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**Climate Variability and Drought Effects on Cattle Stocking Decisions**

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# Abstract

Cattle stocking rate is a key decision in grazing management, influencing forage use, ecosystem resilience, and rangeland sustainability. This study investigates how drought conditions and hay availability affect stocking rates across the U.S. Using county-level panel data from 1978 to 2020, we estimate a fixed-effects model incorporating current and lagged drought indices, agroclimatic variables, and hay stocks. Results show that water deficits significantly reduce stocking rates, with effects persisting into the following year. Lower hay stocks are also associated with reduced stocking, indicating producers adjust stocking intensity in response to feed constraints. We project future stocking rates under CMIP6 climate scenarios (RCP 4.5 and 8.5) through 2099. Projections show gradual declines under RCP 4.5 and sustained reductions under RCP 8.5, especially after mid-century. These findings highlight the vulnerability of grazing systems to climate change and the need for adaptive management to maintain livestock productivity.

# Introduction

Stocking rate is a key decision in grazing management, affecting forage use, ecological resilience, and the long-term sustainability of rangelands (Smart et al., 2010; Holechek, 1988). Optimal stocking prevents overgrazing, while inappropriate rates, either too high or too low, can lead to land degradation, biodiversity loss, and reduced livestock productivity (National Drought Mitigation Center, n.d.; Redfearn and Bidwell, 2017).

Recent evidence shows a long-term decline in cattle stocking rates, with more land now being required per cow to sustain grazing (Dennis, 2021). This trend reflects a combination of factors, including increased cattle weights, shifting land use driven by crop prices, and most notably, climate variability. Rising temperatures and altered precipitation patterns have emerged as key drivers, disrupting forage growth and feed availability (Mu, McCarl, and Wein, 2013). Insufficient rainfall reduces hay and crop residue yields, while excessive precipitation can cause waterlogging, nutrient leaching, and increased dependence on irrigated feed. Intensifying droughts further complicate stocking decisions, undermining both ecological stability and economic resilience (Leeper et al., 2022; Iglesias et al., 2022). Given these dynamics, our aim is to better understand how weather variability, particularly drought, affects cattle stocking rates.

Several studies have examined how climate variability influences cattle production. Klemm and Briske (2019) conducted a retrospective analysis of temporal and spatial distributions of beef cow populations relative to climate variability from 1978 to 2017 across the U.S. Great Plains. Their findings indicate that cattle numbers correlate positively with precipitation and negatively with temperature. Rodziewicz, Dice, and Cowley (2023) employed an econometric framework to analyze drought impacts on beef cattle management, hay production, prices, and farm incomes from 2000 to 2022. Using USDA CropScape data, U.S. Drought Monitor information, and fixed-effects panel regressions, they demonstrated that drought events reduced hay production, increased hay prices, and ultimately decreased income from cattle operations. Mu, McCarl, and Wein (2013) similarly explored adaptations by U.S. agricultural producers to climate change, focusing on land-use changes and cattle stocking rates. Their results indicated that as the summer Temperature-Humidity Index (THI) increases and summer precipitation decreases, cattle stocking rates decline with projected reductions of 10-15% under future climate scenarios due to rising temperatures and the conversion of cropland to pastureland. Ritten et al. (2010) further emphasized optimal stocking decisions on rangelands, stressing flexible management practices to mitigate financial risks posed by extreme weather and drought. While previous studies have provided valuable insights into broad climate-related economic trends, this study extends the existing literature by integrating multiple detailed drought indicators within a comprehensive econometric framework. Specifically, our analysis explicitly accounts for both immediate drought impacts, and delayed effects carried over from preceding years, simultaneously incorporating hay stock data as a measure of supplemental feeding availability. This approach enables a more nuanced and realistic assessment of drought’s influence on cattle stocking rates, capturing the dynamic responses producers adopt in managing forage scarcity.

Building on prior research, this study combines USDA Census of Agriculture data with Parameter-elevation Regressions on Independent Slopes Model (PRISM) weather records to examine how climate stress indicators influence cattle stocking rates. We use Potential Evapotranspiration (PET), Growing Degree Days (GDD), and Extreme Degree Days (EDD) to assess water stress, heat exposure, and thermal pressure on grazing systems. Through an econometric framework, we quantify how drought frequency and severity affect producer decisions and propose adaptive management strategies to support sustainable livestock production.

Our findings indicate that stocking rates are significantly influenced by both current and lagged drought conditions, as well as hay availability. Water deficits, whether experienced in the current year or the year prior, consistently reduce stocking rates, highlighting the persistent effects of drought stress. Additionally, we find that lower hay stocks are associated with reduced stocking intensity, likely reflecting producers’ precautionary responses to limited feed reserves. Climate projections reveal that under a moderate emissions pathway, stocking rates decline gradually, whereas high-emissions scenarios lead to a more pronounced and sustained reduction in grazing capacity. These findings underscore the importance of adaptive grazing strategies and feed security planning to sustain livestock production under increasing climate variability.

This paper is structured as follows: the current section is followed by a description of the data, the econometric methods, results, and a subsequent discussion. The paper concludes with final remarks and highlights relevant policy implications.

**Data**

## Stocking Rate

To estimate cattle stocking rates, county-level beef cow inventory and pastureland acreage data are obtained from the USDA Census of Agriculture for the years 1982-2017[[1]](#footnote-1) (USDA 2024). Figure 1 illustrates the national trends in pastureland area and beef cattle inventory as of December of each census year. Over time, beef cow inventory has fluctuated, with notable declines observed around 1983, 2012, and 2018, while pastureland use has exhibited a steady decline.

A graph showing the growth of cattle

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**Figure 1. Annual US national beef cow inventory and pastureland data.**

Source: USDA, NASS (2024).

Stocking rate is commonly expressed in terms of Animal Units (AU) or Animal Unit Months (AUM) per unit area, where one AU represents a mature cow weighing approximately 1,000 pounds, and one AUM signifies the forage required to sustain one AU for one month (Redfearn and Bidwell, 2017). To quantify total forage demand, the total number of AUs is multiplied by the grazing duration (in months), resulting in the total AUMs required for a specified grazing period. Thus, stocking rate, expressed as AUMs per acre, is calculated for each county and year as follows:

This formula incorporates three key variables: livestock inventory, animal forage demand, and the available pastureland. Specifically, the term standardizes forage requirements based on average cattle weight and grazing duration[[2]](#footnote-2). Adjusting forage demand by total pasture area ensures the stocking rate accurately reflects both forage availability and land capacity constraints[[3]](#footnote-3).

## Weather Data

Drought occurrence and severity are driven by complex interactions between climatic, hydrological, and ecological factors affecting water availability within ecosystems (Srivastava and Maiya, 2023). A central feature of drought is the imbalance between water supply (primarily driven by precipitation) and water demand (driven by temperature, vegetation, and atmospheric conditions). Accurately quantifying drought conditions requires metrics capturing both evaporation and plant transpiration processes (Granger, 1989). To develop comprehensive drought indicators, we estimated Potential Evapotranspiration (PET), a measure representing the maximum rate at which water could evaporate under ideal moisture conditions. PET was computed using the Thornthwaite method (Palmer and Havens 1958):

where is a monthly normative potential evapotranspiration (mm ); is the monthly average temperature (); is an annual heat index; is a monthly heat index; is a constant. To assess water balance, precipitation data is integrated with PET to calculate the water surplus or deficit for each month:

where is a monthly precipitation level (mm ).

Temperature significantly influences cattle stocking rates by affecting both pasture conditions and crop growth. While precipitation reflects moisture availability, high temperatures compound drought impacts by reducing water availability and amplifying plant water stress (Srivastava and Malix, 2023). To effectively quantify these impacts, this study incorporates Growing Degree Days (GDD) and Extreme Degree Days (EDD), widely recognized metrics for assessing thermal impacts on crops. GDD captures the accumulation of thermal time (DTT) above a base temperature, reflecting growth potential (Zhou and Wang 2018), while EDD measures exposure to extreme heat detrimental to forage productivity (Huang, Sassenrath, and Lin 2023). Following Zhou and Wang (2018), these indices are defined as follows:

where , is base temperature and is upper threshold temperature. This analysis uses critical temperature thresholds of 12°C and 31°C, based on established agricultural research (Schlenker and Roberts, 2009).

Collectively, PET, GDD, and EDD offer an integrative view of climate impacts, encapsulating water availability, thermal stress, and heat exposure. To support this analysis, we retrieve high-resolution data from the PRISM for the period of interest. PRISM data includes precipitation, minimum, maximum, and mean temperatures, along with other weather-related variables across the United States (PRISM Climate Group, Oregon State University 2024).

## Hay Stocks

Hay stocks constitute another essential explanatory variable in this analysis, serving as a critical supplemental feed source when natural forage availability is limited by drought conditions. Reduced pasture growth during droughts restricts natural forage production, necessitating supplementary feed sources. Therefore, incorporating hay stock data enables the assessment of supplemental feeding's role in mitigating drought-induced impacts on forage availability and cattle stocking rates. This inclusion provides a comprehensive understanding of interactions among drought conditions, supplemental feeding practices, and grazing management decisions. To ensure robustness, we utilize annual nationwide hay stocks data from USDA NASS (2024) for the period of interest, enabling a detailed evaluation of supplemental feeding during forage scarcity.

## Summary Statistics

The summary statistics presented in Table 1 provide a detailed breakdown of stocking rates by U.S. geographic region[[4]](#footnote-4) across four decades (1980s-2010s), highlighting notable national and regional trends. Nationally, stocking rates increased modestly from 0.69 AUMs per acre in the 1980s to 0.88 AUMs per acre in the 2010s, reflecting an overall growth of approximately 27.5% during this period.

Regional trends exhibit considerable variability. The Northern Plains region experienced a marked decline, with stocking rates dropping from 0.80 AUMs per acre in the 1980s to 0.43 AUMs per acre in the 2010s, representing a nearly 46% decrease. Similarly, the Mountain region consistently exhibited low stocking rates, fluctuating narrowly between 0.15 and 0.20 AUMs per acre, likely indicating limitations in grazing capacity or constraints due to environmental conditions. In contrast, the Lake States demonstrated remarkable growth, increasing from 0.58 AUMs per acre in the 1980s to 1.33 in the 2020s, with a notable 40.27% increase between the 2000s and 2010s. Meanwhile, regions like the Pacific and Southern Plains showed relative stability but maintained consistently low stocking rates. The Pacific region had minimal changes (around 7%), whereas the Southern Plains experienced an overall decline of approximately 6%.

These varied regional trajectories underscore persistent geographical disparities and emphasize the complexity of factors influencing stocking rates - including forage availability, climate stress, grazing practices, and economic drivers. Understanding these patterns provides essential context for evaluating stocking rate adjustments and developing targeted management and policy responses to mitigate drought impacts and enhance agricultural sustainability.

**Table 1. Stocking rate by US geographical region, 1990-2020.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Region | Year | | | | Percent Change (%) | | |
| 1980-1989 | 1990-1999 | 2000-2009 | 2010-2019 | 1990-1980 | 2000-1990 | 2010-2000 |
| Appalachia | 1.1 | 1.4 | 1.37 | 1.43 | 27.43 | -2.01 | 3.83 |
| Corn Belt | 1.1 | 1.18 | 1.34 | 1.53 | 7.69 | 13.15 | 14.68 |
| Delta States | 1.02 | 1.12 | 1.08 | 1.22 | 9.49 | -3.22 | 13.21 |
| Lake States | 0.58 | 0.71 | 0.95 | 1.33 | 23 | 33.33 | 40.27 |
| Mountain | 0.17 | 0.2 | 0.15 | 0.16 | 12.64 | -22.6 | 2.87 |
| Northeast | 0.58 | 0.74 | 0.75 | 1.02 | 28.15 | 1.36 | 34.74 |
| Northern Plains | 0.8 | 0.7 | 0.42 | 0.43 | -12.04 | -40.48 | 1.82 |
| Pacific | 0.27 | 0.3 | 0.28 | 0.29 | 9.39 | -4.86 | 1.18 |
| Southeast | 0.97 | 1.05 | 0.93 | 1.09 | 7.93 | -11.5 | 17.29 |
| Southern Plains | 0.32 | 0.34 | 0.34 | 0.3 | 7.32 | -1.47 | -11.52 |
| National | **0.69** | **0.77** | **0.76** | **0.88** | **12.03** | **-1.68** | **15.41** |

Source: USDA NASS (2024) and authors' calculations.

# Econometric Methods

Drought impacts on stocking rates may manifest both immediately and over extended periods, reflecting short-term responses and delayed management adjustments by livestock producers. Klemm and Briske (2019) emphasize that drought effects might lag behind the actual onset of drought conditions, as ranchers’ responses and forage availability do not immediately reflect changing environmental conditions. Initially, producers may rely on hay reserves or supplemental feed to sustain their herds, temporarily delaying necessary adjustments to stocking rates. However, as drought conditions persist, the depletion of hay stocks and the rising costs of replenishment can force producers to lower stocking rates to prevent overgrazing and long-term pasture degradation. Even after normal precipitation resumes, pastures often require extended periods to recover, further prolonging the effects of drought on forage availability.

To capture both immediate and delayed drought impacts comprehensively, our analysis employs one-year-lagged climate-related variables indicative of water availability, specifically the water deficit or surplus variable . Our empirical investigation utilizes a panel fixed-effects model specified as follows:

where the dependent variable is the natural logarithm of the stocking rate[[5]](#footnote-5) for county and year . The independent variables include the current water deficit or surplus variable and its one-year-lagged value reflecting delayed drought conditions, as well as Growing Degree Days (), Extreme Degree Days () and hay stocks (). The model also incorporates county-level fixed effects () to control for unobserved, time-invariant heterogeneity, such as soil type, topography, and geographic characteristics, thus ensuring robust estimation results. This comprehensive approach provides a robust framework to analyze how climatic factors and feed availability interact to influence stocking rates. It highlights the importance of supplemental feeding strategies and the role of climatic variability in shaping livestock management decisions.

# Results

Table 2 reports the pairwise Pearson correlations among the main explanatory variables. The correlation between current and one-year-lagged indices is moderate (0.62), suggesting temporal persistence in drought without excessive multicollinearity. Climatic stress variables Growing Degree Days () and Extreme Degree Days () are highly correlated reflecting overlapping temperature dynamics yet remain statistically distinguishable in the regression framework. Correlations between hay stocks and all climatic variables are low (|r| < 0.10), indicating that feed availability captures a distinct management dimension not strongly tied to current-year weather outcomes.

**Table 2. Pearson correlation matrix for variables used in the stocking rate regression model.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable |  |  |  |  |  |
|  | 1.00 |  |  |  |  |
|  | 0.62 | 1.00 |  |  |  |
|  | -0.12 | -0.25 | 1.00 |  |  |
|  | -0.47 | -0.52 | 0.71 | 1.00 |  |
|  | 0.01 | 0.01 | -0.07 | -0.05 | 1.00 |

Source: Authors' calculations.

Table 3 presents the estimated effects of drought and climatic stressors on cattle stocking rates. Across all model specifications, the coefficients on both the current and one-year-lagged water deficit or surplus variable are positive and statistically significant. This finding provides strong evidence of both immediate and delayed effects of drought conditions on stocking decisions. The positive sign indicates that higher water availability, whether concurrent or lagged, is associated with increased stocking rates, likely reflecting improved forage productivity and grazing capacity during and following wetter periods.

**Table 3. Regression analysis results.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variable | (1) | (2) | (3) | (4) | (5) |
|  | 0.0007\*\*\* | 0.0005\*\*\* | 0.0006\*\*\* | 0.0005\*\*\* | 0.0005\*\*\* |
|  |  | 0.0003\*\*\* | 0.0004\*\*\* | 0.0004\*\*\* | 0.0004\*\*\* |
|  |  |  | 0.0080\*\*\* | 0.0104\*\*\* | 0.0098\*\*\* |
|  |  |  |  | -0.0240\*\*\* | -0.0238\*\*\* |
|  |  |  |  |  | -0.0003\*\*\* |
|  | 0.62 | 0.63 | 0.65 | 0.65 | 0.66 |
|  | 0.07 | 0.10 | 0.14 | 0.14 | 0.16 |
| N | 16,116 | 16,116 | 16,116 | 16,116 | 16,116 |

Source: Authors’ calculations.

Note: \*\*\* p < 0.01, \*\* p < 0.05, and \* p < 0.10.

Although the estimated coefficients are numerically small (e.g., 0.0005 and 0.0004), their interpretation within a log-linear model implies that each unit increase in the drought index raises the stocking rate by approximately 0.05% and 0.04%, respectively. For instance, a 50-unit increase in water availability (e.g., transitioning from moderate to high rainfall years) corresponds to an approximate 2-2.5% increase in stocking rate, substantial in a management context where marginal forage gains are highly valued. This interpretation aligns with the positive and significant coefficient observed for Growing Degree Days (GDD), indicating that increased accumulation of GDD, reflective of favorable growing conditions, positively influences stocking rates. Specifically, a higher number of days with optimal temperature conditions supports pasture productivity and enables higher grazing capacities. In contrast, the coefficient for Extreme Degree Days (EDD) is consistently negative and statistically significant across all model specifications, underscoring the detrimental impact of excessive heat conditions on stocking rates. Specifically, a one-unit increase in EDD corresponds to a decrease in stocking rates for approximately 2.4%.

Further, the regression results also reveal a statistically significant negative relationship between hay stock levels and cattle stocking rates. The negative association between hay stocks and stocking rates may reflect a precautionary response by producers managing feed risk. When hay inventories are low, producers face tighter constraints in buffering forage shortages, leading them to reduce grazing intensity to maintain ecological and economic stability. This behavior likely reflects both strategic destocking and the lingering effects of past drought-induced feed stress.

## Stocking Rate Projections

This study employs climate projections from the Coupled Model Intercomparison Project Phase 6 (CMIP6), obtained via the Earth System Grid Federation (ESGF) data portal. The dataset includes simulations under Representative Concentration Pathways (RCP) 4.5 and 8.5, representing moderate and high-emissions scenarios, respectively. These projections are derived from the CanESM5 (Canadian Earth System Model version 5), developed by the Canadian Centre for Climate Modelling and Analysis (CCCma), and have been downscaled for regional analysis (Earth System Grid Federation, 2025).

RCP 4.5 assumes a stabilization pathway in which radiative forcing is maintained at 4.5 W/m² by 2100 through mitigation measures. In contrast, RCP 8.5 follows a high-emissions trajectory, leading to 8.5 W/m² radiative forcing, assuming continued reliance on fossil fuels with minimal mitigation efforts. This study incorporates key climate variables, including monthly precipitation (pr), minimum temperature (tasmin), and maximum temperature (tasmax) from 2020 to 2099, to derive agroclimatic indices such as Growing Degree Days (GDD), Extreme Degree Days (EDD), and potential evapotranspiration (PET). To account for inter-model variability, multiple realizations within CMIP6 are analyzed, enabling an ensemble-based assessment of stocking rate projections under different climate scenarios.

A graph showing the growth of the year

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**Figure 2. Projected cattle stocking rates (2020-2099).**

Source: Earth System Grid Federation (2025) weather projections

Figure 2 presents projected cattle stocking rates across the United States from 2020 to 2099 under RCP 4.5 and RCP 8.5, based on CMIP6 climate projections from the ESGF. Under RCP 4.5 (blue line), stocking rates exhibit a gradual declining trend over the century. While the decrease is moderate, it suggests that even under a mitigation pathway, forage conditions may slowly deteriorate, possibly due to residual climate stressors despite overall stabilization. Nonetheless, the relatively slow rate of decline implies that forage availability may remain sufficient to support grazing systems in the near to mid-term. In contrast, RCP 8.5 (red line) shows a pronounced and sustained decline in stocking rates, especially after mid-century. This pattern reflects the compounded impacts of extreme heat, increased drought frequency, and declining forage productivity under a high-emissions scenario. The results are consistent with expectations that intensified climate stress will substantially reduce grazing capacity and limit sustainable stocking levels.

# Discussions

The results of this study provide valuable insights into the complex relationships between climate variability, hay stock availability, and cattle stocking rates. Our findings confirm that both favorable and extreme weather conditions, alongside supplemental feed resources, play a critical role in shaping the stocking capacity of pastureland. These results align with prior literature identifying climate as a key driver of grazing management decisions (Klemm and Briske, 2019; Mu et al., 2013). However, this study advances the field by explicitly quantifying both the immediate and lagged effects of water deficits, temperature extremes, and forage availability on stocking rates.

These findings are also consistent with Rodziewicz et al. (2023), who documented that extreme weather events often result in herd reductions and financial strain for ranchers. While prior studies have broadly examined the implications of climate variability for livestock systems, our analysis offers a more detailed perspective by capturing the persistence of drought impacts through lagged climatic indicators. Moreover, the use of multiple climate realizations strengthens the robustness of these results, ensuring that our projections reflect a range of plausible future conditions.

Looking forward, climate projections reveal diverging trajectories under RCP 4.5 and RCP 8.5 scenarios. Under RCP 4.5, stocking rates decline modestly, suggesting that mitigation and gradual climate shifts may allow producers to sustain relatively stable grazing systems. In contrast, the sharp and continuous decline in stocking rates under RCP 8.5 reflects compounding stressors, heat, drought frequency, and declining forage productivity, that significantly constrain long-term grazing capacity. These results underscore the vulnerability of cattle systems to climatic extremes and the need for adaptive management frameworks that incorporate forward-looking climate risks. Future work should examine how seasonal precipitation timing, forage species turnover, and producer-level adaptation strategies influence stocking trajectories. Expanding this analysis to include multi-model projections and alternative emission scenarios will further strengthen our understanding of sustainable livestock management under climate change.

## Policy implications

The findings of this study underscore the importance of proactive and adaptive grazing strategies that account for both immediate and delayed drought impacts. To support sustainable stocking decisions, policies should incentivize ranchers to adopt flexible practices such as rotational grazing, conservative stocking rates, and pasture rest periods. These strategies can mitigate pasture degradation and support post-drought recovery. Financial incentives or technical assistance for producers who adopt these practices can help bridge the gap between short-term economic stress and long-term sustainability goals.

Programs like the USDA’s Livestock Forage Disaster Program (LFP) have proven effective in alleviating the immediate economic burden of drought on ranchers. However, as droughts become more frequent and intense, particularly under high-emissions scenarios like RCP 8.5, federal expenditures on such programs are projected to increase substantially. Policymakers should consider refining LFP eligibility criteria, benefit calculations, and targeting mechanisms to ensure that assistance reaches the most affected regions while maintaining fiscal sustainability. Integrating disaster assistance programs into broader adaptation frameworks, including early-warning systems and localized seasonal forecasts, can further strengthen the resilience of livestock systems.

Another critical area for policy intervention is the management of hay and forage resources. This study finds a statistically significant negative association between hay stock levels and cattle stocking rates, suggesting that producers may adopt more conservative grazing practices when hay inventories are low. This behavior likely reflects a precautionary response to feed risk, where ranchers reduce stocking intensity to buffer against forage shortfalls. Policymakers should support improved hay management through investments in storage infrastructure, regional hay supply monitoring, and market stabilization mechanisms. These measures can help producers better anticipate feed constraints, reduce reliance on emergency purchases, and maintain grazing capacity during drought conditions.

Overall, these findings underscore the necessity of proactive climate adaptation strategies in the livestock sector. As climate variability continues to pose challenges for grazing systems, policy-driven investments in sustainable rangeland management, climate forecasting, and economic support mechanisms will be crucial to ensuring the long-term viability of livestock production.

# Conclusion

# Reference

Briske, David D., John P. Ritten, Amber R. Campbell, Toni Klemm, and Audrey E. H. King. "Future Climate Variability Will Challenge Rangeland Beef Cattle Production in the Great Plains." *Rangelands* 43, no. 1 (2020): 29-36. <https://doi.org/10.1016/j.rala.2020.11.001>.

Earth System Grid Federation. 2024. Earth System Grid Federation Data Portal. Accessed March 2025. https://aims2.llnl.gov/search

Hrozencik, R. A., Perez-Quesada, G., and Bocinsky, K. 2024. The stocking impact and financial- climate risk of the Livestock Forage Disaster Program. *U.S. Department of Agriculture, Economic Research Service.* Report No. ERR-329.

Iglesias, Virginia, William R. Travis, and Jennifer K. Balch. "Recent Droughts in the United States Are among the Fastest-Developing of the Last Seven Decades." *Weather and Climate Extremes* 37 (2022): 100491. <https://doi.org/10.1016/j.wace.2022.100491>.

Jacobo, Elizabeth J., Adriana M. Rodríguez, Norberto Bartoloni, and Víctor A. Deregibus. "Rotational Grazing Effects on Rangeland Vegetation at a Farm Scale." *Rangeland Ecology & Management 59*, no. 3 (May 2006): 249–257. <https://doi.org/10.2111/05-129R1.1>.

Klemm, T., and D.D. Briske. "Retrospective Assessment of Beef Cow Numbers to Climate Variability throughout the U.S. Great Plains." *Rangeland Ecology & Management* 78, no. 1 (2019): 273–280. <https://doi.org/10.1016/j.rama.2019.07.004>.

Kuwayama, Yusuke, Alexandra Thompson, Richard Bernknopf, Benjamin Zaitchik, and Peter Vail. "Estimating the Impact of Drought on Agriculture Using the U.S. Drought Monitor." *American Journal of Agricultural Economics* 101, no. 1 (2019): 193-210. <https://doi.org/10.1093/ajae/aay037>.

Leeper, Ronald D., Rocky Bilotta, Bryan Petersen, Crystal J. Stiles, Richard Heim, Brian Fuchs, Olivier P. Prat, Michael Palecki, and Steve Ansari. "Characterizing U.S. Drought over the Past Twenty Years Using the U.S. Drought Monitor." *International Journal of Climatology* 42, no. 12 (2022): 6616–6630. <https://doi.org/10.1002/joc.7653>.

Mu, Jianhong E., Bruce A. McCarl, and Anne M. Wein. "Adaptation to Climate Change: Changes in Farmland Use and Stocking Rate in the U.S." *Mitigation and Adaptation Strategies for Global Change* 18, no. 5 (2013): 713-730. <https://link.springer.com/content/pdf/10.1007/s11027-012-9384-4>.

Palmer, Wayne C., and A. Vaughn Havens. "A Graphical Technique for Determining Evapotranspiration by the Thornthwaite Method." *Monthly Weather Review* 86, no. 4 (1958): 123-128. <https://ion.sdsu.edu/onlinethornthwaitereference.pdf>.

Prasad, P. V. V., S. A. Staggenborg, and Z. Ristic. “Impacts of Drought and/or Heat Stress on Physiological, Developmental, Growth, and Yield Processes of Crop Plants.” *Advances in Agricultural Systems Modeling*, Chapter 11. Madison, WI: American Society of Agronomy, 2008. https://doi.org/10.2134/advagricsystmodel1.c11.

PRISM Climate Group, Oregon State University. *PRISM Gridded Climate Data*. Accessed October 1, <http://prism.oregonstate.edu>.

Redfearn, Daren D., and Terrence G. Bidwell. "Stocking Rate: The Key to Successful Livestock Production." *OSU Extension*, Oklahoma State University. Accessed October 2, 2024. <https://extension.okstate.edu/fact-sheets/stocking-rate-the-key-to-successful-livestock-production.html>.

Ritten, J. P., Frasier, W. M., Bastian, C. T., & Gray, S. T. (2010). Optimal Rangeland Stocking Decisions Under Stochastic and Climate‐Impacted Weather. *American Journal of Agricultural Economics, 92*(4), 1242–1255.

Rodziewicz, David, Jacob Dice, and Cortney Cowley. "Drought and Cattle: Implications for Ranchers." *Federal Reserve Bank of Kansas City*, June 2, 2023. <https://doi.org/10.18651/RWP2023-06>.

Schlenker, Wolfram, and Michael J. Roberts. "Nonlinear Temperature Effects Indicate Severe Damages to U.S. Crop Yields under Climate Change." *Proceedings of the National Academy of Sciences* 106, no. 37 (2009): 15594-15598. <https://doi.org/10.1073/pnas.0906865106&#8203;:contentReference[oaicite:0]{index=0}>.

Smart, A. J., Derner, J. D., Hendrickson, J. R., Gillen, R. L., Dunn, B. H., Mousel, E. M., ... & Olsen, K. C. (2010). Effects of grazing pressure on efficiency of grazing on North American Great Plains rangelands. Rangeland Ecology & Management, 63(4), 397-406.

Srivastava, Aman, and Rajib Maity. “Unveiling an Environmental Drought Index and Its Applicability in the Perspective of Drought Recognition Amidst Climate Change.” *Journal of Hydrology* 627 (2023): 130462. <https://doi.org/10.1016/j.jhydrol.2023.130462>.

U.S. Department of Agriculture. *Census of Agriculture Historical Archive.* Accessed October 1, 2024.<https://agcensus.library.cornell.edu/#:~:text=Search%20Census%20Archive&text=The%20USDA%20Census%20of%20Agriculture,all%20historical%20agricultural%20census%20publications>.

U.S. Department of Agriculture. *National Agricultural Statistics Service (NASS) Quick Stats*. Accessed October 3, 2024. <https://quickstats.nass.usda.gov/>.

Zhou G., and Wang Q. “A new nonlinear method for calculating growing degree days.” *Sci Rep. 2018 Jul 5*;8(1):10149. doi: 10.1038/s41598-018-28392-z. PMID: 29977001; PMCID: PMC6033920.

1. The Census of Agriculture reports come out every 5 years. [↑](#footnote-ref-1)
2. For this analysis, the grazing period is assumed to span from March through October. [↑](#footnote-ref-2)
3. For example, suppose a pasture is used to graze 50 animals, each weighing 1,200 pounds, for six months. Assuming a standard AU represents 1,000 pounds, each animal equates to 1.2 AUs. If the pastureland is 100 acres, the stocking rate is 3.6 AUMs per acre. [↑](#footnote-ref-3)
4. Regions are grouped based on shared geography, climate, and agriculture. The Lake States (Michigan, Wisconsin, Minnesota) focus on dairy and forage, while the Corn Belt (Iowa, Illinois, Indiana, Ohio, Missouri) leads in grain and livestock feed. The Northern and Southern Plains emphasize beef cattle, with differences in grazing and irrigation. The Delta States and Southeast combine crop cultivation and cattle operations, while Appalachia supports small-scale farming. The Northeast features diversified farming and dairy, the Mountain region specializes in large-scale grazing, and the Pacific excels in diverse, high-value agriculture, with California pivotal for irrigated forage and beef cattle production. These regional adaptations highlight the diversity of U.S. agriculture. [↑](#footnote-ref-4)
5. The log transformation of the stocking rate is employed primarily for two reasons. First, interpreting coefficients from logged dependent variables in percentage terms provides intuitive and easily comparable insights into how explanatory variables influence stocking rates. Second, the log transformation mitigates potential heteroskedasticity by stabilizing the variance of residuals, especially beneficial when the dependent variable demonstrates a right-skewed distribution. Additionally, the log transformation helps normalize the distribution of stocking rates, further improving the robustness of econometric estimations. [↑](#footnote-ref-5)