Intensive forage conditioning applied after mowing: Prototype development and drying experiments

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Descôteaux, S. and Savoie, P. 2002. **Intensive forage conditioning applied after mowing: prototype development and drying experiments.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **44**: 2.15-2.21. Intensive forage conditioning (IFC), also known as maceration, is typically applied by shredding the fresh crop through a series of rapidly turning grooved steel rolls at the time of mowing. This project used an alternative to mowing-maceration by applying IFC independently from mowing, after a field wilting period. A full-scale prototype was built with a windrow pickup and three macerating rolls (2.1 m wide). Field tests in Nappan, Nova Scotia, indicated that maceration applied 6 h after mowing was better in terms of drying than maceration applied 1 h after mowing or no maceration. Laboratory drying showed that maceration was most beneficial with an early maturity alfalfa crop that was well spread out and exposed to radiation that simulated sunny conditions. Maceration was not very effective with late maturity timothy, narrow and thick windrows, and in the shade that simulated overcast conditions. Maceration applied after mowing in favourable conditions could save between half a day and a full day of field exposure during a 2 to 3-day wilting period. **Keywords:** forage, conditioning, maceration, drying, alfalfa, timothy.

Un conditionnement mécanique intense du fourrage, connu sous le nom de surconditionnement, est obtenu par le broyage de l'herbe fraîche à travers une série de rouleaux en acier rainurés tournant à des vitesses différentes qui causent un cisaillement de la plante. Jusqu'ici, le surconditionnement a surtout été proposé en traitement simultané à la fauche. Toutefois dans ce projet, on a appliqué le surconditionnement indépendamment de la fauche, après une période de fanage au champ. Un prototype à grande échelle muni d'un ramasseur d'andains et de trois rouleaux broyeurs de 2,1 m de largeur a été construit. Les essais au champ à Nappan en Nouvelle-Écosse ont démontré que le surconditionnement effectué 6 h après la fauche facilitait le séchage comparativement à aucun surconditionnement ou à celui pratiqué 1 h après la fauche. Les résultats de séchage au laboratoire ont indiqué que le surconditionnement était bénéfique avec une luzerne de maturité précoce, bien étalée de façon à former un andain mince et sous radiation simulant des conditions ensoleillées. Le surconditionnement n'a pas donné de résultats satisfaisants dans le cas d'une fléole tardive, d'andains étroits et épais, et d'un séchage à l'ombre simulant des conditions ennuagées. Sous des conditions favorables, le surconditionnement effectué quelques heures après la fauche peut réduire d'une demie à une journée complète le temps total de séchage au champ pour une récolte qui requerrait normalement deux à trois jours. **Mots clés:** fourrage, conditionnement, surconditionnement, séchage, luzerne, fléole.

INTRODUCTION

The production of good quality hay and silage requires between one and several days of favourable field drying conditions, ideally with sunshine, low air humidity, and light wind. Rain, high air humidity, and overcast conditions can prolong the wilting period and cause nutrient losses by leaching, plant respiration, or mechanical damage. A novel mechanical treatment to enhance the field drying of herbage is intensive forage conditioning (IFC) referred to as maceration, superconditioning, or mat making. IFC is typically applied by shredding the fresh crop through a series of grooved steel rolls operating at differential tip speed. The macerated forage may then be compressed into a thin mat or directly deposited on the stubble as a fluffy windrow.

Savoie (2001) reviewed several technical developments related to forage maceration and their potential impact on feed quality and animal production. He observed that maceration improved the field drying rate, forage quality, animal voluntary intake, and average daily gain in several independent studies, notably when wilting occurred under good weather conditions for natural drying. However, maceration increased respiration loss, degraded forage quality, and resulted in a neutral or a negative impact on animal performance when wilting occurred under poor weather conditions such as rain or high humidity (Rotz et al. 1991; Savoie et al. 1993). To minimize the risk of loss due to maceration, good management is required during mowing and harvest. This can include practices such as limiting the crop area mowed at any given time and postponing mowing until weather forecasts indicate a low probability of rain for several days.

Weather-related losses after mowing can be reduced by applying maceration selectively rather than systematically. Selective application may be done with an independent machine used after mowing, only when the climate is favourable and losses related to the environment such as leaching and respiration are unlikely. When humid and rainy conditions are forecast, maceration would not be applied.

The objective of this project was to build and evaluate in the field a full-scale prototype to apply maceration independently from mowing and after a wilting period, as an optional

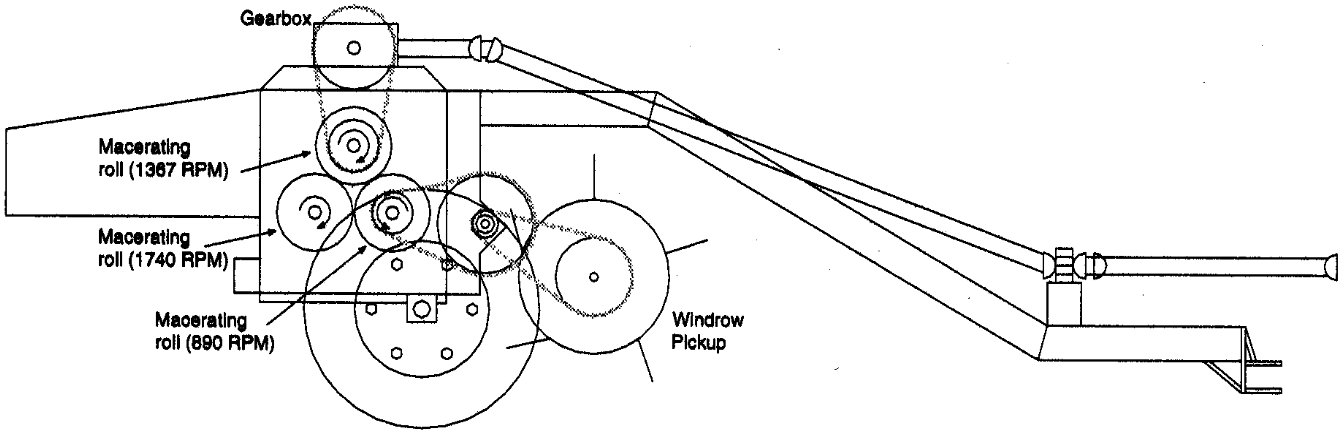

Fig. 1. Side view of the intense forage conditioning unit.

treatment. A laboratory experiment was also conducted to test, under controlled conditions, the effect of maceration at different times after mowing on the drying coefficient.

MATERIALS and METHODS

Field prototype

The main components of the prototype were a windrow pickup and three macerating rolls (Fig. 1). The configuration was adapted from previous work with a self-propelled mower-macerator (Savoie et al. 1999). Mat forming by compression was not included because previous results indicated no benefit in terms of drying rate or loss level compared to simply letting the macerated forage drop directly onto the stubble (May 1994; Savoie et al. 1997). Not originally included, two feeding rollers were later added above the windrow pickup to facilitate handling of fine and leafy grass. The pickup was a component of a New Holland model 575 baler, measuring 1.9 m wide and including 6 bars and 156 fingers. The chain and the sprocket drive of the pickup were reinforced after initial testing because windrows lifted soon after mowing could be very wet (60 to 80% moisture content) and had a weight of 2 to 4 times that of dry windrows typically picked up at baling (15 to 25% moisture content).

The three macerating rolls were 2.14 m long by 0.23 m in diameter. The surface of each roll was corrugated by milling in the same direction as the roll axis. The distance between apexes of each groove was 3.2 mm. The clearance between rolls was set at 1 mm. The rotational speeds were 890 rpm for the first roll, 1367 rpm for the second roll, and 1740 rpm for the third roll. The forage was therefore pulled and accelerated as it moved from the first nip point, between the first and second rolls, to the second nip point.

The gearbox was located on the top centre of the prototype and selected to distribute up to 56 kW from the power-take-off shaft. When viewed from the back, the gearbox transmitted power to the second roll on the right side and to the first and third rolls on the left side. Figure 2 shows the actual prototype as it was built and used during the 1998 harvest season.

Field experiment

The field experiment was carried out at the Agriculture and Agri-Food Canada Research Farm in Nappan, Nova Scotia. Two plots of 50 m by 36 m each, one predominantly composed of timothy and the other of red clover, were split into two blocks (50 m x 18 m). One block of each species was mowed at an early stage of maturity (week of June 8, 1998) while the other block was mowed at a later stage of maturity (week of June 22). All fields were mowed with a disk mower equipped with a rotary flail conditioner (Kuhn FC-300G, Saverne, France) set at a low intensity conditioning level (660 rpm). The effective average mowing width was 2.8 m; the average windrow width was 1.4 m and the average windrow length was 50 m.

Fig. 2. Original forage macerator in June 1998.

Three mechanical treatments were compared: 1) windrows left undisturbed (control), 2) windrows macerated 1 h after mowing, and 3) windrows macerated 6 h after mowing. A maceration treatment consisted of driving the prototype over a selected windrow, picking up the forage, processing it through macerating rolls, and dropping the crop back onto the stubble in the form of a windrow.

A screened tray (1.8 m by 0.9 m) was placed at a random distance along each windrow. A windrow length of 1.8 m was displaced with pitch forks and carefully placed over the tray to maintain the same width and height. Trays were weighed three times per day, at intervals of 4 to 6 h, to estimate water evaporation. A total of 6 trays was placed in each field (3 conditioning treatments x 2 replications in two distinct windrows) per crop and per date.

The drying model was assumed to be an exponential decay function as the one suggested by Rotz and Chen (1985):

$$M = M_0 e^{-kt} \tag{1}$$

where:

M = average moisture content of forage on a dry basis (kg of water/kg of dry matter) at the end of the drying interval,

M_o = initial moisture content,

k = drying coefficient (h^{-1}), and

t = time interval (h).

Moisture was estimated initially by taking one sample of fresh crop (about 300 g) per tray placed in the field. Moisture determination was done by oven drying at 60°C for 72 h according to ASAE standard S358.2. (ASAE 1999). Moisture was also estimated at the end of the 2-d field wilting period (approximately 32 h after mowing) with a grab sample taken from each tray. Intermediate moisture values were calculated on the basis of water loss and the average dry matter for each tray.

A sample of field loss was obtained by hand collecting all particles longer than 10 mm on an area of 0.5 m along the windrow by the effective mowing width (2.8 m). The number of loss measurements was equal to the number of trays. Areas for loss measurement were selected randomly, one along each windrow. Values represented the sum of mechanical losses due to mowing-conditioning and subsequent windrow handling with the macerator prototype. Losses were reported on the basis of percentage of original yield.

Laboratory experiment

A laboratory experiment was conducted in June 1998 to evaluate the concept of maceration applied after mowing under controlled conditions. Maceration was applied either 1, 6, or 24 h after mowing. Two forages (timothy and alfalfa) were mowed without conditioning at the Deschambault Research Station (Deschambault, Québec) and brought to the laboratory. Mowing dates were June 1, 15, and 29, 1998. These three dates corresponded to the boot stage, the early heading stage, and the full heading stage for timothy grass and to the bud stage, the early bloom stage (5-10% flowering), and the full bloom stage for alfalfa. Three mechanical conditioning treatments were considered: 1) a control (no treatment), 2) maceration through three rolls spaced at 1 mm between rolls, and 3) maceration through three rolls spaced at 3 mm. The laboratory macerating unit was composed of three rolls 600 mm long by 254 mm outside diameter with a surface configuration identical to the one of the field prototype.

Fresh forage was placed on plastic sheets for an initial slow wilting period, in the shade, prior to maceration. This initial drying corresponded to an average pan water evaporation rate of 0.066 mm/h. Two windrow thicknesses were used, corresponding to a low or a high yield representing either 0.66 or 1.33 kg DM/m^2. After the specified wilting period (1, 6, or 24 h), the partially dried forage was placed on a conveyor belt (4 m long by 0.6 m wide) at a horizontal speed of 1.1 m/s and fed into the laboratory macerating unit. The macerated crop was then spread manually on screened trays 300 mm wide by 450 mm long; thickness of the crop was about 100 to 200 mm, depending on the selected yield. Trays were left to dry during three intervals. The first interval was in a wind tunnel with radiation lamps simulating sunshine at ambient laboratory temperature (22°C); average wind speed was 0.73 m/s and pan water evaporation averaged 0.48 mm/h. The drying period in this simulated sunshine environment was 4 h. Thereafter, trays were left in the shade for 20 h and finally placed under simulated sunshine for another 4 h.

A total of 108 trays was analysed for drying (2 forage species x 3 dates of mowing x 3 periods of treatment x 3 mechanical treatments x 2 windrow thicknesses). Drying coefficients were estimated for each drying period after maceration (0 to 4, 4 to 24, 24 to 28, and 0 to 28 h).

Statistical analyses

Data from the field were analysed by the General Linear Model procedure of the SAS Institute, Inc. (1990) according to a 2 x 2 x 3 factorial arrangement of treatments (2 forage species, 2 stages of maturity, and 3 methods of conditioning). Data from the laboratory were analysed by linear regression to estimate the drying coefficient as a function of the parameters tested (forage species, date of mowing or maturity, time period to apply maceration, roll clearance and windrow thickness, or yield).

RESULTS and DISCUSSION

Field drying

For early maturity red clover and timothy, the average air temperature during wilting (June 10-11) was relatively cool (13°C) with good pan evaporation (4.9 mm/d) and a small quantity (0.2 mm) of rainfall initially (Table 1). For later maturity crops, the average air temperature during wilting (June 23-24) was slightly higher (16°C) but pan evaporation lower (3.7 mm/d) without rain. Average yields were 4.9 t DM/ha for early red clover, 5.9 t DM/ha for early timothy, 6.7 t DM/ha for late red clover, and 5.8 t DM/ha for late timothy.

The field drying curves of early maturity red clover and timothy are shown in Figs. 3 and 4. Red clover was very wet at mowing (87% moisture). By the end of the first day (10 h after mowing at 1000h), windrows macerated 1 h after mowing (mac-1) did not dry faster than untreated control windrows. These two treatments (control and mac-1) resulted in a moisture content of 81% at the end of the first day. However, windrows macerated 6 hours after mowing (mac-6) dried down to 77% moisture at the end of the first day. By the end of the second day (1900h), control windrows and mac-1 windrows had a similar moisture content of 74% while mac-6 windrows had a moisture content of 62%. For silage making at a typical moisture of 65%, the mac-6 windrows would have been ready by 1600-1700h on the second day whereas the other windrows would require a third day of drying with the inherent risk of rain damage. Similar results were observed with early timothy (Fig. 4) with mac-6 giving better drying results than either mac-1 or the control.

Table 1. Weather conditions on the day prior to mowing and during field wilting of forage crops at two stages of maturity in Nappan, NS (June 1998).

Weather parameter	Early maturity			Late maturity		
	June 9	June 10	June 11	June 22	June 23	June 24
Wind speed (km/h)	5.5	6.5	10.2	10.8	14.3	11.9
Evaporation (mm)	3.0	4.8	5.0	8.8	4.0	3.4
Precipitation (mm)	0	0.2	0	0	0	0
Tmax (°C)	17	20	24	23	20	22
Tmin (°C)	2	2	5	8	12	11
Sky conditions	Sunny	Sunny	Sunny	Cloudy	Cloudy	Cloudy

The second blocks were mowed two weeks later (week of June 22, 1998) and are illustrated in Figs. 5 and 6. More mature red clover behaved in a similar way to early maturity red clover with regards to maceration treatment, i.e. mac-6 windrows dried to a lower moisture level than mac-1 windrows or control windrows. However, macerating mature timothy either 1 or 6 h after mowing did not improve the drying rate compared to the control.

A statistical analysis was done on the final moisture contents after 32 h of field wilting (Figs. 3 to 6). The final moisture content of red clover (average of 66.8%) was significantly higher ($P = 0.001$) than the final moisture content of timothy (53.5%), the main reason being that red clover was initially wetter than timothy (85.0% vs 77.1%, respectively). The final moisture content of more mature crops (55.1%) was lower than the final moisture content of less mature crops (65.1%), as expected, because of the higher initial moisture contents of less mature forage. The final moisture content of macerated crops (61.3% for mac-1 and 56.2% for mac-6) was lower ($P = 0.001$) than the final moisture content of unmacerated crops (63.0%).

There was an interaction between forage species and maceration ($P = 0.06$). Mac-1 was not effective in less mature timothy nor in red clover at either stage of maturity. Mac-1 was effective in more mature timothy (6 percentage units of moisture drop compared to the control). Mac-6 was less effective in timothy (4 percentage units of moisture drop at either stage of maturity) than in red clover (12 and 5 percentage units of moisture drop for early and late stages, respectively).

Table 2 reports the drying coefficients over the field wilting period (32 h). The drying coefficients were not statistically different between red clover and timothy (no forage effect). The drying coefficients tended ($P = 0.08$) to be higher for the late maturity stage ($k = 0.0346\ h^{-1}$) than for the early maturity stage ($k = 0.0316\ h^{-1}$). The drying coefficients were significantly higher ($P = 0.001$) for macerated ($k = 0.0386\ h^{-1}$) than unmacerated ($k = 0.0293\ h^{-1}$) crops. There was a significant interaction between maceration and forage species ($P = 0.04$) and a less significant interaction ($P = 0.08$) between maceration and stage of maturity. Mac-6 was most effective with early timothy and red clover, and less effective than mac-1 in late timothy.

Measured field losses (Table 3) were not statistically different between the three mechanical treatments with an average of 4.5% in unmacerated windrows, 5.2% in mac-1 windrows, and 4.3% in mac-6 windrows. There was an interaction ($P = 0.05$) between forage species and stage of maturity: red clover had more losses at an early stage of maturity (5.9%) than a late stage of maturity (4.2%) while timothy had similar losses at both stages of maturity (4.5 and 4.2%, respectively).

Mechanical performance of the prototype

During the first week in Nappan (June 8-12, 1998), a number of minor adjustments were necessary to pick up windrows adequately and obtain a good treatment (1 mm clearance

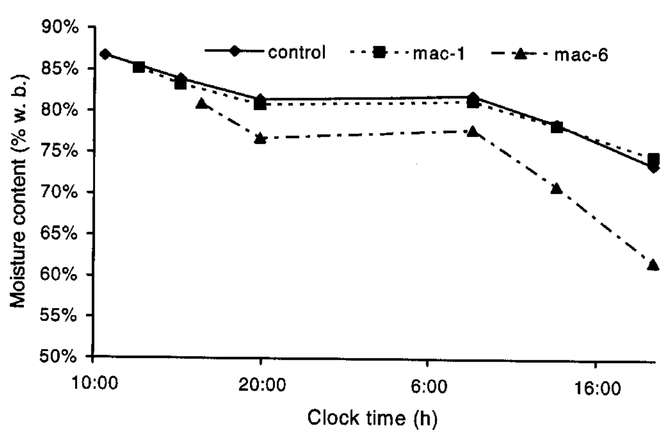

Fig. 3. Moisture content in the field for early maturity red clover mowed on June 10. Windrows were untreated (control), macerated 1 h after mowing (mac-1) or macerated 6 h after mowing (mac-6).

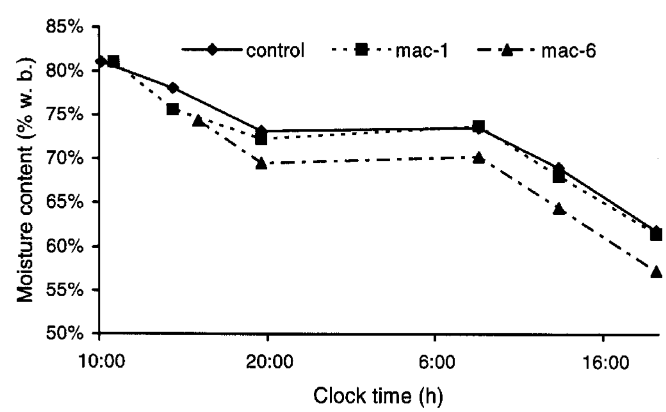

Fig. 4. Moisture content in the field for early maturity timothy mowed on June 10. Windrows were untreated (control), macerated 1 h after mowing (mac-1), or macerated 6 h after mowing (mac-6).

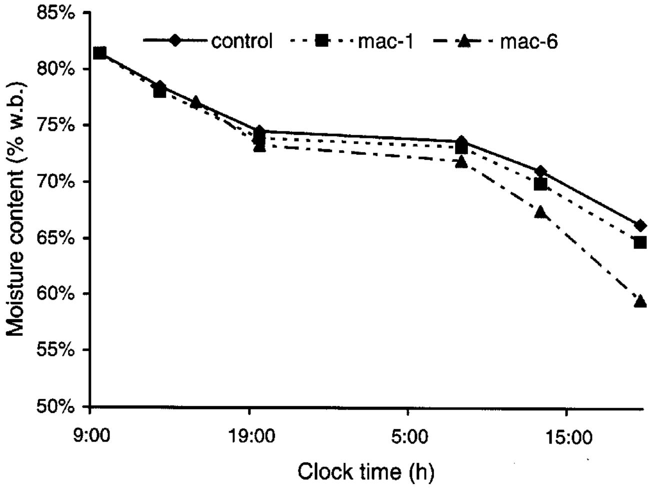

Fig. 5. Moisture content in the field for mature red clover mowed on June 23. Windrows were untreated (control), macerated 1 h after mowing (mac-1), or macerated 6 h after mowing (mac-6).

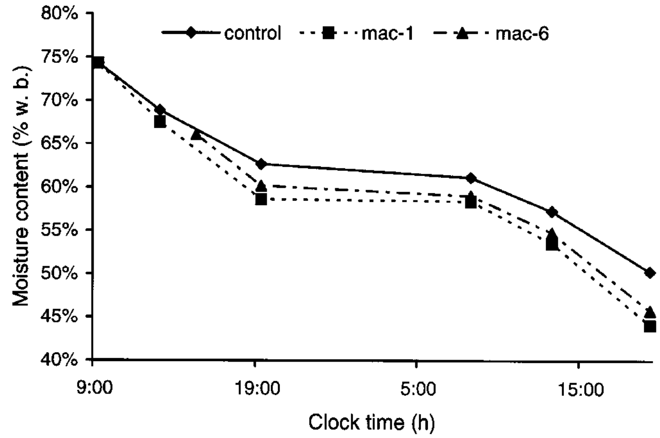

Fig. 6. Moisture content in the field for mature timothy mowed on June 23. Windrows were untreated (control), macerated 1 h after mowing (mac-1), or macerated 6 h after mowing (mac-6).

Table 2. Drying coefficients (h^{-1}) observed in the field over a 32-h wilting period as a function of windrow handling treatment after mowing.

Crop	Maturity stage	Windrow handling treatment		
		Control (no treatment)	Maceration 1 h after mowing	Maceration 6 h after mowing
Timothy	Early	0.0291	0.0295	0.0350
Timothy	Late	0.0323	0.0401	0.0380
Red clover	Early	0.0269	0.0252	0.0437
Red clover	Late	0.0287	0.0306	0.0377
Mean		0.0293	0.0314	0.0386

Table 3. Mechanical losses (% of original dry matter yield) observed in the field due to mowing-conditioning and windrow handling.

Crop	Maturity stage	Windrow handling treatment		
		Control (no treatment)	Maceration 1 h after mowing	Maceration 6 h after mowing
Timothy	Early	4.0	5.3	4.2
Timothy	Late	4.5	4.5	3.7
Red clover	Early	5.5	6.7	5.4
Red clover	Late	4.1	4.4	4.2
Mean		4.5	5.3	4.4

between the rolls). The macerator could move at forward speeds up to 10 km/h and maintain good material flow. During the week of June 22-26, the macerator had to be operated more slowly because the pickup could not lift some of the wet windrows in high yielding fields. A stronger chain and sprocket mechanism was added in early July.

During the last week of July, the machine was used in second cut grass in northern Québec at a commercial farm (Ferme Le Souvenir, Lasarre). The crop was very leafy and wet, creating a slippery surface on the macerating rolls and poor feeding conditions into the first two rolls. Two feeding rollers were added between the pickup and the macerating rolls to direct forage towards the first nip point and to improve the grasp of leafy and other fine material.

The machine worked relatively well the rest of the summer. Future machine design should incorporate a stronger pickup driving mechanism and either a feeding roller system or a redesign to reduce the distance between the pickup and the first nip point to facilitate grasping of light or leafy crops. Surface wear of macerating rolls was not a concern during short term trials in the summer of 1998, but the topic would require some attention in the future. The rolls remained fairly aggressive despite dents due to stones and the appearance of wear or flattening of the apex of grooves. A hardened steel could be used to increase the useful life of the rolls.

Laboratory drying

Averaged over three maturity stages spanning a four-week period and two crop species, maceration applied in the laboratory either at 1, 6, or 24 h after mowing increased the drying coefficient by 41% compared to no treatment (control). Maceration was found to be more

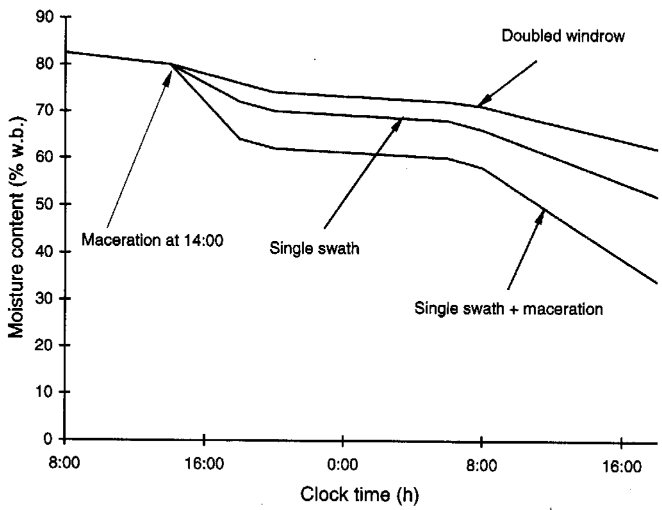

Fig. 7. Simulated drying curves for early maturity alfalfa.

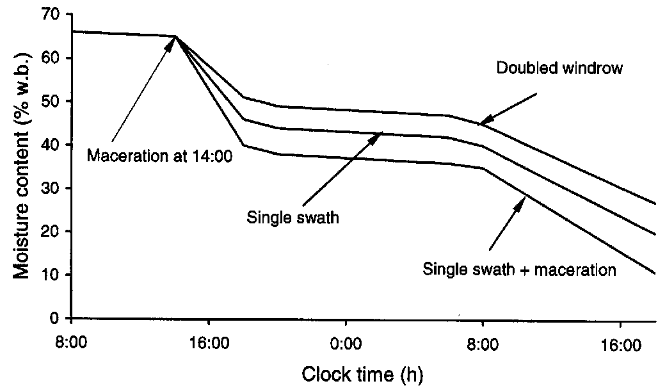

Fig. 8. Simulated drying curves for late maturity timothy.

effective in alfalfa than in timothy and in light windrows rather than in thick windrows. The drying data from 108 trays were analysed with a regression model that indicated the relative influence of various factors. The following model was developed to estimate the drying coefficient (k, units of h^{-1}) during the first 4 hours of drying after treatment:

$$k_{0\text{-}4} = 0.236 + 0.0193*\text{Date} + 0.0011*\text{Period} + 0.0423*\text{Treatment} - 0.0512*\text{Species} - 0.0463*\text{Thickness} + 0.0123*\text{Treatment}*\text{Species} - 0.0237*\text{Treatment}*\text{Thickness}$$

This model had a coefficient of determination of $R^2 = 0.835$. From this equation, the forage is seen to dry faster as it becomes more mature (Date =1, 2, and 3 for June 1, 15, and 29, respectively). The period of treatment (Period = 1, 2, and 3 for 1, 6, and 24 h after mowing) had little influence on the drying rate just after maceration, a result somewhat different from the field results where maceration 6 h after mowing was found to be superior to 1 h after mowing. Maceration significantly increased the drying rate (Treatment = 2, 1, and 0 for 1 mm clearance, 3 mm clearance and control, respectively). Timothy (Species = 1) dried faster than alfalfa (Species = 2). Wide and thin windrows (Thickness = 1) dried faster, as expected, than narrow and thick windrows (Thickness = 2).

The interaction (Treatment*Species), with a positive coefficient of 0.0123, indicated that alfalfa (Species = 2) gained more from maceration than timothy (Species = 1). The interaction (Treatment*Thickness), with a negative coefficient of -0.0237, meant that narrow and thick windrows (Thickness = 2) gained less from maceration than wide and thinner windrows.

A second regression model was obtained for the combined drying effect over the three periods after maceration treatment: 4 h of initial radiation after treatment, 20 h in the shade and 4 more hours under radiation ($k_{0\text{-}28}$).

$$k_{0\text{-}28} = 0.0865 + 0.0084*\text{Date} - 0.0035*\text{Period} + 0.0076*\text{Treatment} - 0.0076*\text{Species} - 0.024*\text{Thickness}$$

This second regression model explained 64% of experimental variation ($R^2 = 0.643$). These two regression models which represent drying data under specific environmental conditions (4 h under sunshine, 20 h under shade, 4 h again under sunshine) were used to simulate drying of treated or untreated windrows over a two-day period (Figs. 7 and 8). In early maturity alfalfa, maceration applied to a spread swath (Thickness = 1) would allow harvesting the crop for wilted silage (60 to 65% moisture content) on the day of mowing rather than having to wait until the next day. This estimation assumes a sunshine period of at least 4 h. In late maturity timothy, spreading the windrow without maceration is good enough to harvest hay (18 to 20% moisture content) within two days. Maceration would save an extra four hours of wilting under such conditions.

Selective application of maceration after a wilting period is an alternative to systematic application of maceration at mowing. The field data showed cases where a 6-h delay before applying maceration reduced the moisture level to a lower level than applying maceration 1 h after mowing, over a two-day wilting period. The later application of maceration may have resulted in an additional benefit from fluffing the windrow and turning the bottom wet layer to the top. An early application of maceration would not provide this benefit from fluffing and turning because the entire windrow is more uniformly wet and compact. However, laboratory results showed that applying maceration 1 h after mowing resulted in faster drying than subsequent applications (6 or 24 h later). The environmental conditions (crop, maturity, temperature, wind, level of sunshine, humidity, etc.) can influence the effect of maceration on drying. Good drying conditions (sunshine, high pan water evaporation, spread swath) generally interact positively with the maceration treatment and favour its early application.

CONCLUSIONS

Field results indicated the value of postponing maceration treatment a few hours after mowing, especially when drying was slow initially such as under overcast conditions. After a field wilting period of 32 h, windrows macerated 6 h after mowing had a lower final moisture content than windrows macerated 1 h after mowing and windrows that were not macerated (control).

Laboratory results indicated a greater drying benefit of maceration with alfalfa rather than with grass, with an early maturity crop rather than with a late maturity crop, and with well spread swaths rather than with narrow and thick windrows.

The laboratory results did not confirm, however, the value of postponing maceration until 6 h after mowing as observed in the field. Under sunny and good weather conditions, maceration may be applied as early as possible to gain the greatest drying benefit.

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