THE DRYING OF HAY AND WILTED SILAGE IN THE FIELD

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ABSTRACT

Two pasture hay drying experiments, conducted during the summer of 1977/78 are described. It is shown that simple measurements of the gravimetric moisture content of the hay, in conjunction with other basic data can provide useful information about the drying of hay swaths. It was found that in a shallow hay swath (30-50 mm deep) covering about 80% of the ground, tedding was of little benefit in increasing the drying rate. Also nocturnal evaporation from the soil/stubble surface under the swath was found to subsequently distill onto the hay and significantly increase the nocturnal hay moisture content over and above that expected from dewfall alone.

INTRODUCTION

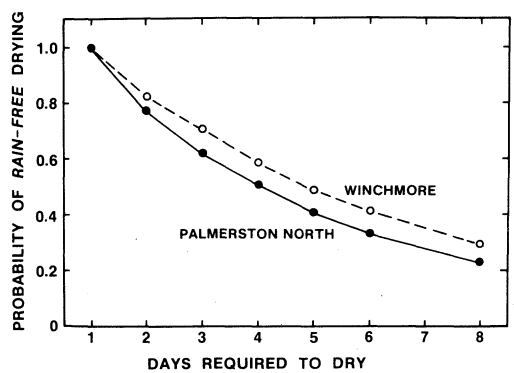
Conservation of pasture in the form of hay, or as silage is the major method by which the New Zealand farmer balances the seasonal pasture production with the requirements of animal nutrition. In 1974-75 some half a million hectares of grass/clover pasture was cut for hay or silage, representing a doubling over the previous 20 years. Hay represents 85% of the total pasture conserved. Haymaking entails the field drying of the cut pasture from gravimetric moisture contents of around 3-4 down to a safe, baleable moisture content of about 0.3 (dry weight basis). For wilted grass silage the preferred ensilable moisture content is around 1.8. Drying for wilted grass silage represents just the early stage of hay drying, so subsequent discussion will relate specifically to hay drying.

Despite the importance of pasture conservation, little research has been conducted into the physical processes involved in the field drying of hay. There has been much study into the effect of different agricultural machinery on the rate of hay drying, and research into the changing nutritive quality of hay has been carried out.

At the most basic level an absence of rain is assumed to provide favourable conditions for the drying of hay. Rainfall frequency distribution data provide a means of estimating the probability of rainfree periods of any given length. For hay drying it is often assumed that a "rainfree" period is one during which less than 2 mm of rain falls. In Figure 1 the probability of "rainfree" summer hay drying for Palmerston North and Winchmore is plotted against the number of days required to dry the hay. As hay drying often takes 3 days the probability of success at Winchmore is 0.70 and 0.63 at Palmerston North. These probabilities assume that the hay is cut on a randomly-chosen fine day. By taking account of the synoptic meteorological situation prior to cutting, it is often possible to increase the probability of successful hay drying. Detection of the position and amplitude of synoptic ridges of high pressure, provides a basis for the extended forecasting of fine weather. This approach was used in South Otago to successfully predict a rainfree hay drying period (Trenberth *et al.* 1978). This promising approach it is hoped can be developed further.

The rate at which hay dries, is controlled by microclimatic factors, so whereas a "rainfree" drying

Figure 1. The probability of the hay drying period being "rainfree" (rainfall $\leqslant$ 2 mm) against the number of days required for drying for Palmerston North and Winchmore. The data apply to the summer period.



is necessary it is not a sufficient condition to ensure successful hay drying. Attempts have been made to link the rate of water loss from hay swaths to meteorological parameters to enable better prediction of hay drying. From growth chamber experiments Kemp *et al* (1972) found that the atmometer evaporation rate correlated well with the drying rate of lucerne. From field data Spatz *et al* (1970) found that the integrated saturation vapour pressure deficit, solar radiation and the number of sunshine hours all correlated well with the declining moisture content of the hay, and concluded that "it is thus not possible to determine to what extent any of the three factors influences the drying process", and subsequently adopted the saturation vapour pressure deficit as their independent variable. These empirical methods lack a sound physical basis that limits their general applicability. It is doubtful that they "could become a powerful tool in field drying experiments" as Kemp *et al* (1972) suggest.

Other studies have related the moisture content of the hay at a given stage to the integrated value of evaporation from a short, well-watered vegetative surface (E_p) (Hayhoe and Jackson, 1974; Dyer and Brown, 1977) by an equation of the form

$$X_T = X_o \exp [C \int_0^T E_p \, dt] \quad (1)$$

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where X_T and X_O respectively represent the moisture content at time T and that prior to cutting and where C is an empirically determined constant. It can be shown by manipulation of equation (1) that the empirical constant C is related to the surface resistance (r_c) in the Monteith (1965) equation

$$E = E_p / [1 + (\gamma / (s + \gamma)) \, r_c / r_a] \qquad (2)$$

where E is the rate of evaporation from the hay swath, r_a the aerodynamic resistance, s the slope of the saturation vapour pressure curve and γ the psychrometric constant. The surface resistance of a drying hay swath is a dynamic parameter related to the character of the soil/stubble surface, the porosity and density of the hay swath, the nature of the plant tissue and the stage of drying, so the empirically-determined constant C covers up and combines the many physical processes involved in hay drying. Clark and McDonald (1977) and Burrows *et al* (1968) have directly applied equation (2) to drying hay swaths to find the change in the resistance to drying of the hay with time. Tanner and Fuchs (1968) and Black *et al* (1970) expressed reservations about the applicability of Monteith's equation to a surface in which the sources of heat and vapour have a dissimilar distribution. In a drying hay swath this may well be the case. So Monteith's equation, as per equation (2), may not hold. To determine the applicability of such an approach requires information about the mechanisms and pathways of water loss, but there is a dearth of such knowledge in relation to drying hay swaths.

The lack of understanding of the physical processes operating in drying hay swaths has lead to the development of such highly empirical procedures for predicting hay drying, as described. During the field drying of hay the evaporation rate at some height above the swath is comprised of water emanating from three sources:

- that evaporated at the soil/stubble surface in the swath-free area.
- that evaporated from the soil/stubble surface and transported through the swath into the atmosphere,
- and that which is lost from plant tissue in the hay swath.

Water lost from plant material at the upper surface of the swath experiences a resistance to movement through the plant tissue, and this resistance increases strongly with decreasing tissue moisture content. Water lost from deeper in the swath experiences in addition to this tissue resistance, a resistance to vapour transport through the tortuous pathway within the swath, out into the atmosphere. It is commonly held that hay-conditioning by lacerating the leaves and especially the stems reduces the tissue resistance and thereby increases the rate of drying and that tedding by reducing the swath resistance also facilitates an increased drying rate.

This paper describes two pasture hay drying experiments conducted during the summer of 1977/78, in which the pathway and mechanisms of water loss were studied. Specifically three aspects of these experiments are reported:

- Whereas it is common practice to ted hay at least once during field drying there is little evidence as to the efficacy of tedding. This paper examines the effect of tedding on the drying rate and discusses the magnitude of the bulk swath resistance to water loss.
- Much is said about the magnitude of soil/stubble evaporation during the field drying of hay, but few data have ever been published. In this paper measurements of the rate of soil/stubble evaporation in relation to the rate of hay drying, for two different levels of soil moisture, are presented.
- Dew is the bane of most field hay drying. The amounts and sources of dew deposition on hay swaths is examined.

It is shown that simple measurements of the gravimetric moisture content of the hay, in conjunction with other basic data can provide useful information about the drying of hay swaths.

MATERIALS AND METHODS

Two experiments were carried out on a ryegrass/clover pasture growing on Tokomaru silt loam, near Massey University. A first cut of hay was removed from the pasture on 16th November, 1977. Then on 17th January two hectares of hay was cut for the first experiment. An additional 2 hectares was cut for the second experiment on 30th January, 1978. Total pasture dry matter yield was found on the 16th January to be 0.44 kg m^{-2}, of which 40% was clover. There was no dry matter accumulation between the first and second experiments as water stress limited growth. Whereas there was 60% inflorescence in the ryegrass very few clover plants had reached flowering. The *in vivo* digestibility of the overall sward was 64% as estimated using the technique of Roughan and Holland (1977). The ryegrass had a digestibility of 58% and the clover of 72%.

A reciprocating sicklebar mower with a cutterbar of width 1.2 m was used to cut the hay. The swath board produced a swath 30-50 mm deep, covering 80% of the ground area (Cross, 1965). The mower cut sufficiently close to the ground, for it to be reasonable to assume that the areal swath density (ρs) corresponded to the dry yield of the standing crop. Tedding was performed with a twin rotary, horizontal tyne machine, without swath boards, which left the tedded swath also covering about 80% of the ground.

Hay samples for gravimetric moisture content were obtained by cutting a 300 mm strip across the entire swath. The swath sample was then separated into an upper half and lower half. Three or four replicates were taken at each sampling. Sample weights before and after drying in a ventilated oven for 24 hours at 95°C were recorded. All hay moisture contents (X) were expressed on a dry weight basis, i.e.

$$X = \frac{\text{mass of water removed by oven drying}}{\text{mass of dry hay}}$$

This enables the equivalent depth of water in the hay (in mm) to be expressed as $\rho s X$, where ρs is in kg m^{-2}. Hence the evaporation rate of the hay (in W m^{-2}) can be found as $\rho_s L \, dX/dt$ where L is the latent heat of vapourization in J kg^{-1}. For studies of the physics of hay drying it is natural to express the moisture content on a dry weight basis, as it reflects the loss of water by the swath. Agronomists and engineers by expressing moisture content as % dry matter or moisture content on a wet basis have concentrated on the changing dry matter content which it is felt has impeded understanding of the process of water loss from hay.

Soil/stubble evaporation was measured at 8 sites (4 in the swath-free cut, and 4 under the swath) by frequent weighing of lysimeters 50 mm deep and radius 76 mm. Thin metal cylinders were pressed into the soil/stubble immediately following cutting then removed so that the bottom could be sealed with plastic. The completed lysimeter was then placed back into the hole to measure soil/stubble evaporation. Soil moisture content in the 0-50 mm zone was found at the end of each experiment by the oven-drying of soil samples at 105°C for 24 hours.

Bowen-ratio energy balance measurements of evaporation were made during both hay drying experiments. The two Bowen ratio units used were similar in design to that described by Black and McNaughton (1971). An on-line computer enabled energy balance components and the other microclimatic measurements to be calculated every half-hour from averaged 30-second samples. Net radiation was measured above the swath.

Integrated daylight net radiation for the three days of the second hay drying experiment was 6.49, 17.48, 17.12 MJ m^{-2} respectively. The values for the first experiment were 17.72, 15.93 and 11.94 MJ m^{-2} on the respective days. As the summer mean daylight net radiation total at Palmerston North is 13.39 MJ m^{-2}, weather conditions for the experiments were typical of hay drying weather in the Manawatu.

RESULTS AND DISCUSSION

Swath Resistance to Drying

Immediately following cutting by the sicklebar mower on the 30th January, half of the cut area was tedded. Following evaporation of the dew the next morning, the tedded area was again tedded. The moisture content of both the hay lying in the swath and that tedded is shown for the three days of drying in Figure 2. Despite tedding, the drying rates of both the undisturbed swath and the tedded hay were not significantly different and both reached a safe baleable moisture content of 0.3 in the early afternoon of the second day. This result suggests that the swath resistance was not limiting the rate of hay drying, in this case of pasture (ρ_s = 0.44 kg m^{-2}) cut by a sicklebar mower. If, in fact, the swath resistance were small relative to the tissue resistance then it would be expected that the lower portion of the swath would dry at a rate similar to that of the upper layers in the swath. Figure 3 shows that this appears to be the case of the pasture similarly cut on 17 January.

A further indication of the magnitude of the swath resistance can be achieved by comparing the rate of soil/stubble evaporation from the swath-free area to that from under the swath, when hay drying has ceased. On the afternoon of 18 January the rate of soil/stubble evaporation from the swath-free area was

Figure 2. The change in moisture content of a ryegrass/clover hay swath cut with a sicklebar and left to dry (○---○) and a hay swath cut with a sicklebar and tedded immediately and tedded again at midday on the second day (●—●). Hay evaporation on each of the three days was 1.49, 0.50 and 0.38 MJ m^{-2} respectively.

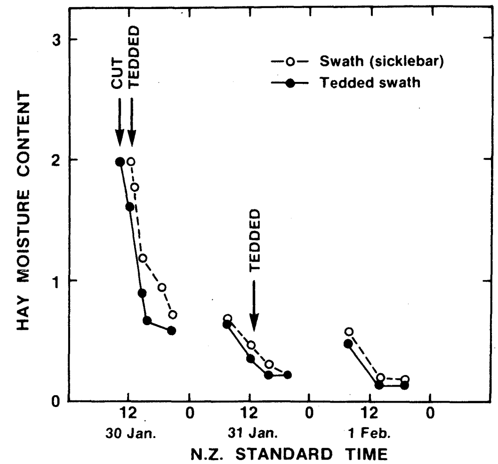
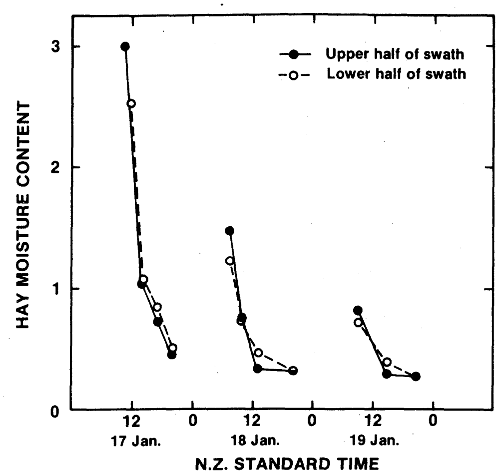


Figure 3. The change in moisture content of both the upper swath (●—●) and lower swath (○...○) of a ryegrass/clover hay swath cut with a sicklebar. Hay evaporation on each of the three days was 2.73, 1.00 and 0.59 MJ m^{-2} respectively.



measured by the small lysimeters at 130 (± 21) W m^{-2}. Over the same period soil/stubble evaporation under the swath occurred at 93 (± 16) W m^{-2}. The similar soil/stubble evaporation rates further supports the notion that the swath resistance was minimal.

In view of the above it is not surprising that tedding had no effect on the rate of hay drying. The swath in this case was only 30-50 mm deep. For deeper swaths of say + 200 mm (Clark and McDonald, 1977) tedding will probably be effective in increasing the drying rate.

Soil/Stubble Evaporation

Evaporation from the soil/stubble surface both under the swath and in the swath-free area, will

TABLE 1: Soil/stubble evaporation rate and the rate of haydrying for two haymaking experiments on ryegrass/clover. Gravimetric soil water content (0-50 mm) was 0.14 on 19th January and 0.09 on 1st February

Date: 1978	Period (hours)	Haydrying rate ($W m^{-2}$)	Soil/stubble evaporation rate ($W m^{-2}$)	Ratio (soil/stubble)/hay
17 January	1000-2000	76	106	1.4
18 January	0730-2000	22	54	2.4
19 January	0730-2000	13	40	3.1
30 January	1100-2100	41	25	0.6
31 January	0730-2000	11	42	3.8
1 February	0800-2000	9	36	4.1

reduce the rate of evaporation from plant tissue in the swath. The amount of reduction will depend in part on the ratio of the soil/stubble evaporation rate to the rate of hay drying. Soil/stubble evaporation was measured during both experiments, and the results are shown in Table 1, along with the rate of hay drying. The gravimetric soil moisture content (0-50 mm) on the 19th January was 0.14, which is close to the -15 bar gravimetric moisture content of 0.15. Despite dry soil evaporation from the soil/stubble was always greater than that from the hay. The soil moisture content had decreased to 0.09 by 1st February and the surface soil pressure potential was then estimated to be drier than -27 bars. Notwithstanding this increase in soil dryness the rate of soil/stubble evaporation is still significant with respect to the rate of hay drying. By how much soil/stubble evaporation reduces the rate of hay drying is not yet clear and will be the subject of further work, but it is obvious that significant rates of soil/stubble evaporation are an integral part of field hay drying.

Dewfall and Distillation

On three of the four nights shown in Figures 2 and 3 significant nocturnal increases in hay moisture content occurred. It is an unfortunate dilemma that the favourable drying conditions of high net radiation occurring on non-cloudy days are often associated with nocturnal clear skies which favour dewfall. During the night of the 17th January the moisture content of the hay increased by 0.37 mm depth equivalent of water. As this took 4 hours next day to evaporate, water must have been re-absorbed into the hay. The nocturnal condensation of water onto hay swaths occurs both from above by dewfall and from below by distillation of water evaporated from the soil/stubble surface. Bowen-ratio energy balance measurements of dewfall were made throughout the night, and showed that the Bowen ratio remained stable at the equilibrium value of γ/s. Consequently dewfall occurred at the maximum potential rate of $(s/(s + \gamma))(R_n - S)$ (Monteith, 1956) and was found to total 0.22 mm. The additional water must have come by distillation from the soil/stubble surface. The lysimeters under the swath measured 0.11 mm of evaporation during the night, this evaporation rate being maintained by the nocturnal upward soil heat flux. The subsequent condensation of this on the hay swath means a total deposition of 0.33 mm of water was measured, agreeing well with the recorded change of 0.37 mm. The treatment of condensation onto hay swaths solely as a dewfall process (Dyer and Brown, 1977) may result in underestimation of the nocturnal gain in moisture by hay swaths.

CONCLUSIONS

Measurement of water loss pathways in these two experiments has suggested that in medium hay swaths cut by a sicklebar mower such that the swath is 30-50 mm deep and covering 80% of the ground, the bulk swath resistance to water removal is sufficiently small, that tedding is of little benefit in increasing the drying rate.

It was found that even with very dry soil conditions the rate of soil/stubble evaporation is significant with respect to the rate of hay drying. Nocturnal evaporation from the soil/stubble surface can, by subsequent distillation, significantly increase the nocturnal hay moisture content over and above that expected from dewfall alone.

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LIST OF SYMBOLS

E	hay drying rate (ρ_s L dx/dt)	W m^{-2}
E_p	evaporation rate from a short, well-watered vegetative surface	W m^{-2}
R_n	net radiation	W m^{-2}
S	change in heat storage of the hay swath	W m^{-2}
s	slope of the saturation vapour pressure temperature curve	mb C^{-1}
γ	psychrometric constant	mb C^{-1}
L	latent heat of vapourization of water	J kg^{-1}
t	time	s
r_c	surface resistance	s m^{-1}
r_a	aerodynamic resistance	s m^{-1}
ρ_s	swath density	kg m^{-2}
X	hay moisture content on a dry weight basis	kg kg^{-1}
c	empirical constant	