Brief #2: Assessing Forage Impacts

Evaluating Yield Performance across a Spectrum of Irrigation Withdrawal Scenarios in Pasture-Livestock Systems

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Overview

- We evaluate how different irrigation curtailment scenarios affect forage yields in pasture-livestock systems across two ranches in western Colorado. This is a companion to Brief #1 that estimated water conservation.
- Biomass yields were modeled across eight irrigation treatments—from full irrigation to complete season withdrawal—at each location across large, field-scale plots.
- The results offer producers and policy makers insight on maintaining forage production while contributing to water conservation—especially under voluntary compensation programs for reduced consumptive use.

Purpose

This brief presents data on forage yields in pasture-livestock systems for a range of irrigation withdrawal strategies.

The insights gained can assist producers, policy makers, and other stakeholders:

- Assess the trade-offs between maintaining forage production and conserving water resources in pasture-livestock systems through voluntary irrigation curtailment.
- Provide data to inform the design and implementation of flexible, site-specific water management practices that support voluntary compensation programs.

Approach

A pasture at each ranch was divided into 8 zones, about 5 acres each, with zones receiving specific irrigation treatments.

- Scenarios ranged from full-season irrigation to various shutoff schedules, compared to a fully irrigated reference.
- Pastures were actively grazed according to typical schedules to replicate real-world conditions.

Forage yields were estimated using spatially-averaged actual evapotranspiration values derived from remote sensing data, which captured field-scale variability in crop water use.

- Modeled forage yields were compared with exclosures in each zone to derive more detail regarding yields.

Findings

ET-based crop production functions provided reasonable estimates of forage biomass across irrigation scenarios.

- Exclosure-measured yields provided some agreement where expected in full-irrigation and withdrawal scenarios.

At Banner Ranch, the more uniform site, dry matter yields for the no irrigation withdrawal strategy measured:

- 1.07 t/ac through July 18 within the exclosure, versus 1.08 t/ac modeled using ET-based production function
- An additional 1-1.5 tons was produced from July 18 through the second sampling in September
- In contrast, the full season irrigation withdrawal strategy yielded 56% lower through the July sampling date

Field ET rates were non-zero, contrasting with greater and almost total forage losses on heavily water stressed fields.

- Reflects stored soil moisture availability and evaporation, highlighting some ET continues even when grazable yield is unavailable for typical stocking rates.
- However, ET thresholds exist, below which grass growth will be functionally useless for pasture operations.

Insights

Partial season strategies show potential for modest water conservation while maintaining some forage output

- A tradeoff will be required under voluntary compensation programs for forage yield versus conserved CU.

ET mapping is a useful proxy for estimating forage biomass production across varied irrigation scenarios

- Offers research-based, landscape-scale approach for conventional CO smooth brome, orchardgrass, tall fescue.
- Important for normalizing against localized variability in species composition, soil moisture, and grazing pressure.

In-field biomass sampling provides valuable ground-truth data for calibrating ET-based yield estimates

- Can help to validate remote-sensing or modeled assessments.
- Diverse range of single-point samples across field conditions is essential

Continued evaluation of fields after withdrawal is important in subsequent years to assess recovery or continued impacts.

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Supplemental Information

Introduction & Objectives

The extensive acreage and consumptive use (CU) of hay production in the Upper Colorado River Basin has attracted attention from voluntary water-sharing programs, which compensate producers for conserved consumptive use (CCU) through temporary irrigation reductions. This has heightened the importance of understanding forage resilience and recovery under water stress (CWCB, 2020; Colorado Water Trust, 2024).

Among forages, alfalfa (Medicago sativa) is the most studied and has shown a strong capacity to tolerate irrigation cutbacks, often recovering fully after a season of full irrigation withdrawal. For example, yield losses during summer irrigation stoppage typically range from 0.2 to 0.7 T/ac (Ottman et al., 1996). Early-season cutoffs can conserve water with limited productivity loss, though yield reductions can be more pronounced depending on soil type or access to water tables (Orloff et al., 2003). Longer reductions (2–3 months) often result in temporary yield declines that rebound when irrigation resumes (Putnam, 2012), with some studies showing a 50% water reduction can yield only a 13–20% seasonal yield loss over two years (Putnam, 2015). Partial-season irrigation strategies may even enhance water use efficiency (WUE), with seasonal yield losses under 20% (Cabot et al., 2017; Li et al., 2023).

In contrast, pasture grasses exhibit greater variability in drought resilience due to species-specific adaptations. Orchardgrass (*Dactylis glomerata*), for instance, performs well below 6,000 ft but suffers in forage quality under drought (Pearson et al., 2010; Xiong et al., 2022). Perennial ryegrass (*Lolium perenne*) offers high nutritive value but is less suited to cooler, high-elevation conditions (Jensen et al., 2003), while bermudagrass (*Cynodon dactylon*) responds well to saline irrigation but is limited by cold sensitivity (Robinson et al., 2003; Glover et al., 2004). These differences highlight the need for site- and species-specific management strategies in water-limited system While smooth brome (*B. inermis* Leyss.) grasses may be less tolerant under active-season water stress, they can rebound well in the early season following a year of reduced irrigation.

Building on this background, an evaluation of irrigation withdrawal practices was initiated in 2023 in western Colorado to examine how different water reduction scenarios affected forage yield in pasture-livestock systems.. This evaluation reports on grass biomass as one of several variables used to evaluate the impacts of irrigation withdrawal. Biomass is relatively straightforward to measure and provides a useful proxy for forage availability; however, its interpretation must be grounded in the broader context of the livestock system. For producers, the value of forage is ultimately tied to its role in supporting animal performance, making it essential to consider biomass alongside other management-relevant metrics such as grazing duration and stocking capacity.

Study Sites & Irrigation Withdrawal Scenarios

The study was conducted on irrigated pastures at two sites in western Colorado: Banner Ranch (36.2 acres; 14.6 ha) and Orchard Ranch at Harts Basin (74.7 acres; 30.2 ha), located at elevations of 5,322 ft (1,622 m) and 5,552 ft (1,692 m), respectively. Both sites were subdivided into eight contiguous treatment zones, each approximately 5 acres in size, within a single managed field. Seven irrigation withdrawal scenarios were implemented across the zones to evaluate the impacts on forage availability and regrowth potential, relative to a reference field in the vicinity of the study fields.

(1) Full season irrigation withdrawal [FSIW]: No irrigation after initial grazing (April 25 to May 2). A second grazing in late May/early June was possible, followed by potential fall regrowth depending on precipitation.

(2) One and done [1AD]: A single early-season irrigation was applied, then shut off soon after water became available. Grazing matched FSIW timing.

(3–5) Shutoffs on June 1, July 1, and August 1 [SO0601, SO0701, SO0801]: Irrigation continued until the specified date, then ceased. Each zone was initially grazed April 25–May 2, with possible second grazing and fall regrowth for winter grazing.

(6) Shoulder month [SM]: Irrigation was applied only in May and September. Grazing followed the standard early-season schedule, with potential for forage re-growth and winter grazing.

(7) Put it to bed wet [PITBW]: No irrigation during the growing season, with a single application in fall. Grazing followed the standard early-season schedule, with potential for late-season regrowth and winter grazing.

(8) No irrigation withdrawal (NIW): Served as fully irrigated reference (REF) zone with uninterrupted irrigation throughout the season and followed the standard season-long grazing timeline, allowing for greater forage regrowth potential.

Forage yield was assessed using data collected from 10 ft × 10 ft livestock exclosures situated within larger 5-acre treatment zones. These exclosures represented a small proportion of each field and were installed to protect specific sampling locations from grazing. While grazing occurred freely outside the exclosures, the interior was managed by cutting vegetation at times that coincided with grazing events to better reflect forage reduction. At Banner Ranch, livestock exclosures were placed at the central centroid of each 5-acre field to ensure uniformity and reduce the risk of site selection bias. Positioning the exclosures at the field center allowed for a more representative sampling of average conditions, rather than edge effects or anomalies. At Orchard Ranch, where the fields are long and narrow due to sideroll irrigation and situated on a pronounced slope, exclosures were installed along a transect. This approach acknowledged the inherent heterogeneity of the site while maintaining an unbiased sampling design, avoiding any practice that might intentionally favor areas with better forage growth.

Sampling within the exclosures followed established field protocols, with forage clipped on July 18, 2023 and September 4, 2023, from a 0.25 m^2 quadrat, as described by Bowman et al. (2008). Samples were then dried at 130°F (54°C) for 72 hours to determine dry matter yield, expressed in T/ac (T/ac). This approach, adapted from Grev et al. (2020), offered a consistent and practical method for evaluating aboveground biomass production across treatment zones and study years.

Small sample plots can provide useful insights into forage yield but extrapolating those results to an entire 5-acre field assumes uniformity in soil, water availability, and other growth conditions. While small plots serve a practical purpose for studying microregions within a field, broader interpretation must account for complexity of real-world field conditions. A companion evaluation involves using data that captures spatial heterogeneity, such as field-scale modeled estimates of actual evapotranspiration (ETa) based on remote sensing. This approach provides a more comprehensive view of actual field conditions by spatially averaging ET over the entire field, reflecting the full variability in crop water use across the landscape, and offering a high-resolution snapshot of how different areas of a field perform. Because the relationship between ETa and biomass yield has been widely studied for numerous crops (Smeal et al, 2005; Howell et al. 2008; Lindenmayer et al. 2010; Xue et al. 2017; Orta and M. Kuyumcu, 2023), including forage grasses, spatially-averaged ETa rates provide a valuable foundation for applying crop production functions. These functions allow yield to be estimated at the field scale with greater accuracy, integrating both biophysical processes and spatial variability to better reflect biomass grass yields under varying irrigation conditions.

Results and Discussion

Crop production functions were used to quantify dry matter yield as a linear function of water applied (Table 1). For grasses consistent with those grown at the Banner and Orchard Ranch sites, Smeal et al. (2005) reported strong linear yield responses between dry forage yield (Mg/ha) and water applied (mm) for meadow brome, orchardgrass, and tall fescue (Equation 1) and smooth brome (Equation 2)

$$Y = -4.3 + 0.0129w \tag{1}$$

$$Y = -3.07 + 0.0096w \tag{2}$$

Given that Smeal et al (2005) reported seasonal water applied, Equations 1 and 2 were adapted to estimate yield as a function of ETa, assuming a typical 80% application efficiency for sprinkler irrigation. This adjustment allowed the crop production to be applied to spatially averaged ETa rates rather than measured irrigation inputs. Additionally, Smeal et al. (2005) does not report any functional yield at ETa rates below approximately 10 in, indicating that forage production is effectively negligible under such limited water availability. This threshold exists because a minimum level of seasonal transpiration is required before meaningful biomass accumulation begins, particularly for cool-season grasses. Below this point, plants likely experience severe water stress, leading to stunted growth and minimal harvestable yield. Lastly, it is important to note that Smeal et al (2005) reported yields as pure oven-dried forage, not adjusted to the typical ≤15% moisture standard for baled hay, and this difference was accounted for in our interpretation.

Although precise records of grazing dates and stocking day rates were not available for the treatment zones, the crop production function can still be applied using ETa accumulated up to the time of grazing or exclosure sampling. This approach provides a practical estimate of forage availability to livestock and enhances the relevance of production function modeling within the context of rotational or deferred grazing systems.

Table 1. Crop Production Functions for Grasses based on Smeal et al. (2005)

meadow brome, orchardgrass, and tall fescue						smooth brome					
Irrigation (mm)	ET (mm)	Yield (Mg/ha)	Irrigation (in)	ET (in)	Yield T/ac	Irrigation (mm)	ET (mm)	Yield (Mg/ha)	Irrigation (in)	ET (in)	Yield T/ac
333	267	0.00	13.1	10.5	0.00	320	256	0.0	12.6	10.1	0.00
350	280	0.22	13.8	11.0	0.10	350	280	0.3	13.8	11.0	0.13
400	320	0.86	15.7	12.6	0.38	400	320	0.8	15.7	12.6	0.34
450	360	1.51	17.7	14.2	0.67	450	360	1.3	17.7	14.2	0.56
500	400	2.15	19.7	15.7	0.96	500	400	1.7	19.7	15.7	0.77
550	440	2.80	21.7	17.3	1.25	550	440	2.2	21.7	17.3	0.99
600	480	3.44	23.6	18.9	1.53	600	480	2.7	23.6	18.9	1.20
650	520	4.09	25.6	20.5	1.82	650	520	3.2	25.6	20.5	1.41
700	560	4.73	27.6	22.0	2.11	700	560	3.7	27.6	22.0	1.63
750	600	5.38	29.5	23.6	2.40	750	600	4.1	29.5	23.6	1.84
800	640	6.02	31.5	25.2	2.69	800	640	4.6	31.5	25.2	2.06
850	680	6.67	33.5	26.8	2.97	850	680	5.1	33.5	26.8	2.27
900	720	7.31	35.4	28.3	3.26	900	720	5.6	35.4	28.3	2.48
950	760	7.96	37.4	29.9	3.55	950	760	6.1	37.4	29.9	2.70
1000	800	8.60	39.4	31.5	3.84	1000	800	6.5	39.4	31.5	2.91

To compare modeled and observed yield values, ETa was calculated for the early growing season up to the sampling date. See Brief 1 "Estimating the Water Conservation Potential of Voluntary Irrigation Withdrawal on Working Livestock Pasture." Cumulative ETa estimates from April 1 through July 18 varied across irrigation scenarios, reflecting differences in water availability and timing. The fully irrigated reference scenario showed the highest seasonal ETa at 16.88 in, while the full season irrigation withdrawal (FSIW) scenario totaled 12.57 in. Mid-range values included 15.79 in for shutoff on June 1, 16.26 in for shutoff on July 1, and 15.30 in for shutoff on August 1. The "Shoulder Months" treatment, which limited irrigation to the spring and fall, yielded an ETa of 12.69 in. The "Put it to Bed Wet" scenario had the lowest ETa at 10.65 in, underscoring its reduced water input and limited forage growth potential. These values frame the range of crop water use conditions influencing yield outcomes.

Values of ETa from various irrigation scenarios were used to estimate forage yields using the crop production functions from Table 1, and these were compared against exclosure-based field measurements. Several scenarios demonstrated good alignment between modeled and measured yields, underscoring the value of integrating ET-based modeling with field observations, particularly in rotational grazing systems where water application and forage use are not spatially uniform.

At Banner Ranch, the most representative site, the cumulative ETa from April 1 to July 18 under full irrigation was 16.88 in. This level of water use would be expected to yield approximately 1.19 T/ac for meadow brome, orchardgrass, and tall fescue, and about 0.95 T/ac for smooth brome, averaging 1.07 T/ac. The exclosure-measured yield at Banner was 1.08 T/ac, providing strong validation for the modeled estimates. At the low end of the irrigation spectrum, the full season irrigation withdrawal scenario produced an ETa of 12.57 in and an exclosure yield of 0.40 T/ac. This result is consistent with the modeled yield curve, which predicts limited but measurable biomass accumulation under reduced water availability.

The July 1 and August 1 irrigation cutoff scenarios offer another useful comparison. Due to carryover soil moisture after irrigation ceased, both scenarios achieved similar ETa values by the July 18 sampling date, 16.26 and 15.30 in, respectively, functioning effectively as replicates. Modeled yields averaged 1.005 T/ac, while exclosure-based yields averaged 0.923 T/ac. Although the model slightly overestimated yield by about 0.08 T/ac, the results remained closely aligned, supporting the utility of ET-based crop production functions for estimating forage yield under variable irrigation timing.

By contrast, the June 1 shutoff and Shoulder Months scenarios illustrate cases where model and exclosure estimates were less consistent. The June 1 scenario had a modeled yield of 1.01 T/ac, while the exclosure yield was only 0.412 T/ac, indicating a clear overestimation. In the Shoulder Months case, the model estimated 0.47 T/ac, whereas the exclosure yielded 0.755 T/ac—resulting in an underestimation. These examples underscore the limitations of modeling in heterogeneous systems and the importance of ground-truthing predictions through field measurements.

Closing Takeaways

In conclusion, the relative alignment between exclosure-based yields and modeled estimates derived from ET-based crop production functions is encouraging, particularly considering the inherent variability in rotational grazing systems and non-uniform irrigation practices. While some inconsistencies emerged under partial irrigation scenarios, the close agreement in several cases, especially at the fully irrigated reference and irrigation deprived sites, demonstrates the utility of the production function method. It is important to note that this analysis involved assumptions about green-up timing and species similarity across treatment areas, which may have introduced some variability in the comparisons. Nevertheless, the recommendation is to rely more heavily on crop production functions when estimating field-scale forage yield. These models are better equipped to capture field heterogeneity by incorporating spatially distributed data, such as ET maps, which reflect actual conditions across the landscape. This broader perspective offers a more robust and scalable approach than small-plot measurements alone, particularly in complex pasture-livestock systems.

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