PROFITABLE ALFALFA PRODUCTION SUSTAINS THE ENVIRONMENT

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ABSTRACT

Although alfalfa, or lucerne (*Medicago sativa L.*), is frequently characterized as a 'low value' crop, this is a misnomer. Alfalfa forage is frequently the number three economic crop in the US, with corn and soybean #1 and 2. However, this valuation does not include the wider economic value of the food end-products that nourish consumers each day originating with alfalfa. Alfalfa is an 'engine of food production', and on-farm profitability can sometimes rival that of high value crops such as processing tomato. High yield is the primary driver for economic value in alfalfa hay. Since high yields are positively correlated with healthy deep root systems, excellent stand density, soil conservation, stand longevity, high CO_2 fixation and high levels of N_2 fixation, high yields of intensive alfalfa production also contribute to environmental goals. These environmental services often go unrecognized, but include soil health, benefits to crop rotations, wildlife habitat, and reduction of the applications of fossil-fuel fertilizers. These benefits are well-known to farmers, but are rarely valued by our society as a whole and minimally monetized. Although the crop is often criticized for its water-wasting ways, the reverse is actually true: the deep roots, high water use efficiency, salinity tolerance, and (most importantly) its ability to produce <u>some</u> economic yield when water supplies are scares make alfalfa an important component for a water-challenged future. 'Profitable alfalfa production sustains the environment' – the title of this year's Alfalfa Congress is a statement of fact as well as a vision for the future.

ALFALFA AND ECONOMIC VALUE

Alfalfa is one of the world's oldest domesticated crop with a history dating to before 2,000 CE. However, what is its relevance today? Alfalfa competes with wheat as the 3rd or 4th most important economic crop for farmers (Table 1), in spite of the decline in acreage over the past 20 years (Figure 1). Alfalfa is important in many other regions of the world as well. It remains a vital component of modern cropping systems due to its high yield, and its high-quality production for dairy animals and other livestock, and its value in rotations. It is a vital component of cropping systems that benefits many farmers. Although not widely recognized as a food-producing crop, hundreds of millions of people consume a food product originating with alfalfa each day.

Table 1. Value of Production, Top 10 Crops, with value of the two major livestock sectors, United States 2019-2021

Crop/Product	2019	2020	2021	RANK ($)
	(US$ Billion Dollars)			
Cattle and Calves	66.3	63.1	72.2	
Corn Grain	48.9	64.3	82.6	1
Soybean	30.5	45.7	57.5	2
Milk and Cream	41.9	40.6	40.7	
Hay/Silage/Greenchop (all)	20.5	19.9	21.9	3*
Hay (alfalfa)	**10.8**	**10.2**	**11.6**	**3rd or 4th**
Wheat (all)	8.9	9.4	11.9	3rd or 4th
Cotton (all)	5.9	4.8	7.5	5
Potatoes	4.2	3.9	4.1	6
Rice	2.6	3.3	3.1	7
Sorghum	1.1	1.8	2.5	9
Peanuts	1.1	1.3	1.5	8
Sugarbeet	1.2	1.1	1.7	10
All Field Crops	**130.8**	**163**	**201.1**	
All Fruit and Nuts	**29.0**	**29.1**	**	

*Source: USDA-NASS (NASS.USDA.GOV). *Hay/Foage/Greenchop includes all harvested grass and alfalfa forage, does not include pasture or rangeland. Alfalfa is a subset of all hay and forage.**data not yet avaialble*

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What is the Value of Alfalfa? Often, the economic 'value' of a crop is simply calculated as the 'farm gate' value. In this ranking, alfalfa is either 3rd or 4th in the US (Table 1), pretty high. However, is that the only way to understand economic value? Wheat, for example is frequently considered a 'low value' crop since returns to growers are relatively low, but thousands of loaves of bread can be produced from an acre of wheat (Table 2). The 'low value' (low price) of a crop is often due to its high productivity! Table 2 compares several 'low and high- value' crops produced in California, the farm gate value, and projects a consumer value of common products produced from these crops on an acre basis. Although the calculation of 'milk yields' coming from an alfalfa field is complex (alfalfa is only one ingredient in a dairy ration), a projection was made using the milk/ton equation from the University of Wisconsin. Alfalfa fields are capable, using average figures in irrigated regions, of producing a potential of over 2,000 gallons of milk per acre.

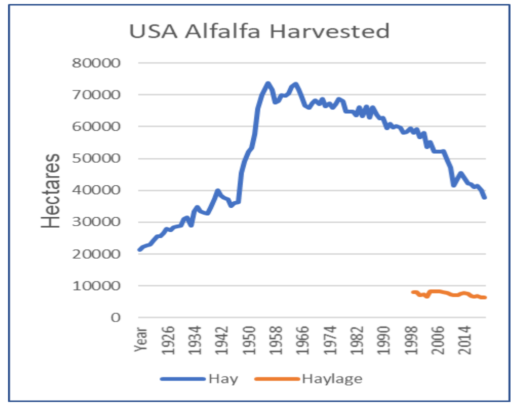

Figure 1. *Alfalfa hectares have been reduced in recent years due to various factors (data USDA-NASS).*

Table 2. Acreage, yield, and per-acre and consumer value of Several important California Crops (2020-2021 data) - Retail value produced per acre given as examples.

Farm Production					Products produced: Value to the Public				
Crop	**CA Acreage**	**Crop Yield**	**Farm Gate Value $$/unit**	**Value ($/acre)**	**Common Retail Product**	**Units Produced**	**Retail Per Unit**	**Retail Value Per Acre**	**California Consumer Value**
	acres	lbs/a	$/pound	$/acre	Item	Product/acre	$/unit	$/acre	
Wheat (grain)	100,000	4,640	$ 0.11	$ 510.40	Loaf of Bread (1 lb)	4,408	$2.50	$11,020	$1,102,000,000
Rice (grain)	407,000	7,200	$ 0.16	$ 1,152.00	Bag of White Rice (1 lb)	6,840	$0.60	$4,125	$1,678,679,640
Alfalfa (hay)	510,000	14,400	$ 0.13	$ 1,800.00	Bottle of Milk (gal.)	2,459	$3.53	$8,680	$4,426,937,700
Almonds (shelled)	1,250,000	2,040	$ 1.76	$ 3,590.40	Nuts in a Can (1 lb)	1,836	$5.50	$10,098	$12,622,500,000
Lettuce (head)	80,000	38,000	$ 0.30	$ 11,400.00	Head of Lettuce (1 lb)	36,100	$1.78	$64,258	$5,140,640,000
Tomato (Processing)	248,900	94,000	$ 0.05	$ 4,794.00	Can of Tomato Sauce (lb)	21,858	$0.89	$19,454	$4,842,006,018
Grapes (wine)	580,000	11,760	$ 0.34	$ 3,963.12	Bottle of Wine (1 liter)	3,772	$8.08	$30,478	$17,677,100,800

**Note; These crops differ significantly in dry matter content. Production data from NASS sources and CA ag. statistics sources. Most retail prices taken from consumer price Index. Wheat and rice assumed to produce products at 95% of crop yield and almonds 90% of nut yield. Alfalfa to milk calculation using the University of Wisconsin milk/ton calculation. Conversions of grapes and tomato based upon industry estimates.*

Why is this type of comparison of interest? First, it illustrates the tremendous productivity of agriculture to the consumer. Secondly, since all crops utilize precious land and water resources, the public needs to know whether such allocations are 'worth it'. Water is widely considered a public resource, and this becomes particularly important in fights over water during drought. Witness the frequent discussions in the media about producing 'low value' crops with water resources, forgetting that these are typically the staples of human diets and of enormously importance to the consumer.

However, are food products and farm profitability the only benefits of alfalfa?

ENVIRONMENTAL SERVICES OF ALFALFA

Sustainability for agriculture has become a catch phrase for government agencies, businesses, farmers and researchers in recent years. Many businesses have 'Sustainability Officers', recognizing the importance of environmental impacts of their activities and supply chains. As the global population closes in on 8 billion souls, the uncertainties of climate change, water supply, loss of habitat, and limitations of soil and water are real concerns for agricultural systems and farmers, as they work to meet global energy and sustenance demands. Of particular concern is the use of water to produce food sustainably, and the protection of soil, water and air resources. After all, a mere 1-meter deep fragile layer of the earths' crust, on only a fraction of terrestrial area suitable for agriculture, must produce sufficient food and fiber for these populations with declining water and energy resources and changes in climate. History and current evidence illustrate the fragility of soil resources (Figure 2).

Figure 2. The dust bowl of the 1930s in the US Great Plains and more recently, water erosion (right) in row crops, is a reminder of the fragility of our soil resource. High-yielding alfalfa crops protect soils from erosion.

Table 3. Environmental Sustainability Benefits of Alfalfa Compared with the two other major crops in the USA and use of short-term cover crops. (adapted from Meccage, 2021)

Sustainability Benefit	Alfalfa	Corn[1]	Soybean[1]	Short Term Cover Crops
Nitrogen Credits in Crop Rotation	++		+	+
Carbon Sequestration	++	0/-	0/-	+
Improved Soil Structure	+			+
Reduced Water Erosion	+			+
Reduced Wind Erosion	+			+
Decreased Nutrient Leaching/runoff	+			+
Increased Soil Microbial Diversity	+			+
Wildlife Habitat Benefit	++			
High Water Use Efficiency	+	+	+	+
Resilience to drought/climate	+			+

1.It should be noted that crops like soybean and corn can also be managed in a way to improve environmental impacts of row cropping, such as conservation tillage, use of compost, crop rotation with legumes, and management of crop residues.

There are a wide range of environmental benefits observed in alfalfa (Table 3). There have been major efforts to introduce short term cover crops (e.g. triticale, vetch) into row-crop rotations, recognizing their benefits on soil preservation and improvements in soil tilth. Each of these benefits of alfalfa have tremendous potential to contribute to societal goals of sustainability.

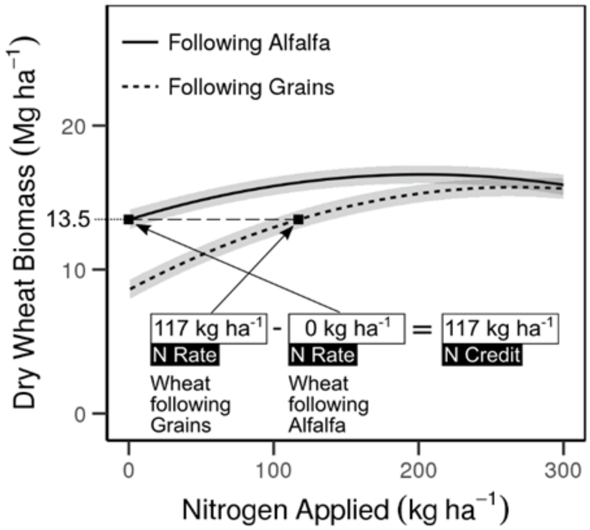

__Figure 3.__ N benefit of alfalfa to subsequent wheat crops in California - 70-160 kg/ha N is credited from the alfalfa crop to wheat, depending upon location, reducing costs and fossil fuel use in agriculture (Lin et al., 2015).

Nitrogen benefits and Crop Rotation. Nitrogen is a critical nutrient for plants, and typically the most limiting nutrient in terrestrial cropping systems, especially for cereal grains (wheat, corn, rice) and vegetables. Seventy-eight percent of the atmosphere consists of nitrogen (N_2), which is unavailable to plants, but can be made available through N_2 fixation by *Rhizobium* bacteria in symbiosis with legumes. Cropping rotations that include corn after alfalfa often do not require synthetic inputs of nitrogen for at least one year, with many fields requiring decreased nitrogen fertilizer even the second year out of alfalfa as well (Creech et al., 2019; Undersander and Barnett, 2008; Sheaffer, 2004, Lin et al., 2015). Figure 3 illustrates this benefit to the subsequent crop – in this case wheat, but we've found similar benefits to corn, tomato and other non-legumes. This leads to significant financial savings, as nitrogen inputs represent a large portion of the input costs (and carbon costs) in row crop production. Furthermore, nitrogen presented to the soil in the form of legume-synthesized nitrogen, versus the more mobile form from synthetic nitrogen fertilizer is more slowly available and decreases the potential for nitrogen leaching into groundwater and aquifers.

Carbon sequestration. Historical data suggests that alfalfa can sequester significant amounts of carbon in the soil and improve carbon concentrations deeper in the soil than many other crops (Figure 4). Jarecki et al. (2005) found that when compared to continuous corn cropping, alfalfa sequestered 22% more soil organic carbon (SOC), in agreement with Cates et al. (2016)

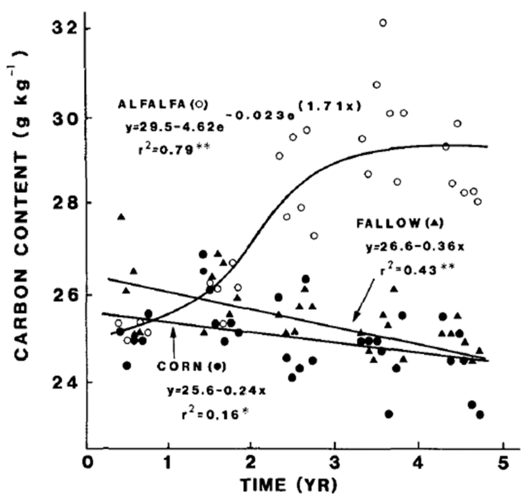

__Figure 4.__ Soil Carbon accumulation under alfalfa, corn and fallow (data from Angers, 1992)

which found that alfalfa sequestered 26% more SOC than rotations that included only annual crops (corn and soybean). Angers (1992) found that alfalfa accumulated carbon in the soil over 5 years, while corn or fallow fields showed a decline (Figure 4). Saliendra et al. (2018) found that when comparing perennial alfalfa to perennial grassland, the amount of SOC was greater in the alfalfa, even when the aboveground biomass was harvested as hay. The amount of C sequestered increased in this study if the alfalfa was irrigated, correlating to the amount of both aboveground and belowground biomass that was produced. This illustrates the concept that high-yielding alfalfa is positively correlated with carbon benefits to soils.

Additionally, alfalfa is deeper-rooted than many crops (Figure 5), especially grasses and annual crops. With many of the other closely studied crops, most of the sequestered carbon is stored in the top 10 cm of soil, close to the soil surface. However, it appears that alfalfa has the ability to place carbon deeper in the soil, with gains found at 30-60 cm (Cates et al., 2016). Interestingly, in that same study the corn-soybean rotation found losses in SOC in those deeper layers.

Figure 5. The deep vigorous roots of alfalfa (>2meters) contribute to carbon capture, protect soil from erosion, improve the soil micro-biome and soil structure, and allow for efficient water-use.

Alfalfa growers have not widely participated in carbon markets. Further data is needed, but the ability of alfalfa fields to contribute to carbon capture should not be ignored.

Soil health and mitigation of nutrient leaching.
Although 'soil health' is not often specifically defined (nor is 'human health' for that matter!), it is a major goal of farmers and those interested in sustainability of systems. It generally refers to the optimal soil structure (aggregates), mix of particles, minerals, pH, air and water, organic matter and microbial biome all of which contribute to the soil's ability to grow crops. This is related to the concept of 'tilth', and improving soils for future generations. Many studies have found that multi-year use of alfalfa in cropping rotations significantly improves soils. Alfalfa improves the size of soil aggregates (Angers, 1992), which helps to improve moisture retention, drainage and water movement, and nutrient availability in the soil. It results in more stable soils that are resilient to changes in climate such as periods of drought or heavy rains. Alfalfa helps to decrease erosion, a benefit that has been shown by research studies that included alfalfa. Wu et al. (2011) found that soils in rotation with alfalfa had infiltration rates that were 1.77 times that of bare soil, and sediment transportation movement away from the field decreased by 78.4%, due to a marked improvement in soil structure.

Included in soil health benefits are qualities such as alfalfa's ability to decrease nutrient leaching, critical in mitigating runoff into water sources. Due in large part to its deep taproot system (Figure 5), alfalfa can "soak up" large amounts of nutrients in the soil that otherwise have the potential to contaminate nearby water sources. Other options such as many species of cover crops are also able to decrease significant amounts of nutrient contaminants; however, alfalfa can reach deeper levels in the soil. It is also efficient at decreasing levels of toxic metals in the soil and has been used in soil remediation and reclamation efforts.

The Carbon Benefit of N_2 Fixation. Another important consideration is the environmental cost of using synthetic nitrogen fertilizers. Most reports estimate that industrial production of urea produces approximately 3 tons of carbon per ton of urea produced, and 2 tons of carbon per ton of ammonium nitrate produced. Added to that is the amount of carbon that is produced during the transport and application process, representing a large financial and environmental cost to growing that non-legume crop. Utilizing alfalfa decreases the dependence on synthetic fertilizers, saving both dollars as well as carbon emissions.

Wildlife Habitat, Biodiversity and Ecosystem benefits. Alfalfa is a great habitat for many species of wildlife, from large herbivores like elk and deer, to smaller mammals such as rodents, as well as soil-dwelling organisms, to a wide range of insects and pollinators (Figure 6). Many bird species (for example, the migratory threatened Swainson's Hawk) prefer alfalfa fields over neighboring landscapes. Pollinators (Figure 6) are critical for a healthy food production system, and alfalfa hosts many species of pollinators. Bees are necessary for alfalfa seed production. Alfalfa is also an important 'insectary' – with up to 1,000 species observed in fields (ask an entomologist!). Over 25% of California's wildlife use alfalfa for cover, reproduction or feeding (Putnam et al., 2001), and similar numbers on a national scale (Fernadez et al., 2019). Alfalfa is commonly used in strips in organic systems due to many 'beneficial' predator insects (e.g. ladybird beetle, Figure 6) which help to control pests such as aphids. Whether it be insect species, diseases or weeds, alfalfa can be utilized to disrupt growth cycles, and decrease the overall negative impact they have on production.

Figure 3. *Examples of biodiversity, wildlife and insect habitat in alfalfa. Alfalfa is the beginning of a high-value food chain. Top left: leafcutter bee pollenating alfalfa flower, top right curlew in alfalfa, bottom left, ladybird beetle which helps control aphids, and bottom right, deer. (Photos by M. Wagner, Washington State)*

WHAT ABOUT WATER AND IRRIGATION?

Approximately 50% of US alfalfa is produced with full- or partial-irrigation (Figure 7). In many areas of the world (Middle East, N. Africa, southern Europe, China, India/Pakistan and Australia, irrigation of alfalfa is the norm. Alfalfa is a very successful crop under irrigation – average yields in long-seasoned California and Arizona (~100% irrigated) are about 20 Mg/ha (9 tons/acre), and maximum yields under good management are 35 Mg/ha (16 tons/acre). The high yields of alfalfa under irrigation exhibit high water-use efficiencies, a key measure of water stewardship.

However variable rainfall and water availability is a major challenge. Over the past 10 years in the USA, major alfalfa growing areas were affected by severe, extreme or exceptional drought much of the time, sometimes over 40% of US acres (Figure 8). Drought conditions can cause reductions in yield, or complete dry-downs of fields. In dry regions like the US West, it is anticipated that drought will become a frequent visitor, challenging farmers and society as a whole. It is important to note that while drought severely limits the production of alfalfa in that given period, alfalfa is unique among the top commodity crops in that it can regrow as soon as moisture returns, and provides perennial cover to protect the soil from erosion.

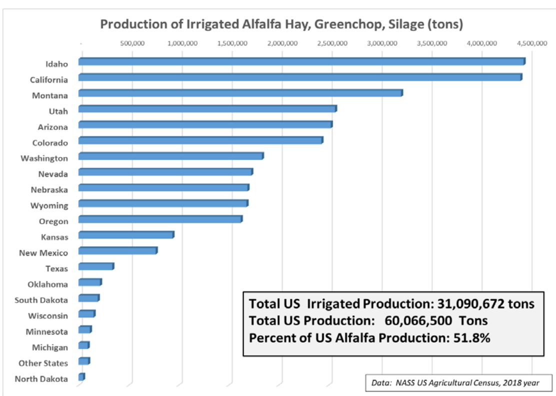

Figure 7. Irrigated alfalfa production in major US states, USA (2018 data)

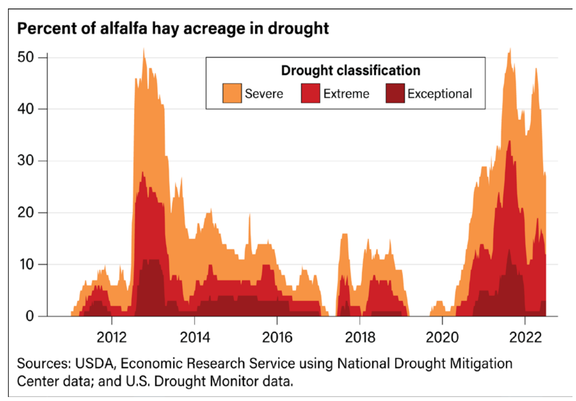

Figure 8. Percentage of US alfalfa hay produced under severe, extreme and exceptional drought, past 10 years.

Increases in extreme weather variation is a frequently predicted outcome of climate change – severe droughts followed by torrential rains. This makes alfalfa's ability to grow once moisture returns even more important, as it can help to provide ground cover during those torrential rains and begin utilizing that moisture versus an annual crop that dies out from lack of moisture.

The need for <u>resiliency</u> of agricultural food-producing systems given the certain <u>variation</u> in water supply is a current and future reality. What are alfalfa's biological properties that are relevant to a water-challenged future?

CHARACTERISTICS OF ALFALFA THAT PROMOTE SUSTAINABILITY OF WATER USE

Although often the target of criticism due to high water use (and low value), alfalfa has a series of qualities that are actually positives when it comes to water resiliency and efficiency.

High Water-Use Efficiency, High Harvest Index. The harvest index (HI), the percentage of above-ground crop harvested for economic product of alfalfa is about 100%, whereas most crops the harvest index range 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. The Water Productivity is even higher with optimum varieties and management: illustrating that high yields and profitability are positively correlated with environmental benefits.

Deep Roots and Utilization of Residual Moisture. Alfalfa roots have been documented as deep as 15 feet (5 m), and routinely explore soils in the 3-9 foot (1-3 m) range when soils provide no impediments (Figure 5). Residual moisture from previous irrigation and rainfall events (months earlier) are often very important in sustaining alfalfa production during periods of insufficient surface water from rain or irrigation (Figure 9). 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 (through soil channels and microbial action) and soil health.

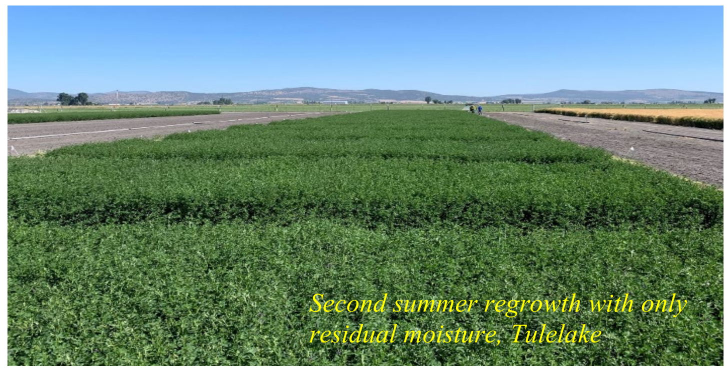

Figure 4. *The resilience and deep rootedness of alfalfa was demonstrated during the 2021-22 drought at Tulelake, CA, where near full yields of alfalfa was observed with zero irrigation, with approximately 14" (350mm) winter rainfall over 2 years. (Photo, July, 2021. D. Culp).*

High flexibility during droughts. There is now considerable data that confirms the ability of this crop to sustain forage production when water is reduced during droughts (Figure 10). 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 when

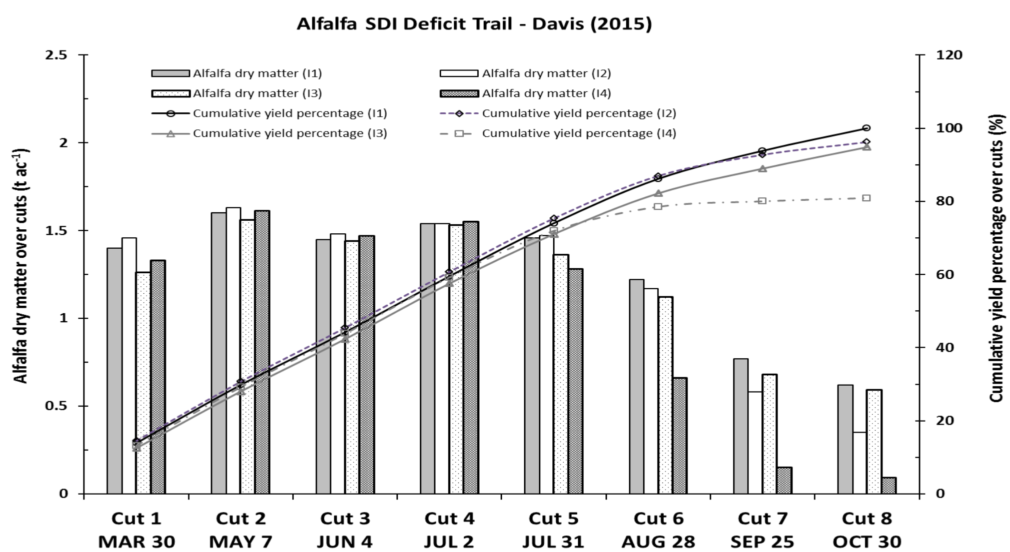

Figure 10. *Cutoff of irrigation water after July 4 of 50% of irrigation applications resulted in about 80% of full yield, while cutoff at 75% of ET irrigation demand resulted in 95% of full yield. Savings of up to 20" of irrigation water were observed. This is due to high productivity in early harvests, and use of residual moisture after irrigations cease (data Davis, CA, 2015).*

irrigations cease (Figure 10). 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 10). In MOST cases, alfalfa can recover from these summer droughts, to be re-watered in subsequent years.

Multiple Harvests, Partial Season Production. While most crops are harvested once during the year, alfalfa is harvested multiple times. In short-seasoned environments, harvest range from 2 to 5 and in longer-season environments 7 to 12 harvests. Yields typically decline later in the season, even if fully watered. "Summer slump" (Ottman and Putnam, 2017) is a common observation in alfalfa (notice yield trends, Figure 10). In most environments, over 60% of the production is realized by mid-summer. 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. This enables partial-season production with limited water (Figure 10).

When partial-season dry-downs are necessary, will the crop survive and recover to produce when watered again? They answer is generally 'yes'. When deficits were applied in Colorado studies (Cabot et al., 2017), in virtually all cases, the fully-watered crop recovered in the following year. 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. We've found similar recovery of previously-stressed alfalfa in California studies (Frate et al., 1991); The only exception to this result are on the harsh cracking-clay soils under high salinity and intense head of the Imperial Valley, where stand decline from summer deficits is more common.

Ability to be over-watered in Winter to Recharge Aquifers. Given the high variation in annual precipitation (Figure 7), 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. (2022, unpublished) have shown winter flooding events not to damage alfalfa yields, in fact benefitted yields due to the early irrigate events if done carefully. Alfalfa has an advantage vs. fallow or other crops, in that nitrate contamination of groundwater is likely to be a lower risk. However, it is well known that alfalfa can be damaged with excess flooding, so only care must be taken to reduce oxygen deficits since flooding can kill alfalfa.

Water Early, Apply Deficits Late. Due to this seasonal production pattern, 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. 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. 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 lack of water and poor drainage. 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 high 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 scarce water supplies.

Table 4. Cumulative effect of salinity on alfalfa yield, average of 35 varieties over four years, Five Points, CA. Trial was planted 3/29/17, so first year data is a partial year result. Water with ECw of 8 to 11 dS/m was applied to the saline plots (high salinity) and water of 1.0-2.0 dS/m to Low Salinity plots. On a deep clay loam soil. Soil salinity at the completion of the trial ranged from 12-17 ECo, 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	

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 water is limited, 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.

SUMMARY

Though often skewered in the press for its ‘low value’ and water use, both the on-farm profitability and broader value of alfalfa to the consumer and environment is frequently underestimated. High crop yields are correlated with a range of environmental benefits, suggesting a need for ‘sustainable intensification’ of alfalfa crop production. The significant role alfalfa plays in, soil conservation, high carbon capture, benefits to non-legumes in rotation, soil health, biodiversity and wildlife habitat, and flexibility during droughts suggest that this crop should be envisioned as a critical aspect of sustainable agricultural systems.

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