CONTROLLED DEFICIT IRRIGATION OF ALFALFA:
Opportunities and Pitfalls

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ABSTRACT

Alfalfa uses approximately 18.7% the state's agricultural water, a larger percentage than any other single crop. Reduced water availability for agriculture is probable in the coming years in many areas of the state, driven by urbanization and environmental demands. Therefore, examination of deficit irrigation strategies is warranted. More information is needed to determine the most profitable irrigation strategy to produce alfalfa with inadequate water supplies. Large-scale field trials were established in the Klamath Basin and the Sacramento Valley in 2003 to evaluate the effects of early-season irrigation cut-off (deficit irrigation) on yield, forage quality, stand persistence and economics. Results of these field trials showed severe yield loss when irrigation was halted in late summer in some cases, but only slight losses in yield in other cases. There appeared to be little to no stand loss in these trials, but it was too early to make an accurate assessment. However, stand losses have been observed in other trials, particularly in the low desert. Research in this area is ongoing. However, these preliminary results suggest that the concept of temporary voluntary water transfers from alfalfa for other uses may have merit. The desirability of this practice from a grower's perspective will depend largely upon economic incentives and the potential for such strategies to sustain long-term alfalfa production on farms.

Key Words: Alfalfa, *Medicago sativa*, irrigation management, water conservation, water transfers, economics

INTRODUCTION

The "Achilles heel" of alfalfa production in California, and throughout most of the West, is unquestionably the crop's water use. In fact, water availability was mentioned as a critical issue in each of the regional reports given at the Western Alfalfa Conference last year. Many outside of the alfalfa industry criticize the crop for it high water use and even consider alfalfa production to be a misuse of this precious resource. Most don't understand or appreciate the value of alfalfa production which is inextricably linked to the multi-billion dollar dairy industry in California. Additionally, most critics do not realize that the water-use-efficiency of alfalfa (amount of water applied per unit of harvested crop) is actually quite high—higher than that of most other crops (Putnam et al., 2001).

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In most years alfalfa receives more irrigation water than any other single crop. According to Department of Water Resources (DWR) 2000 estimates, 18.7% of the irrigation water used in the state is typically applied to alfalfa (Figure 1). The actual percentage varies depending on the watershed—in the major agricultural areas of the state, alfalfa's share of the irrigation water varies from approximately 8 percent in the Sacramento River watershed to around 50% in the south Lahontan and Colorado River watersheds in the Low Desert (Figure 2). Irrigation water applications to alfalfa range from 24 to over 100 inches per year, depending primarily on the region where the crop is grown (DWR estimates). A total of approximately 4 to 5.5 million acre feet of water are applied to alfalfa in CA each year, depending on alfalfa acreage that year, weather patterns, and method of estimation. This amount of water is applied to alfalfa because of the number of alfalfa acres (typically around a million acres) and its long growing season compared with other crops.

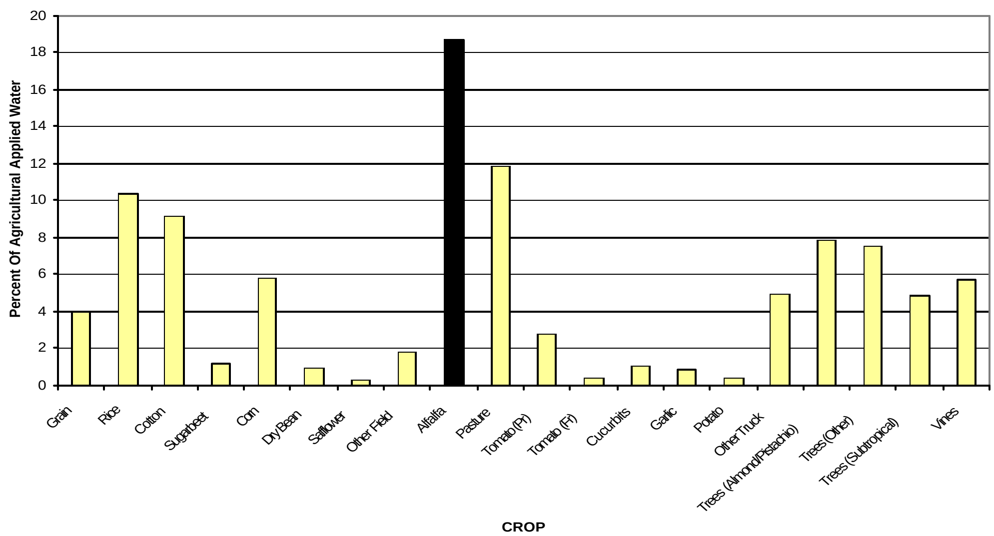

Figure 1. Comparative water used by different California crops
(Source: Data from California Department of Water Resources)

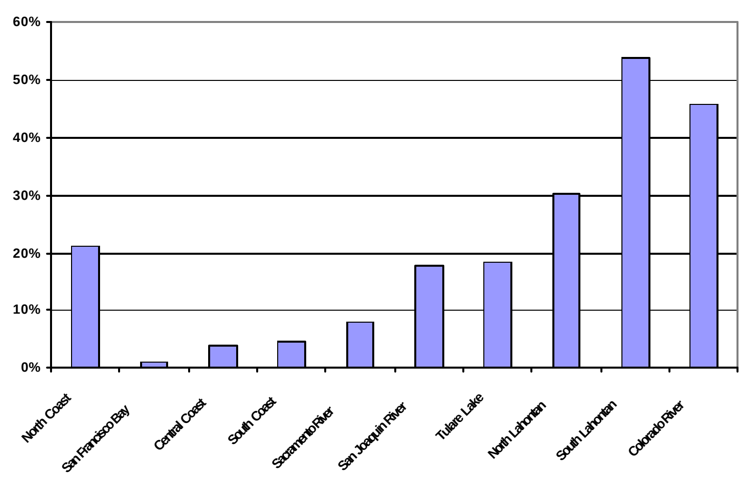

Figure 2. Percentage of agricultural water used by alfalfa for different watersheds in California
(Source: Data from California Department of Water Resources)

WATER ISSUES

Water availability issues span the state. Putnam and Ottman (2002) listed 12 different issues related to irrigation water availability that are currently unresolved but have the potential to drastically impact agricultural water supplies. These issues include water transfers from the Imperial Valley and the Palo Verde Valley to San Diego and Los Angeles, wildlife habitat restoration efforts in the Central Valley and the Bay Delta, water transfers to meet the needs of southern cities from Sacramento Valley water supplies, and uncertainty of agricultural water availability as a result of efforts to meet the habitat needs of endangered species in the Klamath Basin and other areas of the Intermountain Region. These issues are not going to disappear in the foreseeable future. In the long term, competition over limited water resources is likely to intensify. Therefore, resource management strategies are needed that enable growers to cope with the contentious battles over water, yet minimize the negative effects on agriculture.

SHORT-TERM VOLUNTARY WATER TRANSFERS

Water transfers, from agriculture to urban use or for environmental mitigation (either voluntary or regulatory) are a topic of daily news from Imperial Valley to Klamath Falls. Transfers from agriculture are discussed by water agencies as the primary option in drought years. Most discussions revolve around the fallowing of agricultural land with transfer of the agricultural water saved as a result.

However, complete suspension of irrigation water by fallowing of large acreage can have devastating and long-lasting consequences on the farm economy of an area. While individual growers may (or may not) benefit financially from water transfers and fallowing, such actions can negatively affect the well being of an entire community. Furthermore, fallowed fields are often left with no vegetative cover making them susceptible to severe wind erosion. Weed encroachment has also been an issue with fallowed fields. The cost to compensate growers for fallowing their fields is relatively high since the grower is unable to generate any income from the land. The impact on farm laborers and agricultural support industries is serious, as the use of seed, fertilizer, crop protection chemicals, irrigation equipment, tractors, finance institutions, and other farm supplies is greatly diminished. Long-term investments made by individual farmers are uncertain with a complete fallowing strategy.

An alternative approach could be to provide a mechanism so that interested alfalfa growers could voluntarily transfer some irrigation water (typically in summer and fall) for environmental uses in drought years and receive compensation. After a season of imposed deficit irrigation, they could resume full irrigation in normal or above normal precipitation years. While alfalfa requires full irrigation for maximum yield, it is relatively drought tolerant and can usually tolerate periods of drought by going into what is commonly referred to as a drought-induced dormancy. This approach avoids many of the problems associated with complete fallowing and may be considered a more "middle of the road" approach between cessation of agriculture (fallowing) and full agricultural production.

This approach allows some forage production and economic viability of alfalfa in the face of drought and water transfers. The alfalfa cover minimizes the potential for wind erosion and weed invasion. The alfalfa producer harvests at least one cutting (or several cuttings) providing some income, which would reduce the level of compensation required and would help provide support for the state's #1 agricultural industry (dairy). Spring cuttings would be harvested, which in most areas are higher in yield and forage quality than summer cuttings. Seed, fertilizer, labor and other agricultural inputs would still be needed which helps to maintain the viability of agricultural support industries and farm communities.

IRRIGATION CUT-OFF TIMING

One approach to deficit irrigation is irrigation termination during particular times of the year. This is a different strategy than continually providing inadequate irrigation water or continually stressing the crop. Although further research is needed to help define optimum deficit strategies, preliminary thinking is that seasonal dry-down strategies may be better since resources are concentrated to optimize yield in relationship to harvest and other costs.

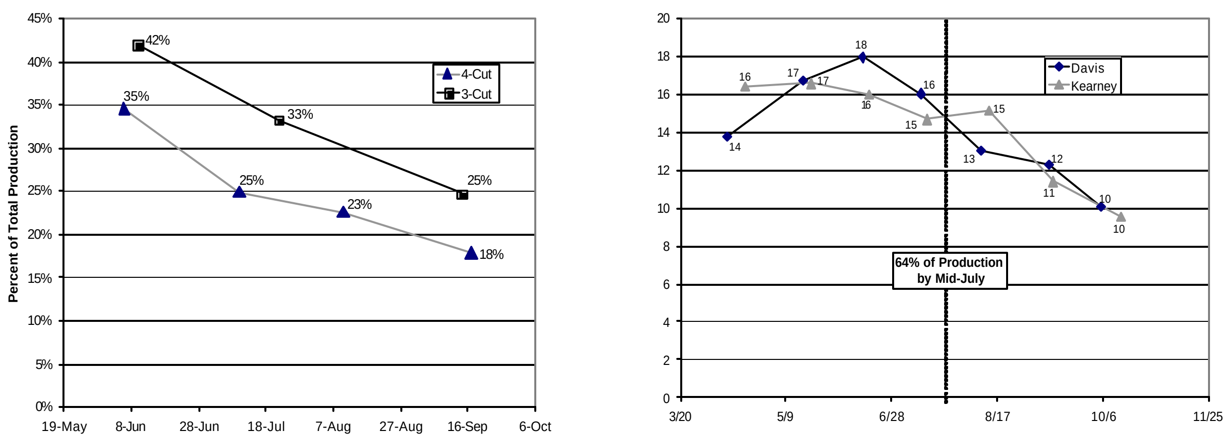

Figure 3. Seasonal yield patterns (proportion of total production per cutting) for the intermountain (left) and Central Valley (right) locations.

In one likely scenario, the alfalfa would receive normal irrigation in the spring through perhaps June or July, and then irrigation would cease. This approach allows for harvest of the first cutting(s) in the spring, which typically represent a significant portion of the annual production. Data from alfalfa variety trials in different California locations show typical seasonal production trends. Yield is typically highest in spring and trails off for the remainder of the season, so a disproportionate amount of the total production occurs in the first or first and second cuttings in the Intermountain area and in the first three of four cuttings in the Central Valley (Figure 3). For example, in the intermountain area irrigation up to June would typically allow for normal first cutting. The first cutting represented 42 percent of the total production for a 3-cut schedule and 35 percent for a 4-cut schedule. A July irrigation cutoff would allow for normal production for the first two cuttings of a 4-cut schedule—61 percent of the annual production. Seventy-five percent of the seasonal production occurs in the first two cuttings of a 3-cut schedule (irrigation up to mid-July).

Seasonal yield patterns are comparable for the Central Valley (Figure 3). While yield per cutting is more consistent in the Central Valley than in the Intermountain Region, more production still occurs in the early season cuttings compared with those in mid summer and fall. The data indicates that a sizeable percentage (approximately 64%) of the seasonal yield is produced before mid-July.

In contrast to yield, peak evapotranspiration occurs in the middle of the summer during the driest hottest time of the year when very little of the crop's evapotranspiration needs are met through precipitation. Therefore, the majority of the water used in a season is applied from mid-summer on. A strategy whereby irrigation is terminated mid-summer takes advantage of the higher water-use-efficiency in spring (less water needs to be applied per unit of alfalfa production). Additionally, water is withdrawn in summer when both yield and forage quality are typically low—this gives greater incentives to growers to be interested in irrigation termination. Hence, the grower is able to capture some of the higher yield and higher quality spring cutting(s) while avoiding the highest water application periods in summer through fall.

ALFALFA DEFICIT IRRIGATION STUDIES

Research on deficit irrigation of alfalfa has been conducted in several areas of the West. Studies in Arizona were conducted in Yuma and Maricopa. In California, studies were conducted in the Imperial Valley and Palo Verde Valley in the Low Desert, Fresno County in the Central Valley, and Siskiyou County in the intermountain area. Different irrigation termination dates were imposed or the number of irrigations between cuttings varied. Results of most of this research were summarized at a previous symposium (Hanson and Putnam, 2000).

The effects of deficit irrigation varied depending on the location and the soil type. It is not surprising that deficit irrigation reduced yield, and that the yield reduction the year the irrigation cut-offs were imposed was generally greatest the earlier the irrigation termination date. The different results between studies relate to how long it took the field to recover from moisture stress and whether or not the alfalfa completely recovered.

EFFECTS ON LONG-TERM PRODUCTIVITY

In considering deficit irrigation strategies, a key issue appears to be whether alfalfa stand density is affected. In most published studies, there was not a significant reduction in stand, with the exception of work conducted in the low desert regions. In the Imperial Valley study there was a significant reduction in stand if the mid-summer irrigation cut-off occurred for more than one year. The Palo Verde study actually showed a significant reduction in stand after just the first year, possibly attributable to the very sandy soils at that location. Results were similar for the Arizona studies. In the Yuma study, alfalfa yield did not recover after irrigation was withdrawn in summer and there was significant stand loss. In contrast, in Maricopa yields recovered during the first growth cycle one year and during the second growth cycle the second (most likely due to difference in precipitation in the different years). Soil type appears to be a determining factor, as severe stand loss occurred on the sand in Yuma and no affect on stand from summer irrigation termination on the sandy loam in Maricopa. However, widespread grower experience with summer dry-down during the Silverleaf Whitefly outbreak of the early 1990s indicates that stand loss remains a considerable risk with regards to irrigation termination in the summer in desert environments. In other regions, stand losses appear to be less of an issue (Hanson & Putnam, 2000), but still a subject for further research and examination.

RESEARCH NEEDS

Before controlled deficit irrigation is employed as a strategy to deal with drought and competing water demands, additional research on deficit irrigation of alfalfa is needed to examine some of the key issues. The objectives are to:

1. Quantify the economic penalty to growers from yield and stand loss, especially in locations in northern California where summers are not as severe and stand loss is less likely.
2. Calculate the potential water savings associated with different approaches.
3. Identify deficit irrigation strategies and management practices that will minimize yield loss and plant mortality. Plant mortality or stand loss is the largest risk to growers since both current-year production, and subsequent years' production are affected.

DESCRIPTION OF RECENT RESEARCH

Field trials were established in the Klamath Basin and in the Sacramento Valley to address these issues and to provide answers to critical questions about the economic and agronomic viability of water savings resulting from deficit irrigation of alfalfa. Trials were established in the summer of 2003 to assess the effects of early season irrigation cut-off. Two trials in each location were conducted with grower cooperators in the Klamath Basin and in the Sacramento Valley. These sites differ dramatically in numbers of cuttings (3-4 for Klamath, 6-7 for Sacramento Valley) and climate (Klamath is cooler, Sacramento Valley much hotter).

The Klamath trial was conducted on two locations with vastly different soil types (a fine sandy loam and a silt loam with high organic matter content). Klamath Basin sites were sprinkler irrigated. There were three irrigation treatments: 1) normal full-season irrigation, 2) no irrigation after first cutting, and 3) no irrigation after second cutting. Irrigation treatments were imposed by plugging three consecutive nozzles on the wheel-line irrigation system for two 12-hour sets so each irrigation treatment was applied to a plot approximately 60 by 120 feet. Only the center area was evaluated to avoid areas where irrigation water may have drifted onto the plots. There were three cuttings at the sandy loam site and 4 cuttings at the silt loam site. Soil moisture content was assessed using a neutron probe every 2 weeks after the first irrigation cut-off occurred. Yield was measured for each cutting after the irrigation treatments were imposed. Forage quality (ADF, NDF, and CP) was measured for all treatments at each cutting.

The Sacramento Valley trials were conducted on two growers' fields in Yolo County, both clay loam soils susceptible to cracking. Both sites were flood irrigated so the irrigation treatments were applied to entire border strips of approximately 40' width X 1200' long. Treatments were: 1) normal full-season irrigation, 2) irrigation cut-off in mid summer (summer dry down), and 3) summer dry down with resumption of irrigation in fall. The idea behind this last treatment is to cease irrigating in mid summer when forage quality and sometimes yield are often low while the water demands of the crop are high. Irrigation resumes in fall when crop evapotranspiration is lower and forage quality is improved. This treatment was not included in the Klamath Basin trials because the growing season is shorter—there is insufficient time left in the fall for the alfalfa to recover after summer irrigation is terminated.

SMALL PLOT STUDIES

In addition to these on-farm trials, experiments were established at the Intermountain Research and Extension Center at Tulelake and at UC Davis, CA in 2002. However, due to lack of on-going funding and the desire to implement deficit irrigation treatments on well-established stands, implementation of irrigation treatments were postponed until 2004.

These more detailed experimental designs will enable the study of more irrigation treatments and the interaction of irrigation with alfalfa variety and other factors. This research will also evaluate in a drought situation whether it is better to cut off irrigations early or try to spread that water over the whole season. More careful measurements of irrigation water are possible in experiment-station managed plots than on growers' fields. Further funding is being sought to implement these trials in 2004.

PRELIMINARY FINDINGS

Klamath Basin Studies Soil moisture showed a gradual decline after irrigation water was withdrawn(data not presented here). Both Klamath Basin locations had a relatively high water table—wet soil occurred at about 3 feet at the sandy loam location and about 3.5–4 feet at the silt loam location. Therefore, soil moisture readings at the deepest depth evaluated (3 feet) did not respond as dramatically to the irrigation treatments as did the shallower depths.

Water application rates were determined by monitoring the flow rate from individual sprinklers and multiplying the flow rate by the number of hours of operation per irrigation. Considerably more water was applied at the silt loam site than the sandy loam site, reflecting differences in grower irrigation practices. The sandy loam soil was irrigated once between cuttings with approximately 5.5 inches of water per irrigation. The silt loam site was irrigated one to two times per cutting and received an irrigation in mid-October after the harvest season was completed. Therefore, the water savings associated with the irrigation cut-off treatments varied considerably between the two locations. Twenty-one inches and 11 inches of water were saved with the irrigation cut-off after 1st cutting for the silt loam and sandy loam sites, respectively. This represents a considerable reduction in applied water, as most alfalfa fields in the Klamath Basin are only irrigated one or two times before first cutting (fields were only irrigated once before first cutting this year because of the moist spring).

Table 1. Water savings associated with deficit irrigation treatments at two alfalfa fields located in the Klamath Basin.

	Water Savings (inches/acre)	
Irrigation Treatment	**Sandy loam site**	**Silt loam site**
No irrigation after 1st cutting	11.0	21.0
No irrigation after 2nd cutting	5.5	16.8

There was a visible difference in alfalfa growth between the fully irrigated plots and the plots with an early irrigation termination. However, even where irrigation was terminated there was still substantial alfalfa growth. Within an irrigation cut-off treatment, there was a high degree of variability in alfalfa growth between plots due to changes in soil texture and moisture holding capacity across the field. This 'patchy' nature of drought effects was commonly seen on alfalfa fields in both locations. Alfalfa as a deep-rooted perennial extracts moisture from several strata in the soil. As drying occurs, the differences in sub-surface soil texture across a field become apparent—some areas show minor moisture stress while others appear very drought-affected.

However, the actual yield reduction resulting from irrigation cut-off was not severe in the Intermountain area (Table 2). The fine sandy loam site was an older field with lower yield potential. Irrigation termination after 1st cutting reduced yield by 0.60 tons per acre over the 2nd and 3rd cuttings. Ceasing to irrigate after 2nd cutting reduced 3rd cutting yield by 0.29 tons. The silt loam site was a younger alfalfa stand with higher yield potential. Second cutting yield declined from 1.24 to 0.95 tons per acre when irrigation was ceased. Third cutting yield was decreased from 1.36 tons per acre to 1.13 and 1.20 tons per acre when water was withdrawn before 2nd and 3rd cuttings, respectively. The total yield reduction from cutting water off at 1st cutting was 0.71 tons per acre and cutting water off after 2nd cutting resulted in a yield reduction of 0.53 tons per acre.

This yield reduction is not severe considering the amount of water saved. The high water table probably supplied some of the water needs of the alfalfa during the latter half of the season in the deficit-irrigated treatments. Soil moisture from the perched water table may not be as accessible in a drought year, especially if the irrigation canals are not full and surrounding fields are not irrigated. These results may be typical for locations in the intermountain region with a relatively high water table. However, the yield reduction would probably be greater at sites without a high water table.

The alfalfa from each of the cuttings was analyzed to determine the effect of the deficit irrigation treatments on alfalfa forage quality. There was no statistically significant effect on forage quality at both intermountain locations (data not shown).

Table 2. The effect of irrigation cut-off on subsequent alfalfa yield on a fine sandy loam soil in Malin, OR (Klamath Basin).

	Yield (tons/acre)		
Irrigation Treatment	**2nd Cut** **7/22/03**	**3rd Cut** **8/30/03**	**Total**
Normal full-season irrigation	1.03	0.67	1.70
No irrigation after 1st cutting	0.88	0.22	1.10
No irrigation after 2nd cutting	1.03	0.38	1.41
LSD 0.05	NS	0.18	0.34

Table 3. The effect of irrigation cut-off on subsequent alfalfa yield on Capjac silt loam soil in Tulelake, CA (Klamath Basin).

	Yield (tons/acre)			
Irrigation Treatment	**2nd Cut** **7/4/03**	**3rd Cut** **8/5/03**	**4th Cut** **9/11/03**	**Total**
Normal full-season irrigation	1.24	1.36	1.21	3.81
No irrigation after 1st cutting	0.95	1.13	1.01	3.10
No irrigation after 2nd cutting	1.22	1.20	0.86	3.28
LSD 0.05	NS	NS	0.33	0.66

Sacramento Valley Studies As mentioned earlier, both of the Sacramento Valley sites were flood irrigated (border-strip flood irrigation method). Irrigation treatments were imposed by preventing water entry into selected irrigation checks (approximately 40 X 1200 feet). Water application per irrigation was determined using irrigation district weir data for the entire field and calculating application rate on a per acre basis. Water application data from the Gnos site were unavailable at the time this paper was submitted. At the Chamberlain site, when no irrigation water was applied after the 3rd cutting, a total of 33.6 inches (2.8 acre feet) were saved (Table 4). The treatment where irrigation resumed after 5th cutting resulted in a water savings of 23.6 inches (about 2 acre feet). However, this may be an over-estimate of the actual amount of water saved for this treatment. Water application rates were calculated based on the amount of water applied to the entire field assuming that each check received the same amount of water. However, irrigators frequently need to apply much larger amounts to very dry cracking soils than on previously-irrigated fields (the surface area absorbs a larger quantity of water during the wetting process). Therefore, the potential water savings may be less for the re-watered treatment than those stated on Table 4.

Table 4. Water savings associated with deficit irrigation treatments at Chamberlain Ranch, Yolo County (Sacramento Valley). Irrigation water was applied using normal practices during the first half of the year, and water withheld in mid July either through the rest of the year or rewatered in September.

Irrigation Treatment	**Water Savings (inches/acre)**
Irrigation cut-off in mid summer	33.6
Irrigation cut-off in mid summer with fall irrigation	23.6*

*Savings amount for this treatment may be lower, see text.

There was a much more dramatic yield response to irrigation cut-off at both of the Sacramento Valley sites than at the Intermountain sites. In the harvest immediately after irrigation water was withdrawn, yield decreased from 1.10 tons for normal irrigation to 0.38 tons without irrigation at the Gnos site (Table 5). When irrigation resumed, yield rebounded somewhat for the following cutting (0.46 tons/A where irrigation resumed versus 0.23 tons/A without irrigation) but was still approximately half of that of the fully irrigated plots (0.86 tons/A). An even more severe drop in yield occurred at the Chamberlain site—yield decreased from 1.56 to 0.35 tons and from 1.35 to 0.25 for the 4th cutting and 5th cuttings, respectively, when irrigation water was withdrawn. At this site when irrigation was resumed yield fully recovered for the 6th cutting.

Table 5. The effect of deficit irrigation treatment on subsequent alfalfa yield on clay loam soil in Yolo County, CA (Circle G Ranch, Sacramento Valley).

	Yield (tons/acre)		
Irrigation Treatment	**5th Cut** 8/29/03	**6th Cut** 10/6/03	**Total**
Normal full-season irrigation	1.10	0.85	1.96
Irrigation cut-off in mid summer	0.38	0.23	0.62
Irrigation cut-off in mid summer with fall irrigation	0.37	0.46	0.82
LSD 0.05	0.19	0.61	0.78

Table 6. The effect of deficit irrigation treatment on subsequent alfalfa yield on a clay loam soil in Yolo County, CA (Chamberlain Ranch, Sacramento Valley).

	Yield (tons/acre)			
Irrigation Treatment	**4th Cut** 8/6/03	**5th Cut** 9/8/03	**6th Cut** 10/23/03	**Total**
Normal full-season irrigation	1.56	1.35	0.85	3.76
Irrigation cut-off in mid summer	0.35	0.25	0.42	1.01
Irrigation cut-off in mid summer with fall irrigation	0.27	0.16	0.96	1.40
LSD 0.05	0.28	0.17	0.62	0.56

FORAGE QUALITY

The deficit irrigation treatments had a large effect on the forage quality at both Sacramento Valley locations. For every cutting except the 6th cutting at the Chamberlain Ranch site, the deficit irrigated plots averaged lower fiber (both ADF and NDF) than the normally irrigated plots. There was a major difference at some cuttings—often between 5 and 7 percentage points ADF or NDF. There was no increase in CP associated with deficit irrigation. While this reduction in fiber concentration with deficit irrigation is of interest, the yield decrease associated with the deficit irrigation treatments is excessive. The reason why there was a significant forage quality difference due to deficit irrigation at the Sacramento Valley locations and not the Intermountain locations may be due to the degree of the yield reduction. At the 6th cutting at the Chamberlain site where the yields were more similar across treatments, there was not a significant difference in forage quality.

Table 7. The effect of deficit irrigation treatment on alfalfa forage quality, Gnos Ranch (Sacramento Valley).

	5th Cut			6th Cut		
Irrigation Treatment	**ADF**	**NDF**	**CP**	**ADF**	**NDF**	**CP**
Normal full-season irrigation	29.8	42.2	23.7	27.1	40.3	25.9
Irrigation cut-off in mid summer	22.8	33.0	24.6	22.7	34.3	26.1
Irrigation cut-off in mid summer with fall irrigation	21.7	31.9	25.2	23.3	36.5	27.1
LSD 0.05	2.2	2.6	1.1	4.8	5.7	NS

Table 8. The effect of deficit irrigation treatment on alfalfa forage quality, Chamberlain Ranch. (Sacramento Valley).

	4th Cut			5th Cut			6th Cut		
Irrigation Treatment	**ADF**	**NDF**	**CP**	**ADF**	**NDF**	**CP**	**ADF**	**NDF**	**CP**
Normal full-season irrigation	29.7	41.5	22.8	29.0	40.7	23.1	28.2	39.2	23.3
Irrigation cut-off in mid summer	25.9	35.2	22.3	24.0	33.4	23.8	27.0	37.9	23.3
Irrigation cut-off in mid summer with fall irrigation	25.1	33.6	22.6	25.0	35.9	23.4	29.0	40.7	23.1
LSD 0.05	6.3	5.0	NS	4.1	6.2	NS	NS	NS	NS

OPPORTUNITIES AND PITFALLS

Opportunities. Deficit irrigation of alfalfa appears to be a viable approach to deal with water shortages in drought years. The water savings can be significant. Alfalfa is currently the state's largest acreage crop, and a large percentage of the agricultural water used for irrigation is applied to alfalfa (estimated to be18.7 % in the year 2000). The amount of water available for transfer obviously depends on the degree of deficit irrigation employed and the number of interested grower participants. However, these data indicate a potential water savings up to 21 inches in the Intermountain area, and up to 34 inches in the Sacramento Valley with some of the deficit irrigation strategies we evaluated in alfalfa.

Deficit irrigation of alfalfa, such as an early season irrigation cut-off, offers a more moderate approach to solving water shortages and appears to make a lot more sense than completely withdrawing water from agriculture. There would be much less of a negative impact on the economy of an area and agricultural support industries. The grower is still able to produce some income from the land. Spring cuttings, which would be unaffected by an early-season irrigation cut-off, are often the most valuable—higher in yield, forage quality, and price—and are produced with less irrigation water. The need for pest management might be reduced under these deficit irrigation strategies. Pest management during late summer months would include control of various pests including the alfalfa caterpillar and fall armyworm; pest control measures may not be necessary under summer deficit irrigation. There were no observations in these studies that weeds would be more severe under deficit irrigation.

Alfalfa is probably better suited to this approach than most other crops. As a deep rooted perennial, alfalfa can survive periods of deficit irrigation, whereas there would be no marketable yield with other crops (especially vegetables or many tree crops) if water is withdrawn midseason. Hence, voluntary deficit irrigation of alfalfa in drought years could potentially free up water for use on other crops depending upon the need.

Pitfalls. Profits with a reduced production season would obviously be less than normal. Therefore, if this practice is to be implemented, compensation for growers is necessary. The studies described above showed a yield reduction of 0.60 and 0.71 tons/A at two Intermountain locations when irrigation was withdrawn after 1^{st} cutting. In the Sacramento studies yield was reduced 1.34 and 2.75 tons/A when irrigation was completely withdrawn in August. For practical purposes the yield reduction may be more than that indicated in these studies. It may not be justified for a producer to harvest a cutting that is less than half a ton because the income from such a small harvest may not cover harvesting costs.

A water transfer system should be designed so that the grower is compensated for the losses (paid for the water transferred) including the risk associated with the early-season irrigation termination. However, the level of compensation with this approach could theoretically be significantly less than the more traditional complete fallow system currently used for water transfer arrangements.

Stand Loss. By far the biggest risk associated with irrigation cut-off or other deficit irrigation strategies is the potential for stand loss. The concept is that water would only be transferred from alfalfa production in drought years so the following year normal irrigation would occur. It is believed that alfalfa produced in the northern part of the Central Valley or the Intermountain area can withstand a single year of early irrigation termination without stand loss. The trials described above are too new to document stand loss—plant density will be assessed next year. Stand loss could potentially occur under some conditions so the water transfer arrangement should allow for this risk. Both Klamath Basin locations had a relatively high perched water table that likely reduced the amount of yield loss from the irrigation cut-off and may affect the possibility of stand loss as well. Research is needed at other locations in the Intermountain Region to document the effects of deficit irrigation when a high water table is absent.

Economic Incentives. A payment for water transferred could benefit alfalfa growers because, as mentioned earlier, mid summer cuttings are often lower in yield and are typically the lowest in forage quality. Therefore, mid-summer cuttings are often more difficult to market and there is an abundance of mediocre quality mid-summer alfalfa hay often resulting in a poor price. A reduction in the supply of mid-summer alfalfa could improve price for all alfalfa hay producers. However, variable alfalfa production on a farm from year to year could be problematic for the producer. Established growers strive to develop a customer base; an interruption in total supply from one year to the next could complicate maintaining that clientele base. On the other hand, depending upon need, certainly not all of a region's or even an individual grower's alfalfa fields may be dried down at one time.

Public Benefits. A water transfer system like the one described also has benefits for resource managing agencies and the general public. It would be far less disruptive to rural culture and economies so it is likely that the water transfers would be less controversial. Dust would be controlled on non-irrigated fields (a significant issue in some areas), compared with fallow fields. The wildlife habitat benefit of alfalfa is superior to that of fallow fields (Putnam et al., 2001), and such a public benefit would be maintained under this scenario. The cost per acre foot of water saved, probably supported by public funds, would probably be less because, as mentioned above, growers would still get some income from fields compared with a complete fallowing system so the value of the water per acre foot might be less. This system would also provide greater flexibility to agencies that are forced to predict water supplies for the season in the spring before total snow pack and spring rainfall and temperatures are known. Since pressure on water supply systems are greatest late in the year, this strategy provides a late-season option, once water supply and demand figures are known. The actual number of alfalfa producers participating in a voluntary transfer could be determined later when a more accurate assessment of water availability and needs is determined.

CONCLUSIONS

While more research is clearly needed, analysis of the concept and initial results suggest that deficit irrigation of alfalfa could provide a partial solution to water shortages in drought years. Alfalfa growers typically are skeptical of proposed irrigation strategies which may result in water savings, since experience has taught them that urban and other elements may use such ideas in a 'no holds barred' effort to permanently transfer ag water for other uses. When dealing with contentious resource management issues there are typically very few win-win scenarios, especially when it comes to water. However, this may be an exception. Under voluntary water transfer agreements, deficit irrigation strategies for alfalfa may provide opportunities for growers to provide relief for other uses while at the same time maintaining on-farm profitability and sustaining agriculture for rural communities. This is a "middle path" approach which potentially avoids contentious water wars, as well as the negative aspects of fallowing for water transfers. Temporary voluntary water transfers from alfalfa may provide opportunities for alfalfa farmers as well as water resource management agencies, environmentalists and the general public to adjust water needs in drought years.

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