The effect of a hay tedder on the field drying rate

E. PATTEY[1], P. SAVOIE[2], and P. A. DUBÉ[1]

[1]Département de phytologie, Université Laval, Sainte-Foy, Québec, G1K 7P4; and [2]Agriculture Canada, Station de recherches de Sainte-Foy, Québec G1V 2J3. *Contribution no. 314, received 18 August 1986, accepted 1 May 1987.*

Pattey, E., Savoie, P. and Dubé, P. A. 1988. **The effect of a hay tedder on the field drying rate**. Can. Agric. Eng. **30**: 43–50. Most herdsmen in Eastern Canada conserve forage as hay to meet their livestock needs during the winter. The hay tedder can improve drying conditions by spreading and fluffing the hay swath and consequently reduce drying time and weather damage risk. The present research was initiated to quantify the effect of tedding on the hay drying rate. A hay tedder was evaluated in 1984 over four large timothy plots (37m by 152 m) and in 1985 over three timothy plots and two alfalfa plots. The forage was mowed at three dates (10 June, 25 June, 9 July) during the first growth cycle to consider the effect of crop maturity. The cut forage was left initially either in a wide swath (1.83 m average) or in a narrow windrow (1.14 m) behind an average mowing width of 2.59 m. The crop was generally tedded in the morning of the second drying day. Under favorable weather, tedding increased the drying rate of narrow (wetter) windrows by 77% and of wide (drier) swaths by 22%, over a 3-h period. Over an 8-h period after tedding, drying rate increases were 58 and 28% for narrow and wide swaths, respectively. Under more humid conditions, tedding increased the drying rates by 46% over a 3-h period and by 39% over an 8-h period with little difference between wide or narrow windrows. Tedding was more efficient in wet and early-maturity hay. No significant differences were identified between alfalfa and timothy in their drying response to tedding. These results should eventually be integrated in a hay harvest management system to help farmers decide whether tedding is appropriate and when it might be applied profitably.

La majorité des éleveurs de l'Est du Canada récoltent le fourrage sous forme de foin pour alimenter le bétail durant l'hiver. Le faneur à toupies peut améliorer les conditions de séchage du foin en soulevant l'andain; de cet fait, le faneur réduit le temps de séchage au champ et le risque pour l'andain d'être avarié par la pluie. Dans ce projet de recherche, on a quantifié l'effet du faneur sur le taux de séchage du foin. On a évalué un faneur à toupies en 1984 sur quatre grandes parcelles de fléole (37 m par 152 m) et en 1985 sur trois parcelles de fléole et deux parcelles de luzerne. On a considéré l'effet de la maturité en fauchant à trois dates au cours du premier cycle végétatif (10 juin, 25 juin et 9 juillet). Les fourrages fauchés sur une largeur moyenne de 2,59 m étaient laissés soit en andain large (1,83 m en moyenne), soit en andian étroit (1,14 m). Le faneur était généralement appliqué le matin suivant la fauche. Sous des conditions climatiques favorables, le fanage a augmenté le taux de séchage d'andains étroits (plus humides) de 77% et celui d'andains larges (plus secs) de 22% pour une période de trois heures. Durant une période de huit heures après le fanage, l'augmentation du taux de séchage était de 58% et 28% dans des andains étroits ou larges, respectivement. Sous des conditions humides, le fanage a augmenté le taux de séchage de 46% pour une période de trois heures et de 39% pour une période de huit heures; il y avait peu de différence entre des andains larges et des andains étroits. Le fanage est plus utile dans le fourrage jeune et humide. On n'a pas noté de différence significative entre la fléole et la luzerne; les changements de taux de séchage étaient sensiblement les mêmes pour les deux cultures à la suite du fanage. Ces résultats pourraient éventuellement être intégrés dans un modèle décisionnel de fenaison pour évaluer l'utilité économique du fanage et établir le meilleur moment d'application.

INTRODUCTION

A majority of farmers in Eastern Canada conserve forage as hay to meet their livestock needs during the winter. Good-quality hay requires a short drying period with minimal material losses during harvest. Fast drying can be achieved with multiple mechanical treatments but such treatments may cause leaf fragmentation losses. If a treatment saves hay from being rained on and allows it to be baled quickly, small treatment losses may well be justified in comparison with the losses that would be incurred through prolonged exposure to the elements.

The hay tedder generally improves the drying conditions by spreading the hay swath over a large area. Losses depend on the moisture content, the maturity of the crop and the species. The present research was initiated because of the lack of quantitative information on the drying rate and losses associated with tedding. This article describes the effect of tedding on the hay drying process; another paper deals with losses due to tedding (Savoie 1988).

LITERATURE REVIEW

The evaporative rate of mowed forage depends on the crop, forage handling and the environment. Forage maturation decreases initial moisture content and the cuticular resistance to water evaporation (Jones 1979; Jones and Pricket 1979).

Evaporation from freshly cut windrows occurs primarily from the surface exposed to direct solar radiation. Spreading the crop at mowing maximizes the energy intercepted for drying (Jones and Harris 1979). Subsequently, the thin layer becomes a disadvantage because it can promote a greater uptake of moisture per unit herbage dry matter from the soil, stubble, rain and dew. Wilman and Owen (1982) recommended raking the crop in a narrow windrow around 0.67 g/g (40% moisture on a wet basis).

Tedding soon after mowing doubled the drying rate; moisture content decreased from 4 to 2 g/g in 6 h (Jones and Prickett 1981). Frequent tedding during the initial drying period ensured a more uniform moisture content throughout the swath but had little effect on the total moisture loss compared with a single tedding treatment. However, frequent tedding was more efficient when swath water content ranged between 1 and 2 g/g. During this stage, a high resistance to water diffusion seemed to develop rapidly at the surface. Frequent disturbances led to a favorable microclimate both inside and at the surface of the swath. At moisture contents below 1 g/g, tedding had little effect on the drying rate. Physiological resistances to moisture loss became more important than the swath environment (Jones and Harris 1979).

Table I. Analysis of variance tables for the two yearly experiments and their combination

Source of variation	1984 df	1985 df	Source of variation	1984–1985 df
Cultivars (C)	3	4	Year (Y)	1
Cutting dates (D)	2	2	C	2
Error *a*	6	8	Error *a*	2
Swath width (W)	1	1	D	2
Tedding (T)	1	1	D × C	4
W × T	1	1	Error *b*	6
W × D	2	2	W	1
T × D	2	2	T	1
W × C	3	4	W × T	1
T × C	3	4	W × D	2
W × T × D	2	2	T × D	2
Error *b*	21	28	W × C	2
Sampling	48	60	T × C	2
			W × T × D	2
			Error *c*	41
			Sampling	72
Totals	95	119	Totals	143

Dernedde (1979) also observed that tedding was more efficient at high moisture contents. Tedding had a greater effect on the windrows conditioned with rollers because they were wetter than windrows conditioned with flails.

Savoie et al. (1982) noted that alfalfa tedded during the first cut had a moisture content of 38% (wet basis) while untedded alfalfa had a moisture content of 42% after 2 or 3 days of field drying. Moisture differences almost disapeared 1 or 2 days after tedding had been applied.

OBJECTIVE

The main objective of the present paper was to quantify the effect of tedding on the drying rate of hay. The research also investigated the importance of initial swath width (wide or narrow), the effect of forage maturity confounded with the climate and the interaction of different forage cultivars and species (timothy, alfalfa) with each mechanical treatment.

EXPERIMENTAL PROCEDURE

Field experiments were carried out at the Deschambault Research Station (Quebec) during the first growth cycle in the summers of 1984 and 1985. The common part of the 2 yr of experiment is constituted by three main plots, measuring 37 m by 152 m each, containing one of three timothy cultivars (*Phleum pratense* L.): Champ, Climax and Bounty. In 1984, there was another plot of Bounty cultivar in the south part of the site. In 1985, two cultivars of alfalfa (*Medicago sativa* L.): Saranac and Dekalb were added to the three cultivars of timothy to establish a comparison between legumes and grasses. Each main plot was subdivided into three subplots measuring 37 m by 51 m, to be cut at 2-wk intervals: 11 June, 27 June and 9 July in 1984; 10 June, 25 June and 9 July in 1985. These dates correspond approximately to the early boot, heading, and half-blooming-half-anthesis stages for timothy. They correspond to bud stage, 10% bloom and full bloom for alfalfa. No maturity difference was observed at the Deschambault site among either timothy or alfalfa cultivars.

Each subplot was mowed in the morning with a 2.7-m-wide Hesston 1091 mower using rubber roll conditioners. Windrows were mowed lengthwise (51 m); three side-by-side windrows represented one experimental unit. Initially, windrows were left either in wide or narrow swaths by adjusting the windrow-forming shields. On average, for the three cutting dates, the mowed width was 2.59 m; narrow windrows were 1.14 m and wide windrows were 1.83 m.

A Kuhn GF 452T, 5.2-m-wide tedder was planned to be used when the moisture content was approximately 60% (wet basis (WB)) and when no rain was forecasted; tedding was generally applied 24 h after mowing, in the morning of the second drying day. The tedder had four rotating elements with six fingers each (1.63 m in diameter). Rotation speed was 235 rpm at 1700 tractor rpm; fingertip speed was 20 m/sec.

Immediately after mowing, short lengths of the windrow were lifted and deposited on 0.90-m by 1.20-m screens made of 25-mm-mesh wire. Two trays (samples) were set at a random distance along the middle windrow of each experimental unit. At the same time, a sample of forage was picked up near each tray for initial moisture content measurement by drying in the oven at 65°C for 72 h (ASAE Standard S358.1). Just before tedding was applied to half the experimental units, another forage sample was taken on each tray located in a tedded experimental unit. Forage on the trays was then emptied in the windrow and trays were removed temporarily as tedding was applied; trays were placed back in the windrow immediately after and forage samples were taken near them. At the end of the drying experiment, another forage sample was taken from each tray. Trays were weighed regularly at 3-h intervals in the daytime to measure the loss of water. The dry matter on each tray at cutting and tedding was the average of dry matters evaluated from samples taken at time zero and at the end of the drying period. Moisture content versus time was established on the basis of water loss from each tray.

The statistical design for each year was a factorial split-split-plot design with one replication. Each year, three timothy cultivars constituted one replicated block; three cutting dates (maturity stages) represented the first split and two mowing treatments (wide and narrow swaths) combined with two late mechanical treatments (tedding and no tedding) were the second split and the whole factorial. At each date and within each cultivar subplot, the four treatment possibilities were applied randomly as were the cutting dates inside the crops. The two trays included in the experimental unit represented two samples. The statistical design for the 2 yr was also a factorial split-split-plot design, but with two replications constituted by the years. The analysis of variance (ANOVA) was done on the common part of each year (Table I).

The statistical comparison of field drying treatments required measuring or calculating a drying parameter. Such a parameter will usually confound biological, man-controlled and environmental factors. Recent drying models have attempted, at least partially, to single out the effect of each group of factors (Thompson 1981; Pitt 1984; Rotz and Chen 1985). If biological and environmental factors are identical during an experiment, differences in the drying parameter would be the result of treatment differences only. Under such conditions, an empirical model describing moisture loss as a function of time may prove adequate. Lewis (1921) proposed that the rate of moisture loss was proportional to the difference between average moisture of the drying material and an equilibrium moisture content.

$$\frac{dM}{dt} = -k\,(M - M_e) \qquad (1)$$

where M is the average moisture content of the forage (g water/g dry matter), M_e is the equilibrium moisture content (g/g), k

Table II. Daily climatic conditions during the hay drying experiment at Deschambault, in summer 1984

Dates	$T_{max.}$ (°C)	$T_{min.}$ (°C)	Radiation (MJ/m²/day)	Rain (mm)	Average wind (m/sec)
1st cutting date					
11 June 1984	27.5	17.0	23.65	0.0	1.97
12 June 1984	25.2	7.0	22.27	0.0	2.91
13 June 1984	23.0	15.0	14.12	8.4	1.05
14 June 1984	15.0	11.0	6.30	11.4	2.00
15 June 1984	15.5	8.0	29.45	0.0	1.47
16 June 1984	23.0	2.5	28.15	0.0	2.19
2nd cutting date					
27 June 1984	18.5	13.0	27.69	0.0	3.79
28 June 1984	25.5	12.0	23.98	1.9	1.74
29 June 1984	26.5	12.0	30.14	0.0	1.69
3rd cutting date					
9 July 1984	27.0	8.5	29.56	0.0	1.16
10 July 1984	28.1	11.0	28.87	0.0	1.95

is the drying constant (h^{-1}) and t is the time (h). After integration, the model becomes:

$$\frac{M-M_e}{M_0-M_e} = \exp(-kt) \qquad (2)$$

where M_0 is the initial moisture content (g/g) and t the time interval between M_0 and M measurements.

Several ANOVA were calculated, with Statistical Analysis Systems Package (1985), for each year and for the 2-yr combination. The first analysis was on the drying constant (k) calculated from Eq. 2 over a 3-h period after tedding, by setting M_e equal to 0.15 based on observations by Pitt (1984) and Savoie and Mailhot (1986). A second analysis compared k-values estimated over 8 drying hours after tedding. The purpose was to assess the instantaneous and day-long effects of the treatment on the drying rate. Homogeneity of the variance was verified using the Bartlett test and the Anderson and McLean (1974) criteria.

RESULTS AND DISCUSSION

Weather was generally favorable for field drying in 1984 but rain occurred during each drying period in 1985 (Tables II and III). The stand purity was above 80% in most fields in both years; in 1985, Champ timothy on the first cutting date and Dekalb alfalfa for all three cuttings were about 50% pure.

The initial moisture content in 1984 and 1985 is illustrated in Figs. 1 and 2. It decreased as the maturity advanced; alfalfa had a higher water content than timothy. Climax was the wettest timothy cultivar during both years.

The short-term effect of tedding on the drying rate was quantified with k values calculated over a 3-h period just after the treatment (Tables IV, V and VI). In 1984, the variance was homogeneous with regard to Bartlett's test; the analysis of variance was performed without any transformation. We obtained statistically significant differences for swath width (α = 0.0226) and for tedding (α = 0.0001) main effects, but the interaction between swath width and tedding was also highly significant (α = 0.0015). Tedding a narrow windrow increased the drying constant by 77%; tedding a wide swath increased the drying constant by 22% (Table IV). Narrow windrows were wetter than wide windrows at the time of tedding; more water was exposed to favorable drying conditions when a narrow

Table III. Daily climatic conditions during the hay drying experiment at Deschambault, in summer 1985

Dates	$T_{max.}$ (°C)	$T_{min.}$ (°C)	Radiation (MJ/m²/day)	Rain (mm)	Average wind (m/sec)
1st cutting date					
10 June 1985	20.2	15.0	17.48	4.2	2.02
11 June 1985	19.5	6.0	26.57	2.4	1.40
12 June 1985	16.2	9.0	10.41	1.0	0.91
13 June 1985	13.0	10.5	7.91	17.6	0.98
2nd cutting date					
25 June 1985	14.5	7.2	10.72	2.3	0.87
26 June 1985	20.6	11.5	22.41	0.0	1.11
27 June 1985	22.7	7.5	26.80	0.0	1.12
28 June 1985	20.3	12.0	13.80	0.1	4.20
3rd cutting date					
9 July 1985	26.0	11.0	20.22	0.0	0.57
10 July 1985	22.5	14.5	12.72	5.8	0.70
11 July 1985	21.3	13.0	26.66	5.7	1.24
12 July 1985	23.0	7.0	30.32	0.0	1.75

Table IV. Average drying constants evaluated over three hours just after tedding at each cutting date in 1984 (four timothy cultivars)

Treatments	Cutting dates: 11 June 1984	27 June 1984	9 July 1984	Average
Narrow, non-tedded	0.0887	0.1351	0.1172	0.1137
Wide, non-tedded	0.1205	0.1762	0.1758	0.1575
Narrow, tedded	0.1757	0.2212	0.2074	0.2014
Wide, tedded	0.1663	0.2004	0.2122	0.1929

Table V. Average drying constants evaluated over three hours just after tedding at each cutting date in 1985 (three timothy cultivars and two alfalfa cultivars)

Treatments	Cutting dates: 10 June 1985	25 June 1985	9 July 1985	Average
Narrow, non-tedded	0.0726	0.1238	0.0716	0.0886
Wide, non-tedded	0.0885	0.1587	0.0931	0.1122
Narrow, tedded	0.1130	0.2006	0.1084	0.1386
Wide, tedded	0.1132	0.2179	0.1406	0.1550

Table VI. Average drying constants evaluated over 3 h just after tedding at each cutting date in 1984 and 1985 (three timothy cultivars)

Treatments	Cutting dates: First	Second	Third	Average
Narrow, non-tedded	0.0849	0.1380	0.1068	0.1093
Wide, non-tedded	0.1079	0.1717	0.1439	0.1404
Narrow, tedded	0.1594	0.2241	0.1705	0.1838
Wide, tedded	0.1483	0.2220	0.1810	0.1828

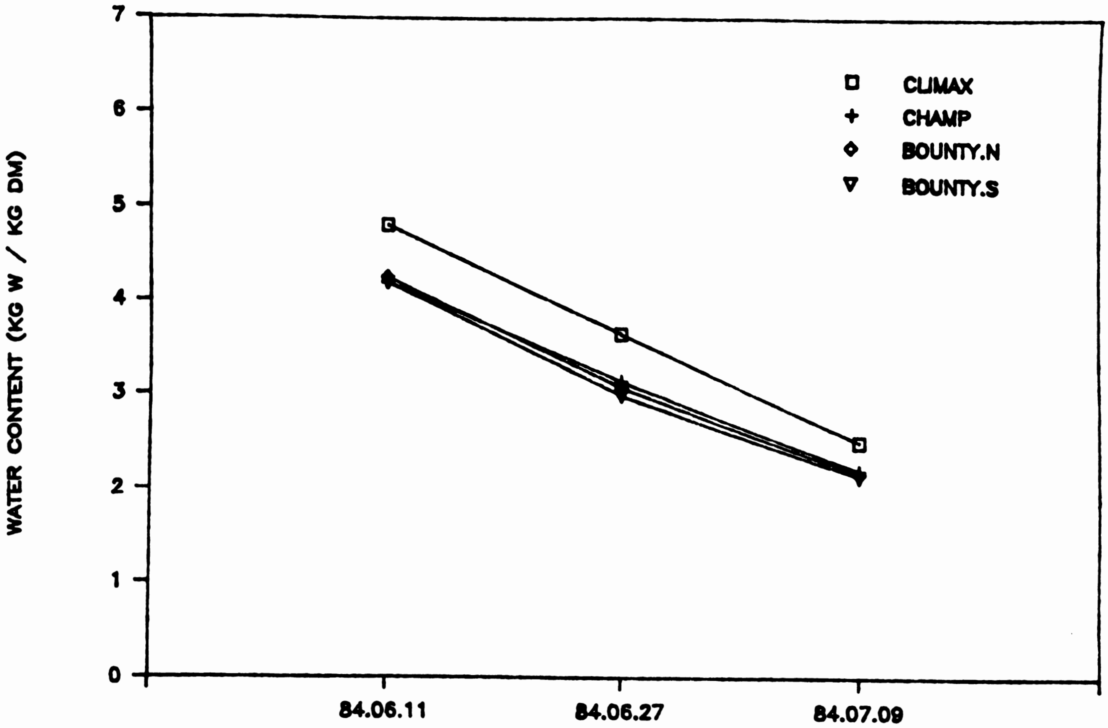

Figure 1. Water content (kg/kg dry matter) of the standing crop at the time of mowing in 1984.

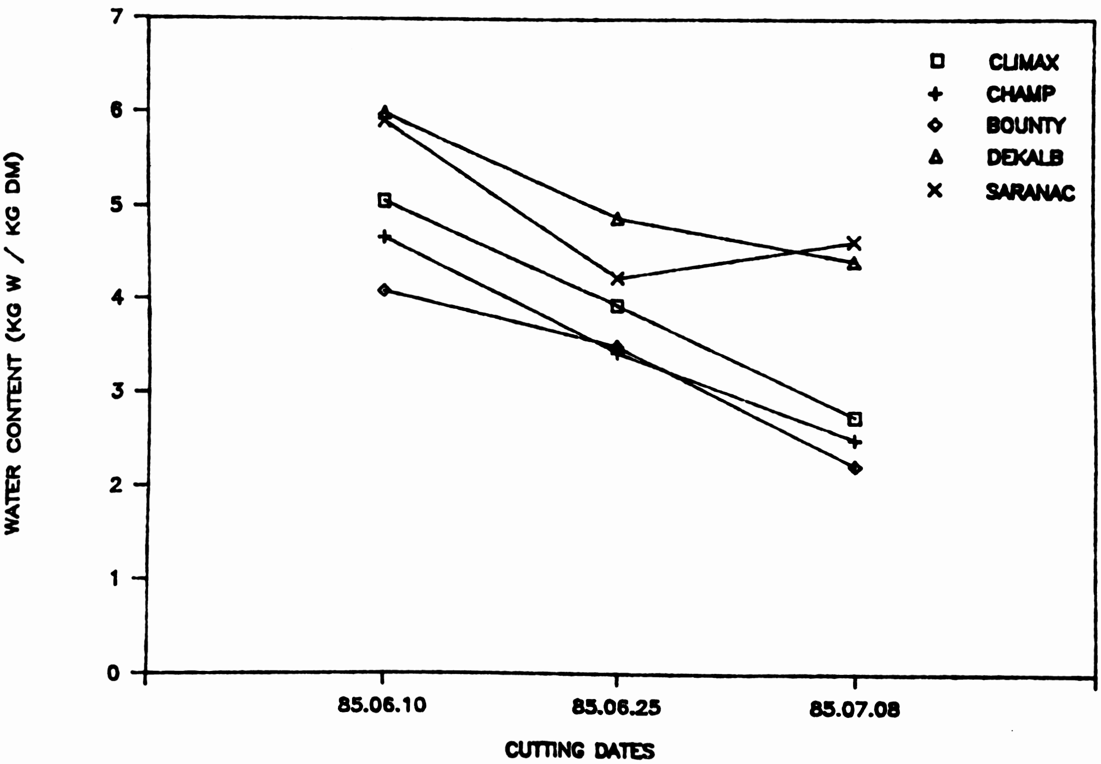

Figure 2. Water content of the standing crop at the time of mowing in 1985.

windrow was spread out. Mechanical treatments had the same influence on various timothy cultivars and on cutting dates.

Differences in k values between the three dates (Table IV) can be explained at least partially by the weather. During the 3-h interval just after tedding, the total solar radiation was 4.48, 6.12 and 6.50 MJ/m^2 on 12 June 1984, 28 June 1984 and 9 Sept. 1984, respectively, when tedding was applied. At the second date, a slight amount of rain fallen the night before tedding favored rapid drying of the superficial water.

The 1985 data revealed heterogeneity and lack of normality due to changes in maturity and climate at the various cutting dates; the data were transformed before doing the analysis of variance. The transformed value $(k + 0.5)^{-1/2}$provided homogeneity of the variance and normality of distribution. Table V indicates that on average tedded windrows ($k = 0.1468$ h^{-1}) had a drying constant 46% greater than the untedded windrows ($k = 0.1004$ h^{-1}). Wide swaths ($k = 0.1331$ h^{-1}) dried 18% faster than narrow swaths ($k = 0.1128$ h^{-1}). Both main effects were statistically significant: $\alpha = 0.0001$ for tedding and $\alpha = 0.0005$ for swath width. Contrary to 1984 results, the tedding-swath width interaction was not significant in 1985: tedding applied to narrow swaths increased k by 0.050 h^{-1}; applied to wide swaths it increased k by 0.043 h^{-1}. In 1984, the drying constant increased by either 0.088 or 0.035 h^{-1} when tedding was applied either to narrow or wide swaths (Table IV). Because weather was generally more favorable in 1984, there was a greater difference in moisture content of wide and narrow swaths at the time of tedding. So the narrow (wetter) swaths responded very favorably to tedding while the wide (dryer) swaths responded less favorably. In 1985, since the weather had been more humid (Table III), both wide and narrow swaths had a more similar moisture content at the time of tedding and responded similarly.

The absolute values of k after tedding in 1985 (Table V) depended, for a large part, on the climatic conditions. The 10 June swaths received 11.00 MJ/m^2 of solar radiation during the 3-h period and were subjected to a small amount of rain that slowed the evaporative rate after tedding. On the 25 June swaths, no rain occurred after tedding and the radiation was 11.94 MJ/m^2, so k values were higher. The third date had a low radiation level of 3.81 MJ/m^2 and low k values during the period after tedding.

In 1985, the interactions swath width-cultivars ($\alpha = 0.7835$) and tedding-cultivars ($\alpha = 0.3001$) were nonsignificant. We could not reject the hypothesis that timothy and alfalfa responded similarly to the mechanical treatments.

Table VI summarizes the drying constants of timothy grass for the 2 yr combined analysis. The data were transformed into $(k + 0.5)^{-1/2}$ for the analysis of variance. Tedding in interaction with swath width was highly significant ($\alpha = 0.0030$). Averaged over 2 yr for timothy hay, the drying constants were practically the same for tedding either narrow windrows ($k = 0.1838$ h^{-1}) or wide ones ($k = 0.1828$ h^{-1}). However non-tedded wide swaths had a higher drying constant ($k = 0.1404$ h^{-1}) than non-tedded narrow windrows ($k = 0.1093$ h^{-1}). Tedding increased the drying constant of narrow windrows by 68%; it increased the drying constant of wide swaths by 30%. Averaged over a 2-yr period, the effect of previous swath width was of little consequence to the subsequent drying rate after tedding during the three-hour period.

The effect of tedding on the drying rate over an 8-h period was also investigated. Results for 1984 and 1985 are in Tables VII and VIII. In 1984, the tedded windrows ($k = 0.1550$ h^{-1}) dried 43% faster than the untedded windrows ($k = 0.1087$ h^{-1}) over an 8-h period. In 1985, the increase was 39%. Absolute increases of k due to tedding correspond to 0.046 and 0.032 h^{-1} for each year. The drying rate increase observed over a 3-h period after tedding is practically maintained over an 8-h period.

Figures 3, 4 and 5 illustrate the change of moisture content versus time for Bounty timothy in 1984. During the first drying day, wide swaths lost more water than narrow swaths. During the second day, after tedding was applied around 0900 h, tedded windrows lost water more rapidly than untedded windrows.

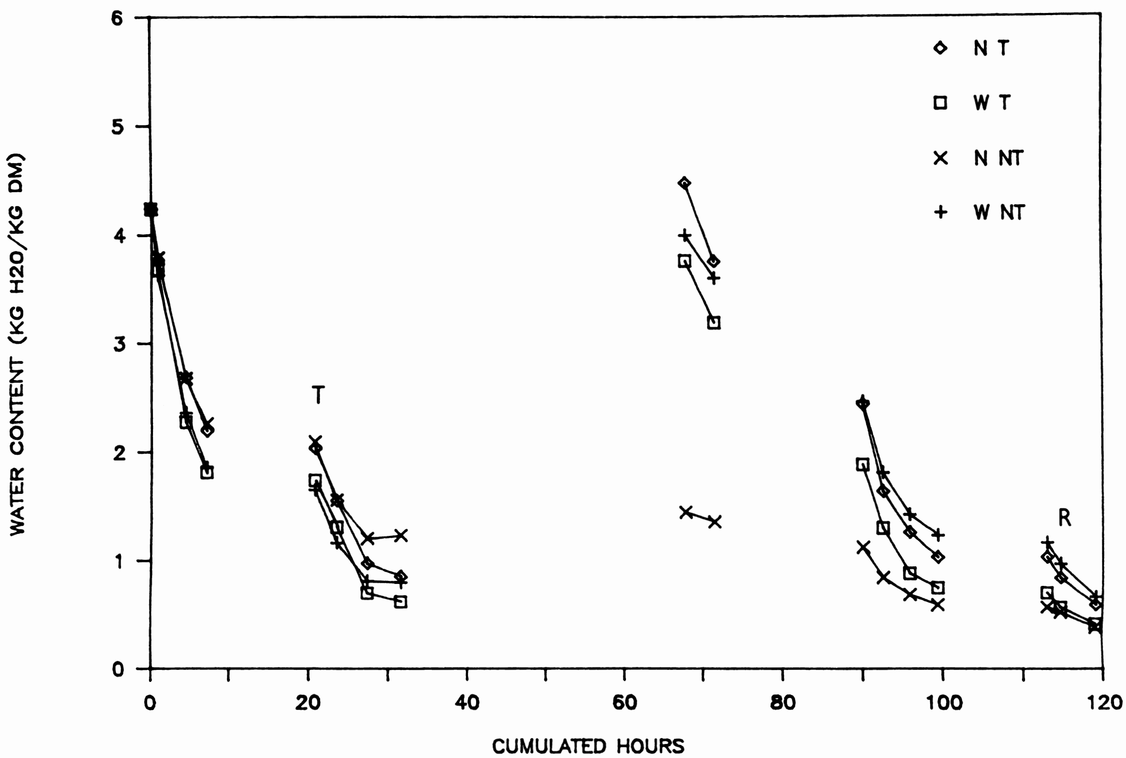

Figure 3. Water content (kg/kg dry matter) versus time of timothy grass, Bounty cultivar, mowed on 11 June 1984. The crop was subjected to four treatment combinations: NT, narrow swath tedded subsequently; WT, wide and tedded swath; NNT, narrow and non-tedded swath; WNT, wide and non-tedded swath.

Table VII. Average drying constants evaluated over 8 h after tedding at each cutting date in 1984 (four timothy cultivars)

	Cutting dates			
Treatments	11 June 1984	27 June 1984	9 July 1984	Average
Narrow, non-tedded	0.0729	0.1243	0.1319	0.1042
Wide, non-tedded	0.0753	0.1470	0.1406	0.1131
Narrow, tedded	0.1107	0.1848	0.2363	0.1649
Wide, tedded	0.0953	0.1591	0.2195	0.1450

Table VIII. Average drying constants evaluated over 8 h after tedding at each cutting date in 1985 (three timothy cultivars) and two alfalfa cultivars

	Cutting dates			
Treatments	10 June 1985	25 June 1985	9 July 1985	Average
Narrow, non-tedded	0.0715	0.0848	0.0727	0.0763
Wide, non-tedded	0.0809	0.0913	0.0914	0.0879
Narrow, tedded	0.0979	0.1298	0.1058	0.1112
Wide, tedded	0.0968	0.1281	0.1238	0.1163

After rainfall the narrow untedded windrows had clearly absorbed much less water than the other windrows (Fig. 3). As the crop matured (Figs. 4 and 5), the initial water content was lower and the effects due to swath width and tedding were small.

A comparison of timothy and alfalfa drying curves (Figs. 6 and 7) in late June 1985 indicates a strong similarity. Alfalfa was initially wetter. Tedding was applied only on the third day because of slow drying during the first 2 days. The wide swaths dried faster than the narrow ones. Tedding applied to the wetter, narrow grass windrow brought the moisture level down to practically the same level as the other windrows. However, the narrow alfalfa windrow was slower to respond to the tedding treatment, perhaps because of the lower moisture content at which the treatment was applied.

CONCLUSIONS

(1) In 1984, under favorable weather, tedding increased the drying rate of narrow windrows by 77% and of wide swaths by 22%, over a 3-h period. Over an 8-h period, tedding increased the drying rate of narrow windrows by 58% and of wide ones by 28%.

(2) In 1985, under more humid drying conditions, tedding increased the drying rate by 46% over a 3-h period and 39% over an 8-h period. The absolute values of the drying constants were lower in 1985 than in 1984. They were practically the same for tedded hay, irrespective of previous swath width.

(3) Tedding was more efficient in wet windrows. The positive effect of tedding on the drying rate is most evident early after mowing, or after a period of rain or dew.

(4) Differences between alfalfa and timothy to swath width and tedding were non significant. The drying rate of both crops responded similarly to mechanical treatments.

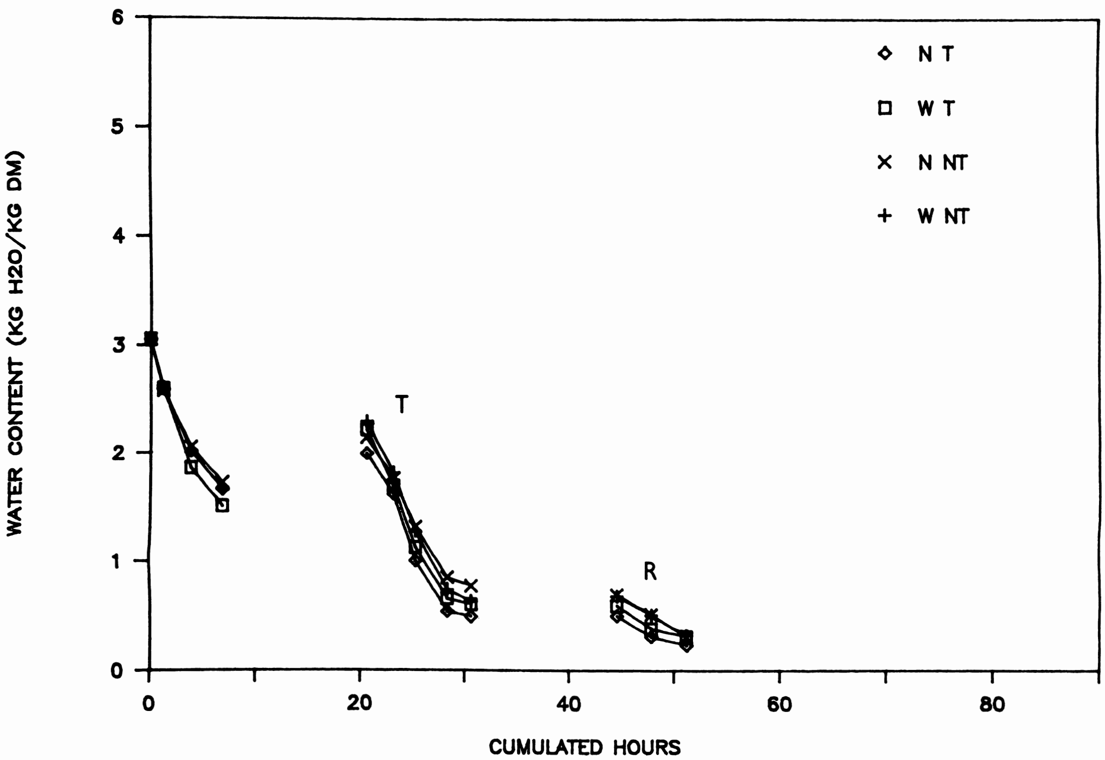

Figure 4. Water content versus time of timothy grass (Bounty) mowed on 27 June 1984. R. stands for time of raking.

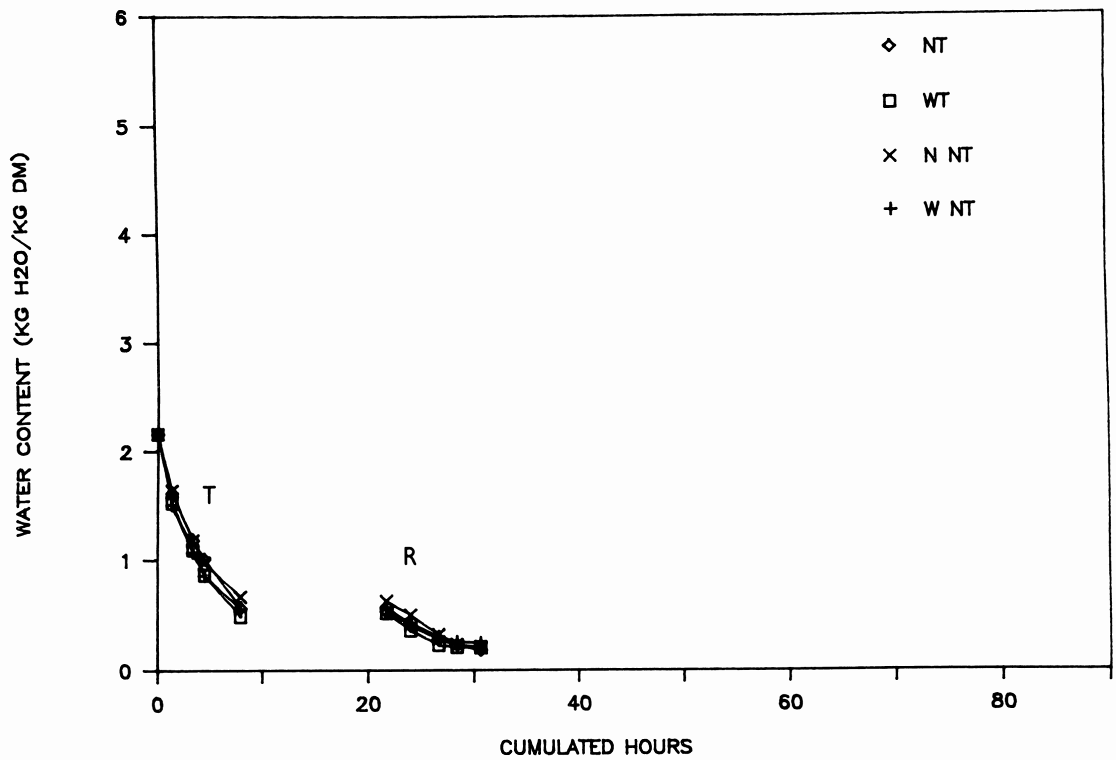

Figure 5. Water content versus time of timothy grass (Bounty) mowed on 9 July 1984.

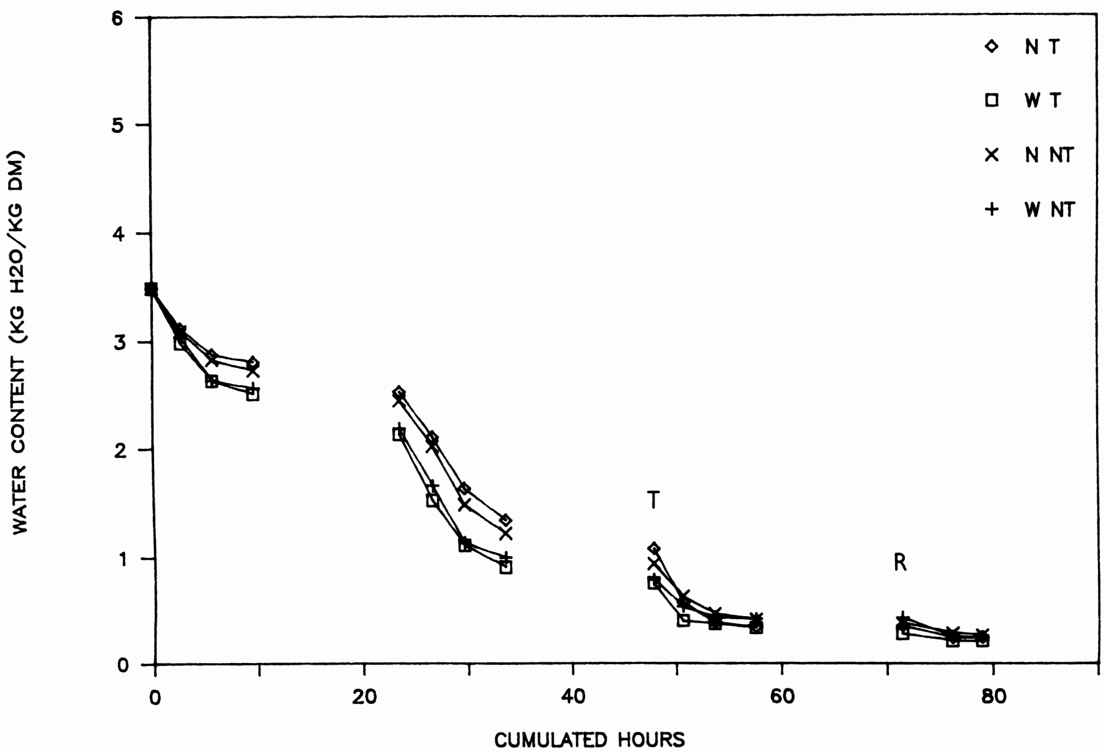

Figure 6. Water content versus time of timothy grass (Bounty) mowed on 25 June 1985.

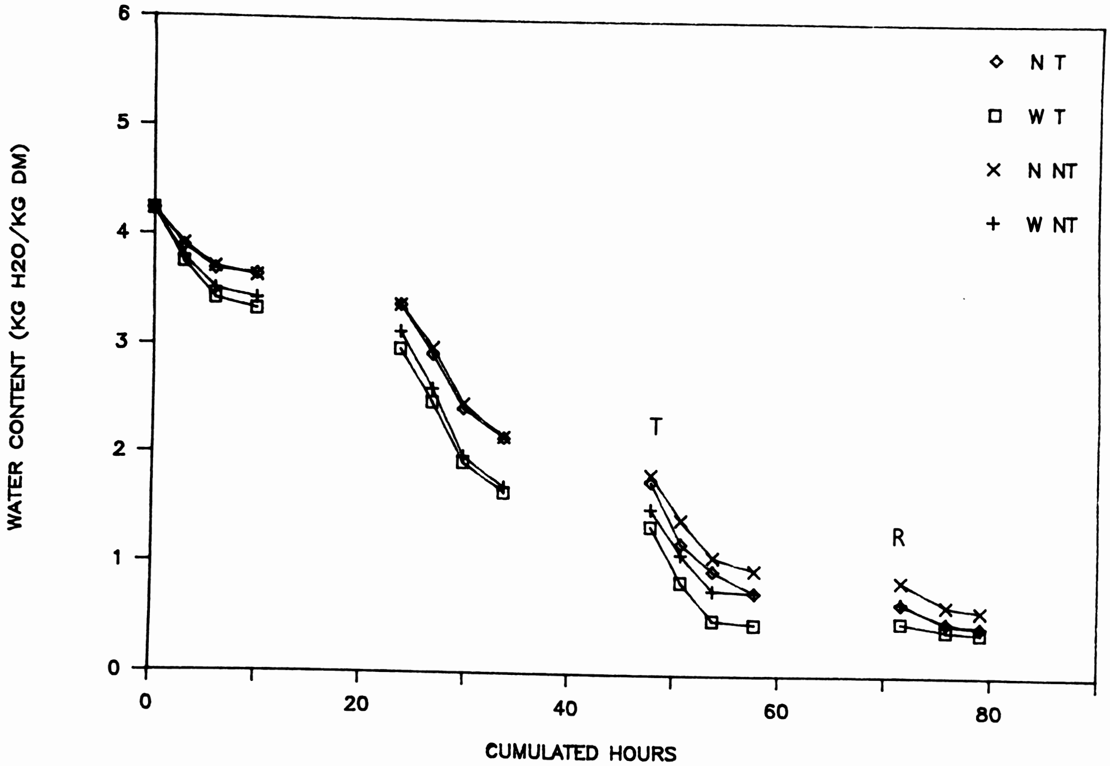

Figure 7. Water content versus time of alfalfa (Saranac) mowed on 25 June 1985.

ACKNOWLEDGMENTS

This research was supported jointly by the Sainte-Foy Research Station of Agriculture Canada and by an operating grant from the Natural Sciences and Engineering Council of Canada. The Deschambault Research Station of the Quebec Ministry of Agriculture provided the physical facilities. The authors thank Stéphane Gariépy and Guy Thibault for their help with the field data collection.

REFERENCES

ANDERSON, V. L. and R. A. McLEAN. 1974. Design of experiments. Marcel Dekker Inc., New York.

DERNEDDE, W. 1979. Treatments to increase the drying rate of cut forage. Pages 61–66 *In* Forage conservation in the 80's, British Grassland Society, Hurley, U.K.

JONES, L. 1979. The effects of stage of growth on the rate of drying of cut grass at 20°C. Grass Forage Sci. 34: 139–144.

JONES, L. and C. E. HARRIS. 1979. Plant and swath limits to drying. Pages 53–60 *In* Forage conservation in the 80's, British Grassland Society, Hurley, U.K.

JONES, L. and J. PRICKETT. 1981. The rate of water loss from cut grass of different species dried at 20°C. Grass Forage Sci. 36: 17–23.

JONES, L. and J. PRICKETT. 1979. Water loss from the swath. Annual Report of the Grassland Research Institute (1978): 64–66.

LEWIS, W. K. 1921. The rate of drying of solid materials. Ind. Eng. Chem. 13: 427–432.

PITT, R. E. 1984. Forage drying in relation to pan evaporation. Trans. (ASAE) Am. Soc. Agric. Eng. 27(6): 1933–1937.

ROTZ, A. C. and Y. CHEN. 1985. Alfalfa drying model for the field environment. Trans. ASAE (Am. Soc. Agric. Eng.) 28(6): 1686–1691.

ROTZ, C. A. and D. J. SPROTT. 1984. Drying rates, losses and fuel requirements for mowing and conditioning alfalfa. Trans. (ASAE) Am. Soc. Agric. Eng. 27(3): 715–720.

SAVOIE, P. 1987. Hay tedding losses. Can. Agric. Eng. 30: 39–42.

SAVOIE, P. and A. MAILHOT. 1986. Influence of eight factors on the drying rate of timothy hay. Can. Agric. Eng. 28(2): 145–148.

SAVOIE, P., E. PATTEY and G. DUPUIS. 1984. Interactions between grass maturity and swath width during hay drying. Trans. ASAE (Am. Soc. Agric. Eng.) 27(6): 1679–1683.

SAVOIE, P., C. A. ROTZ, H. F. BUCHOLTZ and R. C. BROOK. 1982. Hay harvesting system losses and drying rates. Trans. (ASAE) Am. Soc. Agric. Eng. 25(3): 581–585, 589.

STATISTICAL ANALYSIS SYSTEMS. 1985. SAS user's guide: statistics, version 5 edition. SAS Institute Inc., Cary, North Carolina. 956 pp.

THOMPSON, N. 1981. Modelling the field drying of hay. J. Agric. Sci. (Camb.) 97: 241–260.

WILMAN, D. and I. G. OWEN. 1982. Effects of stage of maturity, nitrogen application and swath thickness on the field drying of herbage to the hay stage. J. Agric. Sci. (Camb.) 99: 577–586.