EFFECTS OF IRRIGATION AMOUNT AND TIMING ON ALFALFA NUTRITIVE VALUE

J. Holman, D. Min, N. Klocke, I. Kisekka, R. Currie

ABSTRACT. *Most hay producers in southwest Kansas irrigate their alfalfa (*Medicago sativa *L.) because precipitation is insufficient for profitable rainfed production. However, water supplies in the central Great Plains are dwindling, particularly in the central and southern Ogallala Aquifer region. Irrigating many field crops in this region, including alfalfa, is therefore becoming a challenge. We determined the effects of irrigation quantity and timing on alfalfa forage nutritive value during a five-year field study of alfalfa in southwest Kansas. Nutritive value was quantified in the form of crude protein, acid detergent fiber, neutral detergent fiber, total digestible nutrients, and relative feed value. In general, applying the highest amount of irrigation (610 mm during the growing season) resulted in the lowest forage nutritive value compared to lower amounts of irrigation (0, 200, and 380 mm irrigation). Nutritive value concentrations (g kg^{-1}) under full irrigation averaged 211 for crude protein, 316 for acid detergent fiber, and 422 for neutral detergent fiber, while concentrations (g kg^{-1}) in rainfed production averaged 225 for crude protein, 247 for acid detergent fiber, and 370 for neutral detergent fiber. Alfalfa nutritive value was not affected whether the same amount of irrigation water was applied either before green-up and between each cutting, or before green-up and between all cuttings except between cuttings 2 and 3. However, there was a tendency for lower forage nutritive value at the fourth cutting when irrigation was withheld between cuttings 2 and 3, and that saved water was added to the amount of irrigation applied to the fourth cutting. When averaged over irrigation treatments, alfalfa nutritive value was lower from the first and second cuttings than from the third and fourth cuttings. Annual yields, averaged over years, declined from 1.53 kg m^{-2} with 610 mm of irrigation to 0.43 kg m^{-2} for rainfed production. Annual yields were the same when irrigation was distributed over the growing season or withheld between the second and third cuttings. Irrigation amounts less than full crop requirement resulted in a 13% higher dollar value product based on relative feed value, but decreasing irrigation from 610 to 380 mm reduced yield by 19%.*

Keywords. *Alfalfa, Cattle, Forage quality, Irrigation, Livestock, Nutritive value, Water.*

Alfalfa (*Medicago sativa* L.) is an important forage crop in the Great Plains as well as many other parts of the world for dairy and cattle feeding industries. For 2015, alfalfa was the only crop projected to be profitable under irrigation in southwest Kansas, averaging a net return of \$326 ha^{-1} (Ibendahl et al., 2015). Although not always the case, most other irrigated crops such as corn, grain sorghum, soybeans, wheat, corn silage, and sorghum silage all had negative cash flow projections. Most alfalfa is irrigated in the central Great Plains, but water supplies are dwindling, particularly in central and southern Ogallala Aquifer region, where withdrawals exceed average annual aquifer recharge. Irrigating many field crops in this region, including alfalfa, is therefore becoming a challenge. Thus, the profitability of growing alfalfa relies heavily on how much irrigation can be applied, and how effectively alfalfa uses the applied water. Several studies have reported on the effects of irrigation amount and timing on alfalfa yield and potential economic return (Abdul-Jabbar et al., 1985; Bolger et al., 1990; Retta and Hanks, 1980; Frate et al., 1991; Klocke et al., 2003, 2013). These studies found that alfalfa yield was linearly correlated to crop evapotranspiration (ET_c), i.e., evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions (Allen et al., 1998), but nutritive value was often not reported. Yield results from this study were reported previously by Klocke et al. (2013), who found that alfalfa yield increased from 4.3 Mg ha^{-1} for rainfed production to 15.3 Mg ha^{-1} with 610 mm of irrigation (representing the maximum water allocation in Kansas) during the growing season. This article reports on the effect of irrigation amount and timing on alfalfa nutritive value.

Forage nutritive value can be affected by many factors, including development stage at harvest (Kalu and Fick, 1983), climate (i.e., high temperature and drought), soil fertility, insects (Hutchins et al., 1989; Flinn et al., 1990; Hansen et al., 2002; Sulc et al., 2004), weeds (Temme et al., 1979), and carbon dioxide level (Baslam et al., 2013). Many research projects have evaluated drought effects on forage

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yield and nutritive value in forage legumes (Gifford and Jensen, 1967; Foulds, 1978; Stroth et al., 1972; Fairbourn, 1982; Smith et al., 1986; Marten et al., 1987). Forage nutritive value in alfalfa was usually higher with water stress than without water stress (Vough and Marten, 1971; Snaydon, 1972; Carter and Sheaffer, 1983; Harmoney et al., 2013, Peterson et al., 1992). This study uniquely adds to the database of information on alfalfa nutritive value by reporting results across a complete range of ET_c from fully irrigated to dryland for a complete five-year life-cycle of the crop. In addition, this study compares distributing irrigation over the growing season and withholding irrigation between the second and third cuttings, which is a period of higher temperature stress and ET_c.

The objectives of this study were to evaluate the effects of different irrigation amounts and timing on forage nutritive values, i.e., crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), and relative feed value (RFV) for a five-year field study of alfalfa in southwest Kansas. Alfalfa yield and stand life were reported in a previous article (Klocke et al., 2013).

Materials and Methods

Experimental Site

This research was conducted at the Kansas State University Southwest Research-Extension Center (SWREC) near Garden City, Kansas (38° 1′ 9″ N, 100° 49′ 16″ W, 887 m above mean sea level). The soil type at the study site was a deep, well drained Ulysses silt loam (fine-silty, mixed, mesic Aridic Haplustoll) with soil pH range of 8.1 to 8.3. The silt loam soil extended to the depth of soil water measurements (2.4 m), but the available water capacity from the surface to 1.07 m deep was 0.18 m m^{-1} between field capacity (volumetric water content of 33%) and permanent wilting (volumetric water content of 15%) and 0.12 m m^{-1} from 1.07 to 2.44 m deep between field capacity (volumetric water content of 27%) and permanent wilting (volumetric water content of 15%). The semi-arid climate of the study site had a long-term (1981-2010) average annual precipitation of 489 mm, mean summer growing season daytime high temperature of 29°C (30-year average, May through August), open pan evaporation (April through September) of 1810 mm, and a frost-free period of 170 days. During the study (2007-2011), the average annual precipitation was 429 mm, and reference ET (ET_r) was 1558 mm, calculated with an alfalfa-modified Penman model (Kincaid and Heermann, 1974; Lamm et al., 1994) using weather factors including maximum and minimum air temperature, relative humidity, solar radiation, and wind run (wind speed × time) from an automated weather station near the study site.

Irrigation System and Management

A commercial four-span (44 m span width) linear-move sprinkler system (model 8000, Valmont Corp., Valley, Neb.) was modified to deliver water in any combination of irrigated treatments during an irrigation event (Klocke et al., 2003). The irrigation plots were 13.7 m wide and 27.4 m long. Net application depth (i.e., the water reaching the soil surface) was 25 mm with a uniformity of 0.90 for every irrigation event on all treatments. The net application depth and uniformity of application were confirmed with "catch can" tests (ASABE, 2012). A cluster of spray nozzles with 41 kPa pressure regulators were installed at a height of 2.1 m above the ground in a setup known as MESA (mid-elevation spray application). The MESA design allowed for achieving high uniformity since the irrigation system was set up to irrigate multiple crops including corn, sorghum, wheat, and sunflower. With each pass of the irrigation system, an irrigation treatment was irrigated or not irrigated to achieve the irrigation variable (tables 1 and 2). The time between irrigation events led to the differences in irrigation amount among irrigation treatments. No more than two irrigation events (50 mm) per week were applied in irrigation treatment 1, which received the most irrigation, to simulate the irrigation capacity (7.3 mm d^{-1}) of commercial systems with adequate well yields in the region (Klocke et al., 2013).

The experimental design was a randomized complete block with four replications. The protocol for irrigation timing and amount was intended to provide yield responses from irrigation within the context of best management practices for alfalfa production (table 1). Three of the six irrigation treatments were designed to apply water in accordance with local standard practices (treatments 1, 2, and 5), where irrigation was provided between green-up and the first cutting and between the remaining cuttings. Treatments 2 and 3 received 380 mm, while treatments 4 and 5 received 200 mm. Instead of spreading irrigation events over the whole growing season, irrigation was withheld from treatments 3 and 4 between cuttings 2 and 3. Irrigation may be more effective during other parts of the growing season because temperatures are typically higher between cuttings 2 and 3, which would reduce yield potential. The sixth treatment received no irrigation during the study.

An irrigation scheduling template was formulated as a starting point for timing irrigation events during the growing season (table 2). This template was used for 2009-2011, when alfalfa was cut four times because of very limited regrowth after cutting 4, but a similar template was used in 2007 and 2008, when alfalfa was cut five times. Treatment 1 was allocated a maximum of 610 mm, which is equal to the maximum authorized irrigation in one year for the oldest water rights in Kansas. Six irrigation events were scheduled for treatment 1 before each cutting due to the system capacity limitation that no more than two events could be applied in a week, leaving approximately one week for cutting and harvesting. This limitation was based on the typical pumping capacity of wells in southwest Kansas, which is declining

Table 1. Protocol for total irrigation during growing season at Kansas State University SWREC near Garden City, Kansas, from 2007 through 2011.

Irrigation Treatment	Total Irrigation (mm)	Irrigation Timing
1	610	After green-up and between all cuttings
2	380	After green-up and between all cuttings
3	380	None between cuttings 2 and 3
4	200	None between cuttings 2 and 3
5	200	After green-up and between all cuttings
6	0	None

Table 2. Irrigation application protocol by irrigation treatment and cutting at Kansas State University SWREC near Garden City, Kansas, from 2007 through 2011 (all values are in mm).

Irrigation Treatment	Before Cutting 1							Between Cuttings 1 and 2							Seasonal Total
	1	2	3	4	5	6	Total	7	8	9	10	11	12	Total	
1	25	25	25	25	25	25	150	25	25	25	25	25	25	150	-
2	25	0	25	0	25	0	75	25	25	0	25	25	0	100	-
3	0	25	25	25	0	25	100	25	25	25	0	25	25	125	-
4	0	0	25	0	0	0	25	25	0	25	25	25	0	100	-
5	0	0	25	0	0	0	25	25	0	25	0	25	0	75	-
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
	Between Cuttings 2 and 3							Between Cuttings 3 and 4							
	13	14	15	16	17	18	Total	19	20	21	22	23	24	Total	
1	25	25	25	25	25	25	150	25	25	25	25	25	25	150	600
2	25	0	25	0	25	25	100	25	0	25	25	0	25	100	375
3	0	0	0	0	0	0	0	25	25	25	25	25	25	150	375
4	0	0	0	0	0	0	0	0	25	0	25	0	25	75	200
5	0	25	0	25	0	0	50	25	0	25	0	0	0	50	200
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

due to the depletion of the aquifer. Irrigation events for treatments 2 and 5 were distributed over the time periods before each cutting to simulate wells with even lower capacity. Most of the water not applied to treatments 3 and 4 between the second and third cuttings was applied before the first and fourth cuttings. This template was devised from the best judgment of the research collaborators considering best management practices for irrigation management of alfalfa.

Actual irrigation applications deviated slightly from the template (tables 2 and 3), primarily because of the soil water content and precipitation for the particular year (fig. 1). The total irrigation for each treatment was the same for 2008-2011, except for treatment 1 in 2010 (table 3). The last irrigation of the year was not applied to that treatment due to mechanical problems with the irrigation system. In 2007, the total irrigation in treatments 2 and 3 was 457 mm because some water rights in Kansas limit irrigation to 457 mm per year. After 2007, the interval between irrigation amounts among treatments was made more uniform by applying 380 mm, rather than 457 mm, to treatments 2 and 3. Irrigation amounts before the first cutting were withheld when soil water content in treatment 1 was sufficient for production and was used later in the season, most notably in 2007. Water applications favored higher potential yields for cuttings 1 and 2. All of these management adjustments were intended to make the best use of irrigation to obtain the best yield response rather than to follow the strict schedule of the template.

Agronomic Management

Alfalfa was seeded on 17 August 2006, with a no-till grain drill in rows 190 mm apart into corn residue from the 2005 corn crop. A glyphosate-resistant alfalfa variety (Liberator from Northrup King) was used for the study. This offered the possibility of reducing or eliminating weeds for higher yield. A prophylactic application of glyphosate [N-(phosphonomethyl) glycine] was made one month after alfalfa seedling emergence to ensure the area was free of any winter annual weeds. No further winter annual weeds were noted until the third year of production. These were removed with an early spring application of glyphosate, followed by a pre-emergence application of simazine and pendimethalin

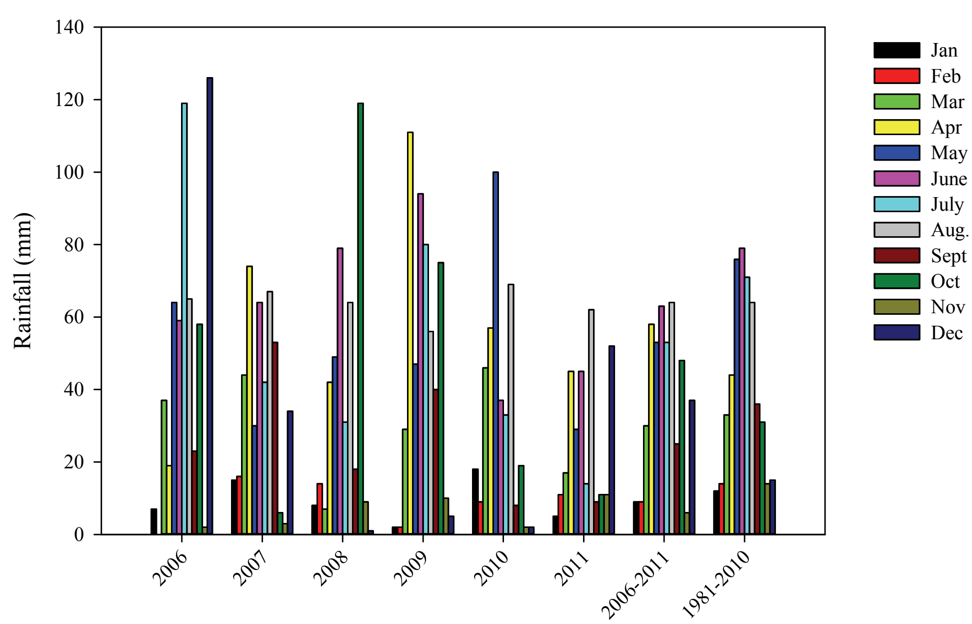

Figure 1. Monthly study period (2006-2011) precipitation and 30-year (1981-2010) mean monthly precipitation at Kansas State University SWREC near Garden City, Kansas.

Table 3. Actual irrigation applied by irrigation treatment for each year, before and between cuttings, and total for the year at Kansas State University SWREC near Garden City, Kansas, from 2007 through 2011 (all values are in mm).

Irrigation Treatment	Before Cutting 1					Between Cuttings 1 and 2					Between Cuttings 2 and 3				
	2007	2008	2009	2010	2011	2007	2008	2009	2010	2011	2007	2008	2009	2010	2011
1	0	76	102	76	152	152	152	102	178	152	152	152	152	152	178
2	0	51	51	51	76	102	102	76	102	102	102	102	102	102	102
3	0	51	76	51	102	127	127	76	152	127	0	0	0	0	0
4	0	0	25	25	25	102	102	76	102	102	0	0	0	0	0
5	0	0	25	25	25	76	76	51	76	76	51	51	51	51	76
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Irrigation Treatment	Between Cuttings 3 and 4					Between Cuttings 4 and 5[a]					Total				
	2007	2008	2009	2010	2011	2007	2008	2009	2010	2011	2007	2008	2009	2010	2011
1	152	152	203	152	127	152	76	25	51	0	610	610	610	584[b]	610
2	76	102	127	102	102	178	25	25	25	0	457	381	381	381	381
3	152	152	203	152	152	178	51	0	25	0	457	381	356	381	381
4	76	76	102	76	76	25	25	0	0	0	203	203	203	203	203
5	51	51	766	51	25	25	25	0	0	0	203	203	203	203	203
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[a] There were five cuttings in 2007 and 2008 and four cuttings in the other years.
[b] The last irrigation not applied due to mechanical failure of irrigation system.

to prevent winter and summer annual weeds. During the first four years, non-economically yield-damaging populations of Palmer amaranth (*Amaranthus palmeri*) were noted after the second or third cuttings. To remove this as a factor among treatments, these weeds were removed with an application of glyphosate. Although aggressive weed control tactics were implemented, control of Palmer amaranth and kochia (*Kochia scoparia* L.) began to fail by the fourth year as stands in the lower irrigation treatments began to thin. By the last cutting of the fifth year, glyphosate-resistant kochia had emerged as the dominant weed species in the lowest irrigation treatments. No summer annual grass species were present during this experiment.

Alfalfa was harvested in the plots when the majority of the plants reached 10% bloom and when more than 50% of crown buds had regrowth of 13 mm. Occasionally there was no regrowth in the dryland treatment, and that treatment had fewer harvests than full irrigation. Harvest was conducted with a sickle-bar swather cutting a 4.27 m wide swath, 7 cm high, from the center of the plot and windrowing it in one operation. Yield samples (3.9 m^2) were obtained manually by collecting a 0.91 m length of the full-width windrow and weighing the sample. Homogenized subsamples of the yield samples were oven-dried at 60°C for at least 48 h or until dry to determine percentage dry matter and forage nutritive value. Stands were counted during the dormant season (late fall and early spring) for each plot by averaging plant counts from four 0.25 m^2 quadrats. Yield and stand were reported previously (Klocke et al., 2013).

Forage Nutritive Value

Forage nutritive value was determined from herbage sampled on harvest dates in 2008-2011. Forage nutritive value was not determined the first year (2007) because soil water content and yields were high in the low irrigation treatments due to higher amounts of irrigation plus precipitation in previous years. The samples were ground to pass a 1 mm Wiley mill screen. Crude protein was analyzed by the Kjeldahl method and was calculated by multiplying the Kjeldahl nitrogen concentration by 6.25, and acid detergent fiber (ADF) and neutral detergent fiber (NDF) were analyzed by the method of Goering and Van Soest (1970). Total digestible nutrients (TDN) and relative feed value (RFV) were estimated according to equations 1 and 2:

$$\text{TDN} = 4.898 + \left(\left[1.044 - \left(0.0119 \times \%\text{ADF}\right)\right] \times 89.796\right) \quad (1)$$

$$\text{RFV} = \text{DMI} \times \text{DDM} \times 0.775 \quad (2)$$

where DMI is dry matter intake (DMI = 120 / %NDF dry matter basis), and DDM is digestible dry matter (DDM = 88.9 − [0.779 × %ADF dry matter basis]) (Lofgreen, 1953; Rohweder et al., 1978). Crude protein is a measurement of protein content (with the assumption that proteins contain 16% nitrogen on average), NDF is a measurement of plant cell wall components (cellulose, hemicellulose, lignin, silica, insoluble CP, and ash), ADF is a measurement of NDF minus hemicellulose, TDN is an estimate of feed energy value, and RFV is an index used to compare the quality of forages relative to the feed value of full bloom alfalfa (Collins and Fritz, 2003). Seasonal forage nutritive values were calculated by the mean values across cuttings, weighted on forage dry matter yield at each cutting, and analyzed by irrigation treatment and year with an analysis of variance method using the Proc Mixed procedure of SAS (ver. 9.1 TS1M3, SAS Institute, Inc., Cary, N.C.). Block was considered a random effect with year as a fixed effect because alfalfa has a limited stand life and age of stand can affect results. Treatment means were separated using Fisher's protected LSD at $p \leq 0.05$. Similarly, forage nutritive values were analyzed by cutting averaged across years with an analysis of variance method using the Proc Mixed procedure of SAS, and treatment means were separated using Fisher's protected LSD at $p \leq 0.05$. The presence or absence of weeds was determined from the whole plot at each harvest by visual determination and was used as a covariate in the model to test for weed effects on forage nutritive value at $p \leq 0.05$.

Results and Discussion

Precipitation, Soil Water, and ET

With the exception of the 2007-2008 and 2010-2011 for which dormant season rainfall was below normal, in all other years of the study dormant season rainfall was equal to or above normal (1981-2010), as reported by Klocke et al.

(2013). On average, growing season rainfall was 61 mm below normal during the study period. Given the relatively flat topography of the study area and the semi-arid climate, all rainfall received was assumed effective in water balance calculations.

Soil water profiles during the spring and fall are shown in figure 2 (for full irrigation, dryland, and average of all six treatments as examples to depict changes in soil water during the study period). The soil water profiles were affected by dormant season rainfall, growing season rainfall, and irrigation amount. Timing of irrigation did not substantially affect soil water; the effect of irrigation amount was greater than the effect of timing. Figure 2 indicates that alfalfa extracted soil water down to 2.4 m or even deeper during the 2007 growing season, as reported by Klocke et al. (2013). This was because the above-normal rainfall in 2006 helped to recharge the soil profile. However, during the other years of the study, very little soil water was extracted at depths greater than 2.0 m because water was not available (volumetric soil water content had approached permanent wilting point). With the exception of 2011 (showing negligible changes in soil water profiles between spring and fall), for all other years the soil water in the top 2.0 m of the profile contributed in varying degrees to ET_c, as shown by the soil water profile in figure 2.

Stored soil water contributed to ET_c for all treatments in

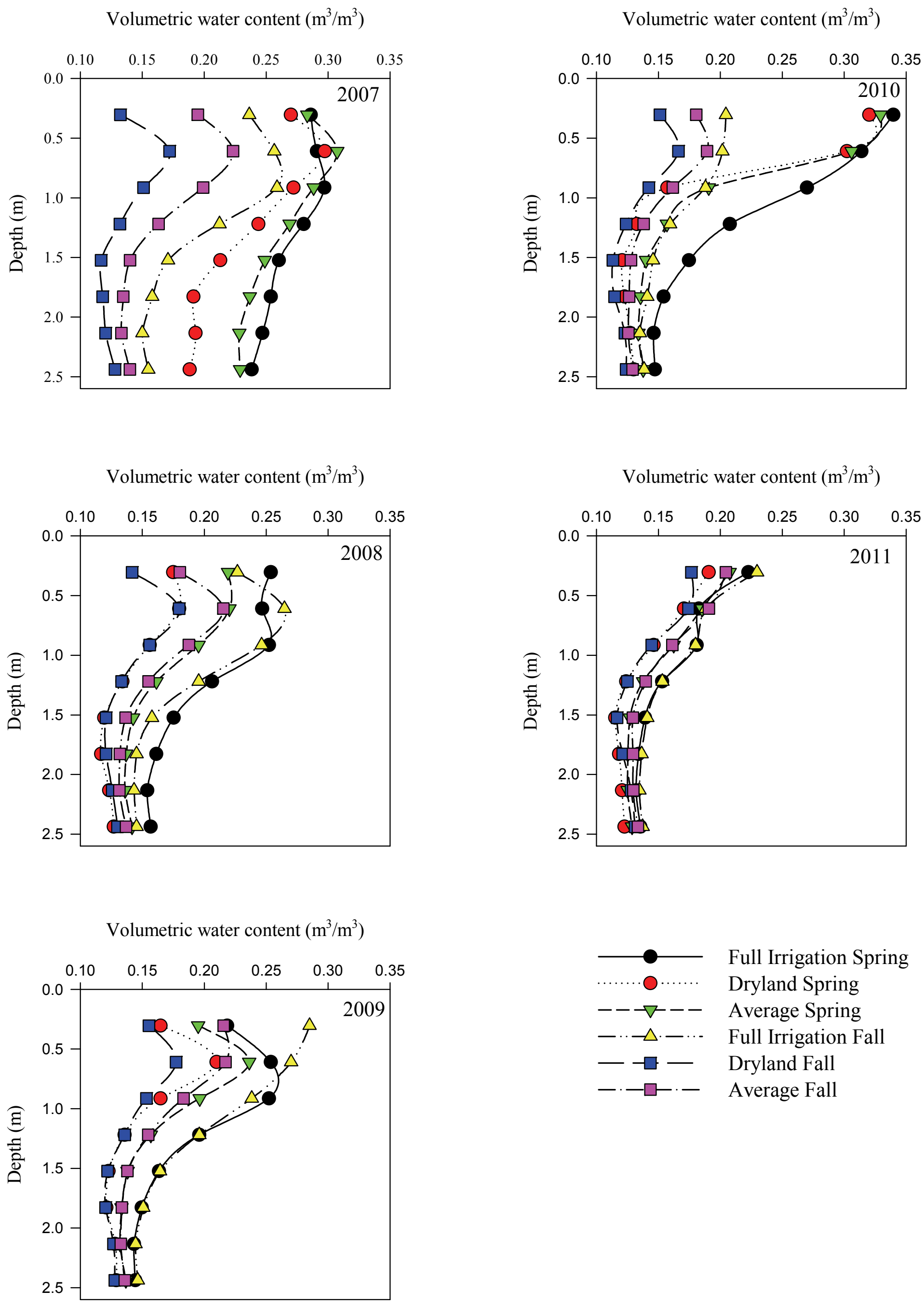

Figure 2. Soil water profiles for full irrigation, dryland, and average of all six treatments during the spring and fall from 2007 to 2011.

most years, as shown in table 4. With the exception of treatments 1, 2, and 3 during the 2009 growing season, in which there was soil water recharge, for all other years stored soil water contributed to ET_c, as estimated by the difference between measured ET_c and the sum of growing season (April to September) precipitation and irrigation. The soil water contribution to ET_c was greatest during the 2007 and 2010 growing seasons due to above-normal annual rainfall in 2006 and 2009 that resulted in large soil water storage during the dormant season. Klocke et al. (2013) reported that the yield response to ET_c was curvilinear for 2007, and additional water beyond that applied to treatment 1 would not have produced substantial increases in yield. Additional irrigation to treatment 1 in 2008, 2010, and 2011 could have produced more yields given the quadratic production functions for these years, as previously reported by Klocke et al. (2013). There was little contribution of soil water to ET_c during the drought of 2011 because available soil water was depleted.

CRUDE PROTEIN (CP)

Crude protein concentration in alfalfa ranged from 195 to 265 g kg^{-1} under six irrigation treatments during 2008-2011 (table 5). Crude protein tended to decrease as irrigation increased. Irrigation treatment 6 had higher CP concentration than other irrigation treatments in 2008, which indicates that rainfed treatments may have an advantage in having higher CP concentrations than irrigated treatments in some years. Previous research showed that drought increased the CP concentration (Vough and Marten, 1971; Peterson et al., 1992).

Table 5. Comparison of seasonal crude protein concentrations calculated from weighted mean values from each cutting using forage dry matter yield at Kansas State University SWREC near Garden City, Kansas.

Irrigation Treatment[a]	Total Irrigation (mm)	Crude Protein (g kg^{-1})[b]			
		2008	2009	2010	2011
1	610	224 Ae	217 ABc	199 Cc	207 BCc
2	380	233 ABde	227 Babc	209 Cbc	243 Aa
3	380	238 Acd	221 Cbc	206 Dbc	223 BCb
4	200	249 Abc	237 Ba	212 Cab	221 Cb
5	200	248 Abc	230 BCab	221 Ca	242 ABa
6	0	265 Aa	231 Bab	212 Cab	195 Dd

[a] In treatments 2 and 5, irrigation was applied after green-up and between all cuttings. In treatments 3 and 4, no irrigation was applied between cuttings 2 and 3.

[b] Different uppercase letters in each row indicate that year is significant within the same irrigation treatment at $p \leq 0.05$. Different lowercase letters in each column indicate that irrigation treatment is significant within the same year at $p \leq 0.05$.

Increased overall forage nutritive value resulted from an increase in the leaf:stem ratio (Vough and Marten, 1971; Carter and Sheaffer, 1983; Halim et al., 1989; Peterson et al., 1992) and a decrease in the rate of plant maturation (Halim et al., 1989). Irrigation amount affected CP concentration similarly to drought in that CP tended to decrease as irrigation level increased. However, this did not occur in 2011 when treatment 6 (rainfed) had lower CP concentration, which was likely due in part to the stand becoming very thin and weeds becoming more prevalent. There was a tendency for weeds to reduce CP concentration (table 6). When comparing applying irrigation between all cuttings and applying

Table 4. Crop evapotranspiration, growing season rainfall (April to September), and irrigation during the study period (2007 to 2011).

Year	Irrigation Treatment	Crop Evapotranspiration (ET_c, mm)	Precipitation During Growing Season (April to Sept.) (mm)	Irrigation (mm)	Sum of Precipitation and Irrigation (mm)	Difference between ET_c and Sum of Precipitation and Irrigation (mm)
2007	1	1137	330	610	940	-197
	2	1042	330	457	787	-255
	3	1026	330	457	787	-239
	4	833	330	203	533	-300
	5	830	330	203	533	-297
	6	602	330	0	330	-272
2008	1	914	283	610	893	-21
	2	701	283	381	664	-37
	3	699	283	381	664	-35
	4	500	283	203	486	-14
	5	500	283	203	486	-14
	6	287	283	0	283	-4
2009	1	956	428	610	1038	82
	2	775	428	381	809	34
	3	765	428	356	784	19
	4	640	428	203	631	-9
	5	647	428	203	631	-16
	6	437	428	0	428	-9
2010	1	1023	304	584	888	-135
	2	796	304	381	685	-111
	3	777	304	381	685	-92
	4	632	304	203	507	-125
	5	636	304	203	507	-129
	6	438	304	0	304	-134
2011	1	828	204	610	814	-14
	2	599	204	381	585	-14
	3	599	204	381	585	-14
	4	418	204	203	407	-11
	5	426	204	203	407	-19
	6	222	204	0	204	-18

Table 6. Weed effects as a covariate on alfalfa nutritive value (CP = crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber, TDN = total digestible nutrients, and RFV = relative feed value).

	N[a]	CP	ADF	NDF	TDN	RFV
Weeds	21	223	231	359	739	187
No weeds	327	228	270	370	697	176
Significance[b]	-	NS	**	NS	**	NS

[a] *N* = number of plots with or without weeds present at harvest.

[b] NS = not significantly different at p ≤ 0.05 level within same column. Asterisks (**) indicate significant difference at p ≤ 0.01.

Table 7. Crude protein comparison averaged across years (2008-2011) by cutting and irrigation treatment at Kansas State University SWREC near Garden City, Kansas.

Irrigation Treatment[a]	Total Irrigation (mm)	Crude Protein (g kg^{-1})[b] First Cutting	Second Cutting	Third Cutting	Fourth Cutting
1	610	177 Aa	212 Ba	213 Ba	216 Ba
2	380	195 Ab	223 AaB	240 Cb	228 DCa
3	380	195 Ab	219 Bab	233 Bb	219 Ba
4	200	206 Ab	231 Bb	236 Bb	221 ABa
5	200	206 Ab	236 BCb	245 Cb	225 Ba
6	0	204 Ab	266 Cc	-[c]	234 Ba

[a] In treatments 2 and 5, irrigation was applied after green-up and between all cuttings. In treatments 3 and 4, no irrigation was applied between cuttings 2 and 3.

[b] Different uppercase letters in each row indicate that cutting is significant within the same irrigation treatment averaged across years at p ≤ 0.05. Different lowercase letters in each column indicate that irrigation treatment is significant within the same cutting averaged across years at p ≤ 0.05.

[c] Alfalfa was not harvested at the third cutting due to dry conditions and no regrowth.

none between cuttings 2 and 3, no significant difference in CP concentration was found in the 200 and 380 mm irrigation treatments during the study except in 2011, when applying irrigation between all cuttings increased CP concentration. These results suggest that irrigation can be withheld in most years between the second and third cuttings without affecting CP concentration.

Within an irrigation treatment, crude protein concentration tended to be lower from the first cutting compared to the other cuttings when averaged across years (table 7). This result concurs with a previous report (Peterson et al., 1992) in which first and second cuttings of alfalfa had average CP concentration of 194 and 233 g kg^{-1} DM, respectively, in Minnesota. In the second cutting, irrigation treatment 6 (rainfed) had the highest CP concentration of any irrigation treatment. At the first and third cuttings, irrigation treatment 1 (610 mm) had lower CP concentration than the other irrigation treatments. Timing did not affect the CP concentration under the same amount of irrigation (i.e., between treatments 2 and 3 or between treatments 4 and 5).

Acid Detergent Fiber (ADF)

The ADF concentration tended to decrease as irrigation decreased (table 8). Averaged across years 2008 through 2011, 610 mm of irrigation had higher ADF concentration than the other irrigation treatments, and 200 mm of irrigation and rainfed production had less ADF concentration than 380 mm of irrigation (table 8). The lower the ADF concentration, the better the forage digestibility; thus, lowering irrigation amounts might improve forage digestibility by reducing ADF concentration. With the exception of applying 200 mm in 2011, no difference was found between treatments 2 and 3 or between treatments 4 and 5, indicating that irrigating at mid-summer does not appear helpful in reducing the ADF concentration in alfalfa under both 380 and 200 mm of irrigation. In 2011, ADF was less when irrigation was applied evenly across all cuttings at the 200 mm amount, which may have been due in part to the presence of weeds. Unlike CP and NDF (tables 6 and 10), ADF was significantly reduced by the presence of weeds in this study. The weeds were harvested at a vegetative stage along with the alfalfa, which may explain why weeds did not have a negative impact on ADF concentration. The lower ADF concentration associated with less water is consistent with other research that found drought tended to increase the leaf:stem ratio, resulting in lower ADF concentration in alfalfa (Vough and Marten, 1971; Peterson et al., 1992). Averaged across legumes such as alfalfa, birdsfoot trefoil, cicer milkvetch, and red clover, drought-stricken legumes decreased their ADF concentration by 38% compared with the non-drought control in Minnesota (Peterson et al., 1992).

Table 8. Comparison of seasonal acid detergent fiber concentrations calculated from weighted mean values from each cutting using forage dry matter yield at Kansas State University SWREC near Garden City, Kansas.

Irrigation Treatment[a]	Total Irrigation (mm)	Acid Detergent Fiber (g kg^{-1})[b] 2008	2009	2010	2011
1	610	319 Aa	335 Aa	332 Aa	277 Ba
2	380	292 ABb	303 Acd	281 Bb	223 Cbc
3	380	287 Ab	304 Ab	293 Ab	231 Bb
4	200	266 Ac	275 Ad	262 Acd	236 Bb
5	200	263 Bc	286 Acd	249 Bd	211 Cc
6	0	227 Bd	273 Ad	263 Acd	224 Bbc

[a] In treatments 2 and 5, irrigation was applied after green-up and between all cuttings. In treatments 3 and 4, no irrigation was applied between cuttings 2 and 3.

[b] Different uppercase letters in each row indicate that year is significant within the same irrigation treatment at p ≤ 0.05. Different lowercase letters in each column indicate that irrigation treatment is significant within the same year at p ≤ 0.05.

The ADF concentrations from the first and second cuttings were higher than the third and fourth cuttings when averaged across irrigation treatments (table 9). Applying 610 mm of irrigation (the highest irrigation amount) produced higher ADF concentrations than all other irrigation treatments at all cuttings. Withholding irrigation mid-summer and applying part of this saved water toward the fourth cutting (i.e., between treatments 2 and 3 or between treatments 4 and 5), tended to increase the ADF concentration of treatments 3 and 4 at the fourth cutting. This trend was consistent with irrigation amount, where applying more irrigation tended to increase ADF concentration (table 8).

Neutral Detergent Fiber (NDF)

The NDF concentrations of alfalfa in 2011, the driest year, were lower than in other years for each irrigation treatment except treatment 6 (table 10). Precipitation in 2010 and 2011 was less than in 2008 and 2009 (fig. 1), and lower precipitation tended to reduce NDF concentration. Peterson et al. (1992) reported that drought-affected alfalfa and red clover had 25% less NDF concentration than their well-watered controls, whereas birdsfoot trefoil and cicer milkvetch had

Table 9. Acid detergent fiber comparison averaged across years (2008-2011) by cutting and irrigation treatment at Kansas State University SWREC near Garden City, Kansas.

Irrigation Treatment[a]	Total Irrigation (mm)	Acid Detergent Fiber (g kg^{-1})[b] First Cutting	Second Cutting	Third Cutting	Fourth Cutting
1	610	324 Aa	312 Aa	329 Aa	284 Ba
2	380	290 Ab	287 Ab	254 Bb	249 Bbc
3	380	292 Ab	286 Ab	235 Bbc	275 Aa
4	200	256 Ac	268 Abc	228 Bc	248 Abc
5	200	261 Ac	255 Ac	223 Bc	239 ABc
6	0	259 Ac	243 Ac	-[c]	221 Bc

[a] In treatments 2 and 5, irrigation was applied after green-up and between all cuttings. In treatments 3 and 4, no irrigation was applied between cuttings 2 and 3.
[b] Different uppercase letters in each row indicate that cutting is significant within the same irrigation treatment averaged across years at p ≤ 0.05. Different lowercase letters in each column indicate that irrigation treatment is significant within the same cutting averaged across years at p ≤ 0.05.
[c] Alfalfa was not harvested at the third cutting due to dry conditions and no regrowth.

Table 10. Comparison of seasonal neutral detergent fiber concentrations calculated from weighted mean values from each cutting using forage dry matter yield at Kansas State University SWREC near Garden City, Kansas.

Irrigation Treatment[a]	Total Irrigation (mm)	Neutral Detergent Fiber (g kg^{-1})[b] 2008	2009	2010	2011
1	610	425 Aa	440 Aa	439 Aa	383 Ba
2	380	389 Ab	403 Abc	385 Ac	318 Bc
3	380	392 Ab	407 Ab	412 Ab	324 Bbc
4	200	362 ABc	373 Ac	380 Acd	345 Bb
5	200	363 ABc	384 Abc	358 Bd	315 Cc
6	0	319 Bd	375 Ac	388 Ac	399 Aa

[a] In treatments 2 and 5, irrigation was applied after green-up and between all cuttings. In treatments 3 and 4, no irrigation was applied between cuttings 2 and 3.
[b] Different uppercase letters in each row indicate that year is significant within the same irrigation treatment at p ≤ 0.05. Different lowercase letters in each column indicate that irrigation treatment is significant within the same year at p ≤ 0.05.

35% less NDF concentration. As NDF concentration increases, feed intake decreases. Similar to ADF concentration, NDF concentration tended to decrease as irrigation decreased. The highest irrigation amount (610 mm) in 2008, 2009, and 2010 produced significantly higher NDF concentrations than the other irrigation treatments. Applying irrigation between all cuttings or withholding irrigation between cuttings 2 and 3 (i.e., treatments 2 and 3 or treatments 4 and 5) did not affect NDF concentrations in 2008 or 2009. However, NDF concentration was less when irrigation of 380 mm was applied between cuttings in 2010 and 200 mm was applied between cuttings in 2011. This indicates that irrigating alfalfa after green-up and between all cuttings tended to lower NDF concentration compared to not irrigating in midsummer in 2010 and 2011. NDF concentration was not affected by weeds when averaged across irrigation treatments and cuttings (table 6).

With the exception of rainfed production, NDF concentration tended to be lower at the third and fourth cuttings compared to the first and second cuttings when irrigation was applied to every cutting (treatments 2 and 5) throughout the growing season. The NDF concentration at the highest

Table 11. Neutral detergent fiber comparison averaged across years (2008-2011) by cutting and irrigation treatment at Kansas State University SWREC near Garden City, Kansas.

Irrigation Treatment[a]	Total Irrigation (mm)	Neutral Detergent Fiber (g kg^{-1})[b] First Cutting	Second Cutting	Third Cutting	Fourth Cutting
1	610	444 Aa	418 Aa	426 Aa	382 Ba
2	380	400 Ab	381 Ab	340 Bb	343 Bbc
3	380	405 Ab	391 Ab	320 Bb	375 Aab
4	200	359 Ac	365 Abc	309 Bb	364 Aab
5	200	375 Ac	353 Acd	310 Bb	323 Bc
6	0	362 Ac	335 Ad	-[c]	358 Aabc

[a] In treatments 2 and 5, irrigation was applied after green-up and between all cuttings. In treatments 3 and 4, no irrigation was applied between cuttings 2 and 3.
[b] Different uppercase letters in each row indicate that cutting is significant within the same irrigation treatment averaged across years at p ≤ 0.05. Different lowercase letters in each column indicate that irrigation treatment is significant within the same cutting averaged across years at p ≤ 0.05.
[c] Alfalfa was not harvested at the third cutting due to dry conditions and no regrowth.

irrigation amount (610 mm) was higher than for other irrigation treatments at all cuttings (table 11). These results indicate that high amounts of irrigation increase NDF concentration similar to the trend for ADF concentration throughout the growing season. Applying irrigation between all cuttings or withholding between the second and third cuttings (i.e., between treatments 2 and 3 and between treatments 4 and 5) did not affect NDF concentration at cuttings 1 to 3, but applying irrigation between all cuttings lowered NDF concentration at the fourth cutting.

TOTAL DIGESTIBLE NUTRIENTS (TDN)

Total digestible nutrients decreased as irrigation increased (table 12). Total digestible nutrients were significantly higher in 2011, a dry year, and significantly less in 2009, a wet year (tables 4 and 12). The impact of weather coincides with the results of TDN and irrigation amount. Total digestible nutrients are an estimate of forage energy, with higher levels having more energy. Lower precipitation might have resulted in higher TDN by increasing the leaf:stem ratio. This result would be consistent with other studies (Vough and Marten, 1971; Carter and Sheaffer, 1983; Peterson et al., 1992) in which forage nutritive value was typically higher during a dry year than a wet year. The effect of irrigation and precipitation on TDN was consistent with the trends for CP, ADF, and NDF measured in this study. TDN concentration was not affected by applying irrigation between all cuttings nor by not irrigating between the second and third cuttings, except for the 200 mm irrigation treatment in 2011, which was associated with more weeds present that year when irrigation was applied between all cuttings. Total digestible nutrients were significantly increased by the presence of weeds (table 6), and this trend concurred with the effect of weeds on ADF content.

Similar to CP, ADF, and NDF, the TDN values were lower at the first and second cuttings than at the third and fourth cuttings (table 13). With the exception of the fourth cutting, TDN tended to increase as irrigation level decreased. Applying irrigation between all cuttings or withholding irrigation between the second and third cuttings did not affect TDN, with the exception of 380 mm at the fourth cutting,

Table 12. Comparison of seasonal total digestible nutrients calculated from weighted mean values from each cutting using forage dry matter yield at Kansas State University SWREC near Garden City, Kansas.

Irrigation Treatment[a]	Total Irrigation (mm)	Total Digestible Nutrients (%)[b]			
		2008	2009	2010	2011
1	610	64.6 Bd	62.9 Bc	63.1 Bc	69.1 Ac
2	380	67.5 Bc	66.3 Bb	68.7 Bb	74.8 Ab
3	380	68.0 Bc	66.2 Bb	67.5 Bb	74.0 Ab
4	200	70.3 Bb	69.4 Ba	71.0 Ba	73.5 Ab
5	200	70.6 Bb	68.1 Cab	72.0 Ba	76.2 Aa
6	0	74.3 Aa	69.6 Ba	70.7 Ba	74.6 Aab

[a] In treatments 2 and 5, irrigation was applied after green-up and between all cuttings. In treatments 3 and 4, no irrigation was applied between cuttings 2 and 3.

[b] Different uppercase letters in each row indicate that year is significant within the same irrigation treatment at $p \leq 0.05$. Different lowercase letters in each column indicate that irrigation treatment is significant within the same year at $p \leq 0.05$.

Table 13. Total digestible nutrients comparison averaged across years (2008-2011) by cutting and irrigation treatment at Kansas State University SWREC near Garden City, Kansas.

Irrigation Treatment[a]	Total Irrigation (mm)	Total Digestible Nutrients (%)[b]			
		First Cutting	Second Cutting	Third Cutting	Fourth Cutting
1	610	657 Bc	668 Bc	642 Bc	700 Ab
2	380	692 Bb	695 Bb	724 Ab	738 Aa
3	380	691 Bb	697 Bb	751 Aab	709 Bb
4	200	730 Ba	717 Ba	759 Aa	736 ABa
5	200	724 Ba	729 Ba	754 Aa	747 ABa
6	0	726 Aa	743 Aa	-[c]	744 Aa

[a] In treatments 2 and 5, irrigation was applied after green-up and between all cuttings. In treatments 3 and 4, no irrigation was applied between cuttings 2 and 3.

[b] Different uppercase letters in each row indicate that cutting is significant within the same irrigation treatment averaged across years at $p \leq 0.05$. Different lowercase letters in each column indicate that irrigation treatment is significant within the same cutting averaged across years at $p \leq 0.05$.

[c] Alfalfa was not harvested at the third cutting due to dry conditions and no regrowth.

which was higher when irrigation was applied to all cuttings. This trend in irrigation timing corresponded with the irrigation timing effect on ADF and NDF content.

Relative Feed Value (RFV)

Like TDN levels, 2011 had the highest RFV (193) compared with other years (table 14), and 2011 also had the lowest precipitation (fig. 1). This indicates that RFV might be higher in dry years than in wet years. The exception was treatment 6 (rainfed), which had the highest RFV in 2008. Treatment 6 was always under drought stress compared to the irrigated treatments. The trend in RFV was correlated to irrigation amount, with the highest amount (610 mm) having a lower RFV value compared with the other irrigation treatments when averaged across years. Quality grades for alfalfa based on RFV are supreme (>185), premium (170 to 185), good (150 to 170), fair (130 to 150), and low (<130). RFV varied by year across irrigation treatments, primarily due to differences in environmental conditions and likely due to slight variability in growth stage at harvest, although every attempt was made to harvest at similar growth stages across all treatments and years. The highest irrigation amount (610 mm) generally had an RFV grade of fair, while all other irrigation treatments had RFV grades of good to supreme. Applying irrigation between all cuttings increased RFV at the 380 mm level in 2010 and at the 200 mm level in 2010 and 2011 compared to no irrigation between the second and third cuttings (table 14).

Relative feed values were lower at the first and second cuttings than at the third and fourth cuttings (table 15), and this result was consistent with the ADF, NDF, and TDN values. Across all cuttings, RFV values tended to decrease as irrigation increased. Applying irrigation between all cuttings compared to not irrigating between the second and third cuttings only affected RFV at the 200 and 380 mm irrigation amounts at the fourth cutting, where applying irrigation between all cuttings improved RFV. This increase in RFV in 2011 was similar to the trend seen for TDN and ADF and was at least partly due to the increased presence of weeds in the final year of the study.

In 2014, supreme grade (\$290 Mg^{-1}) alfalfa sold for 10% more than premium grade (\$260 Mg^{-1}), and premium grade sold for 12% more than fair/good grade (\$230 Mg^{-1}) in southwest Kansas (USDA, 2014). Using a partial budget analysis for irrigated alfalfa, gross and net returns for all treatments were determined (table 16). The partial budget only accounted for variable costs that were affected by irrigation level, including baling, irrigation, and phosphorus (P) expenses, and excluded land rent, crop insurance, interest, and variable or fixed

Table 14. Comparison of seasonal relative feed values calculated from weighted mean values from each cutting using forage dry matter yield at Kansas State University SWREC near Garden City, Kansas.

Irrigation Treatment[a]	Total Irrigation (mm)	Relative Feed Value[b]			
		2008	2009	2010	2011
1	610	143 Bd	134 Bc	135 Bd	166 Ac
2	380	163 Bc	155 Bab	167 Bb	212 Aa
3	380	163 Bc	152 Bb	152 Bc	205 Aab
4	200	180 ABb	174 Ba	170 Bb	193 Ab
5	200	181 Bb	167 Ca	188 Ba	215 Aa
6	0	209 Aa	169 Ba	165 Bbc	168 Bc

[a] In treatments 2 and 5, irrigation was applied after green-up and between all cuttings. In treatments 3 and 4, no irrigation was applied between cuttings 2 and 3.

[b] Different uppercase letters in each row indicate that year is significant within the same irrigation treatment at $p \leq 0.05$. Different lowercase letters in each column indicate that irrigation treatment is significant within the same year at $p \leq 0.05$.

Table 15. Relative feed value comparison averaged across years (2008-2011) by cutting and irrigation treatment at Kansas State University SWREC near Garden City, Kansas.

Irrigation Treatment[a]	Total Irrigation (mm)	Relative Feed Value[b]			
		First Cutting	Second Cutting	Third Cutting	Fourth Cutting
1	610	137 Bc	146 Bc	139 Bc	167 Ac
2	380	161 Bb	166 Bbc	193 Ab	196 Aab
3	380	157 Bbc	161 Bbc	208 Aab	175 Bbc
4	200	184 Ba	177 Bab	216 Aa	183 Bbc
5	200	174 Bab	187 Ba	217 Aa	210 Aa
6	0	179 Aab	200 Aa	-[c]	189 Aabc

[a] In treatments 2 and 5, irrigation was applied after green-up and between all cuttings. In treatments 3 and 4, no irrigation was applied between cuttings 2 and 3.

[b] Different uppercase letters in each row indicate that cutting is significant within the same irrigation treatment averaged across years at $p \leq 0.05$. Different lowercase letters in each column indicate that irrigation treatment is significant within the same cutting averaged across years at $p \leq 0.05$.

[c] Alfalfa was not harvested at the third cutting due to dry conditions and no regrowth.

Table 16. Partial budget for center-pivot alfalfa with each irrigation treatment at KSU SWREC near Garden City, Kansas.

	Irrigation Treatment					
	1	2	3	4	5	6
Income per hectare						
Yield (Mg ha^{-1})	15.3	12.4	11.6	8.9	8.9	4.3
Price ($ Mg^{-1})	230	260	260	260	260	260
Gross returns ($ ha^{-1})	3519	3224	3016	2314	2314	1118
Variable costs per hectare[a]						
Bales (number ha^{-1})	24	20	18	14	14	7
Bale cost ($ bale^{-1})	14	14	14	14	14	14
Bale cost ($ ha^{-1})	337	273	256	196	196	95
Irrigation use (mm ha^{-1})	610	380	380	200	200	0
Irrigation cost ($ mm^{-1})	0.21	0.21	0.21	0.21	0.21	0.21
Irrigation cost ($ ha^{-1})	126	79	79	41	41	0
P use (kg ha^{-1})	92	74	70	53	53	26
P cost ($ kg^{-1})	1.50	1.50	1.50	1.50	1.50	1.50
P cost ($ ha^{-1})	138	112	104	80	80	39
Partial budget net return[b]						
Returns ($ ha^{-1})	2918	2760	2577	1996	1996	985

[a] Expenses obtained from Ibendahl et al. (2015). Variable costs do not include differences in land rent, crop insurance, interest, or those costs that do not vary with irrigation level.

[b] Excludes some variable costs and all fixed costs.

costs not affected by irrigation level (Ibendahl et al., 2015). Treatment 1, despite having a slightly lower alfalfa price per Mg, had the highest gross ($3520 ha^{-1}) and net ($2920 ha^{-1}) returns of all treatments. Treatment 2 had greater net returns than treatment 3 due to more alfalfa yield when irrigation was spread across all treatments, as compared to withholding irrigation between the second and third cuttings when 380 mm of irrigation was applied. There was no difference in net returns between treatments 4 and 5 or whether or not irrigation was withheld between second and third cuttings when 200 mm or irrigation was applied. Treatment 6 produced the lowest net returns of all treatments.

DISCUSSION

Irrigation within most of the South and Central High Plains Aquifer region is unable to meet the full alfalfa crop water requirement. Alfalfa yields in this region are expected to decline as full irrigation shifts to limited irrigation. Averaged across years, dry matter yields were 15.3 Mg ha^{-1} in treatment 1 (610 mm), 12.4 Mg ha^{-1} in treatment 2 (380 mm applied between all cuttings), 11.6 Mg ha^{-1} in treatment 3 (380 mm and withheld between second and third cuttings), 8.90 Mg ha^{-1} in treatment 4 (200 mm and withheld between second and third cuttings), 8.9 Mg ha^{-1} in treatment 5 (200 mm applied between all cuttings), and 4.3 Mg m^{-1} in treatment 6 (rainfed) (table 17) (Klocke et al., 2013). A study comparing different levels of subsurface drip irrigation found that alfalfa yield was unaffected whether 396 or 586 mm of irrigation was applied in an environment and soil type similar to this study (Lamm et al., 2012). Yet in the subsurface drip irrigation study, an additional 125 mm of fall irrigation was applied annually to reduce root intrusion and rodent damage. The difference in alfalfa productivity between these two studies may be due in part to the increased irrigation efficiency of subsurface drip compared to overhead nozzles, and because the subsurface drip irrigation

Table 17. Alfalfa dry matter yields for each cutting and irrigation treatment averaged across years (2008-2011). Complete yield results were presented by Klocke et al. (2013).

Irrigation Treatment[a]	Total Irrigation (mm)	Dry Matter Yield (kg m^{-2})[b] First Cutting	Second Cutting	Third Cutting	Fourth Cutting	Sum[c]
1	610	0.4 a	0.35 a	0.4 a	0.38 a	1.53 a
2	380	0.35 b	0.28 b	0.29 b	0.32 b	1.24 b
3	380	0.35 b	0.31 b	0.15 c	0.36 a	1.16 b
4	200	0.26 c	0.24 c	0.15 c	0.24 c	0.89 c
5	200	0.28 c	0.21 c	0.2 b	0.21 d	0.89 c
6	0	0.21 d	0.12 d	0 e	0.1 e	0.43 d

[a] In treatments 2 and 5, irrigation was applied after green-up and between all cuttings. In treatments 3 and 4, no irrigation was applied between cuttings 2 and 3.

[b] Different letters in each column indicate that irrigation treatment is significant within the same cutting averaged across years at $p \leq 0.05$.

[c] Sum of cuttings averaged across years by irrigation treatment.

study received additional fall irrigation. The additional fall irrigation likely minimized soil water and alfalfa yield differences between irrigation levels in the subsurface drip study.

This study evaluated the effect of irrigation level, timing, cutting, and weeds on alfalfa forage nutritive values (CP, ADF, NDF, TDN, and RFV). In general, applying the highest amount of irrigation (i.e., 610 mm during the growing season) reduced alfalfa forage nutritive values compared to other irrigation treatments. Other studies have also found that moisture stress increases alfalfa nutritive value (Vough and Marten, 1971; Snaydon, 1972; Carter and Sheaffer, 1983; Harmoney et al., 2013, Peterson et al., 1992). The results from this study suggest that any irrigation level less than full crop requirement improved forage nutritive value and suggest that more research is required on irrigation management near the full crop water requirement to determine if forage nutritive value can be improved while still maintaining full yield. There was a general tendency for improved forage nutritive value at the fourth cutting when irrigation was applied between all cuttings, as compared to withholding irrigation between the second and third cuttings and applying the saved water in addition to the irrigation amount of the first and fourth cuttings. The reduction in forage nutritive value at the fourth cutting (when additional saved irrigation water was applied) was consistent with the forage nutritive value differences found across irrigation amount, where applying more irrigation tended to reduce forage nutritive value. In addition to lower forage nutritive value at the fourth cutting, withholding irrigation between cuttings 2 and 3 reduced total forage yield (treatment 3), as compared to applying the irrigation amount equally across all cuttings (treatment 2) (Klocke et al., 2013). To maximize both forage nutritive value and yield, irrigation should be applied all season long and not withheld between the second and third cuttings. Forage nutritive value was lower at the first and second cuttings compared to the third and fourth cuttings when averaged over years and irrigation amount. Irrigation amounts less than full crop requirement increased the forage nutritive value of alfalfa. This increase in forage nutritive value helped offset some of the reduction in forage yield.

CONCLUSION

One must consider both alfalfa yield and forage nutritive value when making irrigation and harvest management decisions. Results from this study suggest that forage nutritive value can be improved by using lower amounts of irrigation, at the cost of reduced alfalfa yield and net returns. Currently, supreme grade alfalfa (\$290 Mg^{-1}) is selling for 10% more than premium grade (\$260 Mg^{-1}), and premium grade alfalfa is selling for 12% more than fair/good grade (\$230 Mg^{-1}) in southwest Kansas (USDA, 2014). In this study, using the forage nutrient value average across years, treatment 1, with 610 mm of irrigation, would have sold for about \$230 Mg^{-1}, and all other irrigation treatments would have sold for about \$260 Mg^{-1}. This 13% increase in price did not make up the 19% yield reduction between treatments 1 and 2, which reduced the net returns by approximately \$158 ha^{-1}. Not surprisingly, net returns decreased as irrigation level decreased, but some of this loss can be recovered by maximizing forage nutritive value. Alfalfa producers with lower-capacity wells should consider growing and marketing alfalfa with the highest forage nutritive value possible and using improved irrigation efficiency methods, such as subsurface drip irrigation or mobile drip irrigation. These results suggest that there will be negative economic implications for the region in the future as irrigation pumping capacity declines.

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