Turkish Journal of FIELD CROPS

Turk J Field Crops
2022, 27(2), 265-275
DOI: 10.17557/tjfc.1187216

IRRIGATION AND PHOSPHORUS MANAGEMENT OF ALFALFA (*Medicago sativa* L.) UNDER SEMI-ARID CONDITIONS

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Received: 11.10.2022

ABSTRACT

The frequency of irrigation and deficit irrigation management are drawing attention because water resources are becoming limited year by year, especially in the last decade. Besides, the rate and application time of P fertilization gained more importance just after the researchers found out it is more effective than N-fertilizing for alfalfa cultivation. This study aimed to determine the effects of different irrigation managements (seasonal deficit, intervals of 5, 7, and 9 days), phosphorus application season (autumn and spring), and the rate of P fertilizer (0, 30, 60, 90 kg ha^{-1}) on the yield and forage quality of alfalfa. The experiment was conducted in the 2019-2020 years, which was the 3rd and the 4th years of alfalfa respectively, under semi-arid Mediterranean conditions. The stand height and fiber content (NDF) were higher in the autumn application. However, forage contained more nitrogen in the spring application. A higher amount of water (1600 mm) with higher irrigation frequency (5 days – I_{5d}) caused a reduction in yield due to water excess. The yield was the highest (21.34 t ha^{-1}) and the forage quality was better in 896 mm water application with 9 days intervals (I_{9d}). Seasonal deficit water management caused a significant loss in yield and quality. Nevertheless, 18.04 t ha^{-1} dry matter yield with 24.05 % CP content was recorded at seasonal deficit water management. P fertilization increased the yield and forage quality. The yield was the highest (20.23 t ha^{-1}) at the rate of 90 kg ha^{-1} P fertilizer, but yield and forage quality characteristics were similar between 30, 60, and 90 kg ha^{-1} P. The results showed that P fertilization could be done in both autumn and spring at the rate of 30 kg ha^{-1} and 896 mm water could be applied at 9 days intervals for fulfilling performance under semi-arid Mediterranean conditions. When water resources are very scarce, the seasonal water deficit should be applied, especially in late summer.

Keywords: Alfalfa, deficit irrigation, fertilization, phosphorus

INTRODUCTION

The globally changing climate has been challenging plant production all over the world and its negative effect is mostly due to the unstable water availability, especially in arid and semi-arid regions of the world. Growers are driven to cultivate drought-tolerant species or to make some water management strategies such as deficit or precision irrigation to alleviate the negative effects of drought (Kandelous et al., 2012; Cavero et al., 2017) because of irregular precipitation and significant reduction of water resources, especially in the dry and temperate summer season. Water management has become very critical for irrigated crops production in dry and warm periods of the year because precipitation distribution patterns are changing and decreasing water availability necessitating lesser irrigation application in arid and semi-arid areas of the world (Lindenmayer et al., 2011; Cavero et al., 2017). Total annual precipitation is in a decreasing trend (FAO, 2021), and annual precipitation decreased by nearly 40 % in Anatolia only in 2021 (Anonymous, 2021). These data indicate that new crop management strategies are required to provide sufficient production, especially for perennial forage crops such as alfalfa because they are significantly affected by annual rainfall distribution.

Alfalfa is one of the most cultivated forage crops in the world, which is highly nutritive and has a high-yielding capacity. The plant has a wide adaptation ability (FAO, 2021), and thereby, the cultivation area ranges from the United States (Djaman et al., 2020) to China (Jia et al., 2018), and Russia (Rovkina et al., 2018) to Africa (Wayu and Atsbha, 2019) in the world. The alfalfa's water requirement is high; therefore, a locally changing precipitation regime or water deficit could affect the yield significantly (Djaman et al., 2020). It was suggested that deficit irrigation or adequate irrigation frequency might provide significant water savings (El-Din and Assaeed, 1995; Putnam et al., 2005) and in addition, it could increase the forage quality (Lindenmeyer et al., 2008; Ismail and Almarshadi, 2013) and water-use efficiency (Lindenmeyer et al., 2011). This could be due to the relative drought tolerance of the plant due to the deep rooting system (Irmak et al., 2007) but the most limiting factor for the yield of alfalfa is water (Undersander et al., 2011), especially in the regions, where precipitation could not compensate the water loss through evapotranspiration (Djaman et al., 2020). In some years, water availability may critically decrease during the dry and hot summer periods in semi-arid regions and alfalfa may not be irrigated due to scarce water resources. In such years, the tolerance capacity of the alfalfa is crucial for the sustainability of the production. Jin et al. (2015) suggested phosphorus fertilization for increased drought tolerance by increasing root growth. However, warm summer temperatures cause a summer slump in alfalfa due to the cool season characteristics of the crop (Ottman and Mostafa, 2014), and thereby, water use is reduced. Productivity of the plant could decrease due to the summer slump but sustainable production might be ensured by deficit irrigation and phosphorus fertilization. Deficit irrigation practices might have different effects on alfalfa and it should be experienced under different ecological conditions.

Phosphorus is generally associated with a higher root growth rate of the plant (Malhi and Gill, 2002; Berrada and Westfall, 2005), which might help to increase drought tolerance. Besides, N_2-fixing species like alfalfa require P to increase nitrogen-fixing capacity (Reed et al., 2007; Divito and Sadras, 2014), especially in calcareous alkaline soils of the semi-arid regions due to low mobility and bioavailability in such environments (Gu et al., 2018; Kong et al., 2020). Some researchers indicated the effect of P is not on the yield of alfalfa (Macolino et al., 2013), but on the forage quality (Berrada and Westfall, 2005; Lissbrant et al., 2009). Contrarily, some research results are showing the significant positive effect of P fertilization on the forage yield of alfalfa (Berrada and Westfall, 2005; Berg et al., 2005; Fan et al., 2016). Regardless of its effect on forage yield or quality, P should be applied one time every year (James et al., 1995; Macolino et al., 2013) because it is fairly immobile considering other elements (Berrada and Westfall, 2005). In the Mediterranean region, P is generally applied in early winter (Macolino et al., 2013), when alfalfa is sensitive to P deficiency (James et al., 1995). But some researchers suggest P fertilizing in early spring (Malhi et al., 2001; Divito and Sadras, 2014) or both in late autumn and early spring by dividing the total annual amount into two (Koenig et al., 1999; Lissbrant et al., 2009). The efficiency of P fertilizer may greatly change due to application season (James et al., 1995; Malhi et al., 2001; Divito and Sadras, 2014), and there is a lack of knowledge about the effects of different P fertilizing seasons for alfalfa production in semi-arid regions.

The yield and quality of alfalfa could change significantly at different amounts of P applications (Berg et al., 2007; Lissbrant et al., 2009). Berg et al. (2003) determined that approximately 70 kg ha^{-1} P fertilizer caused nearly 1 t ha^{-1} increment in annual dry matter production. In another research, Li et al. (2022) determined that increasing P fertilizer increased the yield of alfalfa up to 100 kg ha^{-1}. According to Lissbrant et al. (2009), a significant increment in alfalfa forage yield could be observed at 25 kg ha^{-1} P fertilization or more. Increasing the dosage of P might increase the yield and quality significantly (Berg et al., 2003) but excessive P fertilizer could cause a hazardous accumulation in soil (Macolino et al., 2013) and increase the production costs. Therefore, determining the proper P amount for different types of soil and climates is essential in alfalfa fertilizing.

This two-year experiment was carried out under semi-arid Mediterranean conditions. The first hypothesis to be tested was irrigation frequency significantly affected the yield and the quality of alfalfa and deficit irrigation practice ensured high-quality hay production during the dry and temperate summer period. The second hypothesis to be tested was there were significant yield and quality differences between late-autumn and early-spring phosphorus fertilizing of alfalfa. The third hypothesis to be tested was alfalfa showed better drought tolerance to summer drought by increasing phosphorus fertilizer in semi-arid Mediterranean conditions.

MATERIALS AND METHODS

Study area

The experiment was conducted in the Mayıslar experimental station of Eskisehir Osmangazi University, Faculty of Agriculture during the years 2019 and 2020. The station is located in a microclimate area in Central Anatolia (Figure 1), therefore Mediterranean climate characteristics prevail at the station with an altitude of 250 m above sea level. The area is classified as semi-arid because the LTA of precipitation is 366.4 mm. Precipitation mostly falls in winter and spring, but irregular precipitation was observed (Table 1). Precipitation was lower in the second year because a severe drought was observed in the summer of 2020. The average temperature was 15.8 ^{0}C and it did not decrease below zero in winter but short-term decreases might occur occasionally. Humidity was relatively lower in the experimental years than in the LTA (Table 1).

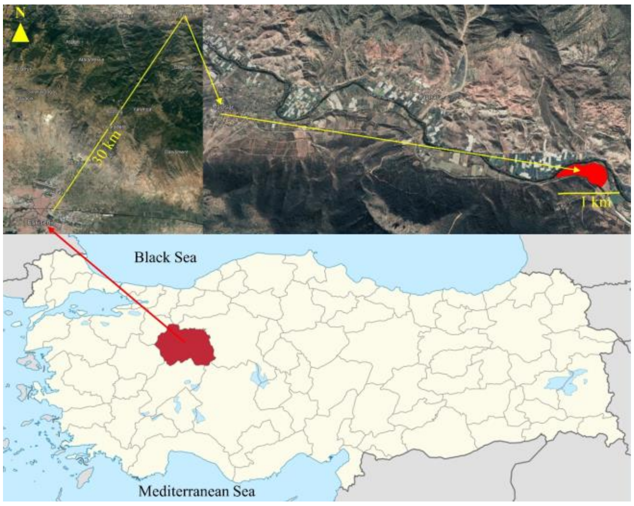

Figure 1. Location of the Mayıslar experimental station

Soil samples of the experimental field were taken from a depth of 0-30 cm and were analyzed at the Soil Laboratory of Eskisehir Osmangazi University, Faculty of

Agriculture. According to the analysis report, the soil texture was sandy-loam, soil pH was 8.06 and it has an alkaline characteristic. The content of organic matter content was 0.85 % (very low), corresponding available P_2O_5 was 25.9 kg ha^{-1} (very low) and K_2O was 958 kg ha^{-1} (sufficient).

Field studies

The experiment was conducted on the alfalfa production facility, which was established in 2016 using the Gozlu cultivar of *Medicago sativa* L. It was the 3rd and 4th years of the plants when the experiment was established. Sowing density was 5 kg ha^{-1} with 30 cm rows during the sowing. In the experiment, the effects of phosphorus application seasons (autumn, spring), irrigation frequencies (seasonal deficit, 5, 7, 9 days intervals), and phosphorus dosages (0, 30, 60, 90 kg ha^{-1}) on the yield and quality characteristics of alfalfa were examined. Plots were placed in late autumn of 2017 to be 15 × 20 meters (300 m^2) and the experiment was designed due to a randomized complete block design with split-split plots arrangement and four replications. Fertilizer application season was considered as the main plot, irrigation frequency as the sub-plot, and phosphorus amount as the sub-sub plot. Years were considered random. Triple super phosphate (TSP) was used as fertilizer and was applied by hand. Irrigation was carried out from March to October every year using a sprinkler system at 5 (I_{5d}), 7 (I_{7d}), and 9 (I_{9d}) days intervals, and 32 mm of water was applied with every irrigation. Total amounts of water applied annually were 1600 mm, 1152 mm, and 896 mm for I_{5d}, I_{7d}, and I_{9d} treatments respectively. In the plots, in which seasonal deficit (I_{SD}) was applied, irrigation was carried out at 5 days intervals but ceased about 45 days from mid-June to September to simulate the effect of summer drought on water resources. The total amount of applied water was 1280 mm annually for I_{SD} treatment.

Table 1. Meteorological data of the experimental area

	Precipitation (mm)			Temperature (ºC)			Humidity (%)		
Months	2019	2020	LTA	2019	2020	LTA	2019	2020	LTA
January	48.4	45.7	31.2	5.5	3.3	4.8	75.5	77.5	77.1
February	33.3	41.1	27.4	6.7	6.8	7.9	72.3	70.6	72.5
March	7.8	22.1	31.1	9.5	10.6	10.8	58.8	64.7	65.9
April	19.3	22.5	29.4	12.9	13.1	14.7	61.1	57.6	60.5
May	34.7	40.4	59.6	20.4	18.7	19.9	55.6	57.9	64.8
June	93.5	77.7	69.0	23.8	22.2	23.2	62.9	62.7	63.1
July	41.7	0.2	10.5	24.9	26.8	26.3	53.3	51.4	50.0
August	16.2	0.2	18.0	26.0	27.0	26.8	51.7	45.5	52.1
September	0.8	5.9	12.6	22.1	24.7	23.1	51.0	54.3	55.0
October	9.9	30.6	33.0	17.8	19.2	16.4	60.6	59.4	65.9
November	17.8	1.9	16.0	12.9	8.8	10.7	62.0	68.6	69.8
December	65.3	0.0	28.7	6.6	2.0	4.9	79.9	67.5	77.7
Tot./Ave.	*388.7*	*288.3*	*366.4*	*15.8*	*15.3*	*15.8*	*61.5*	*62.1*	*64.5*

LTA: Long-term average

Data collection and analysis

The plant height was measured before every mowing from randomly selected 4 points within every plot and the results were averaged to be one measurement for every plot. Plants were harvested in the early bud stage (Macolino et al., 2013) 5 times from April to October in both years using a hand sickle. Plants were harvested from four different areas, each 1m^2 in every plot, and weighed. Dry matter yield was determined by sampling 500 g in every mowing, and by oven-drying at 60 ^{0}C until reached constant weight. Crude protein (CP), NDF, and ADF contents were determined using near infra-red spectroscopy (NIRS). To calibrate the NIRS values, CP and NDF-ADF contents were determined due to the Kjeldahl method and in the ANKOM fiber analyzer respectively. Analysis results had a high correlation ($r^2 \geq 0.9$, $P \leq 0.01$) with NIRS results. Nitrogen and phosphorus contents were determined in NIRS and multiplied by dry matter yield to determine N and P harvest.

All data were tested by the Shapiro Wilk test to fulfill the assumptions of analysis of variance (Zar, 2013) and then, normally distributed data were subjected to analysis of variance using SAS (SAS Institute 2011) to determine the effects and interaction of the factors. The means were compared using Tukey Multiple Comparison Test.

RESULTS AND DISCUSSION

Plant height

The average plant height was 73.96 cm and it did not change significantly between years. Although the autumn application of phosphorus application caused a statistically significant increase in plant height compared to the spring application, this increase was not high numerically (only, 0.55 cm). The highest plant height was measured in the stand received 30 kg P_2O_5 ha^{-1}. While the shortest plant height was recorded at seasonal deficit irrigation applied plots, the highest plant height was recorded at the plots irrigated 7 days interval (Table 2). As is the effect of the treatments, most of their interaction effect was statistically significant but there were no prominently differences among the interaction effects for plant height (Figure 2) (Table 2).

The height of alfalfa could positively correlate with the yield (Lyons et al., 2016) and even the forage quality (Owens et al., 1995) and therefore, it has been used to estimate yield or forage quality characteristics by many researchers (Ventroni et al., 2010; Noland et al., 2018). Height is mainly characterized by genetic factors (He et al., 2020) but environmental factors might have a substantial effect on the height of alfalfa (Jia et al., 2022). Besides, Cui et al. (2021) determined that the height of alfalfa decreased with the advancing years of the plantation. However, climatic differences between 2019-2020 did not cause a significant variation in plant height of alfalfa, and two years results did not reveal a significant decrement in plant height. Plant height was higher at autumn P application. Similarly, Jacobsen and Surber (1995) suggested autumn P application for alfalfa/grass mixtures for forage production. Researchers stated that the amount of irrigation is effective on the height of alfalfa (Hanson et al., 2007; Cavero et al., 2017). In our study, the highest amount of water (1600mm) was applied by 5 days interval irrigation frequency (I_{5d}) but the plant height was the longest for I_{7d} treatment. Besides, seasonal irrigation deficiency negatively affected the height of alfalfa. The utilization ratio of the crops from P fertilizers could not reach above 25 % even just after the P application (Johnson et al., 2014). The amount of the applied P could affect growth performance but the excessive application is not beneficial for crops as well as causes environmental pollution (Conley et al., 2009). The height of the alfalfa increased at 30 kg ha^{-1} P rate but it decreased at 60 and 90 kg ha^{-1} rates of P fertilizer.

Table 2. The results of the effect of treatments on investigated characteristics of alfalfa.

	Plant height (cm)	DM yield (t ha^{-1})	CP (%)	NDF (%)	ADF (%)	N harvest (kg ha^{-1})	P harvest (kg ha^{-1})
Years (Y)							
2019	74.00	21.01^{a}	23.99	38.10^{B}	31.56^{b}	806.57^{a}	68.59
2020	73.92	18.26^{b}	24.49	40.46^{A}	31.69^{a}	715.45^{b}	66.31
P application season (S)							
Autumn	74.23^{A}	19.43	24.16	38.98^{A}	31.57	749.41^{b}	67.00
Spring	73.68^{B}	19.84	24.31	39.58^{B}	31.67	772.60^{a}	67.90
Irrigation treatments (I)							
I_{SD} (1280mm)	56.42^{C}	18.04^{D}	24.05	39.13^{B}	31.55^{B}	692.82^{D}	62.02^{D}
I_{5d} (1600mm)	78.88^{B}	19.00^{C}	24.41	38.99^{B}	31.51^{B}	741.27^{C}	65.84^{C}
I_{7d} (1152mm)	81.74^{A}	20.16^{B}	24.23	39.15^{B}	31.69^{AB}	781.24^{B}	69.27^{B}
I_{9d} (896mm)	78.79^{B}	21.34^{A}	24.26	39.85^{A}	31.74^{A}	828.70^{A}	72.66^{A}
P_2O_5 rate (P)							
0 kg ha^{-1}	73.58^{C}	18.85^{C}	24.55^{A}	39.23^{ab}	31.60^{B}	738.93^{B}	65.14^{B}
30 kg ha^{-1}	75.75^{A}	19.51^{BC}	23.98^{B}	38.99^{b}	31.54^{B}	748.30^{AB}	67.48^{AB}
60 kg ha^{-1}	72.17^{D}	19.95^{AB}	23.96^{B}	39.68^{a}	31.79^{A}	765.34^{AB}	67.47^{AB}
90 kg ha^{-1}	74.33^{B}	20.23^{A}	24.47^{AB}	39.22^{ab}	31.56^{B}	791.46^{A}	69.70^{A}
Mean	*73.96*	*19.63*	*24.24*	*39.28*	*31.62*	*761.01*	*67.45*
Y	ns	*	ns	**	*	*	ns
S	**	ns	ns	**	ns	*	ns
I	**	**	ns	**	**	**	**
P	**	**	**	*	**	**	**
Y×S	ns	*	**	ns	ns	ns	*
Y×I	ns	**	ns	**	ns	**	**
Y×P	ns	**	ns	ns	*	**	**
S×I	**	**	*	ns	ns	**	**
S×P	**	**	ns	**	*	**	**
I×P	**	**	ns	ns	ns	**	**
Y×S×I	ns	**	*	**	ns	*	**
Y×S×P	ns	**	ns	**	**	ns	ns
Y×I×P	ns	*	ns	ns	ns	ns	*
S×I×P	**	*	**	ns	ns	ns	ns
Y×S×I×P	ns	ns	*	*	ns	ns	ns

ns: non-significant, *: P≤0.05, **: P≤0.01

Dry matter yield

In the first year, dry matter yield was higher about 2.75 t ha^{-1} than in the second year (Table 2). Dry matter yield increased as the irrigation frequency decreased and the highest yield was recorded at 9 days interval (21.34 t ha^{-1}). The lowest dry matter yield was recorded in the seasonal deficit irrigation treatments. Phosphorus increased the dry matter yield of alfalfa and the highest value was recorded in the plots, which were fertilized with 90 kg ha^{-1} P_2O_5. However, a statistically similar DM yield was recorded between 60 and 90 kg ha^{-1} P_2O_5 application. Most of the treatment interactions were significant for DM yield (Table 2). The responses of DM yield were different concerning interactions but the three-way interaction suggested that the best results were obtained from the plots that received 30 kg P_2O_5 ha^{-1} and irrigated 9 days interval in both P application seasons (Figure 3).

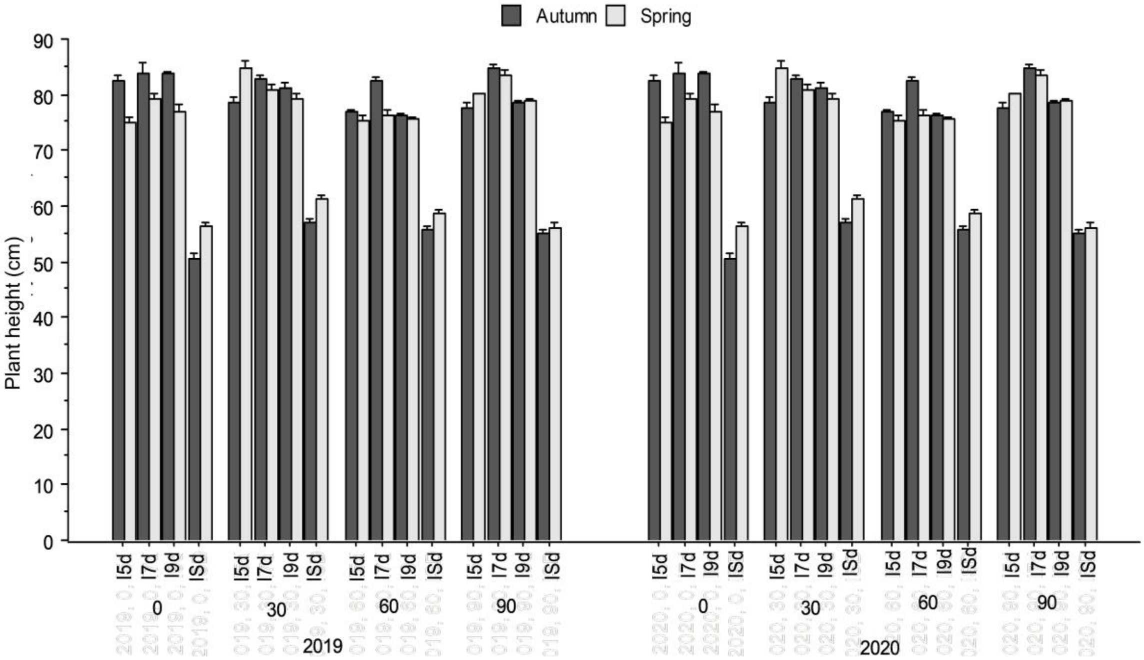

Figure 2. The four-way interaction for plant height

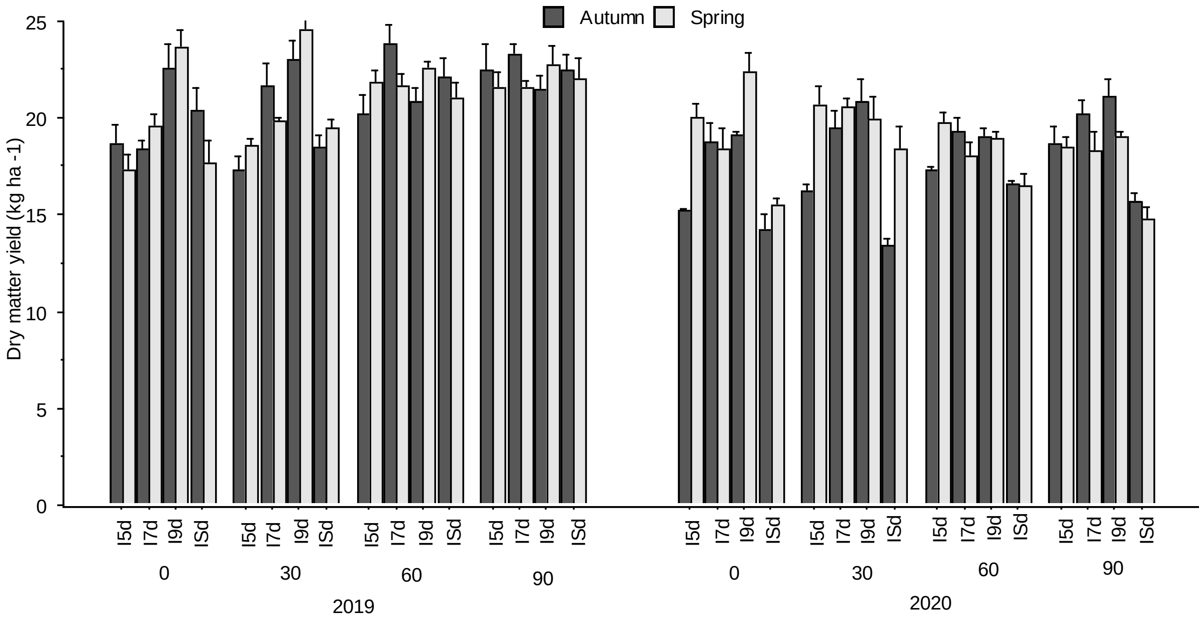

Figure 3. The four-way interaction for dry matter yield

Dry matter yield was higher in the first year possibly due to drought in the second year, especially in July and August (Table 1). Summer drought could affect the yield of alfalfa negatively under Mediterranean climate conditions (Bouizgaren et al., 2013; Annicchiarico, 2021). Even though the experiment was carried out under irrigated conditions; the severe summer drought in 2019 could be responsible for the significant dry matter decrement. Plant height was affected significantly by P application season but it did not affect DM yield and this might be indicating an effect of application season on agronomic traits such as stem diameter or leaf ratio, which was also indicated by Liu et al. (2020). Higher frequency of irrigation negatively affected the DM of alfalfa (Table 2) and the highest yield was recorded for 9 days intervals (I_{9d}). Irrigation increases the yield of alfalfa (Cavero et al., 2017; Djaman et al., 2020). DM yield was the highest at the I_{9d} treatment, which indicates the lowest amount of irrigation (896 mm) in the study (Table 2). The I_{5d} and I_{7d} treatments possibly did not enable sufficient root activity due to excessive water at the root zone. Other researchers also determined the negative effects of excessive water on the yield of alfalfa (Li et al., 2017; Dahlke et al., 2018). A higher amount of water was applied by I_{SD} treatment considering I_7 and I_9, but DM was the lowest. The I_{5d} treatment might be caused excess water damage, and seasonal deficiency decreased the DM production of alfalfa and this might explain the lowest DM yield for I_{SD} treatment. Orloff et al. (2003) determined that yield significantly decreases under late-summer irrigation deficiencies. Phosphorus fertilizer increased the DM yield of alfalfa (Table 2), which was more than 1 t ha^{-1} by 60 kg ha^{-1} P. Similarly, Berg et al. (2003) stated that 70 kg ha^{-1} P fertilizer could increase the DM yield of alfalfa by 1 t ha^{-1}. Other researchers stated the yield increment by P fertilizing (Fan et al., 2016; Gu et al., 2018).

Crude protein content

The average crude protein content was 24.24% and it did not vary significantly between years, seasons, and irrigation frequencies but 30, and 60 kg ha^{-1} phosphorus fertilization significantly decreased ($P \leq 0.01$) the crude protein content of alfalfa (Table 2). Since the combined effects of treatments were not consistent (Figure 4), most of their interaction effects were statistically significant.

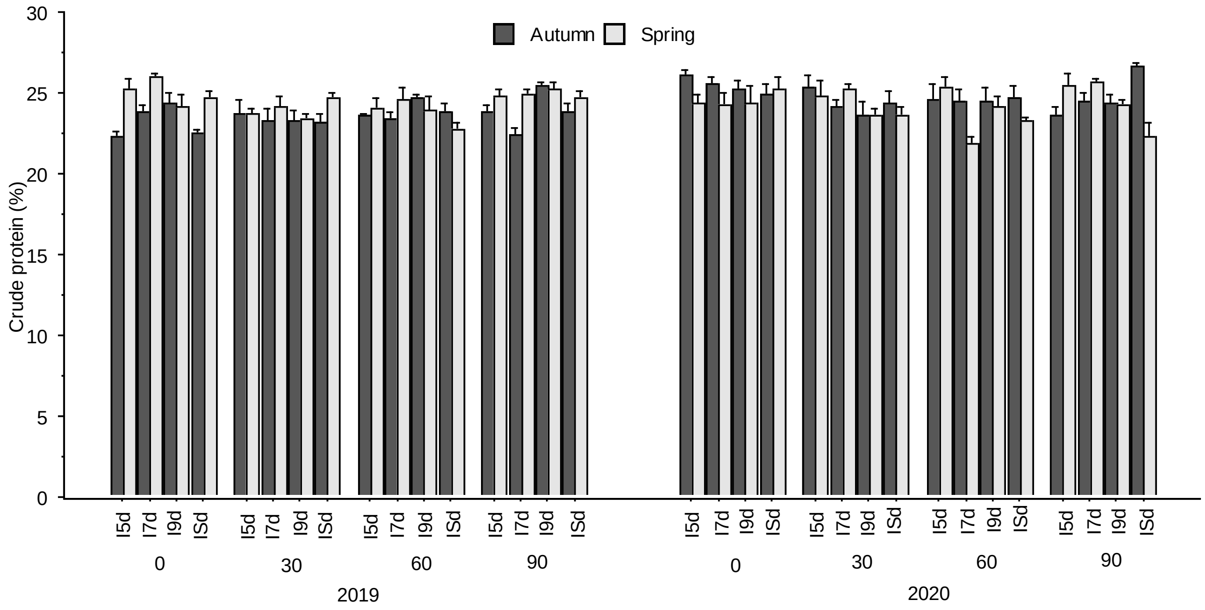

Figure 4. The four-way interaction for crude protein content

The CP of alfalfa was not affected significantly by inter-annual climatic variations, application season of the P fertilizer, and irrigation treatments. Some researchers indicate that forage quality could increase under deficit irrigation (Lindenmayer et al., 2008; Ismail and Almarshadi, 2013) but seasonal deficit treatment did not affect the CP content (Table 2). Phosphorus fertilizer increases the activity of nitrogen-fixing bacteria (Chapin et al., 2011) and therefore, CP content could increase (Berg et al., 2003; Lissbrant et al., 2009) but phosphorus could also increase the maturity of the plant (Sanderson, 1993). Decreasing the CP content of the alfalfa by P fertilizing might be explained by the P-induced maturity of alfalfa. Besides, P fertilizer could decrease the plant density of alfalfa (Berg et al., 2003), and structural carbohydrate content increases under lower densities, which in turn decreases the CP content (Collins and Fritz, 2003). Plant density data is not recorded in this study but this might be another explanation for the lower CP content of P-fertilized alfalfa.

Fiber content (NDF and ADF)

The average NDF content was 39.28 % and all factors caused significant variations (Table 2). NDF content was

38.10 % in 2019 but increased to 40.46 % in 2020. Autumn-fertilized alfalfa had higher NDF content the spring-fertilized. The highest NDF content was determined at the I_{9d} treatment. Among all P rates, only 30 and 60 kg ha^{-1} rates of P fertilizer had significant variations in terms of NDF content and it was the highest when alfalfa was fertilized using 60 kg ha^{-1} P_2O_5. NDF content did not show a consistent response against treatment combinations (Figure 5), hence most of the interactions were statistically significant.

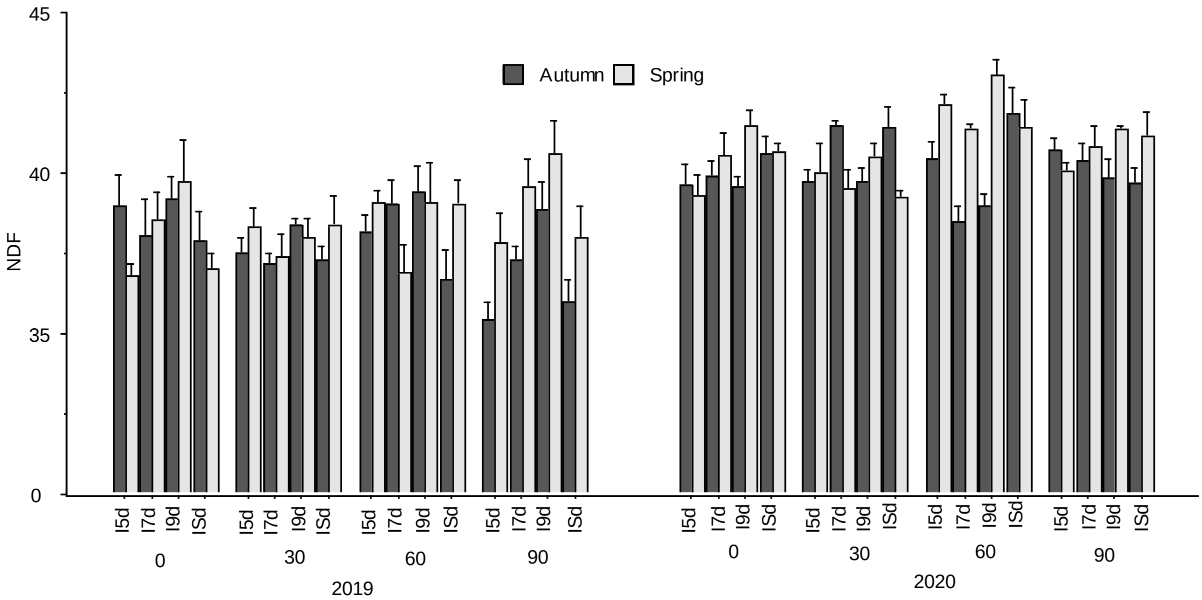

Figure 5. The four-way interaction for NDF content

The average ADF content was 31.62 % and it was higher in the second experimental year. Alfalfa ADF content did not change as the irrigation frequency decreased up to 9 days intervals but a significant increase was determined at I_{9d} treatment. The phosphorus rate of 60 kg ha^{-1} increased the ADF content of alfalfa compared with the 0, 30, and 90 kg ha^{-1} P. Although some interactions were also significant for ADF content, there were no huge changes recorded in interaction effects.

Fiber contents such as NDF and ADF are related to plant maturity and leaf-stem ratio (Liu et al., 2018). The NDF and ADF contents were higher in the year, which received less precipitation (Table 1, 2). The distinct drought in the second might be responsible for the early maturation of the plants and increased NDF and ADF contents of alfalfa. The season of P fertilization was effective on NDF content, not on ADF content. Therefore, it could be stated that autumn P fertilization could increase the hemicellulose content, roughly the digestibility, of alfalfa comparing the spring application because the hemicellulose is the only difference between NDF and ADF contents (Collins and Fritz, 2003). While I_{9d} treatment increased the NDF and ADF contents of alfalfa, the seasonal deficit irrigation did not affect these structural carbohydrate contents. A higher amount of irrigation could increase NDF and ADF content as long as the nitrogen supply is sufficient (Kamran et al., 2022) but these contents were lower for the higher amount of precipitation in our study because no nitrogen fertilizers were applied. The rate of P fertilizer slightly affected NDF and ADF contents. It was reported that P fertilization could increase the NDF and ADF contents of alfalfa (Zhang et al., 2020). Our results showed that the increment in NDF and ADF contents ceased after the rate of 60 kg ha^{-1} P (Table 2). Liu et al. (2020) also reported that NDF and ADF content decreased if more than 50 kg ha^{-1} P fertilizer was applied.

Nitrogen and phosphorus harvest

The average amount of N harvest was 761.01 kg ha^{-1}. More N were harvested in the first year than in the second year. Spring application of P caused a higher N harvest than autumn application, and it increased as the irrigation frequency decreased. The highest amount of N was harvested at the I_{9d} treatment. The increasing rate of phosphorus also increased the N harvest and the highest value was recorded at the rate of 90 kg ha^{-1} P fertilization. The highest N harvest amount was recorded in 9 days interval irrigation application in both P application seasons in the first year (Figure 7). In the second year, N harvest was also higher at 5 days interval irrigation practices but this amount was statistically similar with 9 days interval irrigation practices in spring P treatments.

Averagely 67.45 kg P_2O_5 ha^{-1} was harvested and it increased as the irrigation interval increased. The highest phosphorus was harvested from the plants fertilized with 90 kg ha^{-1} P, while it was the lowest in the plants which were not fertilized (0 kg ha^{-1} P_2O_5). The highest P_2O_5 harvest was recorded in the plots that received 60 kg P_2O_5 and irrigated 7 days interval in the first year but the plots that received 30 kg P_2O_5 had substantially similar P_2O_5 harvest value to the highest value in the first year (Figure 8).

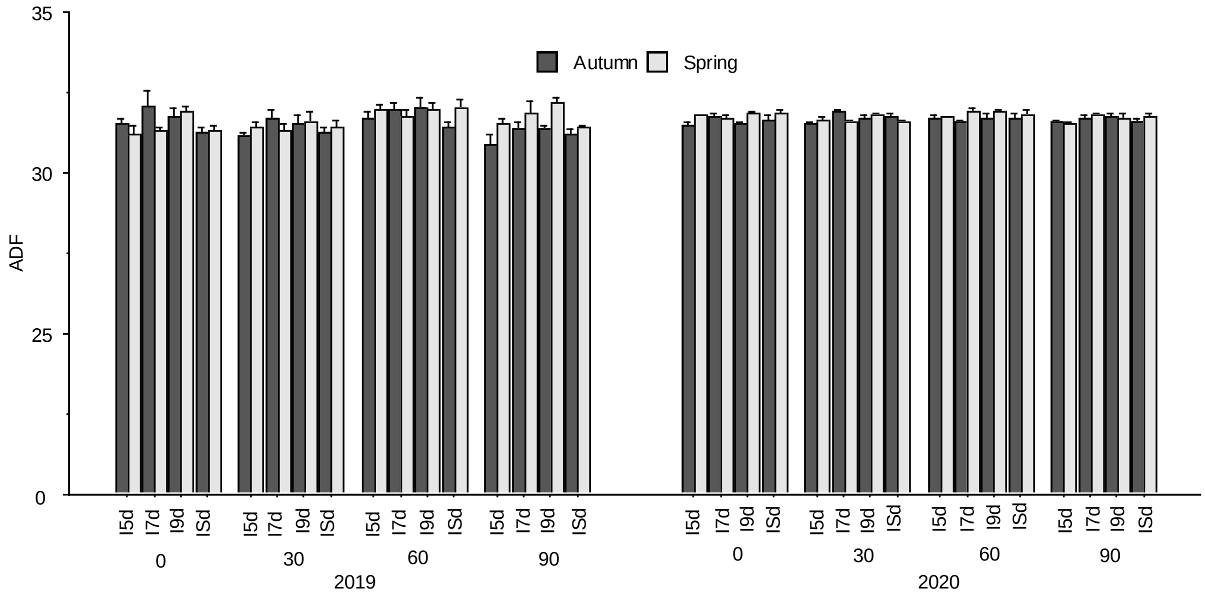

Figure 6. The four-way interaction for ADF content

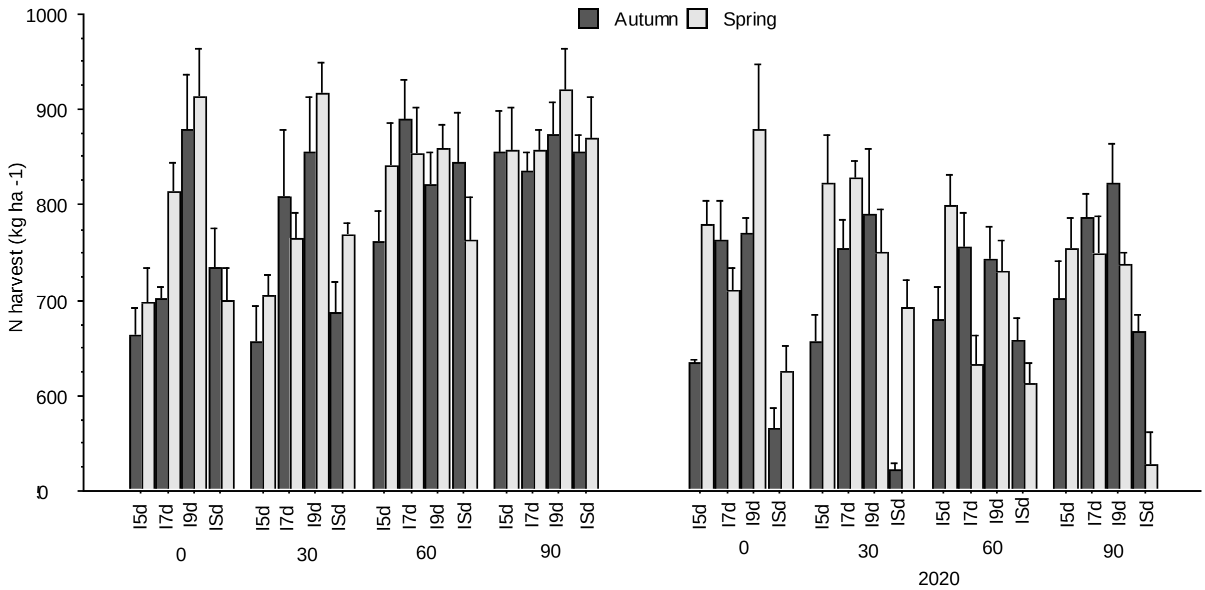

Figure 7. The four-way interaction for nitrogen harvest

The harvested amounts of nitrogen and phosphorus are indicating the nutritive value of forage (Gokkus et al., 1999; Wu et al., 2003). Alfalfa forage contained more nitrogen in the year, which received more precipitation but phosphorus content was not affected by year-to-year climatic variations (Table 2). The higher N harvest by spring P-fertilization might be explained by the positive correlation of phosphorus-N fixing bacteria (Liu et al., 2018). Spring fertilization slightly increased also the CP content and DM yield but the increments were statically non-significant (Table 2). However, the P harvest was not affected by the application season of P fertilizer. The effect of irrigation treatments on N and P harvest was similar to the effect on DM yield. Gokkus et al. (1999) indicated higher dry matter production as the reason for higher N harvest. This could explain the highest N and P harvests by I_{9d} irrigation treatment and the lowest by seasonal deficit irrigation. The P fertilizer caused a significant increment in N and P harvests only at the rate of 90 kg ha^{-1}, which was also related to DM yield (Table 2).

Biological processes are affected positively or negatively by so many environmental factors solely or combined (Cavero et al., 2017; Djaman et al., 2020). In this study, the interaction effect was criticized only over dry matter production (Table 2). When the effects of treatments were considered solely, the best result was recorded by 60 kg P_2O_5 ha^{-1} application and 9 days interval irrigation practices and P applying season was insignificant (Table 2). Whereas the interaction effect on dry matter production was considered, the best results were recorded from 30 kg P_2O_5 ha^{-1} application with 9 days irrigation interval (Figure 3) and the season effect was insignificant. As is well known that alfalfa roots show the best performance under well-aerated soils with no water deficiency (Irmak et al., 2007; Jin et al., 2015). In this experiment, the plant roots showed good performance in 9 days irrigation interval, they uptake phosphorus efficiently and 30 kg P_2O_5 ha^{-1} was enough for the best performance. The results figured out that frequent irrigation should not be suggested for alfalfa production since increasing phosphorus fertilizer amounts for sustainable dry matter production.

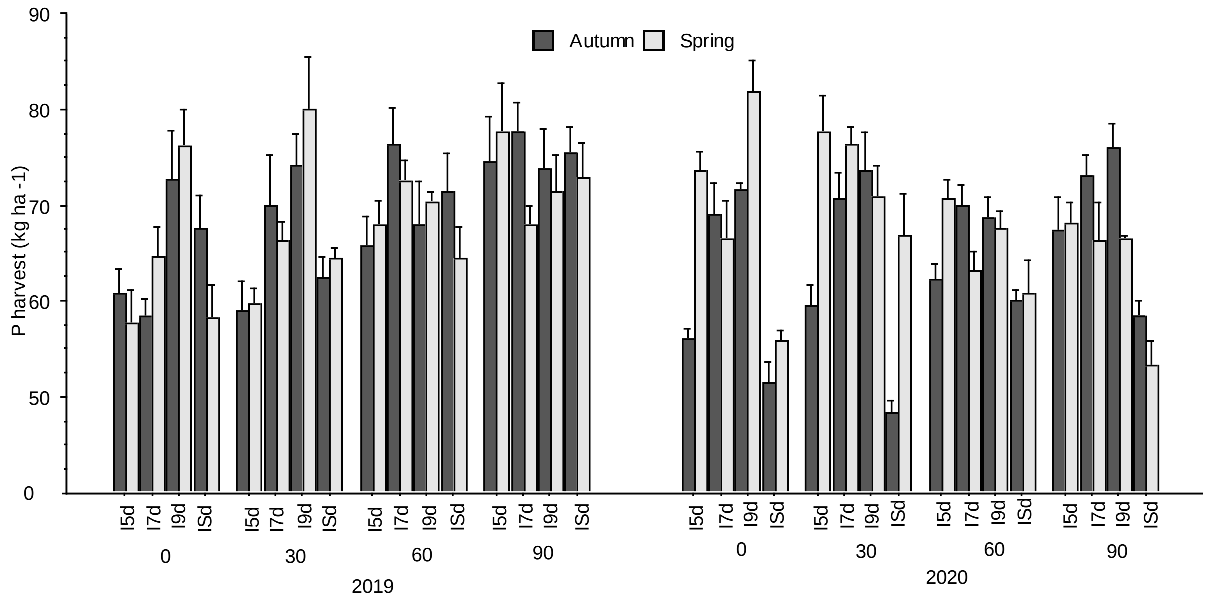

Figure 8. The four-way interaction for phosphorus harvest

CONCLUSION

Yearly climatic characteristics, especially precipitation, have significant effects on the yield and quality characteristics of alfalfa, even under irrigated conditions. Yearly P fertilization of alfalfa could be done in autumn or spring in Mediterranean conditions but it should be considered that spring-fertilized plants were shorter with higher N content and autumn-fertilized plants had higher fiber content. Results showed that the frequency of irrigation is more important than the total amount of water applied. Digestibility might be better for the higher amount of irrigation for alfalfa but yield and quality could decrease if irrigation was carried out frequently because it could create excess water damage. It could be suggested that 9-day intervals (I_9) with 32 mm m^{-2} of water application per irrigation under semi-arid Mediterranean climate conditions. Ceasing irrigation in the second half of summer (seasonal deficit) for water saving significantly decreased both the yield and quality of alfalfa. However, a considerable amount of forage is produced in good quality with seasonal deficit irrigation management and this system could be applied, where semi-arid conditions prevail and water resources are not available for irrigation in late summer. Fertilizing with P increased both the yield and quality of alfalfa but the fulfilling yield was recorded for the rate of 30 kg ha^{-1} P under 9 days interval irrigation regime.

ACKNOWLEDGMENTS

This work has been supported by Eskisehir Osmangazi University Scientific Research Projects Coordination Unit under grant number 2019-23009.

LITERATURE CITED

Annicchiarico, P. 2021. Breeding gain from exploitation of regional adaptation: An alfalfa case study. Crop Sci. 61(4): 2254-2271

Anonymous, 2021. Report of Regional Precipitation Distribution in Turkey, Turkish State Meteorological Service. https://www.mgm.gov.tr/veridegerlendirme/yagis-raporu.aspx (Accessed 07 December 2021)

Berg, W.K., S.M. Brouder, B.C. Joern, K.D. Johnson, J.J. Volenec. 2003. Improved phosphorus management enhances alfalfa production. Better Crops. 87(3): 20-23.

Berg, W.K., S.M. Cunningham, S.M. Brouder, B.C. Joern, K.D. Johnson, J. Santini, J.J. Volenec. 2005. Influence of phosphorus and potassium on alfalfa yield and yield components. Crop Sci. 45(1): 297-304.

Berg, W.K., S.M. Cunningham, S.M. Brouder, B.C. Joern, K.D. Johnson, J.B. Santini, J.J. Volenec. 2007. The long-term impact of phosphorus and potassium fertilization on alfalfa yield and yield components. Crop Sci. 47(5): 2198-2209.

Berrada, A. and D.G. Westfall. 2005. Irrigated alfalfa response to phosphorus and potassium in a calcareous soil. Comm Soil Sci Plant Anal. 36(9-10): 1213-1227.

Bouizgaren, A., M. Farissi, C. Ghoulam, R. Kallida, M. Faghire, M. Barakate, M.N. Al Feddy. 2013. Assessment of summer drought tolerance variability in Mediterranean alfalfa (Medicago sativa L.) cultivars under Moroccan fields conditions. Arch Agron Soil Sci. 59(1): 147-160.

Cavero, J., J.M. Faci, E.T. Medina, A. Martinez-Cob. 2017. Alfalfa forage production under solid-set sprinkler irrigation in a semi-arid climate. Agric Water Manag. 191: 184-192.

Chapin, F.S., P.A. Matson, P.M. Vitousek. 2011. Nutrient cycling. In: Principles of Terrestrial Ecosystem Ecology, 259-296, Springer, New York.

Collins, M. and J.O. Fritz. 2003. Forage quality. In: Forages: An Introduction to Grassland Agriculture 6th ed, eds. Barnes, R.F., Nelson, C.J., Collins, M., Moore, K.J., 363-390, Iowa State Press, Ames.

Conley, D.J., H.W. Paerl, R.W. Howarth, D.F. Boesch, S.P. Seitzinger, K.E. Havens, C. Lancelot, G.E. Likens. 2009. Controlling Eutrophication: Nitrogen and Phosphorus. Science. 323(5917): 1014-1015.

Cui, G., F. Tian, Y. Hu, X. Wei, X. Zhu, X. Wang, C. Wang, J. Li, A.A. Degen, H. Duan. 2021. Photosynthesis, fluorescence, and nutrition of Z honglan N o. 2, a new alfalfa cultivar. J Sci Food Agric. 101(15): 6434-6442.

Dahlke, H., A. Brown, S. Orloff, D. Putnam, T. O'Geen. 2018. Managed winter flooding of alfalfa recharges groundwater with minimal crop damage. Calif Agric. 72(1): 65-75.

Divito, G.A. and V.O. Sadras. 2014. How do phosphorus, potassium and sulphur affect plant growth and biological nitrogen fixation in crop and pasture legumes? A meta-analysis. Field Crop Res. 156: 161-171.

Djaman, K., D. Smeal, K. Koudahe, S. Allen, 2020. Hay yield and water use efficiency of alfalfa under different irrigation and fungicide regimes in a semiarid climate. Water. 12(6): 1721.

El-Din, S.S.T. and A.M. Assaeed. 1995. Effect of phosphorus fertilizer and irrigation frequency on yield and protein content of alfalfa. J King Saud Uni Agri Sci. 7: 49–60.

Fan, J.W., Y.L. Du, B.R. Wang, N.C. Turner, T. Wang, L.K. Abbott, K. Stefanova, K.H.M. Siddique, F.M. Li. 2016. Forage yield, soil water depletion, shoot nitrogen and phosphorus uptake and concentration, of young and old stands of alfalfa in response to nitrogen and phosphorus fertilization in a semiarid environment. Field Crops Res. 198: 247-257.

FAO. 2021. Crop Prospects and Food Situation - Quarterly Global Report No. 3, September 2021. Rome.

Gokkus, A., A. Koc, Y. Serin, B. Comakli, M. Tan, F. Kantar. 1999. Hay yield and nitrogen harvest in smooth bromegrass mixtures with alfalfa and red clover in relation to nitrogen application. Eur J Agron. 10(2): 145-151.

Gu, Y.J., C.L. Han, J.W. Fan, X.P. Shi, M. Kong, X.Y. Shi, K.H.M. Siddique, Y.Y. Zhao, F.M. Li. 2018. Alfalfa forage yield, soil water and P availability in response to plastic film mulch and P fertilization in a semiarid environment. Field Crops Res. 215: 94-103.

Hanson, B., D. Putnam, R. Snyder. 2007. Deficit irrigation of alfalfa as a strategy for providing water for water-short areas. Agric Water Manag. 93(1-2): 73-80.

He, F., R. Long, T. Zhang, F. Zhang, Z. Wang, X. Yang, X. Jiang, C. Yang, X. Zhi, M. Li, L. Yu, J. Kang, Q. Yang. 2020. Quantitative trait locus mapping of yield and plant height in autotetraploid alfalfa (*Medicago sativa* L.). Crop J. 8(5): 812-818.

Irmak, S., D.R. Hay, B.E. Anderson, W.L. Kranz, C.D. Yonts. 2007. Irrigation Management and Crop Characteristics of Alfalfa, University of Nebraska - Lincoln Extension, Institute of Agriculture and Natural Resources, Lincoln NE.

Ismail, S.M. and M.H. Almarshadi. 2013. Maximizing productivity and water use efficiency of alfalfa under precise subsurface drip irrigation in arid regions. Irrig Drain. 62(1): 57-66.

Jacobsen, J.S. and G.W. Surber. 1995. Alfalfa/grass response to nitrogen and phosphorus applications. Commun Soil Sci Plant Anal. 26(7-8): 1273-1282.

James, D.W., T.A. Tindall, C.J. Hurst, A.N. Hussein. 1995. Alfalfa cultivar responses to phosphorus and potassium deficiency: Biomass. J Plant Nutr. 18(11): 2431-2445.

Jia, Q., M. Kamran, S. Ali, L. Sun, P. Zhang, X. Ren, Z. Jia. 2018. Deficit irrigation and fertilization strategies to improve soil quality and alfalfa yield in arid and semi-arid areas of northern China. PeerJ. 6: e4410.

Jia, X., Z. Zhang, Y. Wang. 2022. Forage yield, canopy characteristics, and radiation interception of ten alfalfa varieties in an arid environment. Plants. 11(9): 1112.

Jin, J., D. Lauricella, R. Armstrong, P. Sale, C. Tang. 2015. Phosphorus application and elevated CO2 enhance drought tolerance in field pea grown in a phosphorus-deficient vertisol. Ann Bot. 116(6): 975-985.

Johnston, A.E., P.R. Poulton, P.E. Fixen, D. Curtin. 2014. Phosphorus: its efficient use in agriculture. Adv Agron. 123: 177-228.

Kamran, M., Z. Yan, Q. Jia, S. Chang, I. Ahmad, M.U. Ghani, F. Hou. 2022. Irrigation and nitrogen fertilization influence on alfalfa yield, nutritive value, and resource use efficiency in an arid environment. Field Crop Res. 284: 108587.

Kandelous, M.M., T. Kamai, J.A. Vrugt, J. Simunek, B. Hanson, J.W. Hopmans. 2012. Evaluation of subsurface drip irrigation design and management parameters for alfalfa. Agric Wat Manag. 109: 81-93.

Koenig, R., C. Hurst, J. Barnhill, B. Kitchen, M. Winger, M. Johnson. 1999. Fertilizer management of alfalfa. http://extension.usu.edu/files/agpubs/ag-fg-01.pdf (Accessed 14 December 2021).

Kong, M., J. Kang, C.L. Han, Y.J. Gu, K.H. Siddique, F.M. Li. 2020. Nitrogen, phosphorus, and potassium resorption responses of alfalfa to increasing soil water and P availability in a semi-arid environment. Agron. 10(2): 310.

Li, M., Y. Liu, H. Yan, R. Sui. 2017. Effects of irrigation amount on alfalfa yield and quality with a center-pivot system. Trans ASABE. 60(5): 1633-1644.

Li, S., X. Liu, Y. Sun, C. Ma, X. Gu, Q. Zhang. 2022. Yield, nutrient quality and water and phosphorus recovery efficiencies of alfalfa under different drip irrigation and phosphorus levels in Northern Xinjiang, China. Grass and Forage Science 77(3): 189-200.

Liu, A., C.A. Contador, K. Fan, H.M. Lam. 2018. Interaction and regulation of carbon, nitrogen, and phosphorus metabolisms in root nodules of legumes. Front Plant Sci. 9: 1860.

Lindenmayer, R.B., N.C. Hansen, M. Crookston, J. Brummer, A. Jha. 2008. Strategies for reducing alfalfa consumptive water use. In: Proc. Hydrology Days, 52–61, Colorado State University, Fort Collins, CO, USA.

Lindenmayer, R.B., N.C. Hansen, J. Brummer, J.G. Pritchett. 2011. Deficit irrigation of alfalfa for water-savings in the

Great Plains and Intermountain West: A review and analysis of the literature. Agron J. 103(1): 45-50.

Lissbrant, S., S. Stratton, S.M. Cunningham, S.M. Brouder, J.J. Volenec. 2009. Impact of long-term phosphorus and potassium fertilization on alfalfa nutritive value–yield relationships. Crop Sci. 49(3): 1116-1124.

Liu, Y., Q. Wu, G. Ge, G. Han, Y. Jia. 2018. Influence of drought stress on afalfa yields and nutritional composition. BMC Plant Biol. 18(1): 1-9

Liu, J., X. Liu, Q. Zhang, S. Li, Y. Sun, W. Lu, C. Ma. 2020. Response of alfalfa growth to arbuscular mycorrhizal fungi and phosphate-solubilizing bacteria under different phosphorus application levels. AMB Exp. 10(1): 1-13.

Lyons, T., D. Undersander, R. Welch, D. Donnelly. 2016. Estimating alfalfa yield from plant height. Crop, Forage Turfgrass Manag. 2(1): 1-3.

Macolino, S., L.M. Lauriault, F. Rimi, U. Ziliotto. 2013. Phosphorus and potassium fertilizer effects on alfalfa and soil in a non-limited soil. Agron J. 105(6): 1613-1618.

Malhi, S.S., R.P. Zentner, K. Heier. 2001. Banding increases effectiveness of fertilizer P for alfalfa production. Nutr Cycl. 59(1): 1-11.

Malhi, S.S. and K.S. Gill. 2002. Fertilizer N and P effects on root mass of bromegrass, alfalfa and barley. J Sustain Agric. 19(3): 51-63.

Noland, R.L., M.S. Wells, J.A. Coulter, T. Tiede, J.M. Baker, K.L. Martinson, C.C. Sheaffer. 2018. Estimating alfalfa yield and nutritive value using remote sensing and air temperature. Field Crop Res. 222: 189-196.

Orloff, S., D. Putnam, B. Hanson, H. Carlson. 2003. Controlled deficit irrigation of alfalfa: opportunities and pitfalls. In: Proceedings, 33rd California Alfalfa Symposium, 17–19 December, California, USA

Ottman, M. and A. Mostafa. 2014. Summer slump in alfalfa (University of Arizona Cooperative Extension Publication No. AZ1611). Tucson, AZ: University of Arizona College of Agriculture and Life Sciences.

Owens, V.N., K.A. Albrecht, R.W. Hintz. 1995. A rapid method for predicting alfalfa quality in the field. J Prod Agric. 8(4): 491-495.

Putnam, D., S. Orlaff, B. Hanson, H. Carlson. 2005. Controlled deficit irrigation of alfalfa in differing environments. In: Abstracts, International Annual Meetings, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Salt Lake City, UT, USA, 6–10 November, Madison, WI, USA.

Reed, S.C., T.R. Seastedt, C.M. Mann, K.N. Suding, A.R. Townsend, K.L. Cherwin. 2007. Phosphorus fertilization stimulates nitrogen fixation and increases inorganic nitrogen concentrations in a restored prairie. Appl Soil Ecol. 36(2-3): 238-242.

Rovkina, K.I., S.V. Krivoshchekov, A.M. Guryev, M.S. Yusubov, M.V. Belousov. 2018. Water-soluble polysaccharides of alfalfa (Medicago sativa (Fabaceae)) of Flora of krasnoyarsk krai. Russ J Bioorganic Chem. 44(7): 854-859.

Sanderson, M.A. 1993. Maturity and quality of alfalfa as affected by phosphorus fertility. Commun Soil Sci Plant Anal. 24(19-20): 2715-2724.

Undersander, D. and D. Cosgrove. 2011. Alfalfa management guide. American Society of Agronomy Crop Science Society of America Soil Science Society of America.

Ventroni, L.M., J.J. Volenec, C.A. Cangiano. 2010. Fall dormancy and cutting frequency impact on alfalfa yield and yield components. Field Crop Res. 119(2-3): 252-259.

Wayu, S. and T. Atsbha. 2019. Evaluation of dry matter yield, yield components and nutritive value of selected alfalfa (Medicago sativa L.) cultivars grown under Lowland Raya Valley, Northern Ethiopia. Afric J Agric Res. 14(15): 705-711.

Wu, Z., S.K. Tallam, V.A. Ishler, D.D. Archibald. 2003. Utilization of phosphorus in lactating cows fed varying amounts of phosphorus and forage. J Dairy Sci. 86(10): 3300-3308.

Zar, J.H. 2013. Biostatistical Analysis: Pearson New International Edition.

Zhang, Q., J. Liu, X. Liu, Y. Sun, S. Li, W. Lu, C. Ma. 2020. Optimizing the nutritional quality and phosphorus use efficiency of alfalfa under drip irrigation with nitrogen and phosphorus fertilization. Agron J. 112(4): 3129-3139.