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Intensive Conditioning of Alfalfa: Drying Rate and Leaf Loss

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Abstract. A laboratory test fixture was used to evaluate the effect of roll type, roll clearance, mass-flow-rate and swath density. These variables were also considered in field-tests with mower-conditioners and windrowers. Intensive crushing rolls improved drying rate by 3 to 6% (test fixture) compared to intermeshing urethane or steel rolls, respectively, and by 0 to 22% (field tests) compared to intermeshing steel rolls. In field tests, intensive crushing rolls had 38% greater DM loss than the intermeshing steel rolls (4.0 vs. 2.9%) primarily due to poor feeding with the former roll type. Intensive steel rolls with high specific crushing area (96%) and an intermesh to aid in feeding increased drying rate by an average of 7% compared to intermeshing urethane rolls with no difference in DM loss. Machined rolls with many lugs in a closely intermeshing involute pattern produced an average drying rate 17% faster than intermeshing urethane rolls. With two roll types, there was a trend for smaller clearance to improve the drying rate with the most evident improvement when clearance was less than 2 mm. Mass-flow-rate through the conditioners did not significantly affect drying rate. Tandem roll conditioning did not significantly improve drying rate compared a single roll set. Drying rate of conditioned windrows, unconditioned swaths, and conditioned swaths was greater than an unconditioned windrow by an average of 24, 30 and 61%, respectively. There was no statistical difference in drying rate between conditioned material in a windrow and unconditioned material in a swath.

Keywords. Alfalfa, conditioning, drying rate, losses, swath, windrow

Introduction

The field drying rate of alfalfa after cutting plays a major role in the ability to harvest a high-quality crop. Fast drying reduces losses and improves alfalfa quality. The plant continues to respire until it reaches about 40% moisture (w.b.), losing valuable carbohydrates during respiration. Respiration can result in DM losses of 5 to 10% (Rotz and Muck, 1994). Fast drying reduces the exposure to inclement weather. Rain during field curing can leach soluble nutrients from the plant, resulting in DM losses that range from 5 to 30%, depending upon rainfall intensity (Rotz and Muck, 1994). Finally, prolonged exposure to the sun can cause green color bleaching, reducing the commercial value of baled hay.

The geometry and structure of the plant stem is the principal impediment to rapid drying (Bagnall et al., 1970). Alfalfa leaves have high surface to volume ratio and numerous stomata which promote rapid drying. Alfalfa stems have lower surface to volume ratio, fewer stomata, and a semi-impervious epidermis. A large proportion of the initial water lost from a plant is through the stomata (Jones and Palmer, 1932); hence, alfalfa leaves often dry faster than the stem (Bagnall et al., 1970; Fairbanks and Thierstein, 1966). Once the stomata close in response to water loss, the main path for water loss is through the epidermis of the stem.

Drying rate of alfalfa stems can be improved by use of a mechanical conditioner that crushes, breaks or abrades the stem to provide an exit route for moisture. Mechanical conditioning increased alfalfa drying rate by up to 80% (Rotz et al., 1987). The impact of conditioning is influenced by plant, swath, and environmental conditions during field curing (Iwan et al., 1993; Rotz, 1995). Conditioning is most effective when swath density is low and weather conditions favorable. Crop drying rate is highly correlated with solar intensity, and slightly less correlated with air temperature, humidity, and soil moisture level (Rotz, 1995; Sweeten et al., 2003). Conditioning is less beneficial when drying conditions are poor.

Either rolls or impellers are used for conditioning. Rolls condition the stem by crimping or crushing the stem. A crimping device passes the crop between intermeshing, non-contacting rolls, which bend and crack the stem at intervals. A crushing device passes the crop through intermeshing rolls with small clearances, intermittently flattening the stem. In either case, plant moisture evaporates more easily from these breaks in the epidermis. Impeller conditioners use rotating fingers to abrade the plant cuticle and to intermittently crack the stem. Comparisons between impeller and roll designs show varied affects with a slight trend toward faster drying of alfalfa with rolls and slightly faster drying of grass with impeller conditioning (Rotz and Sprott, 1984; Greenlees et al., 2000).

Several recent innovations in conditioning systems are intended to increase alfalfa drying rate by increasing the severity of conditioning. Greater conditioning level is achieved by either increased roll specific crushing area or by increasing the number of stem locations conditioned. Specific crushing area is defined here as that fraction of the roll circumference where clearance can be adjusted small enough to crush the stem. For instance, two smooth, non-intermeshing rolls would have a specific crushing area of 100%. Intermeshing rolls must have some clearance between the lug sidewalls to prevent lug-to-lug interference due to drive backlash, so specific crushing area is lost when more lugs are used. Intermeshing rolls have some crimping effect and feed more aggressively than non-intermeshing rolls. Conditioning level can be increased with intermeshing rolls by reducing the number of lugs or using multiple rolls.

Research has not conclusively proved that one type of conditioner produces the fastest drying rate under all situations. Rotz and Sprott (1984) conducted field tests on five different mower-conditioners and found that drying rates for each machine did not show large, consistent differences between treatments. Shinners et al. (1991) found no significant difference in drying rate between four different types of roll conditioners.

The objectives of this research were to conduct laboratory and field evaluations of intensive conditioning systems, and to compare the effect of roll geometry, swath density, mass-flow-rate and roll clearance on alfalfa drying rate

Materials and Methods

Conditioning System Test Fixture

A laboratory test fixture was designed and fabricated to allow controlled testing of different conditioning mechanisms in an expedient fashion. The test fixture had a fixed base which contained the conditioner drive system and hydraulic cylinders to provide roll pressure, removable top fixtures that housed the conditioning devices, and input and output conveyors. A key feature of the design was that each of the conditioning mechanisms was housed in their own removable top fixture which facilitated rapid changes. The top fixture could be removed by simply disconnecting the splined drive shaft(s) and cables from the hydraulic cylinders; and lifting the top fixture off the base. With this design, it took approximately 5 minutes to make a change from one conditioner type to another.

The top fixture was typically configured with a single set of conditioning rolls that were nominally 76 cm wide. The bottom roll was fixed in the frame and the top roll was placed on pivots which allowed adjustment of clearance between the rolls. The top roll was loaded against its stop by a hydraulic cylinder on either side of the roll. The roll loading system consisted of a hand-actuated pump and an accumulator. Roll clearance was controlled by a pair of threaded rods that suspended the pivoting end of the top roll pivot. Additional top fixtures were configured so that a tandem set of conditioning rolls could be tested. The second roll set also had a fixed bottom roll and pivoting top roll. The second roll set was driven through a roller chain drive from the first set. The second roll set rotated approximately 14% faster than the first rolls in order to help minimize the risk of plugging, similar to Helwig et al. (1983). The sprockets on the second roll sets were attached to their hubs through circumferential slots that allowed adjustment of relative angular position between the two roll sets to facilitate timing of the two roll sets. A final top fixture was configured so that an impeller conditioner could be tested (described below).

Table 1 contains some of the specifics of the conditioner types used in this study. Unless otherwise noted, the roll sets used were commercially available. Radial high and low spots were identified on the roll using a dial indicator and the high and low spots meshed when the roll sets were placed in the top fixture during final assembly to assure that differences in roll clearance could be minimized.

Rolls were of one of three types: crimping, crushing or combination crushing/crimping (fig. 1). Crimping rolls have many deep lugs that intermesh between the two rolls and are intended to create faster stem drying by bending and breaking the stem multiple times along its length as it passes through the meshed rolls. Roll clearance is typically not sufficiently small with this roll type to accomplish much conditioning by crushing. The intermeshing steel rolls used here were considered crimping rolls. Crushing rolls have no lugs and do not intermesh, so they are intended to improve stem drying by flattening the stem along its length. Stem flattening is achieved by roll clearances less than the stem diameter. Rolls without lugs have high specific crushing area, but are known to be difficult to feed. The intensive crusher rolls used here were considered crushing rolls. A crushing/crimping roll is essentially a crushing roll with a series of lugs to improve feeding. These rolls have fewer lugs with greater land area than the crimping rolls. The intermeshing urethane and ti-core rolls were considered crushing/crimping rolls (fig. 1).

For crushing to take place, the roll clearance must be less than the stem diameter. Achieving this roll clearance can be difficult if roll fabrication techniques result in rolls with too much radial runout. Small runout can be achieved by rigorously maintaining fabrication tolerances or by a final machining operation. The machined steel rolls (fig. 1) were intended to improve conditioning effectiveness by using many deep lugs with a machined outer diameter than allowed tightly held roll tolerances. The intensive steel crusher rolls (fig. 1) were intended to have high specific crushing area, with a lugged design for improved feeding. The steel construction would provide superior wear resistance compared to urethane or ti-core rolls. These rolls were only available for tests in full-scale machines.

The involute rolls were intended to be a highly machined roll set that would provide crushing along the whole stem length while also provide some crimping due to the number and depth of the lugs. The rolls were fabricated using polyurethane (95 shore A durometer) molded onto 250 mm diameter steel cores. Convex and concave mill cutters were then used to machine the 12 lobes of 28 mm depth so that the final roll diameter was 25 cm. These rolls were very similar to an intermeshing set of gear teeth so that conditioning took place throughout the roll mesh (fig. 1).

The impeller conditioner consisted of 20 tines that were 5 mm thick steel, 180 mm long and 75 mm wide. The tines were attached to a 125 mm diameter core so that they were free swinging and at each pivot location there were two tines in a v pattern. The distance between the conditioning hood and the tine tips was 3 mm and the rotor speed was 624 rpm.

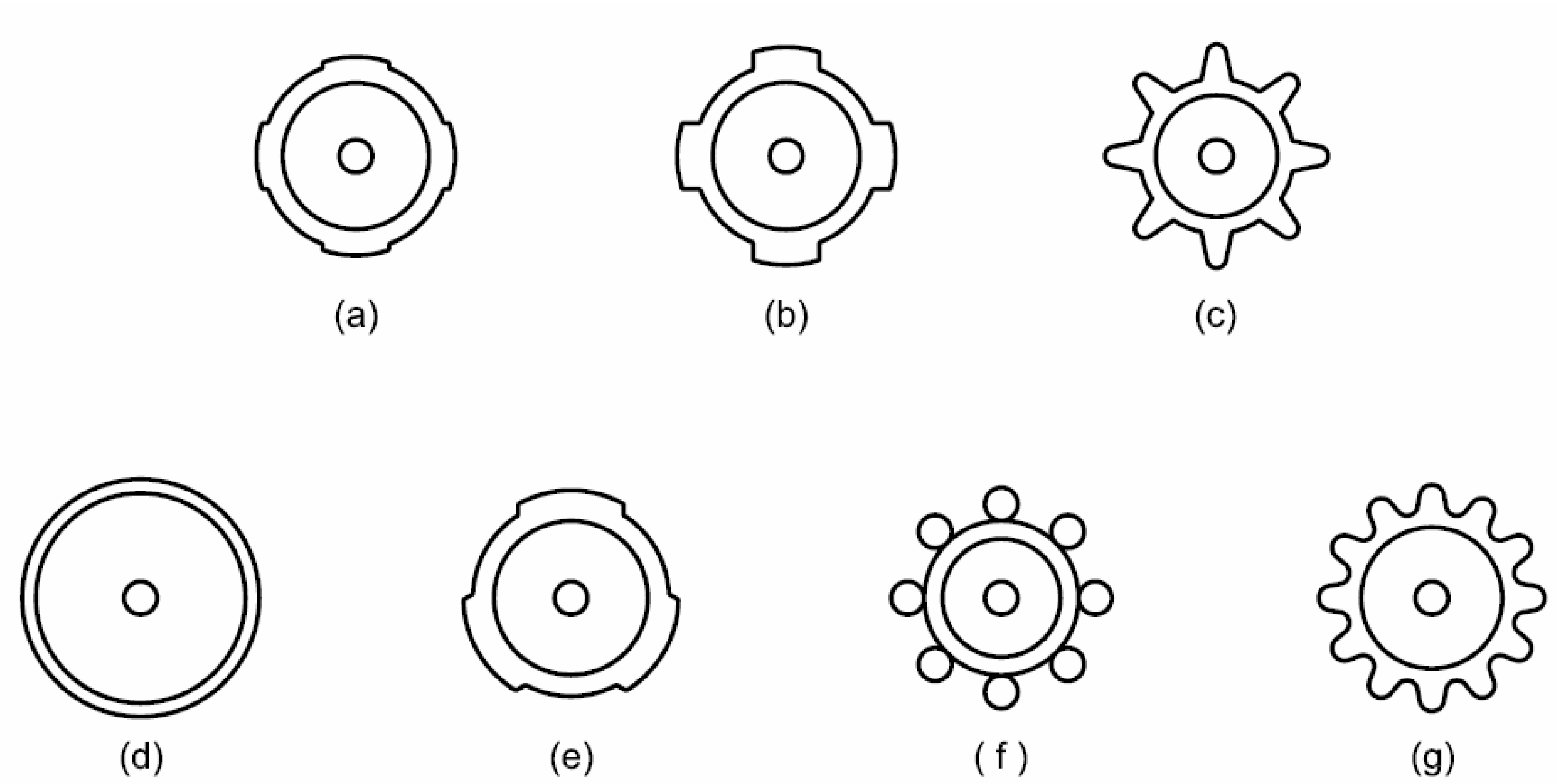

Figure 1: Schematic representation of rolls used in the laboratory test fixture or in field-tests with mower-conditioners and windrowers: (a) intermeshing ti-core, (b) intermeshing urethane, (c) intermeshing steel, (d) intensive crusher, (e) intensive steel (field tests only), (f) machined steel and (g) involute.

Table 1. Specifications of rolls used in experiments using the laboratory test fixture .

Conditioner type	Outer diameter	Lug depth	No. of lugs	Lug pattern	Roll material	Specific crushing area*	Durometer
	cm	cm				%	
Intermeshing urethane	25	2.5	4	Helical	Urethane	78	95
Intermeshing steel	25	3.8	8	Straight	Steel	24	N/A
Intermeshing ti-core	25	1.3	4	Helical	Ti-core	86	
Intensive crusher	26	-	-		Rubber	98	45
Intensive steel#	25	1.3	3	Straight	Steel	96	N/A
Involute#	25	2.9	12	Straight	Polyurethane	100^	95
Intermeshing machined steel#	25	3.8	8	Straight	Steel	40	N/A

– Experimental rolls that were designed and fabricated as part of this research. All other roll types were commercially available. Intensive steel rolls were only available for field tests with mower-conditioners and windrowers.

* – The fraction of the roll circumference where roll clearance can be set to 2 mm with the mating roll.

^ – Crushing area of 100% achievable if drive backlash was sufficiently small enough to prevent roll-to-roll contact.

Laboratory Test Procedure

To collect material for a drying trial, a sickle mower-conditioner, with the conditioning rolls blocked open 8 cm to ensure that no conditioning occurred, was used to first cut and windrow the crop. The cut crop was gathered by hand and transported to the laboratory. The required sample mass was weighed on a 45 kg capacity platform scale with 0.1 kg resolution. The mass of the material conditioned per sample was determined as follows. It was assumed that a mower-conditioner with a 4.9 m cut was traveling at 9.7 km/h and 95% of the cut width was being used, so 4.5 ha/h were being mowed. If crop yield was 22.5 Mg WM/ha, then mass-flow-rate through the harvester would be 28 kg/s. The test fixture conditioners were 76 cm wide and a 4.9 m wide mower-conditioner typically has a conditioner width of 280 cm. Therefore, in order to have the equivalent throughput, the mass-feed-rate to the test fixture was set at 7.6 kg/s.

After conditioning, four 4.5 kg sub-samples were collected and placed into plastic bags and temporarily stored in a cool, shaded location. Then a conditioner adjustment was made or another conditioning unit placed on the test fixture and the process was repeated until all treatments were completed. Next, the samples were taken to the field and their contents were spread out evenly onto drying trays. The trays measured 0.91 m wide by 1.52 m long, and were covered with nylon mesh window screen. These trays and their contents would then be weighed numerous times throughout the drying period with a hanging scale having a capacity of 23 kg with 0.1 kg resolution.

Trays were weighed approximately every two hours for one or two days until the hay reached typical raking moisture, about 40% w.b. Then the material was turned in such a manner that the wet side (original bottom) was on top of the tray. Care was taken so as not to excessively disturb the hay mat or loose material during this operation. The trays were then weighed until they reached approximate baling moisture (20% w.b.) or adverse weather intervened. The content of each tray was then gathered by hand and placed into plastic bags. The bags were taken back to the lab where the hay was chopped using a stationary forage chopper. After the samples were chopped, three sub-samples were taken from each treatment, placed in paper bags, weighed, and then oven dried for 24 h at 103ºC as per ASAE Standard: S358.2 (ASAE, 2004). After the 24-hour oven drying period the dry mass of the tray contents were calculated, and used to back calculate the moisture of the material on each tray at every weighing period.

To quantify leaf loss as affected by conditioner type or configuration, a pickup from a forage harvester was mounted at the end of the output conveyor. The pickup was 76 cm wide with a tine spacing of 75 mm tine an extended diameter of 55 cm. The tip speed of the tines was set to 1.4 m/s, about 10% greater than the linear speed of the output conveyor. Material not captured by the pickup was identified as loss, which was expressed as a fraction of the total DM. During leave loss experiments, crop flow-rate and other operating parameters were similar to those described above.

Laboratory Experiments Conducted

Five experiments were conducted to investigate the effect of conditioner type, roll clearance, mass-flow-rate, number of rolls and swath density. A control treatment of unconditioned material was included in all the experiments. Each treatment was replicated four times during each experiment. All experiments were conducted in the summer of 2001 at the West Madison Agricultural Experimental Station using alfalfa from various cuttings as specified below (table 2).

The conditioner type experiment included all the conditioners described in table 1. Mass-flow-rate was 7.6 kg/s and roll linear force was 35 N/cm. Roll clearance was adjusted to 1.5 mm for all intermeshing roll sets and the crusher clearance was 0.5 mm. Impeller to hood clearance was 3 mm. The experiment was replicated three times on May 28th – 30th, June 7th – 9th and June 9th – 11th, 2001 using first cutting alfalfa that ranged from pre-bloom to half flower.

The roll clearance experiment used the urethane and machined steel rolls at four roll clearances each: nominally 0.75, 1.75, 2.75, and 3.75 mm. Mass-flow-rate was 7.6 kg/s and roll linear force was 35 N/cm. The experiment was replicated twice on June 13th – 17th and June 20th – 23rd using first cut alfalfa that ranged from half flower to full bloom.

The mass-flow experiment included the intermeshing urethane and steel rolls and impeller conditioner. The roll clearance was 1.5 mm for both roll sets and the impeller hood clearance was 3 mm. Mass-flow rates were 6.2, 7.6 and 9.0 kg/s. The experiment was replicated twice on June 26th – 27th and June 28th – 29th using second cut alfalfa that ranged from pre-bloom to half flower.

The multiple-roll experiment compared the drying performance of alfalfa conditioned with a single set of urethane rolls to that of ti-core rolls followed immediately by the crushing rolls. The roll clearance was 1.5 mm for the urethane and ti-core rolls and was 0.5mm for the crushing rolls. Mass-flow-rate was 7.6 kg/s and roll linear force was 35 N/cm. The experiment was replicated twice on July 9th – 11th and July 19th – 20th using second cut alfalfa that ranged from half flower to full bloom.

The final experiment considered the effect swath density using the intermeshing urethane and machined steel rolls. The roll clearance was 1.5 mm for the urethane and 0.75mm for the machined steel rolls. Mass-flow-rate was 7.6 kg/s and roll linear force was 35 N/cm for both roll sets. Material conditioned with either roll set was placed on the drying trays at either 0.7 or 1.1 kg DM/m^2. If the assumed yield was 22.5 Mg WM/ha (see above) and the initial moisture was 80% (w.b.), then these densities represented a swath laid at 64 to 40% of cut width. This experiment was replicated three times on August 7th- 9th, August 13th-14th and August 20th – 21st using third cutting alfalfa that that ranged from pre-bloom to half flower.

<u>Field Test Procedures</u>

Field tests using full-scale mower-conditioners or windrowers were conducted to compare various conditioner types. These tests were conducted in SE Wisconsin, NC Utah or SW Kansas (table 3 and 4). The machines tested were owned by cooperating alfalfa producers. When the focus of the test was the conditioning system, the machines tested on a cooperating farm were the exact same model and cutting width but with different conditioning systems. Prior to testing, the machines were cleaned and the cutting platforms adjusted to have similar reel speed, cutting angle, push bar height, cutting height, roll force

Table 2. Average ambient conditions during the daytime drying period when weight measurements were recorded for the five different laboratory conditioning experiments conducted in Wisconsin in 2001 using the conditioning test fixture.

Date	Ambient temperature	Solar radiation	Wind speed	Relative humidity	Table number#
	°C	W / m^2	m/s	%	
Conditioner Type					
May 28th – 30th	17.7	577	4.1	49	6
June 7th – 9th	22.2	552	2.8	57	"
June 9th – 11th	26.2	561	5.3	54	"
Roll Clearance					
June 13th – 17th	25.1	568	5.6	61	12
June 20th – 23rd	21.5	647	3.4	51	"
Mass-Flow-Rate					
June 26th – 27th	28.3	717	3.8	48	13
June 28th – 29th	27.4	620	4.6	54	"
Multiple Rolls					
July 9th – 11th	27.5	695	4.7	44	15
July 19th – 20th	28.4	543	3.1	73	"
Swath Density					
August 7th – 9th	30.6	614	4.1	72	16
August 13th – 14th	22.2	645	3.1	52	"
August 20th – 21st	24.8	613	1.9	49	"

– tables where results from each experiment can be found.

Table 3. Specifications of mower-conditioners or windrowers used in field tests where effect of conditioner type was examined.

Location and Date	Cutter-bar	Cutting width	Cutting Speed	Roll Clearance	Roll Force	Number of replicated tests	Table number^
		m	km/h	mm	N/cm		
Utah – 1999							
Intermeshing steel	Sickle	4.9	9.7	3.5	16	3	7
Intensive crusher	"	"	"	0.3	35	"	"
Wisconsin – 1999							
Intermeshing steel	Sickle	4.9	9.5	2.5	16	1	8
Intensive crusher	"	"	"	0.3	35	"	"
Kansas – 2000							
Intermeshing steel	Sickle	5.5	8.9	4.5	16	1	9
Intermeshing urethane	"	"	"	3.5	31	"	"
Intensive crusher	"	"	"	0.3	37	"	"
Wisconsin – 2002							
Intermeshing urethane	Disk	3.5	11.0	1.2	35	5	10
Intensive steel	"	"	"	1.5	"	"	"
Utah – 2003							
Intermeshing urethane	Disk	4.5	13.2	1.0	35	5	11
Intermeshing steel	"	"	"	1.9	"	"	"
Intensive steel	"	"	"	0.6	"	"	"
Impeller#	"	"	"			"	"

– Impeller speed was 624 rpm and hood clearance 25 mm.
^ – tables where results from each experiment can be found.

Table 4. Specifications of mower-conditioners or windrowers used in field tests where effect of mass-flow and swath density was examined.

Location, Date and Experiment	Cutter-bar	Cutting width	Cutting Speed	Roll Clearance	Roll Force	Number of replicated tests	Table
		m	km/h	mm	N/cm		
Wisconsin – 2002							
Mass-flow-rate							
Intermeshing urethane	Disk	3.5 – 4.0	13.1	1.5	35	4	14
Impeller	"	"	"			"	"
Wisconsin – 2003							
Swath width							
Intermeshing urethane	Disk	3.5	13.0	0.8	35	2	17

and swath width. Roll clearance was adjusted to the desired setting and then crop harvested to confirm that the set clearance did not result in excessive plant damage as judged subjectively by researchers and farm cooperators. If excessive damage was evident, then roll clearance was increased slightly.

Roll clearance was quantified by hand feeding three hollow rolls of aluminum foil through the conditioning rolls. The hollow rolls were formed by wrapping pieces of 45 x 90 cm foil around a 0.95 cm mandrel. The three rolls were hand fed about 25 cm from each end of the rolls and at the roll center. A digital caliper was then used to measure the crushing points on each piece of foil. At least three crushing points on each foil roll was then averaged together to determine the average roll clearance of the machine

The field was laid out in plots based on the number of treatments and replicates. Each treatment was randomly assigned to a sub-plot within each plot and the plots replicated from four to six times. The machine would then be used to cut a full-width strip in the field at a ground speed typically used by the cooperator. A full-width strip was assured by leaving a thin strip of uncut material between treatments, which was subsequently shredded back onto the ground with a lawn mower. Blocks were about 150 m long and contained as many sub-plots as treatments. Cutting typically started at 8:00 am and every effort was made to complete the cutting as rapidly as possible to insure all treatments experienced the similar drying conditions. Drying rate was quantified using two different methods: drying trays and swath sampling.

Table 5. Average ambient conditions during the daytime drying period for the conditioning experiments conducted in 1999 – 2003 using field tests of mower conditioners.

Location – Date – Experiment	**Ambient temperature**	**Solar radiation**	**Wind speed**	**Relative humidity**	**Table number**
	º C	W / m^2	m/s	%	
Utah – 1999 – Conditioner Type					
June 14th – 18th	28.3			41	5
June 16th – 20h	29.5			33	"
July 21st – 24th	31.7			21	"
Wisconsin – 1999 – Conditioner Type					
August 3rd – 5th	25.0			69	6
Kansas – 2000 – Conditioner Type					
June 26th – 27th	28.1			40	7
Wisconsin – 2002 – Conditioner Type					
June 27th – 29th	26.1	593	4.1	60	8
July 1st – 3rd	29.8	665	6.5	59	"
July 11th – 13th	24.6	689	3.2	46	"
July 15th – 17th	28.4	661	3.3	55	"
August 6th – 8th	22.7	640	2.2	59	"
Utah – 2003 – Conditioner Type					
June 3rd – 5th	24.4			30	9
June 6th – 8th	21.7			28	"
June 10th – 12th	23.1			35	"
July 16th – 18th	31.4			27	"
July 19th – 21st	26.1			25	"
Wisconsin – 2001 – Mass-Flow					
June 8th – 11th	25.3	584	4.6	53	12
June 14th – 17th	23.9	541	5.1	62	"
June 20th – 23rd	21.0	571	3.2	56	"
July 4th – 6th	22.5	674	5.5	47	"
Wisconsin – 2003 – Swath Density					
July 22nd – 24th	22.4	679	4.0	58	15
August 4th – 6th	24.3	549	2.9	68	"

The drying trays used were similar to those described above. After all the treatments and replicates had been cut, two drying trays were placed in the swath formed in each sub-plot. A shears was used to cut out a 1-m wide sample across the swath where a drying tray was to be located and two fifteen-tine forks were used to gently lift the swath and place it on the drying tray. The trays were then placed back in the swath. The procedures for weighing and quantifying the contents drying rate are the same as described above.

The swath sampling technique involved periodically removing two samples per sub-plot, typically four to five times per day. At sampling, about 0.5 m of material was collected across the full width and depth of the swath, placed in a container and then chopped. No sample was taken immediately adjacent to a previous sample to eliminate edge effects. The chopped material was mixed and then three sub-samples collected and oven dried using procedures described above. Moisture was calculated at each sampling time.

Leaf loss was quantified when time and resources permitted. Thin sheets of plastic (30 m length) were wrapped around a tube that was placed on a mandrel underneath and behind the conditioning rolls. The free end of the plastic was staked to the ground. As the machine drove away, the plastic unrolled onto the stubble so that the conditioned forage would fall onto the sheet. To insure that machine equilibrium had been reached, samples were taken toward the end of the sheet. A sample was taken by first placing a 2.4 m square frame across the sheet and then shears used to cut along the outside edge of the frame to separate the sample from the swath. The material within the frame was gently lifted with a five-tine fork (51 mm tine spacing) and then weighed. The unrecovered (i.e. lost) material was then collected and weighed. Sub-samples of recovered and lost material were oven dried for moisture determination as described above. Losses were represented as a percentage of the total dry matter from the 2.4 m sample section. Two samples were taken per sheet and each treatment was replicated at least three times.

Field Test Experiments Conducted

Experiments were conducted to investigate the effect of conditioner type, crop mass-flow-rate, and swath density. When cooperators allowed, a control treatment of unconditioned material was included. Field tests were conducted in NC Utah, SE Wisconsin and SW Kansas to investigate drying rate differences between intensive conditioning rolls and conventional intermeshing rolls (table 5). Additional tests in NC Utah and SC Wisconsin compared drying rate differences between intensive steel conditioning rolls and conventional intermeshing rolls. A final set of tests were conducted in SC Wisconsin to determine the effect of mass-flow and swath-density on drying rate.

Data Analysis

No matter if the drying tray or swath sampling technique was used, the data was analyzed assuming that the data fit the following exponential model (Rotz and Chen, 1985):

$$\frac{M}{M_0} = e^{-kt} \qquad (1)$$

where:

M	=	dry basis moisture at the end of the time interval,
M_0	=	dry basis moisture at the beginning of the time interval,
k	=	drying constant (h^{-1})
t	=	length of time interval (h)

For each day and treatment, the drying constant was then transformed based on the least square linear regression model of several data points (Greenlees et al., 2000):

$$k = \frac{n\sum t_i \ln \mu_i - (\sum t_i)\sum \ln \mu_i}{n\sum {t_i}^2 - (\sum t_i)^2} \qquad (2)$$

where:

k	=	transformed drying rate constant (h-1)
n	=	number of observations in each day
t_i	=	actual drying time between each observation
μ_i	=	dry basis moisture content

A daily transformed k-value was calculated for each treatment and an average drying constant also determined over the period of the study. A single factor analysis of variance was conducted on all the experiments to determine statistically significant differences in the treatment averages for each day. A two-way analysis of variance was used to block confounding effects of different days when analyzing the data across single or multiple tests. The statistical significance of the variables was based on a least significant difference (LSD) with a probability of 95%. This value used the mean square of the error within each group and was calculated using one treatment degree of freedom and setting the residual degree of freedoms equal to number of samples.

Results

Conditioner Type

When tested in the conditioner test fixture, the conditioners were statistically grouped into four groups from fastest to slowest drying. The conditioners producing the fastest drying were the involute and the machined steel roll sets, followed by the ti-core and the crusher rolls, the intermeshing steel and urethane rolls and finally the impeller conditioner (table 6). The involute and intermeshing machined steel rolls produced the most thorough conditioning because they were machined rolls that produced the most uniform roll clearance. These rolls also had more and deeper lugs than the other rolls types, so crop was conditioned not only by crushing but also by crimping. The involute roll set was very difficult to operate because backlash in the roll drive resulted in roll interference, which produced considerable roll noise. The ti-core rolls were also machined, but did not have as high a specific crushing area as the involute rolls, which may have slightly reduced the conditioning effectiveness for the former roll type. The intermeshing steel and urethane rolls had the smallest specific crushing area of the commercial roll sets, which probably led to less effective crushing and slower drying. Of the four commercially available roll sets (table 3), there was only a 9% difference between the smallest and largest drying rate constants. This equated to a final moisture difference of only three percentage units between the intermeshing urethane and ti-core roll treatments.

Table 6. Average drying rate of first cutting alfalfa in 2000 as affected by conditioner type in the conditioner test fixture.

Conditioner type[#]	Average drying rate constant .. h^{-1}				Average moisture .. % w.b.		Average density of swath kg DM / m^2
	May 28th – 30th	June 7th – 9th	June 9th – 11th	Overall average	Initial	Final	
Intermeshing steel	0.103_{c}	0.133_{c}	0.175_{cd}	0.137_{cd}	81.3	21.6_{b}	0.74
Intermeshing urethane	0.104_{c}	0.133_{c}	0.164_{c}	0.133_{c}	82.0	22.6_{b}	0.72
Intermeshing ti-core	0.104_{c}	0.145_{d}	0.188_{e}	0.145_{e}	80.8	19.5_{ab}	0.77
Intensive crusher	0.107_{cd}	0.134_{c}	0.183_{de}	0.141_{de}	81.2	20.2_{b}	0.74
Intermeshing machined steel	0.115_{de}	0.151_{d}	0.190_{e}	0.152_{f}	81.3	17.0_{a}	0.74
Intermeshing involute	0.123_{e}	0.149_{d}	0.194_{e}	0.155_{f}	81.5	16.5_{a}	0.73
Impeller[^]	0.089_{b}	0.111_{b}	0.138_{b}	0.113_{b}	81.6	30.6_{c}	0.73
No conditioning	0.079_{a}	0.095_{a}	0.121_{a}	0.098_{a}	81.8	36.7_{d}	0.72
LSD[*] (P = 0.05)	0.009	0.007	0.012	0.005	1.6	3.1	0.06

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

\# – Intermeshing rolls were set to common average clearance of 1.5 mm. Intensive crusher clearance was 0.5 mm. All roll sets set to roll force of 35 N/cm. Mass-flow-rate into conditioners was 7.6 kg WM/s.

^ – Impeller to hood clearance was 3 mm and impeller speed was 624 rev/min.

The intensive crusher rolls improved alfalfa drying by 3 to 6% compared to intermeshing urethane or steel rolls, respectively. The commercially available roll sets improved alfalfa drying by 36 to 48% compared to no conditioning. The impeller dried 15% faster than no conditioning at all, but still significantly slower than all of the roll-type conditioners.

The intensive crusher rolls were tested against commercially available intermeshing steel, urethane, or steel/rubber roll sets in three locations in the US (tables 7 – 9). The intensive crusher rolls improved drying rate by 0 to 22%, with statistically faster drying rates in three of the five replicated tests conducted. In the first series of tests conducted, the intensive conditioner only improved drying of windrows, not swaths (table 7). The differences were greater than those found with the conditioner test fixture most likely because clearances for the intermeshing roll sets were greater in the full-scale machines. Smaller clearances could be achieved in the test fixture because radial runout was less than in the full-scale machines. In some climates, these drying rate differences might have little practical implication. For instance, in arid climates where baling occurs at night, there are no practical advantages if both intensive crusher and intermeshing rolls produce drying rates that result in the crop being less than 18% moisture (w.b.) the same afternoon.

Averaged over 10 replicated tests, there were no statistical difference between the drying rate created by the intermeshing urethane and intensive steel rolls in field tests with full-scale machines (table 10 – 11). However, the intensive conditioner rolls produced statistically faster drying of alfalfa in 4 of the 10 tests, and numerically faster drying in 8 of 10 tests. Averaged across the 10 replicated tests, the intensive steel rolls produced a 7% faster drying rate. In the tests conducted in an arid climate (table 11), the intensive steel rolls produced a 10 and 16% faster drying rate than that produced by intermeshing steel and impeller conditioners, respectively.

The impeller conditioner was included as a treatment in four experiments involving 11 replicated tests with full-scale machines and three tests with the conditioner test fixture. Compared to the most common commercially available roll conditioning systems (intermeshing urethane or steel), the impeller dried statistically slower in all the test fixture experiments (table 6) and in 7 of the 10 full-scale machine replicated tests (tables 11, 13 and 14). Averaging across all experiments, the impeller dried 16% slower in the tests fixture experiments and 9% slower in the full-scale tests. Compared to not conditioning, conditioning with common commercially available rolls or the impeller improved drying rate by 36 and 17%, respectively.

Roll Clearance

For the two roll types studied, there were essentially no statistical difference in the drying rate of the crop across the clearances studied, but there was a trend for smaller clearance to improve the drying rate (table 12, fig. 2). Normalizing the data by dividing the treatment drying coefficient by the untreated coefficient shows how much faster each treatment dried in relation to the unconditioned treatment. The largest incremental improvement in drying rate occurred when roll clearance was set under 2 mm for either roll type. The largest stem diameter when this experiment was conducted was about 3 mm, so at roll clearances above this value, conditioning was most likely caused by crimping of the stem as it passed through the roll intermesh. At clearances below this value, conditioning was a combination of crimping and crushing, which led to faster drying than crimping alone.

Mass-Flow

Mower-conditioner productivity continues to grow by increased use of wider cutting platforms. However, design constraints limit the growth in width of the conditioning rolls, so as machines cut wider; more crop mass is often conditioned in the same width rolls. The same phenomenon occurs when speed is increased to increase productivity. A disk cutterbar can mow nearly twice as fast as sickle cutterbar, which produces twice the mass-flow through the conditioners of disk mower-conditioners. When swath density was the same for all treatments, there was no trend for mass-flow rate through the conditioner to effect drying rate for any of the conditioners tested (tables 13 and 14). The linear speed of the conditioning systems was at least six times that of the incoming material, so there was probably a significant thinning of the layer of material as it passed through the conditioner, which mitigated the effect of mass-flow entering the conditioning fixture. When swath width was set equal for two machines with different cutting width, drying rate was statistically slower for the high density swaths created with the wider machines (table 14). It can be concluded that the dominant factor affecting drying rate is not the mass-flow of crop through the conditioner, but the density of the created swath, and it is this factor that penalizes wider mower-conditioners with slower drying rate.

Number of Rolls

Non-intermeshing crushing rolls have an advantage in that they have the highest specific crushing area of all the roll types studied (table 1). However, non-intermeshing rolls do not feed well, especially if the crop is wet. This was an observation made in several of the field tests conducted with full-scale machines using intensive crushing rolls. One solution to this problem is to use two roll sets. The first set would be an intermeshing set acting as feedrolls to a set of smooth crushing rolls. Hellwig et al. reported on a tandem roll mower-conditioner to hasten the drying of Coastal bermudagrass (1983). They reported that a tandem roll mower-conditioner only slightly improved the drying rate compared to that produced with a single rolls set, and the differences were not statistically different. Similar results were found here as there was no significant difference in alfalfa drying when conditioned with a single set of intermeshing urethane rolls or by the intermeshing ti-core rolls followed immediately by the crushing rolls (table 15). With either conditioner type, conditioning improved drying rate by 35 to 40% compared to no conditioning.

Swath Density

The drying rate of a narrow windrow of unconditioned alfalfa could be improved by conditioning, or by placing it in a wide swath or by both treatments. In tests using the laboratory test fixture, these three treatments improved drying rate of the unconditioned narrow windrow by 19, 25 or 71%, respectively (table 16). In field tests using a mower-conditioner, these three treatments improved drying rate of the narrow windrow by 29, 34 or 51%, respectively (table 17). Therefore, for the roll types and swath densities studied, swath density had greater impact on alfalfa drying than conditioning. In both studies, there was no statistical difference in drying rate between conditioned material in a high density windrow and unconditioned material in a low density swath. Essentially, placing material in a narrow windrow masked the benefits gained from conditioning.

Leaf Loss

In tests involving the conditioning test fixture, there were no significant differences in leaf loss between most of the roll types, with the exception of the involute rolls (table 18). The involute rolls had many lugs and operated at very close clearances. Due to backlash in the roll drive, there was frequent contact between the two rolls, which lead to clipped leaves and upper plant parts and greater DM loss. In four field tests comparing leaf loss from sickle windrowers with intermeshing steel or intensive crusher rolls, the latter roll type produced 33% greater leaf loss (table 19). The differences between the laboratory and field results were most likely due to differences in feeding characteristics of the intensive crushing rolls. In the field, it was observed that crop would sometimes momentarily slip at the nip of the intensive crushing rolls before being pulled through, which likely led to leaf and stem fragmentation. This feeding phenomenon was not evident in the laboratory test fixture. Field tests of intermeshing urethane and intensive steel rolls showed no difference in leaf loss, so the drying improvements of this roll type occurred without added DM loss. Small roll clearance created faster drying rate (fig. 2), but also created greater leaf loss (table 21).

Table 7. Average drying rate of first and second cutting alfalfa in northern Utah in 1999 as affected by conditioner type using field tests of sickle cutterbar windrowers.

Conditioner type#	Roll clearance mm	Roll force N/cm	Average drying rate constant .. h^{-1} June $15^{th} – 17^{th}$	July $17^{th} – 19^{th}$	July $21^{st} – 23^{rd}$	Overall average	Average final moisture % w.b.	Average time when 18% w.b. was reached
			Windrow density#					
Intensive crusher	0.3	35	0.111_b	0.095_c	0.128	0.111_b	11.5_a	3:45 PM
Intermeshing steel	3.5	16	0.085_a	0.078_a	0.118	0.094_a	17.6_b	5:30 PM
			Swath density#					
Intensive crusher	0.3	35	0.108_b	0.092_{bc}	0.126	0.109_b	11.3_a	3:45 PM
Intermeshing steel	3.5	16	0.098_{ab}	0.096_c	0.130	0.108_b	14.5_{ab}	3:45 PM
LSD* (P = 0.05)			0.014	0.015	0.035	0.009	3.8	

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

– Average initial moisture was 74.5% w.b., cutting speed was 9.7 km/h, and cut width was 4.9 m. Swath and windrow width were 1.8 and 1.2 m and swath and windrow density was 0.74 and 1.19 kg DM/m^2, respectively.

Table 8. Average drying rate of third cutting alfalfa in east central Wisconsin on August 14th – 16th, 1999 as affected by conditioner type using field tests of sickle cutterbar windrowers.

Conditioner type#	Roll clearance mm	Roll force N/cm	Average drying rate constant .. h^{-1}	Final moisture % w.b.
Intensive crusher	0.3	35	0.073_b	26.8_a
Intermeshing steel/rubber	2.5	16	0.060_a	32.9_b
LSD* (P = 0.05)			0.009	3.3

* – Averages with different subscripts in the same column are significantly different at 95% confidence.
# – Average initial moisture was 75.2% w.b., cutting speed was 9.5 km/h, cut width was 4.9 m, swath width was 1.5 m and swath density was 0.76 kg DM/m^2.

Table 9. Average drying rate performance of first cutting alfalfa in south western Kansas on May 23rd – 25th, 2000 as affected by conditioner type using field tests of sickle cutterbar windrowers.

Conditioner type#	Roll clearance mm	Roll force N/cm	Average drying rate constant .. h^{-1}	Final moisture % w.b.
Intensive crusher	0.3	30	0.139_b	15.4_a
Intermeshing steel	4.5	31	0.110_a	26.2_b
Intermeshing urethane	3.5	37	0.115_a	23.4_b
LSD* (P = 0.05)			0.010	3.3

* – Averages with different subscripts in the same column are significantly different at 95% confidence.
# – Average initial moisture was 78.4% w.b., cutting speed was 8.9 km/h, cut width was 5.5 m, swath width was 2.0 m and swath density was 0.90 kg DM/m^2.

Table 10. Average drying rate of second and third cutting alfalfa in south central Wisconsin in 2002 as affected by conditioner type using field tests of disk cutterbar mower-conditioners.

Conditioner type[#]	Average drying rate constant .. h^{-1}						Average final moisture % w.b.	Average time when 18% w.b. was reached
	June 27th – 29th	July 1st – 3rd	July 11th – 13th	July 15th – 17th	August 6th – 8th	Overall average		
Intermeshing urethane	0.075_a	0.093_a	0.093	0.132	0.129	0.104_a	25.0_b	3:00 PM
Intensive steel	0.085_b	0.102_b	0.103	0.137	0.136	0.113_b	21.5_a	4:00 PM
LSD[*] (P = 0.05)	0.009	0.008	0.016	0.010	0.008	0.008	2.1	

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

 # – Average initial moisture was 78.3% w.b., cutting speed was 11.0 km/h, cut width was 3.5 m, and swath width was 2.3 m. Average roll clearance was 1.2 and 1.5 mm for the urethane and steel rolls, respectively.

Table 11. Average drying rate of first and second cutting alfalfa in northern Utah in 2003 as affected by conditioner type using field tests of disk cutterbar windrowers.

Conditioner type[#]	Average drying rate constant .. h^{-1}						Average final moisture % w.b.	Average time when 15% w.b. was reached
	June 3^{rd} – 5^{th}	June 6^{th} – 8^{th}	June 10^{th} – 12^{th}	July 16^{th} – 18^{th}	July 19^{th} – 21^{st}	Overall average		
Intermeshing urethane	0.087_{b}	0.115_{b}	0.103_{b}	0.126_{b}	0.126_{b}	0.111_{cd}	14.0_{a}	12:30 PM
Intermeshing steel	0.098_{c}	0.116_{b}	0.081_{a}	0.104_{a}	0.132_{bc}	0.106_{bc}	17.1_{b}	3:30 PM
Intensive steel	0.106_{d}	0.105_{b}	0.104_{b}	0.123_{b}	0.146_{c}	0.117_{d}	13.6_{a}	11:45 AM
Impeller	0.092_{bc}	0.102_{b}	0.084_{a}	0.106_{a}	0.119_{b}	0.101_{b}	19.0_{c}	4:30 PM
No conditioning	0.069_{a}	0.078_{a}	0.079_{a}	0.098_{a}	0.075_{a}	0.080_{a}	24.1_{d}	_
LSD[*] (P = 0.05)	0.007	0.016	0.012	0.012	0.019	0.007	1.7	

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

– Average initial moisture was 75.3% w.b., cutting speed was 13.2 km/h, cut width was 4.5 m, and swath width was 1.7 m. Impeller to hood clearance was 25 mm and impeller speed was 624 rev/min. Roll clearance averaged 1.0, 1.9 and 0.6 mm, for the intermeshing urethane, intermeshing steel and intensive steel conditioners, respectively. Average yield was 18.1 and 16.4 Mg WM/ha for first (June) and second (July) cutting, respectively.

Table 12. Average drying rate of first cutting alfalfa in 2001 as affected by conditioner roll clearance using the conditioner test fixture.

Conditioner type#	Roll clearance mm	Average drying rate constant .. h^{-1} June $13^{th} – 17^{th}$	June $20^{th} – 23^{rd}$	Overall average	Average moisture .. % w.b. Initial	Final	Average density of swath kg DM / m^2
Intermeshing urethane	1.0	0.157_{bc}	0.155_{cde}	0.156_{bc}	78.6_{abc}	13.0_{bc}	0.78_{ab}
	1.9	0.149_{b}	0.147_{b}	0.149_{bc}	79.4_{c}	13.9_{c}	0.75_{a}
	2.9	0.146_{b}	0.146_{bcd}	0.146_{bc}	79.3_{c}	12.8_{bc}	0.75_{a}
	4.1	0.146_{b}	0.143_{b}	0.145_{b}	78.9_{bc}	13.4_{c}	0.78_{ab}
Intermeshing machined steel	0.7	0.171_{c}	0.175_{f}	0.173_{d}	79.0_{c}	10.8_{a}	0.75_{a}
	1.8	0.158_{bc}	0.162_{ef}	0.159_{c}	77.8_{ab}	11.4_{ab}	0.80_{ab}
	2.7	0.148_{b}	0.159_{de}	0.152_{bc}	77.5_{a}	12.2_{abc}	0.81_{b}
	3.3	0.149_{b}	0.158_{de}	0.153_{bc}	77.6_{ab}	11.9_{abc}	0.82_{b}
No conditioning		0.108_{a}	0.108_{a}	0.108_{a}	78.5_{abc}	20.2_{d}	0.81_{b}
LSD* (P = 0.05)		0.016	0.010	0.011	1.3	1.9	0.05

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

– Average roll force was 35 N/cm and mass-flow-rate through conditioners was 7.6 kg/s.

Table 13. Average drying rate of second cutting alfalfa in 2001 as affected by mass-flow-rate through the conditioner using the conditioner test fixture.

	Mass-flow-rate kg WM / s	Average drying rate constant .. h^{-1}			Average moisture .. % w.b.		Average density of swath kg DM / m^2
		June 26^{th} – 27^{th}	June 28^{th} – 29^{th}	Overall average	Initial	Final	
Intermeshing urethane	6.2	0.201_{d}	0.172_{d}	0.189_{cd}	77.4	19.3_{a}	0.69_{ab}
	7.6	0.206_{de}	0.176_{d}	0.188_{cd}	76.4	18.4_{a}	0.70_{abc}
	9.0	0.200_{d}	0.169_{d}	0.183_{cd}	78.2	19.9_{a}	0.68_{ab}
Intermeshing steel	6.2	0.215_{e}	0.167_{d}	0.192_{d}	78.3	19.4_{a}	0.67_{a}
	7.6	0.211_{de}	0.168_{d}	0.190_{d}	77.5	19.4_{a}	0.69_{ab}
	9.0	0.207_{de}	0.171_{d}	0.189_{d}	77.1	19.1_{a}	0.70_{abc}
Impeller	6.2	0.173_{bc}	0.152_{c}	0.163_{b}	76.4	24.0_{b}	0.70_{abc}
	7.6	0.176_{c}	0.131_{a}	0.154_{ab}	77.5	26.6_{bc}	0.72_{bc}
	9.0	0.163_{ab}	0.144_{bc}	0.154_{ab}	76.7	27.5_{c}	0.74_{c}
No conditioning		0.158_{a}	0.137_{ab}	0.148_{a}	77.6	28.6_{c}	0.70_{abc}
LSD* (P = 0.05)		0.011	0.009	0.010	2.1	2.6	0.04

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

– Average roll clearance was 1.5 mm and roll force was 35 N/cm. Impeller to hood clearance was 6.5 mm and impeller speed was 624 rev/min.

Table 14. Average drying rate of first and second cutting alfalfa in 2002 as affected by mass-flow-rate through the conditioner and swath density using field tests of disk cutterbar mower-conditioners.

Conditioner type[#]	Cut width M	As-cut swath density: Average drying rate constant … h^{-1}, June $8^{th} – 11^{th}$	June $14^{th} – 17^{th}$	June $20^{th} – 23^{rd}$	Overall average	Average density of swath kg DM / m^2	Uniform swath density: Drying constant h^{-1} July 4^{th}- 6^{th}	Average density of swath kg DM / m^2
Intermeshing urethane	3.5	0.104	0.153_{b}	0.144_{c}	0.134_{c}	1.25_{a}	0.137_{ab}	1.13
	4.0	0.103	0146_{ab}	0.125_{b}	0.125_{b}	1.43_{c}	0.143_{b}	1.09
Impeller	3.5	0.097	0.135_{a}	0.130_{b}	0.121_{b}	1.36_{b}	0.138_{ab}	1.09
	4.0	0.095	0.133_{a}	0.111_{a}	0.113_{a}	1.50_{c}	0.134_{a}	1.08
LSD[*] (P = 0.05)		0.010	0.016	0.011	0.007	0.07	0.007	0.05

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

\# – Average initial moisture content was 79.1 % (w.b.), ground speed at cutting was 13.1 km/h, roll clearance was 1.5 mm, and roll force was 44 N/cm. Impeller to hood clearance was 70 mm and impeller speed was 871 rev/min.

Table 15. Average drying rate of second cutting alfalfa in 2001 as affected by number of conditioning rolls using the conditioner test fixture.

Conditioner type[#]	Average drying rate constant .. h^{-1}			Average moisture .. % w.b.		Average density of swath kg DM / m^2
	July $9^{th} – 11^{th}$	June $28^{th} – 29^{th}$	Overall average	Initial	Final	
Intermeshing urethane	0.149_b	0.105_b	0.127_b	77.0	28.4_a	0.88_{ab}
Intermeshing ti-core & intensive crusher	0.152_b	0.112_b	0.132_b	77.2	27.0_a	0.87_a
No conditioning	0.113_a	0.075_a	0.094_a	76.6	36.2_b	0.92_b
LSD[*] (P = 0.05)	0.010	0.007	0.005	1.9	1.6	0.04

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

– Average roll force was 35 N/cm and mass-flow-rate through the conditioner was 7.6 kg WM/s. Roll clearance was 2.3, 2.2 and 0.7 mm for the intermeshing urethane, intermeshing ti-core and intensive crusher rolls, respectively.

Table 16. Average drying rate of third cutting alfalfa in 2001 as affected by swath density using the conditioner test fixture.

Conditioner type[#]	Average drying rate constant .. h^{-1}				Average moisture .. % w.b.		Average density
	August $7^{th} - 9^{th}$	August $13^{th} - 14^{th}$	August $20^{th} - 21^{st}$	Overall average	Initial	Final	of swath kg DM / m^2
Intermeshing urethane	0.169_d	0.170_c	0.176_d	0.172_d	80.9	30.9_a	0.70_a
" " .	0.109_a	0.122_{ab}	0.125_{ab}	0.119_{ab}	78.0	43.9_{cd}	1.17_b
Intermeshing machined steel	0.167_d	0.198_c	0.213_e	0.193_e	80.6	27.4_a	0.70_a
" " .	0.122_b	0.134_b	0.149_c	0.135_c	81.0	40.8_{bc}	1.13_b
No conditioning	0.141_c	0.126_b	0.135_{bc}	0.134_c	80.9	38.1_b	0.72_a
" " .	0.102_a	0.105_a	0.115_a	0.107_a	79.2	47.0_d	1.19_b
LSD* (P = 0.05)	0.012	0.030	0.015	0.012	4.3	5.5	0.06

*** –** Averages with different subscripts in the same column are significantly different at 95% confidence**.**

\# – Average roll force was 35 N/cm and mass-flow-rate through the conditioner was 7.6 kg WM/s. Roll clearance was 1.7 and 1.6 mm for the intermeshing urethane and machined steel rolls, respectively.

Table 17. Average drying rate performance in 2003 of third cutting alfalfa in Wisconsin as affected by swath density using field tests of a disk cutterbar mower-conditioner.

Conditioner type[#]	Average drying rate constant .. h^{-1}			Average final moisture %w.b.	Swath width m
	July 22nd – 24th	August 4th – 6th	Overall average		
Intermeshing urethane	0.102_c	0.118_c	0.110_c	20.9_a	1.9
	0.085_b	0.102_b	0.094_b	29.2_b	0.9
No conditioning	0.089_b	0.107_b	0.098_b	28.9_b	1.9
	0.065_a	0.081_a	0.073_a	35.2_c	0.9
LSD[*] (P = 0.05)	0.009	0.010	0.007	1.7	

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

\# – Average initial moisture was 75.7% (w.b.), cut width was 3.5 m cut width. Average roll clearance was 0.8 mm, roll force was 35 N/cm and ground speed was 13.0 km/h.

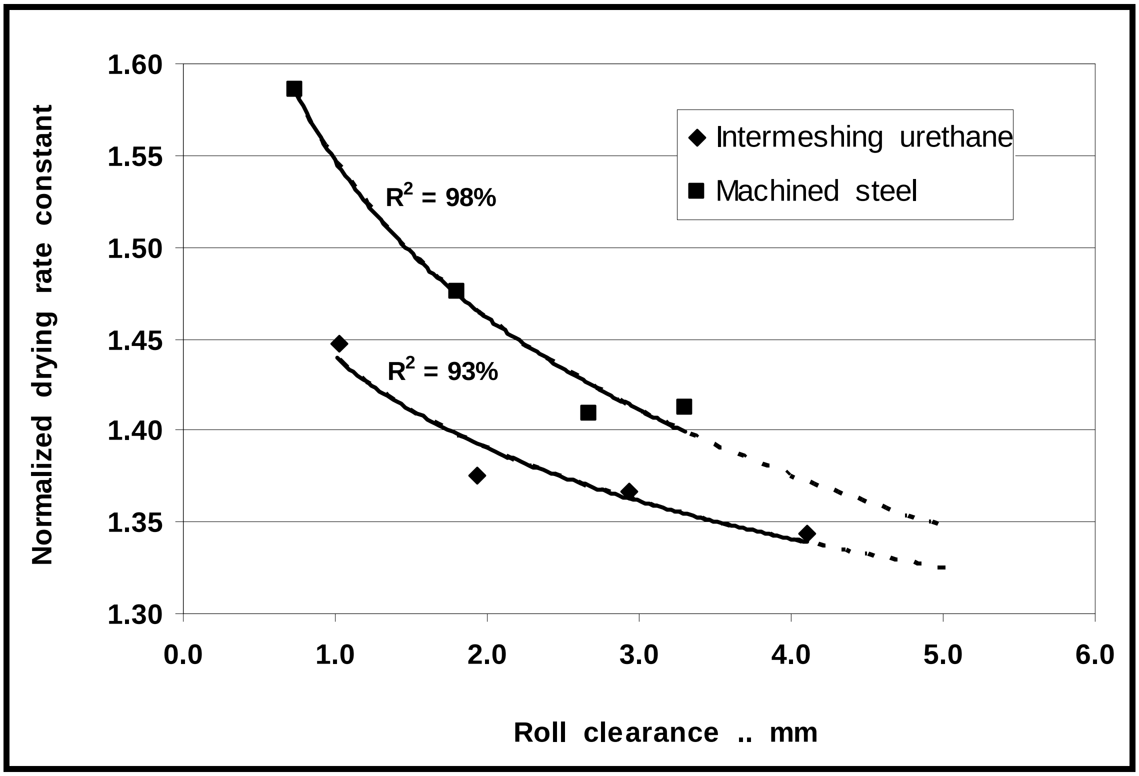

Figure 2. Effect on alfalfa drying rate of roll clearance for two different roll types.

Table 18 **–** Leaf loss of first cutting alfalfa in 2000 as affected by conditioner type in the conditioner test fixture.

	Dry matter loss … % of total		
	June 11th	June 13th	Average
Intermeshing urethane	1.5_{a}	2.2_{b}	1.9_{ab}
Intermeshing steel	1.8_{ab}	2.6_{b}	2.2_{b}
Intermeshing ti-core		1.4_{a}	
Intensive crusher	1.3_{a}	1.5_{a}	1.4_{a}
Involute	2.8_{b}	3.4_{c}	3.1_{c}
LSD* (P=0.05)	1.1	0.7	0.6

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

Table 19 **–** Leaf loss of first and second cutting alfalfa in northern Utah in 1999 as affected by conditioner type using field tests of sickle cutterbar windrowers.

	Dry matter loss … % of total				
	June 11th	June 13th	June 17th	July 14th	Average
Intermeshing steel	3.0_a	2.2_a	3.9_a	2.4_a	2.9_a
Intensive crusher	3.9_b	3.3_c	5.2_b	3.5_b	4.0_b
LSD (P=0.05)	0.7	0.6	0.9	0.7	0.6

Table 20 **–** Leaf loss of second and third cutting alfalfa in south central Wisconsin in 2002 as affected by conditioner type using field tests of disk cutterbar mower-conditioners.

	Dry matter loss … % of total		
	June 17th	July 31st	Average
Intermeshing urethane	1.8	3.4	2.6
Intensive steel	1.9	3.6	2.8
LSD (P=0.05)	0.6	0.7	0.5

Table 21 **-** Leaf loss as affected by intermeshing urethane roll clearance in of first cutting alfalfa in 2001

Treatment	Roll clearance … mm	Dry matter loss … % of total
Intermeshing urethane	1.2	3.3_b
"	1.9	2.9_{ab}
"	2.6	2.2_a
LSD (P = 0.05)		0.9

Alphabetic subscripts within columns denote differences @ P=0.05

Conclusions

- In a laboratory test fixture, intensive crushing rolls improved drying rate by 3 to 6% compared to intermeshing urethane or steel rolls, respectively. In field tests with windrowers, intensive crushing rolls improved drying rate by 0 to 22% compared to intermeshing steel rolls.

- Intensive conditioning rolls had similar DM loss compared to intermeshing urethane and steel rolls in the laboratory test fixture. In field tests with windrowers, intensive crushing rolls had 38% greater DM loss than the intermeshing steel rolls (4.0 vs. 2.9%).

- Machined rolls with many lugs in a closely intermeshing involute pattern produced an average drying rate 17% faster than intermeshing urethane rolls. However, practical application of this roll type was difficult due to backlash in the roll drive and subsequent roll interference.

- Intensive steel rolls with high specific crushing area (96%) and an intermesh to aid in feeding increased drying rate by an average of 7% compared to intermeshing urethane rolls. There was no difference in DM loss between the two roll types.

- For the two roll types studied, there were no statistical difference in drying rate across the clearances studied (~1 – 4 mm), but there was a trend for smaller clearance to improve the drying rate with the most evident improvement when clearance was less than 2 mm.

- Mass-flow-rate through roll and impeller conditioners did not significantly affect drying rate of alfalfa in tests using the laboratory test fixture or field-tests with mower-conditioners

- Use of an intermeshing ti-core roll followed in tandem by an intensive crushing roll did not significantly improve drying rate compared to an intermeshing urethane rolls in tests using a laboratory test fixture.

- Drying rate of conditioned windrows, unconditioned swaths and conditioned swaths was greater than an unconditioned windrow by an average of 24, 30 and 61%, respectively. There was no statistical difference in drying rate between conditioned material in a windrow and unconditioned material in a swath.

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