BENEFITS AND IMPACTS OF PARTIAL SEASON IRRIGATION ON ALFALFA PRODUCTION

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ABSTRACT

Prolonged drought and increasing demand for water resources has caused growing concern over Colorado's ability to fulfill legal water obligations as identified in the Colorado River Compact. A Western Slope Water Bank, which would entail agricultural water users entering into short-term leases and temporarily withholding or reducing irrigation, could be a partial solution to free up water to fulfill these obligations. Alfalfa (*Medicago sativa* L.) hay may be ideal for inclusion in a water bank as it is one of the primary users of agricultural water in this region and may have a greater ability to withstand water stress in comparison to other crops. This study was conducted to determine effects of implementing partial season irrigation on lower elevation alfalfa hayfields on forage yield, nutritional quality, and associated recovery. A total of 6 established alfalfa fields were subjected to irrigation treatments including normal irrigation (REF), irrigation stopped later (low-risk) in the growing season, and irrigation stopped early (high-risk) in the growing season for 2 consecutive years. All fields then received consistently full irrigation in the third and final year. In the final study year of recovery evaluation, average 1st cutting yield on control, low-risk and high-risk plots was 2279, 2524, and 2869 kg ha^{-1}). Similarly, during the fully irrigated recovery year, 2nd cutting yield on control, low-risk and high-risk plots was 2616, 2392, and 2794 kg ha^{-1}. Third cutting yields on control, low-risk and high-risk plots was 2298, 2392, and 2357 kg ha^{-1}. Total fiber concentrations (aNDF) were greatest in the control at 34.6% and lowest in SA1 plots at 28.2%. By the 2nd cutting, SA1 plots had the highest digestibility (IVTD) at 80%, and by the 3rd cutting, SA2 and SA1 plots were equally greater than the control (80 vs. 75%). Effects on CP content were inconsistent. These results suggest that reduced irrigation may improve forage quality slightly, but will significantly reduce yields. When irrigation is returned the following year, alfalfa yields may fully recover depending on length and severity of reduced irrigation. Due to its ability to recover, using partial season irrigation treatments on alfalfa hayfields may be a practical approach to make water available to a Western Slope Water Bank.

Key Words: partial-season irrigation, water banking, alfalfa forage quality

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APPROACHING WATER BANKING IN COLORADO

This project incorporated sites that are currently under study for the Colorado River Water Bank Workgroup (CRWBWG). Water banking is a strategy to facilitate water sharing arrangements, whereupon water is "banked" in storage for later use. There is not currently a water bank in Colorado, although CRS Title 37 under "Water and Irrigation" (§37-80.5-104.5) contains provisions stating "[u]pon request by a water conservancy district or water conservation district, the state engineer shall promulgate program rules necessary or convenient for the operation of a water bank within the division in which such district is located." The statute contains a notable limitation that "[t]he rules shall authorize, facilitate, and permit the lease, exchange, or loan of **stored water** within a water division." and that "[t]he **banks** shall operate within existing requirements of Colorado water law … including specifically the requirement that water transferred through the banks be put to a **beneficial use**." (emphasis added).

The CRWBWG supports a water bank approach for targeted locations on the Western Slope as part of demand management contingency planning to prevent Lake Powell from declining below minimum power levels. Guided water banking could prevent shortages under the Colorado River Compact or allow Colorado water users to weather regional shortages. A water banking approach would cooperate with agricultural and other water users to implement voluntary, interruptible supply agreements, making water available on a temporary basis.

The total amount of irrigated land and water supply on the West Slope that could occasionally sustain limited irrigation (and therefore potentially participate in water banking) has been assessed previously as part of the Colorado River Water Bank Phase I Feasibility Study (Natural Resources Consulting Engineers, 2012). One aspect of this assessment suggested a focus on irrigated alfalfa (*Medicago sativa*) fields, of which a total of over 90,000 acres exists in Colorado's portion of the Upper Colorado River basin. The focus on alfalfa is justified by the fact that this crop constitutes a large fraction of the agricultural water use on the West Slope, grown in concentrated regions of irrigated agriculture, and can withstand occasional limited irrigation in some areas without significant long-term effects. Other studies have similarly evaluated alfalfa under irrigation curtailment regimes, whereby water applications were to be suspended by the first day of certain calendar months (Ottman et al., 1996; Hanson et al., 2007). Consistent with other studies (Orloff et al, 2005), this study imposed irrigation curtailment regimes congruent with the cutting dates chosen by the farmer.

ON-FARM FIELD STUDIES

This study was conducted at established alfalfa hayfields on the Western Slope of Colorado. Site selection criteria was heavily geared towards farmer willingness to engage in side-by-side plots irrigated for a full season as a reference (REF), along with two partial-season irrigation treatments. The study was undertaken in two separate phases, first in 2013-2015 and then in 2015-2017. These timeframes corresponded to Phase II-B and Phase II-C of the CRWBWG project. Phase II-B and

Phase II-C were located in regions of varying climate (Table 1). The Fruita and Yellow Jacket sites were located at Colorado State University research centers. Each site produced 3 to 4 cuttings of hay each year. Gated pipe furrow irrigation systems were used at Fruita, Loma, and Eckert (II-B). Center pivot and sideroll sprinkler systems were used at Yellow Jacket (II-B) and Yellow Jacket (II-C), respectively. Concrete lateral furrow irrigation with some gated pipe was used at Eckert (II-C).

Table 1. Characteristics of CRWBWG Phase II-B and II-C Western Slope alfalfa study sites.

Location	County	Elev.	Annual Precip.	Growing Season*	Cuttings	Area	Dominant Soil	Irrigation
		(*m*)	(*mm*)	(*days*)		(*ha*)		
Fruita	Mesa	1,380	223	173	4	0.81	silty clay loam	furrow
Loma	Mesa	1,434	234	184	4	8.27	silt loam	furrow
Eckert (II-B)	Delta	1,697	318	166	3	3.48	loam	furrow
Eckert (II-C)	Delta	1,678	318	166	3	6.51	loam	furrow
Y. Jacket (II-B)	Montezuma	2,103	407	136	3	6.07	loam	sprinkler
Y. Jacket (II-C)	Montezuma	2,120	407	136	3	11.22	loam	sprinkler

* Growing season length estimated using the *Western Regional Climate Center* freeze-free (-2.2˚C) season probabilities.

In general, the irrigation regimes were defined by producer tendency towards risk, so not all regimes were identical across sites, although all study fields were divided into equal aliquots. Phase II-B sites received irrigation corresponding to a fully-irrigated reference (REF), irrigation stopped after the 1st cutting (SA1), and irrigation stopped after the 2nd cutting (SA2). The SA2 and SA1 regimes were considered "low-risk" and "high-risk." Treatments SA1 and SA2 continued for 2 years (2013-2014). Phase II-C sites were more contrasted, after conversations with farmers as to what approaches they would favor under a water leasing arrangement. In Eckert (II-C), irrigation corresponded to REF control, irrigation stopped after the 2nd cutting (SA2), and waiting until after 1st cutting (WA1) to irrigate. Yellow Jacket (II-C) followed the SA1 and SA2 regime. Fields in Loma had irrigation corresponded to REF control, irrigation stopped after the 2nd cutting (SA2), and irrigation stopped after the 3rd cutting (SA3). Treatments continued for 2 years (2015-2016). Plots were fully irrigated in 2015 and 2017.

Ten samples for yield and quality samples were collected prior to hay harvest at each site. Yield samples were collected using a 0.25 m² frame, hand clipped at 7.5 cm to simulate approximate cutter-bar height. Plant material was dried in a forced-air oven at 55°C for 72 hours. Dry weights were then converted to kilograms per hectare. 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 for quality analysis.

Ground samples were used to determine neutral detergent fiber (aNDF), in vitro true digestibility (IVTD), and crude protein (CP) concentration, for each treatment. Each of the 10 samples from all treatments was used to determine aNDF. One duplicate, blank, and standard (mixed cool-season grass hay) bag were included in each set of 24 samples that were run through an Ankom® 200 fiber analyzer (ANKOM Technology, Macedon, NY). To determine IVTD, 4 samples were randomly selected from each set and duplicates of these samples were tested. Rumen fluid was collected from 2 rumen fistulated steers that were being fed a mixed forage and corn diet. Samples were incubated in a Daisy II Incubator (ANKOM Technology, Macedon, NY) using the in vitro true digestibility method (Method 3). Crude protein content was measured using a LECO TruSpec® CN268 Elemental Combustion Analyzer (LECO Corp., St. Joseph, MI) to determine nitrogen content. All 10 samples from every treatment were analyzed. Crude protein was estimated by multiplying percent nitrogen by a factor of 6.25. If there were insufficient amounts of sample available for measurement, the initial 10 were combined into no less than 4 samples.

FORAGE YIELDS

Partial season irrigation treatments not surprisingly reduced plant growth and yields relative to the irrigated control. In the 1st cutting of year 2, REF plot yields averaged 3243 kg ha^{-1}, while the "low-risk" and "high-risk" plots averaged 2839 and 2262 kg ha^{-1} after a single year of stress. These results are supported by previous reports (Carter and Sheaffer, 1983; Halim et al., 1990; Hattendorf et al., 1988; Lindenmayer, 2008; Peterson et al., 1992).

Alfalfa yields were largely positive once fields were returned to full irrigation after two seasons of partial-season irrigation (Tables 2a, 2b, 2c, 2d). In the final year of recovery, average 1st cutting yield on REF, low-risk and high-risk plots was 2279, 2524, and 2869 kg ha^{-1}. Similarly, during the fully irrigated recovery year, average 2nd cutting yields on control, low-risk and high-risk plots was 2616, 2392, and 2794 kg ha^{-1}. Average third cutting yields on control, low-risk and high-risk plots was 2298, 2392, and 2357 kg ha^{-1}. The general trend was for alfalfa yields to improve in a fully-irrigated year of recovery after stress (Figure 1). A minor exception of the low-risk 2nd cutting yield, can be explained by a relatively low yield at the Yellow Jacket site in the recovery year on the low-risk plot. In a number of the evaluations, it was observed that some of the fields on which irrigation was curtailed showed improved yields once these fields were returned to full irrigation. This work supports the findings of others who reported yield recovery of alfalfa subjected to partial season water stress (Lindenmayer, 2008). Extensive alfalfa tap roots are notable in their ability to tap deep soil moisture to maintain production under high levels of water stress (Hattendorf et al., 1988). Alfalfa has also been observed to react to water stress by accumulating total nonstructural carbohydrates in plant roots (Ottman et al., 1996).

Average plot-relative yield changes from year 2 to year 3 on REF, low-risk and high-risk fields was -26.6%, 13.6% and 27.8%, respectively, for the 1st cutting. A student's T-test identified the yield increases from the "low-risk" and "high risk" irrigation regimes as having a probability of 7.5 and 4.2% due to chance. In other words, a relatively significant probability exists that stopping irrigating after the 1st cutting can lead to yield increases during the year after stress. Slightly lower, but still significant probability exists that stopping after 2nd cutting is positive.

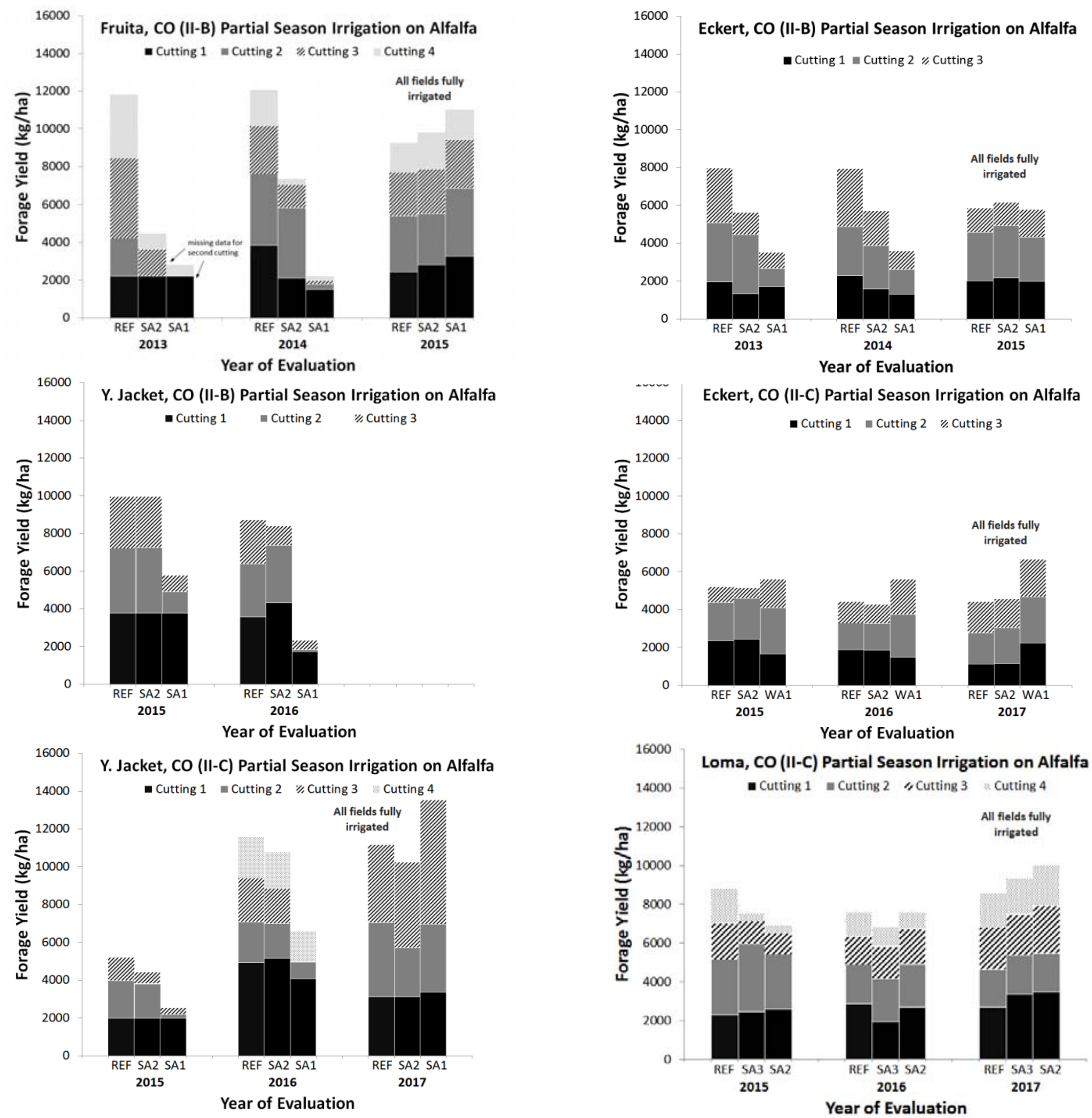

Figure 1. Forage yields (kg/ha) of alfalfa fields under irrigation regimes for Western Slope of Colorado.

Table 2a. Forage recovery (% relative to same year REF - **Cutting 1**) under different patterns of irrigation CRWBWG Phase II-B and II-C Western Slope alfalfa study sites (Cuttin

Location	Year and Irrigation Treatment Regime											
	2014		2015		2016†		2017†		2016		2017	
	SA2	SA1	SA2	SA1	SA2	SA1	SA2	SA1	SA2	WA1	SA2	WA1
Fruita (II-B)	-45%	-60%	15%	34%								
Eckert (II-B)	-31%	-43%	7%	-1%								
Y. Jacket (II-B)	21%	-52%										
Loma (II-C)					-32%	-7%	25%	30%				
Eckert (II-C)									-2%	-22%	2%	99%
Y. Jacket (II-C)					5%	-17%	0%	8%				

† Irrigation regime for Loma, CO was SA3 and SA2, rather than SA2 and SA1. Due to a producer mistake, the Loma, CO field intended for SA3 had to be modified. This field experienced SA2 by mistake, but was irrigated in the fall to contrast with other SA2.

Table 2b. Forage recovery (% relative to same year REF – **Cutting 2**) under different patterns of irrigation CRWBWG Phase II-B and II-C Western Slope alfalfa study sites.

Location	Year and Irrigation Treatment Regime											
	2014		2015		2016†		2017†		2016		2017	
	SA2	SA1	SA2	SA1	SA2	SA1	SA2	SA1	SA2	WA1	SA2	WA1
Fruita (II-B)	-1%	-93%	-8%	20%								
Eckert (II-B)	-12%	-49%	8%	-8%								
Y. Jacket (II-B)	8%	-96%										
Loma (II-C)					8%	11%	1%	1%				
Eckert (II-C)									1%	62%	16%	48%
Y. Jacket (II-C)					-15%	-59%	-34%	-8%				

† Irrigation regime for Loma, CO was SA3 and SA2, rather than SA2 and SA1

Table 2c. Forage recovery (% relative to same year REF – **Cutting 3**) under different patterns of irrigation CRWBWG Phase II-B and II-C Western Slope alfalfa study sites.

Location	Year and Irrigation Treatment Regime											
	2014		2015		2016†		2017†		2016		2017	
	SA2	SA1	SA2	SA1	SA2	SA1	SA2	SA1	SA2	WA1	SA2	WA1
Fruita (II-B)	-53%	-92%	3%	14%								
Eckert (II-B)	-40%	-68%	-3%	12%								
Y. Jacket (II-B)	-55%	-78%										
Loma (II-C)					15%	25%	-2%	14%				
Eckert (II-C)									-11%	66%	-6%	22%
Y. Jacket (II-C)					-19%	-100%	10%	60%				

† Irrigation regime for Loma, CO was SA3 and SA2, rather than SA2 and SA1

Table 2d. Forage recovery (% relative to same year REF – **Cutting 4**) under different patterns of irrigation CRWBWG Phase II-B and II-C Western Slope alfalfa study sites.

Location	Year and Irrigation Treatment Regime											
	2014		2015		2016†		2017†		2016		2017	
	SA2	SA1	SA2	SA1	SA2	SA1	SA2	SA1	SA2	WA1	SA2	WA1
Fruita (II-B)	-84%	-88%	24%	1%								
Eckert (II-B)												
Y. Jacket (II-B)												
Loma (II-C)					-16%	-29%	9%	19%				
Eckert (II-C)												
Y. Jacket (II-C)					-11%	-23%						

† Irrigation regime for Loma, CO was SA3 and SA2, rather than SA2 and SA1

Although these evaluations were largely concerned with the SA1 and SA2 treatments of irrigation curtailment, a few minor points should be made regarding the other irrigation regimes evaluated. For instance, due to a participant mistake of curtailing irrigation after 2nd cutting on both treatment fields at the Loma site in 2015, it was necessary to modify an irrigation regime. The decision was made to irrigate the intended SA3 field once before winter, in order to create some contrast with the intended SA2 field. The modified SA2 field (irrigation before winter) actually exhibited a 32% decline, versus the intended SA2 field that experienced only a 7% decline. The WA1 field in Eckert also provided some interesting, albeit anecdotal observations. During the 2nd and 3rd study years, the WA1 field exhibited strong growth in the 2nd and 3rd cuttings. Specifically, WA1 fields in the recovery year yielded at 99%, 42% and 22% higher than the companion REF field for cuttings 1, 2 and 3. One interesting possibility for this occurrence was the lack of alfalfa weevil pressure on WA1 in early season, due to diminished stand height.

FORAGE QUALITY

Forage quality results are based only on the Phase II-B sites sampled in 2013 and 2014. Forage quality generally increased with partial season irrigation treatments as indicated by reduced total fiber content as measured by neutral detergent fiber (aNDF) and increased digestibility as measured by in vitro true digestibility (IVTD) (Tables 3 and 5). Generally, water stress and other factors that stunt plant growth result in higher quality forage while factors that hasten growth result in reduced quality (Mueller and Orloff, 1994). In this study, quality tended to be lowest in the 2nd cutting in regards to increased aNDF and decreased IVTD which was likely due to higher temperatures resulting in an increased rate of lignification (Putnam and Ottman, 2013). Increased growth observed in this cutting may have also contributed to reduced quality.

Neutral detergent fiber (aNDF)

Based on results from this part of the study, fiber concentrations were affected by irrigation treatment (P=0.0900) and differed between cuttings (P=0.0111) (Table 3). Fiber concentrations were lowest in SA1 plots and greatest in the control ranging from 27.9 to 33.9%. Enhanced quality is likely due to delayed maturity resulting in a greater leaf-to-stem ratio and finer stems (Lindenmayer, 2008; Peterson et al., 1992). Our results also indicated a relationship between fiber content and cutting.

Table 3. Neutral detergent fiber (aNDF) and crude protein (CP) concentrations of alfalfa from hayfields in western Colorado under full and partial season irrigation treatments of stopping irrigation after the 2nd cutting and stopping irrigation after the 1st cutting.

	aNDF (%)	*CP (%)*
Treatment^{+}		
Irrigated Control (REF)	33.9 ^{a*}	27.4 ^{a}
Stop after 2nd (SA2)	31.0 ^{ab}	26.6 ^{a}
Stop after 1st (SA1)	27.9 ^{b}	27.2 ^{a}
Cutting^{+}		
1	29.9 ^{b}	27.0 ^{a}
2	33.8 ^{a}	23.9 ^{b}

3	29.1 [b]	25.8 [b]

⁺Means averaged over years 1 and 2 due to no interaction with year (P=0.2240 for aNDF and 0.2639 for CP).
*Means followed by the same letter within a column and variable are not significantly different at the P=0.15 level.

When averaged over all treatments, aNDF was greatest in the 2nd cutting with equally reduced concentrations of 15% in the 1st and 3rd cuttings. Similarly, when testing alfalfa for relative feed value (RFV), Lindenmayer (2008) observed lower quality in the 2nd cutting. Increased growth, plant maturity, management, and environmental factors may have contributed to the reduced quality observed in the 2nd cutting.

Crude Protein (CP)

An inconsistent response in CP was observed as demonstrated by the year by cutting interaction (P=0.0288) (Table 2). In year 1, when averaged across all treatments, CP content was greatest in the 1st cutting. The 2nd and 3rd cuttings were similar with 13 and 15% lower CP contents, respectively. In year 2, the 2nd cutting generally had the lowest CP content with a value similar to the previous year. In year 2, CP content was 10% lower in the 1st cutting and 7% higher in the 3rd cutting resulting in similar values. Averaged over both years, CP was greatest in the 1st cutting (Table 4). Differing protein concentrations were likely due to plant maturity at harvest and environmental factors. No relationship between CP content and irrigation treatment was observed. The relationship between water stress and protein content in alfalfa has been inconsistent in the literature. Many have also reported no relationship, (Carter and Sheaffer, 1983; Halim et al., 1989; Hanson et al., 2007; Vough and Marten, 1971) while others have reported mixed findings of both increasing and decreasing forage protein content (Halim et al., 1990; Peterson et al., 1992; Vough and Marten, 1971). In contrast, others have reported greater CP content with reduced water availability (Walgenbach et al., 1981; Gifford and Jensen, 1967). Inconsistent results may also be caused by differences in nitrogen fixation capabilities in plants (Carter and Sheaffer, 1983; Antolin et al., 1995).

Table 4. Interaction effect of year by cutting on crude protein (CP) content of alfalfa from hayfields in western Colorado.

	CP (%)	
	Year 1	Year 2
Cutting		
1	28.6 [Aa*]	25.6 [Ba]
2	24.4 [Ab]	23.3 [Ab]
3	24.8 [Ab]	26.8 [Ba]

*Means with the same lowercase letter within a year, or uppercase letter within a cutting do not differ significantly at the P = 0.15 level.

In vitro true digestibility (IVTD)

Digestibility as measured by IVTD demonstrated a treatment by cutting interaction (P=0.1214), but generally increased with increasing water stress (Table 5). In the 1st cutting, irrigation treatments did not differ. By the 2nd cutting, SA1 plots were highest in digestibility averaging 6% greater than the control. By the 3rd cutting, the lowest digestibility occurred in the control with SA2 and SA1 plots being equally greater (5%). The control demonstrated the highest digestibility in the 1st cutting at 79% and lowest in the 2nd cutting at 74.3%. Likewise, SA2 plots had the lowest digestibility in the 2nd cutting at 74.4% with cuttings 1 and 3 being similar with an average of 81.2%. SA1 plots maintained similar values throughout all cuttings, averaging 79.2%. While response of alfalfa digestibility to water stress is inconsistent in the literature, our results are consistent with many previous reports (Snaydon, 1972; Vough and Marten, 1971). Carter and Sheaffer (1983) found that digestibility increased under severe, prolonged water stress, but did not differ with moderate stress and determined this was not related to leaf-to-stem ratio. In contrast, Buxton (1996) reported moderate stress resulted in increased digestibility and severe stress reduced digestibility due to greater leaf loss. Conflicting results may be due to plant maturity at harvest and varying environmental factors. Harvest dates in this study were commonly delayed due to weather. Alfalfa quality can decline significantly by delaying harvest only a few days (Buxton, 1996).

Table 5. Interaction effect of irrigation treatment and cutting on in-vitro true digestibility (IVTD) of alfalfa from hayfields in western Colorado under full and partial season irrigation treatments of stopping irrigation after the 2nd cutting (SA2) and stopping irrigation after the 1st cutting (SA1).

	Treatment		
	Fully Irrigated	Stop after 2nd	Stop after 1st
Cutting 1	$79.0^{+\ Aa*}$	82.0^{Aa}	79.8^{Aa}
Cutting 2	74.3^{Bb}	74.4^{Bb}	80.4^{Aa}
Cutting 3	76.7^{Bab}	80.4^{Aa}	80.4^{Aa}

+Means averaged over years 1 and 2 due to no interaction with year (P=0.3906).
*Means followed by the same lowercase letter(s) in a column or uppercase letter(s) within a row do not differ significantly at the P = 0.15 level.

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