Evaluating Conserved Consumptive Use in the Upper Colorado: 2022 Annual Report

Hay and Pasture Grass Recovery in Year Two after Withholding Irrigation

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Abstract

A specific objective within the project, "Evaluating Conserved Consumptive Use in the Upper Colorado Basin," is the evaluation of hay and pasture grass recovery in high-elevation fields after a phase of reduced irrigation. The investigation was conducted in proximity to Kremmling, Colorado, encompassing multiple fields where irrigation was intentionally withheld during the 2020 growing season and subsequently reverted to historical irrigation practices in 2021. An extensive dataset of forage production and quality was collected from 2020-2022 on fields where water had been withheld and reference fields where water was applied according to normal irrigation practices. The purpose of restricting irrigation to the fields in the investigation was to mimic the institution of a temporary water leasing arrangement that would compensate farmers for intentional foregone diversions.

To assess the pace of forage recovery, fields with fully withheld or reduced irrigation were paired with similar reference fields that were irrigated according to historic practices throughout the study period. Key results from 2020 and 2021, reported on in detail in previous reports, are summarized below:

- As anticipated and reported in the project's 2020 report (Cabot, Derwingson, & Torres-Rua, 2021), forage productivity on the fully curtailed fields was very low compared to the productivity on reference fields in 2020, when irrigation was withheld.
- In 2021, when these fields were returned to full irrigation, productivity on treated fields compared with reference fields was mixed, while quality was typically the same or higher on treated fields compared with reference fields. Detailed data on forage yields and quality in 2021 is provided and discussed in the 2021 annual report (Cabot, Holm & Brummer, 2022).

This report focuses on yield and quality data in 2022, the second year in which all fields were returned to full irrigation following the 2020 treatment year. It also reviews trends in productivity and quality in both treated and reference fields over the course of the project to date and discusses how climate conditions may have influenced those trends. This report includes data that has been processed for fields not included in the 2021 report. Results showed yields on most treatment fields that increased from 2021, but still trended lower than on reference fields, although there was high variability between sites. Crude protein comparisons were also highly variable.

This study demonstrates that impacts to productivity of high elevation grasses can persist for multiple years after irrigation has been withheld, although these impacts are highly variable between fields, with some showing near complete recovery. It is possible that the negative impacts may be magnified if the year in which irrigation was withheld is particularly dry, as it was in 2020.

1. Introduction

Assessing the recovery of forage on high-elevation hay and pasturelands after a period of withheld or reduced irrigation is an important research topic because these lands account for a large portion of consumptive water use in the Upper Colorado River Basin (MWH Americas, Inc., 2012), which is becoming increasingly water stressed (Santos & Pantos, 2022). As programs that pay producers to temporarily withhold irrigation gain interest as a water sharing strategy, the multi-year impacts of irrigation reductions on high-elevation fields is a major concern expressed by potential participants (CWCB, 2020).

The limited amount of previous research on the topic indicated that yields on grass forages may be significantly impacted by withholding irrigation, often for multiple years. Jones (2015), for example, documented an average 49% yield reduction in the first year of full irrigation after a year of withheld irrigation and then effective recovery to pre-restriction conditions in the second year of full irrigation in a study of 6 fields across Western Colorado. Building on that previous work, this study concentrated on fields in the Upper Colorado River Basin near Kremmling, Colorado, where a similar program was adopted. The objective is to acquire additional data to support broader conclusions on how field conditions in this elevation zone (~ 7,000 ft MSL), are affected by withheld and reduced irrigation. This is an interim report, capturing data through 2022. The study will continue through 2023.

In this report, recovery is assessed in terms of yields and quality, using data collected from areas previously identified as having higher and lower hay production. Where possible, data are reported separately for these production levels, as well as averaged across entire fields. This report also reviews trends in productivity and quality in both treated and reference fields over the course of the project to date and discusses how climate conditions may have influenced those trends.

2. Materials and Methods

For this report, we assessed data from four fields in the study area that were subjected to full irrigation withdrawal in 2020, one field that received no irrigation after June 15 in 2020, and five reference fields that were irrigated in accordance with conventional amounts and timing in 2020. Grasses in this region are largely Timothy (*Phleum pratense*) and 'Garrison' creeping meadow foxtail (*Alopecurus arundinaceus* Poir.). Along with Smooth bromegrass (*Bromus inermis*), these species are typical in periodically inundated and well sub-irrigated conditions. Continued analysis identified sedges (*Carex* genus), rushes (*Juncus* spp.), and spikerushes (*Eleocharis* genus) that are typical in saturated soil profiles where irrigation flooding occurs dominantly during the season. Previous reporting (Carlson et al., 1991) has detected wild barleys (*Hordeum* species), clover (*Trifolium*), Tufted hair (*Descharysia*), red top (*Agrostis*), and bluegrass (Poa annua) although our analysis has not located the presence of these species yet.

This report focuses on forage data collected at sub-field locations where instruments accompanying other objectives of the project were also installed. These sub-field locations are described in Table 2.1 using an alpha-numeric code based on the ranch name and research condition (i.e., reference or treatment). For example, GPR R1 designates the 3-letter code for the ranch, 1-letter designation for R or T (Reference = conventional irrigation or Treatment = irrigation restriction), and 1-number designation for field name.

Table 2.1. Sites evaluated for CU and CCU in Kremmling, CO			
Site Name	**Irrigation Practice**	**Acres**	**Hectares**
BJM T1 2020	Full season, no irrigation	31.3	12.7
GPR T1 2020	Full season, no irrigation	203.7	82.4
GPR T2 2020	Full season, no irrigation	344.9	139.6
HSR T1 2020	Full season, no irrigation	83.6	33.8
JLM T1 2020	Full season, no irrigation	15.8	6.4
RCR T1 2020	Split Season, no irrigation after June 15	36.7	14.9
RSR T1 2020	Split Season, no irrigation after June 15	122.8	49.7
SBR T1 2020	Full season, no irrigation	70.2	28.4
SBT T1 2020	Full season, no irrigation	9.1	3.7
SPR T1 2020	Full season, no irrigation	220.6	89.3
	Total Treatment Sites	**1138.7**	**460.8**
GPR R1 2020	Reference, historical irrigation	94.5	38.2
RCR R1 2020	Reference, historical irrigation	226.8	91.8
RSR R1 2020	Reference, historical irrigation	20.1	8.1
SBR R1 2020	Reference, historical irrigation	28.5	11.5
SPR R1 2020	Reference, historical irrigation	30.0	12.1
	Total Reference Sites	**400.0**	**161.9**

Some fields were further divided into sub-locations that the landowners identified as either “high” or “low” producing in terms of yield, designated by H and L, respectively, based on rancher knowledge from previous years’ harvest. At several locations, a small area (~ 10 ft diameter) was enclosed by cow panels to protect instrumentation that was measuring evapotranspiration and maintain an undisturbed patch of grass. Forage samples were taken from within enclosures, and at least three random samples were taken around each enclosure to calculate average yields. Samples were taken using standardized methods (Jones, 2015) at monthly intervals in 2020, the year during which project fields experienced fully curtailed or reduced irrigation, and in 2021, when all fields were irrigated normally.

Samples within and around the enclosures were materially similar unless the field was grazed. Therefore, yield averages were calculated as composites of all samples, except in rare instances when fields were unexpectedly grazed. In these cases, only yield data from within the enclosures was used, noted by italicization in the tables below.

The samples were dried and weighed and were results converted to tons/acre of dry matter forage productivity for each sub-field location at the time of sampling. Several forage quality parameters were also analyzed, although this publication reports solely on crude protein as percentage of dry matter biomass or simply crude protein content - a measure commonly used by producers. Following weighing, individual samples were ground through a Thomas Model 4 Wiley® Mill (Philadelphia, PA) with a 2 mm screen followed by a Foss™ Tecator Cyclotec Sample Mill Model 1093 (Eden Prairie, MN) with a 2 mm screen to homogenize the sample.

3. Results

As was previously reported, forage productivity on fields with fully withheld irrigation was uniformly well below that on reference fields during the year (2020) when irrigation was reduced or completely withheld, while in the first year (2021) of return to typical irrigation practices, the results were more diverse.

3.1 Yield and Quality in Second Year of Normal Irrigation Following Restriction (2022)

In 2022, the second year in which irrigation resumed fully for all fields, yields on the water-limited fields averaged higher than in 2021, but tended to be lower than yields on the reference fields that had been irrigated continuously. There continued to be large differences between how different treatment fields compared to their reference fields, with July yields on treated fields where irrigation had been fully withheld in 2020 ranging from 2.7% to 61% below yields on reference fields.

Yields on fields where irrigation was withdrawn after July 15 fared better in comparison to their reference fields, with yields ranging from 7% below to 27% above yields on reference fields. July crude protein levels on the fields where irrigation was fully withdrawn in 2020 were also highly variable, ranging from 33.2% below to 45.3% above crude protein levels on their reference fields, with higher crude protein levels corresponding to lower yields. Results were similar for the fields where irrigation was withdrawn after July 15 in 2020.

Table 3.1.1 Grass Forage Impact of Full Irrigation Curtailment in 2020 on Yield and Crude Protein in 2022 under Normal Irrigation

		Low Production Areas						High Production Areas (or full fields, if not divided.)					
Site	Date	Ref T/ac	Trt T/ac	**Yield Diff**	Ref CP%	Trt CP%	**CP Diff**	Ref T/ac	Trt T/ac	**Yield Diff**	Ref CP%	Trt CP%	**CP Diff**
BJM	June							1.60	1.61	0.6%	15.12	11.77	-22.2%
	July*							**3.66**	**2.58**	**-29.5%**	9.93	10.48	**5.5%**
GPR 1	June	1.38	0.65	-52.9%	20.03	14.83	-26.0%	1.60	0.63	-60.6%	15.12	14.22	-6.0%
	July	**3.39**	**3.3**	**-2.7%**	**11.73**	**8.77**	**-25.2%**	**3.66**	**3.40**	**-7.1%**	**9.93**	**6.64**	**-33.2%**
GPR 2	June	1.38	0.86	-37.7%	20.03	9.74	-51.4%	1.60	0.92	-42.5%	15.12	16.13	6.7%
	July	**3.39**	**2.43**	**-28.3%**	11.73	12.79	**9.1%**	**3.66**	**2.49**	**-32.0%**	9.93	8.34	**-16.0%**
HSR	June							1.60	3.36	110.0%	15.12	10.20	-32.6%
	July							**3.66**	**3.53**	**-3.6%**	9.93	7.74	**-22.1%**
JLM	June							1.60	3.11	94.4%	15.12	12.19	-19.4%
(reseeded)	**July**							**3.66**	**4.64**	**26.8%**	9.93	8.25	**-16.9%**
SBR	June	1.33	0.84	-36.8%	19.71	21.62	9.7%	2.47	0.37	-85.0%	16.77	21.03	25.4%
	July	**1.89**	**1.44**	**-23.8%**	11.34	13.35	**17.7%**	**3.21**	**1.25**	**-61.1%**	9.51	13.81	**45.3%**
SBT	June							1.60	1.52	-5.0%			
	July							**3.66**	**1.73**	**-52.7%**			

* The same reference field is used for BLM, GPR 1&2, HSR JLM and SBT.

**July samples are highlighted, because they correspond most closely to when hay is typically harvested.

Table 3.1.2 Grass Forage Impact of Partial Irrigation Curtailment in 2020 (Curtailed after July 15) on Yield and Crude Protein in 2022 under Normal Irrigation

		Low Production Areas						High Production Areas (or full fields, if not divided)					
Site	Date	Ref T/ac	Trt T/ac	**Yield Diff**	Ref CP%	Trt CP%	**CP Diff**	Ref T/ac	Trt T/ac	**Yield Diff**	Ref CP%	Trt CP%	**CP Diff**
RSR	June	0.44	0.50	13.6%		13.74		0.63	0.46	-27%	12.79	13.43	5.01%
	July	**2.84**	**2.64**	**-7.0%**	9.18	9.52	**3.7%**	**2.2**	**2.67**	**21%**	8.67	7.78	**-10.29%**
RCR-1	June							0.59	0.79	34%	14.41	10.38	-28.01%
	July							**1.16**	**1.47**	**27%**	10.67	7.59	-28.89%

3.2 Comparing Yields Across Study Years

Data on July yields in each of the study years for both reference and treatment fields for which we have the most complete data sets are shown in Table 3.2 and Figure 3.2.

As noted previously, a very clear difference was observed between 2020 yields on treatment and reference fields, with irrigation-limited fields uniformly showing yields upwards of 70% below reference fields. Average July yields in 2020 for reference and treatment fields were 3.10 and 0.27 T/c, respectively, with a paired two-sample t-test for means calculated at $p < 0.01$.

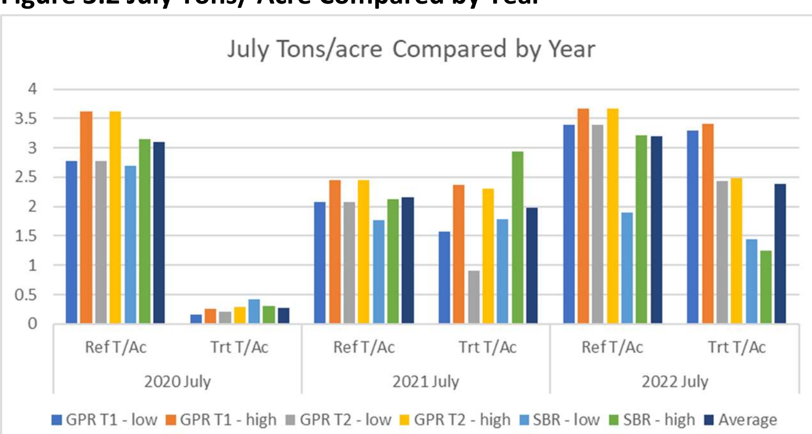
In 2021, reference field yields were lower than in 2020, likely reflecting very dry conditions at the end of 2020, while the treatment fields exhibited substantial recovery, albeit inconsistently. Average July yields in 2021 were 2.16 T/ac ($\sigma^2 = 0.07$) and 1.98 T/ac ($\sigma^2 = 0.51$) for reference and treatment fields, respectively. For 2021, the variance on the treatment fields was considerably higher, likely owing to local conditions that allowed some fields to exhibit greater recovery during this particular year. The paired two-sample t-test for means produced a p-value = 0.27 demonstrating the variance of the recovery on the irrigation-limited fields.

In 2022, the reference field yields were larger than in 2021, and the treated field yields were also generally above what they were in 2021, but lower than for the reference field yields. Average July yields in 2022 were 3.20 T/ac ($\sigma^2 = 0.44$) and 2.39 T/ac ($\sigma^2 = 0.81$) for reference and treatment fields, respectively. Despite variances of the reference and treatment yields, a paired two-sample t-test for means produced a p-value < 0.05.

Table 3.2 July Tons/ Acre Compared by Year

	2020 July		2021 July		2022 July	
Site	Ref T/Ac	Trt T/Ac	Ref T/Ac	Trt T/Ac	Ref T/Ac	Trt T/Ac
GPR T1 - low	2.77	0.16	2.07	1.57	3.39	3.3
GPR T1 - high	3.62	0.26	2.45	2.37	3.66	3.4
GPR T2 - low	2.77	0.21	2.07	0.9	3.39	2.43
GPR T2 - high	3.62	0.29	2.45	2.31	3.66	2.49
SBR - low	2.69	0.42	1.76	1.79	1.89	1.44
SBR - high	3.14	0.3	2.13	2.93	3.21	1.25
Average	3.10	0.27	2.16	1.98	3.20	2.39

Figure 3.2 July Tons/ Acre Compared by Year



4. Discussion

In 2022, the second year in which treated fields were returned to full irrigation, yields on the treated fields were on average higher than they were in 2021, but still tended to be lower than yields on the reference fields. The average yields on the treated fields for 2020, 2021 and 2022 were 91.2%, 8.2%, and 25.5% lower than the average yields on the reference fields.

The first year of this study, when irrigation water was withheld from treatment fields, was extremely dry, with water year precipitation of only 64% of average, and July, August and September monthly, precipitation of 28%, 23% and 9% of average, respectively (Colorado Climate Center). Because of these conditions and despite being irrigated in accordance with typical practices, reference fields effectively experienced water stress. The resulting average yield decline of 32% that appeared in the following year (2021) may therefore reflect the carryover effects of the late 2020 soil moisture deficit. Failing to account for this reduction in yields on the reference fields, and solely comparing treatment vs reference yields, could lead to an exaggerated impression of the level of recovery on treated fields in 2021. These drier conditions may also have intensified the impacts of withholding irrigation from the treatment fields on both 2020 yields and subsequent recovery. Under different local weather conditions, it is likely that the impacts of withholding irrigation from water-stressed fields on both immediate and subsequent yields would be less. The impact of effective precipitation in the year in which irrigation is withdrawn on subsequent recovery will be a useful area for further investigation.

The high variability of reference vs. treatment yield and crude protein measures two years following irrigation withdrawal or reduction also points to a need for further study to gain insight into potential determining factors, which could include distance to groundwater, species mix, soil type or other variables.

5. Conclusions

This study demonstrates that significant impacts to productivity of high elevation grasses can persist for multiple years after irrigation has been withheld, although these impacts are highly variable between fields, with some showing near complete recovery. It is possible that the negative impacts on some fields may be magnified if the year in which irrigation was withheld is particularly dry, as it was in 2020, when treatment fields underwent full or partial season irrigation withdrawal.

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