DEFICIT IRRIGATION OF ALFALFA AND GRASSES: WHAT ARE THE IMPACTS/OPTIONS?

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ABSTRACT

Forage grasses and alfalfa differ significantly in their tolerance to water deficits. Partial season irrigation of alfalfa in a drought year is a viable practice, with partial-season yield losses depending upon soil type and climate. Most perennial pasture grasses are not as drought tolerant as alfalfa, and grass species and varieties differ greatly in drought tolerance. In alfalfa, spring to early summer cuttings produce a high proportion of the total annual yield (approximately two-thirds by mid-July) and irrigation after that can be ceased without excessive yield loss in most situations. Yield losses are greatest on light textured soils with low water holding capacity and in areas with a long, hot growing season. Alfalfa plants have the ability to go into a drought-induced dormancy, and provided the duration of the water stress is not too long and the plants have adequate carbohydrate reserves, alfalfa should survive and recover once moisture is returned. The high flexibility of alfalfa to short-term water deficits is an important characteristic that should help growers and water managers cope with drought events.

Key Words: Drought, irrigation management, limited water supply, evapotranspiration, water use efficiency

INTRODUCTION

As every California resident is all too aware, the drought this year has been of historic proportions. Its impact on agriculture has been particularly devastating. Drought has a greater impact on agriculture than perhaps any other industry, due to California agriculture's dependence on adequate water supplies for irrigation for profitable crop production. Along with the lack of rainfall, 2014 so far has been the hottest year on record since 1895 when temperature record-keeping began. Hot temperatures, low soil moisture reserves going into the crop production season and reduced irrigation water supplies left growers scrambling for ways to cope with irrigation demands that exceed supplies.

Figure 1. Five-year old alfalfa variety trial after two years of drought conditions, 2013 and 2014 (Western Fresno County, CA). Alfalfa has a remarkable ability to survive long droughts due to its deep roots.

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In drought years when water supplies are tight, alfalfa is often the first crop that people consider—and not just because it starts with the letter "a". Alfalfa is the single largest user of agricultural water, accounting for nearly 20% use of applied water. This water demand should not be construed to mean that alfalfa is a "water waster". In fact, the water use efficiency (WUE) or the amount of crop produced per drop of applied water is actually quite favorable for alfalfa compared with many other crops. The large quantity of water applied to alfalfa on a statewide basis is due in part to the extensive acreage of the crop (typically between 900,000 and a million acres) and its long growing season (February through December in southern areas) compared with many other crops.

Alfalfa Offers Flexibility in Water Use. Conventional wisdom would suggest that alfalfa would be one of the worst crops to have in a drought year. However, this is actually not the case. Compared with most other crops, alfalfa is actually relatively drought tolerant, and has a high degree of flexibility with regards to water. First, because of its deep root system, it is able to access moisture lower in the soil profile that is unavailable to other crops. Therefore, depending on the soil type and environmental conditions, alfalfa growth can continue long after irrigation is terminated. Eventually, after soil moisture is depleted, alfalfa growth ceases but the crop enters into what is commonly called a "drought-induced dormancy" and can survive extended periods without irrigation.

For example, a three-year old alfalfa stand at West Side Research and Extension Center (Five Points, CA) was abandoned to Mother Nature, and season-long water deficits (from April through November) in both 2013 and 2014 and the stands largely survived (Figure 1, photo taken November, 2014 after a single irrigation). This was interesting, since saturated paste soil EC was recorded at about 9 dS/L in early 2014. The crop is likely tapping into a perched water table. This trial will be harvested in 2015 to ascertain long-term drought influence on yield. However, plant survival is very likely highly dependent upon soil type and degree of subsurface moisture.

Many other crops are NOT flexible. Alfalfa is better adapted to drought conditions than most other crops. For example, if water is withdrawn midseason from vegetable crops (such as onions, tomatoes, potatoes or lettuce) there may be nothing to harvest and even if there is a harvestable crop the quality may be so adversely affected that it is unmarketable. Similarly, there may be no marketable crop to harvest with tree fruits or nuts and the effect is likely to carry-over into future years. Tree and vine crops have been especially problematic during the 2013-14 drought; since they have such a substantial establishment cost, growers cannot risk losing this long-term investment. Even many agronomic crops like wheat, corn or sunflower can be uneconomical when irrigation water supplies are limited.

OPTIONS FOR IRRIGATING ALFALFA WITH LIMITED WATER SUPPLIES

When faced with limited water supplies [supplies are less than the potential seasonal evapotranspiration (ET) needs of the crop], there are three basic strategies:

1. Triage - Reduce irrigated acreage of alfalfa (cease irrigating some fields while fully irrigating others).

2. Starvation Diet - Deficit-irrigate the entire acreage during the crop season (less water per irrigation or fewer irrigations) so that less than full potential ET is applied.
3. Cold Turkey Cutoff - Fully irrigate all fields for the early cuttings and then cease irrigation part way through the season when alfalfa ET demands are high. Resuming irrigation in the fall (summer deficit irrigation only) may be advised in some areas of the state like the Low Desert.

There are pros and cons to each strategy and which approach a grower selects may be dictated by water availability and the price of water and hay. Is water available for the entire season? Is there water available season-long but at a reduced delivery rate? Or, in a water-short year is there only water available in the spring and then the water runs out? Is there potential to use saved water on other more drought-sensitive crops or to transfer conserved water to other regions to meet existing water transfer agreements? Groundwater availability and pumping costs should also be considered – these are often the fallback during droughts.

In most cases, we believe that provided there is sufficient water available early to mid-season, the third option may be the most economical choice. Growers should assure that fields have a full profile of water at the beginning of the season, calculate the water available, and water fully to a mid-point in the season and then quit.

The reasons this strategy may be best is several fold:
1) Alfalfa exhibits superior yield patterns early in the year – Figures 2-4 show the percentages of alfalfa yields realized in the early cuts of the year, depending upon location. This is also the period for highest quality.
2) Water may be more available or cheaper during early periods, and less available later.
3) 2-3 month dry-downs can save money on pest management requirements as well as harvesting costs.

Option 1 – Triage (Irrigation on some fields would cease completely while other fields are fully irrigated) may make sense especially if some fields are older, less productive, or near the end of their stand life anyway. The problem with this approach is that there is a high likelihood of significant plant mortality in most alfalfa production areas if whole fields are left unirrigated for the entire season. However, this is likely to be specific to soil type, residual moisture, and weather. A dryland alfalfa field cannot sustain the plant population that an irrigated field can. The risk of plant mortality is discussed in more detail later in this paper.

Option 2 – Starvation Diet. The second option, which is to deficit irrigate all fields and apply less water than the alfalfa needs throughout the season, is also considered to be less viable. Alfalfa yield increases with applied water in a linear fashion up to full potential ET. In other words, each additional unit of applied water produces the same increase in yield up to the point where full ET is applied. Applying less water during each growth period, will result in a higher percentage of the water being lost to evaporation (especially with sprinkler irrigation) and low yields at each cut. Evaporation losses are true losses to the system and do not increase alfalfa yield; whereas, water transpired through the plant contributes to yield. In addition, a lower yield over a larger acreage is less profitable than the same yield on fewer acres due to reduced harvest efficiency and perhaps increased costs associated with having to apply herbicides or insecticides to the entire acreage.

Water Early, then Cut-off– "Cold Turkey" Option 3. The best option for irrigating alfalfa when water supplies are insufficient is to fully irrigate all fields for the early cuttings and then cease irrigation part way through the season. This approach is often referred to as partial-season irrigation, early irrigation cutoff or summer dry-down. There are several advantages to this tactic. Spring and early summer cuttings are typically the highest yielding. In the Intermountain area approximately 75% of the annual production occurs by the second cutting in mid-July (Figure 1). And for the Central Valley and the Imperial Valley, approximately two-thirds of the annual production occurs by mid-July (Figure 2, 3).

Some alfalfa growth continues even after irrigation water is withdrawn utilizing stored soil moisture. Because yields are typically higher in spring and the ET rate is less than the summer, the water use efficiency (yield per unit of water) of the applied water is greater in spring than in mid-summer or fall. For this reason, if water supplies are low and the grower is forced to deficit irrigate, returns should be higher when the crop is fully irrigated in the spring than when the water is applied later in the year. In addition, alfalfa forage quality is higher in spring than summer and therefore demands a higher price.

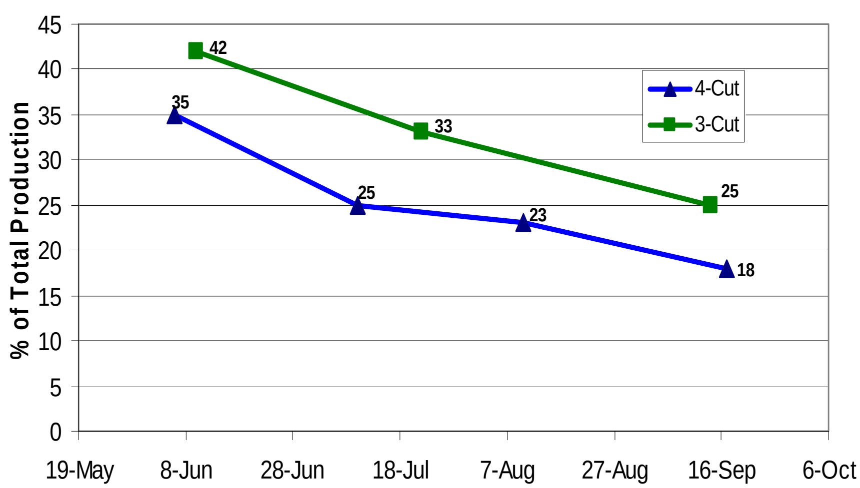

Figure 2. Percent of total seasonal production that occurs at each cutting with 3- and 4-cut schedules in the Intermountain area of California.

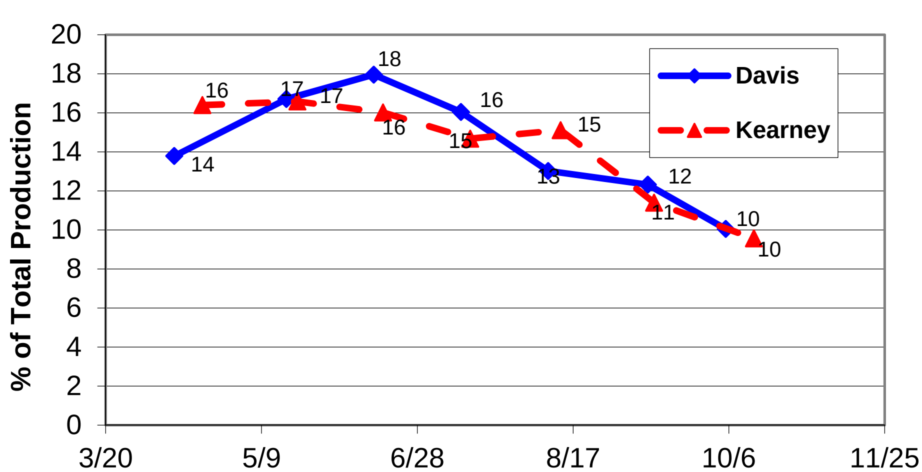

Figure 3. Percent of total seasonal production that occurs at each cutting in Davis and at the Kearney Research and Extension Center in Fresno County.

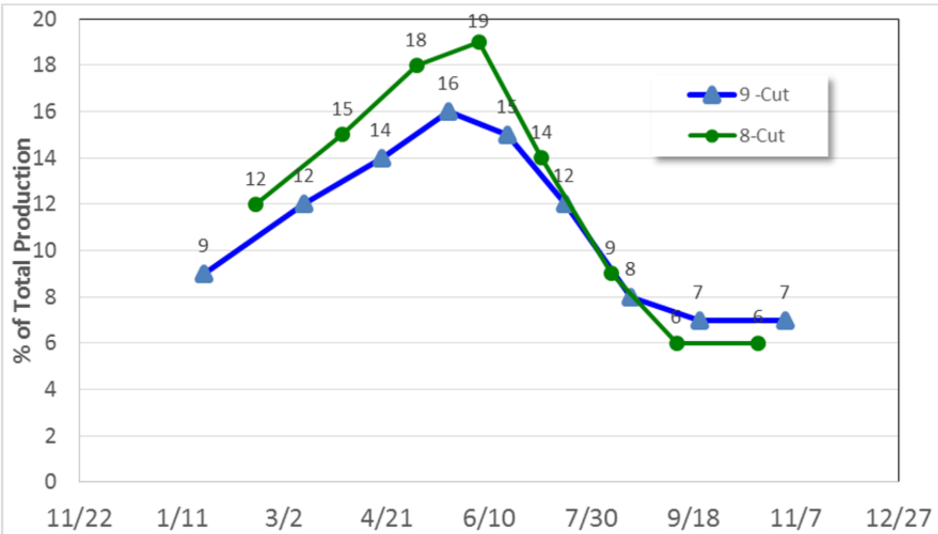

Figure 4. Percent of total seasonal production that occurs at the Desert Research and Extension Center in Imperial County for 8 and 9 cutting schedules.

IRRIGATION CUTOFF RESEARCH EFFORTS WITH ALFALFA

The big question with any partial-season irrigation program is "*What is the impact on yield?*" And, perhaps the more significant looming question is "*How is stand longevity and future performance affected?*" To help answer these questions we have conducted several trials in the Intermountain area, Central Valley, and Low Desert areas of California.

For the Intermountain studies, normal full-season irrigation was compared with cutting off irrigation before 1st cutting (June 1st) and cutting off irrigation before second cutting (typically July 15). For the Sacramento Valley studies, full season irrigation was compared with an early summer cut-off (no irrigation for 3rd, 4th or 5th cutting) or an early summer cut-off with a fall irrigation. For the Low Desert studies conducted in the Palo Verde Valley, full irrigation (a total of 6 irrigations from mid-July to mid-October) was compared with two summer deficit irrigation treatments. One summer deficit treatment had no summer irrigation and another had a single irrigation in July. Irrigation resumed after the September cutting.

It is no surprise that early irrigation cut-off reduced alfalfa yield at all locations and in all years (Figures 1, 2). With a forage crop like alfalfa nearly the entire above-ground biomass is harvested so it is logical that omitting irrigations would reduce yield. The level of yield loss was very site specific, primarily depending on the region of the state, the soil type and the depth to groundwater.

Intermountain Studies. The yield reduction that occurred in the Intermountain Region with the early irrigation cutoff ranged from 0.65 to 2.82 tons per acre (averaging 1.31 tons/A). The yield reduction when irrigation ceased before 2nd cutting ranged from 0.31 to 1.42 tons per acre (averaging 0.75 tons/A). This range in yield loss is significant, greater than a fourfold difference. The sites with that suffered the least yield reduction were those with an organic clay loam soil and/or a high water table.

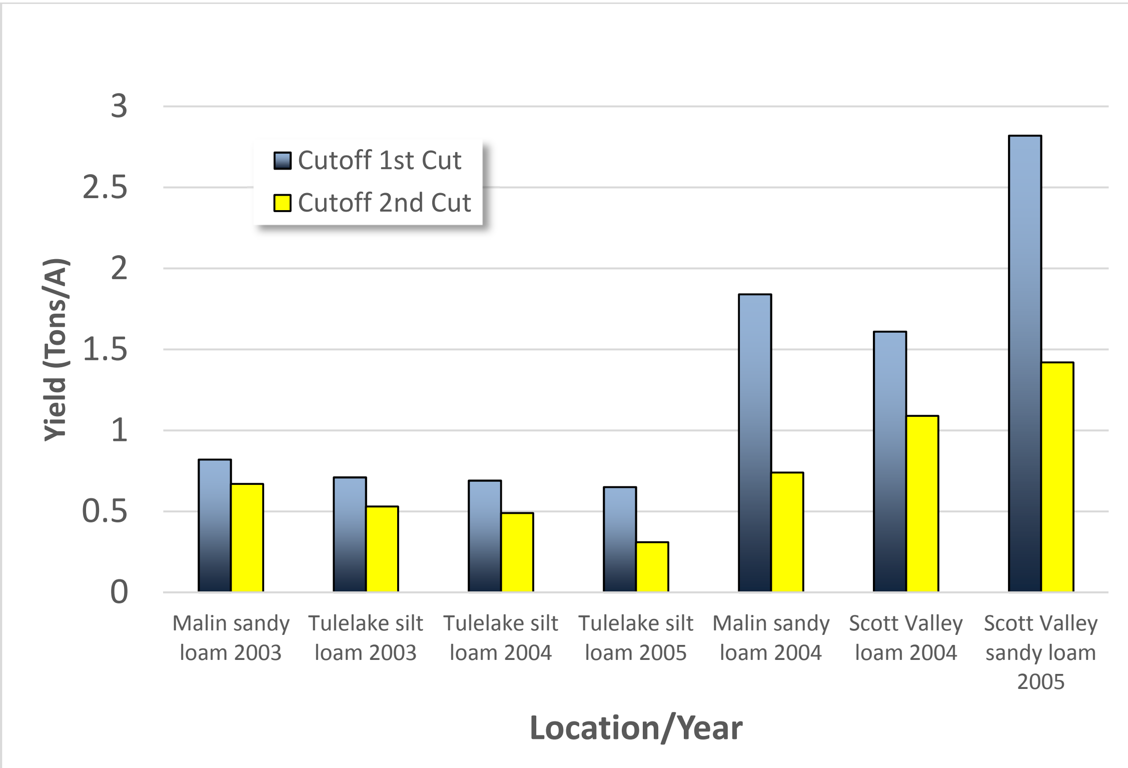

Figure 4. The reduction in alfalfa yield at several sites in different years from early-season irrigation termination (irrigated up until 1st or 2nd cutting) compared with full-season irrigation in the Intermountain Region of Northern California. Note the sites on the left of the graph had a heavier soil type and/or perched water table so the yield penalty was greatly reduced.

Sacramento Valley Studies. Yield reduction with a July irrigation cutoff in the Sacramento Valley studies ranged from 0.47 to 2.69 tons per acre, again depending mostly on soil type and soil moisture status. The seasonal yield reduction wasn't much less when the field was re-watered again in the fall. The amount of yield saved with a fall irrigation compared with the July cutoff and no subsequent irrigation that season was less than half a ton in most cases. There is a recovery period required after an alfalfa plant is severely moisture stressed resulting in a delay until normal growth resumes. In addition, in a flood irrigated field the irrigation after an extended drought period typically requires more water than a "normal" irrigation to refill the cracks and refill the soil profile. For these reasons, a single fall irrigation after a summer drought is generally not recommended in this area.

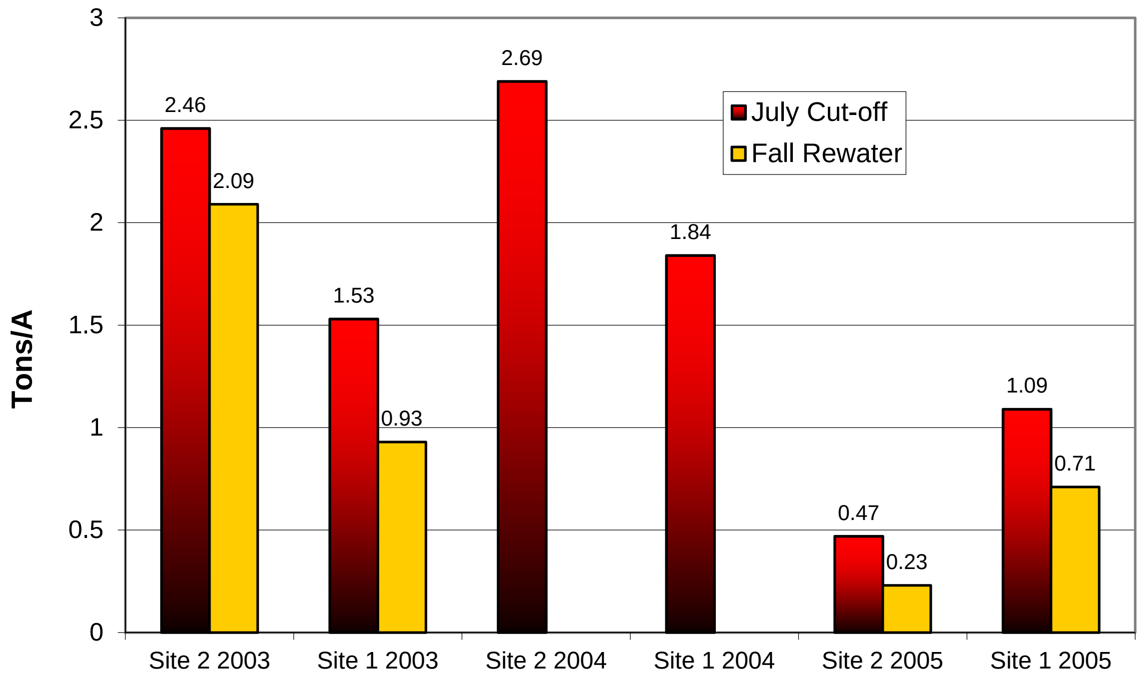

Figure 5. The reduction in alfalfa yield from a July irrigation cutoff or a July cutoff with fall irrigation compared with full-season irrigation in the Sacramento Valley. (The fall rewater treatment did not occur in 2004.)

Low Desert Studies. The net average yield loss at all four study sites was 2.16 tons per acre (Table 1). Water use efficiency during the summer was calculated to be approximately 45% lower than the first six month of the year. Implementing deficit irrigation practices during summer time where the water use efficiency is relatively low minimizes the impact of deficit irrigation on yield loss.

Table 1. The effect of summer deficit irrigation on the number of irrigations, water saved and the associated yield loss in the Palo Verde Valley of the Low Desert.

Irrigation Treatment	Number of summer irrigations	Water Saved (in)	Total Summer Yield Loss (tons/A)
Full Irrigation	6	0	0
No summer irrigation	0	23	2.16
Single summer irrigation	1	20	2.16

Effects on Stand Survival

Perhaps even more important than the effect of deficit irrigation on yield the year deficit irrigation is imposed is the long-term effect on stand survival and productivity in subsequent years. A grower may be willing to forgo irrigation for part of a season if forced to do so or if the water was needed for other crops or other uses provided there would be no long-lasting deleterious effect on the alfalfa. For most of the field trials mentioned above, we measured yield the following year and assessed the stand using visual stand ratings and counts of the number of stems per unit area. At the Intermountain and Sacramento Valley sites we observed no difference in stand or yield the following year whether the field was fully irrigated for the season or irrigation water was withdrawn part way through the season.

While we did not observe plant mortality or reduced yield in subsequent years, this will not be the case for all fields and all locations. Alfalfa survivability after drought conditions is highly dependent on environment, length of the growing season and duration of the drought period, soil type, depth to the water table, salinity and perhaps even the alfalfa variety. The intermountain area has a shorter growing season and is cooler than other parts of California and therefore, least likely to see a lasting negative effect from deficit irrigation. In addition, there is limited dryland alfalfa production in the Intermountain area, an indication that alfalfa can survive extended periods without irrigation in that environment. However, even in the Intermountain Region stand loss has been observed when alfalfa was only irrigated part of the year the year of seeding and the subsequent year. It appears that alfalfa needs to become sufficiently established or reach a critical size before it can sustain prolonged periods without irrigation. Stand loss has also been observed in commercial fields where irrigation water was withdrawn for most of the year. Alfalfa plants died in areas of the field with shallower soil where the alfalfa plants were weakened and likely had lower stored carbohydrate root reserves.

The greatest injury from partial-season irrigation has occurred in the Low Desert of California—likely due to the length of the growing season and the extremely high temperatures. In the studies mentioned above in the Palo Verde Valley, one field fully recovered after the summer deficit irrigation period while stand loss and reduced productivity occurred on a second field. Crop ET was monitored on these fields in the deficit and full irrigation areas. In one field, after irrigation was resumed following the September cutting, ET returned to the rates observed in the fully irrigated area. However, in another field, ET was still significantly less than the fully irrigated area even after full irrigation resumed. This is an indication of stand loss and/or severely reduced alfalfa vigor.

In general, alfalfa grown on medium textured soils has fared the best after a period of no irrigation, whereas stands have been lost on sandy soils or very heavy cracking clay soils. This is believed to be due to the hydraulic conductivity of the soils, or the speed at which water can travel through the pore spaces in soils to the plant roots. Many areas of the Low Desert have a relatively high water table or perched water table. In sandy soils not enough water can move upward from the water table to keep the plant sufficiently hydrated to be able to survive and in a heavy clay soil the rate of upward movement is too slow. In medium textured soil with relatively shallow water table, alfalfa roots can utilize the water table to survive if the salinity of the root zone is less than 15-20 dS/m. Once root zone salinity is above this limit, alfalfa roots may not be able to extract water from the soil profile despite the relatively wet soil profile near the water table.

Consider Mild Deficit Irrigation in a Drought Year to Save Water

No irrigation application method is 100 percent uniform and portions of the field receive more water than others. To compensate for this non-uniformity and to ensure that nearly the entire field receives enough water to satisfy ET, it is ordinarily recommended that growers apply more than ET. The amount needed to satisfy ET (net water application) is ordinarily divided by the application efficiency to arrive at the total amount of irrigation needed (gross water application). However, there are diminishing returns in terms of yield per unit of applied water when water is applied in excess of ET because some of the water is lost due to deep percolation or runoff. Ordinarily, this approach is accepted and is the recommended practice. Growers are averse to seeing dry spots in a field and their presence is generally considered to be a sign of improper irrigation management. However, in drought years when water is at a premium and supplies are insufficient, or water is needed for other crops, it may be advisable not to apply enough water to fully compensate for non-uniformity and apply closer to just the ET value. This will likely result in a few dry spots and the fields may not look as impressive to the neighbors, but it could save water and improve overall water use efficiency. This approach is effective during drought and water shortages, however, additional water should be applied in the future to compensate for the potential increase in salinity in the areas that experienced deficit irrigation.

DEFICIT IRRIGATION OF PERENNIAL FORAGE GRASSES

Perennial cool season grasses grown for hay and pasture are important forage crops in California and the West, and on a statewide basis second to alfalfa in terms of water use. Irrigated pastures are a very important part of western agriculture, consisting of about 15% of Western and about 7% of California’s irrigated acreage (Table 2). California’s cow-calf and beef industry is highly dependent upon this sector, worth over $3 billion/year.

Compared with alfalfa, the most common cool-season grass species in California (orchardgrass and Timothy for hay and tall fescue for pasture) are far less drought tolerant. Grasses have a fibrous root system unlike the taproot of alfalfa and their rooting depth is much shallower than that of alfalfa. As a result, alfalfa is better able to access deep soil moisture. And, as mentioned earlier, when moisture levels are extremely low alfalfa goes into a “drought-induced dormancy” and the plant typically recovers fully and resumes growth when sufficient water becomes available. In contrast, some grasses are not as resilient and plant vigor and density suffer after an extended drought period.

Table 1. Irrigated Pasture Acreage in Western States and US (source: 2012 Census of Agriculture)						
	Irrigated Pasture			Percent of Irrigated land		
State	2002	2007	2012	2002	2007	2012
Arizona	43,769	52,680	26,098	4.9%	6.4%	3.1%
California	760,302	741,911	490,553	9.6%	10.2%	6.7%
Colorado	411,906	571,192	406,654	18.9%	24.9%	19.3%
Idaho	458,432	432,671	320,782	16.2%	15.1%	10.5%
Montana	419,455	455,045	420,660	26.9%	29.2%	28.4%
Nevada	212,001	188,052	126,589	39.7%	37.4%	22.6%
New Mexico	190,627	181,776	90,214	29.1%	28.0%	15.3%
Oregon	491,801	511,453	363,479	34.7%	38.3%	28.7%
Utah	310,776	346,939	250,382	39.8%	44.1%	29.3%
Washington	153,227	146,399	83,433	9.2%	9.2%	5.4%
Wyoming	581,258	525,541	418,965	60.5%	51.3%	41.2%
Western States:	4,033,554	4,153,659	2,997,809	18.8%	20.1%	14.5%
USA	4,977,214	5,062,201	3,729,847	9.9%	9.8%	7.2%

Irrigation Cutoff Studies. Similar to the alfalfa irrigation cutoff studies mentioned above, research was done comparing the drought tolerance of different cool season perennial grasses to withdrawing water after first cutting and after second cutting in the Intermountain are of northern California (Tulelake). A total of 26 perennial grasses were evaluated: 10 tall fescue cultivars, 7 orchardgrass cultivars, 4 brome species, 3 wheatgrass species, a festulolium and a harding grass variety.

There was a striking difference between the results with pasture grasses and those we have seen with alfalfa. Alfalfa showed little effect immediately after irrigation water was withdrawn relying on deep stored soil moisture for growth; but perennial grass yields dropped off dramatically as soon as irrigation was withdrawn. Grass yield dropped off to an even greater degree on third cutting than second cutting and there was no forage to harvest for many of the varieties.

There was also a significant difference in the drought tolerance of the different species. Brome species and wheatgrasses were more drought tolerant than tall fescue or orchardgrass varieties. However, it was interesting to note that these drought tolerant species did not tolerate full-season irrigation and when fully irrigated for the entire season their stand declined dramatically. Orchardgrass varieties tended to tolerate a single season of deficit irrigation well but over time the stand did not persist as well as tall fescue varieties. It should be noted that the soil in Tulelake is an organic clay loam with exceptional water holding capacity. Orchardgrass would not likely last even a single season in other areas that have soil with a lower water holding capacity or hotter temperatures.

Some grasses appear to perform better under full irrigation and others under partial-season irrigation. However, the grasses that are best adapted to early irrigation termination (wheatgrass and smooth brome) do not tolerate full irrigation. Overall, tall fescue seemed to be the species best adapted to the combination of full irrigation and deficit irrigation. However, tall fescue would likely not tolerate early season irrigation termination at other sites as well as it did at IREC due to the depth and water-holding capacity of the soils in Tulelake.

Recommendations to Minimize Drought Impacts on Existing Fields

Pastures and grass hay fields are rarely replanted and growers must deal with the effects of the drought this year on their current fields. Steve Fransen, Forage Grass Specialist with Washington State University, has some advice for how to manage irrigated pastures and grass hay fields under drought conditions. The calendar for grass plants actually starts in the fall when root growth is initiated and new growing points (or meristematic tissue) are formed. This sets the stage for forage production potential for the following year. Root shedding in grasses typically occurs from late June until early September when the roots begin to regenerate. Then over the winter root shedding occurs again (roots turn from white to tan to brown to black as they decompose) until new roots are formed again in spring.

The plant crown or stubble is extremely important for grass survival. That is where the plant stores sugars and carbohydrates for respiration and subsequent plant growth. Alfalfa stores most of its sugars and carbohydrates in the tap root and crown (commonly called root reserves). In contrast, around 85 to 90% of the stored grass sugars are in the stubble internodes—only a small amount of sugar is stored in the roots. If grass plants do not have adequate stubble for carbohydrate storage, plant mortality can occur.

It may be tempting in a water-short year like this to get as much as you can out of a pasture and graze it to the ground. However, even though the stubble may appear brown and dead, it is not. It is simply dormant and the sugars and starches can be remobilized and used for respiration and plant growth. Therefore, it is important not to cut too short hayed fields too short or graze the bottom 3-4 inches of the grasses because their storage function is critical for next year's production.

If plants are mowed or grazed too short the following can occur:

- The newly forming tillers can be starved of important sugars and starches
- The plant is more exposed and less protected from extreme weather
- Root formation is curtailed
- New tillers the following spring grow slower with fewer roots to support them

So even though it may be tempting to graze drought-stressed pasture close to the ground to greater utilize the available forage or cut short to maximize production, this is a mistake in the long-term and is likely to affect future productivity. Leave 3-4 inches un-grazed from fall throughout the winter even if that plant material appears dead.

The fertility status of the field is another factor to consider to help revive grasses after drought stress. Fall is a good time to fertilize pastures, including moisture-stressed pastures, with phosphorus and potassium. Fall is a good time to make an application because these nutrients are needed for the development of new roots and meristematic tissue.

There is no simple surefire way to improve the productivity of perennial grass fields after drought. However, to maximize the likelihood of recovery, it is important to leave 3-4 inches of stubble un-grazed or un-mowed, fertilize with P and K in the fall if needed, and irrigate properly once irrigation water is available again.

SUMMARY

Alfalfa can be produced under deficit irrigation conditions, even during droughts. The best strategies in dealing with water deficits are to 1) If possible, move water from older fields to newer, more productive fields, and abandon weedy, non-productive fields, 2) Water alfalfa fields starting with a full soil profile in the spring, and water fully through mid-summer, then cease irrigations for the remainder of the season. This has the effect of maximizing both yield and quality, as well as the water-use efficiency of crop production. Cool season grasses are less tolerant of drought than alfalfa, but there are some significant differences between species and varieties. Tall fescue varieties are likely the best option for optimum survival during drought, as well as maximizing yields during fully-watered periods. The flexibility of alfalfa to be deficit-irrigated is a major advantage to irrigation districts and farmers who need to determine strategies to continue viable agriculture during severe drought periods.

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