Leaf and Stem Properties of Alfalfa Entries

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ABSTRACT

Alfalfa (*Medicago sativa* L.) has been considered as a biofuel feedstock. A system has been proposed to produce electricity from the stems and utilize the leaves as a livestock feed. We determined the effects of harvest regimes on yield and quality of leaf, stem, and total herbage of six alfalfa entries. We applied three harvest regimes involving three harvests per year at bud stage or early flower, or two harvests per year at late flower. An early flower harvest regime had the highest leaf yield (average of 5.6, 4.5, and 4.5 Mg ha^{-1} for the early flower, late flower, and midbud regimes, respectively), and the late flower harvest regime had the highest stem yield (average of 5.8, 5.3, and 3.9 Mg ha^{-1} for the late flower, early flower, and midbud regimes, respectively). Leaf concentration decreased with increased herbage maturity (average of 540, 517, and 458 g kg^{-1} for the midbud, early flower, and late flower regimes, respectively) and was associated with total herbage crude protein (CP) (r = 0.65, $P < 0.05$) and acid-detergent fiber (ADF) and neutral-detergent fiber (NDF) ($r = -0.76$, $P < 0.05$). Harvest regime did not affect total seasonal herbage yield or stand persistence. Alfalfa entries differed in herbage quality, leaf concentration, and leaf yield, but did not consistently differ in total herbage or stem yield. Herbage yield and quality differences among entries were similar for all harvest regimes. Producers can affect stem and leaf yields by selection of harvest regime.

Public concern about the environmental impact and the sustainability of our current coal- and nuclear-based electricity production system has prompted the study of renewable biofuels for electricity production (Easterly and Burnham, 1996). The primary biofuels that have been investigated are switchgrass (*Panicum virgatum* L.) and hybrid poplar (*Populus* spp.) (Downing et al., 1996; Graham et al., 1996). Alfalfa is the primary biofuel source in the Minnesota Agri-Power (MAP) project proposed by the Minnesota Valley Alfalfa Producers (Wilbur et al., 1998). Alfalfa is a widely grown traditional crop that fits well into a typical crop rotation. It can be harvested for biomass in the year of planting and provides N to the soil for use by subsequent cereal crops in rotation. For the proposed MAP project, alfalfa hay will be fractionated into leaf and stem fractions. The leaves will be used as a high protein feed supplement for livestock, and stems for electricity generation. To produce electricity, stems will be gasified under high pressure and high temperature to produce a fuel gas that is combusted in a turbine.

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In the North Central region, producers typically initiate harvesting when alfalfa maturity reaches bud to early flowering. This often results in three or four harvests per season. Harvest maturity is determined by producer need to optimize herbage yield, nutritive value, or nutrient yield. Highest herbage nutritive value and intake potential usually occur with preflowering alfalfa with the highest yields of nutrients at early flowering (Sheaffer et al., 1988). Herbage harvested at full bloom is expected to have a higher stem proportion than less mature herbage (Fick and Holthausen, 1975; Kilcher and Heinrichs, 1974). A biofuel production system that adds value to stem components of alfalfa may favor a shift to harvesting at more mature stages with fewer harvests per season.

Recommended harvest schedules for modern alfalfa cultivars in a biofuel system are unknown because the relative value of leaf and stem components is expected to vary with energy and livestock feed prices. Compared with the currently used three- or four-cut schedules, a two-cut schedule with alfalfa harvested at full bloom could potentially increase stand persistence, reduce the seasonal cost of harvest, provide for more flexibility in seasonal harvest scheduling, and provide greater habitat for nesting wildlife. However, previous work showed that seasonal yield of herbage, CP, and total digestible nutrients in Wisconsin from a three-cut schedule applied to 'Vernal' alfalfa were 20, 46, and 31% higher, respectively, than from a two-cut schedule (Smith, 1968). Newer disease-resistant cultivars have not been evaluated in a two-cut harvest regime.

Data on quality changes of leaves and stems of modern alfalfa cultivars subject to varying harvest regimes will be needed for an alfalfa biofuel system in which both leaves and stems are processed into value-added products. Leaf NDF concentration and digestibility typically decline slowly with increasing maturity, while stem NDF and ADF concentration increase (Fick and Onstad, 1988). Leaf CP concentration declines slightly with maturity, but less than stem CP concentration does.

Our objective was to determine the effects of harvest regimes with varying maturity on yield and quality of total herbage, stems, and leaves from modern alfalfa entries. We also evaluated 'ORCA-WTS', an experimental alfalfa selected for woody, tough stems (Lamb et al., 1997). These traits may be useful in a biomass production system.

MATERIALS AND METHODS

Plot Establishment

The field plot design was a randomized complete block in a split-plot arrangement with two or three harvest regimes as

Abbreviations: ADF, acid-detergent fiber; CP, crude protein; MAP, Minnesota Agri-Power; NDF, neutral-detergent fiber; NIRS, near infrared reflectance spectroscopy.

Table 1. Mean air temperature and cumulative precipitation at Minnesota field research sites from 1996 to 1998.

Site	Year	Temperature† High	Temperature† Low	Precipitation May–Sept.	Precipitation Total/year
		°C		mm	
Lamberton	1996	23.6	10.7	574	889
	1997	24.0	10.0	450	607
	1998	25.5	12.8	353	655
Morris	1996	22.0	13.1	338	633
	1997	22.3	11.5	367	630
	1998	24.5	12.7	432	716
Rosemount	1996	23.0	11.3	369	843
	1997	22.9	11.6	642	856
	1998	24.9	13.3	645	1003

† Mean of monthly high and low air temperatures from May to September.

whole plots and six alfalfa entries as subplots. There were four replicates at each of three locations. Two harvest regimes were used at Lamberton (44°15′ N, 95°19′ W) and Morris (45°35′ N, 95°53′ W), and three harvest regimes were used at Rosemount (44°53′ N, 93°13′ W). Six alfalfa cultivars (MP2000, 5444, 5262, and WL 252 HQ, and the experimental germplasms ABI 9239 and ORCA-WTS) were planted at Rosemount, Lamberton, and Morris, MN, on 15 May 1995. The soil at Rosemount was a Tallula silt loam (coarse-silty, mixed, mesic Typic Hapludoll) with a pH of 7.0, P greater than 60 kg ha^{-1}, and K greater than 400 kg ha^{-1}. At Lamberton, the soil was a Normania loam (fine-loamy, mixed, mesic Aquic Hapludoll) with a pH of 6.1, P greater than 48 kg ha^{-1}, and K greater than 390 kg ha^{-1}. The Morris soil was a McIntosh silt loam (fine-silty, frigid Aeric Calciaquoll) with a pH of 7.8, P greater than 45 kg ha^{-1}, and K greater than 450 kg ha^{-1}. Growing season temperature and precipitation information for each location is shown in Table 1. Average number of days between the last occurrence of −2.2°C in the spring and the first occurrence of −2.2°C in the fall is 185, 163, and 161 d for Rosemount, Lamberton, and Morris, respectively.

Plots were 1.9 by 6.2 m. A seeding rate of 15 kg ha^{-1} of pure live seed resulted in stand densities for all plots greater than 270 plants m^{-2} and greater than 98% ground cover for all plots in the fall of 1995. Weeds were controlled using a preplant incorporation of 0.5 kg ha^{-1} of trifluralin (α,α,α-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-1-*p*-toluidine). Plots were sprayed as needed with permethrin [(3-phenoxy-phenylmethyl) ± *cis,trans*-3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate] for potato leafhopper [*Empoasca fabae* (Harris)] control.

Herbage Yield, Herbage Sampling, and Stand Estimation

Plots were harvested in the first, second, and third production years (1996, 1997, and 1998) when alfalfa reached midbud (1–65% of stems having one or more buds); early flower (1–65% of stems having one or more flowers); or late flower (66–100% of stems having one or more flowers). The midbud harvest regime was used only at Rosemount. Plots in the midbud and early flower harvest regimes were harvested three times per season; plots in the late flower harvest regime were harvested twice per season. To reduce the risk of winter injury, no harvests were taken after 1 September. Average harvest dates for each location are shown in Table 2. ORCA-WTS was not harvested at Lamberton due to winterkill following the seeding year.

Herbage yields were determined each year by harvesting a 1-by-5-m strip of forage to a 2-cm height from the center of each plot. At harvest, two random 1000-g samples of the standing forage were taken from each plot and dried for 72 h at 60°C. Dry matter percentage was determined on these samples and yields were adjusted to a dry weight basis. In 1996 and 1997, one of the two dried samples was manually separated into leaf and stem fractions. The leaf, stem, and the remaining total herbage samples were ground through a 1-mm screen in preparation for forage quality analysis.

Table 2. Average harvest dates for midbud, early flower, and late flower harvest regimes.

Location/ harvest regime	Harvest 1	Harvest 2	Harvest 3
Lamberton			
Early flower	7 June	9 July	22 Aug.
Late flower	24 June	16 Aug.	
Morris			
Early flower	10 June	17 July	24 Aug.
Late flower	21 June	7 Aug.	
Rosemount			
Midbud	3 June	8 July	10 Aug.
Early flower	15 June	18 July	23 Aug.
Late flower	1 July	16 Aug.	

Stand survival (in terms of percentage ground cover) was visually estimated in early May of each year with final stands and evaluated in May 1999.

Forage Quality Analysis

Quality of leaf, stem, and total herbage samples was analyzed in 1996 and 1997. Crude protein, ADF, and NDF were determined via near infrared reflectance spectroscopy (NIRS) analysis (model 6500, NIRSystems, Silver Springs, MD)[1] using NIRS equations developed in Minnesota. Equations for NIRS were developed using the software program Calibrate (NIRS 3 version 4.0, Infrasoft International, Port Matilda, PA) with the modified partial least squares regression option (Shenk and Westerhaus, 1991a and 1991b). Random subsets of 10 samples were chosen from each of the leaf, stem, and total herbage samples; subjected to conventional chemical analysis for CP (Kjeldahl N × 6.25), ADF, and NDF (Goering and Van Soest, 1970); and used as monitoring sets. Predicted values for CP, ADF, and NDF were adjusted for bias based on conventional analysis results from the monitoring sets. Statistics for the prediction equations and monitoring sets are shown in Table 3.

Statistical Analysis

Yield, leaf concentration, and CP, ADF, and NDF data were subjected to analyses of variance via the general linear models (GLM) procedure of SAS (SAS Inst., 1996). Whole-season yield, whole-season weighted averages for herbage quality, and stand survival percentages were analyzed as a split-plot design (Gomez and Gomez, 1984) with harvest regimes as whole plots and alfalfa entries as subplots. Within-season yield and herbage quality were analyzed as a strip-plot design with entries and harvests as strips. Analyses of variance were done first within locations and years. Bartlett's test (Gomez and Gomez, 1984) revealed nonhomogeneity of error variances among the six location × year environments; the nonhomogeneity arose from the Rosemount location. Years within locations were homogeneous with few exceptions; therefore, for each location we conducted combined analyses

[1] Mention of a proprietary or USDA product does not constitute a recommendation or warranty of the product by the University of Minnesota and does not imply approval to the exclusion of other suitable products.

Table 3. Calibration statistics from near infrared reflectance spectroscopy analysis of forage quality.

	Crude protein		Acid-detergent fiber		Neutral-detergent fiber	
	SE†	R^2	SE	R^2	SE	R^2
	g kg^{-1}		g kg^{-1}		g kg^{-1}	
Prediction equations						
Leaf and stem	3.8	1.00	8.5	1.00	10.1	1.00
Total herbage	5.9	0.96	8.1	0.98	09.8	0.98
Monitoring sets						
Leaf	5.9	0.94	8.2	0.83	06.0	0.96
Stem	3.9	0.98	7.8	0.95	06.2	0.89
Total herbage	9.6	0.96	6.2	0.95	07.7	0.96

† SE, standard error of calibration (SEC) for the prediction equations; standard error of prediction (SEP) for the monitoring sets.

Table 4. Whole-season leaf, stem, and total herbage yields for the midbud, early flower, and late flower harvest regimes.†

	Lamberton			Morris			Rosemount		
Harvest regime	Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total
	Mg ha^{-1}								
Midbud							4.5	3.9	8.4
Early flower	5.5	5.1	10.5	5.5	4.7	10.2	5.7	6.2	11.8
Late flower	4.6	5.9	10.5	4.9	5.2	10.1	4.2	6.4	10.6
$LSD_{0.05}$‡	0.4	0.8	NS	0.4	0.3	NS	0.2	0.5	0.6

† Values are averages for the years 1996 and 1997 and for six alfalfa entries.
‡ Least significant difference (α = 0.05) for comparing harvest regimes within a location and plant fraction. NS, not significant.

of variance across the years 1996 and 1997 for whole-season and within-season yield and CP, ADF, and NDF concentrations. The third production year, 1998, was analyzed separately using the same models. Residuals from the split-plot and strip-plot analyses were subjected to tests of normality in the UNIVARIATE procedure of SAS and were plotted against predicted values to verify that there were no serious departures from normality in any of the data sets. Pearson's correlation coefficients were calculated for each alfalfa entry via the CORR procedure of SAS for the relationships between leaf concentration and CP, ADF, NDF, and yield of the leaf, stem, and total herbage plant fractions.

RESULTS AND DISCUSSION

Leaf, Stem, and Total Herbage Yield in First and Second Production Years

Harvest regime effects were consistent across years and alfalfa entries at all locations (i.e., no significant harvest regime × entry interaction or harvest regime × entry × year interaction). The early flower harvest regime produced the largest whole-season leaf yield at all locations (Table 4). Whole-season stem yields were larger for the late flower than the early flower harvest regime at Lamberton and Morris, but stem yields for the late flower and early flower regimes were similar at Rosemount. Differences in leaf and stem yield due to harvest regimes were associated with leaf concentration of the forage. At all locations, leaf concentration decreased as alfalfa maturity at harvest increased (Table 5). Alfalfa subject to the midbud regime at Rosemount had a season average leaf concentration of 540 g kg^{-1}. Averaged across locations, the early flower and late flower harvest regimes had season-average leaf concentrations of 520 and 460 g kg^{-1}, respectively. Similar declines in leaf concentration with advancing maturity were reported by Fick and Holthausen (1975) and by Kilcher and Heinrichs (1974).

Total herbage yields for the early flower and late flower harvest regimes were similar at Lamberton and Morris (Table 4). At Rosemount, total herbage yield for the early flower regime was 40% more than for the midbud regime and 10% more than for the late flower regime. The lower yield from the midbud and late flower regimes at Rosemount agrees with work by Smith et al. (1966), who reported that cutting prior to first flower reduced yields 16 to 47%; and by Smith (1968), who found lower yields from cutting twice per season at full flower than from cutting three or four times per season at first flower. Our results show that harvesting at late flower had the consistent disadvantage of low leaf production but had the advantage of similar herbage yield and sometimes greater stem yield with fewer harvests than the first flower harvest regime.

Of the six alfalfa entries included in this study, WL 252 HQ consistently was among the entries with the

Table 5. Leaf concentrations for three harvest regimes and six alfalfa entries at Lamberton, Morris, and Rosemount, MN.

	Leaf concentration		
Variable	Lamberton	Morris	Rosemount
	g kg^{-1} dry matter		
Harvest regime†			
Midbud			540
Early flower	520	551	481
Late flower	481	492	401
$LSD_{0.05}$‡	20	21	10
Entry§			
WL 252 HQ	500	531	487
MP2000	494	529	484
ABI 9239	479	517	477
5444	476	523	466
5262	474	498	456
ORCA-WTS¶	–	502	468
$LSD_{0.05}$	20	16	15

† Values are averages for 1996 and 1997 and for six alfalfa entries.
‡ Least significant difference (α = 0.05) for comparing entries.
§ Values are averages for two years (1996 and 1997) and two harvest regimes (early flower and late flower).
¶ Winter-killed at Lamberton.

Table 6. Whole-season leaf, stem, and total herbage yields for alfalfa entries at Lamberton, Morris, and Rosemount, MN.†

	Leaf			Stem			Total Herbage		
Entry	Lamberton	Morris	Rosemount	Lamberton	Morris	Rosemount	Lamberton	Morris	Rosemount
	Mg ha^{-1}								
WL 252 HQ	5.3	5.7	5.0	5.3	5.1	5.4	10.7	10.8	10.4
MP2000	5.1	5.2	4.9	5.3	4.7	5.3	10.4	9.9	10.2
ABI 9239	5.2	4.9	4.9	5.7	4.6	5.5	10.9	9.5	10.4
5444	4.6	5.3	4.8	5.3	4.8	5.6	9.9	10.1	10.4
5262	5.0	5.1	4.6	5.7	5.2	5.6	10.7	10.2	10.2
ORCA-WTS‡	–	5.1	4.6	–	5.1	5.4	–	10.3	10.1
LSD$_{0.05}$§	0.3	0.5	0.2	NS	NS	NS	NS	NS	NS

† Values are averages for harvest regimes and for 1996 and 1997.
‡ ORCA-WTS was winter-killed at Lamberton.
§ Least significant difference ($\alpha = 0.05$) for comparing entries. NS, not significant.

highest leaf concentration (Table 5) and the highest leaf yield (Table 6). ORCA-WTS had lower leaf concentration and leaf yield than WL 252 HQ at Morris and Rosemount. Entries did not differ for whole-season stem yield or total herbage yield at any location. These results suggest that selection for high forage quality was associated with increased leafiness of WL 252 HQ. Similar responses of increased leaf concentration following breeding for improved quality were reported by Kephart et al. (1990) and Shenk and Elliott (1971). The lower leaf concentration of ORCA-WTS may be related to its selection from European germplasm that is noted for its production of large, lodging-resistant stems (Lamb et al., 1997). Leaf concentration was negatively correlated with total herbage yield ($r_{\text{average}} = -0.44$; $P \leq 0.05$) for four of six alfalfa entries; the correlation was not significant for WL 252 HQ and ORCA-WTS.

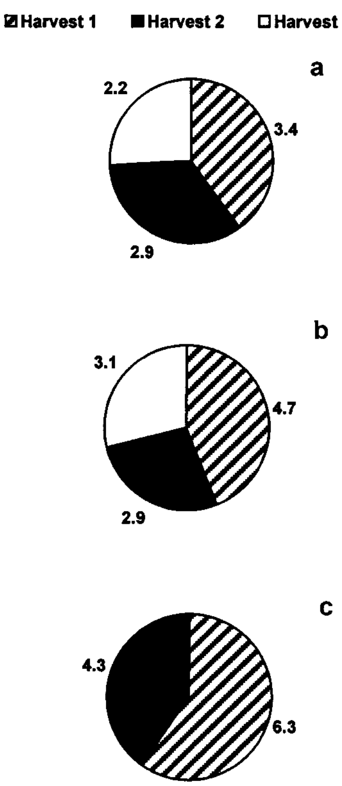

Fig. 1. Distribution of total herbage dry matter yield (Mg ha^{-1}) for the midbud, early flower, and late flower harvest regimes. (*a*) First, second, and third harvest of the midbud harvest regime. Values are averages for 1996 and 1997 for Rosemount. (*b*) First, second, and third harvests of the early flower harvest regime. Values are averages for 1996 and 1997 for Lamberton, Morris, and Rosemount. (*c*) First and second harvests of the late flower harvest regime. Values are averages for 1996 and 1997 for Lamberton, Morris, and Rosemount.

The first harvest consistently gave the highest yield of leaf, stem, and total herbage for all locations, years, and harvest regimes. The first harvest of the midbud regime produced about 40% of the whole-season total herbage yield (Fig. 1a). The early flower regime produced 44% of its whole-season yield in the first harvest (Fig. 1b). First harvest accounted for 60% of whole-season yield for the late flower regime (Fig. 1c). A shift to a late flower harvest regime will increase the producer's reliance on the first harvest of the season for production of forage.

Total Herbage Yields in Third Production Year

Total herbage yields in the third production year were uncharacteristically similar to those in the first and second production years. In Minnesota, forage yields typically decline in the third year as a result of stress due to winter injury; however, during these studies, winter conditions were relatively mild at all locations. At all locations, harvest regime and entry effects on total herbage yield were not significant. Average yields for Lamberton, Morris, and Rosemount were 11.6, 12.7, and 12.3 Mg ha^{-1}, respectively. The midbud harvest regime at Rosemount produced 49% of the whole-season yield in the first harvest of 1998, a change from the 40% of yield at first harvest in the first and second production years. For the early flower and late flower regimes, the percentage of whole-season yield at each harvest (data not shown) closely followed the percentages seen in the first and second production years.

Stand persistence as measured by ground cover was excellent (greater than 98% ground cover) for all plots except for ORCA-WTS at Lamberton at the start of harvest treatments in the spring of 1996. Stands declined each year thereafter (data not shown), and final ground cover was similar for all harvest regimes (Table 7). Location differences in ground cover may be related to the greater growing season and yearly precipitation at Rosemount than at Morris and Lamberton. We conclude that under the conditions of our experiment, the late flower harvest regime did not provide an advantage regarding

Table 7. Ground cover for harvest regimes and alfalfa entries in 1999 at Lamberton, Morris, and Rosemount, MN.

Variable	Lamberton	Morris	Rosemount
	% ground cover		
Harvest regime			
Midbud			44
Early flower	62	68	42
Late flower	63	63	45
$LSD_{0.05}$†	NS	NS	NS
Entry			
WL 252 HQ	62	65	46
MP2000	58	62	43
ABI 9239	76	70	48
5444	63	69	33
5262	67	73	61
ORCA-WTS	–‡	55	30
$LSD_{0.05}$	9	8	12

† Least significant difference (α = 0.05). NS, not significant.
‡ ORCA-WTS was winter-killed at Lamberton during the winter of 1995–1996.

stand persistence. Alfalfa entries were ranked similarly for stand survival at all locations, which suggests that there were inherent differences for persistence in these entries. ORCA-WTS consistently had the poorest stand survival, as low as 30% ground cover at Rosemount. ABI 9239 and 5262 were consistently among those entries with the highest final ground cover. The reduced persistence of ORCA-WTS is in part related to fall dormancy. ORCA-WTS is less fall dormant (rating of 5) and potentially less winter hardy than other entries with fall dormancy of 2 (5262, ABI 9239), 3 (MP2000), or 4 (5444, WL 252 HQ).

Leaf, Stem, and Total Herbage Forage Quality

At all locations, average seasonal CP concentration decreased and ADF and NDF concentration increased in leaf, stem, and total herbage as alfalfa maturity at harvest increased (Table 8). The quality differences between harvest regimes were consistent for all years and alfalfa entries (i.e., no significant entry × harvest regime × year interaction). Many previous studies have shown that the quality of alfalfa total herbage declines with increasing maturity; that is, CP concentration declines and fiber content increases as forage matures (Buxton et al., 1985; Fick and Onstad, 1988; Sanderson et al., 1989). This decline in the quality of total herbage has often been attributed to a decrease in leaf and increase in stem proportion with advancing maturity. Our results show that the inverse relationship between forage quality and maturity occurs for both alfalfa leaves and stems and exists regardless of changes in environment as represented by diverse locations and years. However, stems appear to have a greater detrimental impact on total herbage quality than leaves do, because stem concentration increases with maturity, while stems also increase in fiber concentration to a greater extent than leaves.

Alfalfa entries differed for whole-season leaf, stem, and total herbage CP concentration at all locations; for leaf ADF and NDF concentration at Morris; for stem ADF and NDF concentration at Morris and Rosemount; and for total herbage ADF and NDF at all locations (Table 9). At all locations, ORCA-WTS and 5444 had lower leaf, stem, and total herbage CP concentration than WL 252 HQ or ABI 9239. ORCA-WTS had the highest ADF and NDF concentration in leaves, stems, and total herbage at Morris and in stems and total herbage at Rosemount. For all locations, WL 252 HQ consistently had high CP and low ADF and NDF in all plant fractions, although at some locations ADF and NDF concentration of WL 252 HQ was similar to that of MP2000 and ABI 9239. Selection of ORCA-WTS for increased stem strength and improved lodging resistance (Lamb et al., 1997) may have resulted in the higher fiber concentration in stems of ORCA-WTS.

For all entries, increased leaf concentration was associated with increased leaf CP ($r_{average} = 0.51$, $P \leq 0.01$) as well as increased total herbage CP ($r_{average} = 0.65$, $P \leq 0.01$). Increased leaf concentration was associated with decreased leaf ADF and NDF ($r_{average} = -0.70$, $P \leq 0.01$), decreased stem ADF and NDF ($r_{average} = -0.38$, $P \leq 0.01$), and decreased total herbage ADF and NDF ($r_{average} = -0.76$, $P \leq 0.01$).

For the early flower and late flower harvest regimes, the first harvest of the season had the lowest total herbage CP and leaf concentration and highest total herbage

Table 8. Harvest regime means for crude protein (CP), acid-detergent fiber (ADF), and neutral-detergent fiber (NDF) in leaf, stem, and total herbage at Lamberton, Morris, and Rosemount, MN.†

Harvest regime	Leaf			Stem			Total herbage		
	CP	ADF	NDF	CP	ADF	NDF	CP	ADF	NDF
	$g\ kg^{-1}$ dry matter								
Lamberton									
Early flower	284	177	214	115	511	606	200	338	404
Late flower	269	190	228	96	560	657	170	399	473
$LSD_{0.05}$‡	8	3	2	3	4	6	3	9	10
Morris									
Early flower	304	163	194	113	520	614	210	337	395
Late flower	264	185	221	96	573	672	170	397	467
$LSD_{0.05}$	7	3	4	4	3	5	7	8	10
Rosemount									
Midbud	310	169	205	138	485	575	229	316	375
Early flower	301	173	209	114	531	624	206	359	427
Late flower	278	194	238	102	565	663	174	414	492
$LSD_{0.05}$	3	6	9	3	5	7	6	12	15

† Values are averaged for six alfalfa entries.
‡ Least significant difference (α = 0.05) for comparing harvest regime means within a location.

Table 9. Whole-season means for crude protein (CP), acid-detergent fiber (ADF), and neutral-detergent fiber (NDF) in leaf, stem, and total herbage of six alfalfa entries at Lamberton, Morris, and Rosemount, MN.†

	Leaf			Stem			Total herbage		
Entry	CP	ADF	NDF	CP	ADF	NDF	CP	ADF	NDF
	g kg^{-1} dry matter								
Lamberton									
WL 252 HQ	284	181	219	108	533	628	194	361	429
MP2000	276	186	223	106	535	631	185	370	440
ABI 9239	278	185	222	107	534	630	186	369	439
5444	267	185	223	102	537	635	178	370	442
5262	276	182	219	103	539	636	184	372	443
$LSD_{0.05}$‡	5	NS	NS	3	NS	NS	4	7	8
Morris									
WL 252 HQ	292	171	203	110	540	634	199	360	421
MP2000	285	174	207	103	545	644	193	360	424
ABI 9239	289	171	205	106	542	639	194	363	427
5444	270	177	211	102	545	642	183	365	431
5262	284	174	208	107	545	642	188	372	438
ORCA-WTS	282	176	210	101	560	658	185	379	446
$LSD_{0.05}$	5	4	5	4	7	8	4	8	9
Rosemount									
WL 252 HQ	305	178	217	123	525	618	212	359	425
MP2000	298	177	213	118	523	619	207	354	421
ABI 9239	300	179	218	120	524	618	209	357	425
5444	287	181	220	115	523	616	194	367	437
5262	298	179	219	119	526	620	200	370	440
ORCA-WTS	291	179	218	115	540	634	196	372	442
$LSD_{0.05}$	3	NS	NS	4	7	9	4	9	11

† Values are averages for 1996 and 1997 and for the early flower and late flower harvest regimes.
‡ Least significant difference ($\alpha = 0.05$) for comparing alfalfa entry means. NS, not significant.

ADF and NDF concentration, even though maturity at harvest was similar for all harvests within a regime during the season (Table 10). The lower quality at the first harvest was consistent for most entries, locations, and years (i.e., no significant interaction of harvest number with entry; significant interactions with location or year due to magnitude differences rather than rank changes). These results agree with findings of Griffin et al. (1994) and Sheaffer et al. (1998), who reported lower-quality forage in the first harvest of alfalfa than in subsequent harvests at the same maturity. In contrast to the early and late flower harvest regimes, the midbud harvest regime at Rosemount had higher total herbage CP concentration at the first harvest than at the second and third harvests, and total herbage ADF and NDF concentration was similar at all harvests. In contrast to total herbage, there was no consistent effect among location-years of within-season harvest number on leaf and stem CP, ADF, or NDF concentration in any harvest regime (data not shown). This suggests that increases in total herbage forage quality after first harvest for the early flower and late flower harvest regimes were primarily associated with changes in leaf concentration rather than changes in forage quality of the leaf and stem plant fractions.

Table 10. Within-season variation in total herbage crude protein (CP), acid-detergent fiber (ADF), neutral-detergent fiber (NDF) and leaf concentration in the midbud, early flower, and late flower harvest regimes.†

Harvest regime no.	CP	ADF	NDF	Leaf conc.
	g kg^{-1} dry matter			
Midbud‡				
1	239	315	373	500
2	226	321	381	540
3	222	311	370	590
$LSD_{0.05}$§	5	NS	NS	10
Early flower				
1	192	363	432	480
2	214	336	394	550
3	216	324	388	540
$LSD_{0.05}$	3	3	4	10
Late flower				
1	164	413	490	420
2	184	389	459	490
$LSD_{0.05}$	3	5	6	10

† Values are averaged for 1996 and 1997 and for the Lamberton, Morris, and Rosemount locations.
‡ The midbud harvest regime was used only at Rosemount.
§ Least significant difference ($\alpha = 0.05$) for comparing harvests. NS, not significant.

SUMMARY

Producers can consistently alter leaf yield and quality by increasing the maturity of alfalfa at harvest from early to late flower, but effects of alfalfa maturity at harvest on stem and total herbage yield was less consistent over locations. An early flower harvest regime had the highest leaf yield at all three locations, and the late flower harvest regime had the highest stem yield at two of three test locations, but total herbage yield was similar for the early and late flower harvest regimes at two of three locations. Early flower leaf, stem, and total herbage plant fractions consistently had higher forage quality (i.e., higher CP and lower ADF and NDF) compared with late flower leaf, stem, and total herbage. Harvest regime had no effect on final ground cover (stand persistence). The selection of a specific harvest regime for an alfalfa biofuel system where stems are gasified for electrical production will depend on the relative value of alfalfa leaves and stems and the location.

First harvest gave the highest yields of leaf, stem, and total herbage for all harvest regimes. First harvest

accounted for 60% of the season total yield for the late flower harvest regime. Total herbage forage quality and leaf concentration was lower at the first harvest than at later harvests for the early and late flower harvest regimes but not for the midbud harvest regime. Improved quality at later harvests was apparently related to increases in leaf concentration rather than to changes in quality of leaves and stems.

Alfalfa entries differed in whole-season leaf yield and leaf, stem, and total herbage CP at all locations, but differences in ADF and NDF were less consistent. Entries did not differ for whole-season stem or total herbage yield. WL 252 HQ, an entry selected for forage quality, was consistently among the entries with the highest forage quality in all plant fractions and highest leaf concentration, while ORCA-WTS, an entry selected for lodging resistance and stem strength, was consistently among those entries with the lowest herbage quality. ORCA-WTS also had the poorest stand survival of all entries at the three locations because it is less winter hardy. Herbage quality and yield differences among alfalfa entries were consistent for all harvest regimes.

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