THE IMPORTANCE OF ALFALFA IN A WATER-UNCERTAIN FUTURE

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ABSTRACT

It is a favorite sport of journalists to point to crops that use lots of water (almonds, alfalfa) as being worthy of scorn during a drought. However, this simplistic examination of water demand vs. supply is not likely to be productive. Water use should be balanced with productivity, economic return, and…food production. A more important consideration is the resiliency of agricultural food-producing systems given the certain variation in water supply which is a current and future reality. Alfalfa has a key role to play in a water-uncertain future due to its high flexibility during times of insufficient and excess water, due to important biological features: 1) its deep roots which allow the use of residual moisture, 2) multiple harvests can give partial economic yields when irrigation ceases, 3) alfalfa roots survive summer dry-downs, and regrows when re-watered, 4) it can be flooded in winter to recharge aquifers, and 5) high salinity tolerance. Alfalfa has proved to be highly flexible and resilient in surviving droughts while sustaining productivity, even when as little as ½ the water requirement is applied. Contrary to superficial thinking on crop choice concerning water supply, alfalfa, with its high flexibility, is an important component to adjust to a water uncertain future.

Figure 1. *The resilience of alfalfa was demonstrated during the 2021 drought at Tulelake, CA, where a full yield of two-cuts of alfalfa was observed with zero irrigations. Only six inches of rainfall occurred before March. Roots were deeper than 8 feet. This is an unusual result due to the excellent water holding capacity of this soil, but illustrates the resiliency of alfalfa with limited water supply (Photo, July, 2021. D. Culp).*

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INTRODUCTION

Signs on many highways in the West read 'Food Grows Where Water Flows". A deeper truth for agriculture could not be spoken. Crops and plants simply use a lot of water to grow. It's just a fact. This is illustrated by the fact that California (for example) utilizes approximately 40-42% of its water for agriculture, while total urban use for 40 million people in the most populous US state is about 10-12% (Mount and Hanak, 2019; DWR, 2021). Environmental allocations account for the remainder, either policy-driven environmental allocations or excess river flows during high runoff. The oft-quoted '80% used in agriculture' (Guo, 2015) considers only the water controlled for human use.

It is often surprising to urban dwellers that food production takes so much water as illustrated by the fact that many will use 'gallons' as a measure, whereas agriculture uses 'acre-feet' (AF). An AF is about 326,000 gallons. Most crops use 1.5-4.5 AF per acre, with the total used by ag in California ranging from 25.8 million AF to 33 million AF per year (Johnson and Cody, 2015).

Why do plants require so much water? Physiologically, plants require 'turgor pressure' to drive photosynthesis and growth. The very moment turgor pressure is lost (wilting), cell expansion stops, growth ceases, carbon dioxide cannot be taken into the stomates (Figure 2), photosynthesis slows and stops. Water must be present in a continuous stream from soil through roots and xylem to evaporate from leaves. If humans were plants, we'd require 50-gallon drums of water attached to each foot! While many plants can sustain short-term deficits, plant growth of any type sufficient to produce the yields required for a productive agriculture must be grown (generally) in a water-rich environment. This is especially true with herbaceous crops like alfalfa.

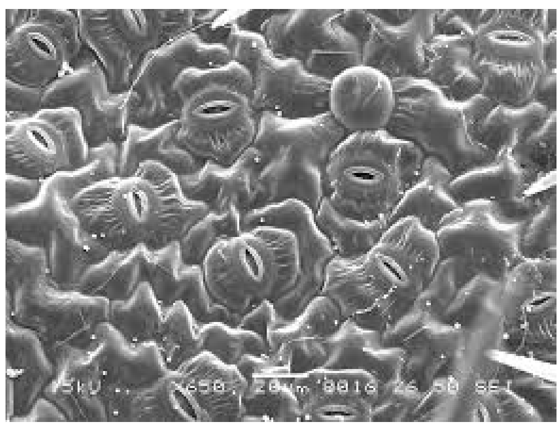


Figure 2. *The stomates on leaves must have turgor from adequate water, allowing* CO_2 *to enter the plant for photosynthesis.*

However, crops differ in their pattern of water use, annual demand and drought tolerance. Annuals, for example require water for germination and establishment and often have shallow root systems, but can be easily fallowed during drought and grown during winter. Trees and perennials have deep roots and (as with alfalfa) often grow all season long. Orchards are more difficult to stop watering during droughts. Crops differ in harvest index (HI-percentage of the crop harvested), which affects Water Productivity (crop yield produced per unit of water). Crops differ in the timing of water demand and rooting depth. Here, we examine the characteristics of alfalfa vis-à-vis its ability to sustain production during variation in annual water supplies.

DROUGHT CRISES – VARIATION IN SUPPLY IS THE KEY ISSUE

Periodic Crises. While droughts get most of the attention, variation in water supply in the West is probably a more important consideration. Periodic drought, disappearing groundwater, and even flooding events have been a reality in western states for decades and are likely to be

Figure 3. The 2017 California floods in (Elk Grove, CA) were followed in 2021 with severe drought (Folsom Lake, CA). Coping with variation in water supply is a key component of the future. Photos: NY Times (top), CNN.

exacerbated in the future due to climate-change and increased demand. As recently as 2017, the Central Valley of California experienced floods, while 2021 saw the most severe drought seen many years (Figure 3). For the first time ever in 2021, Colorado River managers reduced allocations to water users in Nevada and Arizona due to the ever-decreasing supplies in Lake Mead and Lake Powell (Wilson and James, 2021). Crop growers in the Klamath watershed were suddenly cut off in 2021 due to the drought and the Endangered Species act, causing tremendous disruption and anger (Baker, 2021). This year was one of the worst droughts we've seen throughout the West, but we must admit, the pattern is nothing new. The 2021 Klamath situation mirrored 2001, when water was cutoff to protect the Klamath sucker fish.

There are few simple answers to these large looming issues for the West. High demand by all players is a key component. However, variation in water supply is likely to be the more prominent feature of water supply situation in the future, not just drought. Some reservoir and aquifers (not all) can be re-filled with a few years of good precipitation. Excesses followed by drought are an on-going reality. In a time when satellites can monitor water use and laws can dictate water usage (Charles, 2021), and tools like Open ET (NASA 2020) can be estimate the amount of water different crops, all crops will be the subject of intense scrutiny. The SGMA regulation of groundwater in CA (DWR, 2021a) will have profound effects on cropping systems. Re-envisioning cropping systems that will adjust to these conditions is key. How can alfalfa contribute to these systems?

CHARACTERISTICS OF ALFALFA THAT PROMOTE SUSTAINABLE IRRIGATED CROPPING SYSTEMS – HIGH FLEXIBILITY IS KEY

Economic and food-producing value. First, all crops within a region must pass the test of profitability as well as beneficial food production. Alfalfa is often one of the more important crops in economic returns to growers in many western states, and sustains many farms. Additionally, alfalfa is a significant food producer, though not often considered as such. Dairy is the most important agricultural enterprise in California at over $7.5 billion/year in farm value ($19 billion in other values). Similarly, dairy is economically critical in other western states (particularly ID, OR, NM, TX, WA). Western states now produce about 50% of the nations' milk. Alfalfa and other forages are 'engines of food production', and the basis of on-farm profitability for thousands. Water impacts must be balanced with the value created.

Deep Roots and Utilization of Residual Moisture. Alfalfa roots have been documented as deep as 15 feet (Figure 4), and routinely explore soils in the 3-8foot range when soils provide no impediments (Figure 1). Residual moisture from previous irrigation and rainfall events (months earlier) are often very important in sustaining alfalfa production during times of lack of surface water from rain or irrigation. The deep roots of alfalfa prevent over-irrigation past the root zone, improving utilization of water to produce crop yield (water-use efficiency). These vigorous root systems also improve soil water infiltration and soil health.

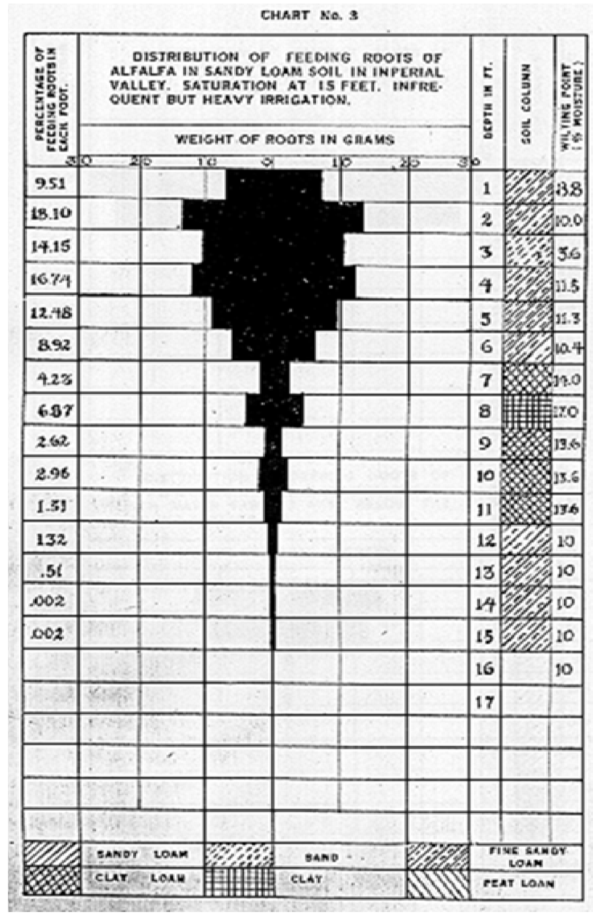
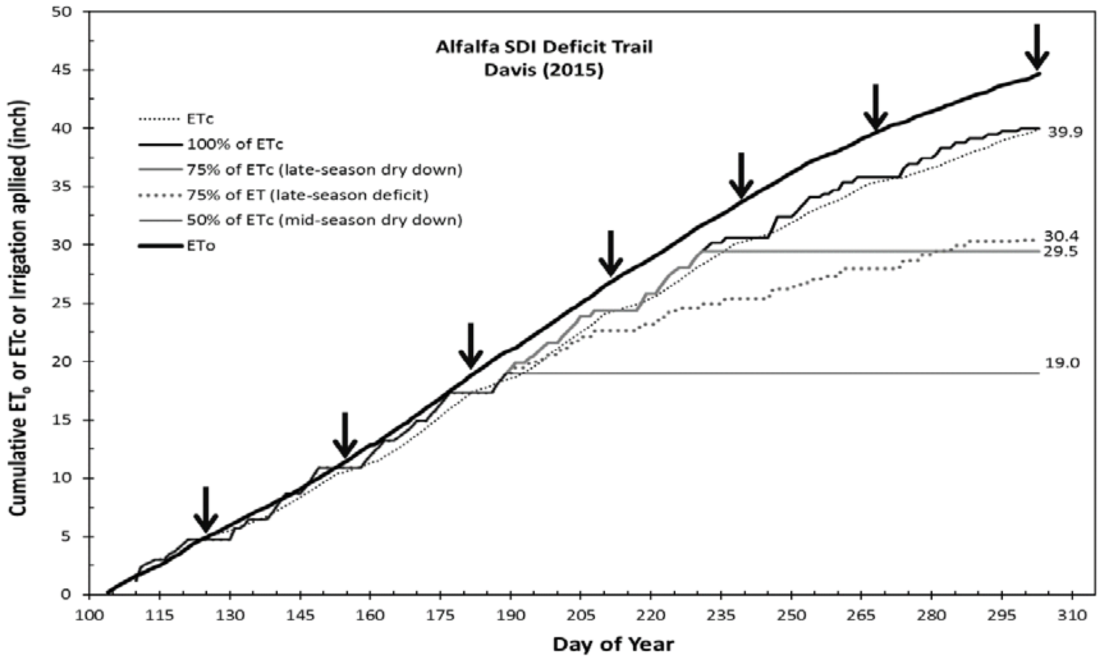


Figure 4. Distribution of alfalfa roots at depths showing most activity in the top 6 feet of depth, but roots were observed to 15 feet in the Imperial Valley of California (USDA publication, circa 1910).

High flexibility during droughts. There is now considerable data that confirms the ability of this crop to sustain forage production when irrigation is reduced during droughts. No grower would prefer to under-irrigate their crop, but when necessary, this crop tolerates short-term droughts in most cases. Yields are almost always lower when under-irrigated, but the crop can still produce adequate yields (Figure 5). Yield penalties from deficit irrigation strategies widely vary by soil type and environment (Cabot et al., 2017, Montazar, 2020). Alfalfa often enters a 'summer dormancy' in most cases after utilizing residual moisture. This is not a zero-irrigation strategy, but offers the ability to 'turn off the tap' when water is simply not available or needed for other uses. Savings in water during summer months can be as much as ½ of full watering normally applied through irrigation systems (Figure 5).

Multiple Harvests, Partial Season Production. While most crops are harvested once during the year, alfalfa is harvested multiple times. In most environments, over 60% of the production is realized by mid-summer (Figure 6). In short-seasoned environments, harvests range from 2 to 5 and in longer-season environments 7 to 12 harvests. Yields typically decline later, even if fully watered (Figure 5, 6). "Summer slump" (Ottman and Putnam, 2013) is a common observation in alfalfa. Some of the later cuttings may not be fully economic even if fully irrigated. The highest alfalfa yields (and highest quality) occur during the first few months of production at a time of highest water use efficiency and lowest ET (Figure 5). This enables partial-season production with limited water.



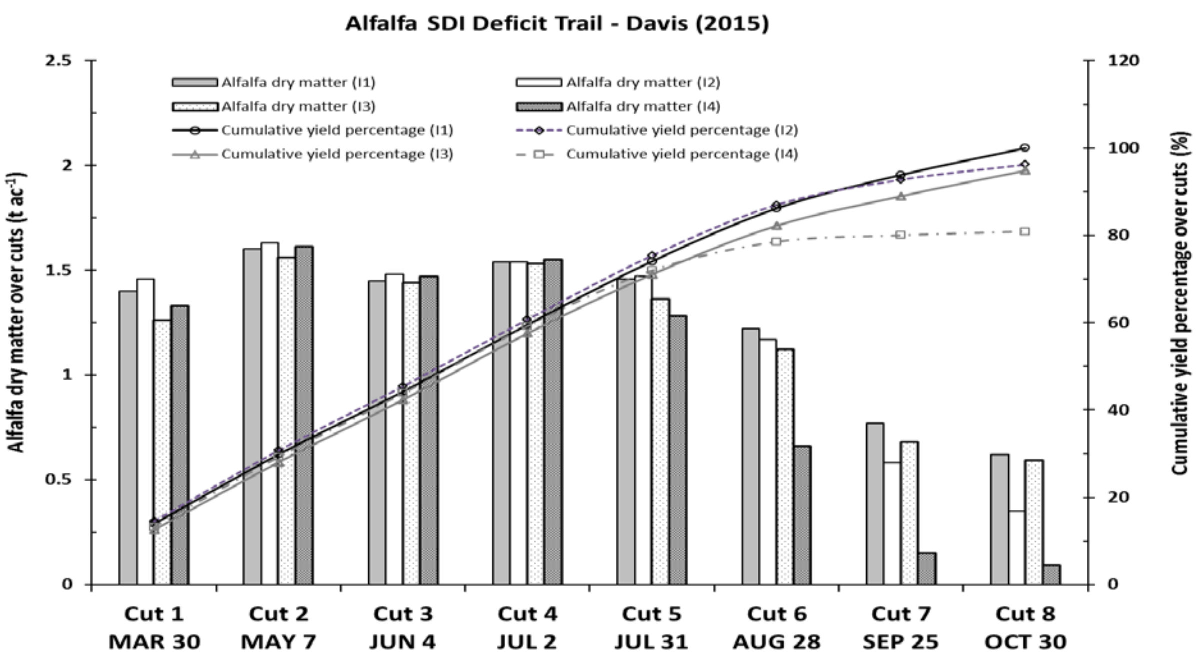


Figure 5. *Cutoff of irrigation water after July 4 of 50% of irrigation applications (top graph), resulted in about 80% of full yield, (bottom graph) while cutoff (gradual or sudden) at 75% of ET irrigation demand resulted in 95% of full yield. Savings of up to 20" of irrigation water were observed. This is due to the high productivity in early harvests, and use of residual moisture even after irrigations cease (data Davis, CA, 2015).*

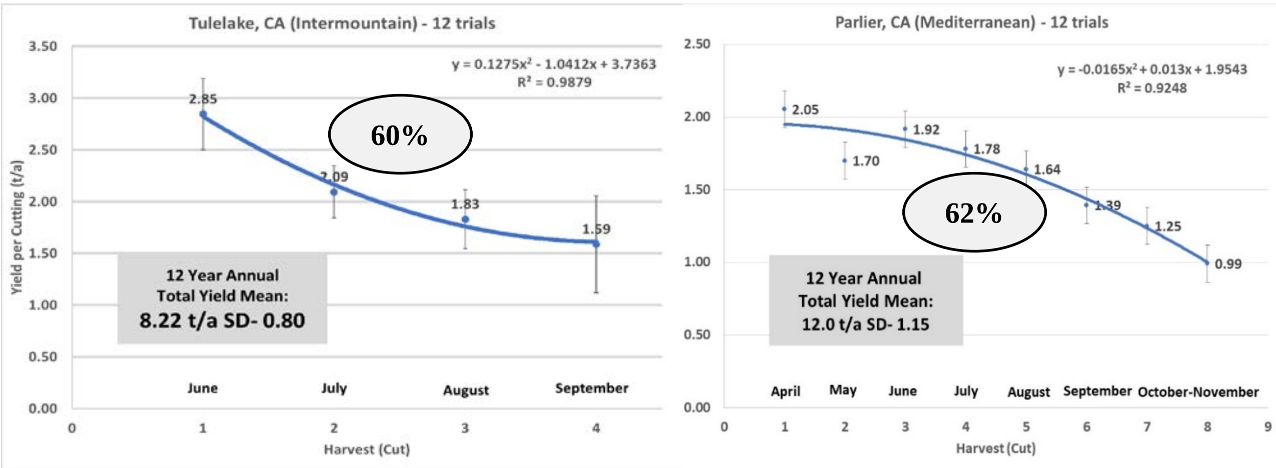


Figure 6. *Alfalfa yield patterns in a short-season 4-cut system (Tulelake, CA) and 8-cut long-season system (Parlier, CA), average of 12 years of variety trials at these locations. Over 60% of seasonal yields are obtained before early-July at times of greatest Water-Use Efficiency.*

Drought Survival, Production upon re-watering. When partial-season dry-downs are necessary, will the crop survive and recover to produce when watered again? The answer is generally 'yes'. When deficits were applied in Colorado studies, in virtually all cases, the fully-watered crop recovered in the following year (Figure 7-Cabot et al., 2017). In several of these on-farm Colorado studies, the production of re-watered crops following two years of stress was superior to fields that were previously well-watered (Cabot et al., 2017). We've found similar recovery of previously-stressed alfalfa in California studies (Figure 7, Frate et al., 1992); About

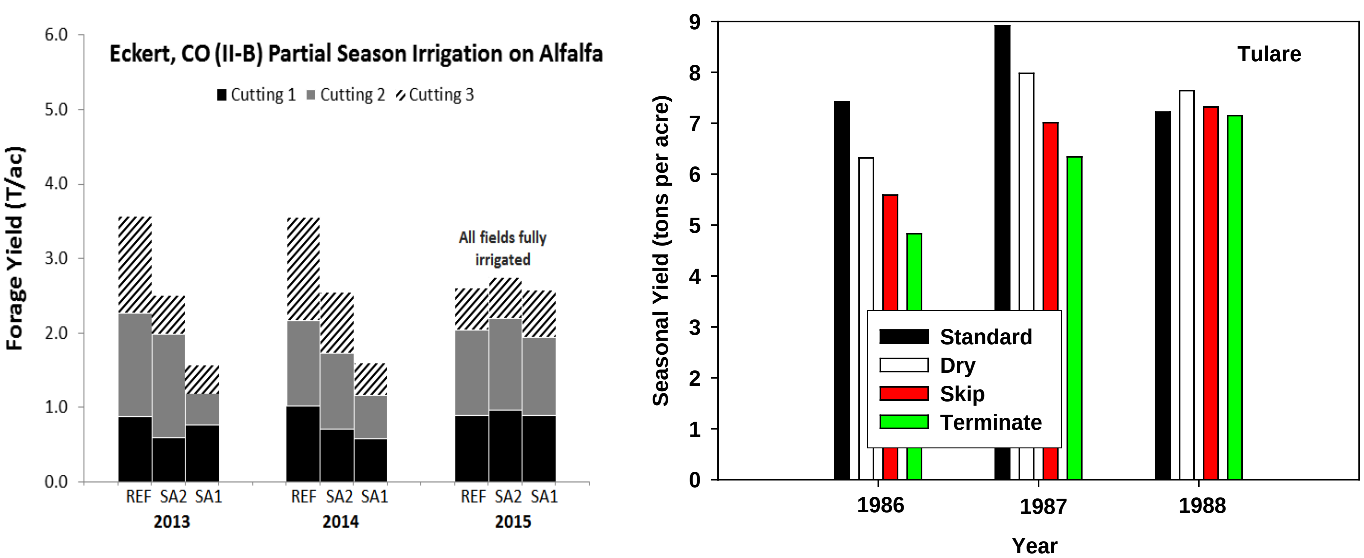


Figure 7. *Deficit irrigation treatments in Colorado (left) and Fresno Co., California (right) both showed yield reductions during dry-downs, but the crop recovered fully in the follow year when the crop was re-watered (Cabot et al., 2017, Frate et al., 1992)*

½ the irrigation water was saved in the Fresno study. The only exceptions to this result have been on the harsh cracking-clay soils under high salinity and intense heat of the Imperial Valley, where stand decline from summer deficits is more common.

High Water Productivity, High Harvest Index. The harvest index (HI-the percentage of above-ground crop harvested for an economic product) of alfalfa is about 100%, whereas in most crops the harvest index is from 10-50%. This, in addition to its high yield and deep roots, is the reason that alfalfa is among the most efficient plants in Water Productivity (sometimes called Water-Use Efficiency) – the amount of dry matter produced per unit water.

Ability to be over-watered in Winter to Recharge Aquifers. Given the high variation in annual precipitation (Figure 3), the value of excess capture has not escaped the attention of water managers. The concept of Flood-MAR (Managed Aquifer Recharge) which promotes flooding of fields during times of high river flows have been studied (DWR, 2021b). Alfalfa has been found to be suitable to this practice, with up to 30 feet of water applied to permeable soils with minimal crop damage in Intermountain and Valley locations (Dahlke et al., 2018). More recently, Bali et al. have shown winter flooding events not to damage alfalfa yields, in fact

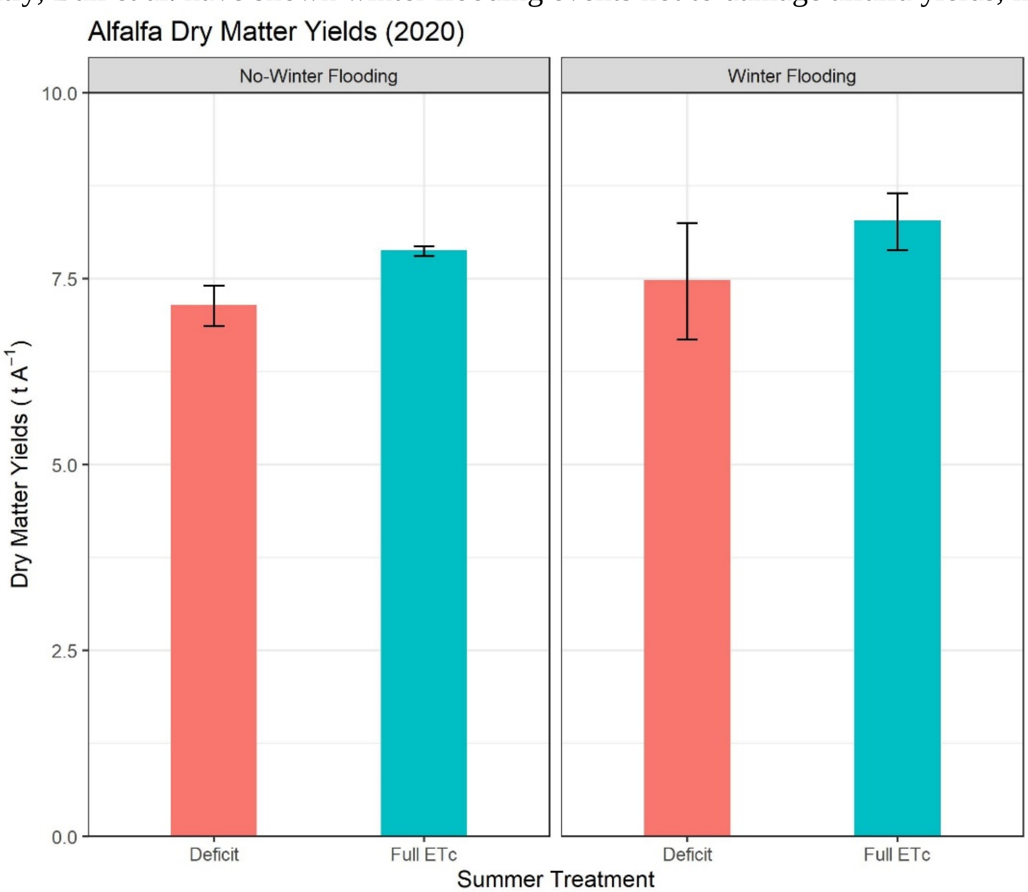


Figure 8. *Effect of winter flooding on alfalfa yield, Parlier, CA, 2020. Treatments that were deficit irrigated (red columns) in the previous year were compared with fully irrigated 2019 treatments (blue). Crop regrowth benefitted from winter applications. From 8-10 AF of water was applied during winter periods with the intent to recharge aquifers.*

benefitted yields due to the early irrigation events (Figure 8), which were similar to the results found at Davis (Figure 9). Alfalfa has an advantage vs. fallow or other crops, in that nitrate contamination of groundwater is likely to be a lower risk during excesses. However, it is well known that alfalfa can be damaged with excess flooding, so only some soils are suitable for this practice, and care must be taken to reduce oxygen deficits since flooding can kill alfalfa stands.

Water Early, Apply Deficits Late. Due to this seasonal production pattern (Figures 5 and 6), emphasis on early production is key. Irrigation water is typically more available early in the season or winter periods, and more precious in mid-late-summer. In 2021, we flood-irrigated selected plots of an alfalfa study field that was full and deficit irrigated in previous two years under advanced overhead linear move irrigation systems. We found that early season (February-March) irrigations not only increased yields in the first three cuttings, but also sustained stands and yields later in the year, even when deficits were applied in the summer (Figure 9). Early season irrigation followed by summer cutoffs are recommended to cope with lack of water over the summer months. This technique may be an important strategy to cope with droughts.

Salinity tolerance. Buildup of salinity is an unwanted consequence of drought. Contrary to some published accounts, alfalfa is highly tolerant of salinity. Over four years of field trials in Fresno County with applications of saline waters (ECw from 8-11 dS/m), we observed a buildup of salinity effects over time, and the average yield effects was about 22% penalty over the four years (Table 1). However, yields in this case were still high and economically viable in saline plots. It is obviously not desirable to continually build up salinity, but these data confirm the tolerance of this crop to these harsh saline conditions. This would enable alfalfa to be grown utilizing degraded water (municipal wastewater, manure water, drainage water), a valuable trait to extend water supplies.

Table 1. Effect of salinity on yield, average of 35 alfalfa varieties, over four years, Five Points, CA, 2017-2020 (planted 3/29/17). Water with ECw of 8 to 11 dS/m was applied to saline plots, and 1-2 dS/m to low saline plots. Soil salinity at the completion of the trial ranged from 12-16 dS/m EC depending upon depth. Unpublished data (D.H. Putnam, UC Davis).

	2017 Season Yield - 4 cuts		2018 Season Yield 7 cuts		2019 Season Yield 8 cuts		2020 Season Yield 7 cuts		Cumulative Average (t/A)	
	Salinity Level									
	Low	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
	tons/acre									
Minimum	3.5	3.6	10.2	7.9	11.4	9.9	12.0	7.7	39.0	30.5
Maximum	6.0	5.5	14.6	11.3	16.2	13.3	17.3	13.0	52.7	42.7
Average	4.8	**4.6**	12.3	**9.6**	14.4	**11.5**	**14.7**	**10.2**	**46.1**	**36.1**
Yield loss	**4%**		**22%**		**20%**		**31%**		**22%**	
Treatment Mean	4.7		11.0		13.0		13.0		41.1	
CV%	16.3		16.5		12.8		20.5		10.0	
LSD (p=0.05)	0.2		1.8		1.6		0.6		1.0	

SUMMARY

Although the sum-total water demand for a fully-watered alfalfa crop is high, this is mostly a function of its high yield and season-long growth pattern. Under highly variable water supplies, alfalfa cropping systems offers tremendous flexibility due to its ability to be deficit irrigated and recover from droughts to yield normally. Alfalfa should be considered an important element of future irrigated cropping systems designed for highly variable water supplies. Techniques for growers to adapt to ongoing water challenges are necessary.

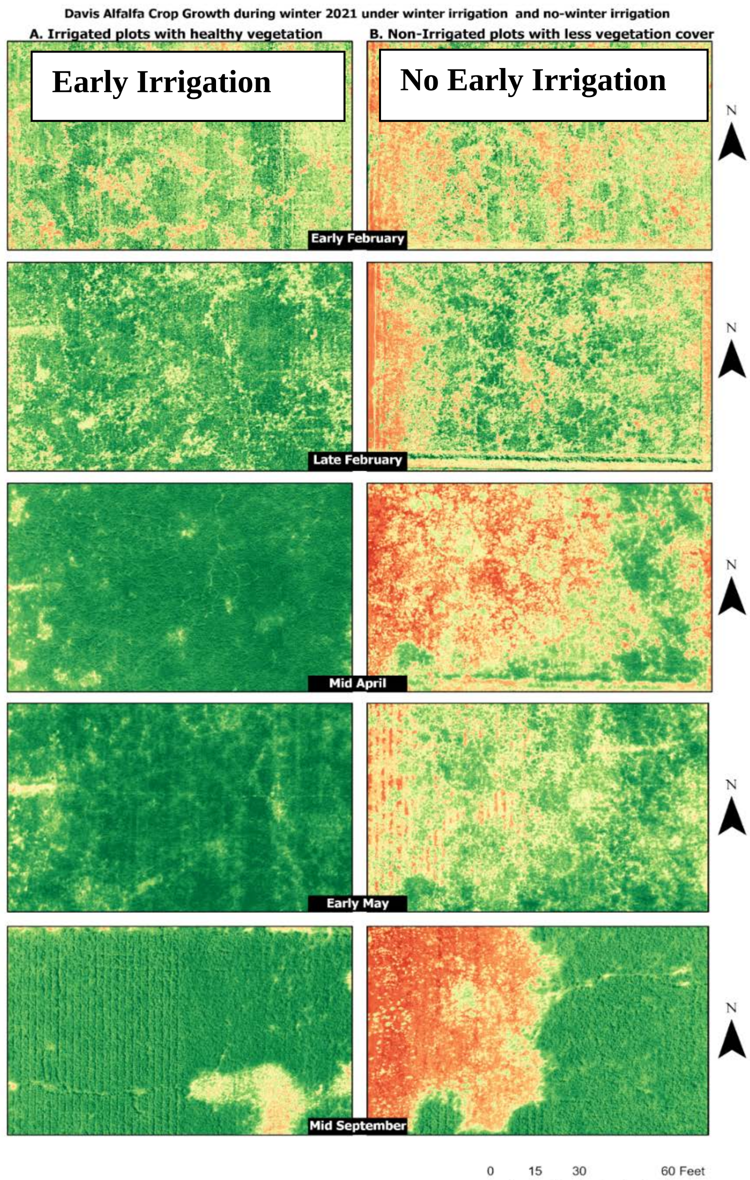


Figure 9. *Value of early season irrigation during drought periods, Davis, CA, 2021 illustrated with drone images. February and March flood irrigations greatly benefitted early growth and yields, and the benefit was observed even as late as September. Red/yellow areas indicate crop stress and poor growth.*

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