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Yield and Nutritive Values of Semi- and Non-Fall Dormant Alfalfa Cultivars under Late-Cutting Schedule in California's Central Valley

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Abstract

California is one of the major alfalfa (*Medicago sativa* L) forage-producing states in the U.S, but its production area has decreased significantly in the last couple of decades. Selection of cultivars with high yield and nutritive value under late-cutting schedule strategy may help identify cultivars that growers can use to maximize yield while maintaining area for sustainable alfalfa production, but there is little information on this strategy. A field study was conducted to determine cumulative dry matter (DM) and nutritive values of 20 semi- and non-fall dormant (FD) ratings (FD 7 and FD 8 - 10, respectively) cultivars under 35-day cut in California's Central Valley in 2020-2022. Seasonal cumulative DM yields ranged from 6.8 in 2020 to 37.0 Mg·ha^{-1} in 2021. Four FD 8 - 9 cultivars were the highest yielding with 3-yrs avg. DM greater than the lowest yielding lines by 46%. FD 7 cultivar "715RR" produced the highest crude protein (CP: 240 g·Kg^{-1}) while FD 8 cultivar "HVX840RR" resulted in the highest neutral detergent fiber digestibility (NDFD: 484 g·Kg^{-1}, 7% greater than the top yielding cultivars) but with DM yield intermediate. Yields and NDFD correlated positively but weakly indicating some semi- and non-FD cultivars performing similarly. These results suggest that selecting high yielding cultivars under 35-day cutting schedule strategy can be used as a tool to help growers to maximize yield while achieving good quality forages for sustainable alfalfa production in California's Central Valley.

Keywords

Alfalfa, Maximizing Yield, Nutritive Value, Cultivar, Cutting Schedule, Production Area, California

1. Introduction

Alfalfa is the most widely grown valuable perennial legume forage crop in many regions of the world. It is the third or fourth most valuable field crop in the United States depending on year [1]. Conducive climatic conditions for dairy-alfalfa farming systems have led the Western U.S., California in particular, to become the major supplier of both processed dairy products and forage inputs to meet the requirement of domestic dairy market and the growing demand of these products in Asia [2]-[4]. However, California's alfalfa production area has decreased significantly, from 405,000 ha in 2009 to 182,000 ha in 2022 [1]. Among many factors, disappointing yield is frequently considered by producers as one of the main reasons for reduced production of alfalfa (CAFA and NAFA, pers. Comm.). Successful and profitable alfalfa production depends primarily upon higher yield and secondarily on nutritive value [5]. Sustainable and profitable alfalfa production may lead growers to maintain or increase alfalfa production area in California. Alfalfa is known more for its economic value while its agronomic and environmental benefits often being undervalued and underappreciated. Alfalfa being fourth valuable field crops in the United States with estimated economic value more than 12 billion in 2022 [1] and maintains its place as the most valued crops to generate billions of dollars of net revenues for growers [1] [6] while reducing soil erosion and helping to sequester carbon in the soil. Continuous agronomic management strategies including cultivar selection and cutting schedules remain to be an important tool that growers can use not only to maximize yield for a profitable alfalfa production but also to keep alfalfa in their farming systems.

Selecting high yielding cultivars are crucial for alfalfa growers to profitably grow the crop and realize it's environmental and economic values. Cultivar selection is one of the most important agronomic management strategies that an alfalfa grower can control in alfalfa production. Alfalfa breeders continue to develop new cultivars with improved yield, quality, and tolerance to both biotic and abiotic factors. Cultivars vary in yield potential. Cultivars adapted to long-season environments have greater yield potential than cultivars that are grown in a short growing season area. Cultivars grown in long-season area are semi-dormant and non-dormant based on fall dormancy (FD) ranking. These types of cultivars are generally higher yielding than dormant types owning to their inherent abilities to be winter active, faster in green up in spring, quicker recovery after a harvest and greater growth in fall and adaptation to a long-growing season environment. Semi- and non-dormant alfalfa cultivars may also vary in yield potential. Therefore, evaluating cultivars of semi- and non-dormant types with improved traits, especially yield and quality, is critical to help growers have a sustainable and profitable alfalfa production. However, the commonly practiced 28-days based cutting schedule may not maximize yield production of alfalfa. In Californian, growers often cut alfalfa using a fixed schedule (e.g., 28-day interval); which usually does not take into account factors such as market conditions, alternative marketing strategies, impact on the overall plant physiology and stand life, season, and weather conditions. All these factors can have significant impact on economic return [7]. The most common cutting interval in the Central Valley of California is 28-d with produced hay resulting in a 20% yield loss and reduced persistence compared with longer intervals between cuts [8]-[10].

Delayed cutting of more matured plants often results in high forage yields but with higher fiber, reduced protein, and fiber digestibility. Within each alfalfa growth period, alfalfa yield increases while nutritive value decreases; this negative relationship is called the yield-quality tradeoff [11] [12]. Longer harvest intervals enables plants to increase carbohydrate reservation in roots and plant vigor, which improves stand persistence, while short intervals between harvests often leads to stand decline [13] [14]. This yield-quality tradeoff, along with the need for long-term stand persistence, is an ongoing quandary and challenge for alfalfa producers [15]. Nutritive value is of key importance for dairy producers, however, the price of alfalfa hay in markets is determined primarily by supply-demand factors, and secondarily by nutritive value [16]. Nutritive value is generally evaluated through multiple predictive measurements, including crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin content, and NDF digestibility (NDFD), [17] [18]. With advancement in cultivar development in attempt to improve yield and quality using conventional and genetic engineering-based breeding selection, it may be necessary to grow high yielding cultivars under delayed cutting schedule so growers could grow alfalfa profitably and sustainably and maintain the crop as an integral part of their crop production systems in California. The objective of this study was to evaluate forage yield and nutritive value of 20 semi- and non-cultivars (conventional, higher quality and experimental lines) managed under 35-days (delayed) cutting schedule strategy in California's Central Valley under Mediterranean environment conditions.

2. Materials and Methods

2.1. Experimental Site

The field experiment was conducted during 2020 through 2022 at USDA-ARS Sanquan Valley Agricultural Science Center in Parlier (36˚59'61.5"N 119˚51'19.4") located in the Central Valley of California, USA. The soil type is Hanford sandy loam (coarse-loamy, mixed, superactive, nonacid, thermic Typic Xerorthents), and the area has an environmental condition typical of the Mediterranean climate with hot and dry summers and mild and wet winters. Monthly average precipitation and air temperature for experimental years were collected from a nearby weather station, belonging to the California Irrigation Management Information Systems or CIMIS network station no. 39) (**Table 1**). Average yearly precipitation was 146, 224, 132 mm for 2020, 2021, and 2022, respectively, which is less than the 30-year average of 272 mm. However, the average yearly temperature was 18.3, 18.6, 18.2 C for 2020, 2021, and 2022, respectively and slightly warmer than the 30-year average (17.7˚C) (**Table 1**).

Table 1. Monthly, long-term precipitation and average air temperature in Parlier, CA.

	2020	2021	2022	30 yrs avg.
Month		Precipitation (mm)		
January	15.2	61.0	2.3	56.1
February	0.0	4.8	3.8	47.5
March	68.8	22.6	34.8	47.6
April	29.7	4.6	5.3	23.5
May	8.1	0.0	0.0	10.6
June	0.0	0.0	1.3	3.9
July	0.0	0.0	0.0	1.9
August	0.0	0.0	2.5	2.3
September	0.3	1.5	3.0	1.9
October	0.0	35.1	0.0	12.1
November	6.4	6.9	4.3	20.2
December	17.5	87.6	74.2	44.4
Total	146.0	224.1	131.5	272.0
		Temperature (˚C)		
January	8.2	8.8	7.8	8.0
February	10.6	10.6	9.6	10.5
March	12.5	12.0	13.7	13.4
April	16.9	17.3	16.3	16.0
May	21.5	21.5	20.2	20.1
June	24.9	26.3	25.3	23.9
July	27.1	29.1	27.7	26.7
August	27.6	27.2	27.8	25.6
September	23.2	23.9	25.1	22.5
October	18.5	15.9	18.3	16.8
November	10.3	11.8	8.2	10.9
December	7.5	8.3	7.2	7.3
Mean	18.3	18.6	18.2	17.7

2.2. Experimental Design and Treatments

A randomized complete block design with four replicates was used in the study. Twenty semi- and non-dormant commercial and experimental cultivars with fall dormancy rating of 7 - 10 including the standard check cultivar "CUF-101" included in the experiment (**Table 2**).

Inoculated alfalfa seed was planted at a rate of 28 kg·ha^{-1} into a prepared seedbed on March 10, 2020. The experimental plots were 6.1 by 0.9 m with 4 rows and 15.2 cm spacing, planted to a depth of about 1.3 cm. Soil was fertilized according to soil analysis results and recommendations for alfalfa hay production in the region. Triple Pro 15-15-15, a homogenous multi-use fertilizer with a 1:1:1 ration containing equal amounts of nitrogen, phosphate, and potash plus sulfur at a rate of 224 Kg·ha^{-1} was broadcasted and incorporated in the soil. Insect pressure was insignificant, and application was needed only in 2021. Insecticide Sivanto Prime at 980 mL·ha^{-1} was applied to control aphids. Herbicides Raptor (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid), Prowl H_20 (pendimethalin: N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine) and adjuvant Ad-Max 90 (1,2,3-Propanetriol, Dimethylbenzenesulfonic acid, sodium salt and alkyl phenol ethoxylate), respectively, at 420, 2240, and 1120 mL·ha^{-1}, in August 20, 2020, on March 30, 2021 and on April 13, 2022 were used to control weeds.

Table 2. Alfalfa cultivar and types used in the study.

Cultivar number	Cultivar name	Fall dormancy (FD)	Type	Source	Roundup Ready (RR)
1	98218	8	Exp. Line	Alforex Seeds	
2	715RR	7	Conv.	Alforex Seeds	RR
3	AFX779	7	HiGest	Alforex Seeds	
4	CUF-101	9	Conv.	UC-Davis	
5	Desert-Rose	8	Conv.	WinField United	
6	HVX840RR	8	Reduced-lignin	FGI International	RR
7	Magna-905	9	Conv.	Alforex Seeds	
8	Super-Sonic	9	Conv.	S & W Seeds	
9	SW10	10	Conv.	S & W Seeds	
10	SW8421RRS	8	Conv.	S & W Seeds	RR
11	SW8421-S	8	Conv.	S & W Seeds	
12	SW88-304	8	Conv.	S & W Seeds	
13	SW9215RRS	9	Conv.	S & W Seeds	RR
14	SW9812	9	Conv.	S & W Seeds	
15	SW9813	9	Conv.	S & W Seeds	
16	UC-2705	9	Exp. Line	UC-Davis	
17	UC-Cibola	9	Conv.	UC-Davis	
18	UC-Highline	9	Conv.	UC-Davis	
19	UC-Impalo	9	Conv.	UC-Davis	
20	UC-2693	9	Exp. Line	UC-Davis	

Conv. (Conventional), Exp. (Experimental). Hi-Gest and Reduced-lignin types are marketed as higher quality cultivars.

Plots were irrigated with a target of creating non-water limiting conditions for crop growth, according to ET_c, using a solid-set overhead sprinkler irrigation system and the water volume was tracked using a flow meter to calculate required irrigation amount weekly. Irrigation applied was 906.0 mm, 1119.9 mm, and

1245.3 mm for 2020, 2021, and 2022, respectively.

2.3. Data Collection

A 35-day cutting schedule was chosen to represent the delayed cutting regime with the goal of producing the highest yield and stand persistence. Plant fresh subsamples of ~500 g was hand-clipped prior to plot cutting from the middle two rows of each plot for moisture content determination and nutritive value analysis. Then, the plots were harvested using a RCI forage plot harvester (Mayville, Wisconsin) to approximately 5 cm stubble height and the fresh plot weight was recorded. The fresh hand-clipped samples were weighed and then dried in a forced air-dyer oven at 50˚C - 55˚C until no change in dry weight was observed. In 2020 (establishment year), the first cut taken in mid-June was used as "clean up" so not part of the yield summary but in 2021 and 2022, the first cut is part of the yield summary. The yield per unit area was calculated for each cultivar from the dry matter (DM) and total fresh weight from the plot harvest and the hand-clipped samples.

Dried samples from each plot were ground to pass through a 2-mm screen using a Wiley Mill (Thomas Manufacturing, Sweedesboro, NJ), then passed through a riffle splitter and reground to pass a 1-mm screen using an abrasion-type Cyclotec^{TM} 193 mill (Foss NA, Eden Prairie, MN). Samples were analyzed for quality using a Near-infrared spectrometer at Cumberland Valley Analytical Services (Zullinger PA), to determine concentrations of CP, ADF, NDF, ADL, and NDFD.

2.4. Statistical Analysis

Yield and nutritive value data were analyzed using SAS Proc Mixed procedure utilizing a randomized complete block model. Year and cultivar were designated as fixed effects while replicate was as random effect. Denominator degrees of freedom were approximated by using DDFM = KENWARD-ROGER prompt option in the Proc Mixed procedure to get appropriate standard errors and F-statistics in Restricted Maximum Likelihood (REML) [19]. The REML method was used for estimating variance components. Main treatment effects and interactions were tested for significance at a $p < 0.05$ significance level. Variables analyzed includes forage dry matter yield (DM) (yearly and three-years cumulative), and 2021-2022 seasonal average nutritive values. Based on full production years, yield accumulation patterns over the season and each cutting's contributions to total dry matter yield were also graphed and discussed. Additionally, a regression analysis was performed to develop the relationships between selective cultivar nutritive value parameters and harvesting time during the year; and NDFD and cultivar yields (on 2 full production years and 15 harvests average), where the coefficient of determination, R^2 was used to judge the goodness of fit of these relationships.

3. Results and Discussion

3.1. Growing Conditions

Monthly and yearly average temperatures in 2020, 2021 and 2022 growing seasons were similar but slightly higher than the long-term averages (**Table 1**). March 2020, the alfalfa planting month and April, the establishment month were much wetter than 2021, 2022 and the long-term averages. Precipitation received during these two months were higher by 72%, 59% and 28%, respectively, than in 2021, 2022 and the long-term, resulting in delayed emergence and crop establishment leading to establishment year having not only much fewer cuts but also much lower yearly cumulative DM yield. May through August, temperatures of the cropping seasons were much higher than the long-term with departure from the long-term temperature ranging from 0.5˚C to 2.4˚C, indicating the warmer growing conditions. Growing seasons precipitation were variable and dry with yearly total precipitation received in 2020, 2021 and 2022 at 54%, 82%, and 48% of the long-term, respectively (**Table 1**). During summer (May through August), except for the precipitation received amounting to 8.1 mm in May of 2020 and 1.3 and 2.5 mm in 2022, this part of the growing season is commonly dry but much dryer conditions compared to the long-term (**Table 1**). Precipitation during late-summer and fall (September through November) in 2020 and 2022 was similar but lower than the 2021 and long-term average. Nevertheless, agriculture in this area of semi-arid environment is irrigation dependent and alfalfa was grown under non-water limiting conditions by irrigation.

3.2. Dry matter Yields

A significant year, cultivar, and year × cultivar interaction effects were observed in yearly and 3-yrs cumulative dry matter yield (**Table 3**).

Table 3. Mixed model analysis of variance with probability level for main and interaction effects of year and variety on yearly and 3-yrs cumulative DM yield and yearly average nutritive value parameters in 2020-2022, in Parlier, CA.

Source	Year (Y)	Cultivar (C)	Y × C
Yield		*p-value*	
Yearly cumulative DM	<0.0001	<0.0001	<0.0001
3-yrs cumulative DM	-	<0.0001	-
Nutritive value parameters⁺			
Crude protein	0.0165	<0.0001	0.5466
Acid detergent fiber	0.0181	0.0014	0.5219
Neutral detergent fiber	0.0075	0.0007	0.6118
Acid detergent lignin	0.0728	<0.0001	0.6264
Neutral detergent fiber digestibility	0.0007	<0.0001	0.2183

DM ((Mg·ha^{-1}); nutritive values (g·Kg^{-1}). ⁺Analysis involved two full production years data (2021-2022).

All cultivars produced significantly lower DM yield in 2020 (establishment year) (ranging from 8.2 to 13.0 Mg·ha^{-1}) than in full production years 2021 (18.2 to 37.0 Mg·ha^{-1}) and 2022 (12.1 to 35.9 Mg·ha^{-1}). Yield, averaged over cultivars, was significantly lower in 2020 (10.2 Mg·ha^{-1}) than in 2021 (31.5 Mg·ha^{-1}) and 2022 (29.5 Mg·ha^{-1}) (**Table 4**). Growing conditions, including time of planting, and genetic background of cultivars had a strong influence on observed yield. The greatest DM yield (13.0 Mg·ha^{-1}) was produced by conventional, FD 9 cultivar "SW9813" in 2020 while the lowest yielding cultivars were experimental lines "UC-2705" and "UC-2693" both FD 9 with yield averaging 6.8 Mg·ha^{-1}. In 2021, cultivars "SW9812", "Desert-Rose", "SW8421RRS", "SW9813" and "CUF-101" were the top yielding (averaging 35 Mg·ha^{-1}) belonging to FD 8-9 while the lowest yield was produced by the experimental lines that underperformed in 2020 with their yield only 43% of the highest yielding (**Table 4**). These experimental lines remained underperforming in production year 2022 and their poor performance also reflected in the 3-yrs cumulative DM yield (**Table 4**). However, the difference in yield between cultivars in the high yielding group and other cultivars in 2020 and 2021 was not significant. In production year 2022, 75% of the cultivars fall in the top yielding group indicating that the variability in yield observed among the cultivars in 2022 was small and nonsignificant suggesting that yield was stabilized in year 3. Our two full production years yields results are similar to the yields (31.0 Mg·ha^{-1}) reported by Anderson *et al.* [20] comparing alfalfa cultivars for yield under low-salt irrigation water with research conducted in California's Central valley. However, the 35-days based cutting schedule used in our study did not result in higher yields than the yields reported by Anderson *et al.* (19) although the cutting schedule was on 28-days, and this could be linked to the two low yielding (15 and 22 Mg·ha^{-1}) experimental cultivars used in our study lowering the average yield by ~5%. Nevertheless, ours and their yield results are much higher than the average alfalfa yields achieved in California's Fresno County (19.0 Mg·ha^{-1}) and California state-wide average yields (13.1 Mg·ha^{-1}) [1]. Yields reported from cultivar studies in many places including ours, generally are much higher than what farmers commonly achieve in their fields, and this is referred as the "yield gap" [21] and could be linked to the difference in environmental and production management practices. Most importantly, based on 3-yrs cumulative DM yield, four of the cultivars with FD 8 - 9 ("SW8421S", "Desert-Rose", "SW9812", and "SW9813") were identified as the top yielding (averaging 81 Mg·ha^{-1}) producing significantly greater yield not only than the lowest yielding experimental lines with FD 9 (averaging 44 Mg·ha^{-1}) but also greater than seven of the other cultivars (with yield ranging between 66.0 to 71.8 Mg·ha^{-1} (**Table 4**). The difference between the lowest "UC-2705" and highest "SW9813" yielding cultivars of both FD 9 in the first and second years amounted 48 to 51% while this difference was as high as 66% in 2022, indicating significant yield variability among these cultivars over the years. Although there are other cultivar traits that need to be considered as criterion for selection, yield is often the first and most important factors used for cultivar selection to maximize profit from alfalfa production. Cultivars cultivated under the same growing conditions may differ up to 30% in yield resulting in growers return loss by thousands of dollars per ha if grower plant a low yielding

[22] cultivar. It is also worth noting that the lowest-yielding cultivars in this study were experimental lines of FD 9, and this was across the years, indicating the progress made and still to be made in alfalfa breeding to improve yield. However, cultivar "CUF-101" a FD 9 which was developed and released in California in 1976 and often used as a standard check in alfalfa cultivar testing is among the high yielding cultivars suggesting alfalfa breeding program still has potential to push yield beyond what is currently being achieved. The two FD 7 cultivars are in the intermediate yielding cultivars group encompassing FD 7 - 10, suggesting their similar yielding potential as many of the FD 8, 9, 10 cultivars. Both FD 7 and FD 8 - 10 cultivar groups are winter active although FD 7 is semi-dormant, and hence the yield advantage of one group over the other group is not apparent. This suggests that both semi- and non-dormant cultivars response to the available environmental resources similarly.

Table 4. Cumulative yearly and 3-yrs DM yield of semi- and non-fall dormant alfalfa cultivars under 35-days cutting schedule in Parlier, CA in 2020-2022.

			2020	2021	2022	3-yrs
Cultivar number	Cultivar name	FD	DM yield (Mg·ha^{-1})			
11	SW8421-S	8	12.0	33.7	35.9	81.6
5	Desert-Rose	8	11.9	35.9	33.0	80.8
14	SW9812	9	12.1	37.0	31.5	80.6
15	SW9813	9	13.0	35.0	32.2	80.2
10	SW8421RRS	8	9.7	35.2	32.9	77.8
12	SW88-304	8	10.8	32.7	33.7	77.1
4	CUF-101	9	10.2	34.7	30.6	75.6
8	Super-Sonic	9	9.8	32.9	32.1	74.8
3	AFX779	7	11.2	32.9	30.4	74.4
6	HVX840RR	8	10.6	31.1	31.2	72.9
13	SW9215RRS	9	9.9	31.4	31.2	72.5
2	715RR	7	11.1	32.4	28.3	71.8
17	UC-Cibola	9	8.7	31.4	30.2	70.4
1	98218	8	10.6	29.3	30.4	70.3
9	SW10	10	9.9	30.3	30.0	70.2
7	Magna-905	9	9.4	29.8	29.6	68.8
18	UC-Highline	9	8.4	31.5	27.9	67.8
19	UC-Impalo	9	8.2	30.1	27.7	66.0
16	UC-2705	9	6.8	24.0	19.8	50.7
20	UC-2693	9	6.9	18.0	12.1	37.0
	LSD ($p < 0.05$)		5.6	9.6	9.5	16.3
	Mean		10.2	31.5	29.5	71

Within columns, two cultivars are significantly different at the 0.05 probability level when means difference is greater than the LSD value. Fall dormancy (FD) rating.

Crop establishment year of perennial crops of both grass and broad leaf types are known to result in lower forage yield than subsequent crop production years. Our results are in line with numerous previous studies where crop stand age found to have strong effect on yield, quality, stand persistence and the expression of agronomic traits and genetic potential of cultivars [23]-[28]. Moreover, the establishment year is the growth period plants invest most of their energy to establishing vigorous root system and aboveground plant parts, so main growth limiting factors (nutrients, water, and sunlight) are used efficiently, and this in turn leads plants to produce greater biomass in subsequent years. The difference in seasonal cumulative DM yield between crop establishment (2020) and the two full production years (2021 & 2022) in this study is as much as 67% which is much higher than results reported in the literature before. However, part of this big difference between establishment and full production years in our study is due to the spring planting we had. Alfalfa spring planting generally is not as conducive as fall planting for securing a strong crop establishment with vigorous plants to result in high forage production in establishment year. Regardless of the growing seasons, Temperate climate (short-growing season) or Mediterranean climate (long-growing season), perennial forage crops production is under. Spring planting depending on planting time provides fewer cuts than fall planted ones with potential to significantly affecting yearly cumulative DM yield. There were 4 cuts (in fact it would have been 3 cuts if the last cut taken in December to be excluded since it was very late and not ideal) in establishment year 2020. Whereas 2021 and 2021 which were full production years resulted in 8 and 7 cuts, respectively, and this is considered a 7 to 8 cuts alfalfa system typical of California's Central Valley's Mediterranean climate with long-growing seasons. Moreover, the more southern, desert region of California allows alfalfa production to be a 9 to 11 cuts system with growers producing hay almost year around on 28-day cutting schedule. The two full production years yields achieved in this study are higher than results reported for cultivar evaluation studies conducted in the same area but using 28-days-cutting schedules. Furthermore, our yield results are much higher than yields reported by researchers in studies conducted in Temperate climate [27]-[30]. This is expected because the Mediterranean climate, long-growing areas, allows growers to have almost double the number of cuts to that of a grower in Temperate climate with short-growing areas achieves.

3.3. Seasonal DM Yield Distribution and Contribution

When individual cut's DM yield distribution and contributions to total seasonal yearly DM yields were examined closely for the two full production years (2021& 2022), contributions to total yields by the different cuts in 2021 and 2022, respectively, ranged from 5% to 17% and 7% to 19% (averaged over the two years, 6 to18%). Greater DM contributions by cuts achieved from the first three to four cuts which can be linked to the higher productivity of the early compared to the later alfalfa growth period. This pattern was observed in all cultivars. The first three to four cuts averaged over cultivars, in 2021 and 2022 respectively, contributed 45% to 61% and 52% to 67% of the annual yields (averaged over years, 49% to 60%) (**Figure 1**), indicating the significant importance of early cuts in determining the total yearly production.

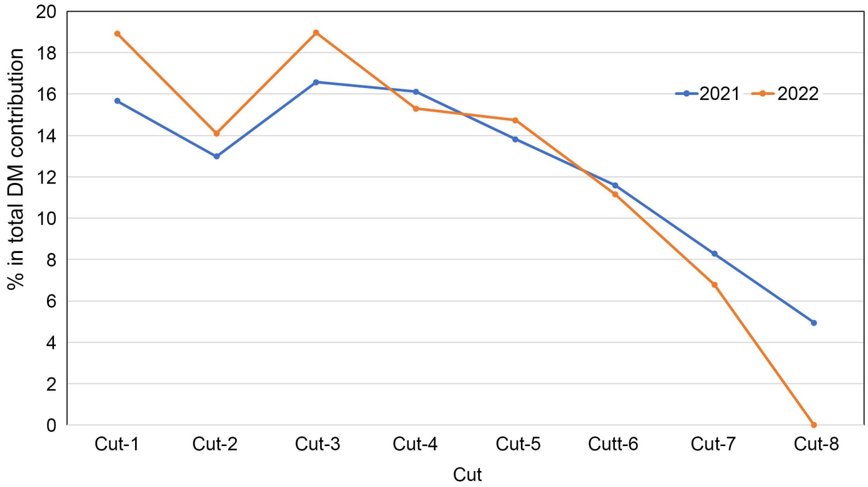

Figure 1. Percentage of individual cut's DM distribution in full production year 2021 and 2022 (20 cultivars average) in Parlier, CA. Mar. 24/April 6, April 29/May 10, June 1/June 14, July 8/July 19, Aug. 12/Aug. 23, Sep. 17/Sep. 28, Oct. 21/Nov. 2, Nov. 29 dates for 2021 and 2022 respectively, for Cut-1 through Cut-8.

The distribution of yearly production by cutting can be used as management strategy by growers not only to plan and target irrigation (for example, planning pre-irrigation to fill the soil profile) for efficient usage of water in the most productive growth period but also cope with the limited water availability that periodically occurs in a semi-arid environment such as the area in California where this study was conducted. Moreover, during early- to late-summer crop growth periods, growers prioritize irrigation for their water stress-sensitive cash crops (example tree crops) over alfalfa. Unlike in Mediterranean climate conditions, the yield of the first alfalfa cutting in Temperate climate with 4 to 5 cuts alfalfa system is more important and biggest contributor to annual yield [30] [31]. The first cutting generally benefits from longer growth period and conducive conditions for photosynthetic activity and growth allowing greater biomass accumulation [30]-[33]. Bolger and Matches [34] reported alfalfa first cut yield to be 41% - 46% of the annual yield while Li and Su [35] reported as 35% - 50%, and Orlloff *et al.* [36] reported as 35% - 42% of the annual forage yield. However, the yield contribution of first cut in annual DM yield in our study was much lower than the above reported results but similar to results reported by Orlloff *et al.* [36] from the research conducted under Mediterranean climate (long-growing season conditions). Thus, such difference in results between our study conducted in Mediterranean climate and studies conducted in Temperate climate is expected since the growing conditions and alfalfa systems used in these areas are different, (3 to 5 cuts vs. 7 to 9 cuts alfalfa system).

3.4. Nutritive Value

Nutritive value parameters were affected by year and cultivar significantly but not by year × cultivar interaction (**Table 3**). All nutritive value parameters measured in the study, averaged over cultivars, were higher in 2021 than in 2022. This reflects seasonal variation which commonly occurs and affects yield and quality measurements in field studies conducted in multiple years. Nutritive values differed among cultivars in both 2021 and 2022 (**Table 2**). The highest CP concentration was produced by cultivars "715RR" and "98218" (240 g·Kg^{-1}) in 2021 and by "715RR" in 2022 while the lowest CP concentrations were produced by cultivar "SW84421RR" (226 g·Kg^{-1}) in 2021 and by cultivars "CUF 101", "SW9812", "SW84421RR", and "UC-Highline" (221 g·Kg^{-1}) in 2022 but the difference between the highest and lowest CP producing cultivars were significant only in 2022 (**Table 5**). The consistently higher CP value achieved by "715RR" cultivar could be linked to its semi-dormant characteristics, although one of the other semi-dormant cultivars displayed a lower CP value. Dormant and semi-dormant cultivars are generally shorter in height than non-dormant cultivars, generally resulting in a higher leaf-to-stem ratio that favors CP over fiber content. As alfalfa grows taller, in case of non-dormant cultivars, it has to invest a greater proportion of structural tissues (stem) to maintain an erect position to place its leaves (metabolic tissues) in a well position layers in the canopy for more light-capturing even if this favors a lower leaf to stem ratio. ADF and NDF concentrations were the highest for conventional cultivar "SW84421RR" (368 and 431 g·Kg^{-1}) in 2021 and 2022, respectively, while the lowest concentrations of ADF and NDF were recorded for experimental line "98218" (344 and 399 g·Kg^{-1}). In 2022, the value of ADF was the highest for conventional cultivar" SW9812" (355 g·Kg^{-1}) with value higher by 8% than cultivar "UC-Impalo" with the lowest CP. On the other hand, highest NDF was produced by conventional cultivar "UC-Highline" (412 g·Kg^{-1}) while cultivar" 715RR" (*i.e.* a FD 7, Hi-Gest cultivar) produced the lowest (by 8%) NDF concentration (377 g·Kg^{-1}). Conventional cultivars" SW8421-RR", and "UC-Cibola" produced the highest ADL (81 - 82 g·Kg^{-1}) in 2021 and 2022 while the lowest ADL value (74 g·Kg^{-1}) was consistently recorded for cultivars" HVX840RR" (*i.e.* a FD 8, reduced-lignin cultivar) reflecting its reduced-lignin traits, and then followed by cultivar "715RR" and "98218" a FD 8 with ADL value of 76 g·Kg^{-1} (**Table 5**).

Table 5. Nutritive values of semi- and non-dormant alfalfa cultivars under 35-days cutting schedule in Parlier, CA (2021-2022).

			2021				
			CP	ADF	NDF	ADL	NDFD
Cultivar number	Cultivar name	FD			(g·Kg^{-1})		
6	HVX840RR	8	232	347	408	74	505
12	SW88-304	8	235	350	412	77	489
1	98218	8	240	344	399	76	485
8	Super-Sonic	9	233	357	417	78	485

Continued

20	UC-2693	9	238	355	413	78	484
3	AFX779	7	234	358	418	79	483
14	SW9812	9	229	363	424	79	483
7	Magna-905	9	235	354	415	78	481
2	715RR	7	240	352	411	79	481
19	UC-Impalo	9	235	347	407	77	479
16	UC-2705	9	235	353	415	79	479
13	SW9215RRS	9	229	354	415	78	478
5	Desert-Rose	8	231	359	420	79	477
4	CUF-101	9	228	360	423	79	473
9	SW10	10	232	351	412	78	473
15	SW9813	9	230	355	415	78	472
11	SW8421-S	8	231	360	421	80	470
17	UC-Cibola	9	233	362	424	82	466
18	UC-Highline	9	228	361	426	81	465
10	SW8421RRS	8	226	368	431	82	464
	Mean		233	355	416	79	479
	LSD ($p < 0.05$)		14.7	33.3	41.6	7.8	23.5
					2022		
6	HVX840RR	8	227	343	397	74	462
3	AFX779	7	230	338	392	76	443
12	SW88-304	8	232	339	392	77	443
2	715RR	7	239	328	377	74	442
20	UC-2693	9	235	331	380	76	437
1	98218	8	227	341	394	77	436
7	Magna-905	9	230	335	386	76	435
8	Super-Sonic	9	230	334	383	75	435
11	SW8421-S	8	222	352	407	79	433
19	UC-Impalo	9	229	327	380	74	431
16	UC-2705	9	227	341	395	78	431
10	SW8421RRS	8	224	341	396	78	429
9	SW10	10	228	345	394	79	428
15	SW9813	9	229	339	391	78	426
13	SW9215RRS	9	221	348	403	79	425
5	Desert-Rose	8	232	339	389	77	425
17	UC-Cibola	9	225	351	404	80	422
14	SW9812	9	221	356	411	80	420
18	UC-Highline	9	221	355	412	81	417
4	CUF-101	9	221	345	400	79	412
	Mean		227	341	394	77	431
	LSD ($p < 0.05$)		14.7	30.5	37.5	7	29.7

FD: Fall dormancy rating; CP: Crude protein, ADF: Acid detergent fiber, NDF: Neutral detergent fiber, ADL: Acid detergent lignin, NDFD: Neutral detergent fiber digestibility. Within columns, two cultivars are significantly different at the 0.05 probability level when means difference is greater than the LSD value.

NDFD, one of the most important nutritive value parameters from animal productivity perspective, was consistently the highest for cultivar "HVX840RR" in both years (505 & 462 g·Kg^{-1}, in 2021 and 2022, respectively) while conventional cultivars "SW84421RR", and "UC-Highline" in 2021 and cultivar "CUF-101"in 2022 produced the lowest NDFD values with 464 g·Kg^{-1} and 412 g·Kg^{-1}, respectively (**Table 5**).

Nutritive values achieved by most of the cultivars harvested under delayed cutting schedule in this study are within alfalfa nutritive values results reported by many researchers for alfalfa harvested under delayed harvests and, in some cases comparable to 28-day based cutting schedules [8] [9] [37]-[40] in short- and long-growing season areas. Nutritive values changed during growing season with early-(spring harvesting times) and late-growth periods (fall harvesting times), resulting in higher nutritive values while mid-summer growth period resulting in forage with lower nutritive values. These relationships fitted polynomial 2nd and 3rd order functions with R^2 values of 0.82 to 0.84 and 0.91 to 0.96 in 2021-2022 (for crude protein and NDFD, respectively) and polynomial 3rd order functions with R^2 values of 0.81 to 0.95 in 2021-2022 (for NDF and ADF) (**Figure 2**). This type of seasonal changes in nutritive value is commonly seen with alfalfa and can be linked, especially in arid environments, to environmental factors [41] [42], such as high night temperatures resulting in higher respiration with plants using more of the limited products of photosynthesis produced during the hot summer days to maintain normal metabolism.

With the annual and three years cumulative yields produced by most of the cultivars, and seasonal nutritive values achieved, averaged over the two full production years (*i.e.* CP: 224 - 240 g·Kg^{-1}; ADF: 340 - 359 g·Kg^{-1}; NDF: 393 - 417 g·Kg^{-1}; NDFD: 441 - 484 g·Kg^{-1}) comparing well with alfalfa quality marketing groups designation (USDA-Agricultural Marketing Service) as "Supreme", "Good", "Fair", and "Supreme" for the above nutritive value parameters, respectively. This is also in line with the forage quality groups classification designation discussed in detail by Putnam and Orloff [43]. It is noteworthy that all these forage quality parameters, except ADF, mentioned above are ranked as "Fair" to "Supreme" (overall we consider the forage quality achieved by most cultivars in this study as "good") suggesting that maximizing yield while achieving forage quality using 35-days based cutting schedule could be possible and be used as a tool to help farmers not only to grow alfalfa profitably and maintain production and perhaps also increase production area and maintain alfalfa's environmental benefits as part of their farming systems. Yields and NDFD correlated positively but weakly ($R^2 = 0.03$) with some semi- and non-FD cultivars performing similarly (**Figure 3**). The results indicate that the relationship between yield and NDFD of alfalfa was independent of cultivar types and the highest NDFD value seen in one cultivar ("HVX840RR" with FD 8) can be explained by the "reduced-lignin" trait in this cultivar possess which was not associated with fall dormancy ratings.

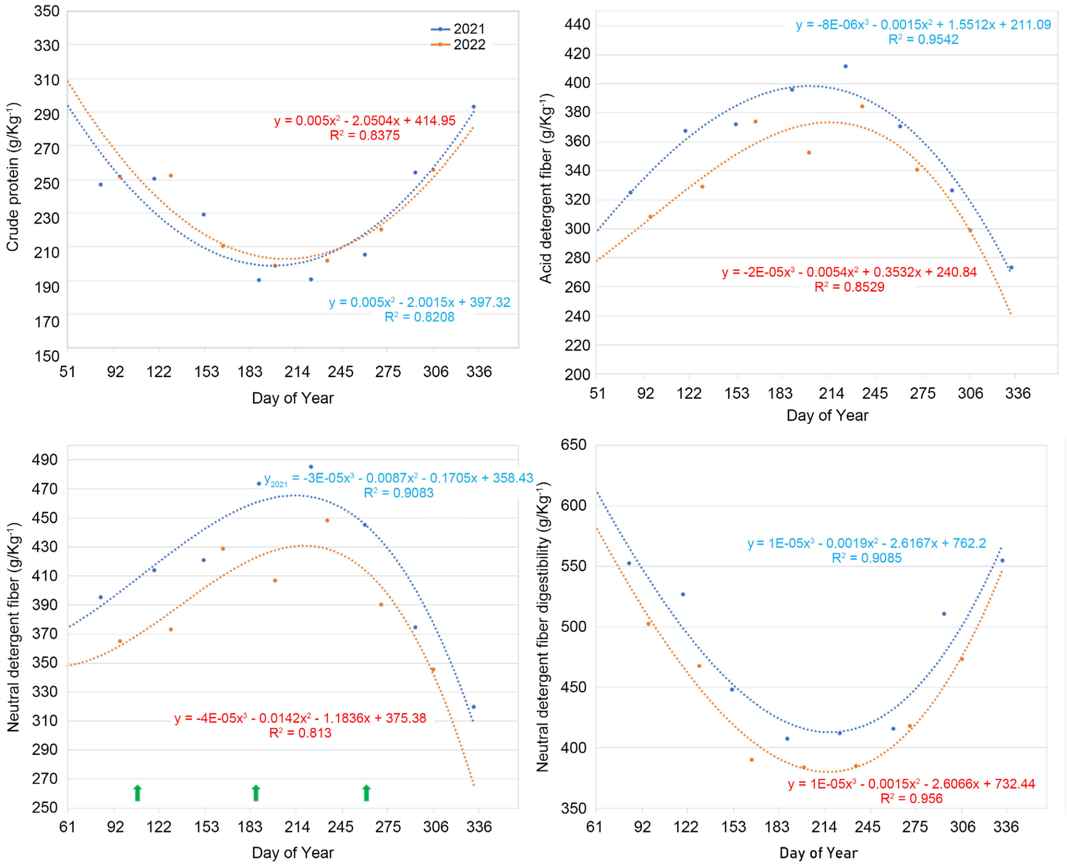

Figure 2. The relationships between nutritive value parameters and harvesting time during the year. Values are averaged over 20 cultivars in each production year of 2021 and 2022. The three upward green arrows represent early- (Cutting 1-2: Mar./Apr.), mid- (Cutting 3-4: June/July) and late-season (Cutting 6-7: Sep/Oct.), respectively for all variables.

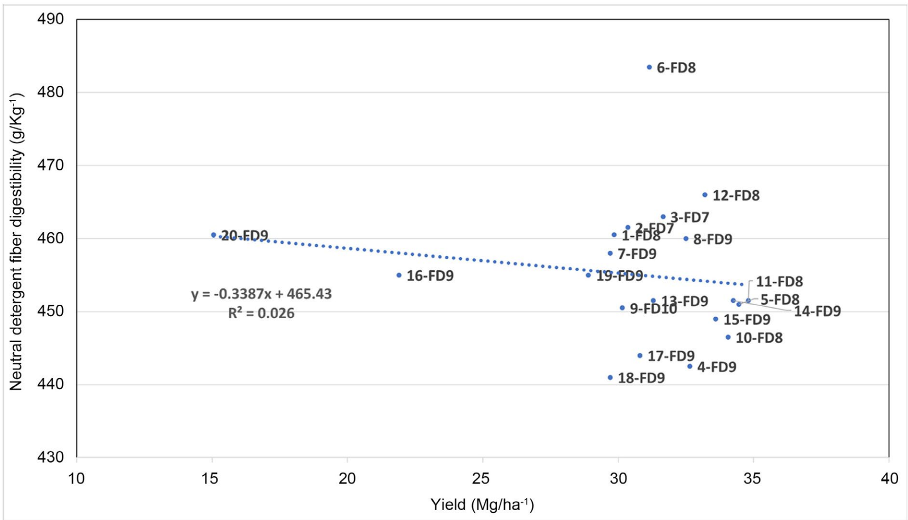

Figure 3. The relationships between yield and neutral detergent fiber digestibility (NDFD), average of 2 full production years and 15 harvests (2021-2022). Numbers and fall dormancy (FD) (see Table 2) in the figure represent cultivar numbers and FD ratings. Cultivars with NDFD values > 480 and 420 to 480 g·Kg⁻¹, respectively, fall in the premium and fair to premium (overall as "good") alfalfa quality marketing groups.

4. Conclusion

The collective results of this study suggest similarities but also important differences among alfalfa cultivars in forage yield and nutritive values under 35-d cutting schedule strategy, and this was generally independent of cultivars fall dormancy rating. Based on 3-yrs cumulative DM yield, four of the conventional cultivars with FD 8 - 9 were the top yielding, producing significantly greater yield not only than the lowest yielding experimental lines (FD 8 - 9) but also than seven of the other cultivars (FD 7 - 10). Generally, based on the two full production years, the first three to four cuts accounted 49% to 64% of the annual cumulative DM yield highlighting the importance of early season growth to achieve high alfalfa productivity. This study also demonstrated that spring and fall growth resulted in higher forage nutritive values than mid-summer growth. NDFD is one of the most important forage quality parameters that explain the nutritive value and impact forage makes in animal productivity. Yields and NDFD correlated positively but weakly with some semi-dormant and non-FD cultivars performing similarly. Nutritive values such as CP and NDFD achieved by most of the cultivars in this study are generally in line with alfalfa quality marketed as “good”. Thus, selecting high yielding cultivars harvested under 35-d cutting schedule strategy can be used as a management tool to help growers maximize yield with forage of good quality to make production profitable and keep alfalfa’s environmental benefit in their farming system.

Author Contributions

Conceptualization, S.B., D.P., D.W. and K.B; methodology, S.B., D.P., D.W. and K.B.; formal analysis, S.B.; investigation, S.B., D.P., and D.W.; writing—original draft, S.B.; writing—review and editing, S.B., D.P., D.W. and K.B., L.Y.; supervision, S.B. and D.W. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

Data can be available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] NASS (2023) Quick Stats. http://quickstats.nass.usda.gov/

[2] IDFA (2019) The International Dairy Foods Association (IDFA). http://www.idfa.org/dairydelivers

[3] Sumner, D.A., Lee, H. and Matthews, W.A. (2015) What Does the Trans-Pacific Partnership Agreement Mean for California Agriculture? *University of California Giannini Foundation of Agricultural Economics*, **19**, 1-5.

[4] USDA-ERS (2017) http://www.ers.usda.gov/data-products/dairy-data/

[5] Long, R., Leinfelder-Miles, M., Light, S.E., Putnam, D.H. and Murdock, J. (2020) Sample Costs to Establish and Produce Alfalfa Hay. University of California Agricultural and Natural Resources, and UC Davis.

[6] Moyer, J.L., Whitworth, R.J. and Davis, H. (2014) Flaming Dormant Alfalfa for Pest Control. *American Journal of Plant Sciences*, **5**, 915-923. https://doi.org/10.4236/ajps.2014.57104

[7] Orloff, S. and Putnam, D. (2010) Adjusting Alfalfa Cutting Schedules for Economic Conditions. *Proceedings of the* 40*th California Alfalfa & Forage and Corn/Cereal Silage Mini-Symposium*, Visalia, 1-2 December 2010, 1-2.

[8] Putnam, D.H., Orloff, S. and Teuber, L.R. (2005) Strategies for Balancing Quality and Yield in Alfalfa Using Cutting Schedules and Varieties. *Proceedings of* 35*th California Alfalfa and Forage Symposium*, Visalia, 12-14 December 2005, 1-15.

[9] Fisher, M. (2017) Reduced-Lignin ALFALFA Provides Flexibility for Farmers. *Crops & Soils*, **50**, 4-9. https://doi.org/10.2134/cs2017.50.0508

[10] Ventroni, L.M., Volenec, J.J. and Cangiano, C.A. (2010) Fall Dormancy and Cutting Frequency Impact on Alfalfa Yield and Yield Components. *Field Crops Research*, **119**, 252-259. https://doi.org/10.1016/j.fcr.2010.07.015

[11] Albrecht, K.A., Wedin, W.F. and Buxton, D.R. (1987) Cell-Wall Composition and Digestibility of Alfalfa Stems and Leaves. *Crop Science*, **27**, 735-741. https://doi.org/10.2135/cropsci1987.0011183x002700040027x

[12] Casler, M.D., Buxton, D.R. and Vogel, K.P. (2002) Genetic Modification of Lignin Concentration Affects Fitness of Perennial Herbaceous Plants. *Theoretical and Applied Genetics*, **104**, 127-131. https://doi.org/10.1007/s001220200015

[13] Undersander, D., Hall, M.H., Vassalotti, P. and Cosgrove, D. (2011) Alfalfa Germination & Growth (A3681). Cooperative Extension Publishing.

[14] Orloff, S. and Putnam, D. (2012) Alfalfa Harvest Management Principles. *Proceedings of the California Alfalfa & Grains Symposium*, Sacramento, 10-12 December 2012, 1-10.

[15] Orloff, S. and Putnam, D. (2006) Cutting Schedule Strategies to Maximize Returns. *Proceedings of the* 36*th California Alfalfa & Forage Symposium*, 12-14 December 2005, 1-15.

[16] Callan, J. (2023) The Hoyt Report. https://www.thehoytreport.com/

[17] Moore, K.J. and Jung, H.G. (2001) Lignin and Fiber Digestion. *Journal of Range Management*, **54**, 420-430. https://doi.org/10.2307/4003113

[18] Van Soest, P.J. (1994) Nutritional Ecology of the Ruminant. Cornell University Press.

https://doi.org/10.7591/9781501732355

[19] Kenward, M.G. and Roger, J.H. (2009) An Improved Approximation to the Precision of Fixed Effects from Restricted Maximum Likelihood. *Computational Statistics & Data Analysis*, **53**, 2583-2595. https://doi.org/10.1016/j.csda.2008.12.013

[20] Anderson, A.W., Gull, U., Benes, S.E., Singh, S., Hutmacher, R.B., Brummer, E.C., *et al.* (2023) Salinity and Cultivar Effects on Alfalfa Forage Yield and Nutritive Value in a Mediterranean Climate. *Grassland Research*, **2**, 153-166. https://doi.org/10.1002/glr2.12061

[21] Russelle, M.P. (2013) The Alfalfa Yield Gap: A Review of the Evidence. *Forage & Grazinglands*, **11**, 1-8. https://doi.org/10.1094/fg-2013-0002-rv

[22] Putnam, D., Orloff, S. and Teuber, L. (2008) Choosing an Alfalfa Variety. In: Summers, C.G. and Putnam, D.H. Eds., *Irrigated Alfalfa management for Mediterranean and Desert Zones*, University of California Division of Agriculture and Natural Resources, 59-72.

[23] Coruh, I. and Tan, M. (2008) Lucerne Persistence, Yield and Quality as Influenced by Stand Aging. *New Zealand Journal of Agricultural Research*, **51**, 39-43. https://doi.org/10.1080/00288230809510433

[24] Sun, Y., Yang, Q., Kang, J., Guo, W., Zhang, T. and Li, Y. (2011) Yield Evaluation of Seventeen Lucerne Cultivars in the Beijing Area of China. *Journal of Agricultural Science*, **3**, 215-223. https://doi.org/10.5539/jas.v3n4p215

[25] Han, B., Hu, T., Yang, P. and Sun, W. (2013) Evaluation of Eight Alfalfa Varieties for Their Production, Quality, and Persistence on the Loess Plateau. *Australian Journal of Crop Science*, **7**, 1093-1099.

[26] Zhang, T., Kang, J., Guo, W., Zhao, Z., Xu, Y., Yan, X., *et al.* (2014) Yield Evaluation of Twenty-Eight Alfalfa Cultivars in Hebei Province of China. *Journal of Integrative Agriculture*, **13**, 2260-2267. https://doi.org/10.1016/s2095-3119(13)60576-6

[27] Cavero, J., Faci, J.M., Medina, E.T. and Martínez-Cob, A. (2017) Alfalfa Forage Production under Solid-Set Sprinkler Irrigation in a Semiarid Climate. *Agricultural Water Management*, **191**, 184-192. https://doi.org/10.1016/j.agwat.2017.06.018

[28] Tucak, M., Horvat, D., Čupić, T., Krizmanić, G. and Ravlić, M. (2023) Assessment of Alfalfa Populations for Forage Productivity and Seed Yield Potential under a Multi-Year Field Trial. *Agronomy*, **13**, Article 349. https://doi.org/10.3390/agronomy13020349

[29] Wang, S., Fang, D., Ameen, A., Li, X., Guo, K., Liu, X., *et al.* (2021) Dynamics of Spring Regrowth and Comparative Production Performance of 50 Autumn-Sown Alfalfa Cultivars in the Coastal Saline Soil of North China. *Life*, **11**, Article 1436. https://doi.org/10.3390/life11121436

[30] Djaman, K., Owen, C., Koudahe, K. and O'Neill, M. (2020) Evaluation of Different Fall Dormancy-Rating Alfalfa Cultivars for Forage Yield in a Semiarid Environment. *Agronomy*, **10**, Article 146. https://doi.org/10.3390/agronomy10010146

[31] Lamb, J.F.S., Jung, H.G. and Riday, H. (2014) Growth Environment, Harvest Management and Germplasm Impacts on Potential Ethanol and Crude Protein Yield in Alfalfa. *Biomass and Bioenergy*, **63**, 114-125. https://doi.org/10.1016/j.biombioe.2014.02.006

[32] Li, M., Liu, Y., Yan, H. and Sui, R. (2017) Effects of Irrigation Amount on Alfalfa Yield and Quality with a Center-Pivot System. *Transactions of the ASABE*, **60**, 1633-1644. https://doi.org/10.13031/trans.12239

[33] Sharratt, B.S., Sheaffer, C.C. and Baker, D.G. (1989) Base Temperature for the

Application of the Growing-Degree-Day Model to Field-Grown Alfalfa. *Field Crops Research*, **21**, 95-102. https://doi.org/10.1016/0378-4290(89)90045-2

[34] Bolger, T.P. and Matches, A.G. (1990) Water-Use Efficiency and Yield of Sainfoin and Alfalfa. *Crop Science*, **30**, 143-148. https://doi.org/10.2135/cropsci1990.0011183x003000010032x

[35] Li, Y. and Su, D. (2017) Alfalfa Water Use and Yield under Different Sprinkler Irrigation Regimes in North Arid Regions of China. *Sustainability*, **9**, Article 1380. https://doi.org/10.3390/su9081380

[36] Orloff, S., Putnam, D. and Bali, K. (2011) Drought Strategies for Alfalfa. UC-Agricultural and Natural Resources.

[37] Min, D. (2016) Effects of Cutting Interval between Harvests on Dry Matter Yield and Nutritive Value in Alfalfa. *American Journal of Plant Sciences*, **7**, 1226-1231. https://doi.org/10.4236/ajps.2016.78118

[38] Kallenbach, R.L., Nelson, C.J. and Coutts, J.H. (2002) Yield, Quality, and Persistence of Grazing- and Hay-Type Alfalfa under Three Harvest Frequencies. *Agronomy Journal*, **94**, 1094-1103. https://doi.org/10.2134/agronj2002.1094

[39] Grev, A.M., Wells, M.S., Samac, D.A., Martinson, K.L. and Sheaffer, C.C. (2017) Forage Accumulation and Nutritive Value of Reduced Lignin and Reference Alfalfa Cultivars. *Agronomy Journal*, **109**, 2749-2761. https://doi.org/10.2134/agronj2017.04.0237

[40] Arnold, A.M., Cassida, K.A., Albrecht, K.A., Hall, M.H., Min, D., Xu, X., *et al.* (2019) Multistate Evaluation of Reduced-Lignin Alfalfa Harvested at Different Intervals. *Crop Science*, **59**, 1799-1807. https://doi.org/10.2135/cropsci2019.01.0023

[41] Putnam, D.H., Robinson, P. and DePeters, E. (2008) Forage Quality and Testing. In: Summers, C.G. and Putnam, D.H., Eds., *Irrigated Alfalfa Management in Mediterranean and Desert Zones*, University of California, Agriculture and Natural Resources, 1-24.

[42] Kalu, B.A. and Fick, G.W. (1983) Morphological Stage of Development as a Predictor of Alfalfa Herbage Quality[1]. *Crop Science*, **23**, 1167-1172. https://doi.org/10.2135/cropsci1983.0011183x002300060033x

[43] Putnam, D.H. and Orloff, S. (2016) Agronomic Factors Affecting Forage Quality in Alfalfa. *Proceedings*, *California Alfalfa and Forage Symposium*, Reno, 29 November-1 December 2016. http://alfalfa.ucdavis.edu