Strategies for Reducing Consumptive Use of Alfalfa

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Introduction

There is increasing competition for a limited water supply throughout much of the western U.S. Urban and municipal water users, declining groundwater levels, and drought are factors that are leading to reduced irrigation water quantities for large areas of agricultural land. As an example, Colorado's population is expected to grow about sixty-five percent in the next twenty-five years (Colorado Water Conservation Board, 2004). Most of this growth will occur in the corridor from Fort Collins to Colorado Springs, CO. As Colorado's population grows, water is expected to shift from agriculture to municipal and industrial uses. Estimates are as high as 400,000 acres of irrigated farmland that will dry up to meet changes in water supply and demand (Colorado Water Conservation Board, 2004). Changes in water allocation have important implications for the economic and environmental sustainability of agriculturally based economies. There is growing interested in the potential of limited irrigation in cropping systems as a means of addressing changing water supply and demand issues while maintaining profitable irrigated agricultural systems. Limited irrigation consists of applying water at rates lower than full ET demand by the crop. Such a practice requires managing crop water stress and depends on the ability to irrigate during critical crop growth stages. This paper outlines strategies for reducing consumptive water use of alfalfa through limited irrigation practices.

Background

There has been much work done in the past to determine the relationship between consumptive water use and alfalfa yield (Daigger, *et al*, 1970; Bauder *et al*, 1978; Retta and Hanks, 1980; Sammis, 1981; Guitjens, 1982; Carter and Sheaffer, 1983; Undersander, 1987; and Smeal *et al*, 1991) . Studies of alfalfa water use conducted across a range of climates and geographic areas in the U.S. illustrate a linear relationship of yield to ET with the slope of this line indicating alfalfa yield per unit of consumed water (Figure 1). The slope of this relationship is 0.18 tons/ac/in can also be interpreted that it requires an average of 5.6 in of ET per ton of alfalfa hay produced. This result corresponds well with a rule of thumb among Colorado irrigators that it takes 6" of water to produce a ton of hay. The data in Figure 1 illustrates that there is a lot of variability in the yield and ET relationship, resulting from the many factors that can affect alfalfa water use efficiency. One study (Undersander, 1987) compared the yield and ET relationships for individual hay cuttings across a growing season and found that the relationship changes depending on the cutting. In that study, the first and fourth cuttings had higher WUE than the middle two cutting. This makes sense because alfalfa is a C3 plant that is adapted to the cooler temperatures in the spring and fall cuttings, while loosing efficiency during the hotter summer cuttings. Thus, we hypothesized in our study that we would get the highest water use efficiency by focusing irrigation water to the early or late season growth.

Alfalfa is a good candidate crop for limited irrigation for several reasons. First, under full irrigation, alfalfa consumes large quantities of water during the growing season, leaving a large potential for water savings under limited irrigation practices. Second, alfalfa has drought tolerance mechanisms that make it biologically suited to deficit irrigation. Alfalfa is a deep rooted perennial crop with the ability to go into dormancy during drought. During dormancy, alfalfa limits above ground growth while storing energy for rapid growth from buds when water becomes available. This characteristic gives the irrigation manager flexibility to apply water during times when it is available and withhold water when it is in short supply. A third reason that alfalfa is suited for limited irrigation is the potential for managing irrigation in a way that promotes higher quality hay, partially offsetting yield reductions with potentially higher price for quality hay.

Objectives

The study objectives were to:

1. Quantify alfalfa growth responses and consumed water (ET) under full and limited irrigation regimes.
2. Evaluate alfalfa forage and stand quality under full and limited irrigation regimes.

Methods

The study was located at the Northern Colorado Water Conservancy District (NCWCD) headquarters in Berthoud, CO. Average rainfall at this site is 13-15 inches and the soil type is a clay loam. The elevation is about 5,000 feet above sea level. The water table is located about 20 ft. which was monitored using on-site observation wells. The study area is about 2.5 acres divided into twelve plots each measuring 290 ft. long by 51 ft. wide with a 15 ft. buffer separating each replicate. There were three replicates of four irrigation treatments and the treatments were randomized within each replicate. The plots were irrigated with a state-of-the-art linear sprinkler that had drop valves with solenoids controlled by GPS to automatically turn on and shut off sections of the sprinkler as it passed over the different plots. The irrigation water was ditch water supplied from a holding pond on the site. Dairyland Magna Graze alfalfa from AgLand was planted in August of 2004 and overseeded in 2005 to improve stand density.

Irrigation treatments began in 2006. The four irrigation treatments applied to the alfalfa crop were as follows:

> Full Irrigation (FI) – No water stress. Crop was irrigated to fully meet crop ET demands.
>
> Stop Irrigation After 2nd Cutting (S2) – Crop was irrigated to meet ET demands through the 2nd cutting then received no irrigation for the rest of the season.
>
> Spring and Fall Irrigation (SF) – Crop was irrigated to meet ET demands through the 1st cutting, was terminated, and was resumed after 3rd cutting to meet ET demands during the 4th cutting.
>
> Stop Irrigation After 1st Cutting (S1) – Crop was irrigated to meet ET demands through the 1st cutting then received no more irrigation for the rest of the season.

Yields samples were collected by weighing a 20 ft. section of windrow. Sub-samples from the large sample were taken to determine percent dry matter as well as for forage quality analysis. Dry matter was determined by drying the sample to 0% moisture in an oven at 105°C until no weight change was detected. Once dry matter was determined, that percentage was applied to the total fresh weight and then extrapolated to a full acre. Forage subsamples were ground and analyzed for protein content and fiber digestibility by standard methods and quality analysis was used to compute relative feed value.

ET was determined using a water balance method. This method balances all of the water inputs and losses according to the following formula:

$$ET = \Delta\Theta + I(Irr.Eff.) + P - R - D$$

Where:

$\Delta\Theta$ is the change in soil moisture during a period of time (ie: cutting).
I is the amount of irrigation applied.
(Irr. Eff.) is an irrigation efficiency factor (95%).
P is the amount of precipitation.
R is run-off (assumed to be zero)
D is the deep percolation (also assumed to be zero)

The $\Delta\Theta$ value was determined at greenup and after each harvest period by taking soil samples down to 8 feet in 1 foot increments. The samples were weighed wet, then oven-dried at 105°C until no weight change was detected, then weighed dry to determine the moisture in each foot. The moistures for each foot were summed to get an 8 foot profile total. Run-off was assumed to be zero because the irrigations were small (~0.75 in) and the plots were fairly flat. Deep percolation was also assumed to be zero because of the small irrigations, the heavy soil type being able to hold large amounts of moisture, and the deep root system of alfalfa. Stand density was assessed in April 2007 by counting the crowns/ft^2 by randomly sampling in each plot four times to get and average stand density.

Results and Discussion

Alfalfa yields were responsive to irrigation level, decreasing with reductions in irrigation amount. The average total season yields for 2006 were 8.2, 6.4, 5.9, and 3.6 tons ac^{-1} for the FI, S2, SF, and S1 irrigation treatments, respectively (Figure 2). It should be noted that the individual average fourth cutting yields for the FI and SF treatments were almost the same even after two months of water stress in the SF treatment indicating the ability of alfalfa to recover after severe water stress within the growing season. The average total season yields for 2007 were 8.5, 7.9, 7.7, and 6.9 tons ac^{-1} for the FI, S2, SF, and S1 treatments, respectively (Figure 2). It should be noted that the average first cutting yields for 2007 were virtually the same for all four treatments, even after one growing season of water stress for the limited irrigation treatments illustrating again the ability of alfalfa to recover from severe water stress across growing seasons. Also, the average fourth cutting yields for the FI and SF treatments were again similar. Individual cutting yields can also be compared for both years in Figures 3 and 4. Over the two years of the study, with 2006 being a dry year and 2007 being a more average year in terms of precipitation, the average yields were 8.4, 7.2, 6.8, and 5.3 tons ac^{-1} for the FI, S2, SF, and S1 treatments respectively.

The average total season ET values for 2006 were 26.6, 15.6, 15.1, and 10.0 inches for the FI, S2, SF, and S1 treatments, respectively (Figure 3) with only 3.7 inches coming from precipitation. Irrigation amounts were 24.0, 12.0, 11.5, and 3.6 inches for the FI, S2, SF, and S1 treatments, respectively. Also, on average, 1.1 inches of soil moisture was stored in the profile in the FI treatment, 0.1 inches were stored in both the S2 and SF treatments, and 2.7 inches of moisture were extracted from the soil profile in the S1 treatment. These results illustrate that alfalfa will utilize moisture from the soil profile to a greater degree under limited irrigation. This moisture depletion has been accounted for in the ET reported in this study. In 2007 the average total season ET values were 34.4, 23.4, 24.7, and 17.9 inches for the FI, S2, SF, and S1 treatments, respectively (Figure 3) with 11.9 inches contributed by precipitation. Irrigation amounts were 21.3, 9.5, 10.4, and 2.7 inches for the FI, S2, SF, and S1 treatments, respectively. On average, 1.2 (FI), 2.0 (S2), 2.4 (SF), and 3.3 (S1) inches of soil moisture were extracted from the soil profile. The average ET values for both years were 30.5, 19.5, 19.9, and 14.0 inches for the FI, S2, SF, and S1 treatments, respectively. When looking at the change in soil moisture it seems strange that during 2006, the drier year, that moisture was actually stored in some treatments. This may be caused by the alfalfa going into dormancy longer in 2006 than in 2007 and using less water in general and therefore storing some in the soil. The exception is the S1 treatment in 2006 where soil moisture was still used. This may have happened because the alfalfa was in dormancy so long and so little water was applied through irrigation and precipitation that it eventually had to use some from the soil. In contrast, soil moisture was used from profile across all treatments in 2007, perhaps because the alfalfa was more actively growing and was supported by timely precipitation keeping it from going completely dormant.

Water use efficiency (WUE) is reported here as a measure of the amount of hay produced per unit of water consumed (Figure 4). The WUE values for 2006 were 0.31 (FI), 0.41 (S2), 0.39 (SF), and 0.39 (S1) tons ac^{-1} in^{-1}. This data shows that alfalfa under the limited irrigation system uses water more efficiently than under furrow irrigation. A similar trend was observed in 2007, where WUE was 0.26 (FI), 0.33 (S2), 0.31 (SF), and 0.39 (S1) tons ac^{-1} in^{-1} (Figure 4). While these WUE values for individual treatment seem high compared to the literature, when all yield and ET data on a seasonal basis are regressed, the slope of that relationship is 0.234 and 0.116 tons ac^{-1} in^{-1} for 2006 and 2007 with an average slope of 0.185 tons ac^{-1} in^{-1} for both years, which matches very well with the average relationship found in the literature (Figure 1).

The stand density assessment yielded some interesting and, at first, counter-intuitive results. Random sampling found that there were a higher number of crowns per square foot in the S1 and S2 treatments than in the FI and SF treatments (Figure 5). One of the main factors that reduces alfalfa plant density is disease. Perhaps, because the limited irrigation treatments have a drier microclimate in the canopy there is less disease pressure acting on the plants and therefore, preserving the stand. The late season irrigation applications must also have an effect to decrease the crown density in the SF treatment, but it is not understood yet.

Summary and Conclusions

The findings of this study have potentially important implications for alfalfa producers with limited irrigation water supply. Over the two years of the study, an average 11.0, 10.6 and 16.5 ac-in of ET water were saved in the S2, SF, and S1 treatments, respectively, relative to fully irrigated alfalfa. These ET reductions resulted in yield reductions of 1.2, 1.6, 3.1 tons ac^{-1} in the S2, SF, and S1 treatments, respectively. However, as ET declined, WUE increased, indicating more efficient use of water by the crop. For alfalfa producers faced with decreasing irrigation water supplies, this is encouraging. Economically speaking, as production decreases, so should most input costs resulting in only a slightly reduced return per acre. On the other hand, if irrigation water is not limiting but limited irrigation strategies are still employed to conserve water for lease to municipalities to supplement farm income, the enterprise would increase in profitability depending on the market price of water. Currently, water rights cannot be partially leased but there is current debate in the state of Colorado that could lead to allowing such transactions in the future.

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Tables and Figures

Table 1. Average seasonal consumptive water savings of limited irrigation alfalfa relative to fully irrigated alfalfa and the corresponding yield reduction. Results are the average values for 2006 and 2007.

Treatment	**Seasonal Consumptive Water Savings (ET ac-in)**	**Seasonal Yield Reduction (tons/ac)**
Full Irrigation	0	0
Stop Irr. After 2nd	11.0	1.2
Spring and Fall Irr.	10.6	1.6
Stop Irr. After 1st	16.5	3.1

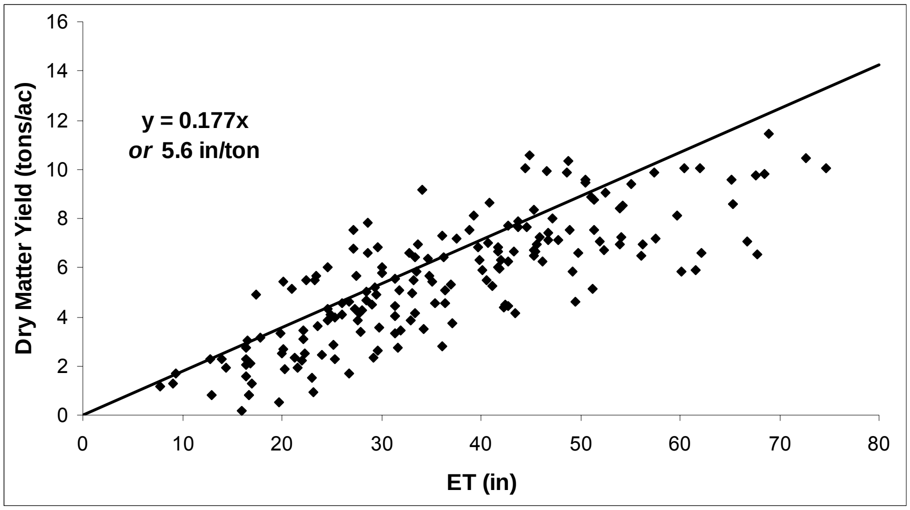

Figure 1. Alfalfa yield response to evapotranspiration (ET) as summarized from published studies (Daigger et al, 1970; Bauder et al, 1978; Retta and Hanks, 1980; Sammis, 1981; Guitjens, 1982; Carter and Sheaffer, 1983; Undersander, 1987; and Smeal et al, 1991). To avoid skewing the fit line towards one study, points were weighted so that indidual study sites are equal in importance, regardless of the number of data points from that site.

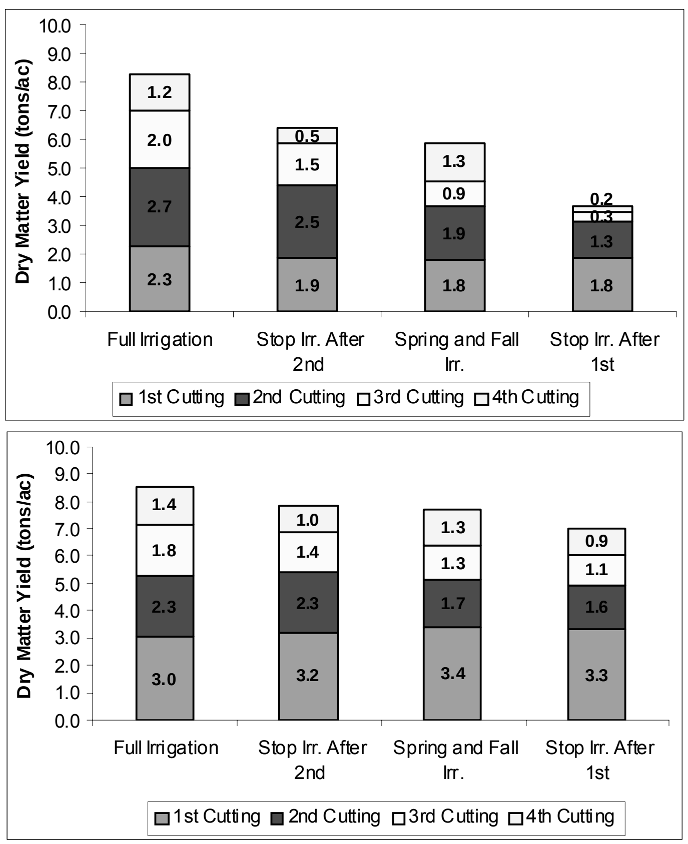

Figure 2. Alfalfa yields as affected by irrigation treatments for 2006 (upper) and 2007 (lower) seasons at Berthoud, Colorado.

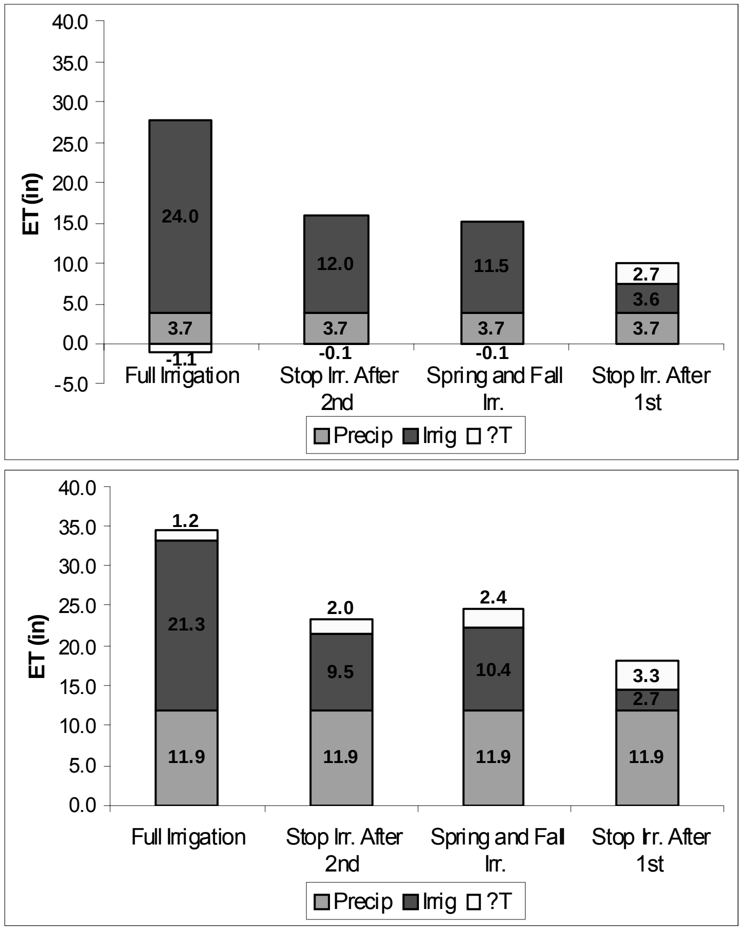

Figure 3. Consumptive water use (ET) from alfalfa as affected by irrigation treatments for 2006 (upper) and 2007 (lower) seasons at Berthoud, Colorado. ET is reported by contribution from precipitation, irrigation, and the use or storage of moisture in the soil profile.

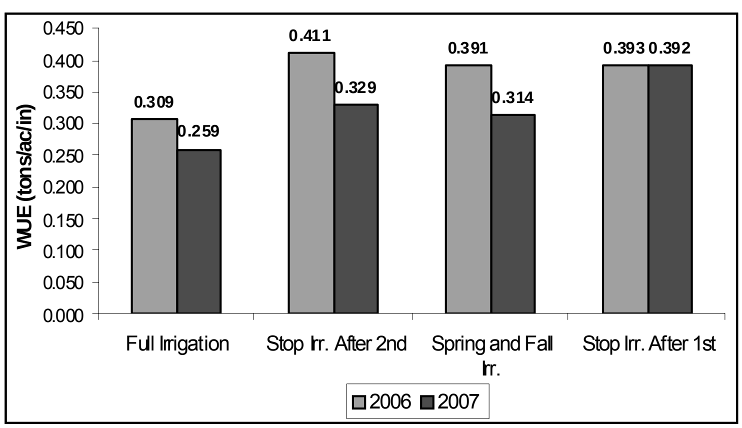

Figure 4. Water use efficiency (WUE) for alfalfa as affected by irrigation treatments for 2006 and 2007 seasons at Berthoud, Colorado.

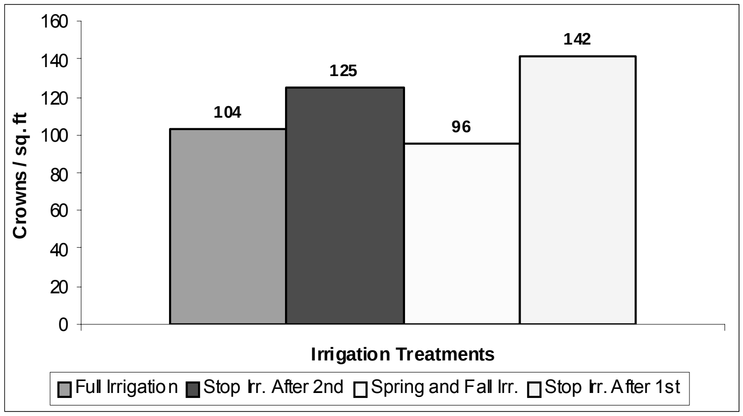

Figure 5. Alfalfa crown density measured in the spring of 2007 to determine the effect of 2006 irrigation treatments on stand at Berthoud, Colorado.