PROCESSING WILTED ALFALFA WITH CROP PROCESSING ROLLS ON A PULL-TYPE FORAGE HARVESTER

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ABSTRACT. *Crop processors on forage harvesters have become readily available and widely used by North American livestock producers. Past research has shown that intensive mechanical processing at the time of cutting can improve the fiber digestibility of alfalfa and grasses, and questions have surfaced as to the potential effectiveness of a crop processor on a forage harvester to also improve the animal utilization of wilted forages. Processing wilted alfalfa with crop processing rolls was effective in increasing the level of plant tissue disruption, as quantified by leachate conductivity, by more than 30% in all cases and similarly reduced particle-size from the theoretical-length-of-cut. Processed material was visibly darker and more bruised than control treatments. Processor roll clearance and cutterhead theoretical-length-of-cut had a greater effect on crop physical properties than did processing roll speed difference. Processing wilted alfalfa increased harvester energy requirements by 36 to 113% depending upon crop moisture and the feeding characteristics of the processing rolls as affected by the aggressiveness of the tooth profile. Processing wilted alfalfa increased the crops in situ dry matter disappearance at 12 and 24 h by greater than six percentage units and increased the instantly soluble fraction by up to seven percentage units. However, processed alfalfa did not affect lactation performance of Holstein dairy cows.*

Keywords. *Forage harvesters, Crop processing, Alfalfa.*

Animal performance benefits can result when forages undergo severe mechanical disruption, or maceration, at cutting when the stem is relatively soft and compliant (Kraus et al., 1997). Maceration breaks down the physical structure of the plant stem and splits it into numerous pieces while the leaves and upper segments are crushed and disrupted (Shinners et al., 1987a). This increases the specific surface area of the crop and increases the rate and extent of fiber digestion in the rumen (Hong et al., 1988a). Intensive mechanical processing also ruptures plant cells such that intercellular constituents are more numerous and accessible to ruminal microbes (Hong et al., 1988b).

Research has shown that intensive conditioning can speed forage field drying rates (Krutz et al., 1979; Shinners et al., 1987b; Savoie and Beauregard, 1991). To reduce the loss of small plant particles, intensive conditioning machines often have incorporated the difficult task of forming the intensively conditioned forage into a mat. Numerous problems are associated with mat making. First, the maceration and mat formation processes are power intensive, which causes either a reduced harvesting rate or greater capital expenditure for additional power availability (Rotz et al., 1990). Second, mat formation requires a heavy and expensive press. Third, there are difficult handling problems relative to swath or windrow merging after the mat is laid on the stubble. Fourth, baling matted material has never been proven to be feasible. Finally, numerous difficulties can be expected in marketing and producer adaptation of such a radically new harvesting technique.

Processing whole-plant corn silage with crop processing rolls onboard the forage harvester is now common and research has shown the animal nutritional benefits of this harvesting practice (Shinners et al., 2000). Animal utilization of wilted forages may be improved by processing the crop with processing rolls onboard the forage harvester as an alternative to the maceration and mat formation concept. With this scenario the benefit of increased drying rates would disappear, as would the opportunity to improve the digestibility of dried forage. Processing onboard the forage harvester could still be a very timely harvesting strategy, however. With the increased use of bunker and bag silos, wilted forage crops can be harvested at moisture contents as high 70% wet basis (w.b.) (Pitt, 1990). This means the field drying time can be reduced to a matter of hours in many cases, making a one-day forage system entirely possible. However, the effects of intensively processing wilted forage in the forage harvester are unknown.

Compared to macerating at the time of cutting when the plant was lush, there was less plant tissue disruption when macerating after wilting because the stem became mechanically stronger and less turgid during wilting (Shinners et al., 1988). It needs to be determined if it is

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possible to improve utilization of wilted forage in ruminant animals after it has been processed with crop processing rolls onboard the forage harvester. The specific objectives of this research were to: (1) measure the physical properties of processed wilted alfalfa under a variety of moistures, maturities, and machine variables such as roll tooth profile, speed difference, and clearance; (2) determine the specific energy requirements and harvester capacities when processing wilted alfalfa; (3) measure the *in situ* digestibility of processed alfalfa in fistulated Holstein dairy cows; and (4) determine the effect of alfalfa processing on the intake and production of Holstein dairy cows.

Description of Crop Processor

A set of grooved counter-rotating rolls was placed after the cutterhead of an experimental forage harvester (fig. 1). With a simple field adjustment, it was possible to direct the crop from the cutterhead toward either the processing rolls (processed treatment) or directly toward the blower (unprocessed treatment). Thus, it was possible to use the same machine to produce both the control and experimental treatments.

In 1997, a set of knurled rolls were fabricated from mild steel to process wilted forage. The rolls were not hardened after knurling. The rolls had a diameter of about 150 mm, tooth pitch of 3.2 mm, tooth depth of 1.6 mm, and 45° angular tooth profile. These rolls were powered via four "A" section v-belts from a sheave driven by the cutterhead. The high-speed roll was driven off the backside of the v-belts via a pulley, thus causing this roll to counter-rotate relative to the lower-speed roll. By changing sheave and pulley combinations, no load speed differences (difference of fast and slow roll rotational speed divided by rotational speed of slow roll, expressed as a percent) of 17 and 50% were obtained.

In 1998, the knurled rolls were replaced with a set of hardened, grooved rolls. The rolls were hardened to Rockwell "C" 56 after fabrication and had a 30° angular tooth profile. The tooth pitch was 3.9 mm and the tooth depth was 3.4 mm. Four "A" section v-belts were used to drive a countershaft. This shaft drove a second countershaft through another series of four "A" section v-belts and finally, one processing roll was driven from the left and right end of this shaft, respectively. This arrangement allowed variable pitch sheaves to be used to drive each roll independently, which allowed the speed difference ratio to range from 10 to 69%.

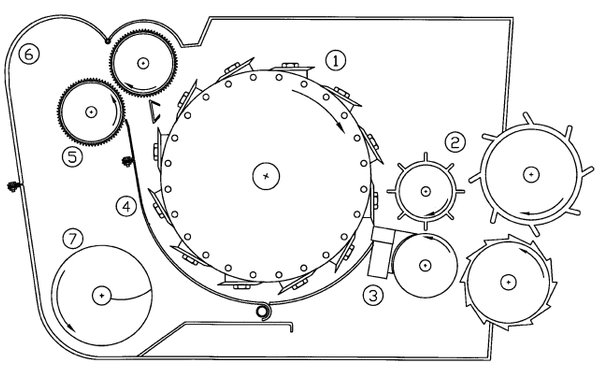

Figure 1–Schematic right-side view of crop processing rolls on the experimental pull-type forage harvester, including ① cutterhead, ② feed rolls, ③ shearbar, ④ removable crop deflector, ⑤ crop processing rolls, ⑥ crop deflector and access panel, and ⑦ cross-auger.

Procedures

Analysis of Physical Properties

Leachate conductivity (LC) was used to quantify the level of crop processing. The magnitude of electrical conductivity of a solution is proportional to the number of ions in solution. Processing reduces the crop's resistance to leaching by increasing its specific surface area, thereby allowing more ions to be released from the plant material. In other words, the more surface area created by processing, the greater the LC of the solution. A method was developed for measuring processing level of non-wilted, macerated alfalfa (Kraus et al., 1999). The dry matter (DM) content of a sample will greatly affect the expected LC. When fresh, lush forage was used by Kraus et al., all samples had about the same DM content so accounting for differences in sample DM was not a concern. A change was made to the Kraus et al. procedure to account for expected changes in sample DM because wilted plant material was used in this research. A 5 g (DM) sample of wilted crop was placed in a 473 mL glass container and 300 mL of distilled water added. A microwave oven and ASAE Standard S358.2 (ASAE, 1997) were used to determine sample DM content before the samples were prepared so exactly 5 g of DM would be used for each sample. The mixture was then shaken for 2 min on an orbital shaker table at 200 cycles/min. Finally, the contents were filtered through two layers of cheesecloth and the conductivity of the leachate immediately measured. The conductivity meter utilized for these experiments was a Hanna Instruments Conductivity and Dissolved Solids Tester, μ-Sensor 3. The μ-Sensor 3 had a range of 10 to 1990 μS/cm and a resolution of 10 μS/cm, was accurate to ±2%, and was temperature compensated. This meter was calibrated at the start of the procedure to 1413 μS/cm using Markson LabSales Conductivity Standard. Unless noted otherwise, the LC reported here is the average of five random samples collected for each experimental condition.

Kraus et al. (1999) suggested that reporting the LC of a treatment as a fraction of the maximum possible LC should normalize LC data. This would allow LC data to be compared across different days or cuttings without bias from changes in leaf-to-stem ratio, maturity or plant chemistry. Toward this goal, an additional treatment was included that attempted to rupture all the plant cells such that day-to-day variation in a treatment's LC would be due to changes in plant properties and/or chemistry. This treatment was similar to that described above except that the shaking step was replaced by processing the mixture in a blender for 1.5 min (Waring blender model 7011 at 22,000 rpm no load speed). Using this treatment, a processing index (PI) was defined as the ratio of the mean treatment LC to the blender treatment LC, expressed as a percent.

Particle-size distribution was quantified using the apparatus and procedure described in ASAE Standard S424.1 (ASAE, 1997). For each experimental condition,

particle-size was determined using three sub-samples. DM content was determined using a separate set of three sub-samples oven-dried at 103°C according to ASAE Standard S358.2 (ASAE, 1997).

Analysis of Machine Operating Variables

In 1997, first, second or third cutting alfalfa was harvested with a 3.6 m mower-conditioner and laid in a windrow. With second and third cutting, a tandem wheel rake was used to merge two windrows after field wilting to desired moistures. The harvester was operated with a particular machine configuration until equilibrium conditions were obtained and sufficient crop for sub-sampling could be collected, typically about 30 to 50 m of windrow length. About 25 kg of crop was collected from several random locations in the trailing wagon, sealed in a plastic bag and transported to the laboratory for analysis of physical properties.

It was initially determined that clearance needed to be quite small in order for crop damage to become visually apparent when processing wilted alfalfa. Also, roll clearance was difficult to alter in the field. Therefore, when harvesting wilted alfalfa, clearance was maintained at the minimum (approximately 0.2 mm) that produced interference between the rolls at localized maximum radii. Initially, the theoretical-length-of-cut (TLC) was 19 mm for both the unprocessed and processed treatments. Later a third treatment, unprocessed at 9.5 mm TLC, was added. No load roll speed differences were measured to be 17 and 50%, depending upon sheave and pulley combinations.

In 1998, first cutting alfalfa (full-bloom) was harvested with a 3.6-m mower-conditioner and laid in a windrow. A 2^3 factorial experiment was conducted in which clearance (0.5 and 1.5 mm), roll speed differences (20 and 60%) and TLC (9.5 and 19 mm) were altered. Two control treatments, unprocessed at 9.5 and 19 mm TLC, were also included. Experimental runs were conducted in random order and at random locations within the field. The factorial experiment was conducted on 16 June and replicated on 17 June using a single replicate for each treatment on each day. The procedures and number of replicate sub-samples used for determining DM, LC, and particle-size were similar to those described above.

Analysis of Harvester Specific Energy

In 1997, field measurements of the forage harvester's specific energy requirements were made while harvesting third cutting alfalfa. During field tests, all the chopped material from the forage harvester was collected in a side-dumping forage box with a weighed container (Kraus et al., 1993). The machine feed rate was determined by dividing the material mass collected during a test run by the test duration. The feed rate chosen was the maximum possible without plugging the harvester at the crop processor (see table 4). After each replicate test, a sample for moisture and particle-size determination was taken. From this sample, particle-size (ASAE S424.2, 1997) and oven dry moisture content (103°C, 24 h, ASAE S328.2, 1997) were determined from two replicate sub-samples. Since most of the field tests lasted all day, the crop's moisture varied between replicate tests. Therefore, the feed rate of each test run was adjusted using a moisture content adjustment factor (ASAE Standards, EP 503, 1997). The moisture adjusted feed rate compensates for the effect of conducting individual tests with crop of different moisture contents and reduces the data scatter associated with data on a wet or dry matter basis.

A torque transducer was mounted between the tractor power take-off (PTO) and the drive shaft of the forage harvester. The torque and PTO speed were measured and stored with a portable, programmable datalogger at 10 Hz. After each test, an average of the collected data was stored by the datalogger. Power requirements were determined from this data. Specific energy was determined by dividing the required power by the moisture adjusted feed rate. Four experimental conditions, unprocessed at 9.5 and 19 mm TLC, and processed with rolls operating at 17 and 50% speed difference (19 mm TLC, 0.2 mm roll clearance), were considered. Four replicates per experimental condition were conducted. The harvester set to one configuration was used to harvest every fourth windrow in the field until the four replicates were completed.

In 1998, field measurements of the harvester specific energy requirements were made while harvesting second cutting alfalfa on 8 July. Procedures used to determine power, throughput, and crop physical properties were the same as those used in 1997 described above. However, the knurled rolls used in 1997 were replaced with the hardened, grooved rolls described above. The variables roll clearance (0.5 and 1.5 mm) and TLC (9.5 and 19 mm) were considered. Roll speed difference was 20%. Two control treatments, unprocessed at 9.5 and 19 mm TLC, were also included.

Analysis of *In Situ* Degradation

On 9 June 1997 an experiment was conducted using the following machine variables: (1) 9.5 mm TLC and unprocessed; (2) 19 mm TLC and unprocessed; and (3) 19 mm TLC and processed (17% speed difference and 0.2 mm roll clearance). The experiment was conducted using first cutting alfalfa at two levels of moisture, about 69% and 47% (w.b.). The crop was harvested using the procedure outlined above. For each experimental condition, about 25 kg of crop was collected, sealed in a plastic bag and placed in a freezer that day (i.e., not fermented into silage). *In situ* 24-h rumen digestion studies were undertaken three separate times in the succeeding six weeks with this material. These experiments used the "macro bag" technique in which about 25 g of DM were placed in 200 × 200 mm polyester bags and sealed (Johnson et al., 1999). Separate sub-samples were oven dried at 60°C for 72 h to determine sample DM. Two or three fistulated Holstein dairy cows with similar milk production and time in lactation were used for each experiment. Typically, *in situ* digestibility tests are conducted using dried and ground forage to produce sample uniformity and to allow many replicates to be placed into the rumen at once. Because the objective of this test was to determine 12 and 24-h ruminal DM disappearance based on physical differences between treatments, samples were placed in the rumen bags in their "as-fed" physical form. This procedure was similar to that successfully used by Johnson et al. (1999). To prevent overfilling of the rumen with these large volume samples, 12 samples, four replicates of each of three treatments, were placed into the rumen 1 h after feeding and all were

removed at the same time. The digestion times of 12 and 24 h were carried out over successive days. The instantly soluble fraction was determined by soaking each treatment in tap water for 30 min and then following conventional washing and oven-drying procedures.

Analysis of Dairy Cattle Performance

Sufficient first cutting alfalfa was harvested for a dairy lactation feeding trial (about 20 t DM/treatment). About 4 ha of alfalfa at about one-fourth bloom was cut each day with a 3.6 m mower-conditioner and laid in a windrow on 31 May, 1 June, and 2 June 1998, respectively. The crop was allowed to wilt for 24 h to about 62% moisture before harvesting. The control silage was harvested with a Gehl 865 pull-type harvester at 9.5 mm TLC and the processed silage was harvested with the experimental pull-type harvester at 19 mm TLC with the processor rolls set at 0.5 mm clearance using the hardened, grooved processing rolls described above. Alternate windrows were harvested with each harvester. All diets were fed as total mixed rations (TMR) containing 60% alfalfa silage on a DM basis (35% DM, 45% NDF). The TMR was formulated to 18.5% crude protein (DM basis) using corn and soybean meal. A total of about 59 and 56 Mg wet matter was harvested with the control and processor harvesters, respectively. Each treatment was placed in separate but similar 3.7 m × 12 m concrete stave silos. About 25 kg of crop were collected from each load, sealed in a plastic bag and transported to the laboratory for analysis of DM, LC, PI, and particle-size using three, two, two, and one replicate samples per load, respectively. Procedures used to determine these physical properties are given above.

A three month feeding trial began in early July 1998, using 16 multiparous Holstein dairy cows (120 days in milk at trial start, half fitted with rumen cannulae), in a replicated 4 × 4 Latin square statistical design (two silage diets both with and without thiamin). Parameters determined included DM intake, milk yield, milk fat and protein contents, eating, ruminating and total chewing time, rumen pH, and *in situ* DM and neutral detergent fiber (NDF) after 24 h of digestion.

Statistical Analysis

All data collected in the machine operating variables and harvester specific energy studies were analyzed using analysis of variance. Statistical differences were determined using a least-square-difference (LSD) at the 95% probability level. The replicated factorial analysis of machine operating variables in 1998 used confidence intervals at the 95% probability level to determine significant effects. The data collected in the *in situ* digestion and dairy cattle performance studies were analyzed using the general linear model procedure of SAS (SAS, 1989).

Results

Analysis of Machine Operating Variables, 1997

The processing rolls altered the physical appearance of wilted alfalfa which was visibly bruised and darker in color than the unprocessed crop and which showed evidence of shredding of the stem. The LC method of determining crop processing level suggested a greater specific surface area for the processed crop at both crop moistures tested (table 1). Processing wilted alfalfa increased LC by more than 45% and reduced particle size by more than 33% compared to the unprocessed control treatment. A large reduction in crop moisture was expected to reduce the effectiveness of processing because the crop was less turgid with greater mechanical strength. In previous work, processing level as quantified by a surface-area-index was reduced when crop moisture went from 72 to 57% (w.b.) moisture when processed in a drum-and-roll macerator (Shinners et al., 1988). Similar results are shown here where the LC test indicated a greater level of processing at 71% moisture compared to 52% moisture where processing increased LC by 56 and 45% compared to the unprocessed control treatment, respectively. Processing reduced particle size by a slightly greater amount at the higher crop moisture, 37 and 33% for 71 and 52% (w.b.) moisture, respectively.

Table 1. Physical properties of processed and unprocessed alfalfa, processed with knurled rolls, and 0.2 mm roll clearance

Operating Conditions			Physical Properties			
Processing	Roll Speed Diff. (%)	TLC (mm)	Moisture Content (w.b.)	Leachate Conductivity (LC) (μS/cm)	Proc. Index (PI) (%)	Geometric Mean Particle-Size (mm)
No	-	19	71	719_a	-	19.3_b
Yes	17	19	”	1125_b	-	12.4_a
LSD (P = 0.05)				39		1.0
No	-	19	52	840_c	-	16.5_d
Yes	17	19	”	1215_d	-	10.9_c
LSD (P = 0.05)				40		0.8
No	-	9.5	64	465_f	39_f	10.9_e
No	-	19	”	402_e	33_e	18.5_g
Yes	17	19	”	652_g	55_g	15.7_f
LSD (P = 0.05)				57	5	2.5
No	-	9.5	69	532_i	36_i	10.5_h
No	-	19	”	470_h	32_h	18.6_i
Yes	17	19	”	696_j	47_j	17.6_i
Yes	50	19	”	754_k	51_k	16.5_i
LSD (P = 0.05)				36	3	3.9

Previous research has shown that two similar fresh alfalfa samples chopped with the same cutterhead but at different TLC produced a different LC (Kraus, 1997). It was speculated that some of the differences in the LC produced by processing and noted above might have been due at least partially to the reduction in particle size created by processing. Therefore, a third treatment, unprocessed cut at 9.5 mm TLC, was added. Processing wilted alfalfa (0.2 mm roll clearance, 17% roll speed difference, 19 mm TLC) reduced particle size by 15% compared to unprocessed alfalfa at 19 mm TLC, but produced a particle size 44% greater than unprocessed cut at 9.5 mm TLC (table 1). Processing wilted alfalfa increased LC by 40 and 62% compared to unprocessed alfalfa cut at 9.5 and 19 mm TLC, respectively. Although reduction in particle size obviously had some effect on increasing LC for the processed treatment, these results suggest that a majority of the increase in LC associated with the processed samples

were due to increased specific surface area from scuffing and shredding of the stem fraction at the processing rolls.

A final experiment was conducted to determine the effect of varying roll speed difference. The results were similar to that reported above in that crop cut at 19 mm TLC and processed at 17% speed difference had 31% greater LC than unprocessed cut at 9.5 mm TLC (see table 5). Increasing the roll speed difference from 17 to 50% increased LC by 8% and reduced particle size by 6%, indicating that higher roll speed difference processed the crop to only a slightly higher level.

Analysis of Machine Operating Variables, 1998

Replicated factorial analysis indicated that both TLC and roll clearance had a significant impact on the crop physical condition as measured by LC and PI (tables 2 and 3). Roll speed difference did not significantly effect LC or PI. Independent of speed difference, operating the harvester at 19 mm TLC and 0.5 mm roll clearance produced a product with about the same LC as when operating at 9.5 mm TLC and 1.5 mm clearance (584 and 586 µS/cm, respectively). However, the particle size for these two machine configurations was 12.5 and 9.3 mm, respectively. The differences in particle-size indicate that the high level of LC for the treatment with short TLC and large clearance was due more to the short TLC than to increased specific surface area from processing. Also, cutting at a shorter TLC and using greater clearance required greater specific energy than using the longer TLC at tighter roll clearance (see table 5). Only TLC had a significant effect on final particle size (table 3). Comparing the unprocessed to the processed treatments indicates that processing reduced the crop particle size (table 2). However, neither clearance nor roll-speed difference significantly affected particle size between processed treatments (table 3).

Table 2. Physical properties of processed and unprocessed wilted alfalfa (processed with hardened, grooved rolls)

TLC (mm)	Speed Diff. (%)	Clear-ance (mm)	Moisture Content (w.b.) (%)	Leachate Conduc-tivity (LC) (µS/cm)	Proc. Index (PI) (%)	Geometric Mean Particle Size (mm)
Unprocessed — 19 mm TLC			63.5_b	366_a	26_a	17.8_e
Unprocessed — 9.5 mm TLC			61.8_a	493_c	35_c	10.6_b
19	20	0.5	64.9_c	612_f	43_e	12.2_c
19	20	1.5	61.7_a	448_b	32_b	12.3_c
19	60	0.5	66.3_d	557_e	40_d	12.7_{cd}
19	60	1.5	64.6_c	525_d	37_{cd}	13.7_d
9.5	20	0.5	63.4_b	660_{fg}	47_f	9.1_a
9.5	20	1.5	63.4_b	542_{de}	38_d	9.4_{ab}
9.5	60	0.5	65.4_c	668_g	47_f	9.1_a
9.5	60	1.5	65.8_d	631_f	45_{ef}	9.3_a
LSD (P = 0.05)			30	2	0.8	1.2

Table 3. 2^3 factorial analyses of effects of operating variables on physical properties of processed wilted alfalfa (processed with hardened, grooved rolls and alfalfa at 64% moisture)

	Average of Parameter at Maximum Setting of Operating Variable	Average of Parameter at Minimum Setting of Operating Variable	Significant Difference*
Leachate Conductivity (LC) (µS/cm)			
TLC — 9.5 or 19 mm	534	625	SD
Speed difference — 20 or 60%	594	565	NSD
Roll clearance — 0.5 or 1.5 mm	534	625	SD
Processing Index (PI) (%)			
TLC — 9.5 or 19 mm	38	44	SD
Speed difference — 20 or 60%	42	40	NSD
Roll clearance — 0.5 or 1.5 mm	38	44	SD
Geometric mean particle size (mm)			
TLC — 9.5 or 19 mm	12.7	9.2	SD
Speed difference — 20 or 60%	11.2	10.8	NSD
Roll clearance — 0.5 or 1.5 mm	11.2	10.8	NSD

* There were no significant interactions between operating variables.

Analysis of Harvester Specific Energy, 1997

Processing wilted alfalfa with processing rolls on the forage harvester considerably increased the machines specific energy requirements (table 4). Also, plugging at the processing rolls hampered the machine feed rate. It was observed that at crop moistures that traditionally produce accumulation of plant sugars and starches (gum), the roll grooves filled and this greatly reduced the ability of the rolls to feed and frequent plugging occurred. The machine was quite sensitive in this respect, where only a small increase in throughput would cause a wedge of crop to form at the roll nip. These tests were conducted late in the season and it was observed that tooth profile on the non-hardened knurled rolls had worn. Measurement of the tooth depth at the end of the season indicated a 36 to 51% reduction in height from initial fabrication. The sharp angular tooth profile was worn flat and the height of the tooth ranged from 0.8 to 1 mm at the edge and center, respectively. As the rolls wore in, it was possible to achieve extremely tight roll clearances that produced a very good level of processing. However, roll wear also reduced feeding effectiveness and caused numerous plugging problems at the roll nip. In both experiments conducted on 7 and 14 August, processing increased machine specific energy requirements by over 105 and 113% compared to the 9.5 and 19 mm TLC control treatments, respectively. Increasing speed difference from 17 to 50% did not produce a significant difference in energy requirements.

Analysis of Harvester Specific Energy, 1998

It was observed that the feeding characteristics of the hardened, grooved processing rolls was considerably more aggressive compared to the knurled rolls used in 1997. When processing alfalfa at relatively high moistures, the

Table 4. Specific energy requirements to harvest processed and unprocessed wilted alfalfa processed with knurled rolls and 0.2 mm roll clearance (avg. of tests conducted on 7 and 14 August 1997)

	Moisture Content (w.b.) (%)	Geometric Mean Particle Size (mm)	Moisture Adjusted Feed Rate (Mg/h)	Moisture Adjusted Specific Energy (kWh/Mg)
Unprocessed — 19 mm TLC	55.8	18.8_a	24.6_a	2.11_c
Unprocessed — 9.5 mm TLC	53.2	7.9_b	27.0_a	2.36_b
Processed — 19 mm TLC 17% speed difference	54.1	8.2_b	20.2_b	4.49_a
Processed — 19 mm TLC 50% speed difference	54.9	8.2_b	21.4_{ab}	4.42_a
LSD (P = 0.05)	3.4	1.7	3.2	0.22

Table 5. Specific energy requirements to harvest processed and unprocessed wilted alfalfa in 1998 (processed with hardened, grooved rolls and 20% roll speed difference)

	Moisture Content (w.b.) (%)	Leachate Conductivity (LC) (µS/cm)	Geometric Mean Particle Size (mm)	Moisture Adjusted Feed Rate (Mg/h)	Moisture Adjusted Specific Energy (kWh/Mg)
Unprocessed — 19 mm TLC	66.9	500_a	23.5_c	32.5	1.79_a
Unprocessed — 9.5 mm TLC	68.8	652_b	14.9_{ab}	32.1	2.28_b
Processed — 19 mm TLC 0.5 mm clearance	71.5	780_c	17.0_b	31.2	2.72_c
Processed — 9.5 mm TLC 1.5 mm clearance	70.7	764_c	13.7_a	29.3	3.10_d
LSD (P = 0.05)		37	2.7	3.3	0.09

harvester was able to maintain a throughput similar to that when the processing rolls were bypassed (table 5). This was in sharp contrast to the research conducted in 1997, when considerable plugging at the processing rolls hampered the machine feed rate. Processing increased specific energy requirements 36 and 52% for 9.5 and 19 mm TLC, respectively (table 5). An interesting comparison might be made between processing at 19 mm TLC and 0.5 mm roll clearance and unprocessed at 9.5 mm TLC because these two treatments produced about the same final particle size (table 5). Here, processing increased specific energy by about 20%. The processed treatments had significantly greater LC than the control treatments, suggesting that the increased specific energy was being used to create greater specific surface area in the crop.

Analysis of *In Situ* Degradation, 1997

Initially, only a 24 h extent of DM disappearance experiment was conducted on crop processed at 69 and 47% (w.b.) moisture. Processing of wilted alfalfa at 69% (w.b.) moisture improved the extent of *in situ* DM disappearance after 24 h by 4.8 percentage units compared to unprocessed cut at 9.5 mm TLC (table 6). However, at 47% (w.b.) moisture, there was no difference in DM disappearance between treatments despite quantified differences in the material LC. Based on these initial results, two additional *in situ* experiments were conducted using only the higher moisture material. This experiment quantified the instantly soluble fraction and the extent of DM disappearance at 12 and 24 h. Results were consistent for both experiments, with the processed crop producing a greater instantly soluble fraction and greater extent of DM disappearance at 12 and 24 h in the rumen (table 6). These results are similar to those found when conducting similar experiments with macerated fresh alfalfa (Kraus, 1997). During the test conducted in August 1997 (table 6), considerable cow-to-cow variation resulted in a large LSD, thus no statistical differences between the treatments were found. However, the processed treatment did produce a numerically greater instantly soluble fraction and a greater extent of DM disappearance at 12 and 24 h.

Table 6. *In situ* DM disappearance of processed and unprocessed alfalfa (processed with knurled rolls at 0.2 mm roll clearance and operating at 17% speed difference)

	Moisture Content (w.b.) (%)	Leachate Conductivity (LC) (µS/cm)	Geometric Mean Particle Size (mm)	Instantly Soluble Fraction (% of total)	12 h *in situ* DM Disappearance (% of total)	24 h *in situ* DM Disappearance (% of total)
Average for Two Cows, June 1997						
Unprocessed — 9.5 mm TLC	69	1078_a	11.7	-	-	55.7_a
Processed — 19 mm TLC	”	1454_b	12.5	-	-	60.5_b
LSD (P = 0.05)		84	1.4			3.9
Unprocessed — 9.5 mm TLC	47	786_c	11.6	-	-	59.5
Processed — 19 mm TLC	”	1044_d	12.6	-	-	59.4
LSD (P = 0.05)		60	1.6			4.2
Average for Two Cows, July 1997						
Unprocessed — 9.5 mm TLC	69	1078_b	11.7	33.4_b	53.6_b	65.6_b
Processed — 19 mm TLC	”	1454_a	12.5	41.0_a	59.6_a	71.7_a
LSD (P = 0.05)		103	1.2	3.4	5.1	5.5
Average for Three Cows, August 1997						
Unprocessed — 9.5 mm TLC	69	1078_b	11.7	41.7	54.9	60.0
Processed — 19 mm TLC	”	1454_a	12.5	43.3	62.1	68.4
LSD (P = 0.05)		103	1.2	11.5	12.4	15.3

Analysis of Dairy Cattle Performance, 1998

Processing increased LC and PI by about 35%, suggesting greater crop specific surface area for the processed treatment (table 7). However, there were no differences in DM intake, milk yield or milk composition between the two treatments (table 8). Ruminating and total chewing time were lower for the 19 mm TLC processed silage compared with the unprocessed silage (table 9), despite the fact that the processed treatment had significantly greater particle size (table 7). Rumen pH and *in situ* 24 h DM disappearance did not differ among the two treatments (table 9). Since the *in situ* work did not

Table 7. Average physical properties of processed and unprocessed wilted alfalfa used in dairy cattle feeding trial, harvested June 1998, and fed July through August 1998 (processed with hardened, grooved rolls at 0.5 mm roll clearance and 50% speed difference)

	Moisture (w.b.) (%)	Leachate Conductivity (LC) (µS/cm)	Proc. Index (PI) (%)	Geometric Mean Particle Size (mm)
Unprocessed — 9.5 mm TLC	62.2	367_b	30_b	11.9_b
Processed — 19 mm TLC	61.9	493_a	41_a	14.5_a
LSD (P = 0.05)	4.5	43	3	1.5

Table 8. Holstein dairy cattle milk yield and composition as affected by silage processing and TLC

	Dry Matter Intake (kg/cow/day)	Milk Yield (kg/cow/day)	Milk Fat (%)	Crude Protein (%)
Unprocessed — 9.5 mm TLC	25.8	40.6	3.66	2.93_a
Processed — 19 mm TLC	26.0	40.5	3.64	2.81_b
LSD (P = 0.05)	1.93	2.1	0.26	0.28

Table 9. Holstein dairy cattle chewing activity, rumen pH, and 24 h *in situ* DM disappearance as affected by silage processing and TLC

	Eating Time (min/day)	Ruminating Time (min/day)	Total Chew. Time (min/day)	Rumen pH 12 h (pH)	24 h *in situ* DM Disappearance (% of total)
Unprocessed — 9.5 mm TLC	207	480_a	687_a	6.32	68.6
Processed — 19 mm TLC	208	425_b	631_b	6.32	69.2
LSD (P = 0.05)	21	39	43	0.14	1.9

prove to be statistically significant, neutral detergent fiber (NDF) 24 h digestion was eliminated from the analysis.

Discussion

Some previous research had shown that processing or macerating forage improved its feed value. Ruminant animals more easily digested processed forage with greater specific surface area compared to conventionally harvested forage. Increased forage surface area can be developed by (a) shredding and abrading the mechanical structure of the stem, and (b) rupturing cells so that cell contents are exposed. Shinners et al. (1987a) found forage will hydrate more rapidly by increasing the specific surface area. Rapidly hydrating particles are more accessible to microbes for digestion and they have a faster increase in specific gravity than particles that absorb water more slowly (Hooper and Welch, 1985). Hong et al. (1988a) found that by rupturing cells, intercellular constituents would be more numerous and accessible to ruminal microbes. Koegel et al. (1992) indicated a 16% improvement in DM digestibility when sheep were fed macerated alfalfa silage compared to conventionally conditioned silage. Hong et al. (1988b) found a significantly higher extent of NDF digestion when processed alfalfa was fed as dry hay compared to conventionally treated alfalfa. Suwarno et al. (1997) reported that processed hay fed to beef steers was 7% more digestible than less processed hay. Mertens and Koegel (1996) reported that cows fed macerated alfalfa silage produced more milk with no difference in DM intake and a decrease in fat content when compared with diets consisting of control silage. Savoie and Block (1994) reported that Holstein dairy animals fed intensively conditioned alfalfa hay had 15% greater DM intake and 15% greater milk yield

On the other hand, some other research regarding crop processing has shown no effect on digestion or lactation performance. Baxter et al. (1966) found no increase in DM consumption and milk production when dairy cattle were fed "lacerated" forage compared to conventionally conditioned forage. Chiquette et al. (1993) found the total digestibility of "super-conditioned" forage was slightly less than conventionally conditioned forage. Koegel et al. (1992) found no increase in milk production when macerated and conventionally harvested silage was fed to 12 dairy cows for eight weeks. In none of the studies mentioned above was the level of crop processing quantified, so differences in animal results could be partially attributed to differences in levels of crop processing.

This research showed mixed results with respect to animal performance. In 1997, processing significantly improved *in situ* DM disappearance. In 1998, processing had virtually no effect on either *in situ* DM disappearance or dairy cattle performance. The mild steel knurled rolls used in 1997 equalized in diameter due to wear, which allowed tight clearances between the rolls. The combination of a very small roll clearance (0.2 mm) and relatively high crop moisture (67%) might have both increased the crops specific surface area by shredding and also resulted in significant cell rupture within the crop. The hardened grooved rolls used in 1998 had some radial run-out that limited roll clearance to a minimum of 0.5 mm. As the crop wilts, the cells become less turgid and more difficult to rupture due to applied pressure from the rolls. The greater roll clearance and drier crop (62% in 1998) might have combined to result in less cell rupture, partially explaining the differences in animal response between 1997 and 1998.

Table 10. LC comparison across two years of alfalfa experiments

	LC: *in situ* Test 1997 69% MC (w.b.) (μS/cm)	LC: Feeding Trial 1998 62% MC (w.b.) (μS/cm)
Unprocessed — 9.5 mm TLC	1078	367
Processed — 19 mm TLC	1454	493
LC ratio*	135%	134%

* Ratio of processed LC to unprocessed LC.

The geometric mean particle size of the processed material was reduced from its TLC by 24% in 1998 (19 to 14.5 mm, table 7). When processing at 0.2 mm roll clearance in 1997, the particle size was reduced by 34% (19 mm to 12.5 mm, table 6). This may indicate that the 1998 feeding trial material was not processed to the same level as the 1997 *in situ* material. However, the ratio of the processed to unprocessed LC was about the same between the DM disappearance work of 1997 and the feeding trail of 1998 (table 10). In this regard, processing level should have been considered similar for both trials.

In 1997, frequent plugging at the roll nip occurred, especially in the moisture range where a "gum" accumulation typically occurs. Since the rolls were not hardened, the rolls wore with use, the roll tooth profile became flat and feeding suffered. Processing at these moistures increased specific energy requirements by more than 100% (table 4). Although the *in situ* DM disappearance appeared promising in 1997, the feeding characteristics of the knurled processing rolls were deemed unacceptable. This lead to the decision in 1998 to obtain hardened grooved rolls with an aggressive tooth profile. Feeding characteristics were improved and the processing increased specific energy requirements by only 36 to 52%. Roberge et al. (1998) reported that processing wilted alfalfa at 67 and 53% moisture (w.b.) increased total harvester energy requirements by 28 and 33%, respectively, considerably less than the 36 to 113% found here. Although level of crop processing was not reported by Roberge et al., they did report an average difference in particle size between processed and unprocessed treatments at the same TLC of approximately 13% compared to 38 to 56% difference found here. This might indicate that Roberge et al. did not process the crop to the extent as reported here, probably due to the greater roll clearance used, and this is why processing specific energy requirements reported by Roberge et al. were not as great as those reported here.

At this time, there are too many problems associated with processing wilted alfalfa with grooved crop processing rolls onboard the forage harvester. Numerous problems such as the danger of picking up rocks from the windrow, frequent plugging, high power requirements, and no statistical increase in dairy cow lactation performance all indicate little incentive for using conventional

processing rolls on wilted alfalfa. Even though these results indicate less than acceptable all around performance when processing wilted alfalfa at the forage harvester, the past successes of various researchers in improving the nutritive characteristics of highly processed forages should provide incentive to further investigate alternative processing methods for wilted crops.

CONCLUSIONS

Processing wilted alfalfa with processing rolls increased crop specific surface area as quantified by leachate conductivity. Processing wilted alfalfa increased the leachate conductivity by greater than 30% in all cases and similarly reduced particle size. Processed wilted alfalfa was visibly darker and more bruised than control treatments.

Processing wilted alfalfa at low moistures increased energy requirements by greater than 100% when throughput was limited by poor feeding at the rolls. Poor feeding was due to a non-aggressive roll tooth profile and gum accumulation in the roll teeth. When harvesting high moisture alfalfa with an aggressive tooth profile, harvester capacity was not limited by roll feeding and processing increased the harvester specific energy requirements by about 36% compared to a control treatment.

Processing wilted alfalfa in 1997 increased the crop's *in situ* DM disappearance at 12 and 24 h by greater than six percentage units and improved the instantly soluble fraction by up to seven percentage units. Processing wilted alfalfa in 1998 did not statistically increase the crop's *in situ* DM disappearance or improve the instantly soluble fraction despite significantly different treatment leachate conductivity. Processing alfalfa silage with an onboard crop processor did not affect digestion or lactation performance of Holstein dairy cattle.

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