

Strategies for Reducing Alfalfa Consumptive Water Use

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Abstract. As competition builds for water resources in the Western U.S., limited irrigation strategies for crop production are emerging to conserve agricultural water for other uses or as a way to continue to produce crops under reduced water allocations. Alfalfa is a crop with potential for water savings in a limited irrigation system. The objective of this study was to evaluate potential water saving strategies for alfalfa on the Front Range of Colorado. A field study evaluated four irrigation strategies: Full Irrigation (FI), Stop Irrigation After 2nd Cutting (S2), Spring and Fall Irrigation (SF), and Stop Irrigation After 1st Cutting (S1). Changes in yield, consumptive water use (ET), water-use efficiency (WUE), stand density, and forage quality were measured. Results of the study showed that yield decreased with ET in a fashion similar to previous research. Over the two year period, average yields were reduced by 3.1, 3.5 and 6.5 Mg ha⁻¹ compared to the FI treatment for the S2, SF, and S1 treatments, respectively. Average ET was reduced by 28.2, 27.2, 48.2 cm compared to the FI treatment for the S2, SF, and S1 treatments, respectively. WUE increased as irrigation decreased with an average WUE of 0.251, 0.327, 0.311, and 0.351 Mg ha⁻¹ cm⁻¹ for the FI, S2, SF, and S1 treatments, respectively. Also, the number of crowns m⁻² was higher in the S2 and S1 treatments compared to the FI and SF treatments. Finally, forage quality increased as ET decreased, which may help economically offset the reduced yield. The limited irrigation of alfalfa is an approach to conserve agricultural water to meet changing water demand while still keeping an irrigated agricultural system in production.

1. Introduction

There is increasing competition for a limited water supply throughout much of the western U.S. Increasing competition from 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 65% in the next 25 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 will shift from agriculture to municipal and industrial uses. An estimated 400,000 acres of irrigated farmland could be dried up to meet future needs (Colorado Water Conservation Board, 2004). Changes in water allocation have important implications for the economic and environmental sustainability of agriculturally based economies. In other areas of the plains, declining groundwater is a bigger threat to irrigated agriculture. There is growing interest in the potential of limited irrigation in cropping systems as a means of addressing changing water supply and demand issues while still supporting profitable agricultural systems. Limited irrigation practices apply water at rates lower than full ET demand by the crop, manage crop water stress, and focus irrigation during critical growth stages. A partial de-watering of irrigated lands that seeks to maintain a profitable level of productivity for farmers while conserving water resources for other uses is being studied as a way to create balance among water users. This paper outlines strategies for reducing consumptive water use of alfalfa.

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2. 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). We evaluated published research on alfalfa water use across a range of climates and geographic areas in the U.S. stretching from Minnesota and Nebraska to New Mexico and Utah and from North Dakota to Texas (Figure 1). The relationship of yield to ET is linear, with the slope of this line indicating an average yield of $0.156 \text{ Mg ha}^{-1} \text{ cm}^{-1}$ (5.6 in ton^{-1}). 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, caused by factors such as climate variation, pest damage, and harvest method and timing. Both spatial and seasonal climatic variation 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 (Fig. 3). 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 and loses efficiency during the hotter summer cuttings. We hypothesized that alfalfa water use efficiency in a limited irrigation system would be improved by applying the limited irrigation only during times with higher seasonal WUE rather than applying reduced amounts of irrigation throughout the entire growing season.

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, thus leaving a large potential for water savings through limited irrigation practices. Second, alfalfa has drought and water stress tolerance mechanisms that make it biologically suited to limited irrigation. For example, alfalfa is a deep rooted perennial crop with the ability to go into dormancy during drought periods. During dormancy, alfalfa limits above ground growth while storing energy for rapid growth 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 limited irrigation supplies in a way that promotes higher quality hay, partially offsetting yield reductions with a higher sale price.

3. Objectives

The objectives of the study were to:

1. Quantify alfalfa yield, consumed water (ET), water-use efficiency, and forage and quality under full and limited irrigation regimes.
2. Evaluate alfalfa stand density under full and limited irrigation regimes.

4. Methods

The study site was located at the Northern Colorado Water Conservancy District (NCWCD) headquarters in Berthoud, CO. The long term average annual rainfall at this site is 36 cm and the soil texture is a clay loam. The elevation is 1,500 m and the water table was located at about 6.1 m, which was monitored using on-site observation wells. The study area was about 1 hectare divided into twelve plots each measuring 88.4 m long by 15.5 m wide with a 4.6 m buffer separating each replicate. There were three replicates and four irrigation treatments were

randomized within each replicate. The plots were irrigated with a 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 was planted in August of 2004 and overseeded in 2005 to establish a 92% stand. Irrigation treatments began in 2006 and 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 and received one more pass of the sprinkler after then resumed irrigation 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.

The hay was harvested on the same day regardless of irrigation treatment. The target harvest timing corresponded to a 10% bloom for the fully irrigated treatment. The limited irrigation treatments were generally observed to have a slightly higher percentage of bloom at that time. Yield samples were collected fresh by weighing a 6.1 m section of windrow (4.9 m swath width). Sub-samples from the yield sample were taken to determine percent dry matter as well as for forage quality analysis. Dry matter was determined by oven drying the sample to 0% moisture at 105°C. Once dry matter was determined, that percentage was applied to the total fresh weight and then extrapolated to a full hectare yield. Forage quality analysis was performed by an independent laboratory.

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 by taking soil core samples down to 2.4 m in 0.3 m increments. The samples were weighed wet, oven-dried at 105°C, then weighed dry. The difference in the weights determined the moisture in each 0.3 m increment. The moistures for each increment were summed to get a full 2.4 m profile total. Run-off was assumed to be zero because the irrigations were small (~2.0 cm) 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 also assessed in April 2007 by counting the crowns m^{-2} in four random samples in each plot to get an average stand density. Stand density is an indication of the health and quality of the alfalfa stand and was measured to evaluate whether dry conditions from limited irrigation would reduce the health of the alfalfa stand.

5. Results and Discussion

The average total season yields for 2006 were 18.3, 13.7, 13.3, and 8.8 Mg ha^{-1} for the FI, S2, SF, and S1 irrigation treatments, respectively (Figure 3). The ability of alfalfa to recover from severe water stress within the growing season is evidenced by almost equal 2006 fourth cutting yields in the FI and SF treatments even after two months of water stress in the SF treatment. The average total season yields for 2007 were 19.1, 17.7, 17.3, and 15.5 Mg ha^{-1} for the FI, S2, SF, and S1 treatments, respectively (Figure 4). The ability of alfalfa to recover from an entire season of water stress is illustrated by nearly equal first cutting yields in 2007 across all irrigation treatments. Also, the average fourth cutting yields for the FI and SF treatments were again similar in 2007. Individual cutting yields can be further compared for both years in Figures 3 and 4. Over the two years of the study, the average yields were 18.8, 16.1, 15.2, and 11.9 Mg ha^{-1} for the FI, S2, SF, and S1 treatments, respectively.

The average total season ET values for 2006 were 67.6, 39.6, 38.4, and 25.4 cm for the FI, S2, SF, and S1 treatments, respectively (Figure 5) with only 9.4 cm coming from precipitation. Irrigation amounts were 60.9, 30.6, 29.2, and 9.1 cm for the FI, S2, SF, and S1 treatments, respectively. Also, on average, 2.7 cm of soil moisture was stored in the profile in the FI treatment, 0.3 cm were stored in both the S2 and SF treatments, and 6.8 cm of moisture were extracted from the soil profile in the S1 treatment. In 2007 the average total season ET values were 87.4, 59.4, 62.7, and 45.5 cm for the FI, S2, SF, and S1 treatments, respectively (Figure 6) with 30.3 cm contributed by precipitation. Irrigation amounts were 54.1, 24.1, 26.3, and 6.9 cm for the FI, S2, SF, and S1 treatments, respectively. On average, 3.0 (FI), 5.0 (S2), 6.2 (SF), and 8.4 (S1) cm of soil moisture were extracted from the soil profile. The average ET values over both years were 77.5, 49.5, 50.5, and 35.6 cm 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.

The water-use efficiency (WUE) values for 2006 were 0.273 (FI), 0.363 (S2), 0.345 (SF), and 0.346 (S1) $\text{Mg ha}^{-1} \text{cm}^{-1}$ and 0.229 (FI), 0.290 (S2), 0.276 (SF), and 0.345 (S1) $\text{Mg ha}^{-1} \text{cm}^{-1}$ in 2007 (Figure 7). These values show a trend of increasing WUE values with decreasing ET levels. This may be due to the ability of the alfalfa plant to more effectively use water from the soil profile and also the ability of alfalfa to go dormant during water stress resulting in lower ET rates. This explains the higher WUE values in 2006, which had lower precipitation compared to 2007. While WUE values for individual treatment seem high compared to the WUE values

summarized from the literature, when all yield and ET data for both seasons on a total season basis are regressed, the relationship is comparable with a slope $0.156 \text{ Mg ha}^{-1} \text{ cm}^{-1}$ (Figure 8).

The stand density assessment yielded some interesting and, at first, counter-intuitive results. Random sampling found that there were, on average, a higher number of crowns per square meter in the S1 and S2 treatments than in the FI and SF treatments (Figure 9). One of the main factors that take plants out of a productive stand 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 yet understood.

Finally, forage quality, as measured by relative feed value (RFV) and crude protein (CP), changed with irrigation treatment. The trend without limited irrigation found in this study is for the first cutting to be relatively high in RFV, decrease during the second cutting, then increase during the third and fourth cuttings reaching a level higher than first cutting. CP increased from the first to the third cutting with a slight decrease during the fourth cutting. When limited irrigation was applied, the quality of the affected cuttings increased beyond what was expected for both RFV and CP. This may be due to finer stems and a higher leaf to stem ratio in the limited irrigation treatments resulting in higher forage quality. Also, 2006 had higher RFV valued compared to 2007, which may be a result of higher yields in 2007 causing a dilution effect.

6. Summary and Conclusions

The findings of this study have potentially very important implications for alfalfa producers. Over the two years of the study, on average 28.2, 27.2 and 42.2 cm of ET water were saved in the S2, SF, and S1 treatments, respectively (Table 1). These ET reductions resulted in yield reductions of 3.1, 3.5, 6.5 Mg ha^{-1} in the S2, SF, and S1 treatments, respectively (Table 1). 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 will input costs. Based on an initial economic comparison, the net income decreases with limited irrigation compared to full irrigation, but not to a level that would make limited irrigation alfalfa production unprofitable. As ET decreased, forage quality was found to increase enough to demand a higher sale price, which can help offset lost income from the reduced yields under limited irrigation. On the other hand, if irrigation water is not a limiting factor but limited irrigation strategies are still employed to conserve water for lease to municipalities to supplement farm income, the enterprise could increase in profitability depending on the market price of water. Currently, water rights cannot be partially leased but there is pending legislature in the state of Colorado that would allow such transactions and this research is critical to determine how such transactions will occur in the future.

Table 1. Effects of full and limited irrigation treatments on average (2006-2007) alfalfa seasonal consumptive water savings (ET) and seasonal yield

Treatment	Seasonal Consumptive Water Savings (ET cm)	Seasonal Yield Reduction (Mg/ha)
Full Irrigation	0	0
Stop Irr. after 2 nd	28.2	3.1
Spring and Fall Irr.	27.2	3.5
Stop Irr. After 1st	42.2	6.5

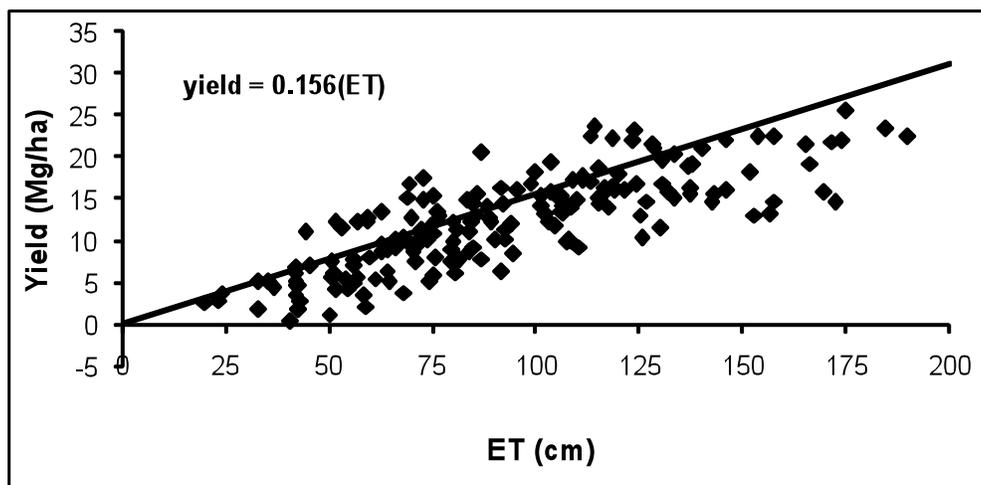


Figure 1. Alfalfa Yield Response to ET. Line based on previous studies with each study weighted equally (not each point. (Adapted from Daigger et al, 1970; Bauder et al, 1978; Retta and Hanks, 1980; Sammis, 1981; Guitjens, 1982; Carter and Sheaffer, 1983; Undersander, 1987; and Smeal et al, 1991)

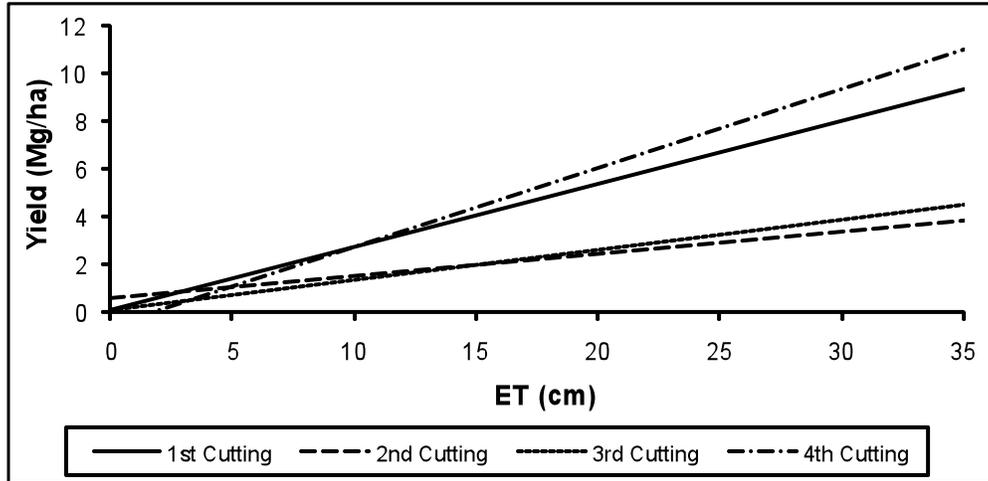


Figure 2. Seasonal climate effects on the relationship between alfalfa water use (ET) and yield (Adapted from Undersander, 1987).

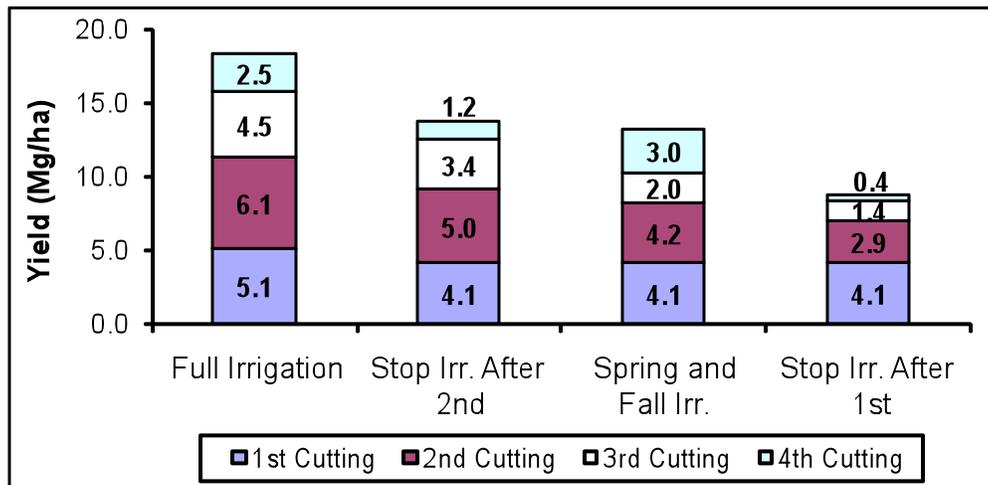


Figure 3. Effect of full and limited irrigation treatments on 2006 cutting and total season alfalfa yields.

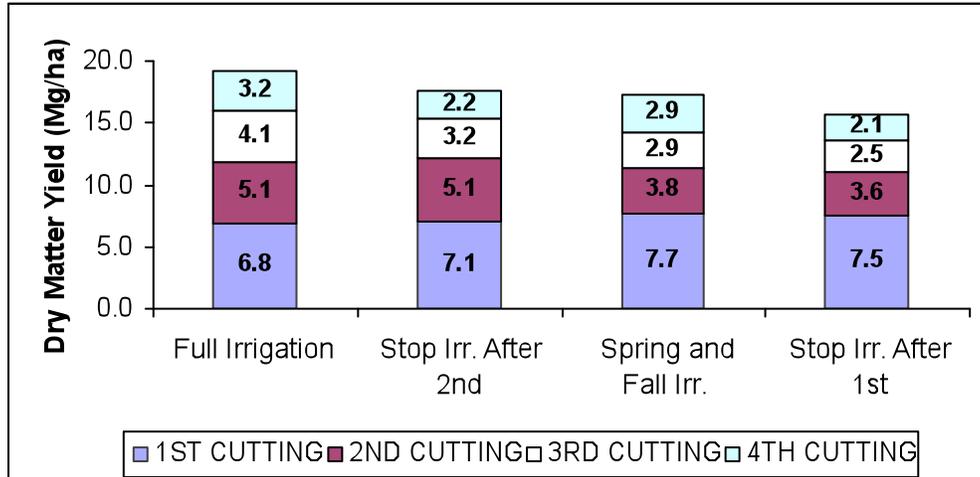


Figure 4. Effect of full and limited irrigation treatments on 2007 cutting and total season alfalfa yields.

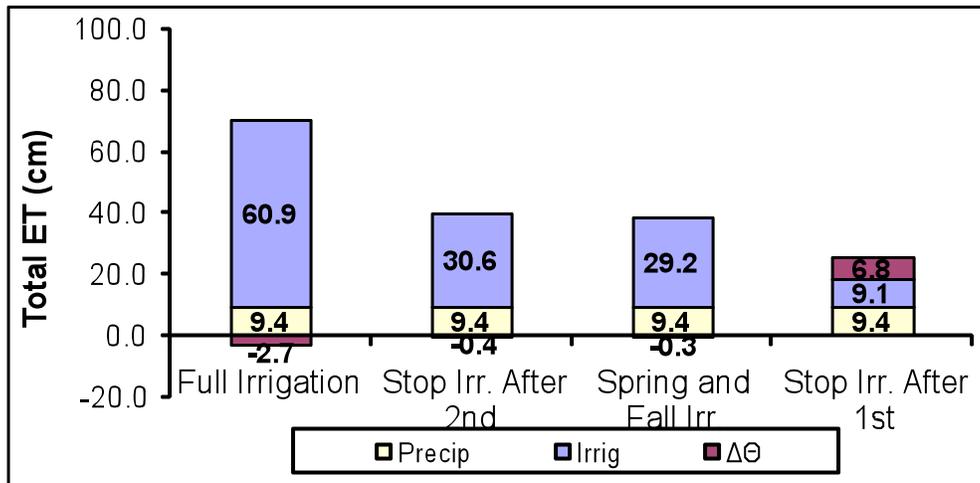


Figure 5. Effect of full and limited irrigation treatments on 2006 total season ET by contribution

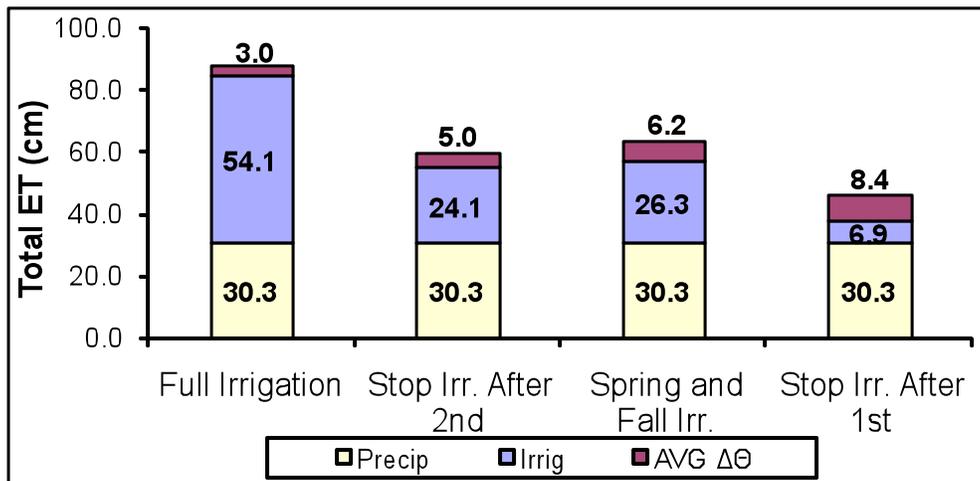


Figure 6. Effect of full and limited irrigation treatments on 2007 total season consumptive water use (ET) by contribution.

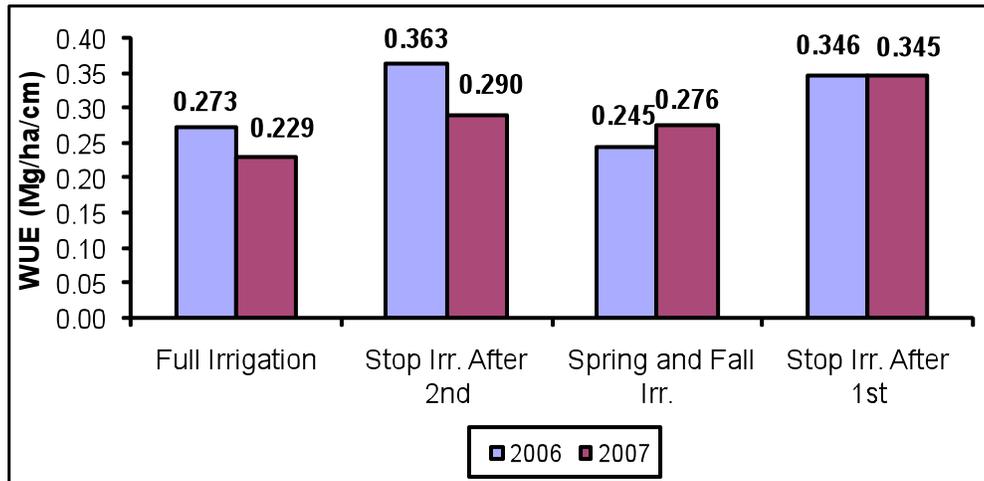


Figure 7. Effect of full and limited irrigation treatments on the average (2006-2007) total season water use efficiency (WUE).

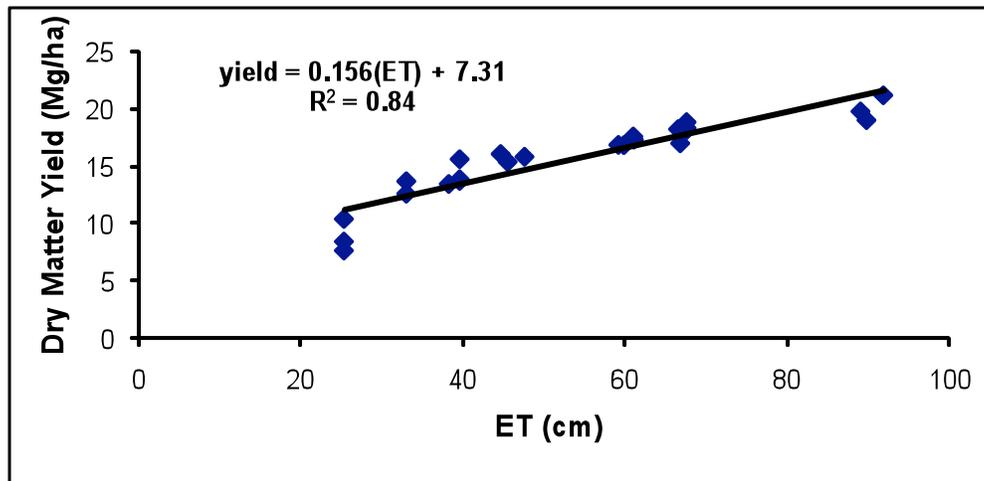


Figure 8. Relationship between alfalfa consumptive water use (ET) and dry matter yield for full and limited irrigation treatments in 2006 and 2007.

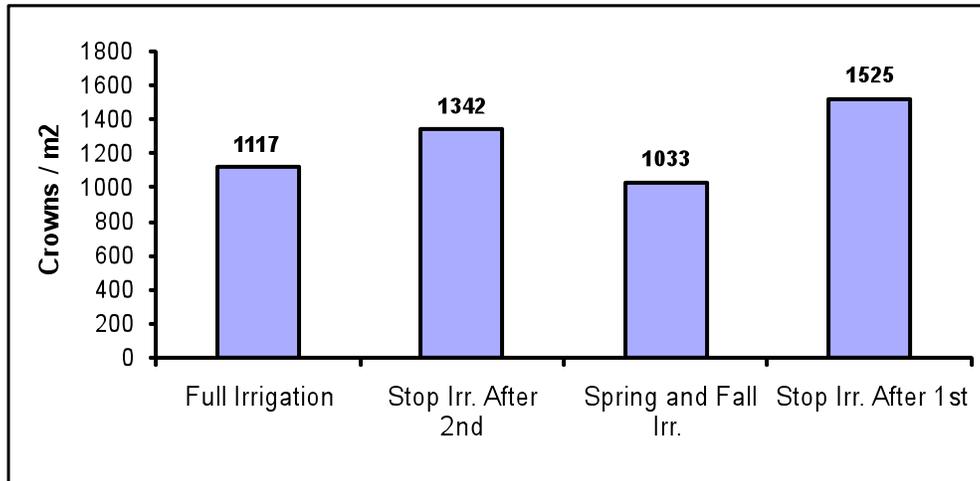


Figure 9. Effect of 2006 full and limited irrigation treatments on alfalfa crown density measured in the spring of 2007

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