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Drought Effects on Perennial Forage Legume Yield and Quality

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ABSTRACT

Drought frequently limits alfalfa (*Medicago sativa* L.) herbage productivity during mid-summer in the North Central USA, but the productivity of other legumes during drought is unknown. We determined the effect of drought on the herbage yield and quality and stand persistence of birdsfoot trefoil (*Lotus corniculatus* L.), cicer milkvetch (*Astragalus cicer* L.), red clover (*Trifolium pratense* L.) and alfalfa. Legumes were established on a sandy, mixed, Udorthentic Haploborolls and subjected to two soil water regimes promoting 'droughted' and 'well-watered' (control) plant growth. Mid-day stem pressure potentials for droughted and control plants ranged from −1.3 to −3.8 MPa and −0.1 to −1.4 MPa, respectively. When drought occurred throughout growth, legume herbage yields of droughted alfalfa, birdsfoot trefoil, cicer milkvetch, and red clover averaged 33, 21, 19, and 13% of their respective controls. Average herbage yield of droughted alfalfa was 120% greater than yields of birdsfoot trefoil and cicer milkvetch, and 165% greater than red clover yield. Averaged for all harvests and species, whole herbage acid detergent fiber (ADF), neutral detergent fiber (NDF), and acid detergent lignin (ADL) concentrations were reduced by 30 to 48%, 26 to 46%, and 0 to 49%, respectively, when drought occurred throughout growth. Effects of drought on lignin in NDF and crude protein concentration were not consistent. Droughted alternative legumes produced herbage with lower ADF, NDF, and ADL concentrations than alfalfa. Improved quality in droughted legumes was related to greater leaf:stem weight ratio, delayed maturity, and often higher quality in both the leaf and stem fractions compared to the control treatment. Although drought reduced the herbage yield of all legumes, alfalfa has the greatest yield potential in drought.

MID-SUMMER DROUGHT frequently limits the forage production of perennial legumes in the North Central USA. Forage yield of alfalfa, the most widely grown perennial legume, is decreased when prolonged soil water deficits reduce plant water potential (Ψ_W), while forage digestibility and intake potential are generally increased (Vough and Marten, 1971; Carter and Sheaffer, 1983; Halim et al., 1989). The decreased yield and increased overall forage quality of alfalfa subjected to drought is associated with an increase in leaf:stem weight ratio (LSWR) (Vough and Marten, 1971; Carter and Sheaffer, 1983; Halim et al., 1989) and a decrease in the rate of plant maturation (Halim et al., 1989).

Information is limited on the relative yields and forage quality of birdsfoot trefoil, cicer milkvetch, and red clover when subjected to drought. These alternative legumes warrant consideration due to limitations of alfalfa, which include bloat inducement in grazing livestock (Marten et al., 1990); poor persistence in soils that are infertile (Smith, 1975), low pH, or poorly drained (Russell et al., 1978); and susceptibility to potato leafhopper [*Empoasca fabae* (Harris)] and alfalfa weevil [*Hypera postica* (Gyll.)] infestation (Kephart et al., 1990).

Foulds (1978a) reported that established birdsfoot trefoil survived drought by developing a vigorous root system and decreasing shoot and seed production. He suggested that the slow growth rate of birdsfoot trefoil may be an advantage in dry soils by reducing the plant's water requirement. Foulds (1978b) also reported that birdsfoot trefoil had greater seedling tolerance to mild drought than black medic (*Medicago lupulina* L.) or white clover (*Trifolium repens* L.). Cicer milkvetch, which has drought tolerance, has been established in Montana and Wyoming on dryland sites that receive less than 350 mm of precipitation annually (Stroh et al., 1972). In Wyoming, cicer milkvetch had a lower transpiration rate than 19 other forage species including alfalfa (Fairbourn, 1982). Fairbourn (1982) suggested that lower water use by cicer milkvetch may be explained by its low root:shoot weight ratio compared to other species. Marten et al. (1987) noted that cicer milkvetch forage had greater in vitro digestible dry matter (IVDDM) concentration than alfalfa, birdsfoot trefoil, and sainfoin (*Onobrychis viciifolia* Scop.) forage during a droughted period of regrowth. Red clover does not grow well in soils with low moisture retention or in low rainfall areas and is more drought susceptible than alfalfa (Smith et al., 1986). Cary (1971) found that while red clover grew best in moist soil at moderately high Ψ_W, it was able to survive low Ψ_W when left unharvested.

The objective of our research was to determine the effect of drought on herbage yield, herbage quality, and stand persistence of red clover, birdsfoot trefoil, cicer milkvetch and alfalfa.

MATERIALS AND METHODS

A field experiment was conducted at the Sand Plains Experimental Station, Becker, MN, on a Hubbard loamy sand (sandy, mixed Udorthentic Haploborolls). Two sets of plots were used. Pure stands of 'DK-120' alfalfa, 'Norcen' birdsfoot trefoil, and 'Monarch' cicer milkvetch were established in August 1985 at seeding rates of 900 seeds m^{-2}. These plots were utilized only in 1987. Pure stands of '526' alfalfa, 'Norcen' birdsfoot trefoil, 'Monarch' cicer milkvetch, and 'Arlington' red clover were established in August 1987 and used for experiments in 1988 and 1989. Soil pH, available P, and exchangeable K were maintained above 6.5, 70 kg/ha, and 300 kg/ha, respectively, throughout the experiment. Forage was harvested on 1 June, 15 July, and 19 Aug. 1987; on 2 June, 6 July, 10 Aug., and 6 Oct. 1988; and on 7 June, 19 July, and 11 Sept. 1989.

The experimental design was a randomized complete block with a two-factor factorial set of treatments. Three replicates were used in 1987 and four replicates in 1988 and 1989. The two factors were legume species and soil water regimes. The two soil water regimes promoted droughted and well-watered (control) plant growth. The well-watered control was maintained by sprinkler irrigation to 85% of

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Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; CP, crude protein; ESW, extractable soil water; IVDDM, in vitro digestible dry matter; LSWR, leaf:stem weight ratio; NDF, neutral detergent fiber; NIRS, near infrared reflectance spectroscopy.

field capacity when 35% depletion of extractable soil water (ESW) occurred. The droughted regime received irrigation to maintain ESW between 50 and 75% depletion. Water was applied to all plots within a water regime when the average ESW reached the lower limit of ESW for each regime. All species within each water regime received the same amount of water from the combination of irrigation and precipitation in an attempt to maintain ESW within the designated ranges. As a result, extractable soil water may have varied somewhat within these ranges because of variation in rooting depth and water use of the different species. Because of the natural variability in rainfall and temperature during the growing season (Table 1), droughted plots were not subjected to this specified range of ESW during all regrowth cycles each year. The desired water treatments were maintained throughout the growth periods culminating in harvests on 15 July 1987, 6 July 1988, and 19 July and 11 Sept. 1989. These water treatments also were achieved during the last 2 weeks of the growth period culminating in the 2 June 1988 harvest. The growth periods culminating in the 10 Aug. and 6 Oct. 1988, and the 7 June 1989 harvests were exposed to little drought because of cool temperatures and normal rainfall (Table 1).

Table 1. Average daily air temperature and total precipitation at Becker, MN averaged for 10-d periods and departures from monthly normals during the 1987, 1988, and 1989 growing seasons.

	1987		1988		1989	
Date	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
	°C	mm	°C	mm	°C	mm
May						
1–10	15.0	9	17.1	67	9.3	36
11–20	16.5	21	15.5	2	17.6	30
21–31	16.8	36	21.7	5	15.9	36
Departure†	+2.8	−26	+4.9	−18	+1.1	+9
June						
1–10	19.1	36	21.8	1	17.1	1
11–20	24.9	18	24.4	2	19.0	19
21–30	21.3	20	22.9	0	22.6	13
Departure	+3.4	−38	+4.6	−109	+1.3	−80
July						
1–10	22.9	25	25.5	1	26.3	11
11–20	22.3	24	23.5	29	22.3	31
21–31	26.8	60	25.4	1	24.0	13
Departure	+3.1	+15	+3.8	−64	+3.2	−39
August						
1–10	22.6	24	24.9	52	22.8	0
11–20	21.7	72	24.1	45	20.7	27
21–31	15.7	6	18.2	15	20.5	64
Departure	+0.3	−9	+2.6	+1	+1.7	−20
September						
1–10	17.7	2	16.9	7	17.0	35
11–20	14.1	54	17.0	50	16.0	22
21–30	15.9	0	13.7	17	13.2	0
Departure	+1.7	−18	+1.7	+1	+1.3	−16

† Departure of actual temperature and precipitation from long-term monthly normals.

Irrigation was applied using a shrub sprinkler system consisting of 50-cm-high sprinklers with 90 degree coverage placed at four corners of a 4.6-by-4.6-m area. This spacing ensured even water application within a set of sprinklers. Plot size was 2.3-by-4.6-m; therefore, two species were randomly assigned to each set of four sprinklers. As a result, each replication consisted of four sets of four sprinklers which included two sets each of randomly assigned droughted, and well-watered treatments. Each set of sprinklers was separated by a 2-m border of alfalfa which received water only from precipitation. This reduced the potential for water movement from control to droughted plots. The treatment design was not a true factorial arrangement, nor was it a true split plot restriction, yet it was necessary due to the constraints of the irrigation system utilized. The experiment was analyzed as a factorial which was judged to be a sufficiently conservative approach for detecting significant treatment effects in the design.

Volumetric soil water content in the upper 2.1 m was monitored at four locations within each water treatment (one location per replicate for each water treatment) throughout the duration of the experiment by summing measurements taken at depths of 15, 30, 45, 60, 90, 120, 150, and 190 cm using a neutron scattering device (Model 503, Campbell Pacific Nuclear, Pacheco, CA) which was field calibrated. These measurements were obtained from neutron probe access tubes which were placed between neighboring plots receiving the same water treatment. Field capacity was determined by measuring the soil profile water content 2 d following full irrigation. Extractable soil water was determined as water held between field capacity and maximum depletion by plants to a 2.1-m depth (Carter and Sheaffer, 1983). Rooting depth of some species, especially alfalfa, may have exceeded the depth to which soil water was measured. However, the water holding capacity of the soil at depths approaching 2.1 m was very limited due to increasing amounts of gravel at depths below about 1 m in the soil profile. Therefore, water extraction from depths greater than 2.1 m was probably insignificant.

Midday stem pressure potentials were monitored weekly in 1987 and 1988 using a pressure chamber. A minimum of one shoot from each field replicate of each species and water regime was excised between the third and fourth nodes from the apex at approximately 1200 h during cloud-free periods for stem pressure potential measurement as described by Brown and Tanner (1981). Species stem pressure potentials varied in response to the imposed water regimes (Table 2).

Table 2. Ranges in stem pressure potential maintained by droughted (DRT) and control (CTL) perennial legumes during growth periods before selected harvest dates in 1987 and 1988.

			1988	
Species	Water Regime	15 July 1987	2 June†	6 July
		MPa		
Alfalfa	DRT	−1.7 to −3.7	−3.2	−3.3 to −3.7
	CTL	−0.2 to −1.0	−0.9	−0.6 to −1.4
Birdsfoot trefoil	DRT	−1.6 to −3.1	−3.1	−1.6 to −3.6
	CTL	−0.1 to −0.4	−0.2	−0.2 to −0.3
Cicer milkvetch	DRT	−1.3 to −2.4	−2.0	−1.5 to −2.5
	CTL	−0.4 to −0.7	−0.6	−0.3 to −0.8
Red clover	DRT	—	−2.5	−3.2 to −3.8
	CTL	—	−0.8	−0.3 to −0.8

† Stem pressure potentials during growth before the 2 June 1988 harvest were measured only once during the last 2 wk of growth.

Forage yield was determined by cutting 1.0-by-4.6-m areas of each 2.3-by-4.6-m plot to a 6-cm stubble height when control alfalfa reached early to late flower in 1987, early to late bud in 1988, and early flower in 1989. Wet forage yield of each plot was adjusted to dry weight by drying an 800-g subsample at 60°C for 48 h to determine dry matter percentage. Persistence of legume stands established in 1987 was determined by visual estimation of stands in June of 1988 and 1989 and in May 1990.

Forage quality was determined on herbage sampled on harvest dates in 1987 and 1988. These samples were obtained by clipping a 0.09-m^2 area in 1987 and a 0.18-m^2 area in 1988 within each plot at a 6-cm stubble height. Forage quality samples were dried at 60°C for 48 h, separated into leaf and stem fractions, weighed, and LSWR

Table 3. Maturity and canopy height (Hgt.) of droughted (DRT) and control (CTL) perennial forage legumes at three harvest dates when drought occurred during regrowth.

Species	Water regime	15 July 1987 Maturity†	15 July 1987 Hgt.	2 June 1988 Maturity	2 June 1988 Hgt.	6 July 1988 Maturity	6 July 1988 Hgt.
			cm		cm		cm
Alfalfa	DRT	EF (5.2)†	45	LV (2.1)	45	LV (2.3)	25
	CTL	LF (5.6)	70	EB (2.9)	70	LB (4.1)	50
Birdsfoot	DRT	LB (4.0)	25	LV (1.8)	30	LV (1.7)	20
trefoil	CTL	LF (6.1)	40	EB (3.0)	50	LB (3.9)	35
Cicer	DRT	MV	15	MV	30	MV	15
milkvetch	CTL	LV	40	LV	55	LV	35
Red	DRT	—	—	LV (2.1)	55	MV	15
clover	CTL	—	—	EB (2.7)	60	LV (1.9)	45

† Kalu and Fick mean-stage-by-weight number in parentheses
MV = mid vegetative, LV = late vegetative, EB = early bud, LB = late bud, EF = early flower, LF = late flower.

determined. The fractions were ground to pass a 1.0-mm screen in a cyclone mill.

Forage crude protein (Kjeldahl N × 6.25), NDF, ADF, and ADL (ash removed) (Goering and Van Soest, 1970) were estimated using near infrared reflectance spectroscopy (NIRS) (Marten et al., 1984). Randomly selected samples representing leaf and stem fractions of all species and both water regimes were analyzed by wet chemistry procedures and used to calibrate and verify the NIRS system. The NIRS prediction equations for crude protein (CP), NDF, ADF, and ADL were developed from 92, 117, 161, and 109 samples, respectively. The coefficients of determination (r^2) and standard errors of selection for the NIRS prediction equations were 0.986, 0.985, 0.988, and 0.962, and 8.7, 17.4, 14.0, and 5.2 g kg^{-1} DM for CP, NDF, ADF, and ADL, respectively. Crude protein, NDF, and ADF were reported on a g kg^{-1} DM basis; lignin was reported on both g kg^{-1} DM and g kg^{-1} NDF bases. Whole herbage forage quality was calculated using LSWR and leaf and stem quality values.

At harvests, maturity of alfalfa and birdsfoot trefoil was determined using the mean-stage-by-weight (MSW) technique (Kalu and Fick, 1981). This procedure was modified to quantify red clover maturity by allotting shoots consisting only of a leaf blade and petiole (no stem) to Stage 1 (mid-vegetative). Cicer milkvetch maturity never advanced beyond the vegetative stage; therefore, maturity was not quantified. Canopy height of all species and both water regimes was measured at harvest.

Significant treatment effects ($P < 0.05$) were identified by ANOVA procedures. When significant treatment effects occurred, means were separated using Fisher's LSD. Heterogeneity of variance was detected among species LSWR values; therefore, LSWR was transformed to log (LSWR × 10) before ANOVA and mean separation.

RESULTS AND DISCUSSION

Plant Maturity

Drought delayed maturity and reduced height of all legumes compared to the control (Table 3). Because legumes matured at different rates and were harvested on the same date, maturities often differed within the droughted and control treatments. Cicer milkvetch was consistently less mature than the other legumes at harvest. Birdsfoot trefoil and red clover, however, were frequently at the same stage of development as alfalfa at harvest. Because of the relationships of plant maturity with herbage yield and quality, maturity differences at harvest, especially that of cicer milkvetch relative to the other species, likely influenced herbage yield and quality results.

Table 4. Herbage yields of droughted (DRT) and control (CTL) perennial legumes in 1987 and 1988†.

Species	Water Regime‡	15 July 1987§	1988 2 June§	1988 6 July§	1988 10 Aug.	1988 6 Oct.
		Mg ha^{-1}				
Alfalfa	DRT	1.8	4.4	1.6	3.5	2.0
	CTL	5.1	5.9	3.5	4.2	2.8
Birdsfoot	DRT	0.9	2.7	0.7	2.9	0.5
trefoil	CTL	3.9	5.0	2.9	3.1	0.4
Cicer	DRT	1.1	2.7	0.6	3.0	0.5
milkvetch	CTL	4.6	4.2	2.1	2.5	0.7
Red	DRT	—	4.0	0.6	3.0	1.5
clover	CTL	—	6.6	3.7	3.5	2.1
LSD (0.05)¶		0.9	0.6	0.8	0.9	0.3

† 1987: second production year, red clover not included; 1988: first production year.
‡ Droughted: Extractable soil water (ESW) maintained between 50 and 75% depletion. Control: ESW maintained between 15 and 35% depletion.
§ Harvest dates for which drought occurred during growth cycle.
¶ For comparison of two species means within or across water regimes.

Table 5. Herbage yields of droughted (DRT) and control (CTL) perennial legumes in 1989†.

Species	Water Regime‡	7 June	19 July§	11 Sept.§
		Mg ha^{-1}		
Alfalfa	DRT	4.5	1.1	0.8
	CTL	4.4	4.0	3.3
Birdsfoot trefoil	DRT	3.4	0.5	0.3
	CTL	3.3	2.5	1.6
Cicer milkvetch	DRT	4.5	0.4	0.3
	CTL	3.9	3.2	2.4
Red clover	DRT	3.3	0.2	0.6
	CTL	2.2	3.0	3.5
LSD (0.05)¶		0.9	0.6	0.7

† 1989: second production year of plots subjected to drought in 1988.
‡ Droughted: ESW maintained between 50 and 75% depletion. Control: ESW maintained between 15 and 35% depletion.
§ Harvest dates for which drought occurred during growth cycle.
¶ For comparison of two species means within or across water regimes.

Herbage Yield

Legume herbage yields were reduced by drought (Tables 4 and 5). When drought occurred throughout regrowth, herbage yields of droughted alfalfa, birdsfoot trefoil, cicer milkvetch, and red clover averaged 33, 21, 19, and 13% of their respective control yields. For the 2 June 1988 harvest, which culminated a growth cycle in which drought occurred only during the last 2 wk of regrowth, droughted legume yields averaged about 63%of control yields.

Alfalfa was either the highest or among the highest yielding legumes under drought and control. When drought occurred throughout regrowth, alfalfa yielded 100% more herbage than the average of the alternative legumes. Droughted birdsfoot trefoil, cicer milkvetch, and red clover yields were similar and generally less than 1 Mg ha^{-1}.

Significant ($P < 0.05$) moisture regime-by-species interactions occurred on 2 June, 6 July, and 6 Oct. 1988, and on 11 Sept. 1989. These interactions were often associated with variation in herbage yield of red clover and cicer milkvetch relative to the other legumes. On 2 June 1988, when drought had occurred only during the last 2 wk of growth before harvest, herbage yield of red clover in the control treatment exceeded that of alfalfa; however, their yields did not differ under drought. On 6 July 1988, control alfalfa and red clover had similar yields, but drought reduced alfalfa yield by about 50% and red clover yield by about 80%. These results indicate that red clover was high yielding when moisture was adequate but was less tolerant to soil water deficits than alfalfa. This observation supports the contention of Smith et al. (1986) that red clover is not tolerant of soil water deficits and is more susceptible to drought than alfalfa. On 2 June and 6 July 1988, forage yield of birdsfoot trefoil in the control treatment was greater than that of cicer milkvetch, but their yields were similar under drought. In contrast, at harvests in 1989, yields of the two species still did not differ under drought, but cicer milkvetch produced more herbage than birdsfoot trefoil under control conditions. At the 11 Sept. 1989 harvest, herbage yields of all species were similar under drought, while differences occurred in control plots. This was the only harvest in which alfalfa yield was not superior to that of the alternative legumes under drought.

Leaf:Stem Weight Ratio

Averaged for all species, legume herbage in the droughted treatment had a higher LSWR than that of controls with LSWR averaging 1.7 and 5.1 at harvests for control and droughted legumes, respectively. Results for LSWR are presented for three harvest dates in 1987 and 1988 which culminated growth periods in which the desired water treatments were achieved (Table 6). Previous investigators have reported a similar preferential partitioning of dry matter to leaves when alfalfa was subjected to water deficits (Vough and Marten, 1971; Carter and Sheaffer, 1983; Halim et al., 1989). This response has been attributed in part to a delayed rate of plant maturation and, more importantly, to reduced stem length in droughted alfalfa (Halim et al., 1989).

Droughted alfalfa herbage consistently had lower LSWR than herbage of any alternative legume. Of the alternative legumes, birdsfoot trefoil herbage had the lowest LSWR when subjected to drought and red clover the highest, frequently consisting entirely of leaves.

Herbage Quality

Droughted legumes consistently had higher forage quality than their controls. Effects of drought on forage quality are illustrated for two harvests in 1988 (Tables 7 to 9); results were similar to those observed in 1987 (data not shown). Drought reduced NDF, ADF, and ADL concentrations (g kg^{-1} DM) at all harvests. Crude protein concentration sometimes increased due to drought but this response was variable. High quality forage of droughted legumes was associated with delayed maturity, higher LSWR, and frequently higher quality of both leaf and stem fractions compared to control legumes. Correlations of whole herbage NDF with LSWR, leaf NDF concentration, and stem NDF concentration were -0.79, 0.75, 0.94, respectively.

Table 6. Leaf:stem weight ratio (LSWR) of droughted (DRT) and control (CTL) perennial legumes on selected harvest dates in 1987 and 1988†.

Species	Water Regime	15 July 1987	2 June 1988	6 July 1988
Alfalfa	DRT	1.4 b	1.0 b	2.0 b
	CTL	0.9 a	0.8 a	1.2 a
Birdsfoot trefoil	DRT	3.1 d	1.4 c	3.4 c
	CTL	1.0 a	0.8 ab	1.4 ab
Cicer milkvetch	DRT	5.2 e	2.3 e	9.9 d
	CTL	1.9 c	1.5 cd	3.2 c
Red clover	DRT	—	2.9 f	L‡
	CTL	—	1.7 d	4.3 c

† LSWR values represent detransformed values from a log (LSWR × 10) transformation. Means followed by different letters are different using LSD (α = 0.05) on transformed values.
‡ L = 100% leaves.

This concurs with previous reports in which alfalfa subjected to drought had increased leafiness, reduced ADF (Vough and Marten, 1971), and increased IVDDM in whole herbage (Vough and Marten, 1971; Sheaffer et al., 1986; Halim et al., 1989) as well as increased IVDDM of both the leaf and stem fractions (Snaydon, 1972). The lack of a consistent response of legume CP to drought in our study was not surprising considering the lack of consistency reported in the literature. Some investigators have reported increased CP in droughted alfalfa (Gifford and Jensen, 1967; Walgenbach et al., 1981) while others have reported no effect of drought on alfalfa CP (Vough and Marten, 1971; Carter and Sheaffer, 1983; Halim et al., 1989).

Herbage fiber

Species differed in extent of reduction of ADF, NDF, and ADL concentrations with drought. Averaged over harvests, droughted alfalfa and red clover had 25% less NDF than their controls while birdsfoot trefoil and cicer milkvetch had 35% less. Average ADL reductions in total herbage were 5, 20, 25, and 40% in droughted compared to control treatments of red clover, alfalfa, cicer milkvetch, and birdsfoot trefoil, respectively.

Droughted alfalfa herbage had greater ADF, NDF, and ADL concentrations than the other legumes (Tables 7 and 8). Red clover had higher ADF and NDF concentrations than birdsfoot trefoil and cicer milkvetch which were similar. Among the alternative legumes, cicer milkvetch, which was consistently the least mature legume, had the lowest ADL concentration. The relatively smaller responses of alfalfa total herbage fiber and ADL concentrations to drought compared to birdsfoot trefoil and cicer milkvetch were likely due to the greater effect of drought on LSWR of the latter two species compared to alfalfa (Table 6). While the LSWR of red clover also was increased considerably by drought, fiber and lignin concentrations of the total herbage were not greatly affected possibly because of the stem-like character of red clover petioles which constituted a considerable portion of the leaf fraction.

Leaves and stems of individual species had variable responses to drought. Alfalfa and red clover leaf and stem fiber and ADL concentrations were frequently less affected by drought than those of birdsfoot trefoil

Table 7. Acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP), and acid detergent lignin (ADL; ash removed) concentrations in leaves, stems, and total herbage of droughted (DRT) and control (CTL) perennial forage legumes on 2 June 1988.

Species	Water Regime	ADF			NDF			CP			ADL		
		Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total
		g kg^{-1} DM											
Alfalfa	DRT	213	446	330	266	543	405	250	141	195	43	87	65
	CTL	211	496	367	273	602	453	275	126	193	42	92	69
Birdsfoot trefoil	DRT	132	413	249	165	500	305	293	148	232	31	91	56
	CTL	164	507	350	216	610	429	308	124	209	43	101	75
Cicer milkvetch	DRT	191	387	251	205	480	290	247	143	215	34	65	44
	CTL	216	486	324	232	582	372	291	132	227	40	68	51
Red clover	DRT	254	375	285	333	466	367	232	137	207	39	56	43
	CTL	257	428	319	325	524	398	256	117	205	40	59	47
LSD (0.05)†		16	21	17	18	32	22	18	12	13	3	8	4

† For comparison of two species means within or across water regimes.

Table 8. Acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP), and acid detergent lignin (ADL; ash removed) concentrations in leaves, stems, and total herbage of droughted (DRT) and control (CTL) perennial forage legumes on 6 July 1988.

Species	Water Regime	ADF			NDF			CP			ADL		
		Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total
		g kg^{-1} DM											
Alfalfa	DRT	152	369	225	212	461	297	307	154	255	29	82	47
	CTL	190	472	319	258	582	407	277	132	211	32	98	63
Birdsfoot trefoil	DRT	112	350	167	140	446	210	305	139	267	21	91	37
	CTL	149	500	298	199	600	369	316	135	239	39	116	71
Cicer milkvetch	DRT	133	296	148	160	385	181	284	149	271	26	57	29
	CTL	198	440	259	214	519	290	299	148	261	38	60	43
Red clover	DRT	195	—	195	257	—	257	283	—	283	38	—	38
	CTL	272	402	297	317	483	349	281	136	254	36	45	38
LSD (0.05)†		20	38	36	16	43	35	17	13	19	5	10	7

† For comparison of two species means within or across water regimes.

Table 9. Lignin concentrations in the NDF fraction of leaves and stems of droughted (DRT) and control (CTL) perennial legumes on 2 June and 6 July 1988.

Species	Water Regime	2 June		6 July	
		Leaf	Stem	Leaf	Stem
		g kg^{-1} NDF			
Alfalfa	DRT	160	163	137	179
	CTL	153	154	126	168
Birdsfoot trefoil	DRT	183	184	147	203
	CTL	166	199	196	193
Cicer milkvetch	DRT	137	167	163	147
	CTL	117	171	176	116
Red clover	DRT	121	116	148	—
	CTL	114	123	115	93
LSD (0.05)†		11	NS	21	14

† For comparison of two species means within or across water regimes; NS indicates that water treatment had no effect.

and cicer milkvetch. Birdsfoot trefoil leaf and stem ADL concentrations were both consistently reduced by drought.

Droughted birdsfoot trefoil leaves were generally lowest in fiber and ADL concentration, while red clover leaves were among the highest. Cicer milkvetch stems had the lowest fiber and ADL concentrations, while alfalfa stems were generally among the highest in fiber. Alfalfa and birdsfoot trefoil stems were highest in ADL.

Herbage ADL was also expressed on an NDF basis (NDF-lignin) to determine if fiber quality was affected by drought (Table 9). The response of NDF-lignin concentration to drought was inconsistent. Alfalfa NDF-lignin in leaves and stems was unaffected by drought. This concurs with previous reports (Albrecht et al., 1987; Halim et al., 1989). Drought resulted in decreased NDF-lignin in leaves of birdsfoot trefoil at two harvest dates (data from one date not shown). Stem NDF-lignin responses were inconsistent in all species. Under drought, birdsfoot trefoil leaf NDF was among the highest in lignin concentration. Red clover stems tended to be lowest in NDF-lignin while birdsfoot trefoil stems were among the highest.

Our results indicate that while fiber and ADL concentrations in herbage dry matter of forage legumes were reduced by drought, quality of the fiber fraction was not greatly affected by drought. Therefore, enhanced quality of droughted legumes was due to greater LSWR and lower fiber concentrations in leaves and stems and not to changes in composition of the fiber fraction.

Crude Protein

The alternative legumes frequently exceeded alfalfa in whole herbage CP concentration when subjected to drought (Tables 7 and 8). The lack of response of cicer milkvetch CP concentration to drought was likely due to a decline in leaf CP due to drought, while stem CP concentration remained unchanged. In contrast, the responses of leaf CP of alfalfa, birdsfoot trefoil, and red clover to drought were inconsistent. Drought tended to increase stem CP of all legumes, but this response was not consistent across all growth periods. Halim et al. (1989) reported a positive association of leaf CP and a negative association of stem CP with increasing irrigation level in alfalfa. Because of the contrasting response between leaves and stems, total herbage CP was not affected by drought in their study. Crude protein responses in whole herbage of droughted legumes in our study were related mainly to changes in stem CP (r = 0.74) and less to LSWR (r = 0.56).

Stand Persistence

Stands of all legumes established in 1987 were favorable (>90% ground cover) at the initiation of moisture treatments in 1988 and in the spring of 1989 except for the red clover control treatment which lost 44% of its stand by the spring of 1989. The 1989–1990 winter was severe with periods of very cold temperatures and no snow cover. This resulted in the death of all birdsfoot trefoil and red clover in both water regimes. Previously droughted alfalfa and cicer milkvetch had about 30% of their stands remaining in May 1990, while their irrigated controls had only 5% remaining. This concurs with the finding of Sheaffer et al. (1986) who reported that after 2 yr of irrigation, alfalfa stand loss was greatest at high levels of irrigation. Well-watered legumes may utilize more photoassimilate for herbage growth and less for carbohydrate storage in roots than droughted legumes and thereby could be more susceptible to winter injury (Hall et al., 1988).

In this study, we used harvest management and soil fertility regimes which were ideal for the herbage production and persistence of alfalfa, although these conditions were not necessarily unfavorable to the other legumes. Alfalfa production and persistence may have been changed relative to the other legumes had harvest management and soil fertility regimes been altered.

SUMMARY

With a harvest management commonly utilized in the North Central USA, drought reduced herbage yield, delayed maturity, increased leafiness, and enhanced herbage quality of alfalfa, birdsfoot trefoil, red clover, and cicer milkvetch. Alfalfa produced more herbage during drought than birdsfoot trefoil, cicer milkvetch, and red clover. Alfalfa herbage yield, LSWR, and herbage quality were often less affected by drought than were the alternative legumes. However, alternative legumes had superior forage quality compared to alfalfa under drought, with birdsfoot trefoil and cicer milkvetch producing the highest quality forage. Nevertheless, because of its superior yield under drought, alfalfa would produce more nutrients per hectare than the alternative legumes. In addition, alfalfa persistence when droughted was as good as cicer milkvetch, and superior to that of birdsfoot trefoil and red clover.

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