

CAN ALFALFA BE PRODUCED WITH LESS WATER?

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ABSTRACT

Alfalfa can be produced with less water, but less water could reduce yields. Yield is directly related to crop evapotranspiration, and less water could decrease evapotranspiration. Maximum yield could be obtained with less water by increasing irrigation efficiency through better irrigation scheduling and improved irrigation systems. In some cases, however, regulated deficit irrigation of alfalfa might improve profit during those times when yield per unit of applied water is low compared to continuous irrigation. Regulated deficit irrigation involves reducing or terminating irrigations during those times.

Key Words: alfalfa, irrigation, evapotranspiration

INTRODUCTION

Can alfalfa be produced with less water? This question is being focused towards alfalfa because of alfalfa uses about 20 to 27 percent of California's water and most likely the increased demand for water by urban and environmental sectors will reduce water allocations for agriculture.

The answer is yes; alfalfa can be produced with less water. But at what cost? This paper examines some approaches for using less water to produce alfalfa and their costs.

ALFALFA YIELD, EVAPOTRANSPIRATION, AND APPLIED WATER

Evapotranspiration

Evapotranspiration is the water used by plants. It consists of two components: transpiration, which is water, evaporated directly from plant leaves, and evaporation, which is water, evaporated directly from the soil surface that is exposed to the sun's rays. When the crop canopy is small, soil evaporation can account for most of the evapotranspiration. When the crop canopy covers most of the soil surface, transpiration accounts for most of the evapotranspiration. At least 95 percent of the water uptake by a plant is transpired.

Climate factors affecting the crop evapotranspiration include solar radiation, temperature, wind, and humidity. Plant factors affecting evapotranspiration include plant type, stage of growth, and health of the plant. However, from an irrigation water management viewpoint, soil moisture is the most critical factor that limits crop evapotranspiration. Crops that are deficit-irrigated may experience reduced evapotranspiration because of the limited soil moisture.

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Yield Versus Evapotranspiration

Crop yield is directly related to crop evapotranspiration as shown in Figure 1 for the San Joaquin Valley of California (Grimes et al., 1992). Maximum yield occurs when the evapotranspiration is maximum, while reduced evapotranspiration decreases crop yield. Maximum evapotranspiration is determined by climatic conditions, while less than maximum evapotranspiration generally results from inadequate soil moisture.

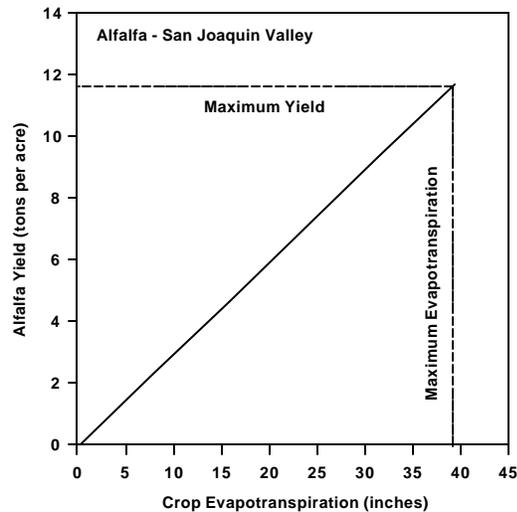


Figure 1. Evapotranspiration versus alfalfa yield for the San Joaquin Valley of California.

This linear or straight-line relationship occurs for many locations throughout the United States as shown in Figure 2 (Sammis, 1981). However, the yield versus evapotranspiration relationship differs among the various locations. For example, larger yields for a given amount of evapotranspiration are found for the San Joaquin Valley compared with the Imperial Valley. Reasons for the different behaviors are not entirely understood, but may include differences among locations in antecedent soil moisture, season length, climatic variability, root development, experimental method, and crop maturity (Smeal et al., 1992).

Yield Versus Applied Water

Relationships between yield and applied water can differ from yield/evapotranspiration relationships depending on the amount of applied water, uniformity and efficiency of applied water, and antecedent soil moisture content from winter and spring snow melt and rainfall. A study in northern California found little response of yield to applied water occurred for the first cutting simply because stored soil moisture from winter and spring precipitation was sufficient for crop growth (Hanson et al., 1989). For the second cutting, yield increased linearly with applied water up to about 6 inches. Thereafter, little or no increase in yield occurred with applied water

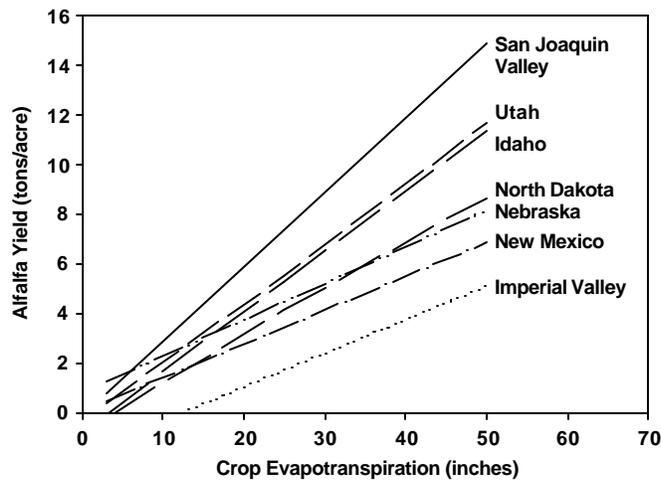


Figure 2. Alfalfa yield versus evapotranspiration for various locations.

Caused by climatic conditions which limited the maximum evapotranspiration rates. The third and fourth cuttings show a linear response of yield to applied water. More water was required to reach high yields for these cuttings than for the second cutting. However, for the latter cuttings, about two to three inches of water was needed before any yield occurred. During the time periods of these cuttings (July and August), little or no stored soil moisture from the winter and spring precipitation apparently existed.

Yield Versus Cutting

It is well known that alfalfa yield per cutting generally decreases with time during the year. Yields are the highest for the first cutting and are the least for the last cutting. This suggests that under limited supplies of irrigation water, such as might occur to meet urban and environmental demands, late summer and fall irrigations might be eliminated to conserve water. Several research projects have been conducted to investigate summer termination of irrigation on the seasonal alfalfa yield and water use, and also on its effect on subsequent alfalfa production. Some strategies for deficit irrigation of alfalfa will be discussed later.

Yield Versus Cultivar

Several studies investigate the response of different cultivars to water. One study in the San Joaquin Valley of California developed yield/evapotranspiration relationships for the cultivars CUF101, WL318, and Moapa69 (Grimes et al., 1992). Results showed little differences between these cultivars. No significant differences were found between cultivars Mesa Sirsa and Salton in the Imperial Valley of California (Donavan and Meeks, 1983). A study in Washington found little differences in yield and water use for cultivars Vernal, Vernema, and CUF101 (Hatterdorf, et al., 1990). No significant differences were found between Vanguard, Cody, Zia, and Dawson cultivars in a Texas study (Undersander, 1987). In contrast, substantial yield differences were found between seven cultivars

grown in the Imperial Valley (Robinson et al., 1994). Project results found CUF101, UC Cibola, and UC150 to have the highest yields, while Moapa 69 was the second best. Cultivars Mesilla and Wilson followed, and Rofaria had the smallest yields. However, no water use data were available for these cultivars.

STRATEGIES FOR APPLYING LESS WATER

Strategies for applying less water for alfalfa production include:

1. Prevent overirrigation through better management of irrigation water.
2. Increase the uniformity and the irrigation efficiency of irrigation systems.
3. Impose deficit irrigation.

Better Management and Irrigation Scheduling

Irrigation scheduling involves answering two questions: when to irrigate and how much water to apply? Methods commonly used to schedule irrigations are the water balance approach and monitoring soil moisture content. The water balance approach consists of estimating crop evapotranspiration until it equals the allowable soil moisture depletion, and then applying an amount of irrigation equal to the crop evapotranspiration plus inefficiencies of the irrigation system. The soil moisture approach involves making direct measurements of soil moisture or soil moisture tension.

A major constraint to using the water balance in alfalfa is that the crop is cut every 26 to 45 days (cutting frequency depends on the production area and season). Thus, it can be difficult to fit irrigations around cuttings. Irrigation water cannot be applied too close to a cutting because of the difficulty in curing hay on wet soil and compaction problems associated with running hay harvesting equipment on wet soil. In addition, because an alfalfa field obviously cannot be irrigated while the hay is curing, there is typically a 6 to 10 day period during which fields cannot be irrigated. Proper irrigation scheduling also requires knowing how much water was applied. This, in turn, requires a flow meter. The depth of the applied water is calculated using the following equation:

$$D = \frac{K Q T}{A}$$

where Q is the flow rate, T is the time required to irrigate the field, and A is the area irrigated. K = 0.0022 where the units are gallons per minute for Q, hours for T, and acres for A. Unfortunately, little information exists on the effect of improved irrigation water management on the amount of applied water. Thus, it is difficult to estimate the potential of better irrigation scheduling for water conservation. It should be noted the improved water management could actually increased the amount of water used if the existing management results in deficit irrigation.

Increase the uniformity and the irrigation efficiency of irrigation

Uniformity

Uniformity refers to the evenness of the applied or infiltrated water. A uniformity of 100% means that all parts of a field received the same amount of water. However, no irrigation system can apply water at 100 percent uniformity. Regardless of the type of irrigation method, some areas of a field receive more water than other areas. If the least-watered areas of the field receive an amount equal to that needed for crop production (referred to as an adequately irrigated field), excess amounts of water will be applied to other areas. These excess amounts cause drainage below the root. The larger the nonuniformity, the larger the differences in applied or infiltrated water throughout the field, and the more the drainage below the root zone. For a distribution uniformity of 93 percent, about 10 percent of the applied water drains below the root zone, while for a DU of 74 percent, drainage is about 34 percent of the applied water.

Irrigation Efficiency

Irrigation efficiency is defined as the ratio of the amount of water needed for crop production to the amount of water applied to the field. The amount of water needed for crop production is the beneficial use. Another term frequently used is the application efficiency, defined as the ratio of the amount of irrigation water stored in the root zone to the amount of applied water.

Crop evapotranspiration is the largest beneficial use of irrigation water. This is water that evaporates from the plant leaves and from the soil surface. More than 95 percent of the water uptake is evapotranspiration. Other beneficial uses include leaching for salinity control, frost protection, and climatic cooling.

Losses affecting irrigation efficiency include drainage below the root zone, surface runoff, and evaporation from sprinklers. Drainage occurs when the amount of infiltrated water exceeds the soil moisture storage capacity of the soil. Surface runoff when the application rate of the irrigation water exceeds the infiltration rate.

The distribution uniformity equals the irrigation efficiency when the irrigation system is properly managed. Table 1 lists potential practical irrigation efficiencies developed from distribution uniformities (Hanson, 1995). A practical irrigation efficiency is one that is technically and economically feasible.

Upgrading existing irrigation systems or converting to a system with an inherently higher uniformity can improve uniformity, and thus efficiency. The following discusses some considerations in improving system uniformity and irrigation efficiency.

Border or Flood Irrigation

The distribution uniformity of border or flood irrigation is affected by varying infiltration opportunity times along the field length and variable infiltration rates. Other considerations include different day and night set times, varying inflow rates during the irrigation, and water temperature differences between day and night irrigations. Potential uniformities of border irrigation are 70 to 85 percent. However, improving the uniformity of these systems is difficult. Improving the uniformity of surface irrigation requires reducing the variability in infiltration throughout the field. Strategies for improving uniformity include decreasing the water advance time to the end of the field and reducing the infiltration rate. Measures commonly recommended for improving the uniformity of surface irrigation are shortening the field length (most effective measure), increasing the unit inflow rate (marginally effective), and improving the uniformity of the field slope. However, implementing these measures will require changes in irrigation set times and could increase surface runoff.

Table 1. Practical potential irrigation efficiencies.
Surface runoff is assumed to be beneficially used.

Irrigation Method	Irrigation Efficiency (%)
Sprinkler	
Continuous-move	80-90
Periodic-move	70-80
Solid-set	70-80
Microirrigation	80-90
Furrow	70-85
Border	70-85

Sprinkler Irrigation

Periodic-move sprinkler systems such as hand-move systems and wheel-line or side-roll systems are commonly used for alfalfa irrigation. Uniformity of these systems depends on hydraulic losses throughout the irrigation system, catch-can uniformity, and maintenance. Hydraulic losses depend on pressure changes throughout the field caused by friction losses and elevation changes. Catch-can uniformity describes the pattern of applied water between adjacent sprinklers and depends on sprinkler spacing, pressure, wind speed, and sprinkler head and nozzle type. Maintenance factors include mixed nozzle sizes, malfunctioning sprinkler heads, non-vertical sprinkler risers, and leaks. Different day and night set times can also affect the field-wide uniformity.

Potential distribution uniformities of periodic-move systems under low wind conditions range between 70 and 80 percent. Under wind conditions, however, relatively low distribution uniformities normally will occur. High uniformities under wind conditions might be obtained by using relatively small sprinkler spacings, but this practice is generally not practical because of cost.

Potential distribution uniformities of center-pivot and linear-move sprinkler machines should be higher than those of the previously mentioned sprinkler systems. The more-or-less continuous movement of these machines reduces the effect of wind on uniformity. Potential distribution uniformities of these irrigation systems are 80 to 90 percent.

Drip Irrigation

Drip irrigation precisely applies water throughout a field both in terms of amount and location. Potential advantages of drip irrigation include increased crop yield, reduced water and energy costs, reduced fertilizer costs, and decreased cultural costs. Potential disadvantages include high capital costs of drip irrigation systems, possible increased energy costs compared to those of flood or border irrigation, and maintenance costs to prevent clogging and repair leaks. The distribution uniformity of drip irrigation systems depends on hydraulic losses (same as for sprinkler systems), clogging, and manufacturing variability of emitters. Potential distribution uniformities of drip systems are 80 to 90 percent.

Several studies on drip irrigation of alfalfa have been conducted in California and Nevada. A study comparing furrow irrigation and subsurface drip irrigation of alfalfa was conducted in the Imperial Valley of California. The initial installation depth of the drip tubing was 16 to 18 inches. Emitter spacing was 40 inches with a nominal emitter discharge rate of 0.5 gallons per hour. Lateral spacings of 40 inches and 80 inches were compared. After several years, the installation depth was increased to between 25 and 28 inches because the initial depth resulted in wetting of the soil surface, which interfered with the crop harvest.

Results of the initial installation showed yields under drip irrigation to be about 22 percent higher compared with furrow irrigation. Crop water use was 6 to 10 percent less for the drip system. Yields under the modified drip system were 12 to 17 percent more than that of the furrow system, while water use was similar for both methods.

The Nevada study (Neufield, 1998) consisted of installing drip tubing at depths of 12 inches and 18 inches and irrigating at rates equal to 75, 100, and 125 percent of the potential evapotranspiration. Soil type was a silt loam. In that location, three cuttings per year are normal. Results showed the yields of drip irrigation to be 14 to 21 percent more compared with a control border system. The effects of installation depth and irrigation amount were insignificant, probably because of rainfall.

Economics

Will converting to a continuous-move sprinkler system or to a drip irrigation system be profitable? The answer depends on whether or not any revenue increase due to higher yields and/or reduced costs due to less water, energy, fertilizers, and other inputs more than offsets the costs of the new irrigation method. It is difficult to predict the effect of any conversion because little information exists on the matter and site-specific conditions will dictate the outcome.

This difficulty is illustrated by data comparing drip and furrow irrigation of cotton (Hanson and Trout, 2000). These comparisons showed that in general, drip irrigation resulted in higher yields with less water compared with furrow irrigation. However, no trend was found for profit, indicating that it was not possible to predict the effect of drip irrigation on profit. This effect will depend not only on any increase in yield due to the conversion, but also on the crop price.

A rough estimate of the amortized capital cost of a drip irrigation system is between \$150 to \$200 dollars per acre. Thus, if the alfalfa price is \$100 per ton, a yield increase of about two tons per acre may be needed to offset the capital cost. However, if the price is \$80 per ton, an increase of 2.5 tons per acre may be needed.

In general, however, the more marginal the site-specific conditions, the more likely that converting to continuous move sprinklers or drip irrigation will increase profit. These conditions include water quality, soil quality (texture, variability within a field, hardpans or clay lenses).

Impose Deficit Irrigation

Normally, deficit irrigation of alfalfa is not recommended because of its adverse effect on yield. However, under some conditions, regulated deficit irrigation might be economical. Regulated deficit irrigation involves reducing or terminating irrigations at times when crop evapotranspiration is relatively high but yields are relatively low. This usually occurs in late summer and early fall for many locations. Regulated deficit irrigation of alfalfa might be feasible during this time when water is limited or costly and/or crop prices are low. A review of studies on regulated deficit irrigation of alfalfa follows.

The hypothesis that alfalfa yield and stand can be permanently damaged by withholding irrigations was studied at two locations in Arizona (Ottman et al., 1996). The treatments at the Yuma site consisted of normal irrigation, summer termination from July through October, and winter termination from November through February. Treatments at the Maricopa site were normal irrigation, summer termination from August through September, and summer and winter termination from August through mid-March.

Results showed yields to be negligible during the summer termination at the Yuma site. At this site, soil type was sand, and little summer rainfall occurred. The alfalfa yield did not recover, and the damage appeared to be permanent due to a significant stand loss.

Summer termination at the Maricopa site had a less dramatic effect where soil type was a sandy loam. For the first year, yield recovered during the first growth cycle, but required two growth cycles for recovery during the second year. A major reason for this behavior appeared to be nearly five times more rainfall during the first termination period (4.9 inches) compared to the second (1 inch). The summer termination did not affect stand count.

Winter termination at the Yuma site appeared to have little effect on yield during the project. However, 33 inches less water was applied compared to the normal irrigation treatment for the 2-1/2 year experiment.

Irrigations were terminated or reduced in a project conducted in the San Joaquin Valley of California (Frate et al., 1991). Soil type was sandy loam. Irrigation treatments consisted of normal irrigation (two irrigations per cutting), wet (three irrigations per cutting), and dry (two irrigations per cutting through May and a single irrigation per cutting from June through September, July through August termination followed by full irrigation in September, and termination from July through the following spring.

A trend of decreasing yield with decreasing applied water occurred for the first two years, but not for the third year. For this year, yield differences between treatments were small for most of the cuttings. Except for the termination treatment, yields appeared to recover during the first growth cycle of the following year. By the second growth cycle, yield of the termination treatment had recovered.

The effect on crop yield of reduced and terminated summer irrigations was investigated in the Imperial Valley of California (Robinson et al., 1994). Soil type was clay loam. A water table fluctuated about 5.5 ft deep. Summer irrigation treatments consisted of optimal irrigation, minimal stress, short stress, and long stress. The numbers of irrigations for each treatment are listed in Table 2. No information was provided on irrigations for the remaining part of the year. Seven cultivars were used for this three-year project.

Table 2. Summer irrigation treatments.

Irrigation Treatment	Number of Irrigations		
	July	August	September
Optimum	3	2	2
Minimal stress	3	1	1
Short stress	3	0	0
Long stress	0	0	0

A decline in yield occurred during the project which corresponded to a decline in the stand count. This behavior was common for all varieties. However, yields of the minimum, short, and long treatments were significantly less compared with the optimal treatment. For the short stress treatment, yields recovered during the first growth cycle after the irrigation terminations. Stand counts were similar for all irrigation treatments for the first two years, but counts were smaller for the short and long treatments of the third year.

The effect of four irrigation termination treatments was evaluated in the Palo Verde Valley of southern California (Putnam et al., 2000). Treatments consisted of a control (normal irrigation), no irrigations for 35-day period starting July 8, no irrigations for a 70-day period starting July 8, and no irrigations for a

105-day period starting July 8. Results showed a significant yield reduction during the periods of irrigation termination.

Economics

The economics of regulated deficit irrigation using the yield and cost data from Palo Verde Valley study is shown in Figure 5. Profit was calculated at the total revenue (yield x \$/ton) minus production and harvest costs minus irrigation water costs. At relatively low water prices, full irrigation is the most profitable for crop prices greater than about \$95/ton. However, as crop prices become less than \$95/ton, terminating irrigations for 105 days during the last part of the summer and during the fall becomes more profitable. For high water costs such as \$110/ac-ft, full irrigations is the least profitable, and no irrigations during the later part of the year becomes the most profitable.

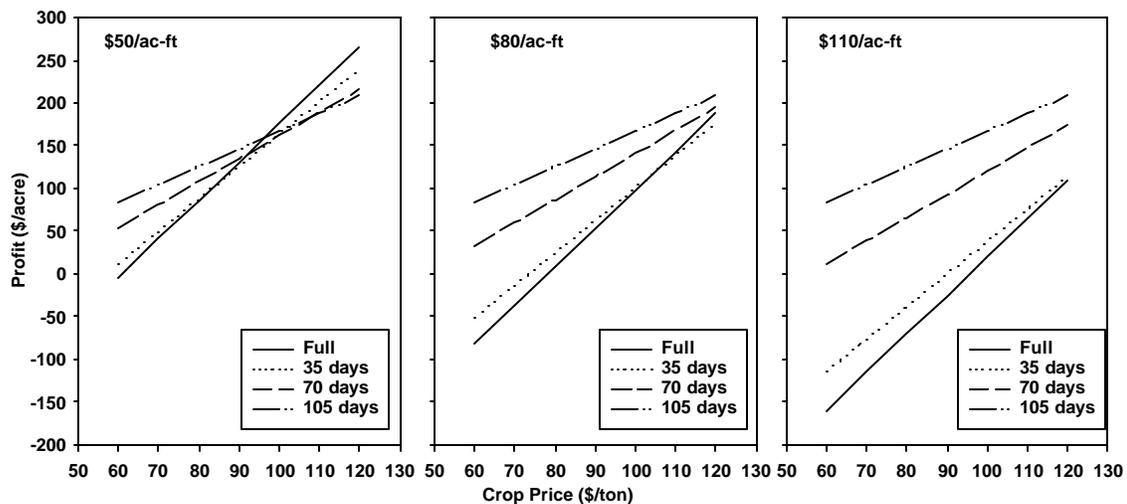


Figure 5. Profit versus crop price for water costs of 50, 80, and 110 dollars per acre-foot using data from the Palo Verde Valley study.

SUMMARY

Alfalfa can be produced with less water. However, if less water reduces crop evapotranspiration, yields will decrease. Less water can be applied without reducing yield by increasing irrigation efficiency through better irrigation scheduling and improved irrigation systems. Regulated deficit irrigation can also reduce water applications by reducing or terminating irrigation during periods when yield per unit of water is relatively small. One study showed that regulated deficit irrigation can improve profit, but further studies are needed to better identify this potential.

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