Limited Irrigation of Alfalfa in the Great Plains and Intermountain West

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Introduction

Water available for irrigation in the Western United States is often limited, and in many cases, declining. Below-average snow pack, drought, interstate conflicts, restrictions on groundwater pumping, and declining groundwater from non-renewable aquifers have all contributed to declining water supplies for irrigation. These water shortages have been occurring in many western U.S. irrigated watersheds and groundwater basins to some degree for the past several years. Combined with water transfers from agriculture to municipal and industrial uses and increasing recreational and environmental demands for water, the relevance of irrigation management with limited water supplies has greatly increased.

This module is the third in a series of six training modules intended to build upon concepts and suggestions for limited-irrigation management, provide updates on research projects relevant to the topic of limited-water irrigation, and suggest further resources and techniques for managing irrigated cropping systems under limited water supplies. Readers unfamiliar with the concepts, terms and practices of limited irrigation management are encouraged to read the CEU module "Principles and Practices for Irrigation Management with Limited Water" before continuing with this module. Readers are referred to Lindemeyer et al., 2010 for a more complete review of literature supporting this module.

Alfalfa (*Medicago sativa L.*) is grown on 12% of irrigated land in the U.S. (National Agricultural Statistics Service, 2007) and due to its long growing season, alfalfa is a relatively high water-use crop (Stanberry, 1955; Broner and Schneekloth, 2003). Therefore, significant water savings can be realized by reducing irrigation on alfalfa (Putnam et al., 2005).

Alfalfa is a good candidate for limited irrigation for several reasons. First, alfalfa is a long-lived perennial, well adapted to dry climates, and alfalfa has the ability to enter dormancy under severe moisture stress conditions. Second, alfalfa has a deep root system that allows it to tap soil moisture reserves when irrigation is unavailable. Finally, once established, alfalfa doesn't have a single critical growing period that will dramatically reduce yield when moisture stress occurs, such as found with many grain crops. These traits give producers more management flexibility under limited water situations in adjusting water applications and harvest intervals to balance quantity and quality to suit their market and needs.

Alfalfa Evapotranspiration and Yield

Like most forage crops, alfalfa will respond to increasing evapotranspiration (ET) by increasing biomass yield. As expected, the yield response to ET is positive and linear. Figure 1 was produced from a review of nine studies of alfalfa under variable irrigation, which were conducted across the Great Plains from North Dakota to Texas (Lindemeyer et al., 2010). Climatic differences among these studies represented growing season ET under full irrigation ranging from 24.2 to 57 inches, with an average of 35.8 inches. (Table 1)

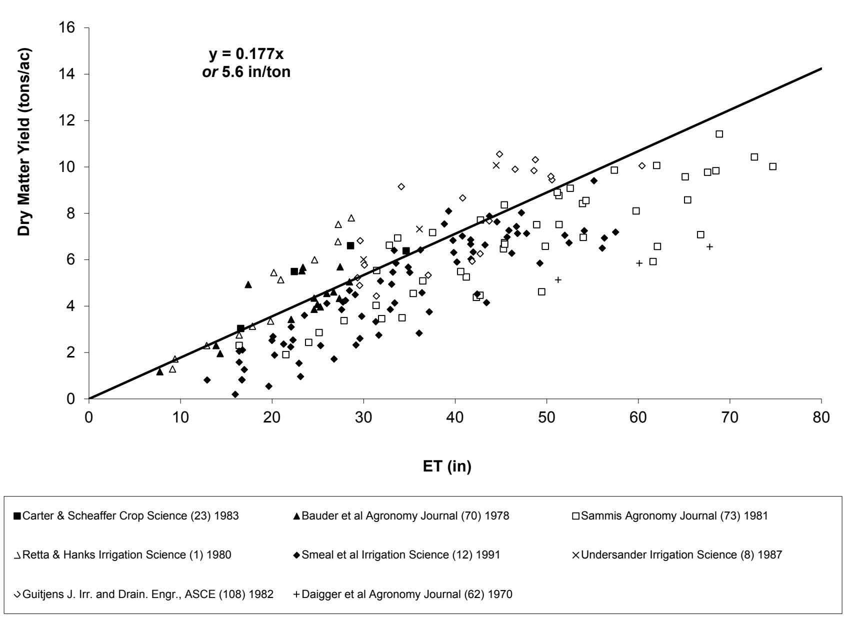

Figure 1. Season-long alfalfa biomass yield and evapotranspiration (ET), from studies with variable irrigation in the Great Plains and Inter-Mountain West of the United States. Each study (not each point) was weighted equally to create the regression line. The slope of the line represents a regional average water use efficiency (WUE) of 0.18 tons $acre^{-1}$ $inch^{-1}$.

Table 1. Average fully irrigated biomass yield and evapotranspiration for studies reviewed.

Author	Location	Fully Irrigated ET (inches)	Fully Irrigated Yield (tons acre^{-1})
Daigger et al., 1970	Nebraska	59.7	5.1
Bauder et al., 1978	N. Dakota	25.4	4.6
Retta and Hanks, 1980	Utah	24.2	5.56
Sammis, 1981	N. Mexico	57.0	9.8
Carter and Sheaffer, 1983	Minnesota	12.8	3.3
Undersander, 1987	Texas	44.4	10.0
Wright, 1988	Idaho	37.0	6.5
Smeal et al., 1991	N. Mexico	42.0	6.6

Using this ET data and biomass yield, the water use efficiency (WUE) under different environments and watering regimes can be calculated. For the purposes of this paper, WUE was calculated as biomass yield per acre divided by the ET reported in the articles. The studies reviewed reported an average yield of 0.18 tons of hay per acre inch of ET (tons acre^{-1} inch^{-1}), but varied widely from 0.09 to 0.26 tons acre^{-1} inch^{-1}. Keep in mind that this is not the actual water applied or precipitation, but ET from the field. The total amount of water required would be greater, when efficiency of the irrigation system is factored in.

Because WUE is defined as production per unit of water, it can be used as a good guideline to assess potential management practices under limited irrigation practices. Therefore, we will use WUE for the remainder of this article to discuss seasonal deficit, variety, harvest timing, and stand age as factors to be considered in assessing potential practices for limited water.

Seasonal Deficit Irrigation

In general, applying less than the amount of water required to match the full rate of ET of alfalfa will cause a reduction in WUE. (Figure 2) This type of reduction has proven to be consistent over a wide range of environmental conditions, including places as warm and dry as New Mexico and even cooler, humid environments such as Minnesota. Water use efficiency also changes from harvest to harvest throughout the season. Studies from Texas (Undersander, 1987), Nebraska (Daigger et al., 1970), Idaho (Wright, 1980) and New Mexico (Smeal et al., 1991) found that WUE was highest with the first cutting and decreased among subsequent harvests later in the growing season. (Table 2) Comparatively cooler temperatures during the spring growing season, than later in the season during subsequent harvest periods, help explain why alfalfa, a cool season crop, would produce more per unit of water use during this time period than during subsequent warmer growing periods. However, the final cutting, usually resulting from growth during cooler, late summer and fall periods, did not have WUE similar to the spring harvest periods.

Two factors, sunlight and the physiology of alfalfa, help explain differences in WUE between the spring and fall. First, the amount sunlight, as measured by solar irradiance (S_d), is greater in the spring than in the fall. Biomass yield per unit of

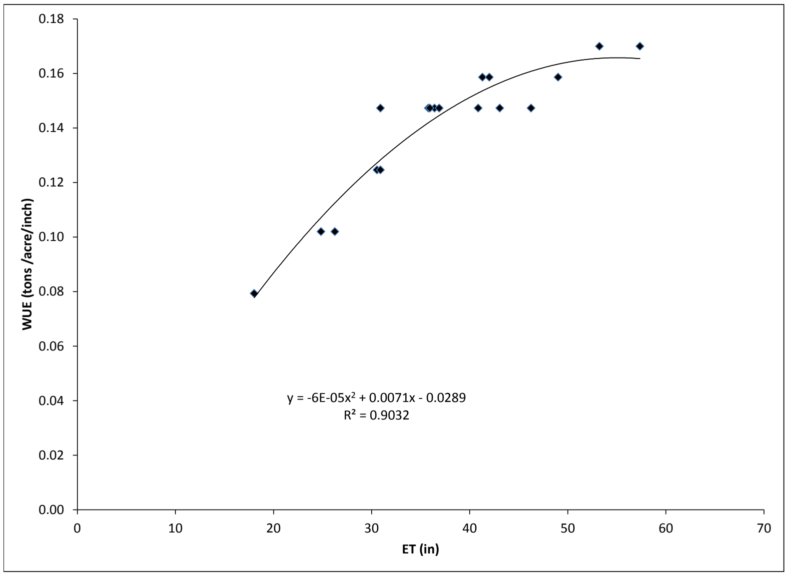

Figure 2. Alfalfa water-use efficiency (WUE) relationship to evapotranspiration (ET) from two deficit irrigation studies in New Mexico (Sammis, 1981 and Smeal et al., 1991).

Table 2. Average water use efficiency (WUE) for increasing number of harvests per season (harvest intervals) from studies in the Great Plains and Inter-mountain West. Average WUE across irrigation treatments and years.

Harvest Interval*	Water Use Effciency (tons^{-1} acre inch^{-1})
1	0.20
2	0.15
3	0.15
4	0.17
5	0.15

*Average from Bogler and Matches, 1990; Daigger, et al., 1970; Undersander, 1987; Wright, 1988; Smeal et al., 1991;

ET increases with S_d up to a maximum level, after which additional sunlight causes yield to plateau or actually decline (Smeal et al. 1991). High light intensity and relatively low temperatures occur only in the spring, contributing to high levels of photosynthesis and low levels of evaporation. But light can be a limiting factor to alfalfa growth in the fall (Figure 3). Thus, harvest intervals corresponding to the greatest WUE occur when solar irradiance is high enough to induce high levels of photosynthesis and temperatures are low enough to keep evaporation at a minimum, such as the first harvest in the spring (Delaney et al., 1974; Leavitt et al., 1979).

Higher WUE during the spring is also explained by carbohydrate reserve flux in the alfalfa plant. Early in the growing season, growth partially depends upon carbohydrate reserves accumulated during the previous fall (Smith 1962, Robinson and Massengale, 1968). After the first harvest, photosynthesis in new leaves produces carbohydrates for growth and restoration of root reserves. Shortened day length and temperature declines during the late summer and early fall result in greater amounts of photosynthate partitioning into root reserves, resulting in lower biomass yield and WUE than in the spring (Hanson et al., 1988).

These observations suggest that concentrating irrigation during the spring, when WUE is the highest, and limiting or withholding water during hotter periods of the growing season, when WUE is lower, may be an approach to efficiently using irrigation water, while also saving water. This approach, referred to as irrigation termination or partial season irrigation, may improve WUE more than limiting irrigation uniformly through-out the growing season. Partial season irrigation was used to reduce the amount of irrigation water applied to alfalfa in the Klamath Basin and Sacramento Valley of California by Putman et al. (2005) with few long term impacts to alfalfa stand. However, in areas with sandy soils and more arid, hotter climates, summer termination of irrigation can reduce alfalfa stands and yield after irrigation is resumed (Ottman et al, 1996), but evidence suggests minimal stand loss in semi-arid environments with finer soil textures (Hansen and Putnam, 2000).

Variety

Drought tolerance and WUE are often different among varieties of many crops. However, there is little published evidence to show that differences in drought tolerance and WUE exist among alfalfa varieties. Researchers in Utah (Retta and Hanks, 1980), Texas (Undersander, 1987) and Washington (Hattendorf et al, 1990) applied varying amounts of water to alfalfa varieties with different fall dormancy ratings, using line-source irrigation methods. None of these researchers reported significant

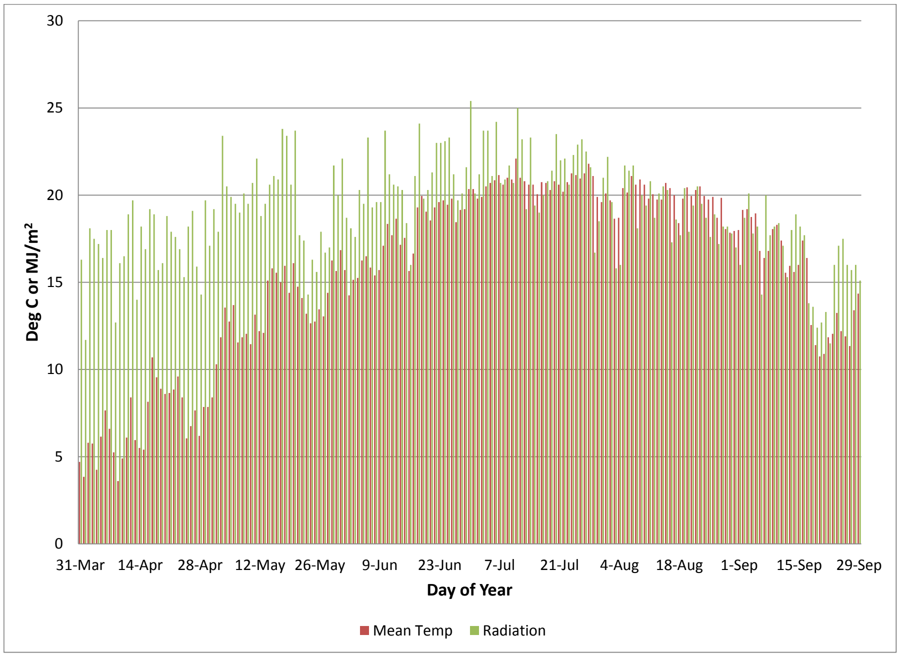

Figure 3. Comparison of average daily temperature to solar radiation from Fort Collins, Colorado.

differences in biomass yield or WUE among different varieties receiving the same amount of water. Another researcher in California (Grimes et al., 1992) found small differences in WUE among varieties during spring and summer seasons, but not across the entire growing season. Therefore, variety selection is not likely to significantly influence either biomass production or WUE for alfalfa under seasonal-long limited irrigation. Less is known about differences in performance of different varieties under partial season irrigation, where water is withheld during less productive time periods, as described above.

Varietal characteristics that should be carefully considered for deficit irrigation include disease and insect resistance. Water stress can exacerbate disease and insect problems and the best protection, particularly for disease, is planting improved varieties that have an “R” rating for pest problems of the area (Lauriault, 2011). Scouting and treating for insect problems is especially important during early green-up for water limited fields. Stress during this time period can be very damaging to stands as plants are growing from depleted root reserves and photosynthesis from a small amount of leaf area.

Harvest Timing

Time of harvest can have a significant effect on alfalfa yield, stand longevity and quality. Researchers have also found that time of harvest influences WUE. When alfalfa was harvested during the period from pre-bud to the bud initiation stages, the WUE was higher than when harvest is done at a later stage (Smeal, 1991). This is likely due to the fact that biomass accumulation in above-ground growth follows a sigmoid, or S-shaped, pattern (Smith, 1960), with alfalfa growth rate declining after the bud stage. About that time, more photosynthate is portioned into crowns, roots and reproductive structures than into new leaves and stems. The post-bud growth period also coincides with higher ET, as the plant stand reaches full canopy cover and remains at or near full canopy cover until the bloom stage. In contrast, cutting early in the season (in advance of pre-bud) will reduce the potential for highest biomass yields. Over time this same strategy will result in reduced plant vigor and decreased stand longevity (Smith, 1972 and Robinson and Massengale, 1968). The risk for reduced stand longevity can easily offset the benefits of increased WUE by harvesting at an earlier growth stage and thus, harvesting early is not a recommended practice for water savings.

Stand Age

Alfalfa is a long-lived perennial forage crop, and well managed alfalfa stands can be productive for 7 to 10 years or more. Aging and old stands of alfalfa will decline in density and vigor over time; correspondingly, stand age is related to WUE (Smeal, 1991). Water use efficiency was found to be the lowest in the establishment year and maximized at year 5. The low WUE during the first year is largely explained by the water loss due to soil evaporation rather than through plant use, until full ground cover is realized. After that, transpiration increases and evaporation decreases with more ground cover (MacAdam and Barta, 2007).

Increase in WUE as a stand ages is also a function of how CO_2 is partitioned by the plant. Much of the carbon that is fixed in photosynthesis during the early years of growth is partitioned into root development. For example, researchers found that only 59% of fixed CO_2 was partitioned into shoots and leaves in the first year, compared to 84% being partitioned into shoots and leaves during the second year (Thomas and Hill, 1949 and Brown et al., 1972).

Smeal (1991) concluded that the amount of water transpired to produce a given amount of above ground biomass progressively decreased until year 5 or 6 when the root system was fully developed. Thus, improved WUE can be obtained by maintaining and continuing to harvest an alfalfa stand beyond 4 -5 years of age. However, as stands age and decline in density, weed control can become more challenging and producers need to watch for thinning stands that allow also for more evaporation water losses (Nelson and Smith, 1968).

Recent Research Example

Researchers at Colorado State University have been comparing deficit and partial season irrigation since 2006 at a research site near Fort Collins, Colorado. Alfalfa yields and WUE have been compared under two irrigation approaches:

1. Deficit irrigation, where irrigation is applied throughout the growing season but with a capacity limitation of one irrigation per week and maximum weekly irrigation of 1.5 inches.

2. Partial season irrigation, with irrigation focused on the first hay cutting and then terminated later in the season.

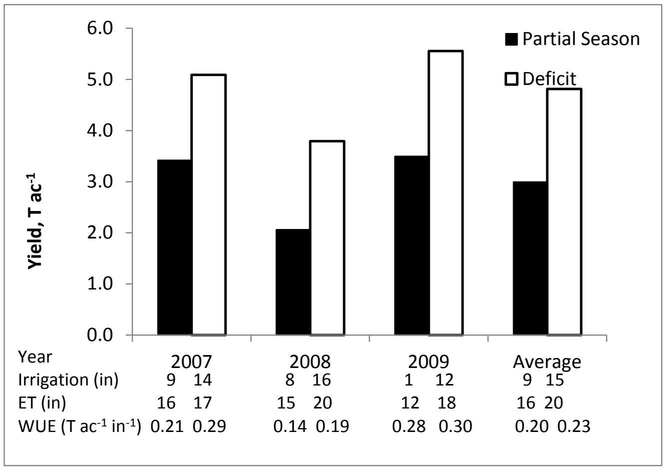

Figure 4: Alfalfa yield, irrigation amount, ET, and water use efficiency resulting from uniform and seasonal deficit irrigation near Fort Collins, Colorado.

The site is located in north-central Colorado at an elevation of 4,982 feet and 40.65620 N latitude. The Fort Collins site receives approximately 14 inches of precipitation a year. The soil at the study site is a Nunn clay loam. The alfalfa was established in 2006 with all treatments being fully irrigated during the establishment year and comparisons of alfalfa yield and WUE were completed for 2007-2009. The site is irrigated with a linear-move sprinkler irrigation system. Soil moisture is measured to a depth of eight feet by neutron probe and reference ET is calculated from temperature, relative humidity, wind and solar radiation measured with an automated weather station installed within ¼ mile of the site. Actual alfalfa ET is confirmed by water balance, using soil moisture measurements, precipitation, and irrigation.

Results

The deficit irrigated alfalfa was watered throughout the entire growing season of each year, but the capacity limitation of the irrigation system was not able to meet the full evaporative demand during peak ET demand periods. Yields for each of the four alfalfa cuttings, averaged over three years, were 1.6, 1.2, 1.2, and 0.8. T ac^{-1}. By contrast, the partial season irrigation alfalfa was irrigated only for the first harvest period, which typically occurred in the first two weeks of June. Yields for each of the four alfalfa cuttings, averaged over three years, were 1.3, 0.8, 0.5, and 0.7. T ac^{-1}. The partial season irrigated alfalfa in late summer grew very little and appeared brittle and brown in the field. However, crown buds remained viable, showing the ability of alfalfa to go into drought induced dormancy. Yields from spring harvests following dry summers of partial season irrigated alfalfa averaged 85% of those of the deficit irrigated alfalfa that did not go through a dormant period.

Applied irrigation for the deficit irrigation system averaged 15 inches and for the partial season irrigation averaged 9 inches per year, while total ET averaged 16 and 20 inches, respectively. The 40% reduction in irrigation resulted only in a 20% reduction of ET because the partial season irrigation alfalfa used more soil moisture. Average annual alfalfa yield was 3.3 T ac^{-1} for the partial season irrigation alfalfa and was 4.5 T ac^{-1} for the deficit irrigation system (Figure 4). Water use efficiency averaged 0.21 tons $acre^{-1}$ $inch^{-1}$ for the partial season irrigated alfalfa and 0.26 tons $acre^{-1}$ $inch^{-1}$ for the deficit irrigated alfalfa. Both of these WUE values are high compared to the range observed in previous studies and are above the regional average of 0.18 tons $acre^{-1}$ $inch^{-1}$. It is not clear why the WUE did not improve as expected when comparing partial season irrigation with deficit irrigation. Consistent with previous work, WUE efficiency was consistently greatest for the first cutting for both irrigation strategies. Results from partial season irrigation show that there was not a decline in stand density in later years.

Summary

Alfalfa offers producers many opportunities to maintain production under limited water situations, not available with other forages and grain crops. Similar to other forage crops, alfalfa responds to water from precipitation and irrigation in a linear fashion. Recently reviewed studies from the Great Plains and Intermountain West reported an average yield of 0.18 tons of hay per acre inch of ET (tons $acre^{-1}$ $inch^{-1}$) or 5.6 inches of ET required per ton. Highest WUE for alfalfa occurs during relatively cooler spring periods with longer days. Thus, most research has shown that targeting water applications during this period and forgoing irrigations during mid-summer cuttings is a better conservation strategy than full season deficit irrigation in semi-arid areas. In arid areas with hotter temperatures, summer termination may result in stand loss on coarse-textured soils. Differences in WUE among varieties are not apparent in the literature, but varietal selection for disease and pest resistance becomes particularly important for water-stressed conditions.

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