Drying of macerated lucerne hay in Australia

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George, D.L., Gupta, M.L. and Sinon, F.G. 2004. **Drying of macerated lucerne hay in Australia**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **46**: 2.7 - 2.12. The effect of maceration on drying time in lucerne grown in southeast Queensland was compared with that of unconditioned and standard roll-conditioned hay in two experiments. Two laboratory macerators, one with steel rolls and the other with rubberised rolls, were used to macerate hay samples. In both experiments, macerated hay reached safe storage moisture contents significantly earlier than unconditioned or standard roll-conditioned hay. In Experiment 1, safe moisture content of both maceration treatments was reached in 6-7 h of field drying due to ideal weather conditions. However, in Experiment 2, in which safe moisture content was not reached until after 26 h of field drying, the drying rate for hay macerated with rubberized rolls was significantly faster than for steel rolls. Thus, maceration with rubberised rolls decreased drying time under more normal summer conditions due to greater maceration, thus reducing the risk of losses due to rainfall. The production of high quality hay in southeast Queensland would be enhanced by adopting maceration by rubberised rolls. **Keywords:** maceration, drying, lucerne, hay.

Deux études ont été menées afin de déterminer l'effet de la macération sur le temps de séchage de la luzerne produite dans la région sud-est du Queensland par rapport à celui requis dans le cas de foin non conditionné et de foin conditionné par des rouleaux conditionneurs conventionnels. Deux macérateurs, le premier muni de rouleaux d'acier et l'autre muni de rouleaux caoutchoutés, ont été utilisés en laboratoire pour macérer des échantillons de foin. Dans les deux études, le foin macéré a atteint une teneur en eau sécuritaire pour l'entreposage plus rapidement que le foin non conditionné ou que celui conditionné par rouleaux conditionneurs conventionnels. Durant la première étude, le foin traité par l'un ou l'autre des deux systèmes de macération a atteint une teneur en eau sécuritaire après 6 à 7 h de séchage au champ en raison de conditions météorologiques idéales. Lors de la deuxième étude, il a fallu 26 h de séchage au champ avant que le foin macéré n'atteigne une teneur en eau sécuritaire. Le taux de séchage pour le foin macéré avec des rouleaux caoutchoutés a été significativement plus rapide qu'avec les rouleaux en acier. De plus, la macération avec des rouleaux caoutchoutés a réduit les risques de pertes causés par la pluie. La production de foin de haute qualité dans le sud-est du Queensland serait favorisée par l'adoption de la macération par rouleaux caoutchoutés. **Mots clés**: macération, séchage, luzerne, foin.

INTRODUCTION

Lucerne hay is an important animal feed worldwide but its quality is subject to the effects of loss of leaf and soluble constituents when weather conditions are not optimal for drying. Shepherd et al. (1954) have shown that these losses are closely related to field drying rates. Conventionally, the drying rate of lucerne hay has been increased by raking and mechanical conditioning (crushing and crimping of leaf and stem material). More extreme mechanical conditioning such as maceration has a greater effect on drying rate (Savoie et al. 1993). The drying rate of lucerne has also been increased by using chemical treatments such as potassium carbonate (Tullberg and Minson 1978; Wiegert et al. 1983).

Maceration is a very intensive conditioning process normally applied at the time of mowing within the same machine (Koegel et al. 1992) but separate pull-type macerators are also available to apply it after mowing as an independent operation (Descoteaux and Savoie 2002). Freshly mown hay is compressed between two or more steel rolls rotating at high but different speeds. The difference in roll speeds shears the plant tissue causing cell rupture and subsequent rapid moisture loss. The main aim is to expedite drying in the field and thus reduce the vulnerability of the freshly mown hay to adverse weather conditions. This allows hay crops of higher quality to be produced or, in cases of impending rain, to be saved. At present in southeast Queensland, typical field drying times are 2 to 3 days in summer and 4 to 8 days in winter.

Corrugating cylindrical steel for a macerating roll is very expensive. Savoie and Tremblay (1997) reduced the cost of corrugations using helically grooved rolls which can be machined by an ordinary metal lathe. In the past, Barnick (1959) found a number of advantages of a rubberised-conditioning roll over a steel roll. It runs quietly, is self-cleaning, resists damage from obstacles such as rocks, and readily crushes the stem. Rubber material also is not corroded by the forage sap.

In a recent review, Savoie (2001) indicated potential benefits of forage maceration. Most of these studies have been undertaken in North America and no research work has been conducted in Australia. Also, there has not been much research conducted on the effect of using a material other than steel as a macerating roll surface. The main objective of this study was to compare the effects of different conditioning/maceration treatments on drying rates of lucerne hay in Australia including the evaluation of a rubberised roll macerator.

MATERIALS and METHODS

Laboratory macerators

Two laboratory macerators were used in this study: a macerator with two corrugated steel rolls (Savoie et al. 1996) and a newly developed 2-roll laboratory macerator with rubberised macerating rolls (Fig. 1). This macerator was similar in design to the corrugated steel rolls machine. The 220 mm diameter smooth rolls were covered with a belting material of 60 duro rubber hardness (Powergrip Industries Pty. Ltd., Brisbane, Australia). This belting material was applied by gluing a strip 90 mm wide and about 5 m long for each roll (Fig. 2). The design pattern formed an 8° angle to the longitudinal axis of the rolls.

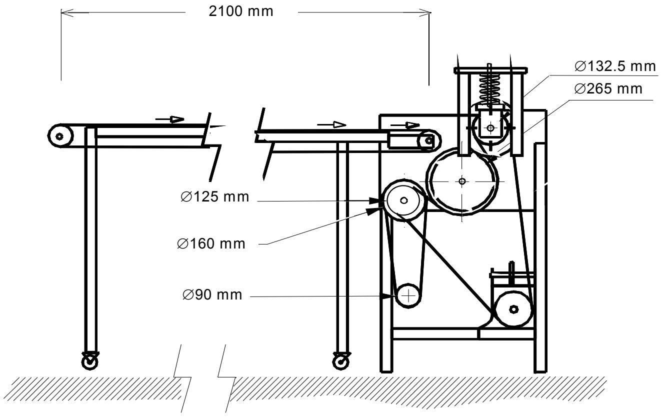

Fig. 1. Schematic diagram of laboratory macerator using rubberised macerating rolls.

The rolls were arranged so that the upper surface pattern of the lower roll crossed at an angle of 16° with the lower surface pattern of the upper macerating roll to provide additional maceration. The feeding conveyor was modified to accommodate both macerators by adding wheels to facilitate movement between them.

Drying experiments

Two drying experiments were conducted at the University of Queensland Gatton farm in January-February 2000 with four treatments: T_1 = unconditioned, T_2 = standard roll-conditioned, T_3 = macerated (steel-rolls) and T_4 = macerated (rubberised-rolls) on lucerne (*Medicago sativa cv. Sequel*) at the full bloom stage. A randomised complete block design with four replications was used. In both experiments the same variety was used but from different fields on the Gatton farm. The crops were cut at the same time in the morning after the dew had disappeared. Physical condition of the crop was noted before the start of each drying experiment. Crop yield was estimated by manually cutting a fresh crop sample quadrat (700 × 700 mm) at four random field locations. These were immediately weighed and dried in an oven at 103°C for 24 h (ASAE 1997). Initial moisture content was computed on a dry matter basis.

A walk-behind, Solo Auto Scythe with 0.80 m reciprocating cutterbar-mower was used for T_1, a Sperry New Holland model 492 with a 2.82 m cutter-bar mower and intermeshing rubber roll-conditioner for T_2, a laboratory macerator with corrugated steel rolls for T_3, and a newly developed laboratory macerator with rubberised rolls for T_4.

All equipment used in these experiments was adjusted to the normal operating settings. The height of the cutter-bar mower was set to cut the crop at approximately 50 mm above the ground. The two macerators were set at 1 mm roll clearance with no additional pressure applied through the two springs located at the ends of the upper rolls. This roll pressure was found to be optimum in previous studies (Gupta et al. 2002). For both macerators, the speed ratio of the upper and lower rolls was fixed at 2.0 using a differential pulley system. To simulate the normal forward speed of operation in the field, the conveyor peripheral speed was set at 2 m/s (7.2 km/h). A 1.25 kg lucerne sample was placed on the conveyor belt area of 600 × 1400 mm to obtain a sample feeding rate of 3 kg s^{-1} m^{-1} of the macerator roll length. This rate corresponded to that of lucerne cut by a

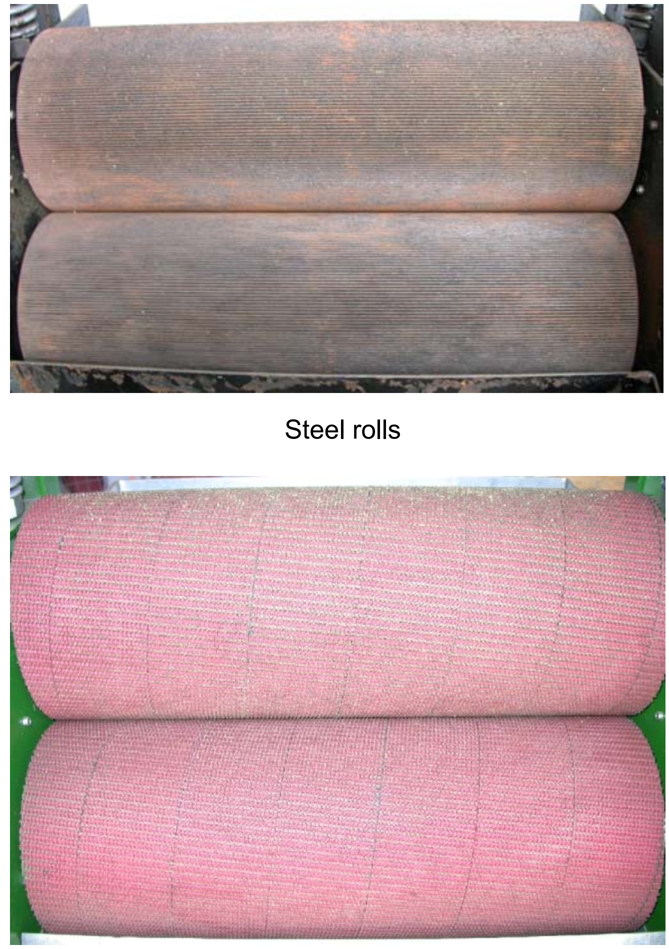

Fig. 2. Macerating rolls used for hay drying experiments.

mower-conditioner with standard rolls operating at a speed of 7.2 km/h in a crop with a density of 1.5 kg/m^2.

The treated samples were spread on 500 × 1000 mm wire mesh drying trays to achieve a density of approximately 2.5 kg/m^2 to simulate field drying conditions. All the sample trays were laid on a grassed area at the same time for natural field drying. The trays with samples were weighed every three hours inside an adjacent shed using an electronic balance with an accuracy of 0.1 g. For each drying day, the samples were also weighed at sunset and sunrise to determine the amount of moisture absorbed overnight. Trays for all blocks were weighed in the same order each time to minimize time differences involved in weighing. As soon as samples for a given treatment reached approximately 25% (db), they were placed in paper bags and oven dried for dry matter determination. Moisture contents at each observation time were then determined from the dry matter mass and mass of the sample recorded during the drying process.

An automatic portable weather station was installed near the experimental site. This consisted of a solar-powered data logger with dry and wet bulb temperature sensors, an anemometer, a solar radiation sensor, and a tipping bucket rain gauge. The anemometer and solar radiation sensor were installed at a reference height of 2 m above ground level. The data logger

Table 1. Weather data for drying experiments (Gatton, Queensland, Australia).

Variable	Experiment 1 (January 2000)		Experiment 2 (February 2000)		
	January 20	January 21	February 18	February 19	February 20
Maximum temperature (°C)	39.0	39.4	28.4	29.2	29.2
Minimum temperature (°C)	22.9	26.7	14.8	18.4	13.7
Mean daytime temperature (°C)	34.2	33.6	21.1	23.9	23.1
Mean daytime RH (%)	75.8	72.1	67.6	60.7	60.4
Mean daytime wind speed (m/s)	6.7	7.6	6.6	7.9	5.1
Daily radiation (MJ/m^2)	27.1	26.5	19.4	22.0	24.4

recorded the mean output from each sensor over 1 hour intervals.

Analysis of data

The effectiveness of treatments on the field drying of hay was investigated by comparing moisture contents and drying constants. Many research workers (e.g. Rotz and Sprott 1984; Rotz et al. 1987; Savoie and Beauregard 1990) have used the thin-layer model (Eq. 1) to represent the drying characteristic of hay over a given interval of time.

$$\frac{M - M_e}{M_o - M_e} = \exp(-kt) \qquad (1)$$

where:

M = moisture content at end of drying interval (%, db),
M_o = moisture content at beginning of drying interval (%, db),
M_e = equilibrium moisture content (%, db),
k = drying constant (h^{-1}), and
t = drying interval (h).

Table 2. Crop characteristics for drying experiments.

Variable	Experiment 1	Experiment 2
Initial moisture content (%, db)	317	342
Crop yield (t DM/ha)	2.2	2.8
Crop maturity	bloom	bloom
Average height (mm)	500	580

Table 3. Moisture content of unconditioned, standard roll-conditioned, and macerated (steel rolls and rubberised-rolls) lucerne hay.

Treatment	Experiment 1 MC (8h) (%, db)	Experiment 2 MC (26 h) (%, db)
Unconditioned	38.2 c*	57.3 d
Standard roll-conditioned	27.4 b	35.3 c
Macerated (steel rolls)	22.8 a	23.9 b
Macerated (rubberised-rolls)	21.7 a	15.9 a
LSD	4.2	6.2

*Means in a column followed by the same letter are not significantly different at 5% level.

The transformed form (Eq. 2) of Eq. 1 was used to determine drying constants for each drying interval. Under field drying conditions M_e is usually very small, and can be assumed to be zero as suggested by Rotz and Sprott (1984).

$$k = -\frac{1}{t}\ln\frac{M}{M_o} \qquad (2)$$

An overall mean drying constant for each replicate of each treatment was determined by averaging drying constants for all intervals (excluding those influenced by rewetting and evaporation of overnight dew) over the complete drying period until hay cut by any of the cutting treatments reached baling moisture content (25% db).

ANOVA was conducted using Minitab Statistical Software, Release 13.1 (Minitab, Inc., State College, PA) and LSD tests were used to compare treatment means at the 5% level of significance.

RESULTS and DISCUSSION

Weather and crop characteristics

Details of the weather parameters during the field drying experiments are presented in Table 1. Weather conditions for Experiment 1 were very favourable for drying, thus all the hay samples dried to the safe storage level in just two days. For Experiment 2, weather parameters, especially maximum temperatures and daily radiation, were more normal for summer. Details of the crop characteristics are given in Table 2. All crop samples were at bloom stage and had initial moisture contents of 317% and 342% (db) for Experiments 1 and 2, respectively.

Experiment 1

The moisture contents of unconditioned, standard roll-conditioned and macerated (steel-rolls and rubberised-rolls) hay are presented in Table 3. The moisture contents of hay macerated by steel-rolls and rubberised-rolls reached safe storage levels of 22.8 and 21.7%, respectively, after 8 h of field drying. The standard roll-conditioned and unconditioned hay did not reach 25% MC (db) by the end of the first drying day. Moisture content of the macerated (steel-rolls and rubberised-rolls) hay was significantly lower than the standard roll-conditioned hay which, in turn, was significantly lower than the unconditioned hay.

Figure 3 shows the drying curves of the unconditioned, standard roll-conditioned, macerated (steel-rolls), and macerated (rubberised-rolls) hay for Experiment 1 during which the

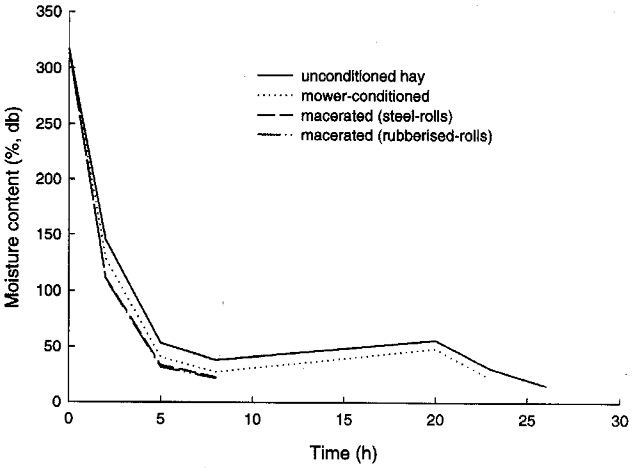

Fig. 3. Drying curves of the unconditioned, standard roll-conditioned, and macerated hay for Experiment 1.

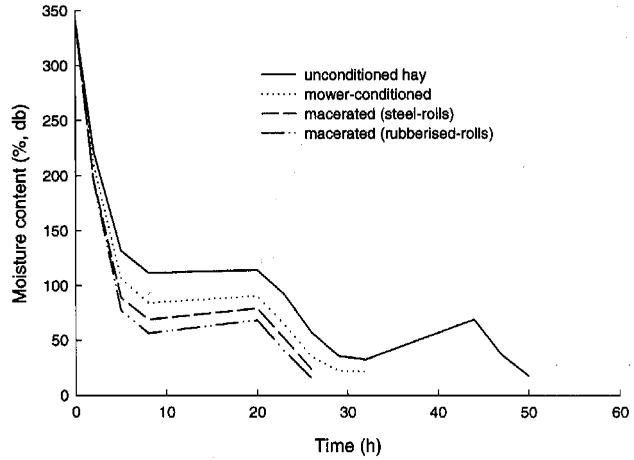

Fig. 4. Drying curves of the unconditioned, standard roll-conditioned, and macerated hay for Experiment 2.

highest monthly temperature of 39°C was recorded in southeast Queensland. Hay macerated with steel-rolls or rubberised-rolls dried to the safe storage level in approximately 6-7 h of field drying whereas the standard roll-conditioned and unconditioned hay took 23 and 25 h of field drying, respectively, to reach 25% MC (db). Thus, under excellent drying conditions, it may be possible to cut the crop and bale it on the same day using the macerator.

The overall mean drying constants were also significantly different ($P<0.05$) between treatments in Experiment 1 (Table 4). The drying constant was greatest for treatment T_4 followed by treatments T_2 and T_1. T_3 was not significantly different from T_4. Compared to unconditioned hay, maceration treatments showed an increase in drying constant of about 26-29% while a 16% increase was noted for the standard roll-conditioned treatment (Table 5). It was apparent that under the extremely favourable drying conditions which occurred in this experiment that rubberised rolls provided similar drying as steel rolls.

Table 4. Overall mean drying constants of lucerne for various treatments.

Treatment	Drying constant (h^{-1})	
	Experiment 1	Experiment 2
Unconditioned	0.278 a	0.135 a
Standard roll-conditioned	0.322 b	0.173 b
Macerated (steel rolls)	0.351 c	0.206 c
Macerated (rubberized-rolls)	0.358 c	0.237 d
LSD	0.022	0.022

*Means in a column followed by the same letter are not significantly different at 5% level.

Experiment 2

Trends in drying behaviour of unconditioned, standard roll-conditioned, macerated (steel-rolls) and macerated (rubberised-rolls) hay were similar to those observed in Experiment 1 (Fig. 4). However, the steel-roll macerator did not perform as well as the rubberised-roll macerator. The low performance of steel macerating rolls could be due to lack of uniformity in maceration of the crop. When the crop was fed into the macerating rolls, the upper portion received better conditioning than the middle and the lower portions as was also expected by Savoie and Tremblay (1997). This variation in conditioning resulted from the shearing action caused by differential roll speed. The rubberised-roll macerated hay showed consistently higher drying rates compared to the steel-roll macerated, standard roll-conditioned, and unconditioned hay. The design pattern or configuration of the rubberised roll forming 8° from the shaft longitudinal line helped in providing uniformity of maceration, because the crop was rolled over as it passed through the macerating rolls. This was evident by the cuts slanting across the plant that were observed on both sides of the plant stem.

Table 5. Relative increase in overall mean drying constant between treatments - Experiment 1.

Treatment	Drying constant (h^{-1})	Increase in drying constant (%)		
		Unconditioned	Standard roll-conditioned	Macerated (steel-rolls)
Unconditioned	0.278	-	-	-
Standard roll-conditioned	0.322	15.8	-	-
Macerated (steel rolls)	0.351	26.3	9.0	-
Macerated (rubberised-rolls)	0.358	28.8	11.2	2.0

Table 6. Relative increase in overall mean drying constant between treatments - Experiment 2.

Treatment	Drying constant (h^{-1})	Increase in drying constant (%)		
		Unconditioned	Standard roll-conditioned	Macerated (steel-rolls)
Unconditioned	0.135	-	-	-
Standard roll-conditioned	0.173	28.1	-	-
Macerated (steel rolls)	0.206	52.6	19.1	-
Macerated (rubberized-rolls)	0.237	75.6	37.0	15.0

The moisture content of the macerated (rubberised-rolls) hay was significantly lower than the macerated (steel-rolls), standard roll-conditioned, and unconditioned hay after 26 h of field drying (Table 3). Moisture content of hay macerated by rubberised-rolls and steel-rolls (15.9 and 23.9%, respectively) was less than the safe storage level but this was not the case for the unconditioned and the standard roll-conditioned hay. Unconditioned hay did not dry to a safe storage level within two drying days but was finally dried to 25% MC (db) on the third day after 49 hours of field drying.

The overall mean drying constants were significantly different ($P<0.05$) between treatments in Experiment 2 and lower than those of Experiment 1 (Table 4). This was due to the lower temperatures and solar radiation for this experiment compared with Experiment 1 (Table 1). The drying constant was greatest for treatment T_4 followed by treatments T_3, T_2, and T_1. Both conditioning and maceration treatments showed greater increases in drying constants over untreated hay compared with Experiment 1. The rubberised roll maceration treatment showed a 76% increase in the drying constant while the steel roll maceration and standard roll-conditioned treatments showed increases of about 53 and 28%, respectively (Table 6). The rubberised roll maceration treatment showed an increase of 15% over the steel roll maceration treatment. In Experiment 2, the drying rate for the rubberised roll maceration treatment was higher than for steel roll maceration due to greater maceration enabling more rapid drying under lower temperature and radiation conditions. In contrast to Descoteaux and Savoie (2002), we found that maceration was more effective under lower radiation and temperatures. However, radiation levels in southeast Queensland are most likely significantly greater than those in their Canadian drying experiments.

CONCLUSIONS

Drying times of macerated hay were significantly faster than for unconditioned or standard roll-conditioned hay. This would reduce the vulnerability of freshly cut hay to weather damage and subsequent downgrading or loss. Under normal drying conditions, hay macerated with the rubberised-rolls dried significantly faster than hay macerated with steel-rolls due to greater maceration. Where drying conditions were extremely favourable, either maceration treatment provided comparable drying. Rubberised macerating rolls present a dual advantage over steel macerating rolls in that they are relatively simple in design and less costly. Maceration with rubberised rolls offers great potential for improving hay production by reducing potential losses from storms and poor weather conditions.

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