month accumulation, 2005–2025 (NOAA).
- ▶ **Alfalfa production:** State-level harvested area, production, and value (USDA NASS QuickStats, Census).
- ▶ **Irrigation:** Share of hay acreage irrigated by state (Census of Agriculture), used to classify irrigation dependence.
- ▶ **Trade:** State-level alfalfa export value and export rate (USDA GATS, literature).
- ▶ **Data quality:** Use coefficient of variation (CV) to construct precision weights ( $1/\text{CV}^2$ ) for regression analysis.

$$\text{CV} = \frac{\text{SE}}{\text{Estimate}} \times 100$$

## Key spatial patterns

State-level Average SPEI (2005–2025)

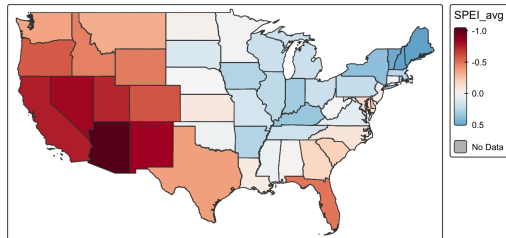


Figure 3: Average SPEI, 2005–2025

Notes: States west of the Rockies exhibit much more negative (drier) SPEI.

Average Export Value by State (2005–2025)

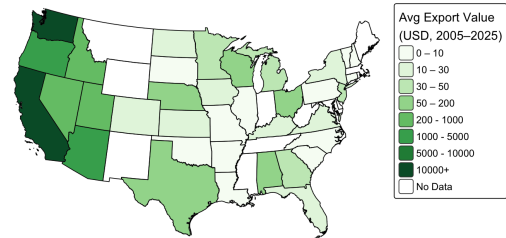


Figure 4: Average alfalfa export value

Note: Export activity is highly concentrated in western states.



## Methods: SPEI time-series modeling: Decomposition and forecasting

- Log-transform to obtain an additive representation: Fit ARIMA to model dynamics and forecast drought conditions.

$$\log(\text{SPEI}_t) = \log(\text{trend}_t) + \log(\text{seasonality}_t) + \varepsilon_t$$

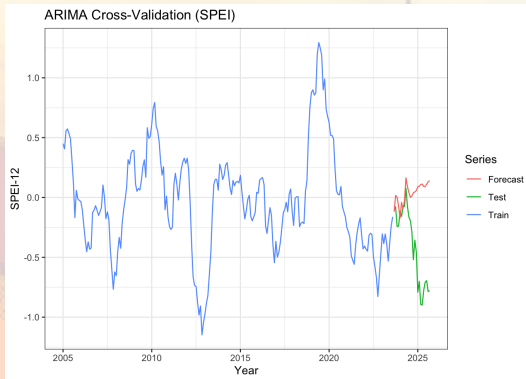


Figure 5: Cross-validation for national SPEI



## Methods: spatial correlation

### Semivariogram and cross-variogram

- ▶ Empirical semivariograms for SPEI and export value show strong positive spatial autocorrelation.
- ▶ Linear model of coregionalization (LMC) fitted for both variables and their cross-variogram.
- ▶ Spatial range  $\approx 500$  km for both drought and export value.
- ▶ Cross-variogram indicates near-zero spatial covariance between SPEI and export value.

Variogram component	Partial sill	Range (km)
SPEI (spatial)	0.0158	500
Export value (spatial)	$5.93 \times 10^6$	500
SPEI–Export (spatial)	61.60	500

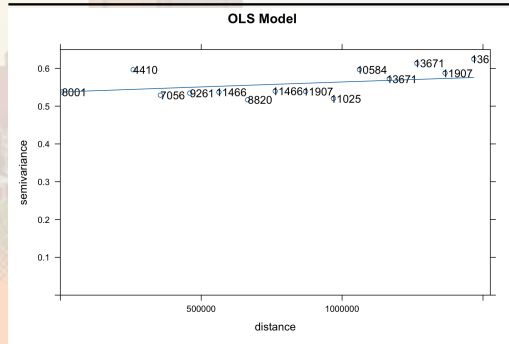


Figure 6: Spatial correlation in export

# Methods: econometric regression models

## Two-way fixed effects

$$Y_{st} = \beta_1 S_{st} + \beta_2 I_{st} + \mu_s + \lambda_t + \varepsilon_{st}$$

$$EV_{st} = \gamma_1 S_{st} + \gamma_2 I_{st} + \gamma_3 P_t + \mu_s + \lambda_t + u_{st}$$

- ▶  $Y_{st}$ : yield (tons/acre);  $EV_{st}$ : export value.
- ▶  $S_{st}$ : SPEI;  $I_{st}$ : irrigation share;  $P_t$ : alfalfa price.
- ▶ State and year fixed effects control for time-invariant heterogeneity and common shocks.
- ▶ Standard errors clustered by state.

## Spatial GAM for export value

$$EV_{st} = \theta_1 S_{st} + \theta_2 Y_{st} + f_1(\text{Price}_{st}) + f_2(\text{lon}_s, \text{lat}_s) + \epsilon_{st}$$

- ▶  $f_1(\cdot)$ : nonlinear price effect.
- ▶  $f_2(\cdot)$ : spatial smooth (captures port access, clustering).

## Results: drought and production

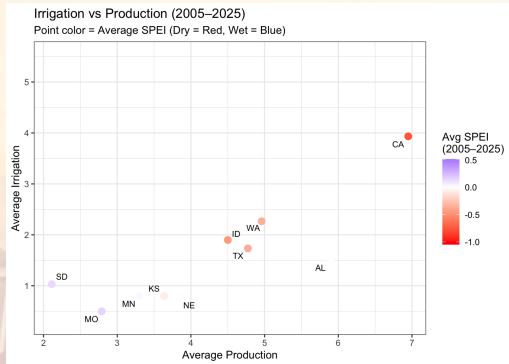


Figure 7: Irrigation, yield, and SPEI

*Note:* Western states: high yields, high irrigation, more negative SPEI. Midwest: rain-fed, moderate yields.

Table Fixed-effects and WLS yield model (SPEI and irrigation)

	Yield (tons/acre)		
SPEI	0.103 <sup>†</sup> (0.053)	0.103* (0.047)	0.103** (0.039)
Irrigation	0.078	0.078	0.078
FE	State	S+Y	S+Y
Obs.	361	361	361

- ▶ Higher SPEI (wetter conditions) significantly increase yield.
- ▶ Drought reduces both yield and harvested area; effects are strongest in irrigation-dependent West.

## Results: export value and spatial structure

U.S. Alfalfa Export Economic Loss (Thousand USD), 2017–2019

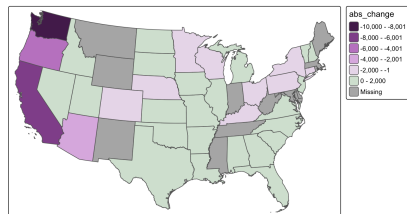


Figure 8: Export value loss, 2017–2019 *Note:* Largest losses in drought-affected western states (CA, AZ, NV).

Table Export value models (summary)

	FE	OLS	GAM	2SLS
Dep. var.	EV	EV	EV	EV
SPEI	ns	—***	ns	343*
Irrig.	ns	ns	ns	ns
Nonlin. price	No	No	Yes ( $p \approx 0.03$ )	No
Spatial smooth	No	No	Yes ( $p < 10^{-16}$ )	No
Adj. $R^2$	0.86	0.04	0.81	0.89

- ▶ Pooled OLS suggests strong negative drought–export link.
- ▶ Two-way FE and GAM show no robust within-state effect of SPEI on export value.
- ▶ Export value driven by spatial clustering and nonlinear price dynamics.

# Drought–export decoupling

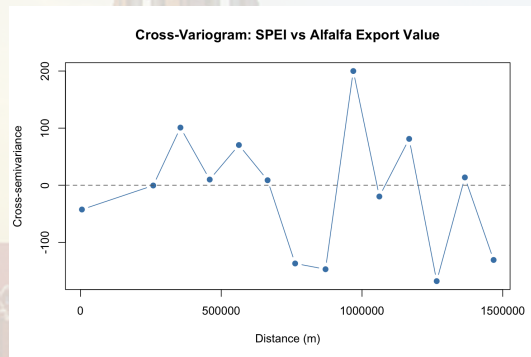
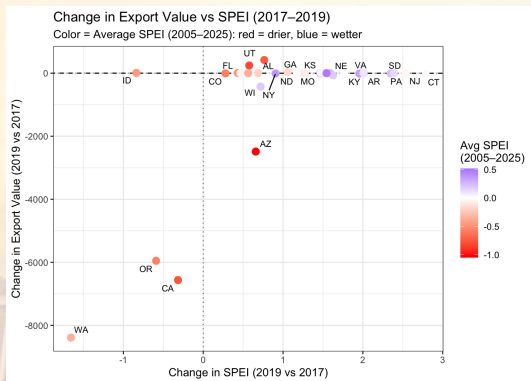


Figure 9: Cross-validation: SPEI vs export

Figure 9: Change in SPEI vs export value

- ▶ No clear systematic relationship between changes in SPEI and changes in export value.
- ▶ Drought-affected western states often maintain export volumes via storage and reallocation from domestic markets.

## Discussion and policy implications

- ▶ **Biophysical:** Drought significantly lowers yields and area, especially in irrigation-intensive western systems.
- ▶ **Economic:** Export value is buffered by market prioritization, storage, and infrastructure.
- ▶ **Regional differentiation**
  - ▶ West: focus on water allocations, irrigation efficiency, storage, and export logistics.
  - ▶ Midwest: focus on feed-cost risk management, insurance, and maintaining local forage supply.
- ▶ **Trade and climate:** Open, flexible trade can dampen price spikes under climate shocks, but also risks shifting land-use and emissions abroad.

# Conclusion and next steps

## Main messages

- ▶ Drought poses a major threat to the U.S. alfalfa forage base, with strong spatial heterogeneity.
- ▶ Irrigation dependence amplifies vulnerability in the West; rain-fed Midwest shows smaller area adjustments.
- ▶ Export outcomes are more shaped by geography and prices than by year-to-year drought severity.

## Next steps

- ▶ Explicitly model acreage dynamics and drought-induced land reallocation.
- ▶ Integrate trade policy scenarios and land-use spillovers into welfare analysis.
- ▶ Extend spatial modeling to county scale and to other forage crops.



# Thank You for Your Attention

## Questions or Comments?

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**Data and Code:**

[github.com/liyoumin/Geospatial-AgEcon](https://github.com/liyoumin/Geospatial-AgEcon)

*Thank you for your time and feedback!*