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A PRELIMINARY INVESTIGATION OF HARVEST-FRACTIONATION OF ALFALFA

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Abstract.. *Harvest fractionation of alfalfa involved stripping the leaves from the stem at the time of harvest using a mutli-tined rotor. The stripped fraction consisted of about 90% leaf tissue,e and 94% of the total leaf DM was removed in the stripped fraction. The standing fraction was either cut immediately after stripping or allowed to stand and re-grow leaves for a period of 7 or 14 days. Leaf re-growth was evident in 3-5 days, but leaf yield was much smaller than at initial stripping. The particle-size of the stripped fraction was no different than 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 density test. The stripped fraction was successfully ensiled in mini-silos using ground corn as an amendment or formic acid as an additive. The drying rate of the standing, cut and windrowed fraction was much greater than that of whole-plant windrows of similar density. The standing fraction consisting of about 92% stems dried to chopping moisture within about 4 to 6 hours after stripping. Therefore, a single-day fractionated harvesting scheme could be a reality.*

Keywords. Alfalfa, bio-mass, fractionation, leaves.

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ABSTRACT

Harvest fractionation of alfalfa involved stripping the leaves from the stem at the time of harvest using a mutli-tined rotor. The stripped fraction consisted of about 90% leaf tissue, and 94% of the total leaf DM was removed in the stripped fraction. The standing fraction was either cut immediately after stripping or allowed to stand and re-grow leaf for a period of 7 or 14 days. Leaves re-growth was evident in 3-5 days, but leaf yield was much smaller than at initial stripping. The particle-size of the stripped fraction was no different than 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 density test. The stripped fraction was successfully ensiled in mini-silos using ground corn as an amendment or formic acid as an additive. The drying rate of the standing, cut and windrowed fraction was much greater than that of whole-plant windrows of similar density. The standing fraction consisting of about 92% stems dried to chopping moisture within about 4 to 6 hours after stripping. Therefore, a single-day fractionated harvesting scheme could be a reality.

BACKGROUND

It is well known that the nutritive value of alfalfa leaves is superior to that of the stems. The crude protein content of the leaves is two to three times that of the stems while the crude fiber and lignin content of the stem is two to three times that of the leaves (Mowat et al., 1965; Albrecht et al., 1987). Peak yield of the valuable alfalfa 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 throughout the growing cycle (Albrecht et al., 1987). The digestibility of alfalfa decreases with maturity due to increased cell-wall material (CWM) in the stems, higher lignin content in the stems and increased proportions of the stem fraction (Mowat et al., 1965; Albrecht et al., 1987). However, little change in leaf digestibility occurs as the plant matures (Mowat et al., 1965; Albrecht et al., 1987).

Alfalfa forage producers struggle to balance the desire for the high quality that occurs at early maturity with the desire for high yield that occurs at later maturity. If poor weather delays alfalfa harvest, then forage quality suffers because the stem fraction dilutes the nutritive value of the leaves when the crop is harvested as a whole plant. The above discussion shows that a system that separately harvested the leaf and stem fractions could help producers better utilize the high quality of the leaf fraction.

Most grain crops are fractionated at harvest where the valuable grain is separated from the less valuable straw or stover. The non-grain fraction is typically not utilized, although there is interest in using this material for a feedstock for production of energy, ethanol, pulp and fiberboard. The grain combine performs a dry-fractionation by threshing, separating and cleaning the grain. McLoed (1998), Shinners et al. (2003) and others have suggested grain harvesters that would fractionate grain crops while simultaneously processing and collecting the non-grain fractions. The most economically important forage crops fed to dairy animals in North America are wilted alfalfa silage, dry alfalfa hay and whole-plant corn-silage. The valuable plant fractions are the protein-rich alfalfa leaves and the energy-rich corn kernels. The high-fiber alfalfa stem or corn stalk are less valuable but serve as an important source of "roughage" for ruminant function. Therefore, forage crops are not harvested using fractionation but rather are harvested, stored and fed in whole-plant form. However, there have been historical efforts to fractionate alfalfa to take economic advantage of the variable value of the different plant constituents.

Alfalfa fractionation can be either a wet- or dry-process. With dry fractionation, alfalfa is cut, allowed to field wilt, chopped or baled and then typically dehydrated in an off-farm processing facility (Mowat and Wilton, 1984; Adapa et al., 2003). The light leaf fractions are then separated from the heavy stem fraction through a combination of mechanical sieving and air separation. The leaf fraction is usually pelleted as an alfalfa-leaf-meal (ALM) fed as an animal protein supplement. The high-fiber stem fraction is used as roughage for ruminants, although it would have industrial uses. Dry-fractionation has several drawbacks, chief among them are: (1) weather related losses during field wilting, (2) high energy costs for dehydration, (3) high equipment costs that makes on-farm processing uneconomical, and (4) transportation costs of low-value stems back to the producing farm. Wet-fractionation is a process where plant juices are expressed from freshly cut and macerated forages. The juice fraction is about half the fresh crop weight and is further processed to obtain high-protein, low-fiber value-added products including neutraceuticals, transgenic enzymes, carotenoids and protein supplements for ruminants, monograstics or humans. The dewatered fiber fraction could be direct ensiled for use as ruminant animal feed or used as a feedstock for paper pulp, fiberboard, lactic acid or ethanol (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: (1) high specific energy costs, (2) high equipment costs that make on-farm processing uneconomical, and (3) transport or disposal costs of the dewatered fraction and the deproteinized juice.

What is proposed here is a novel harvest-fractionation system that involves stripping the leaves from the stem as the first harvest step. The stripped leaves could be used for any number of products including, but not limited to, a high-protein feed preserved by direct ensiling using amendments or additives, dehydrated and pelleted ALM or value-added products processed off-farm. The stem fraction could be simultaneously cut at leaf harvest and allowed to field wilt for ensiling or baling, serving as an on-farm roughage source. Harvested stems could also be a feedstock for value-added products processed off-farm. Another alternative is to allow the stem to stand after stripping and re-grow leaf tissue for a short period before harvesting as silage or dry hay. Currence and Buchele (1967) reported that alfalfa leaves re-grew from stripped stems within seven days of stripping. Harvest fractionation has the following advantages over either the dry- or wet- processes: (1) the high-value leaf fraction is removed immediately at harvest so yield is high and weather related losses are low, (2) fractionation takes place at harvest so no further processing steps or equipment are needed, (3) capital costs of the fractionation equipment is very low compared to wet- or dry- fractionation systems, (4) fractionation takes place on the farm so only the desired fractions need leave the farm, thereby reducing transport costs, and (5) ruminant rations can be custom tailored for optimum economic return when high and low value forage fractions are separated.

It is critical that procedures be developed to allow alfalfa leaves to be direct ensiled for storage because it is not feasible to field wilt the leaves or to artificially de-hydrate them in large quantities. Previous work has shown that leaves and stems have about the same moisture at harvest (Kohler and Chrisman, 1968). Therefore, the expected moisture of the leaves will be 75 to 80% at harvest. At this moisture, direct ensiling would produce undesirable fermentation dominated by clostridia bacteria. The result would be poorly preserved forage with high DM losses and low DM intake by the animal. Direct ensiling of forages is relatively common in Europe and has been suggested for food and agricultural by-products (Huber, 1980; Muck et al., 1999). Direct ensiling typically involves either adding a chemical such as formic acid or formaldehyde to rapidly drop pH and restrict biochemical activity or involves adding amendments to increase silage DM (Pitt, 1990; Muck et al., 1999). The final concern with ensiling alfalfa in two fractions is that of compaction and density. High silage density reduces porosity, which directly affects oxygen infiltration during filling, storage and feed-out. The presence of oxygen directly affects the amount of microbial activity and spoilage losses. High silage density also increases silo capacity. The effects of ensiling fractionated alfalfa on these factors are unknown.

The objectives of this research were to conduct preliminary investigations into (1) the fractional yield of alfalfa stems and leaves using harvest fractionation, (2) the leaf re-growth tendencies of stems stripped of leaves, (3) the ensiling characteristics of the leaf fraction, and (4) the drying rate of the stem fraction after stripping and cutting.

PROCEDURES

Process Description

Harvest-fractionation was accomplished by using a modified stripping rotor and harvester typically used for snap bean harvesting. The rotor had a multiplicity of radial tines to penetrate the crop canopy and strip the alfalfa leaves from the stem. The Pixall model VPCII 1500 bean head was 4.6 m wide and was equipped with a stripping rotor with 16 rows of 50 tines placed in spiral patterns so that tine spacing was about 25 mm. The rotor overall diameter was 667 mm with the tines protruding 187 mm from the center drum. The rotor was operated with a tip speed to ground speed ratio of about 13:1. Speed ratios greater than this typically removed too much of the top portion of the plant while ratios less than this typically caused poor leaf removal. Stem removal was too great when rotor height was too low. The stripped material was conveyed into a side-dumping container on the self-propelled harvester for collection and removal from the field. The remaining stems were generally left erect after stripping except in the harvester tire tracks.

Fractional Yield and Leaf Re-Growth

A randomized block experiment was conducted at the University of Wisconsin Arlington Agricultural Research Station (AARS) in July 2003 with 2nd cutting alfalfa at about ¼ flower maturity, using the following four treatments: stripped and re-growth periods of 0, 7 and 14 days; and a control that was cut, wilted and chopped using traditional techniques. Each plot was 4.5 m wide and 80 m long so that machine equilibrium could be reached. Each treatment was randomly assigned within each block and four replicates were used. Plots were stripped in the morning and representative sub-samples of the stripped and standing fractions collected from each of the plots. Stripped sub-samples were collected from the harvester container and standing sub-samples were hand clipped from the stripped stems. Each of the stripped and standing fractions were further sub-divided by hand into leaf and stem fractions. Petioles were categorized as belonging to the leaf fraction. Each of the four sub-fractions were then oven dried at 103° C for 24 h to determine DM content and the dry mass recorded (ASAE Standard S318.2, 2003). The fraction of the total DM in each of the four sub-samples were then used to back calculate yield of the leaf and stem in the stripped and standing fractions, as well as for calculation of the concentration of leaves and stems in the stripped and standing fractions, respectively. 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. Sub-samples of the four fractions were frozen for later analysis of typical nutrient constituents (CP, ADF, and NDF) by the UW Soil and Plant Analysis Laboratory. Two treatments involved leaf re-growth, so stripping was not conducted when the standing fraction was cut 7 or 14 days after stripping. The procedures described above for determination of DM content, fractional yield and nutritional constituents applied to these treatments as well. Cutting of the standing fraction was done using a disk mower-conditioner operated in the opposite direction that stripping took place.

Drying Rate of Standing Fraction

One harvest fractionation scenario being considered would involve stripping the alfalfa leaves and simultaneously cutting the stems, placing the latter in a harvestable windrow. This harvest scenario might produce a single-day alfalfa harvesting system if the stems dry to chopping moisture sufficiently fast. The modified bean harvester was not configured to cut the stems at stripping, so a mower-conditioner was used immediately following stripping. Multiple tests were conducted using

2nd and 3rd cutting alfalfa in 2003 and 1st cutting in 2004. Crop maturity was roughly ¼ flower in 2003 and ¼ to ½ flower in 2004. A replicated block design was used to evaluate the drying rate of the following treatments: (1) stems with approximately 90% of leaves removed, (2) whole-crop (leaves plus stems) windrowed using the same cutting width as leaf stripper rotor, and (3) 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 window as the first treatment where about 50% of the total DM was removed as leaf tissue. Treatments were randomly assigned within the field. Leaf stripping and subsequent cutting and windrowing occurred in the morning. Moisture samples were collected immediately after cutting and periodically throughout the next two to four days. Samples were collected by hand from across the full width and depth of the windrows and chopped in a stationary chopper. The chopped sample was mixed to homogenize and three sub-samples taken to oven dry at 103° C for 24 h (ASAE Standard S318.2, 2003). At each sampling interval, two replicate samples were collected from each block. Samples were collected from a "virgin" section of the windrow that had not been disturbed by previous sampling. Weather data, such as ambient temperature, solar insolation, relative humidity and wind velocity were collected from the AARS weather station.

Direct Ensiling of Leaves

Laboratory mini-silos were used to evaluate the potential of several alternative methods of direct ensiling of leaves. The experiment was conducted using four treatments: two with amendments; one with an additive; and an untreated control. Amendments were used to reduce the silage moisture and included ground corn grain and wheat straw. Ground corn was considered because would add energy to the leaf silage, it has very high bulk density relative to the leaves, it would dilute protein and minerals from the leaves, it would increase starch and energy of the leaves, and it would serve as a valuable substrate to aide 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 because it is commonly used to preserve direct ensiled grasses in Northern Europe (Pitt, 1990). Moisture of the amendments was determined several days before ensiling by oven drying representative sub-samples at 103° C for 24 h while moisture of the alfalfa leaves was determined by drying representative sub-samples in a microwave oven according to ASAE Standard S318.2 (2003). Based on these moistures, amendments were added at the rate of 0.7 kg to 2.3 kg wet leaves to achieve a target moisture of about 63% (w.b.). Formic acid (88%) was added at the rate of 11 ml per 2.3 kg wet leaves. Mixing of leaves and amendments or additives was done in a large industrial food-mixer in the laboratory.

All silage samples were stored in 5L mini-silos (100 mm diameter by 640 mm height) constructed of PVC pipe with rubber end caps. Filling was carried out by adding about 100 mm of loose material to the silo, and then compacting the forage manually by repeated blows with a special hammer. This process was repeated until the mini-silo was full. The mini-silo and its contents were weighed, the initial mass recorded and mini-silos rejected if wet matter density was not at least 500 kg WM/m^3. Five replicate mini-silos were used for each treatment. Separate sub-samples of the mixed silages were collected for determination of DM content by oven drying at 103° C for 24 h. Silages were stored for 123 days. The silo and its content were weighed and the final mass recorded at the end of the storage period. The removed silage was then sampled for chemical and microbiological characteristics. Sub-samples were collected to determine DM content using procedures similar to those discussed above. Other sub-samples were frozen and then sent to the Dairyland Laboratories in Arcadia, WI for determination of CP, ADF, NDF, and ADIL using wet laboratory techniques. These samples were also used to determine pH; buffering capacity; water soluble carbohydrates; non-protein nitrogen; lactic, acetic, and butyric acids; and ethanol using standardized methods.

Silage Density

Silages are increasingly being stored in bunk or bag silos, so density is produced by dynamic compaction rather than by quasi-static consolidation as might be the case in a tower silo. This experiment was conducted to determine the effect fractionation had on silage density. Three treatments were considered: stripped leaves; stripped and chopped stems, and chopped whole-plant alfalfa. The latter two treatments were chopped in a laboratory-scale chopper at a TLC of 13 mm. A "drop hammer" apparatus was used to dynamically compact the material (Shinners et al., 1988). The treatments were compacted in a 20 cm diameter PVC cylinder using 75 blows with a 10 kg steel hammer from a height of about 30 cm. Samples consisted of about 2.5 kg of forage that was placed into the container approximately ⅓ at a time by volume. Twenty-five blows were applied to the material while continuously moving the hammer around the cylinder. The procedure was repeated with the remaining material and the final sample height measured to determine the compacted volume and density. The material was then removed, weighed and allowed to relax for about 20 min. Height measurements were then taken to determine relaxed density. Prior to compaction, replicate sub-samples of the treatments were collected for moisture and particle-size analysis using the procedures described in ASAE Standard S424.1 (ASAE, 2003).

RESULTS AND DISCUSSION

Fractional Yield and Leaf Re-Growth

Harvest-fractionation by using a modified stripping rotor was quite successful. Leaf tissue made up just under 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. Stripping removed about 94% of the total leaf mass (table 1). The stripping rotor was operated at a relatively aggressive peripheral to ground speed ratio, so just short of 60% 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 treatment that used harvest-fractionation and no leaf re-growth had almost 30% greater yield than the control, with the stripped fraction yielding 38% more leaf mass and 21% more stem mass. After stripping, the stem fraction was immediately cut and windrowed at the same time as the control treatment. A 38 mm rainfall occurred that evening which may have caused much greater losses from the control because the plant leaves were exposed to the rain. Windrows of both treatments had to be raked with a rotary rake prior to harvest. Less than 6% of the total leaf mass was present in the standing/cut fraction, so separation losses from raindrop impact and raking would have had much greater impact on the yield from the control. Leaching losses were reported to be greater with leafy crops and crops with high leaf to stem ratios (Collins, 1985; Rotz and Muck, 1995). Leaching losses were most likely much greater for the control windrows where 53% of the mass was leaves compared to the stripped treatment where only 8% of the mass was leaves. This yield difference highlights a major potential advantage of the harvest-fractionation system where the high-value leaves can be harvested without exposure to losses from weather or further mechanical manipulation.

Leaves were observed to re-grow within 3 to 5 days after stripping, with much more leaf re-growth occurring in the 7 to 14 day period. The size of all new leaves was much smaller than the original harvested leaves. Leaf re-growth was observed to be slight, if at all, in the harvester wheel tracks, where new growth from the crown was more likely to occur. After about 14 days, it was observed that leaf re-growth appeared to stall and new growth from the crown was quite evident. If it is assumed that the proportion of leaves remaining in the standing fraction after the initial leaf harvest was the same for the 7 and 14 day re-growth treatments as for the stripped and cut treatment, then leaf

Table 1. Fractional DM yield of alfalfa leaves and stems after various leaf re-growth periods.

Leaf regrowth period	Leaf strip date	Stripped fraction					Standing fraction					Total			
					Leaves as fraction of					Stems as fraction of					Fraction of total DM as leaves
		Leaf	Stem	Total	Stripped fraction	Total leaf mass	Leaf	Stem	Total	Standing fraction	Total stem mass	Leaf	Stem	Total	
		Mg DM / ha			%	%	Mg DM / ha			%	%	Mg DM / ha			%
Control	–											1.43_a	1.32_a	2.75_a	52.0
0 days	7/14	1.86	0.22	2.08	89.5	94.3	0.11	1.32	1.43	92.1	87.7	1.97_b	1.54_b	3.51_b	56.1
7 days	7/14	2.06	0.25	2.31	89.5										
"	7/21	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
"	Sum	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	7/14	1.97	0.25	2.22	89.9										
"	7/28	0.31	0.27	0.58	53.8	66.7	0.16	1.75	1.91	91.8	86.7	0.47	2.02	2.49	20.8
"	Sum	2.28	0.52	2.80	82.3	93.6	0.16	1.75	1.91	91.8	78.0	2.44_c	2.27_c	4.71_d	51.8
LSD (P = 0.05)												0.16	0.20	0.34	

re-growth produced a 6 and 17% increase in leaf mass harvested, respectively (table 1). Compared to the leaf strip and immediate cut treatment, allowing leaf re-growth produced 17 and 24% greater leaf yield and 12 and 45% greater stem yield for the 7 and 14 day re-growth treatments, respectively.

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 is 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.

Table 2. Quality constituents for standing and stripped fraction of 2nd cutting alfalfa fractionated at the ¼ flower stage.

	CP	ADF	NDF	NDF_d*	NFC#	Fat	Ash	RFQ&
	% of DM							
Stripped	26.6	18.4	22.8	62.7	39.4	3.2	11.3	344
Standing	13.1	47.1	55.1	43.2	22.4	1.8	11.0	89

* - Neutral detergent Digestible fiber # - Non-fiber carbahrdrates. & - Relative forage quality

Drying Rate of Standing and Cut Fraction

Stems stripped of leaves but left standing lost about 3 percentage units of moisture during the first several hours after leaf removal but maintained an equilibrium moisture of about 77% (w.b.) (fig. 1). Moisture was lost from the standing plant because the stripping action tended to do some damage to the top of the stem, which probably facilitated egress of moisture similar to conditioning. However, the data shows that stripping damage would not facilitate drying to silage moisture without cutting the stem from its root structure first. The windrow density of the standing / cut and whole-plant/narrow treatments were 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 probably facilitated good air movement because the leaves were essentially all removed. The high surface to volume leaves tended to fill in the skeletal structure formed by the stems of the other windrows, and this most likely slowed drying rate of these treatments. The weather on August 14th 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 PM after being stripped at noon. The drying weather on August 19th 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, which would create harvest challenges. When whole-plant alfalfa passes well through the acceptable silage moisture range, producers often allow the material to dry to hay moisture and bale the crop. This would be a concern with the standing / cut fraction because uses for bales of essentially stems must be available. Weather conditions for tests 3 and 4 were quite typical for mid-June in Wisconsin. In both tests, the standing / cut fraction dried to chopping moisture in roughly 6 h (figs. 3 and 4).

The initial data clearly shows that alfalfa stems with the majority of the leaves removed can dry 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 where the leaves would be stripped in the morning and the stems immediately cut, windrowed and allowed to wilt. The drying rates produced here would 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 may be needed to retard the drying rate to produce an acceptable harvest window.

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

Date	Temperature	Solar radiation	Relative humidity	Wind speed
.	° C	W / m^2	%	m / s
Test 1				
8/14/03	28	450	62	2.4
8/15/03	29	637	62	3.6
Test 2				
8/19/03	28	607	46	4.7
8/20/03	30	572	60	5.5
8/21/03*	30	635	51	5.2
Test 3				
6/7/04	29	625	61	9.5
6/8/04	28	516	66	6.8
6/9/04	26	460	71	4.1
Test 4				
6/14/04	25	627	60	4.5
6/15/04	24	674	50	2.2
6/16/04	25	452	70	2.7

* - A rainfall of 1 mm fell during the early morning of August 21st, 2003.

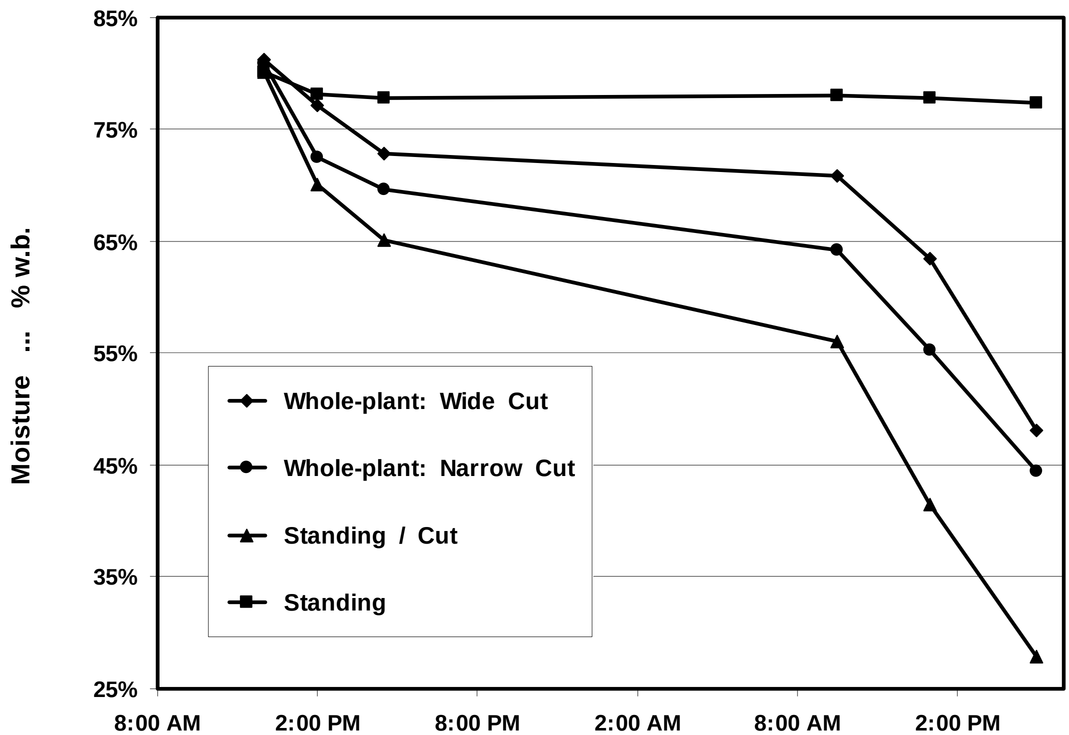

Figure 1. Moisture history of four treatments from an experiment conducted on August 14th and 15th, 2003. Rainfall on August 16th halted the experiment.

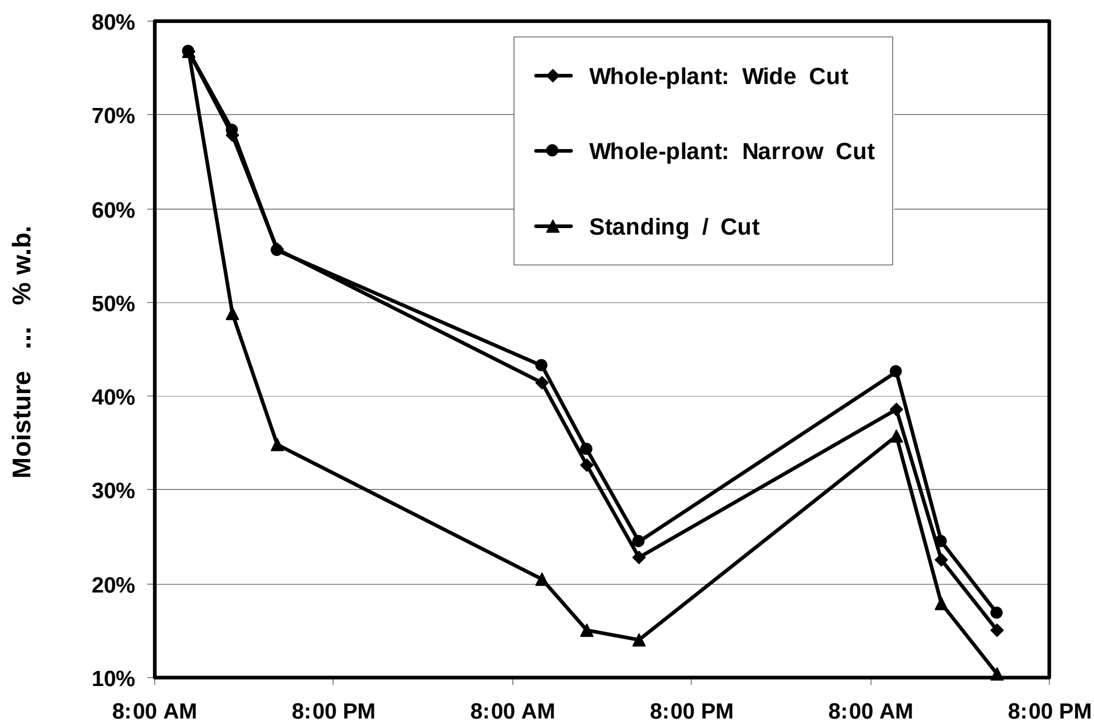

Figure 2. Moisture history of three treatments from an experiment conducted on August 19th through 21st, 2003. Rainfall of 1 mm fell during the early morning of August 21st.

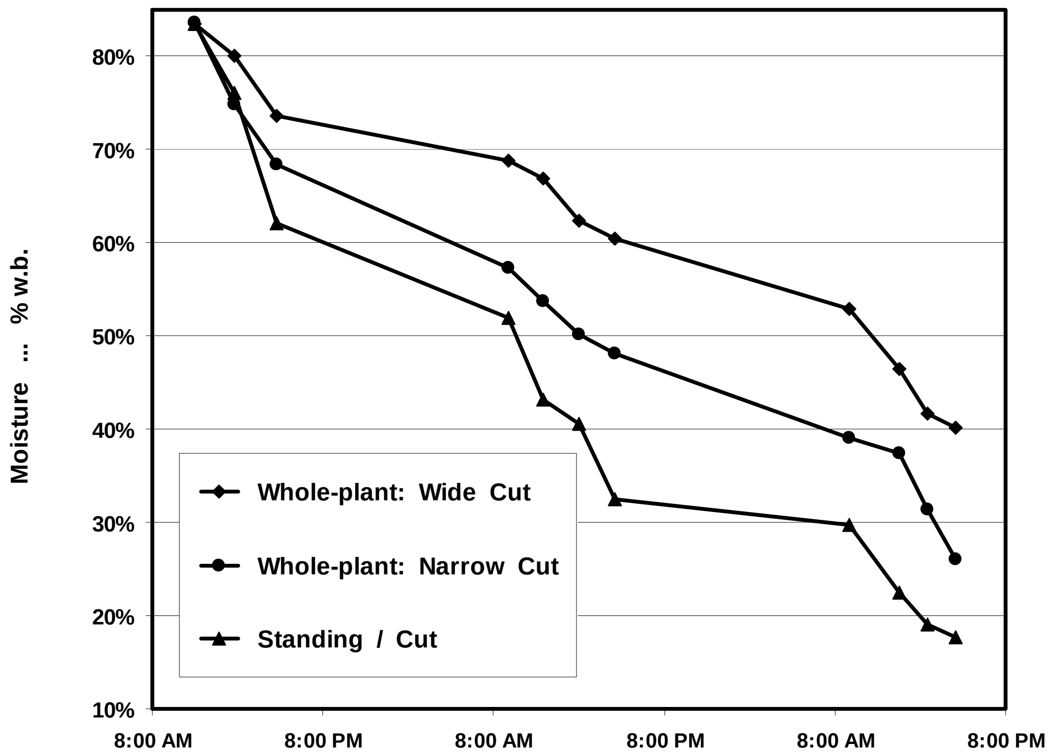

Figure 3. Moisture history of three treatments from an experiment conducted on June 7th through 9th, 2004 using 1st cutting alfalfa.

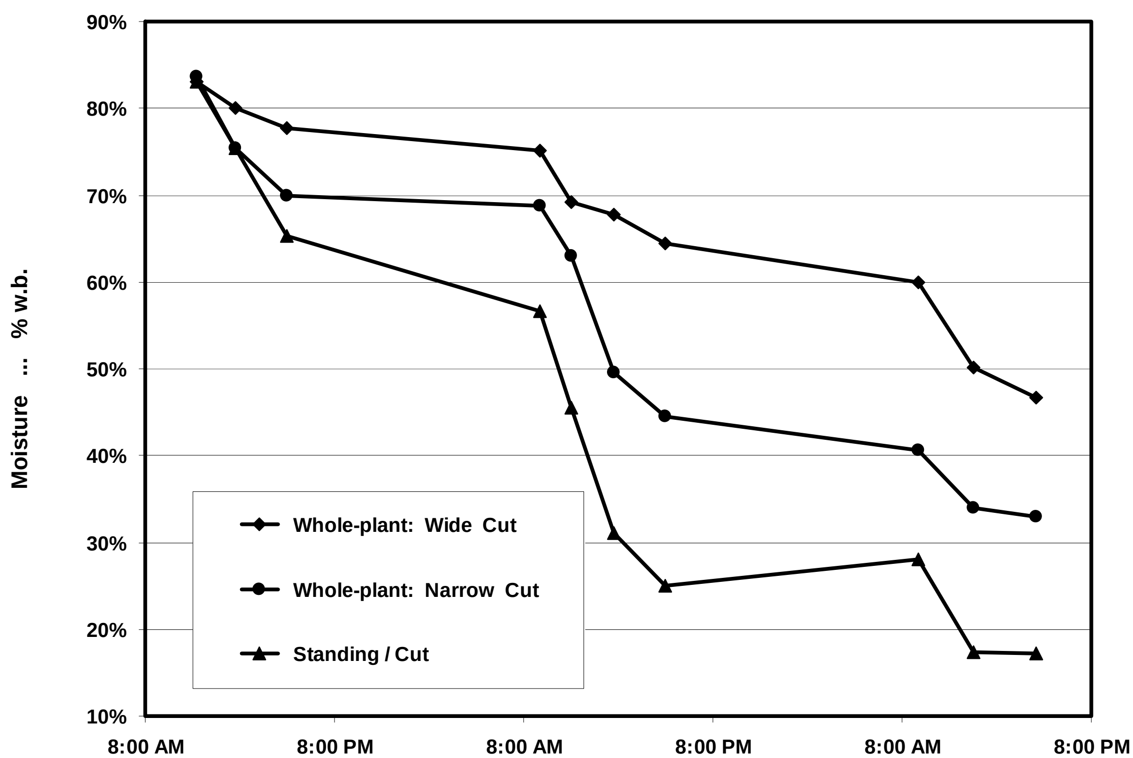

Figure 4. Moisture history of three treatments from an experiment conducted on June 14th through 16th, 2004 using 1st cutting alfalfa.

Silage Density

The whole-plant and standing fractions 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 of the whole-plant and stripped and standing fractions were not significantly different (table 4). However, the standing fraction was slightly longer with more long material than the whole-plant or stripped treatments. These results would indicate that the stripped fraction could be stripped and placed directly into storage without any further size-reduction. The initial and relaxed dry densities of the stripped fraction were significantly greater than the whole-plant (initial only) or standing treatments (table 4). The relative lack of the rigid, cylindrical stems in the stripped fraction compared to the other two treatments probably was a major reason why the stripped fraction had higher compacted density. Shinners 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 vast majority of the leaves from the standing fraction would have low compacted density because the leaves would not be present to fill in the "skeletal" area between the stems. However, the standing fraction density was similar to that of the whole-plant. The silage density work needs to be repeated at lower moistures more typical of the ensiling range because the stem fraction will gain mechanical strength as it dries.

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

Treatment	Moisture	Particle-size		Dry density	
		Mean	Long fraction[#]	Initial	Relaxed
	% w.b.	mm	%	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[*] (P = 0.05)	1.3	4.2	9.1	11	9

- Fraction of total sample residing on the top two screens of the particle-size separator (ASAE Standard S424.2, 2003).

* - Averages within columns with different subscripts are significantly different at 95% confidence.

Direct Ensiling of Leaves

Silage samples were removed after 123 days in storage. The control treatment had a disagreeable odor, was very dark in color and there was some effluent collected at the bottom of the mini-silo. The leaf/straw treatment had a good color and there was no effluent, but there was evidence of mold in some locations and the silage had a slight disagreeable odor. The leaf/corn and leaf/acid treatments both had good color and smell, although there was some effluent at the bottom of the leaf/acid treatment. Dry matter loss was significantly greater for the control and leaf/straw treatments compared to the leaf/corn and leaf/acid treatments (table 5). These former two treatments had a significantly higher pH (control only), lower level of desirable lactic acid and higher level of undesirable butyric acid than the latter two treatments which led to the high DM loss (table 5). Clearly, direct ensiling of alfalfa leaves produced unacceptable fermentation and preservation as measured by DM loss, pH and high levels of undesirable fermentation products. The leaf and 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. The straw was not chopped finely (~ 25 mm TLC) so it had greater relative surface area than the ground corn. Plus, the straw had natural barriers to moisture migrating back into the stem because of its waxy cutin. Therefore, it is likely that early in the fermentation process, the alfalfa leaves in this mixture fermented similar to those of control, producing the poor silage conservation. The ground corn not only reduced DM content and pH to levels that prevented clostridia fermentation, but the sugar content of the grain 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 (Pittt, 1990) and in fact no effluent was observed. Clostridial fermentation in direct-cut grasses is most typically prevented by the application of formic acid at about 1% of DM (Leibensperger and Pitt, 1987 and 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% of DM 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 because preservation was poor (see above) and it has very low bulk density. Amendment bulk density is important because in a large-scale practical system high bulk density amendments will minimize added mixing and handling costs. 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 preservation excellent but the amount of product to achieve the desired moisture of the mixture would be reasonable.

Conclusions

- A stripping rotor was successfully used to fractionate 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 re-grow on the standing fraction for 7 or 14 days. Leaf re-growth was evident in 3 to 5 days, with much more leaf re-growth occurring in the 7 to 14 day period. Leaf re-growth produced a 6 and 17% increase in leaf DM harvested, for the 7 and 14 day re-growth 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. This fraction dried to 65% (w.b.) moisture in 1.5 to 6 hours. Therefore, a single-day harvesting system could be possible.
- Stripped leaves were direct ensiled successfully in mini-silos using ground corn as an amendment (1 kg corn per 3.3 kg wet leaves to attain a target moisture of 63%) or formic acid as an additive (1 ml acid per 4.8 kg wet leaves). The particle-size of the stripped fraction was similar to that of chopped whole-plant alfalfa, indicating 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 density test.

Table 5. Dry matter loss, nutrient constituents and fermentation products for four alfalfa leaf silages stored in mini-silos.

	Moisture			Final nutrient composition				
	Into storage	Out of storage	DM loss	CP	ADF	NDF	Lignin	Ash
	% w.b.		% of DM	% of DM				
Control	78.4_b	81.2	17.2_c	21.5_b	26.3_c	39.6_b	6.3_c	12.4_c
Leaf / Straw	62.2_a	64.2	10.8_b	13.0_a	44.8_d	59.9_c	7.9_d	9.0_b
Leaf / Corn	62.5_a	63.3	3.9_a	20.9_b	13.6_a	25.1_a	2.9_a	6.1_a
Leaf / Acid	78.5_b	78.2	1.6_a	25.4_c	22.7_b	36.1_b	4.8_b	9.5_b
LSD* (P = 0.05)	0.5	0.8	3.2	3.7	3.2	9.2	1.2	1.1

	Fermentation products					
	pH	Lactic	Acetic	Butyric	Ethanol	Ammonia N#
	% of total DM					
Control	5.9_b	0.0_a	4.3_c	6.2_c	1.6_c	14.3_b
Leaf / Straw	4.8_a	1.6_b	0.6_a	3.6_b	0.4_b	3.2_a
Leaf / Corn	4.3_a	5.9_c	1.5_{ab}	0.0_a	0.6_b	2.9_a
Leaf / Acid	4.3_a	5.5_c	1.8_b	0.0_a	0.0_a	2.3_a
LSD* (P = 0.05)	1.0	1.7	1.0	1.4	0.2	1.7

* - Averages within columns with different subscripts are significantly different at 95% confidence.

\# - Ammonia N as a fraction of CP

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