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Effect of Potassium Application Rate on Dry Matter Yield and Forage Nutritive Value in Alfalfa

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Abstract

The United States is the largest producer of alfalfa (*Medicago sativa* L.) however there is still a wide variation in yield among states. Potassium (K) is one of the key plant macronutrients that affect alfalfa yield and stand persistence. To the best of our knowledge, the evaluation of K rates on alfalfa forage yield and quality attributes at different harvesting intervals has not been studied in the United States. Thus, the main objective of this study was to evaluate the effect of K rates along with harvesting intervals (HI) and varieties on alfalfa dry matter yield (DMY), forage nutritive value, and soil K content. The experiment was carried out in a split-split plot with two HI (28 and 35-day after the first cut), two varieties (Hi–Gest 360: reduced-lignin and AFX 457: conventional), and four K application rates (0, 56, 112, and 168 kg K_2O ha^{-1}) in a randomized complete block with four replications. The results indicated that harvesting alfalfa at shorter interval (28-day) resulted in higher dry matter yield and forage nutritive value than a longer harvest interval (35-day). Yield, nutritive values, and soil K content were, however, not significantly influenced by alfalfa variety and K rates. Further research is essential to quantify the actual trade-off between applied K and soil and plant K content in alfalfa production.

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Alfalfa; Forage; Dry Matter Yield; Forage Nutritive Value; Potassium.

Introduction

The increasing demand for meat and dairy products has increased the livestock population in the United States (U.S.).[1] However, the decreasing trend of forage production has created pressure to produce more forage and to improve forage quality. Thus, it is important to understand the effect of major yield drivers including plant nutrients on forage yield, quality, and stand persistence. Potassium (K) is one of the three essential plant macronutrients that plays a key role in major biochemical and physiological processes that influence plant growth and metabolism. The major functions of K include activation of cellular enzymes for photosynthesis and transport of ATP (adenosine triphosphate), stomatal regulation, synthesis of proteins, starch,

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cellulose, and vitamins, resistance to abiotic and biotic stresses, nitrogen fixation, improvement of Nitrogen and phosphorus (P) use efficiency.[2-4]

Alfalfa (*Medicago sativa* L.) is a widely grown perennial forage worldwide. It has several competitive advantages over other forage crops such as high yield, high forage nutritive value, multiple harvest, nitrogen fixation and low lignin. In the U. S., alfalfa is grown on more than 5 million hectares and produces over 42 million MT of hay and haylage with an approximate average value of $10.5 billion per year for the last 10-year period.[5] However, there is still a large variation in yield (4.0 Mg ha^{-1} in North Dakota to 18.7 Mg ha^{-1} in Arizona) among states.[5] Russelle.[6] reported a wide yield gap (up to 70%) in the U.S.

As a perennial crop, alfalfa needs to survive in cold winter (below 5^{o}C) to hot summer (above 35^{o}C). Winter kill at a temperature below 5^{o}C and fall dormancy above 35^{o}C is the common yield-limiting factors in alfalfa. Berg *et al.*[7] reported that the application of P and K increases yield, forage quality, and stand productive age. However, many previous studies have found inconsistent results on the effect of K application on alfalfa yield, forage nutritive value and stand persistence. Some studies documented that the application of K in alfalfa plots has positive effects in terms of winter survival, forage dry matter yield (DMY), and stand persistent.[2,7-10]

K requirement for alfalfa is relatively higher than other grain crops which removes up to 67 kg K per hectare.[9,11,12] Some researchers observed greater biomass per shoot in K applied alfalfa plots.[2,3,13,14] Smith[10] measured the highest DMY and stand persistent in alfalfa with 672 kg ha^{-1} of K top-dressed plots. A growth chamber experiment conducted by Collins and Duke[15] found that the application of high level of K increased shoot number per plant by 51% and shoot dry weight by 20%. They argued that K and Sulfur (S) fertilization can increase carbon exchange rate, nodule numbers, and enhanced nitrogen fixation and carbohydrate movement from the shoot. Harrewijn[16] reviewed 2449 research papers and found that the application of K decreased the incidence of fungal diseases by 70%, bacteria by 69%, insects and mites by 63%, viruses by 41%, and nematodes by 33%, contributing to higher yield and quality of field crops. On the other hand, Bailey,[17] Havlin *et al.*[18] and Yost *et al.*[19] did not observe any significant effect of K on alfalfa yield and forage quality. Jungers *et al.*[2] observed little increase in forage biomass yield but had negative effect on forage nutritive value. Barbarick[20] and Lloveras *et al.*[21] found that K fertilization slightly increased alfalfa forage yields but did not compensate the cost of K application. They did not recommend to use large amount of K fertilizer in the alfalfa field because the plant utilizes excess K without increasing yield.

The effect of varieties and harvesting interval on forage dry matter yield and forage nutritive value has been widely studied in the past[22-27] however, to the best of our knowledge, the effect of K rates on harvesting interval, different alfalfa varieties, and soil K have not studied in the United States recently. In this context, the objective of this study was to examine the effect of the K application rates on alfalfa dry matter yield and forage nutritive value. Furthermore, the yield and forage quality in alfalfa is strongly influenced by cutting frequency and varieties.[28-30] Thus, we have also examined the effect of harvesting interval (HI) and two different commercial varieties on forage yield and quality together with different rates of K application. The findings of this study could be relevant for alfalfa producers, farm managers and researchers for improving yield and production.

Materials and Methods

Study Site

A field trial was carried out at Kansas State University Agronomy North Farm, Manhattan, Kansas, USA (39°20´ N, 96°59´W, 314 m above sea level) from 2017 to 2019. The average maximum temperature, minimum temperature, and annual rainfall of the study location during the experiment years were recorded at 18.6±11.2 ^{o}C, 6.3±8.7 ^{o}C and 991±142 mm respectively.[31]

The soil of the experimental plots was Smolan silt loam (fine, smectitic, mesic Pachic Argiustolls). Before alfalfa establishment, the soil samples were collected from the depth of 0-15 cm from the experimental plots and analyzed soil fertility status in 2017 and soil N and K content were tested in 2018 to compare soil K content after applying K-rate in the first production year. The initial soil test result was provided by Kansas State Soil Testing Laboratory in Manhattan, Kansas (Table 1).

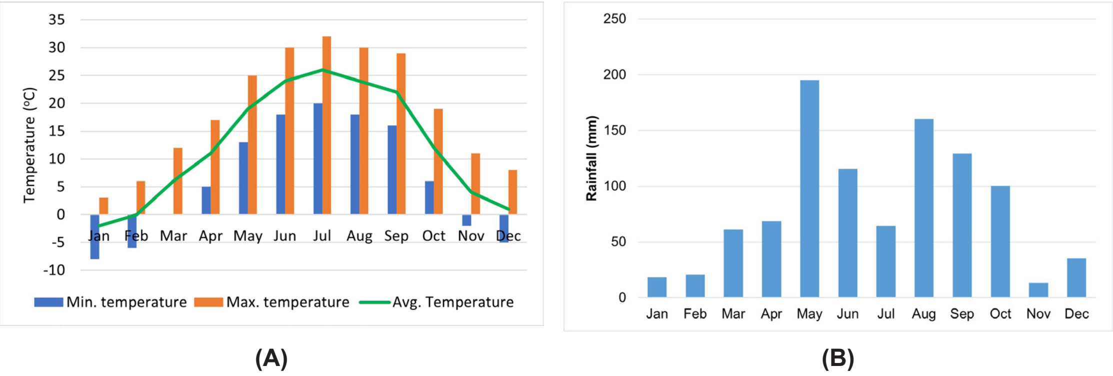


Fig.1: Monthly average temperature (A) and rainfall (B) of the study location during the study period (2017-2019)

Table 1: Soil fertility status of experimental plots before planting in 2017

Soil chemical properties	2017
Calcium (mg/kg)	2662.5
Electric conductivity (ds/m)	0.3
Magnesium (mg/kg)	454.8
Sodium (mg/kg)	24.1
OM (%)	3.0
Mehlich-3 Phosphorous (mg/kg)	6.9
pH	5.7
NO_3-N (mg/kg)	2.2
NH_4-N (mg/kg)	9.9
Potassium (mg/kg)	303.5
Sulfur (mg/kg)	10.1

Experimental Design and Plant Establishment

The experiment was designed in a randomized complete block with four replications. The study was arranged in a split-split plot with two varieties (Hi–Gest 360: reduced-lignin and AFX 457: conventional), two harvesting intervals (28 and 35-day after the first cut), and four K application rates (0, 56, 112, and 168 kg K_2O ha^{-1}). The HI was the main plot, subplots were alfalfa varieties, and sub-sub plots were potassium rates. Plot size was 1 m wide and 6 m long for a total of 64 plots. The seeding rate of each variety was 20 kg PLS (pure live seed) ha^{-1}. The seeds were placed 1.2 cm deep in rows of 20 cm apart on 22 April 2017. The K rate of 0 kg ha^{-1} was considered as the control. The above-mentioned rates of K were broadcasted to the soil before the seeding and in the last week of March in each production year.

Yield Measurements and Forage Quality Analysis

The first cutting was done in mid-May of 2018 and 2019 when the plant reached 1/10th bloom stage followed by subsequent cuttings at 28 and 35-day intervals during each production year. The forage samples were collected before each cutting using a 0.15 m^2 quadrat placed randomly in each plot. After collecting each sample, the plots were mowed. The collected samples were dried in a hot air oven at 60°C designed by Kansas State University Agronomy Research Farm for 72 hours and forage yield was estimated on a dry weight basis. The dried samples were then ground in a Wiley mill with a 1 mm screen for forage nutritive value parameters such as crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), neutral detergent fiber digestibility (NDFD), total digestible nutrient (TDN), in-vitro true dry matter digestibility (IVTDMD), relative feed value (RFV), relative forage quality (RFQ). Alfalfa samples were analyzed using near-infrared spectroscopy (NIRS) at the Ward Lab in Nebraska.

Statistical Analysis

A three-way analysis of variance (ANOVA) was performed using the Proc Glimmix function in SAS version 9.4.[32] The Harvest Interval, alfalfa variety, and K-rate were the class variables, and forage yield and forage nutritive value parameters (CP, ADF, NDFD, TDN, IVTDMD, RFV, and RFQ) were the response variables in the ANOVA. For mean comparisons, the least significant difference (LSD) test was used at $p = 0.05$. The interaction effect between Harvest Interval, alfalfa variety, and K application rate was also examined.

Results and Discussion

Forage Yield

There were no interactions in harvest interval, alfalfa variety, and potassium application rate. The dry matter yield was affected by harvesting intervals (Fig. 2A). The average forage dry matter yield of alfalfa harvested at 28-day intervals was found 17.3 Mg ha^{-1} which was 22% greater than the 35-day harvest interval (14.2 Mg ha^{-1}) in the first production year, 2018 (Fig. 2A). Our results, however, showed that the application of four different rates of K (0, 56, 112, and 168 kg ha^{-1}) on the alfalfa crop and the use of two different varieties (conventional and reduced-lignin) did not affect alfalfa forage dry matter yield significantly (p=0.05) in 2018 (Fig. 2B and 2C).

Like 2018, the forage yield did not vary both with K-rate and variety in 2019 but the average yield of alfalfa harvested at 28-day interval was 18 Mg ha^{-1} which was 19% greater than the average yield of alfalfa harvested at 35-day interval (Fig. 2 A). This might be due to more cuttings in the 28-day interval (i.e., 5 cuttings) than in the 35-day interval (i.e., 4 cuttings), resulting in higher yield with more frequent cuttings than less frequent cuttings. This finding was not consistent with some of the studies conducted on the effect of Harvest Interval on alfalfa DMY[28,29] who observed that less frequent cuttings resulted in higher forage yield than frequent cuttings during the growing season specifically due to the shorter regrowth period and decrease in root carbohydrates. However, several previous studies' findings showed that the application of K increased shoot biomass, regrowth, and stand persistence.[2,3,10,13-15] Thus, faster regrowth due to sufficient K and more cuttings might be the reasons for the higher DMY of alfalfa harvested at 28-day intervals.

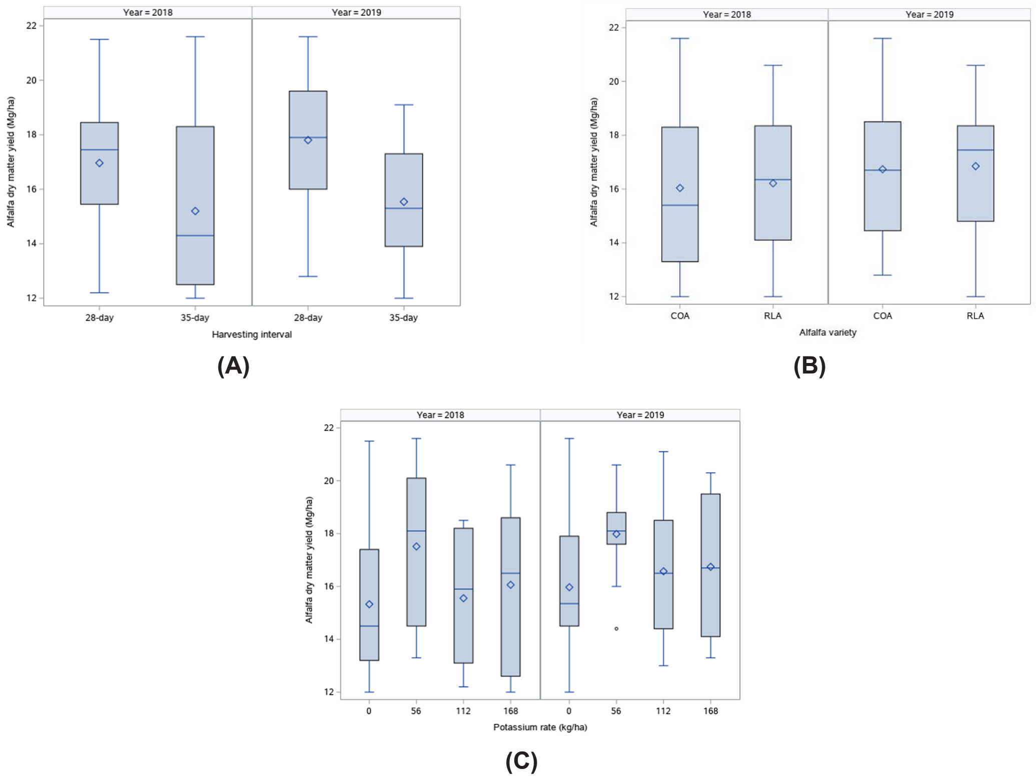
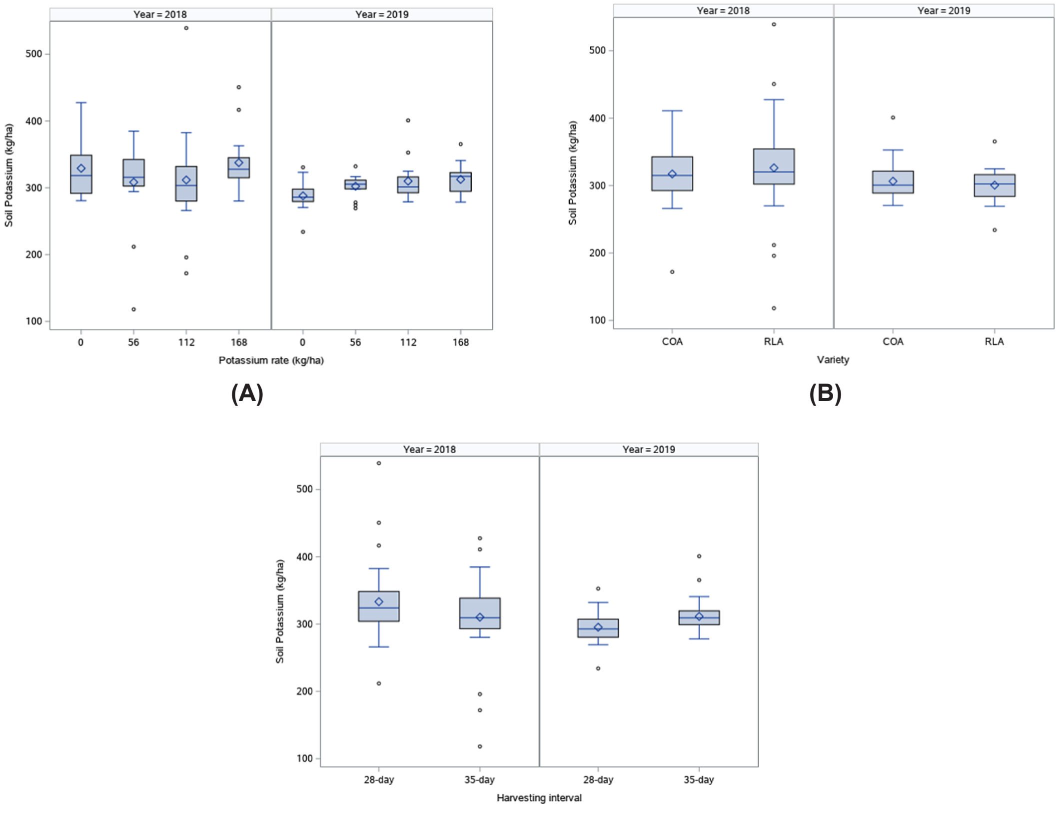


Fig. 2: Comparison of alfalfa dry matter yield between 28 and 35-day harvesting intervals (A), between two varieties (B), and between four K application rates (C) during the study period (2017-2019). In figure 2B, COA represents conventional alfalfa and RLA represents reduced-lignin alfalfa

Soil K content was not influenced by variety, HI and K-rate (Fig. 3) in both production years. Though, applied K rates varied from 0 to 168 kg ha^{-1}, K content in soil did not vary accordingly. This result suggests that initial levels of K in soil were sufficient, thus the need for subsequent application of K might not be necessary. A little response of K-rate (varied from 1.0 to 1.5 Mg ha^{-1}) in forage yield in both production years could be due to the availability of a sufficient amount of plant-available K in the soil (Table 1). Furthermore, we found the same K content (304 Mg kg^{-1}) in the soil in the second production year and was not influenced by HI and variety although we applied K rates ranging from 0 to 168 kg ha^{-1}. This result indicates that the K removal rate of alfalfa is high. In both production years, the control treatment (0 K rate) had significantly lower potassium in the soil. Also, highest K-rate (i.e., 168 kg ha^{-1}) resulted in the highest soil potassium content. Our two years research findings are consistent with the findings of many previous studies conducted by Jungers *et al.*,[2] Bailey,[17] Havlin *et al.*,[18] Lutz Jr,[32] and Yost *et al.*[19] who did not find the effect of K rate on alfalfa forage yield at the site with sufficient soil K.



(A) (B) (C)

Fig. 3: Effect of applied potassium (A), varieties (B), and HI (C) on soil potassium concentration. COA represents conventional and RLA represents reduced-lignin alfalfa.

Based on two production years, harvesting alfalfa at 28-day intervals appeared to be a better option for a higher yield than those at 35-day harvest intervals in this study. Furthermore, the yield variation affected by harvesting interval was aligned with Ghandorah *et al.*,[34] and Katanski *et al.*[35] who also recorded the highest forage yield when alfalfa was harvested below 35-day HI. The results of both years indicate that alfalfa can provide the greatest yield to farmers when harvested more frequently using every 28-day harvesting interval than 35-day HI. Thus, farmers could manage harvest intervals to maximize alfalfa biomass yield. Furthermore, there was no interaction effect among K rate, harvesting interval, and alfalfa variety in both production years. In overall, the forage DMY was observed higher in the second year (2019) for all treatments which might be because of the higher rainfall (1,188 mm) received in 2019 than in 2018 (927mm). No significant yield differences were noted between reduced-lignin alfalfa (RLA) and conventional alfalfa (COA), which was consistent with our previous studies[36,37] where we did not find significant dry matter yield difference between RLA and COA.

Forage Nutritive Value

Our results showed that the several forage nutritive value parameters in alfalfa were decreased as maturity advanced (Table 2). We observed that the shorter harvesting interval (28-day) resulted in higher CP contents than the longer harvesting interval (35-day). The CP was decreased by 6-7% when delayed one week from 28 to 35-day intervals. A similar trend was observed by Grev *et al.*[38] and Palmonari *et al.*,[39] and Yu *et al.*[40] The ADF content remained almost the same at both HI but cutting alfalfa at 28-day intervals in the first production year resulted in a significantly higher NDFD (11%) than those harvested at 35-day intervals but was not much difference in the second production year. In the first production year, alfalfa harvested at 28-day intervals had similar IVDMD to those harvested one week later (35-day). Both RFV and RFQ were decreased by 6-17% when extending the HI by one week (from 28-day to 35-day). These results suggest that the shorter HI increases RFV and RFQ of alfalfa and could be used by farmers to increase the feeding value of alfalfa.

Table 2: Effect of alfalfa harvesting interval (HI) on forage nutritive value in 2018 and 2019

Parameter	2018			2019		
	28-day	35-day	*p*-value	28-day	35-day	*p*-value
Crude protein (%)	24.1a	22.3b	0.02*	25.8a	24.3b	0.01**
Acid detergent fiber (%)	25.3	27.6	0.15	26.5	26.9	0.65
Neutral detergent fiber digestibility (%)	48.3a	44b	0.001**	30.7	31.4	0.38
In-vitro total dry matter digestibility (%)	84	81.9	0.12	85.4	84.3	0.11
Total digestible nutrient (%)	63.4	61.63	0.15	62.4	62.2	0.64
Relative feed value	251.8a	214.5b	0.05*	212.4	205.3	0.28
Relative forage quality	256.7a	213.5b	0.04*	245.2	231.3	0.09

*** Significant at *p*=0.001, **significant at *p*= 0.01 and *significant at *p*=0.05. Different letters in the same column are significant at α level of either 0.05 or 0.01.

Table 3: Effect of alfalfa varieties on forage nutritive value in 2018 and 2019

Parameter	2018			2019		
	COA	RLA	*p*-value	COA	RLA	*p*-value
Crude protein (CP)	22.9 b	23.6a	0.0001**	24.9	25.1	0.27
Acid detergent fiber (ADF)	27.2a	25.7b	0.002**	26.8	26.6	0.49
Neutral Detergent Fiber Digestibility (NDFD)	45.4b	46.9a	0.0001***	31	31.1	0.77
In-vitro total dry matter digestibility (IVTDMD)	82.3b	83.6a	0.0006***	84.8	84.9	0.47
Total digestible nutrient (TDN)	62b	63.1a	0.002**	62.2	62.4	0.49
Relative feed value (RFV)	227.6b	238.5a	0.02*	208.1	209.6	0.54
Relative forage quality (RFQ)	228.9b	241.3a	0.01*	237.7	238.9	0.67

*** Significant at *p*=0.001, **significant at *p*= 0.01 and *significant at *p*=0.05. Different letters in the same column are significant at α level of either 0.05 or 0.01. COA: Conventional alfalfa; RLA: Reduced-lignin alfalfa.

We found some differences in forage nutritive value parameters between the two varieties in 2018 but not in 2019 (Table 3). RLA had little higher nutritive values (1-12%) than COA except for ADF in 2018 but it was not affected by variety in 2019. Our results indicate that the RLA variety could be used as high-quality forage for hay marketing purposes by farmers.

Like forage dry matter yield, we did not find any significant effect of K-rate on CP, ADF, NDF, IVTDMD, TDN, RFV, and RFQ in both production years (Table 4). Our results are consistent with similar studies conducted by Lloveras et al.[21] that potassium application rate did not affect the nutritive value of alfalfa. Although potassium content in the alfalfa plant was not measured, high potassium content in alfalfa is not recommended for lactating dairy cows due to the concern of milk fever.[41,42]

Table 4: Effect of potassium rate on forage nutritive value in 2018 and 2019

Parameter	2018					2019				
	Potassium (K_2O) rate (kg ha^{-1})					Potassium (K_2O) rate (kg ha^{-1})				
	0	56	112	168	*p*-value	0	56	112	168	*p*-value
Crude protein (CP)	23.4	23.1	23.2	23.1	0.4	25.0	24.9	25.2	25.0	0.4
Acid detergent fiber (ADF)	25.7	27.2	26.8	26.1	0.1	26.4	26.8	26.6	27.0	0.5
Neutral Detergent Digestibility (NDFD)	46.6	45.8	46.2	45.8	0.1	30.9	31.2	31.0	31.3	0.7
In-vitro total dry matter digestibility (IVTDMD)	83.7	82.4	82.7	83.1	0.1	85.1	84.8	84.9	84.6	0.3
Total digestible nutrient (TDN)	63.1	62.0	62.2	62.8	0.1	62.5	62.3	62.4	62.1	0.5
Relative feed value (RFV)	239.9	228.8	229.3	234.6	0.3	211.5	207.8	209.3	206.7	0.6

Conclusions

Our results revealed that harvesting alfalfa every 28-day resulted in significantly higher dry matter yield and forage nutritive value than the 35-day harvest interval in this study. However, alfalfa variety and potassium application rate did not affect yield, nutritive values, and soil potassium content. Because of the limited response of K-rate on dry matter yield and forage quality, the application of potassium fertilizer might not be necessary for alfalfa growers in Kansas, particularly in the area where initial soil K is >180 mg kg^{-1}. Further research is essential to quantify the actual trade-off between applied K and soil and plant K content in alfalfa production.

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Conflicts of Interest

The authors declare no conflict of interest.

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