

HARVEST FRACTIONATION OF ALFALFA

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ABSTRACT. Fractionation of alfalfa leaves and stems at harvest could allow ruminant rations to be tailored for optimum economic return or improve the viability of alfalfa as a biomass feedstock. Harvest fractionation was done by stripping the leaves from the stem at the time of harvest using a tined rotor. The stripped fraction consisted of about 90% leaf tissue, and 94% of the available leaf dry matter (DM) yield was removed in the stripped fraction. The standing fraction was either cut immediately after stripping or allowed to stand and regrow leaves for a period of 7 or 14 days. Leaf regrowth was evident in three to five days, but leaf yield was much less than that at initial stripping. The particle size of the stripped fraction was no different than chopped whole-plant alfalfa, so no further size reduction of the stripped fraction was needed before ensiling. The density of the stripped fraction was 11% greater than that of the chopped whole-plant in a drop hammer density test. The stripped fraction was successfully ensiled in mini-silos using ground corn grain as an amendment or formic acid as an additive. After cutting and windrowing, the drying rate of the standing fraction (mainly stems) was greater than that of whole-plant windrows of similar density. The standing fraction, consisting of 92% stems, dried to ensiling moisture typically within about 4 to 6 h after stripping and cutting but in as short as 1.5 h under very good drying conditions. Therefore, a single-day fractionated harvesting scheme is possible.

Keywords. Alfalfa, Biomass, Drying rate, Ensiling, Fractionation, Leaves, Lucerne.

The crude protein of alfalfa leaves is two to three times that of the stem, while the crude fiber and lignin of the stem is two to three times that of the leaves (Mowat et al., 1965; Albrecht et al., 1987). Peak dry matter (DM) yield of the leaves occurs early in the plant growth cycle and slowly decreases due to leaf senescence and abscission from the lower, shaded portions of the plant, while stem yield continues to increase with time (Albrecht et al., 1987). The digestibility of alfalfa stems decreases with maturity due to increased cell-wall and lignin content, while leaf digestibility changes little with maturity (Mowat et al., 1965; Albrecht et al., 1987).

Alfalfa fractionation has been used to take advantage of the variable value of the plant fractions. With dry fractionation, alfalfa is cut, allowed to field wilt, chopped or baled, and then dehydrated in an off-farm processing facility (Mowat and Wilton, 1984; Adapa et al., 2003). The leaf and stem fractions are then separated by mechanical sieving and air separation, with the former used as an animal protein and the latter

as fiber roughage for ruminants. Dry fractionation has several drawbacks, including weather-related losses during wilting, and high costs for equipment, fuel for dehydration, and transportation.

With wet fractionation, plant juices are expressed from freshly cut and macerated alfalfa. The juice fraction is about half the crop weight and is processed to obtain high-protein, low-fiber, value-added products. The dewatered fiber fraction is ensiled as a ruminant animal feed, or it can be used as a biomass feedstock (Koegel et al., 1998). Wet fractionation has several advantages over the dry system, principally lower field losses, greater weather independence, and greater potential utilization of the end products. However, wet fractionation has several drawbacks, including higher costs for equipment and operation, and for transport or disposal of the deproteinized juice.

A harvest fractionation system was developed that involved stripping of leaves from stems. The stripped leaves can be used as a high-protein feed preserved by direct ensiling or processed into value-added products. The stem fraction can serve as an on-farm roughage source or as biomass feedstock. The stem can also be left standing to regrow leaves before being harvested as an animal feed. Currence and Buchele (1967) reported that alfalfa leaves regrow from stripped stems within seven days. Harvest fractionation has the following advantages over either the dry or wet processes: (1) the high-value leaf fraction is removed at harvest, so yield is high and weather losses are low; (2) capital costs of fractionation equipment are low; (3) only the desired fractions need leave the farm, reducing transport costs; and (4) ruminant rations can be tailored for optimum economic return.

Breeding efforts are underway to develop biomass alfalfa varieties with reduced population density, delayed harvest, and fewer cuttings per growing season to maximize leaf and stem yield (Lamb et al., 2006). Harvest fractionation could be used to improve the viability of alfalfa as a biomass feedstock.

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With harvest fractionation, procedures are needed to directly ensile alfalfa leaves because it is not feasible to field wilt the leaves. Alfalfa leaves and stems are both about 75% to 80% moisture at harvest (Kohler and Chrisman, 1968). Direct ensiling at these moistures produces undesirable fermentation, poorly preserved forage, high DM losses, and low DM intake by the animal. Direct ensiling of forages is relatively common in Europe (Huber, 1980; Muck et al., 1999). Direct ensiling involves either adding a chemical such as formic acid to rapidly drop pH and restrict biochemical activity or adding amendments to increase silage DM (Pitt, 1990; Muck et al., 1999).

The objectives of this research were to investigate (1) the fractional yield of alfalfa stems and leaves using harvest fractionation, (2) the leaf regrowth tendencies of stems stripped of leaves, (3) the direct ensiling characteristics of the stripped (leaf) fraction, and (4) the drying rate of the standing (stem) fraction after stripping and cutting.

MATERIALS AND METHODS

STRIPPING MACHINE

Alfalfa harvest fractionation was accomplished using a modified stripping unit typically used for snap bean harvesting. The rotor utilized a multiplicity of 9 mm diameter radial tines to penetrate the crop canopy and strip the alfalfa leaves from the stem. The Pixall model VPCII 1500 bean head (Oxbo, 2005) was 4.6 m wide and was equipped with a stripping rotor with 16 rows of 50 tines placed in spiral patterns so that lateral tine spacing on the rotor was 25 mm. The rotor's overall diameter was 831 mm, with the tines radially protruding 187 mm from the drum. The rotor was operated with a tip speed to ground speed ratio of about 13:1. Higher speed ratios typically removed too much of the top of the alfalfa plant, while lower ratios resulted in poor leaf removal. The remaining stems were generally left erect and standing after stripping. Modifications to the crop unit included removing the aligning rotors and ground roller, and opening the front concave to improve crop flow into the stripping rotor.

FRACTIONAL YIELD AND LEAF REGROWTH

A randomized block experiment was conducted at the University of Wisconsin Arlington Agricultural Research Station (AARS) in July 2003 with second cutting alfalfa at about one-quarter flower maturity. The following treatments were used: stripped with regrowth periods of 0, 7, and 14 days; and a whole-plant control that was cut, wilted, and chopped. Each plot was 4.5 m wide × 80 m long. Each treatment was randomly assigned within each block, and four replicate blocks were used. Plots were stripped, and the mass of the stripped and standing fractions was determined by weighing the material harvested from each plot using a side-dumping forage wagon equipped with a weighing system. Cutting of the standing fraction was done using a disk mower-conditioner operated in the opposite direction of stripping.

Representative subsamples of stripped material were collected from the harvester container, while standing subsamples were hand-clipped from the stripped stems. Each of the stripped and standing fractions was further subdivided by hand into leaf and stem fractions. Petioles were categorized as belonging to the leaf fraction. Each of the four subfractions was oven dried at 103 °C for 24 h to determine DM content

(ASABE Standards, 2006). The dry mass of the four subsamples was used to back-calculate leaf and stem DM yield and concentration in the stripped and standing fractions, respectively. Additional subsamples of the four fractions were frozen for later analysis of typical nutrient constituents (crude protein, acid-detergent fiber, and neutral-detergent fiber) by the UW Soil and Plant Analysis Laboratory using standard wet laboratory techniques.

DRYING RATE OF STANDING FRACTION

Stripping of alfalfa leaves and simultaneously cutting the stems might produce a single-day alfalfa harvesting system, provided that the stems stripped of leaves can quickly dry to ensiling moisture. The modified bean harvester was not configured to cut the stems at stripping; therefore, a mower-conditioner was used immediately following stripping. Multiple tests were conducted using second and third cutting alfalfa in 2003 and first cutting in 2004. Crop maturity was roughly one-quarter flower in 2003 and one-quarter to one-half flower in 2004. A replicated block design with treatments randomly assigned was used to evaluate the drying rate of stems with approximately 90% of leaves removed, whole-crop windrowed using the same cutting width as the leaf stripper rotor, and whole-crop windrowed using 50% of the cutting width of the stripper rotor. The third treatment was included because it had approximately the same DM density in the windrow as the first treatment, where about 50% of the total DM was removed at stripping. All windrows were roughly 1.4 m wide. Leaf stripping and subsequent cutting and windrowing occurred in the morning. Two replicate samples were collected from each plot immediately after cutting and periodically throughout the next two to four days. Samples were hand-collected from across the full width and depth of the windrows, chopped, and mixed to homogenize. Three subsamples were then oven-dried at 103 °C for 24 h (ASABE Standards, 2006). Weather data measured hourly, including ambient temperature, solar insolation, relative humidity and wind velocity, were collected from the AARS weather station.

DIRECT ENSILING OF LEAVES

Four treatments were used: ground corn, wheat straw, formic acid, and stripped leaves alone. Ground corn and wheat straw were used as amendments to reduce the overall silage moisture. Ground corn was used because of its energy and starch content and high bulk density; in addition, it would serve as a valuable substrate to aid fermentation. Wheat straw was used because it had been suggested previously as an amendment for direct ensiling of potato vines (Muck et al., 1999). Formic acid was used as an additive to inhibit undesirable microbial action. It is commonly used to preserve directly ensiled grasses in northern Europe (Pitt, 1990).

Ground corn and wheat straw were added at a rate of 0.3 kg DM per kg of wet leaves to attain a target moisture of about 63% (w.b.). Formic acid (88% concentration) was added at the rate of 2.5 mL per kg wet leaves based on recommendation by Kung et al. (2003). Mixing of leaves and amendments or additives was done in a large industrial food mixer. All silage samples were stored in 5 L mini-silos (100 mm diameter × 640 mm height) constructed of PVC pipe with rubber end caps. Filling of the mini-silos was carried out by repeatedly adding a small amount of material, fol-

lowed by manual compaction by repeated blows. The mini-silo and its contents were weighed, the initial mass was recorded, and mini-silos were rejected if the wet matter density was not at least 500 kg WM m⁻³. Five replicate mini-silos were used for each treatment. Separate subsamples of the mixed silages were collected for determination of DM content by oven-drying at 103 °C for 24 h. The silos were opened after 123 days, the final weight was determined, and the contents were sampled for DM (60 °C, 72 h) and constituent analysis (wet laboratory techniques). Other subsamples were collected to determine pH, buffering capacity, water-soluble carbohydrates, non-protein nitrogen, lactic, acetic, and butyric acids, and ethanol by Dairyland Labs (Arcadia, Wisc.) using standard high-performance liquid chromatography (HPLC) methods.

SILAGE DENSITY

A dynamic compaction test was used to determine the density of three treatments: stripped leaves, stripped and chopped stems, and chopped whole-plant alfalfa. The latter two treatments were chopped in a laboratory-scale chopper at a theoretical length of cut (TLC) of 13 mm. A “drop hammer” apparatus was used to dynamically compact the material (Shinners et al., 1988). Samples were compacted in a 20 cm diameter PVC cylinder using 75 blows with a 10 kg hammer from a height of about 30 cm. Samples consisted of about 2.5 kg of wet forage that was placed into the container approximately one-third at a time by volume. Twenty-five blows were applied to the material, the procedure was repeated with the remaining material, and the final sample height was measured to determine the compacted volume and density. The material was removed, weighed, and allowed to relax for about 20 min before height measurements were again taken. Prior to compaction, replicate subsamples of the treatments were collected for moisture (103 °C, 24 h) and particle-size analysis using the procedures described in ASAE Standard S424.1 (ASAE Standards, 2003).

Differences between treatments in individual experiments were analyzed using analysis of variance, and statistical differences were determined using a least significant difference (LSD) test at the 95% confidence level.

RESULTS

FRACTIONAL YIELD AND LEAF REGROWTH

Harvest fractionation of alfalfa using a modified bean stripping rotor was quite successful. Leaf tissue made up almost 90% of the DM in the stripped fraction (table 1). It was observed that the majority of the stems in the stripped fraction were from the succulent top portion of the plant. When no regrowth was involved, stripping removed about 94% of the total leaf yield available (table 1). The stripping rotor was operated at a relatively aggressive peripheral to ground speed ratio (~13:1), such that 59% of the available DM was harvested in the stripped fraction (table 1). Less aggressive speed ratios were observed to leave more leaf tissue in the standing fraction, a technique that could be used to balance the harvested mass ratio and the nutritional composition of the standing fraction.

The stripped with no regrowth treatment had 28% greater yield than the control, with 38% more leaf mass and 17% more stem mass. After stripping, the standing fraction was immediately cut and windrowed at the same time as the control treatment. The stripped treatment dried quickly (figs. 1 through 4) and was chopped after a short wilting period, while the control remained in the field overnight. A 38 mm rainfall occurred that evening, which caused leaching losses and mechanical losses from raking, explaining the differences in yield. This yield difference emphasizes the major advantage of the harvest fractionation system, where the high-value leaves can be harvested with reduced risk.

Leaves were observed to regrow within three to five days after stripping, with the greatest leaf regrowth occurring in the 7 to 14 day period. It was observed that the size of all new leaves was much smaller than the original harvested leaves. After about 14 days, it was observed that leaf regrowth appeared to stall, and new growth from the crown was quite evident. Leaf regrowth was observed to be minimal, if at all, in the harvester wheel tracks, where new growth occurred only from the crown. Compared to the stripped and immediately cut treatment, leaf regrowth produced an overall increase of 17% and 24% in leaf DM yield and 12% and 47% greater stem DM yield for the 7 and 14 day regrowth treatments, respectively.

Table 1. Fractional DM yield of alfalfa leaves and stems after various leaf regrowth periods.

Leaf Regrowth Period	Leaf Strip Date	Stripped Fraction					Standing Fraction					Total			Fraction of Total DM as Leaves (%)				
		Dry Matter Yield (Mg DM ha ⁻¹)			Leaves as a Fraction of:		Dry Matter Yield (Mg DM ha ⁻¹)			Stems as a Fraction of:		Dry Matter Yield (Mg DM ha ⁻¹)							
		Leaf	Stem	Total	Stripped Fraction (%)	Total Leaf Mass (%)	Leaf	Stem	Total	Standing Fraction (%)	Total Stem Mass (%)	Leaf	Stem	Total					
Control ^[a]	--																		
0 days	14 July	1.86	0.22	2.08	89.5	94.3	0.11	1.32	1.43	92.1	85.7	1.97 b	1.32 a	2.75 a				52.0	
7 days	14 July	2.06	0.25	2.31	89.2														
	21 July	0.18	0.18	0.36	50.2	72.7	0.07	1.30	1.37	95.2	87.8	0.25	1.48	1.73				14.5	
	Total	2.24	0.43	2.67	84.0	97.1	0.07	1.30	1.37	95.2	75.3	2.31 c	1.73 b	4.04 c				57.2	
14 days	14 July	1.97	0.25	2.22	88.9														
	28 July	0.31	0.27	0.58	53.8	65.7	0.16	1.75	1.91	91.8	86.7	0.47	2.02	2.49				18.8	
	Total	2.28	0.52	2.80	81.4	93.6	0.16	1.75	1.91	91.8	77.0	2.44 c	2.27 c	4.71 d				51.8	
LSD ^[b] (P = 0.05)												0.16	0.20	0.34					

^[a] Control was whole-plant cut, wilted, and chopped.

^[b] Statistical analysis was conducted using analysis of variance. Averages within columns followed by different letters are significantly different at the 95% confidence level.

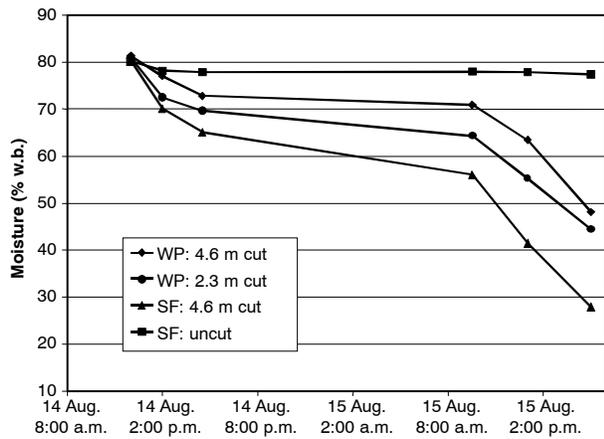


Figure 1. Drying rates of whole-plant (WP) and standing fraction stripped of leaves (SF) with cut widths of 2.3 or 4.6 m on 14 and 15 August 2003. Rainfall on 16 August halted the experiment.

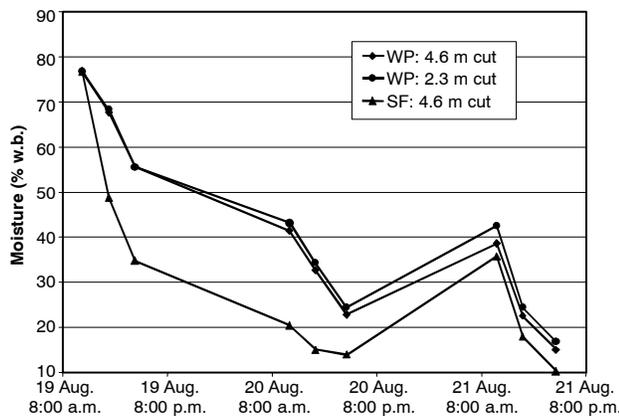


Figure 2. Drying rates of whole-plant (WP) and standing fraction stripped of leaves (SF) with cut widths of 2.3 or 4.6 m on 19 through 21 August 2003. Rainfall of 1 mm fell during the early morning of 21 August.

Previous research reported that crude protein content of the leaves was two to three times that of the stems, while the crude fiber and lignin content of the stem was two to three times that of the leaves (Mowat et al., 1965; Albrecht et al., 1987). Similar results were found with the stripped and standing fractions (table 2). Stripped material had roughly twice the protein and 40% of the fiber of the standing fraction.

DRYING RATE OF STANDING AND CUT FRACTION

Stems stripped of leaves but left standing lost about three percentage units of moisture during the first several hours after leaf removal, but maintained equilibrium moisture of about 77% (w.b.) (fig. 1). Moisture was lost from the standing plant because the stripping action resulted in damage to the top of the stem, which probably facilitated the egress of moisture. However, the data show that stripping damage would not facilitate drying to silage moisture without first cutting the stem from its root structure. The windrow density of the standing/cut and whole-plant/narrow windrow treatments was comparable, but the drying rate of the former treatment was greater than that of the latter, especially on the second test (fig. 2). The standing/cut windrows were observed to have a well formed structure that facilitated good air movement because the leaves were essentially all removed. The

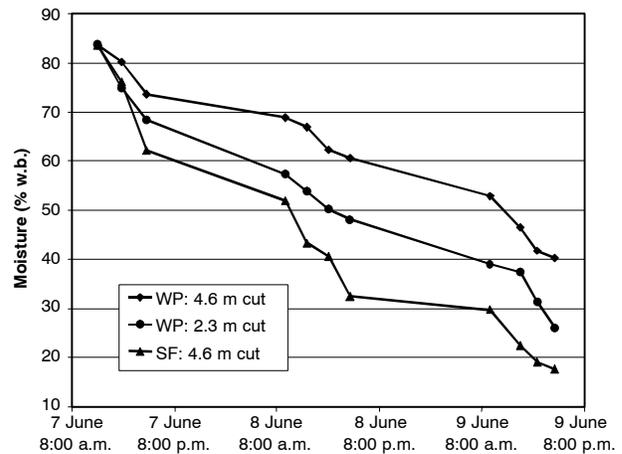


Figure 3. Drying rates of whole-plant (WP) and standing fraction stripped of leaves (SF) with cut widths of 2.3 or 4.6 m on 7 through 9 June 2004 using first cutting alfalfa.

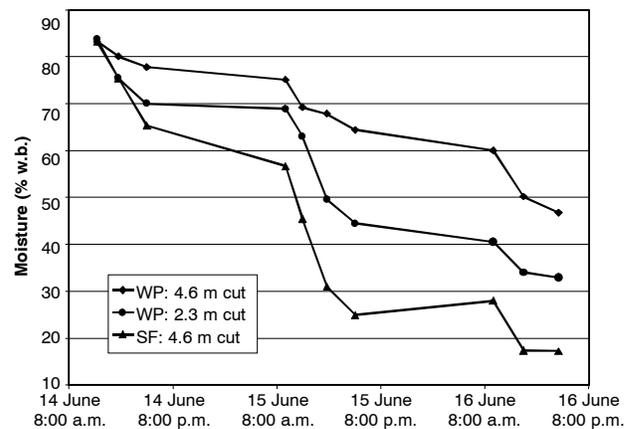


Figure 4. Drying rates of whole-plant (WP) and standing fraction stripped of leaves (SF) with cut widths of 2.3 or 4.6 m on 14 through 16 June 2004 using first cutting alfalfa.

high surface-to-volume ratio of the leaves tended to fill in the skeletal structure formed by the stems of the other windrows, and most likely resulted in slower drying rates. The weather on 14 August was typical of Wisconsin in mid-August (table 3). Lack of recent rainfall had made the soil moisture lower than typical. Given these conditions, the standing/cut treatment dried to acceptable silage moisture (~65% w.b.) by 4:30 p.m. after being stripped at noon. The drying weather on 19 August was excellent for Wisconsin in late August (table 3). With these conditions, the standing/cut treatment dried to 65% (w.b.) moisture in less than 1.5 h. The drying rate was so fast that the harvest window was very small,

Table 2. Constituents analysis for the standing and stripped fractions of second cutting alfalfa fractionated at one-quarter flower maturity.

	Constituent (% of DM)							
	CP	ADF	NDF	NDF _d ^[a]	NFC ^[b]	Fat	Ash	RFQ ^[c]
Stripped (leaf)	26.6	18.4	22.8	62.7	39.4	3.2	11.3	344
Standing (stems)	13.1	47.1	55.1	43.2	22.4	1.8	11.0	89

[a] NDF_d = neutral detergent digestible fiber.

[b] NFC = non-fiber carbohydrates.

[c] RFQ = relative forage quality.

Table 3. Average weather conditions at the Arlington (Wisconsin) Agricultural Research Station from 8:00 a.m. to 6:00 p.m. when the five drying tests were conducted.

	Date	Temp. (°C)	Solar Radiation (W m ⁻²)	Relative Humidity (%)	Wind Speed (m s ⁻¹)
Test 1	14 Aug. 03	28	450	62	2.4
	15 Aug. 03	29	637	62	3.6
Test 2	19 Aug. 03	28	607	46	4.7
	20 Aug. 03	30	572	60	5.5
	21 Aug. 03 ^[a]	30	635	51	5.2
Test 3	7 June 04	29	625	61	9.5
	8 June 04	28	516	66	6.8
	9 June 04	26	460	71	4.1
Test 4	14 June 04	25	627	60	4.5
	15 June 04	24	674	50	2.2
	16 June 04	25	452	70	2.7

^[a] Rainfall of 1 mm fell during the early morning of 21 August 2003.

which would create silage harvest challenges. Weather conditions for the third and fourth tests were typical for mid-June, and the standing/cut fraction dried to chopping moisture in roughly 6 h (figs. 3 and 4).

These results show that alfalfa stems with the majority of the leaves removed dried much faster than the whole-plant, even when windrow density was similar between treatments. It appears that a single-day alfalfa harvest system is possible in which the leaves could be stripped in the morning and the stems immediately cut, windrowed, and allowed to wilt. The drying rates produced here imply that the standing/cut fraction could then be chopped in the afternoon. In fact, drying rate may be so fast that tactics such as merging multiple windrows at cutting may be needed to retard the drying rate to produce an acceptable harvest window.

SILAGE DENSITY

The whole-plant and standing fraction were chopped at a TLC of 13 mm prior to compaction, while the stripped fraction was compacted without any size reduction. The particle size and long fraction were similar for all three treatments (table 4). Therefore, the stripped fraction could be directly stored without size reduction. The initial compacted density of the stripped fraction was significantly greater than the whole-plant or standing treatments (table 4). The relative lack of the rigid, cylindrical stems in the stripped fraction probably was a major reason why the stripped fraction had higher compacted density. Shinnars et al. (1988) reported that macerated alfalfa had greater compacted density than chopped alfalfa because the maceration process destroyed the stiff, tubular structure of the stem. There was concern that the removal of the leaves from the standing fraction would cause low density because the leaves would not be present to fill in the “skeletal” area between the stems; however, the density of the standing fraction was similar to that of the whole-plant.

DIRECT ENSILING OF LEAVES

At removal, the directly ensiled leaves without treatment had a disagreeable odor, were very dark in color, and effluent was evident. It was observed that the leaf/corn and leaf/acid treatments both had good color and smell, although there was effluent produced in the latter treatment. The leaf/straw treatment had a good color and there was no effluent, but there was

Table 4. Particle size and dry density of alfalfa stripped (leaf) and standing (stem) fractions after being subjected to dynamic compaction.

Treatment ^[a]	Moisture % w.b.	Particle Size		Dry Density	
		Mean (mm)	Long Fraction (%) ^[b]	Initial (kg m ⁻³)	Relaxed (kg m ⁻³)
Whole-plant	75.0 b	13.6	24.3	131 a	103 ab
Stripped (leaf)	75.5 b	13.2	23.1	146 b	110 b
Standing (stem)	71.3 a	14.7	28.9	134 a	98 a
LSD ^[c] (P = 0.05)	1.3	4.2	9.1	11	9

^[a] The whole-plant and standing treatments were chopped at 13 mm TLC. The stripped fraction was compacted as harvested.

^[b] Fraction of total sample residing on the top two screens of the particle-size separator (ASAE Standards, 2003).

^[c] Statistical analysis was conducted using analysis of variance. Averages within columns followed by different letters are significantly different at the 95% confidence level.

evidence of mold in some locations and the silage had a slight disagreeable odor.

Dry matter loss was significantly greater for the control and leaf/straw treatments compared to the leaf/corn and leaf/acid treatments (table 5). The former two treatments had a significantly higher pH values, lower levels of desirable lactic acid, and higher levels of undesirable butyric acid than the latter two treatments. Direct ensiling of alfalfa leaves without treatment produced unacceptable fermentation and preservation, as measured by DM loss, pH, and production of undesirable fermentation products. The leaf/straw mixture did not preserve well, as evidenced by high DM loss and high level of butyric acid. This latter result was most likely due to slow moisture equalization between the leaves and straw. It is likely that early in the fermentation process, the alfalfa leaves fermented similar to those of the control. The addition of ground corn reduced DM content and dropped the pH, preventing clostridia fermentation (low butyric acid). The sugar content of the grain also provided a valuable substrate for desirable fermentation microorganisms. Muck et al. (1999) reported that barley grain provided better preservation as an amendment for direct-harvested potato vines than alfalfa hay for exactly these reasons. The addition of dried ground corn increased the DM content of the mixture to a level where effluent production would not be expected (Pitt, 1990), and in fact no effluent was observed. Clostridial fermentation in direct-cut grasses is typically prevented by the application of formic acid at about 1% of DM (Leibensperger and Pitt, 1987, 1988). Application of formic acid is intended to rapidly decrease pH, reduce the amount of fermentation acid needed, and restrict protein breakdown during ensiling. The addition of formic acid at 2.5 mL per kg provided good preservation of direct-harvested alfalfa leaves with the numerically lowest DM loss of all treatments.

The use of straw as a silage amendment diluted the mixture CP and greatly increased the fiber and lignin contents, diluting the worth of this mixture as a high-value animal ration (table 5). Straw would not be considered an ideal leaf silage amendment due to poor preservation characteristics and low bulk density. Bulk density is important because high bulk density amendments will minimize added mixing and handling costs in a large-scale practical system. The use of ground corn grain as a silage amendment diluted the mixture CP, fiber, and lignin contents, producing a highly digestible and energy-rich ruminant ration ingredient. Corn grain would be considered an excellent amendment because not only was

Table 5. Dry matter loss and constituent analysis for four alfalfa leaf silages stored in mini-silos.

Treatment	Moisture (% w.b.)			Final Nutrient Composition (% of DM)						Fermentation Products (% of total DM)				
	Into Storage	Out of Storage	DM Loss (% of DM)	CP	ADF	NDF	Lignin	Ash	pH	Lactic Acid	Acetic Acid	Butyric Acid	Ethanol	Ammonia N ^[a]
Control	78.4 b	81.2 d	17.2 c	21.5 b	26.3 c	39.6 b	6.3 c	12.4 c	5.9 b	0.0 a	4.3 c	6.2 c	1.6 c	14.3 b
Leaf/straw	62.2 a	64.2 b	10.8 b	13.0 a	44.8 d	59.9 c	7.9 d	9.0 b	4.8 a	1.6 b	0.6 a	3.6 b	0.4 b	3.2 a
Leaf/corn	62.5 a	63.3 a	3.9 a	20.9 b	13.6 a	25.1 a	2.9 a	6.1 a	4.3 a	5.9 c	1.5 ab	0.0 a	0.6 b	2.9 a
Leaf/acid	78.5 b	78.2 c	1.6 a	25.4 c	22.7 b	36.1 b	4.8 b	9.5 b	4.3 a	5.5 c	1.8 b	0.0 a	0.0 a	2.3 a
LSD ^[b] (P = 0.05)	0.5	0.8	3.2	3.7	3.2	9.2	1.2	1.1	1.0	1.7	1.0	1.4	0.2	1.7

^[a] Ammonia N as a fraction of CP.

^[b] Statistical analysis was conducted using analysis of variance. Averages within columns followed by different letters are significantly different at the 95% confidence level.

preservation excellent but also the volume of product to achieve the desired moisture of the mixture would be reasonable.

CONCLUSIONS

A tined rotor successfully fractionated alfalfa at harvest by stripping the leaves from the stem. The stripped fraction consisted of about 90% leaves (by dry mass), and 94% of the total leaf DM yield was located in the stripped fraction. The standing fraction was 92% stem, and about 88% of the stem DM yield was located in the standing fraction.

Leaves were allowed to regrow on the standing fraction for 7 or 14 days. Leaf regrowth was evident in three to five days, with much more leaf regrowth occurring in the 7 to 14 day period. Leaf regrowth produced a 6% and 17% increase in the total leaf DM harvested for the 7 and 14 day regrowth periods, respectively.

The drying rate of the standing fraction after cutting and windrowing was greater than that of a windrow of whole-plant alfalfa of similar density. Stems typically dried to 65% (w.b.) moisture in 4 to 6 h, but in as short as 1.5 h under very good drying conditions. Therefore, a single-day harvesting system could be possible.

Stripped leaves were directly ensiled successfully in mini-silos using ground corn as an amendment (0.3 kg corn per kg wet leaves to attain a target moisture of 63% w.b.) or formic acid as an additive (2.5 mL acid per kg wet leaves). The particle size of the stripped fraction was similar to that of chopped whole-plant alfalfa, indicating that no further size reduction of the stripped fraction would be needed before ensiling. The density of the stripped fraction was 11% greater than the chopped whole-plant in a drop hammer test.

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