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Wide-Swath Drying and Post Cutting Processes to Hasten Alfalfa Drying

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Abstract. A variety of swath widths and post cutting processes, including tedding, re-conditioning and re-orientation, were applied to alfalfa to determine the effects on alfalfa drying rate. Conditioned and unconditioned alfalfa was placed in swaths of three widths: roughly 25-35 (windrow), 45-55 (swath) and 70-95% (wide-swath) of cut width. The latter swath width was formed by tedding the crop right after cutting. Conditioned crop placed in a wide-swath dried significantly faster than all other treatments. A conditioned swath dried faster than an unconditioned wide-swath. Drying rate was maximized when conditioning was combined with placing the crop as wide as possible, either by producing the widest swath available from the mower-conditioner or by tedding right after cutting and conditioning. Tedding at cutting to produce conditioned wide-swaths had a positive to neutral effect on drying compared to tedding the next day. Re-orientating or fluffing the windrow to mix the crop and improve aeration did not have a significant positive effect on drying rate that could be sustained through the whole drying period. There was no difference in drying rate when re-orientation occurred at cutting or after a period of wilting. Re-conditioning the crop 3 h after cutting increased the crop's drying rate from 12 and 40% compared to a windrow. At the same time, tedding at cutting increased drying rate by 23 and 51% compared to the windrow. Re-conditioning resulted in DM loss of 6.2%, similar to that experienced with the mower-conditioner.

***Keywords*:** Alfalfa, conditioning, drying rate, leaf loss, tedding

Introduction

Forages are the backbone of sustainable agriculture and contribute extensively to the US economy because they help prevent soil erosion, improve soil fertility and tilth, and provide feed for livestock, which convert the fiber and nutrients from forage crops into human foods such as milk and meat. Alfalfa is the most valuable forage crop in North America because of its wide spread use and superior nutrient characteristics (NAAIC, 2004). It has the highest feeding value of all commonly grown hay crops and produces more protein per hectare than grain or oil seed crops (Barnes et al., 1995; Marten et al., 1988).

Alfalfa drying rate after cutting plays a major role in the ability to harvest a high-quality crop. Fast drying improves alfalfa quality by reducing losses from respiration and weather. The plant continues to respire until it reaches about 40% moisture (w.b.). Respiration uses valuable carbohydrates that result in DM losses of 5 to 10% (Rotz and Muck, 1994). Fast drying reduces the exposure to rain that 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 while the 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 leaf stomata (Jones and Palmer, 1932); hence, alfalfa leaves often dry faster than the stem (Bagnall et al., 1970; Fairbanks and Thierstein, 1966). Drying rate of alfalfa stems can be improved by use of systems to crush, break or abrade the stem to provide an exit route for moisture. 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).

There have been recent attempts to increase alfalfa drying rate through the use of new conditioning systems which include new roll geometries, multiple conditioning rolls and impeller conditioners. Research has shown that swath density may have a more important role in alfalfa drying rate than conditioning level. Shinners et al. (1991) reported that roll geometry had little effect on alfalfa drying rate while drying in narrow windrows reduced alfalfa's drying rate by 34% compared to drying in a wide swath. More recent work has shown that swath density had a greater impact on alfalfa drying rate than type of conditioner or number of conditioning rolls (Shinners et al., 2006).

Even wider swaths and faster drying rates can be produced by tedding. Tedding is the process of lifting and throwing the cut alfalfa crop to hasten drying by increasing air circulation and exposing new surface areas of the plant to the elements. Pattey et al. (1988) found that under favorable weather, tedding increased the drying rate of narrow windrows by 77% and of wide swaths by 22%. Under more humid conditions they found that tedding increased the drying rate by 46% over a three hour period and 39% over an eight hour period. Timing of tedding may play a role in subsequent drying rate. Some alfalfa producers prefer to windrow the crop for a day to allow drying of the soil between windrows because high soil moisture negatively affects alfalfa drying rate (Rotz, 1995). However, this approach forces the crop to dry slowly at first because the total solar insolation is not used for crop drying and stomata of the shaded plants inside the windrow will close prematurely. Tedding right at cutting could reduce leaf loss because the leaves are wet and pliable; therefore, they are more resistant to the impact of the tedder's tines. Dry matter losses when leaves are in this condition can be around 3 to 10% (Rotz and Muck, 1994).

There other post cutting processes that can positively affect alfalfa drying rate. Raking or inversion helps move the crop off of wet soil, re-orients the wet bottom layer toward the sun and the re-orientation of the crop helps promote air movement through the formed windrow. Raking provides a 10 to 20% increase in drying rate on the day of raking (Rotz, 1995), but following the initial improvement, the heavy swath formed by raking can slow the drying rate. Re-conditioning after a period of field drying has also been suggested as a means of improving alfalfa drying. Re-conditioning after a short wilting period was found to slightly improve alfalfa drying rate in two studies (Hanson, 2002).

The objectives of this research were to determine the effect of various post-cutting treatments to improve the drying rate of alfalfa. Specific objectives were to compare tedding to fluffing and re-conditioning, compare timing at which tedding took place and to determine the interactive effect of conditioning level and swath density.

Materials and Methods

Data Collection

For all studies conducted in 2003 and 2004, each treatment was replicated four times during each study and each treatment was randomly assigned within the replicated block. All experiments were conducted at the University of Wisconsin Arlington Agricultural Experimental Station using first, second or third cutting alfalfa.

Immediately after cutting, material was randomly collected from all treatments and combined into two covered barrels. The collected material was size-reduced in a stationary chopper, the material mixed and then three sub-samples were taken from each barrel. The sub-samples were weighed and then oven dried at 103°C as per ASAE Standard S358.2 (ASAE, 2003) in order to calculate the initial aggregate moisture of the crop at cutting. Samples were then collected periodically from each plot over the next two to four days, typically four to five times per day. At each sampling, two replicate samples were collected from each of the two replicate plots. 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 transported to the farmstead. No sample was taken immediately adjacent to a previous sample to eliminate edge effects. For each replicate sample, the material was size-reduced, mixed, and then three sub-samples collected and oven dried using procedures described above.

When it was felt that any treatment had reached typical raking moisture (~40% w.b.), it was raked with a rotary rake. Tedded treatments typically reached this moisture on the second day, so it was raked by itself on that day while other treatments were typically raked on the third day of the study. A drying study was considered over when most of the treatments had reached typical baling moisture, or when rain threatened. Weather data, such as ambient temperature, solar insolation, relative humidity and wind velocity were collected from the Arlington Agricultural Research Station weather station.

In this research, the goal was to produce crop placed on the ground in three different widths: windrows, swaths and wide-swaths. The approximate ratio of the laid to cut width for windrows, swaths and wide-swaths was 25–35, 45–55 and 70–95%, respectively. Even when similar machine settings were used from day-to-day, crop conditions such as maturity, initial moisture, crop height, and yield had an affect on the actual width produced.

Conditioner roll clearance was quantified by first wrapping a 45 x 90 cm piece of aluminum foil around a 0.95 cm diameter mandrel to form a hollow foil roll. Three foil rolls were then fed through the rolls by hand at three locations - about 30 cm from each end and one at the center. Each “conditioned” foil roll was then measured at the crush points using a digital caliper, and three readings from each foil were averaged to get the roll clearance. The average of the three foil rolls was used as the machine’s conditioning roll clearance. Roll clearance was adjusted if measurements determined that the clearance was not between 0.8 and 1.6 mm. After cutting, swath width was quantified to the nearest 2 cm in at least 10 random locations per treatment.

<u>Drying Rate Data Analysis</u>

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%.

Conditioning Level and Swath Width

Rotz (1995) reported that swath width was an important factor influencing alfalfa drying rate. Ideally, the fastest drying occurs when the crop is placed in a swath as wide as the cutting platform, but there are currently no commercially available mower-conditioners or windrowers that can achieve this. Roll or impeller conditioners must be situated between the machines wheels so that the ejected crop will not be run over by these wheels and wheel spacing is limited by road travel restrictions. There are other design constraints that limit conditioner width. So machines with narrow cutting platforms have more favorable swath:cut width ratios than wide platforms, but narrow machines may not meet the productivity needs of many alfalfa producers. One way to achieve wide-swath drying with a wide cutting platform is to post-process the crop with a tedder to spread the formed swath to the full width of the cutting platform. A mower without a conditioner can form a swath as wide the cutting platform by simply laying the crop off the cutterbar, but the crop would not be conditioned. To investigate the effect of conditioning level and swath width, two studies each were conducted in 2003 and 2004. In 2003, six variables were considered: conditioned and unconditioned crop at three different swath widths. In 2004, six variables were again considered: conditioned and unconditioned at swath and windrow width, plus a tedded treatment that was split between tedded at cutting or tedded the next day.

In 2003, a John Deere[1] model 935 mower-conditioner (3.5 m cut width) with intermeshing urethane conditioning rolls was used. Average roll clearance for the conditioned material was 0.8 mm and unconditioned material was harvested by blocking open the conditioning rolls to approximately 5 cm. Material was cut at a ground speed of approximately 11 km/h. The targeted swath widths were approximately one, two, and three meters. The mower-conditioner was not able to produce a three meter swath so a tedder was used immediately after cutting to produce this swath width. Tedding was done with a Fahr four-rotor tedder towed in the same direction of cutting at approximately 6.4

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[1] Mention of trade names in this manuscript are made solely to provide specific information and do not imply endorsement of the product or service by the University of Wisconsin-Madison.

km/hr with pto speed of 440 rpm. These tests were the fourth and fifth drying studies conducted in 2003 (tables 1 and 3).

In 2004, a John Deere model 4990 windrower (4.5 m cut width) with intermeshing steel conditioning rolls was used. Average roll clearance for the conditioned material was 0.9 mm and unconditioned material was harvested by blocking open the conditioning rolls to approximately 5 cm. Tedding at cutting to produce a full-width swath was shown to be beneficial in 2003, but required an additional post-cutting pass. To eliminate the need for this additional pass, modifications to the windrower and a New Holland model 158 tedder were made so that tedding could occur simultaneously with cutting (fig. 1). Design details of these modifications can be found in Herzmann (2005). The tedder could easily be removed for non-tedded treatments by removing three pins and the pto shaft. The windrower was operated at 8.8 km/h for all treatments. These tests were the sixth and seventh drying studies conducted in 2004 (tables 2 and 4).

Timing of Tedding

When tedding occurs the day following cutting, it allows the ground between the windrows to dry so that the spread crop will be thrown onto drier soil, possibly enhancing the overall drying rate. However, with this approach, the crop cannot take full advantage of the solar insolation available during the first day and another field operation is required. Combining cutting, conditioning and tedding into a single machine eliminates these concerns but this approach does not allow the ground dry, which may slow overall drying rate. To investigate the effect of the timing of tedding, four and seven drying studies were conducted in 2003 and 2004, respectively. In both 2003 and 2004, three treatments were considered: tedding either at cutting or the next day with a control treatment of a typical windrow width.

In 2003, a New Holland model 1431 mower-conditioner (3.9 m cut width) was used to form windrows with a target width near 1.6 m. Average roll clearance for the conditioned material was 1.3 mm and crop was cut at a ground speed of approximately 11 km/h. The pull-type tedder described above was used to ted the crop either right after cutting or the morning of the next day. These experiments were the first through fourth drying studies conducted in 2003 (tables 1 and 3).

In 2004, the combined windrower-tedder described above was used for the experiments that investigated the timing of tedding. These experiments were the first through seventh drying studies conducted in 2004 (tables 2 and 4). To accomplish the next day tedding treatment, the windrower cutting platform was maintained in the raised the position and the tedder operated.

Windrow Re-Orientation and Re-Conditioning

Two other post cutting processes were investigated to determine their effects on alfalfa drying rate: windrow re-orientation (fluffing) and re-conditioning. Fluffing is accomplished with a tined reel that lifts and mixes the windrow without turning or rolling it from its original location. This process is intended to mix the dry top of the windrow with the wetter bottom layer while simultaneously re-structuring the windrow to improve aeration. When crop is formed into a windrow at cutting, it can be ejected toward the ground with sufficient velocity such that the subsequent windrow is not supported off the ground by the stubble. Fluffing at cutting could help bring the windrow off the ground so that it is supported by the stubble, improving aeration. Re-conditioning essentially sends the partially dried windrow through another conditioning process, while also mixing and re-orientating it as well. To investigate the effect of post cutting processes on alfalfa drying rate, four studies were conducted in 2003. The material was cut with the New Holland model 1431 mower-conditioner described above.

Tests involving the timing of fluffing were conducted during the first and second drying studies of 2003 (table 1 and 3). An H & S hay fluffer (2.1 m width) was used either right after cutting or on the morning of the next day. The fluffer was operated at about 6.5 km/h and an engine speed of 1,600 rpm and was operated in the direction of cutting. Three treatments were considered: fluffed either at cutting or the next day with a control treatment of a typical windrow that was slightly less than 2 m wide.

Reconditioning was compared with the two other post cutting processes previously considered: fluffing and tedding. Five treatments were considered: conditioned and unconditioned windrows as controls; and conditioned windrows fluffed, reconditioned or tedded about 3 h after cutting. The tedder and fluffer were operated as described above. All treatments were first placed in a windrow slightly less than 2 m wide. The re-conditioner was an Agland 6600 operated at of about 5.0 km/h, a pto speed of 950 rpm, and roll clearance of 2.6 mm. This clearance level was greater than typically recommended for mower-conditioners, but was within the range recommended by the manufacturer. These experiments were the sixth and seventh drying studies conducted in 2003 (tables 1 and 3).

Re-Conditioner Leaf Loss

Leaf loss quantified for the mower-conditioner and re-conditioner. 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 three times.

Figure 1. Windrower with rear attached tedder for simultaneously cutting, conditioning and placing crop in swath as wide as cutting platform.

Table 1 – Summary of treatments used during each drying study conducted in the summer of 2003.

Treatment / Study	1st	2nd	3rd	4th	5th	6th	7th
Unconditioned							
Windrow				X	X	X	X
Swath				X	X		
Windrow – tedded				X	X		
Conditioned							
Windrow	X	X	X	X	X	X	X
Swath				X	X		
Windrow – fluffed	X	X				X	X
Windrow – tedded	X	X	X	X	X	X	X
Windrow – reconditioned						X	X

Table 2 - Summary of treatments used during each drying study conducted in the summer of 2004.

Treatment / Study	1st	2nd	3rd	4th	5th	6th	7th
Unconditioned							
Windrow						X	X
Swath						X	X
Conditioned							
Windrow	X	X	X	X	X	X	X
Swath						X	X
Tedded – cutting	X	X	X	X	X	X	X
Tedded – next day	X	X	X	X	X	X	X

Table 3 - Average weather conditions at the Arlington Agricultural Research Station (Arlington, WI) during the typical drying period from 8:00 AM to 6:00 PM during the summer of 2003.

Date	Temperature	Solar radiation	Relative humidity	Wind speed
	°C	W/m^2	%	m/s
1st study				
June 11th	15.7	175	80	4.2
" 12th	19.7	349	76	3.1
" 13th	24.4	527	58	1.8
" 14th	24.5	512	63	4.4
2nd study				
June 16th	23.7	619	47	4.1
" 17th	25.1	566	46	2.5
" 18th	26.5	664	31	2.0
3rd study				
June 30th	25.8	694	46	2.6
July 1st	27.1	731	45	2.5
" 2nd	27.9	652	50	3.5
4th study				
July 22nd	20.5	607	63	4.8
" 23rd	22.0	707	58	3.9
" 24th	23.9	666	55	3.5
5th study				
August 4th	20.8	398	78	2.9
" 5th	25.1	548	67	2.1
" 6th	25.9	612	64	4.0
6th study				
August 6th	25.9	612	64	4.0
" 7th	24.6	641	68	4.8
" 8th	22.5	536	73	4.0
7th study				
August 11th	19.8	188	84	4.3
" 12th	22.6	458	71	3.7
" 13th	25.7	584	64	2.9
" 14th	27.3	517	65	2.3

Table 4 - Average weather conditions at the Arlington Agricultural Research Station (Arlington, WI) during the typical drying period from 8:00 AM to 6:00 PM during the summer of 2004.

Date	Temperature	Solar radiation	Relative humidity	Wind speed
	^oC	W/m^2	%	m/s
1st study				
June 2nd	18	495	65	3.8
" 3rd	20	735	43	2.8
" 4th	21	715	40	2.1
2nd study				
June 7th	27	608	64	9.2
" 8th	29	516	65	6.8
" 9th	26	460	70	4.2
3rd study				
June 14th	24	557	67	5.2
" 15th	25	688	49	2.2
" 16th	25	405	70	2.8
4th study				
June 18th	21	380	63	4.9
" 19th	17	748	45	3.3
" 20th	20	685	47	5.8
5th study				
June 28th	20	659	59	4.2
" 29th	25	700	46	5.1
" 30th	25	653	51	5.2
July 1st	26	613	61	3.8
6th study				
July 14th	24	647	62	5.5
" 15th	25	658	57	3.5
" 16th	21	453	83	4.0
7th study				
July 26th	24	663	49	1.8
" 27th	25	571	57	1.5
" 28th	25	669	54	5.4

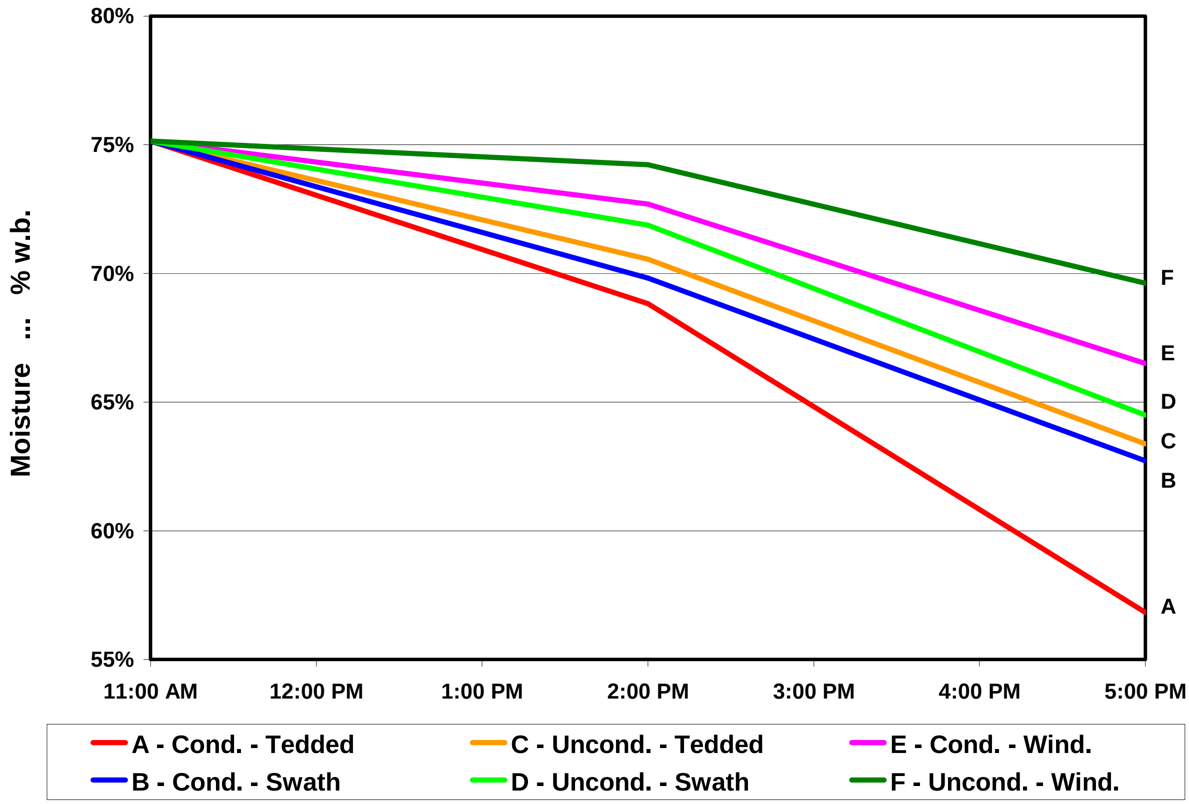
Results

Conditioning Level and Swath Width

In 2003, the conditioned wide-swaths dried statistically faster than all other treatments (tables 5 and 6). The conditioned swath dried at the next fastest rate while the drying rate of the conditioned windrow and unconditioned wide-swaths and swath treatments were statistically similar during both studies. The unconditioned windrow dried statistically slower than all other treatments. In almost all cases, the conditioned treatments dried statistically faster than the corresponding treatments of similar width that was not conditioned, clearly showing the benefit of conditioning no matter the width laid. In both studies, the only treatments to achieve safe baling moisture by the end of the third day of drying were the conditioned treatment placed in the wide-swath or swath widths.

In 2004, the conditioned full-width swath (tedded) treatment again dried statistically faster than all other treatments with the exception of the conditioned swath (tables 7 and 8). Independent of treatment width, conditioned treatments dried faster than unconditioned treatments. Drying conditions were not favorable on the last day of the sixth drying study (table 4) so none of the treatments was able to produce crop dry enough to bale. On the seventh study, only the wide-swath treatments produced crop dry enough to bale by the end of the third day (table 8).

Of interest to silage producers is the time it takes for the crop to reach acceptable moisture for ensiling. The initial drying rate of the crop showed that the conditioned material tedded at cutting to produce a wide-swath reached harvesting moisture the quickest, followed by the conditioned material at swath width (fig. 2). Similar results were found during the fifth drying study and these results are also shown by differences in drying rate constant on the first day of both studies. The results show that conditioning and placing in a swath dried as fast or faster to chopping moisture than unconditioned alfalfa placed in a wide-swath. If an unconditioned swath is compared to a conditioned windrow with respect to drying, the unconditioned swath dried faster. Producers considering not conditioning will need to lay unconditioned crop nearly twice as wide as the conditioned crop to produce a drying advantage for the unconditioned material.



<u>Figure 2</u>. Initial drying of second cutting alfalfa during the fourth drying study conducted on July 22nd, 2003.

<u>Timing of Tedding</u>

Tedding at the time of cutting to produce a full-width, conditioned swath produced the fastest time to chopping or baling (tables 5 – 8). But tedding is typically applied to the crop the day after cutting because this practice allows the ground between the windrows to dry so that the spread crop will be thrown onto drier soil. A comparison was made between producing a wide-swath at cutting or the next day four times in 2003 and seven times in 2004. In these eleven studies, the tedded at cutting treatment produced a statistically greater drying rate than the tedded next day treatment only three times, but it produced a numerically greater drying rate in all eleven studies. Averaged over all the studies there was no significant differences in drying rate between the two tedding treatments (tables 11 and 12). Compared to drying in a windrow, drying rate was improved by 28 and 42% when creating a wide-swath by tedding occurred the next day or at cutting, respectively.

Table 5: The effect of conditioning level and swath width on alfalfa drying rate during the fourth drying study of 2003.

Treatment	Drying rate coefficient h^{-1}				Final moisture % w.b.	Treatment width[#] m
	July 22nd	July 23rd	July 24th	Average		
<u>Unconditioned</u>						
Windrow	0.057_{a}	0.061_{a}	0.078_{a}	0.065_{a}	35.0_{e}	0.9
Swath	0.114_{c}	0.081_{b}	0.071_{a}	0.089_{b}	26.8_{d}	1.8
Wide-swath (tedded)	0.111_{c}	0.075_{ab}	0.082_{ab}	0.089_{b}	24.7_{c}	3.2
<u>Conditioned</u>						
Windrow	0.085_{b}	0.075_{a}	0.094_{bc}	0.085_{b}	26.5_{d}	1.0
Swath	0.116_{c}	0.091_{b}	0.099_{c}	0.102_{c}	18.0_{b}	1.9
Wide-swath (tedded)	0.167_{d}	0.091_{b}	0.099_{c}	0.119_{d}	16.3_{a}	3.1
LSD* (P=0.05)	0.018	0.017	0.014	0.009	1.4	

* - Alphabetic subscripts within columns denote differences @ P=0.05 # – cut-width was 3.5 m.

Table 6: The effect of conditioning level and swath width on alfalfa drying rate during the fifth drying study of 2003.

Treatment	Drying rate coefficient h^{-1}				Final moisture % w.b.	Treatment width[#] m
	Aug 4th	Aug 5th	Aug 6th	Average		
Unconditioned						
Windrow	0.056_{a}	0.070_{a}	0.116_{ab}	0.081_{a}	35.4_{c}	1.0
Swath	0.065_{ab}	0.135_{c}	0.122_{b}	0.107_{b}	31.1_{b}	1.9
Wide-swath (tedded)	0.078_{b}	0.144_{c}	0.095_{a}	0.106_{b}	29.6_{b}	2.4
Conditioned						
Windrow	0.076_{ab}	0.101_{b}	0.131_{b}	0.102_{b}	31.9_{b}	1.0
Swath	0.105_{c}	0.115_{bc}	0.123_{b}	0.114_{b}	23.9_{a}	1.7
Wide-swath (tedded)	0.143_{d}	0.122_{bc}	0.130_{b}	0.132_{c}	20.8_{a}	2.5
LSD* (P=0.05)	0.021	0.030	0.025	0.014	3.2	

* - Alphabetic subscripts within columns denote differences @ P=0.05 # – cut-width was 3.5 m.

Table 7: The effect of conditioning level and swath width on alfalfa drying rate sixth drying study of 2004.

Treatment	Drying rate coefficient h^{-1}				Final moisture % w.b.	Treatment width[#] m		
	July 14th	July 15th	July 16th	Average		Initial	Tedded	Raked
Wide-swath (tedded)								
Cutting	0.173_d	0.107_b	0.103_c	0.127_e	28.6_a	-	3.1	0.7
Next day	0.103_b	0.135_c	0.128_c	0.122_{de}	32.3_{ab}	1.4	3.7	-
Conditioned								
Windrow	0.112_b	0.095_b	0.115_c	0.107_c	34.8_{bc}	1.5	-	-
Swath	0.127_c	0.102_b	0.107_c	0.112_{cd}	37.7_c	1.9	-	-
Unconditioned								
Windrow	0.077_a	0.065_a	0.018_a	0.053_a	54.4_e	1.6	-	-
Swath	0.101_b	0.093_b	0.069_b	0.088_b	45.9_d	1.9	-	-
LSD* (P=0.05)	0.012	0.025	0.052	0.013	4.3			

* - Alphabetic subscripts within columns denote differences @ P=0.05   # – cut-width was 4.5 m.

Table 8: The effect of conditioning level and swath width on alfalfa drying rate seventh drying study of 2004.

Treatment	Drying rate coefficient h^{-1}				Final moisture % w.b.	Treatment width[#] m		
	July 26th	July 27th	July 28th	Average		Initial	Tedded	Raked
Wide-swath (tedded)								
Cutting	0.175_{d}	0.102_{a}	0.103_{b}	0.127_{c}	19.4_{a}	-	3.3	0.8
Next day	0.120_{bc}	0.149_{b}	0.114_{b}	0.128_{c}	22.5_{a}	1.5	4.6	0.8
<u>Conditioned</u>								
Windrow	0.085_{a}	0.091_{a}	0.122_{b}	0.099_{b}	27.2_{b}	1.6	-	0.8
Swath	0.134_{c}	0.108_{a}	0.108_{b}	0.116_{c}	26.3_{b}	2.0	-	0.9
<u>Unconditioned</u>								
Windrow	0.097_{ab}	0.076_{a}	0.071_{a}	0.082_{a}	36.9_{c}	1.6	-	0.8
Swath	0.125_{c}	0.107_{a}	0.059_{a}	0.097_{ab}	37.2_{c}	2.0	-	0.7
LSD* (P=0.05)	0.024	0.034	0.027	0.016	3.4			

* - Alphabetic subscripts within columns denote differences @ P=0.05 # – cut-width was 4.5 m.

In most cases, the tedded at cutting treatment dried significantly faster than the tedded next day treatment because the latter treatment was at approximately 50% of cut width the first day (tables 9 – 12). Typically, the tedded next day treatment would have greater drying rate on the second day (tables 10 – 12), which was due to several reasons. The material that was tedded the day after cutting had the wet and dry portions of the crop mixed at tedding and then thrown onto drier ground between the windrows. The tedder also threw the partially dried crop further, resulting in a wider swath than the tedded at cutting treatment (table 10).

The results show that tedding to produce a full-width, conditioned swath at cutting has positive to neutral effect on drying compared to tedding the next day. This result would support the integration of a tedding device onto the mower-conditioner or windrower. This merging of functions would reduce production costs by eliminating the separate tedding process. Tedding when the leaves have not dried may reduce overall leaf loss. The integration of the tedder with the windrower as reported here was generally successful with only a few changes needed to improve the spread width.

Windrow Re-Orientation and Re-Conditioning

Re-orientating or fluffing the windrow to mix the crop and improve aeration did not have a significant positive effect on drying rate (table 13). In the first study in 2003, drying conditions were not good (table 3) so initial drying rate of all treatments was poor. Drying conditions were good during the second study and fluffing at cutting did improve the drying rate during the first day, but this improvement was not sustained through the whole drying period (table 13). Shearer et al. (1992) reported that windrow inversion, which was a similar process to re-orientation, had no significant effect on alfalfa drying. Savoie and Beauregard (1990) found that swath inversion improved drying rate by 15% on the first day, with little effect the following days. It was observed that the windrow fluffed right after cutting had a more open structure than the windrow treatment, but that within an hour or so, this open structure was lost as the crop wilted. In neither study did fluffing the next day improve overall drying rate.

Re-conditioning significantly improved the drying of windrows that were 40% of cut width. It was not possible to lay the crop wider than this because this was the maximum width the re-conditioner could pick-up. In both studies, tedding produced numerically greater drying rates than re-conditioning (tables 14 and 15), although the results were not statistically significant. Fluffing again did not significantly improve drying of the windrows.

Averaged across two studies, re-conditioner leaf loss was not significantly different than that experienced with the mower-conditioner (table 16), despite the fact that leaf moisture was 50 and 61% (w.b.), respectively, when conditioning took place. Stem moisture was 61 and 75% (w.b.), respectively. The re-conditioner leaf loss was similar to that of the mower-conditioner because the roll clearance for the re-conditioner was 4.5 times that greater than for the mower-conditioner as per recommendations of the re-conditioner manufacturer (table 16).

Table 9: The effect of timing of tedding operation during the second drying study of 2003.

Treatment[#]	Drying rate coefficient h^{-1}				Final moisture % w.b.
	June 16th	June 17th	June 18th	Average	
Tedded – cutting	0.144_c	0.123	0.090_b	0.119_b	14.4_a
Tedded – next day	0.102_b	0.094	0.106_b	0.101_b	15.5_a
Windrow	0.066_a	0.095	0.060_a	0.074_a	21.0_b
LSD* (P=0.05)	0.024	0.065	0.045	0.020	3.4

* - Alphabetic subscripts within columns denote differences @ P=0.05 # – cut-width was 3.9 m.

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Table 10: The effect of timing of tedding for the second drying study of 2004.

Treatment	Drying rate coefficient h^{-1}				Final moisture % w.b.	Treatment width[#] m		
	June 7th	June 8th	June 9th	Average		Initial	Tedded	Raked
Tedded – cutting	0.168_b	0.028_a	0.077	0.091_b	23.9_a	-	2.8	0.7
Tedded – next day	0.078_a	0.104_b	0.077	0.086_b	27.5_a	1.4	3.2	0.8
Windrow	0.096_a	0.046_a	0.073	0.072_a	40.2_b	1.4	-	0.8
LSD* (P=0.05)	0.023	0.027	0.021	0.013	7.5			

* - Alphabetic subscripts within columns denote differences @ P=0.05 # – cut-width was 4.5 m.

Table 11: The effect of timing of tedding averaged over the first three days of the first through fourth drying studies conducted in the summer of 2003.

Treatment	Drying rate coefficient h^{-1}				Final moisture % w.b.
	Day 1	Day 2	Day 3	Average	
Tedded – cutting	0.114_c	0.127_b	0.093	0.111_b	19.8_a
Tedded – next day	0.085_b	0.116_b	0.092	0.097_b	21.7_a
Windrow	0.063_a	0.083_a	0.070	0.072_a	31.1_b
LSD* (P=0.05)	0.016	0.029	0.023	0.017	4.4

* - Alphabetic subscripts within columns denote differences @ P=0.05

Table 12: The effect of timing of tedding averaged over the first three days of the first through seventh drying studies conducted in the summer of 2004.

Treatment	Drying rate coefficient h^{-1}				Final moisture % w.b.
	Day 1	Day 2	Day 3	Average	
Tedded – cutting	0.133_b	0.098_b	0.086	0.105_b	26.6_a
Tedded – next day	0.075_a	0.120_c	0.095	0.097_b	29.8_b
Windrow	0.075_a	0.076_a	0.090	0.080_a	37.8_c
LSD* (P=0.05)	0.008	0.009	0.009	0.008	1.5

* - Alphabetic subscripts within rows denote differences @ P=0.05

Table 13: The effect of timing of fluffing during the first and second drying studies in 2003.

Treatment#	Drying rate coefficient h^{-1}					Final moisture % w.b.
	June 11th	June 12th	June 13th	June 14th	Average	
Fluffed – cutting	0.033	0.060	0.063	0.077	0.058	38.3
Fluffed – next day	0.013	0.044	0.070	0.060	0.047	44.1
Windrow	0.015	0.057	0.050	0.087	0.052	41.1
LSD* (P=0.05)	0.044	0.021	0.040	0.047	0.019	13.2
	June 16th	June 17th	June 18th			
Fluffed – cutting	0.114_{b}	0.096	0.088		0.099	17.9_{a}
Fluffed – next day	0.089_{a}	0.097	0.079		0.088	18.3_{a}
Windrow	0.066_{a}	0.095	0.060		0.074	21.0_{b}
LSD* (P=0.05)	0.024	0.065	0.045		0.027	2.1

* - Alphabetic subscripts within columns denote differences @ P=0.05 # – cut-width was 3.9 m.

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Table 14: The effect of various post cutting processes on alfalfa drying rate for the sixth drying study of 2003.

Treatment	Drying rate coefficient h^{-1}				Final moisture % w.b.	Initial treatment width# m
	Aug 6^{th}	Aug 7^{th}	Aug 8^{th}	Average		
Unconditioned						
Windrow	0.085_{a}	0.078_{a}	0.069_{a}	0.077_{a}	37.8_{d}	1.6
Conditioned						
Windrow	0.127_{b}	0.099_{bc}	0.120_{d}	0.115_{c}	24.0_{b}	1.5
Fluffed	0.137_{b}	0.117_{c}	0.117_{cd}	0.124_{cd}	23.2_{b}	1.5
Reconditioned	0.141_{b}	0.115_{bc}	0.132_{d}	0.129_{de}	21.4_{b}	1.5
Tedded	0.195_{c}	0.111_{bc}	0.118_{d}	0.141_{e}	18.3_{a}	2.9
LSD* (P=0.05)	0.021	0.020	0.022	0.012	2.7	

* - Alphabetic subscripts within columns denote differences @ P=0.05 # – cut-width was 3.9 m.

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Table 15: The effect of various post cutting processes on alfalfa drying rate for the seventh drying study of 2003.

Treatment	Drying rate coefficient h^{-1}					Final moisture % w.b.	Initial treatment width# m
	Aug 11th	Aug 12th	Aug 13th	Aug 14th	Average		
Unconditioned							
Windrow	0.028_{ab}	0.057_{a}	0.124	0.083_{ab}	0.073_{a}	30.6_{c}	1.6
Conditioned							
Windrow	0.034_{ab}	0.086_{ab}	0.128	0.066_{a}	0.079_{a}	22.4_{b}	1.4
Fluffed	0.020_{a}	0.080_{ab}	0.132	0.091_{b}	0.081_{a}	20.5_{b}	1.5
Reconditioned	0.045_{b}	0.123_{b}	0.121	0.155_{c}	0.111_{c}	14.5_{a}	1.5
Tedded	0.037_{ab}	0.139_{b}	0.158	0.140_{c}	0.119_{c}	15.7_{a}	2.1
LSD* (P=0.05)	0.019	0.062	0.069	0.020	0.023	2.2	

* - Alphabetic subscripts within columns denote differences @ P=0.05 # – cut-width was 4.5 m.

Table 16: Loss of crop material averaged over two studies from New Holland 1431 roll-type mower-conditioner and Agland 6600 re-conditioner.

Treatment	Average roll clearance	Loss
	mm	% of total DM
Mower-conditioner	0.7	5.9
Re-conditioner	3.1	6.2
LSD (P=0.05)		0.9

* - Alphabetic subscripts within columns denote differences @ P=0.05

Conclusions

- Conditioned and unconditioned alfalfa was placed in swaths of three widths: roughly 25-35, 45-60 and 80-100% of cut width. The latter swath width was formed by tedding the crop right after cutting. In all cases, conditioned crop dried faster than unconditioned. Conditioned crop placed in a wide swath dried significantly faster than all other treatments. A conditioned swath at 45 – 60% of cut width dried faster than an unconditioned wide-swath.

- Drying rate was maximized when conditioning was combined with placing the crop as wide as possible, either by producing the widest swath available from the mower-conditioner or by tedding right after cutting. This was true when the crop was to be harvested as silage or dry hay. Producers considering not conditioning will need to make unconditioned swaths nearly twice as wide as the conditioned swaths to produce a drying advantage for the unconditioned material.

- Tedding to produce a full-width, conditioned swath at cutting had positive to neutral effect on drying compared to tedding the next day. This result would support the integration of a tedding device onto the mower-conditioner or windrower to produce full-width, conditioned swaths.

- Re-orientating or fluffing the windrow to mix the crop and improve aeration did not have a significant positive effect on drying rate that could be sustained through the whole drying period. Re-orientation at cutting or after a period of wilting did not significantly affect alfalfa drying rate.

- During two studies, reconditioning the crop 3 h after cutting increased the crop's drying rate from 12 and 40% compared to a windrow placed at 40% of cut width. For the same two studies, tedding at cutting increased drying rate by 23 and 51% compared to the windrow. Reconditioning resulted in DM loss of 6.2%, similar to that experienced with the mower-conditioner.

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