Basis Risk and Indemnity Performance in the Pasture, Rangeland, and Forage Insurance Program (PRF): Evidence from the U.S. Northern Great Plains

Abstract

The Pasture, Rangeland, and Forage Insurance Program (PRF) is a major federal risk-management instrument for U.S. rangeland producers, covering 314 million acres and accounting for 56% of all Federal Crop Insurance Program acreage in 2025. Because PRF indemnities are triggered by a grid-level rainfall index rather than observed forage production, producers face basis risk when index-triggered payments do not correspond to actual forage losses. This article evaluates basis risk across 548 grids in Nebraska, North Dakota, and South Dakota by pairing satellite-derived forage production with USDA-RMA rainfall-index values and identifying each grid's best-performing two-interval rainfall combination. Our results show that rainfall explains only a moderate share of forage variability. Optimal interval pairs vary substantially across grids and, on average, account for roughly 40% of annual forage fluctuations. At the 90% coverage level, basis risk remains sizable: 37.0% of forage shortfalls trigger only one interval and 8.4% trigger none. Indemnities are systematically skewed toward overcompensation. Conditional on both a forage loss and a triggered payment, 78.8% of indemnities exceed the value of the loss, with an expected net overpayment of $2.55 per acre. In addition, 56.1% of grid-years without forage shortfalls receive indemnities averaging $3.40 per acre. These findings suggest a need to reassess whether current subsidy levels, interval designs, and weighting rules effectively balance program expenditures with the goal of delivering actuarially sound forage risk protection.

Keywords: index insurance, basis risk, Pasture Rangeland and Forage, timing mismatch, spatial heterogeneity, northern Great Plains

1. Introduction

Rangeland and pastureland constitute the primary resource base for livestock production throughout the western United States, supporting cow–calf and stocker enterprises that underpin rural economies and contribute substantially to the national beef supply. However, the increasing frequency and intensity of drought events have amplified weather-related production risks. When drought occurs, producers must make timely adjustments to align animal demand with diminished forage supplies, such as culling or liquidating animals to reduce stocking rates, leasing additional pasture, or purchasing hay and other supplemental feeds (Kachergis et al., 2014; Haigh et al., 2019). The associated economic impacts are considerable; for instance, the 2011 Texas drought generated an estimated $3.23 billion in livestock losses and $750 million in hay production losses (Anderson et al., 2012).

The Pasture, Rangeland, and Forage Insurance Program (PRF), administered by USDA's Risk Management Agency (RMA), has become the primary risk-management instrument for rangeland producers. Since its introduction in 2007, PRF enrollment has expanded rapidly from 52 million to 314 million acres between 2016 and 2025, representing 56% of all Federal Crop Insurance Program acreage in 2025. Unlike traditional yield-based insurance, which relies on verifying realized productivity, PRF bases indemnities on a grid-level rainfall index (USDA-RMA, 2025b). As an index insurance product, PRF could mitigate moral hazard concerns commonly associated with conventional insurance mechanisms (Shrum and Travis, 2022).

Despite its advantages, index insurance exposes producers to basis risk, a key limitation to its effectiveness (Miranda and Farrin, 2012; Clarke, 2016). High basis risk has been shown to reduce demand for index insurance and diminish potential welfare gains (Giné et al., 2008;

Binswanger-Mkhize, 2012; Elabed et al., 2013). In the PRF program, basis risk occurs when indemnity payments triggered by the rainfall index fail to align with producers' actual forage losses. Two sources of mismatch are commonly identified: (1) design risk, when the rainfall index does not accurately track forage outcomes, and (2) measurement risk, when the index diverges from true local precipitation. Measurement risk is generally small, as correlations between the index and gauge data exceed 90% in the southern Great Plains (Maples et al., 2016). It accounts for only 5–9% of total basis risk in the Northern Great Plains (Yu et al., 2019). In contrast, design risk can be substantial because forage production depends not only on rainfall but also on local environmental conditions such as soil quality and temperature

Under the PRF insurance program, insured ranchers could either have forage losses left uncompensated because insured rainfall intervals do not trigger an indemnity (false negatives) or receive payments without a real loss (false positives). For producers, false negatives cause more detrimental effects because drought-induced feed purchases, leased pasture, or herd-liquidation losses can go largely uncompensated. This shortfall can impede timely destocking and elevate grazing pressure (Kachergis et al., 2014; Haigh et al., 2019), contributing to grassland degradation and undermining long-run ecosystem productivity (Briske, 2011)

To our knowledge, only three studies have estimated PRF basis risk, typically measured as the probability of false negatives, yet all are limited in their geographic coverage, focusing on ranch-level analyses or single-state applications. Among these, Yu et al. (2019) examined three research ranches in Kansas and Nebraska using historical yield and rainfall data and reported an overall false-negative probability of roughly 26%. Feuz et al. (2023) analyzed 12 monitoring sites along California's central coast and documented a 48% false-negative rate. Given the substantial cost and logistical challenges of field-level forage measurement, remotely sensed satellite data has emerged as a scalable and consistent proxy capable of supporting analysis across extensive geographic areas. Using NDVI-based forage estimates, Keller and Saitone (2022) expanded coverage to approximately 62.7 million acres of California rangeland and found substantial basis risk, with false-negative probabilities ranging from 31% to 46%.

This article evaluates PRF performance at the grid level across three U.S. Northern Great Plains states, namely Nebraska, North Dakota, and South Dakota, which differ considerably in precipitation regimes, growing-season length, and forage sensitivity to rainfall. We first examine the extent to which rainfall index intervals predict forage production through pairwise regressions. We then quantify basis risk by estimating false-negative probabilities, which measure the likelihood that producers incur forage shortfalls without receiving corresponding indemnity payments. Beyond quantifying basis risk, the statistical alignment between rainfall and forage production, we also evaluate PRF contract quality by determining whether indemnity payments sufficiently compensate ranchers when forage losses occur. This allows us to assess the economic adequacy of PRF payouts from the producer's perspective.

Our study provides the first multistate, grid-level assessment of PRF basis risk using spatially continuous forage production data from the Rangeland Analysis Platform (RAP), a satellite-derived product that estimates rangeland biomass at 30-meter resolution using Landsat imagery and machine-learning methods (Allred et al., 2021; Jones et al., 2021). We compare PRF performance across the three states using data from 548 grids. Conducting the analysis at this finer spatial resolution highlights substantial local heterogeneity and reveals how PRF performance varies across grids and across rainfall-interval pair options. The remainder of the article is organized as follows. The next section describes the PRF program structure and study area, followed by the forage production and rainfall-index data. We then present the methodology, including construction of the forage production index, selection of best-performing interval pairs, and definitions of false-negative probabilities and contract quality. The results and discussion section reports our findings, and the final section concludes.

2. The PRF Program and Study Area

2.1. PRF Program Structure

The PRF program, as an insurance plan that covers perennial pasture, rangeland, or forage, bases its contracts on gridded areas established by the National Oceanic and Atmospheric Administration (NOAA)'s Climate Prediction Center (CPC). Each grid measures 0.25° latitude by 0.25° longitude. NOAA calculates daily precipitation for each grid using an interpolated value derived from at least four nearby reporting stations, with the contributing stations varying by day depending on data availability. As a result, the precipitation data used in the program reflects an estimated average for the entire grid and cannot be attributed to any single location or weather station.

The rainfall index for grid *g*, interval *i*, and year *t* is defined as:

$$RI_{g,i,t} = \frac{r_{g,i,t}}{\bar{R}_{g,i,t-2}} \tag{1}$$

where $r_{g,i,t}$ represents the total precipitation in grid *g* during interval *i* of year *t*, and $\bar{R}_{g,i,t-2}$ is the long-term average precipitation for that same grid and interval, calculated using historical NOAA data from 1948 through year $t-2$. An index value of 1 indicates precipitation equal to the long-term average, while values below or above 1 reflect below-average and above-average precipitation, respectively.

Coverage under the PRF program is available throughout the year, and producers are required to purchase insurance for year t by November 15 of the preceding year. As part of enrollment, producers must choose at least two distinct, non-overlapping two-month intervals. For instance, January–February and March–April are valid selections, whereas January–February and February–March are not. By offering multiple intervals across the calendar year, the program encourages producers to target the periods when precipitation is most critical for forage growth in their region. The weights assigned to the selected intervals should sum to 1, with allowable weights ranging from 0.1 to 0.5 for any individual interval.

The premium paid by the insured for grid g, interval i, and year t is given by:

$$K_{g,i,t} = \phi_i \cdot A \cdot B_g \cdot P \cdot C \cdot \sigma_g \cdot (1 - S) \tag{2}$$

where ϕ_i is the weight assigned to interval i, A is the number of acres insured, B_g is the county base value for grid g. The base value, set by RMA, reflects the estimated income generated by an acre of land under normal precipitation conditions and is derived from county-level information on stocking capacity, forage productivity, and forage value. As of 2024, county-level base values range from \$15.20 to \$58.90 per acre in Nebraska, \$12.10 to \$57.40 in South Dakota, and \$15.20 to \$29.80 in North Dakota.

The parameter P denotes the productivity factor, which producers choose within the range of 0.60 to 1.50 to tailor coverage to the productivity of their acreage. The term C is the selected coverage level, which producers choose from five options: 0.70,0.75,0.80,0.85, or 0.90, σ_g is the county-level base premium rate for grid g, and S is the federal subsidy rate associated with the selected coverage level, with $S = 0.59$ for coverage levels of 0.70 and 0.75, 0.55 for coverage levels of 0.80 and 0.85, and 0.51 for the 0.90 coverage level.. For a producer selecting two intervals k and l, the total premium cost is $K_{g,k,t} + K_{g,l,t}$.

An indemnity payment is triggered in grid *g*, interval *i*, and year *t* when rainfall index $RI_{g,i,t}$ falls below the selected coverage level *C*. The size of the payment depends on the magnitude of the shortfall between the coverage level and the realized rainfall index. Formally, indemnity is defined as:

$$I_{g,i,t} = \begin{cases} 0 & \text{if } RI_{g,i,t} \geq C \\ \left(\dfrac{C - RI_{g,i,t}}{C}\right) \phi_i \cdot A \cdot B_g \cdot P & \text{if } RI_{g,i,t} < C \end{cases} \tag{3}$$

where all variables retain the same definitions as in equation (2).

2.2.Study Region

This study examines the U.S. Northern Great Plains region, encompassing the states of North Dakota, South Dakota, and Nebraska (Figure 1). The region is characterized by a continental climate with a pronounced east–west precipitation gradient. Annual precipitation ranges from less than 16 inches in northwestern North Dakota, around 16 inches in northwestern South Dakota, and just over 17 inches in the Nebraska Panhandle, to approximately 24 inches in southeastern North Dakota, about 28 inches in southeastern South Dakota, and more than 34 inches in southeastern Nebraska (Frankson et al., 2022a, 2022b, 2022c). This gradient drives a transition from tall-grass prairie and rainfed row-crop agriculture in the east to mixed- and short-grass prairie and rangeland in the west. The region also experiences substantial interannual precipitation variability, contributing to recurrent drought risk. Notable examples include Nebraska’s driest year on record in 2012 and the severe 2017 Northern Plains drought that heavily affected both North Dakota and South Dakota.

These three states encompass a substantial share of the Great Plains' rangeland base and support the cattle-based agricultural economies in the United States. South Dakota has 22.3 million acres of range and pasture, supporting more than 17,000 ranches and roughly 4 million beef cattle (USDA, 2022). Nebraska contains approximately 23 million acres of pasture and rangeland, including the globally unique Sandhills mixed-grass prairie, which underpins one of the nation's largest cattle herds and contributes nearly $12 billion annually to the state economy (Nebraska Department of Agriculture, 2023). North Dakota, while more cropland-oriented, still maintains 11 million acres of pasture and rangeland that are central to its mixed crop–livestock systems (USDA, 2022).

PRF adoption has expanded substantially across the region over the past decade. In 2016, insured acreage totaled approximately 1.6 million acres in North Dakota, 2.1 million acres in South Dakota, and 1.6 million acres in Nebraska. By 2025, coverage had increased to 5.2, 8.1, and 9.5 million acres in North Dakota, South Dakota, and Nebraska, respectively, amounting to 22.8 million acres across the three states, an increase of 326% since 2016 (USDA-RMA, 2025a). Relative to available pasture and rangeland, PRF-insured acreage in 2025 represented 48.2% in North Dakota, 44.3% in Nebraska, and 36.4% in South Dakota, ranking 12th, 14th, and 17th nationally.

Within this area, 1,113 PRF grids are delineated: 369 in Nebraska, 385 in North Dakota, and 359 in South Dakota. Because PRF coverage is intended exclusively for perennial pasture, rangeland, and forage rather than cropland, forest, developed land, or water, each grid is classified using land-cover composition from the 2019 National Land Cover Database (NLCD) (Dewitz, 2021). Grids are retained only when PRF-eligible land-cover categories (grassland/herbaceous, pasture/hay) constitute the predominant land-cover type within the grid. Applying this criterion yields a final analytical sample of 548 PRF-relevant grids: 204 in Nebraska, 140 in North Dakota, and 204 in South Dakota.

3. **Data**

3.1.Forage Production

We quantify realized forage production during the May–August growing season, when northern Great Plains vegetation is most responsive to precipitation (Smart et al., 2007; Lauenroth and Sala, 1992), using annual perennial forb and grass (PFG) biomass estimates from the Rangeland Analysis Platform (RAP). Developed in 2018 through a partnership among USDA NRCS, the Bureau of Land Management, and the University of Montana, RAP provides model-derived aboveground biomass estimates at 30-m resolution across U.S. rangelands from 1986 to the present. These estimates integrate Landsat-derived NDVI, plant functional type (PFT) cover, and GridMET meteorological inputs (Allred et al., 2021; Jones et al., 2018, 2021; Robinson et al., 2018, 2019).

While prior PRF basis-risk work relied on NDVI-based proxies (Keller and Saitone, 2022), we use RAP for forage production estimation at PRF grid level for three main reasons. First, RAP reports biomass in physical unit directly representing forage production (lbs/acre), whereas NDVI is a unitless index that saturates in high-biomass systems and is sensitive to soil variation (Robinson et al., 2019). Second, RAP partitions biomass by plant functional type and isolates perennial forbs and grasses, the component insured by PRF, while NDVI aggregates spectral signals from all cover types within a pixel, including annual vegetation, shrubs, trees, litter, and bare ground (Robinson et al., 2019). Third, RAP has strong empirical validation, with correlations of 0.63–0.82 against major field- and grid-based production datasets (Jones et al., 2021), and its underlying PFT model shows low error and high agreement for perennial forbs and grasses (Allred et al., 2021). These advantages have led to broad adoption of RAP across rangeland science and federal land management, including applications in vegetation trend analysis, productivity monitoring, and fire and drought assessment (e.g., Naugle et al., 2020; Roberts et al., 2022; Kleinhesselink et al., 2023; Maestas et al., 2023; Reeves et al., 2023).

3.2.Rainfall Index

Historical rainfall-index data for the PRF program are obtained from the RMA's Rainfall Index Historical Index files. These files report grid-level index values by crop year and by bimonthly index interval. The available rainfall-index series spans 1948 through 2024. The dataset corresponds to the PRF rainfall index and provides the realized grid-level index values used to determine whether indemnities are triggered for each interval and year. Within the study area, the dataset includes rainfall-index observations for all 548 PRF grids and for all 11 bimonthly index intervals, ranging from January–February through November–December.

4. **Methodology**

4.1.Forage Production Index

To understand forage shortfall conditions, we construct a forage production index using RAP PFG biomass data aggregated over the May–August growing season, the period when Northern Great Plains rangeland vegetation is most responsive to precipitation (Smart et al., 2007; Lauenroth and Sala, 1992). The forage index is defined as

$$F_{g,t} = \frac{f_{g,t}}{\bar{f}_{g,t-2}} \tag{4}$$

where $f_{g,t}$ reflects growing-season PFG biomass in grid g and year t, and $\bar{f}_{g,t-2}$ is the historical mean biomass for that grid, derived from RAP data available from 1986 through $t-2$. A forage-index value below one indicates below-normal growing-season forage production, whereas a value of one or greater reflects production at or above the historical mean. Although RAP forage production is available from 1986 onward, the forage-index sample begins in 1990 to ensure at least three lagged observations for constructing the historical mean. The final dataset covers 1990–2024 and comprises 19,180 grid-year observations across 548 grids.

4.2. Selection of Best-Performing Rainfall Interval Pairs

As in Keller and Saitone (2022) and Feuz et al. (2023), we impose a two-interval choice structure with equal weights of 0.5 to simplify the analysis. Under this restriction, the 11 bimonthly PRF intervals generate 45 unique non-overlapping interval combinations for evaluation. To assess the extent to which each interval pair aligns with realized forage conditions, we estimate the following grid-level panel regression for every admissible pair (k, l):

$$F_{g,t} = \beta_0 + \beta_1 RI_{gkt} + \beta_2 RI_{glt} + \varepsilon_{gt}, \tag{5}$$

where $F_{g,t}$ is the forage production index for grid g in year t, as defined in Equation (4), and RI_{gkt} and RI_{glt} denote the PRF rainfall-index values for intervals k and l, respectively. For each interval pair, we calculate the corresponding R^2 and use it as the evaluation criterion. The pair with the highest R^2 is selected as the best-performing combination because it accounts for the greatest proportion of variation in the forage production index.

4.3. False Negative Probabilities

Building on the basis-risk framework of Elabed et al. (2013) and its application to PRF by Yu et al. (2019) and Keller and Saitone (2022), we quantify the probability that insurance fails to trigger despite a realized forage shortfall. Conditional on the forage index falling below coverage ($F_{gt} < C$), these non-indemnification probabilities are

$$FNP^1 = \Pr\left(RI_{gkt} \geq C,\, RI_{glt} < C \mid F_{gt} < C\right), \tag{6a}$$

$$FNP^2 = \Pr\left(RI_{gkt} < C,\, RI_{glt} \geq C \mid F_{gt} < C\right), \tag{6b}$$

$$FNP^3 = \Pr\left(RI_{gkt} \geq C,\, RI_{glt} \geq C \mid F_{gt} < C\right). \tag{6c}$$

where FNP^1 and FNP^2 represent partial non-indemnification (one interval fails to trigger), while FNP^3 captures complete non-indemnification (both intervals fail). These probabilities are estimated empirically for each interval pair and coverage level.

4.4. Contract Quality

The contract quality analysis examines whether PRF indemnity payments are sufficient to cover realized forage losses. For each grid g and year t, realized forage loss per acre is defined as:

$$L_{g,t} = \begin{cases} (1 - F_{g,t})B_g, & \text{if } F_{g,t} < 1, \\ 0, & \text{if } F_{g,t} \geq 1, \end{cases} \tag{7}$$

where $F_{g,t}$ is the forage production index and B_g is the county base value. This converts proportional forage shortfalls into dollar-per-acre losses using the same base-value structure as PRF.

For each grid g, indemnity per acre is calculated using the best-performing interval pair (k_g^*, l_g^*). For either interval in this pair $(i = k_g^* \text{ or } l_g^*)$, indemnity is defined as

$$I_{g,i,t} = \begin{cases} 0, & RI_{g,i,t} \geq C, \\ \left(\frac{C - RI_{g,i,t}}{C}\right) \phi \, B_g \, P, & RI_{g,i,t} < C, \end{cases} \tag{8}$$

where $RI_{g,i,t}$ denotes the rainfall index for grid g, interval i, and year t; C is the selected coverage level; ϕ is the interval weight (assumed to be 0.5 throughout); B_g is the county base value; and P represents the productivity factor, assumed to be 1 throughout.

The total indemnity received by producers in grid g under the best-performing interval pair can be calculated as:

$$I_{g,t} = I_{g,k_g^*,t} + I_{g,l_g^*,t}. \tag{9}$$

A paid forage-loss case ($F_{g,t} < 1$ and $I_{g,t} > 0$) is categorized as an underpayment when $I_{g,t} < L_{g,t}$ and as an overpayment when $I_{g,t} \geq L_{g,t}$.

5. Results and Discussion

5.1. Spatial Patterns in Best-Performing Rainfall Intervals

For each of the 548 grids in the study region, we estimated 45 regressions (one corresponding to each admissible interval pair) to assess the extent to which each pair accounts for year-to-year variation in growing-season forage production, as specified in Equation (5). The interval pair yielding the highest R^2 was subsequently identified as the best-performing combination for that grid. Figure 2 reveals a clear spatial pattern in the rainfall intervals most strongly associated with forage production across the region. Of the 45 admissible interval pairs, 25 are selected in at least one grid, whereas 20 are never selected, indicating that only a limited subset of rainfall windows consistently aligns with forage dynamics. This distribution underscores the presence of distinct hydroclimatic regimes across the Northern Great Plains, with certain rainfall intervals emerging as systematically more informative predictors of forage production than others.

Three interval pairs dominate the landscape, together accounting for 58.4% of all selections. The prevalence of April–May plus June–July (173 grids; 31.6%) and May–June plus July–August (85 grids; 15.5%) underscores the central role of growing-season precipitation in driving forage outcomes: nearly half of the region's rangeland responds most strongly to rainfall that falls during the months when plants are actively growing, indicating that forage production across much of the Northern Great Plains is governed primarily by contemporaneous moisture availability rather than precipitation accumulated earlier in the year. This pattern is consistent with ecological evidence. Smart et al. (2021) show that April–June precipitation reliably predicts annual forage production across the central and northern Great Plains, with the specific predictive window varying by ecoregion: May–June in shortgrass prairie, April–June in mixed-grass prairie, and May–July in tallgrass prairie.

At the same time, the emergence of May–June plus November–December (62 grids; 11.3%) as the third most common pair highlights a distinct hydrologic dynamic. This is the only top-five combination that includes a winter interval, and its clustering in western Nebraska points to a distinct hydrologic regime in which precipitation during the winter months replenishes soil moisture that becomes available to plants as they initiate growth the following spring.

Figure 2 also reveals pronounced spatial clustering in interval-pair selection and heterogeneous interval distributions across the three states. April–May plus June–July dominates in 40% of Nebraska grids and 30% of South Dakota grids, but only 21% of North Dakota grids. This pattern indicates that the interval pair most closely aligned with forage dynamics is shaped by localized climatic and ecological conditions. From a producer standpoint, enhancing the effectiveness of PRF coverage requires selecting intervals tailored to local hydroclimatic regimes, thereby improving the alignment between the rainfall index and on-the-ground forage outcomes.

5.2.Spatial Variation in Rainfall–Forage Predictive Strength

The explanatory power of bimonthly rainfall intervals varies substantially across the landscape. Comparing Figures 2 and 3 shows that grids selecting the two dominant interval pairs, April–May + June–July and May–June + July–August, tend to align with regions exhibiting higher R^2values, whereas grids selecting less common interval pairs more often correspond to lower-fit areas. The strongest fits cluster in central and southern South Dakota, extend into portions of Nebraska, and appear in localized areas of west-central North Dakota. In contrast, lower R^2values are more prevalent in northeastern North Dakota and along several eastern margins.

Across the 548 grids, the mean best-interval R^2 is 0.40, indicating that the two most predictive rainfall windows account for roughly 40% of interannual forage-production variability. This magnitude aligns closely with long-term rangeland studies. Using a 52-year record from the North American shortgrass steppe, Lauenroth and Sala (1992) reported that precipitation explained 39–45% of long-term forage variation, with annual precipitation alone explaining 39% and growing-season precipitation 43%. The remaining unexplained variation likely reflects climatic and hydrologic influences not captured by the rainfall index, such as temperature variability, plant community composition, soil water-holding capacity, and other site-specific factors (Lauenroth and Sala, 1992; Smart et al., 2021). This moderate explanatory power highlights that even the best rainfall-interval pair is an imperfect proxy for realized forage outcomes, and thus basis risk remains inherent.

State-level means follow a clear gradient: South Dakota (0.43), Nebraska (0.40), and North Dakota (0.37). Pairwise Mann–Whitney tests with Bonferroni correction confirm that South Dakota's distribution is significantly higher than both Nebraska's ($p < 0.01$) and North Dakota's ($p < 0.001$), while the Nebraska–North Dakota difference is marginal (adjusted $p = 0.052$). Together, these spatial and statistical patterns indicate that the predictive strength of rainfall intervals is not uniform but instead reflects underlying climatic and ecological gradients across the Northern Great Plains.

5.3.Evaluating PRF Performance Using False-Negative Probabilities

Given that the analysis above shows even the best rainfall-interval pair captures only about 40% of interannual forage variation, we next estimate the probability that PRF fails to trigger an indemnity when forage production falls below the insured coverage level (i.e., the false-negative probability). These probabilities are computed using Equations (6a)–(6c) and each grid's own best-performing interval pair. Table 1 reports the partial non-indemnification rate ($FNP^1 + FNP^2$) and the complete non-indemnification rate (FNP^3) at different PRF coverage levels for the ten most frequently identified best-performing interval pairs shown in Figure 2. All statistics are calculated only for grids in which a given pair is identified as optimal.

According to USDA-RMA's Summary of Business (2025a), the 90% coverage level accounts for 75.3% of insured PRF acres in the three-state region (93.2% in North Dakota, 78.5% in South Dakota, and 62.8% in Nebraska). Reflecting this dominance in producer choice, we emphasize the 90% coverage level in interpreting results. At 90% coverage, the most frequently identified pair (April–May plus June–July, 173 grids) yields a partial non-indemnification rate of 32% and a complete non-indemnification rate of 8%, indicating that even on grids where this pair is optimal, substantial residual basis risk remains. Across the ten interval pairs, $FNP^1 + FNP^2$ at

90% coverage ranges from 27% (January–February plus April–May) to 61% (May–June plus September–October), with the six most common pairs falling within the 31%–39% range. Complete non-indemnification (FNP^3) ranges from 4% (May–June plus July–August) to 17% (May–June plus September–October), indicating that in some cases (typically below 10%), producers received no payment for either interval despite forage falling below coverage.

Table 2 presents the false-negative probabilities aggregated by state at the 90% coverage level. Rates of partial non-indemnification ($FNP^1 + FNP^2$) are relatively uniform across states, ranging from 35.3% in North Dakota to 37.6% in South Dakota. In contrast, complete non-indemnification (FNP^3) exhibits more pronounced variation, with 10.0% in Nebraska, 7.5% in South Dakota, and 6.0% in North Dakota. These differences are consistent with underlying patterns of forage variability: North Dakota displays the lowest year-to-year variability in the forage index (average grid-level standard deviation = 0.14) and the lowest frequency of qualifying shortfalls (8.8%), whereas Nebraska exhibits both the highest shortfall frequency (17.1%) and the highest FNP^3.

Across all 548 grids, 37.0% of forage shortfalls receive only partial indemnification and 8.4% receive none, yielding a total false-negative rate of 45.4%. This magnitude is broadly consistent with Yu et al. (2019), who report basis-risk rates between 26% and 43% using site-level forage and precipitation data from three university-managed ranches in Kansas and Nebraska. Our partial-indemnification rate also aligns with Keller and Saitone (2022), who find rates ranging from 33% to 45% across 327 California rangeland grids using NDVI-derived forage estimates. However, our complete-non-indemnification rate is substantially lower than theirs, which ranges from 14% to 24%. Taken together, these comparisons indicate that although PRF provides some drought-related protection, the rainfall index does not consistently track realized forage conditions.

As a result, producers remain exposed to uncompensated losses in a sizable share of shortfall years. In our study region, nearly one-half of all forage-shortfall years go without full indemnification, underscoring the limited ability of the rainfall-based index to track realized production conditions.

5.4. Assessment of PRF Payment Alignment

To assess PRF performance conditional on payment, we compare indemnity values with realized forage losses following the contract quality framework introduced earlier. This metric complements the false-negative analysis by evaluating contract quality when the index does trigger. Table 3 reports the frequency and magnitude of underpayment and overpayment at the 90% coverage level for the ten most frequently selected best-performing interval pairs.

Across all interval pairs, the incidence of overpayment far exceeds that of underpayment, with overpayment shares spanning from 60.6% (May–June plus August–September) to 90.4% (January–February plus April–May). The most frequently selected pair (April–May plus June–July, 173 grids) exhibits underpayment in 20.0% of paid-loss cases and overpayment in 80.0%, with corresponding mean values of $-1.73 and $3.65 per acre. The magnitude of overpayment consistently exceeds that of underpayment by approximately a factor of two. Consequently, the expected net payment, calculated as the probability-weighted difference between overpayment and underpayment magnitudes, is positive for all top-ranked pairs, indicating that indemnities systematically exceed realized forage losses on average. These results parallel those of Keller and Saitone (2022), who document underpayment in 36% of cases, with average underpayments of $1.74–$2.73 per acre and average overpayments of $4.81 per acre.

The interval pairs that include winter months stand out for producing the highest positive expected net payments. Examples include January–February combined with April–May ($3.84), April–May combined with November–December ($3.75), and May–June combined with November–December ($3.37). These results help explain producers' frequent selection of winter intervals with limited agronomic relevance, a behavior documented in prior (Westerhold et al., 2018; Goodrich et al., 2020; Cho and Brorsen, 2021; Goodrich et al., 2026).

Table 4 summarizes the magnitude and frequency of over- and under-payments across states. North Dakota displays the most pronounced asymmetry, with 14.3% of paid-loss cases underpaid and 85.7% overpaid, and mean amounts of -$0.97 and $3.58 per acre. Nebraska exhibits the largest dollar magnitudes in both directions (-$1.82 for underpayment and $4.08 for overpayment), consistent with its higher county base values and greater variability in forage and rainfall. State-level expected net payments range from $2.10 in South Dakota to $2.93 in North Dakota, the latter reflecting the state's high proportion of overpayment outcomes.

When aggregated across all 548 grids, the expected net indemnity payment conditional on both a forage loss and a triggered payment is $2.55 per acre, indicating systematic overcompensation relative to realized losses. At the same time, PRF frequently pays when no forage loss occurs, because the rainfall index can fall below the coverage threshold even when forage production remains normal. These instances constitute false positives. At the 90% coverage level, 56.1% of grid-year observations (7,371 of 13,137) with normal forage production still receive an indemnity, with an average payment of $3.40 per acre. State-level false-positive rates range from 52.2% in South Dakota to 64.2% in North Dakota. Taken together, these patterns suggest that PRF functions partly as a subsidized transfer mechanism rather than a strictly actuarial insurance product, consistent with longstanding critiques of federal crop insurance programs as income-transfer vehicles (Goodwin and Smith, 2013).

6. **Conclusions**

This study evaluates basis risk in the Pasture, Rangeland, and Forage Insurance Program across Nebraska, North Dakota, and South Dakota using more than three decades of satellite-derived forage production data paired with USDA–RMA grid-level rainfall index values. Program performance is comprehensively assessed along three dimensions: the probability that indemnities fail to trigger during forage shortfalls, the probability that indemnities occur in years with normal forage production, and the degree of alignment between indemnity magnitudes and realized losses when payments are made.

Our article yields three central findings. First, rainfall explains a moderate share of forage variation, with the best-performing two-interval combination for each grid accounting for approximately 40% of annual fluctuations. Optimal interval pairs represent only a subset of those available, and growing-season combinations are selected most frequently, consistent with their agronomic importance. The pronounced spatial heterogeneity in optimal interval choices suggests that a uniform approach to interval selection is unlikely to serve producers well, underscoring the value of more localized guidance to improve PRF interval choices and reduce basis risk.

Second, basis risk in the form of false negatives remains substantial even under each grid's best-performing interval pair. At the 90% coverage level, 37% of forage shortfalls result in partial non-indemnification and 8% in complete non-indemnification. These rates vary systematically across interval types, with pairs that include shoulder or winter months exhibiting markedly higher probabilities of complete trigger failure. This highlights the need for program adjustments to reduce the likelihood of missed triggers when forage losses occur.

Third, indemnities are skewed toward overcompensation. Among cases in which a forage loss occurs and the contract triggers, 78.8% are overpayments, and the expected net indemnity payment conditional on both a forage loss and a triggered payment is $2.55 per acre. In addition, 56.1% of no-shortfall grid-years receive indemnities averaging $3.40 per acre. This systematic pattern of overcompensation raises questions about whether the current program appropriately targets risk mitigation rather than unintended income support. It suggests the need to reassess whether existing subsidy levels, interval structures, and weighting rules strike an appropriate balance between fiscal cost and the program's objective of providing actuarially sound forage-loss protection.

Several caveats merit attention. We adopt simplifying assumptions, including a two-interval structure with equal weights and a fixed productivity factor of one, which may influence the scale of the basis-risk estimates. In addition, our forage proxy is derived from satellite-based aboveground biomass rather than ground-measured yield, and associated measurement error may contribute to unexplained variation in forage outcomes. Future research could explore alternative interval weighting schemes, incorporate alternative forage measures, and extend the analysis to other major U.S. rangeland regions.

Table 1. False Negative Probabilities (FNP) by best-performing interval pair and coverage rate

Interval combination	# Grids	Coverage rate 0.70	0.75	0.80	0.85	0.90
		FNP¹ + FNP² {FNP³} (%)				
Apr-May + Jun-Jul	173	34 {7}	28 {8}	28 {8}	30 {8}	32 {8}
May-Jun + Jul-Aug	85	58 {3}	47 {1}	36 {3}	35 {4}	35 {4}
May-Jun + Nov-Dec	62	11 {14}	18 {8}	32 {8}	38 {11}	39 {12}
Mar-Apr + May-Jun	45	30 {14}	34 {9}	41 {2}	30 {7}	35 {6}
Apr-May + Jul-Aug	32	59 {0}	51 {2}	56 {1}	50 {6}	38 {9}
Jan-Feb + May-Jun	26	13 {22}	17 {14}	22 {10}	28 {5}	31 {7}
May-Jun + Aug-Sep	24	69 {22}	65 {21}	60 {17}	52 {17}	51 {15}
Jan-Feb + Apr-May	22	10 {10}	18 {18}	18 {6}	14 {8}	27 {9}
Apr-May + Nov-Dec	16	0 {0}	25 {0}	31 {15}	44 {16}	48 {15}
May-Jun + Sep-Oct	12	68 {5}	64 {8}	53 {13}	58 {13}	61 {17}

Note: Each cell reports $FNP^1 + FNP^2$ $\{FNP^3\}$, expressed as percentages. $FNP^1 + FNP^2$ captures partial non-indemnification (only one of the two selected intervals triggers); FNP^3 (in braces) captures complete non-indemnification (neither interval triggers), given a forage shortage. The table lists the ten most frequently selected interval pairs, representing 497 of 548 grids. # Grids denotes how many grids identify each pair as the best-performing combination. All statistics are computed only for grids in which that pair is optimal.

Table 2. State-level false negative probabilities at 90% coverage

State	# Grids	$FNP^1 + FNP^2$ (%)	FNP^3 (%)
Nebraska	204	37.13	10.00
North Dakota	140	35.27	6.03
South Dakota	204	37.62	7.50
Overall	**548**	**37.03**	**8.39**

Note: False-negative probabilities are computed at 90% coverage using each grid's best-performing interval pair, and then aggregated across all covered grids within the state. $FNP^1 + FNP^2$ captures partial non-indemnification (only one of the two selected intervals triggers conditional on forage index falling below 90%); FNP^3 captures complete non-indemnification (neither interval triggers). # Grids is the number of analyzed grids in each state.

Table 3. Probability and scale of underpayment and overpayment at the 90% coverage level

Interval Combination	# Grids	Underpayment ($I_{g,t} < L_{g,t}$)	Overpayment ($I_{g,t} \geq L_{g,t}$)	Expected Net Payment ($)
		Pr. % [Mean $]	Pr. % [Mean $]	
Apr-May + Jun-Jul	173	20.0 [−1.73]	80.0 [3.65]	2.58
May-Jun + Jul-Aug	85	23.6 [−1.22]	76.4 [3.19]	2.15
May-Jun + Nov-Dec	62	17.2 [−1.19]	82.8 [4.32]	3.37
Mar-Apr + May-Jun	45	22.4 [−1.16]	77.6 [3.22]	2.23
Apr-May + Jul-Aug	32	19.3 [−1.51]	80.7 [3.26]	2.34
Jan-Feb + May-Jun	26	19.0 [−1.70]	81.0 [3.25]	2.31
May-Jun + Aug-Sep	24	39.4 [−1.65]	60.7 [4.03]	1.80
Jan-Feb + Apr-May	22	9.6 [−1.63]	90.4 [4.42]	3.84
Apr-May + Nov-Dec	16	15.3 [−1.00]	84.7 [4.61]	3.75
May-Jun + Sep-Oct	12	34.3 [−1.34]	65.7 [2.42]	1.13

Underpayment denotes cases where indemnity falls below realized forage loss ($I_{g,t} < L_{g,t}$); Overpayment denotes cases where indemnity meets or exceeds realized loss ($I_{g,t} \geq L_{g,t}$). Each cell reports the probability (%) of the case, with the conditional mean per-acre dollar amount in brackets (in 2024 dollars). Expected net payment = (Overpayment Pr. × Mean) − (Underpayment Pr. × Mean). # Grids denotes how many grids identify each pair as the best-performing combination. All statistics are computed only for grids in which that pair is optimal, conditional on both a forage loss and a triggered payment at 90% coverage. The table lists findings for the ten most frequently selected interval pairs, representing 497 of 548 grids.

Table 4. State-level probability and scale of underpayment and overpayment

State	# Grids	Underpayment ($I_{g,t} < L_{g,t}$)	Overpayment ($I_{g,t} \geq L_{g,t}$)	Expected Net Payment ($)
		Pr. % [Mean $]	Pr. % [Mean $]	
Nebraska	204	22.6 [−1.82]	77.4 [4.08]	2.75
North Dakota	140	14.3 [−0.97]	85.7 [3.58]	2.93
South Dakota	204	23.7 [−1.36]	76.3 [3.18]	2.10
Overall	**548**	**21.2 [−1.51]**	**78.8 [3.64]**	**2.55**

Underpayment denotes cases where indemnity falls below realized forage loss ($I_{g,t} < L_{g,t}$); Overpayment denotes cases where indemnity meets or exceeds realized loss ($I_{g,t} \geq L_{g,t}$). Each cell reports the probability (%) of the case, with the conditional mean per-acre dollar amount in brackets (in 2024 dollars). Expected net payment = (Overpayment Pr. × Mean) − (Underpayment Pr. × Mean). # Grids is the number of analyzed grids in each state. All statistics are computed only for grids in which that pair is optimal, conditional on both a forage loss and a triggered payment at 90% coverage. The table lists findings for the ten most frequently selected interval pairs, representing 497 of 548 grids.

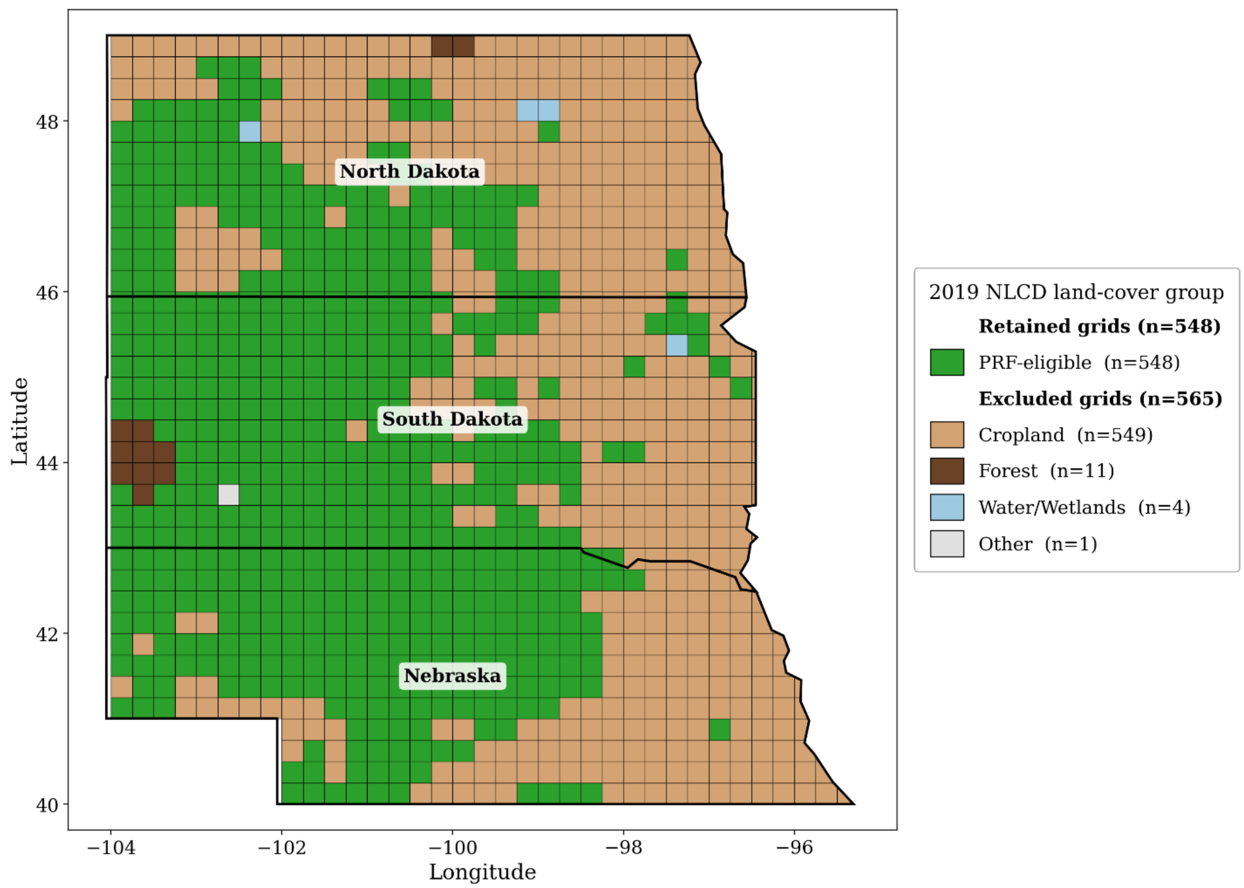

Figure 1. PRF-eligible grid sample based on 2019 National Land Cover Database (NLCD)

Grids are retained when PRF-eligible land cover (grassland/herbaceous and pasture/hay) is the dominant category. All other grids are excluded and labeled by their dominant non-PRF land-cover class using 2019 NLCD data.

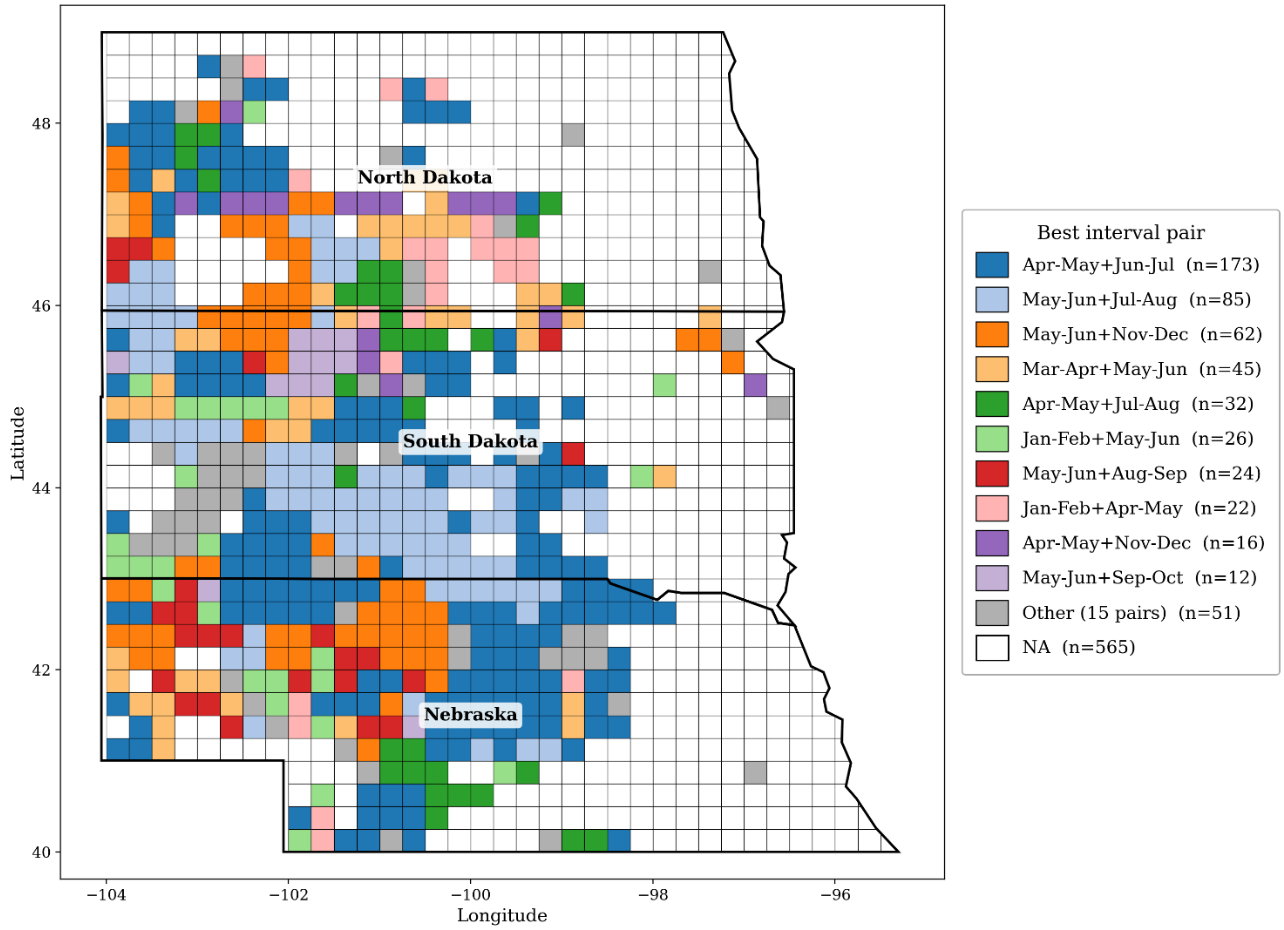

Figure 2. Best-performing interval pair selected by grid

Only the ten most frequently selected interval pairs are shown; all remaining pairs are grouped under "Other."

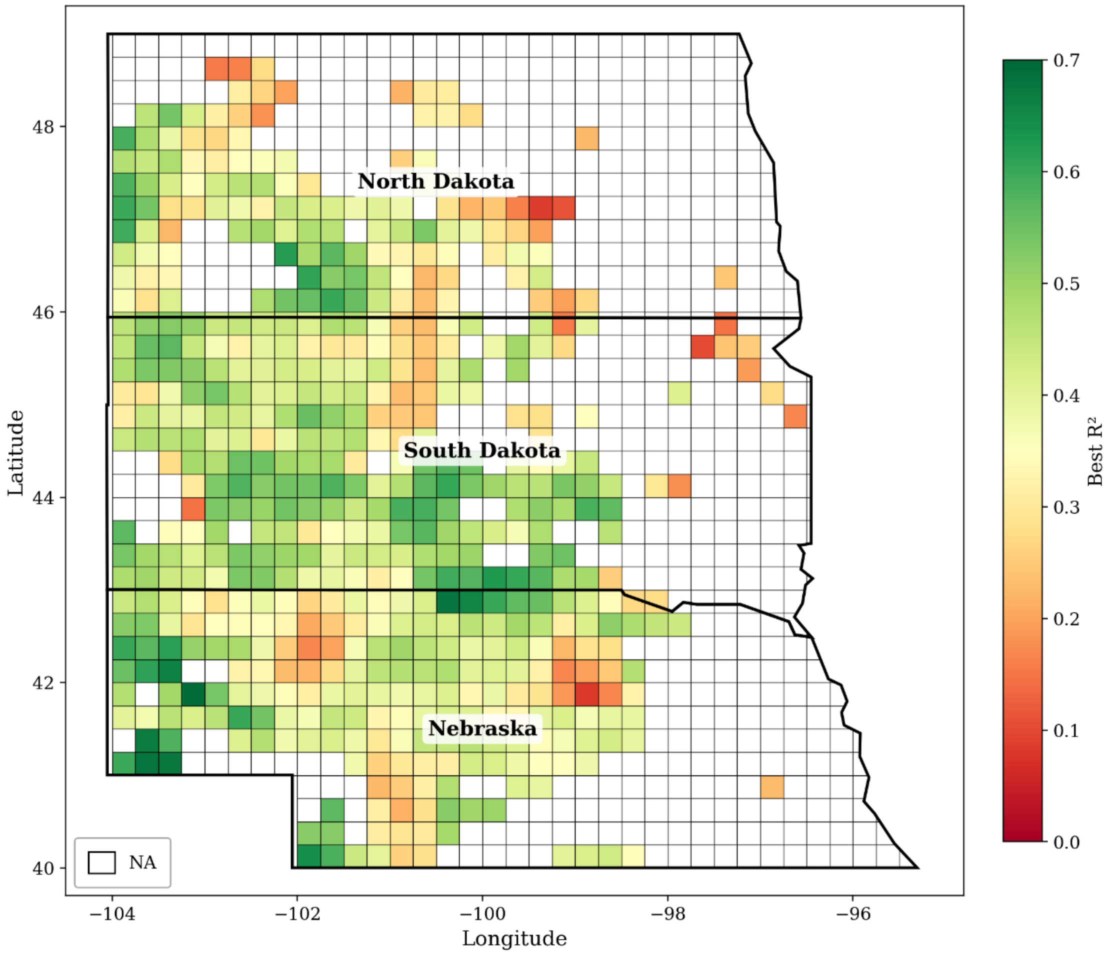

Figure 3. Spatial distribution of grid-level best-fit R^2 values

The color scale ranges from red (low R^2) through yellow (moderate R^2) to green (high R^2) across the 0.0–0.7 interval. Higher values indicate grids where the rainfall index provides a better explanation of interannual variation in growing-season forage production.

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