# Comparative characteristics during wilting for alfalfa conditioned by maceration or by a conventional roller-conditioner

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[1]*Department of Animal Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2; and* [2]*Agriculture and Agri-Food Canada, Brandon, Manitoba, Canada R7A 5Y3.* *Received 1 March 1999, accepted 3 August 1999.*

Suwarno, Wittenberg, K. M. and McCaughey, W. P. 1999. **Comparative characteristics during wilting for alfalfa conditioned by maceration or by a conventional roller-conditioner.** Can. J. Anim. Sci. **79**: 509–517. A study was conducted to monitor nutrient and microbial count changes during wilting of alfalfa (*Medicago sativa* L.) in response to varying degrees of maceration at mowing. Early bloom alfalfa was mowed with either a roller-conditioner (CONV) or a macerator set to deliver four degrees of maceration during alfalfa mowing: LIGHT, LIGHT+, SEVERE, and SEVERE+. Macerated alfalfa reached 80% dry matter in 9 – 11 h compared with alfalfa mowed by roller-conditioner, which required 54 h. The most rapid wilting rates were associated with LIGHT+, SEVERE, and SEVERE+ maceration treatments when alfalfa was not exposed to precipitation. The wilting coefficient in the first 24 h was increased by more than 100% for the SEVERE treatment compared with alfalfa mowed using a conventional roller-conditioner in alfalfa that was not exposed to precipitation. Precipitation at 1.5 h post-mowing increased wilting time by 8.3 h to achieve 45% DM, and by 17.5 to achieve 80% DM in the SEVERE+ maceration treatment relative to alfalfa from the same conditioning treatment that was not exposed to precipitation. Precipitation at 24 h post-mowing increased wilting time to reach 80% DM by 11 h and 21 h for the LIGHT and LIGHT+ maceration treatments relative to alfalfa of the same mowing treatments not exposed to precipitation. Maceration of alfalfa resulted in a 24.2 to 26.8 h shorter wilting time relative to the conventional roller-conditioner treatment when alfalfa was exposed to precipitation at 24 h post-mowing. SEVERE and SEVERE+ maceration treatments at mowing resulted in higher ($P < 0.05$) neutral detergent fibre and acid detergent fibre levels post-wilting. Lactic acid bacteria populations on alfalfa tended to be higher with maceration within 1 h post-mowing ($P < 0.10$) and post-wilting ($P < 0.08$).

**Key words**: Alfalfa, maceration, precipitation, wilting time, bacteria, nutrient profile, compressibility

Suwarno, Wittenberg, K. M. et McCaughey, W. P. 1999. **Caractères comparatifs du fourrage de luzerne durant le fanage selon qu'il a subi un surconditionnement mécanique ou un passage à la conditionneuse à rouleaux standard**. Can. J. Anim. Sci. **79**: 509–517. L'objet de nos travaux était de suivre l'évolution de la valeur nutritive et des numérations microbiennes durant le fanage de la luzerne selon divers degrés de conditionnement mécanique exécuté lors de la fauche. Un peuplement de luzerne (*Medicago sativa* L.) en début de floraison était fauché au moyen, soit d'une conditionneuse à rouleaux classique, soit d'un «triturateur» réglé à 4 niveaux d'intensité: léger, modérément intense, intense et très intense. Le fourrage conditionné au triturateur atteignait le point de 80 % m.s. en 9 à 11 h contre les 54 h requises pour la luzerne fauchée à la conditionneuse standard. Les taux de fanage les plus rapides correspondaient aux intensités de surconditionnement mécanique modérément intense, et très intense, pour autant que la luzerne ne soit pas exposée à des précipitations atmosphériques (artificielles). Le coefficient de fanage dans les 24 h suivant la fauche était augmenté de plus de 100 % dans le traitement de trituration intense par rapport à celui de la luzerne fauchée à la conditionneuse à rouleaux classique et non exposée à la pluie. Une pluie survenant 1 h et demie après la fauche accroissait de 8,3 h le temps requis par la luzerne pour atteindre le point de 45 % m.s., et de 17,5 h pour arriver à 80 % m.s. dans le traitement de trituration très intense, par rapport au même traitement sans exposition à la pluie. Des précipitations survenant 24 h après la fauche allongeaient de 11 et 21 h, respectivement, le temps de fanage à 80 % m.s. dans les traitements de trituration léger et modérément intense, par rapport aux mêmes traitements sans précipitations. Par ailleurs, la trituration de la luzerne donnait lieu à un raccourcissement de 24,2 à 26,8 h du temps de fanage par rapport au traitement par conditionneur à rouleaux, lorsque la luzerne était exposée à la pluie 24 h après la fauche. Les traitements de trituration intense et très intense donnaient un fourrage plus riche ($P < 0,05$) en FDN et en lignocellulose au terme du fanage. Les populations de bactéries acidolactiques présentes dans la luzerne étaient généralement plus élevées 1 h après la fauche ($P < 0,10$) et au terme du fanage ($P < 0,08$) dans les traitements avec trituration.

**Mots clés**: Luzerne, trituration mécanique, précipitations (artificielles), durée de fanage, bactérie, profil nutritionnel, compressibilité

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**Abbreviations**: **ADF**, acid detergent fibre; **ADIN**, acid detergent insoluble nitrogen; **CFU**, colony forming units; **CONV**, conventional mowing treatment; **CP**, crude protein; **DM**, dry matter; **LAB**, lactic acid bacteria; **NDF**, neutral detergent fibre; **SN**, soluble nitrogen; **TB**, total bacteria; **TN**, total nitrogen

Conventional harvest with mowing equipment utilising rollers or crimpers and leaving alfalfa in wide swaths on the field requires 3–4 d of wilting to reach 80% DM content in good weather conditions under eastern Canada/Maritime environments (Savoie et al. 1984). A long wilting period will result in quality loss primarily due to leaching, prolonged plant respiration (Savoie and Beauregard 1991) or undesirable microbial growth (Dawson et al. 1950). Attempts to shorten wilting time can be achieved by conditioning the alfalfa during mowing or subsequent windrow handling operations, the reduction being from 20 to 60% depending on procedure used and crop conditions (Klinner 1975; Rotz and Sprott 1984).

Longitudinal splitting and crushing of the stem by running cut plant material through a series of serrated steel rollers rotating at different speeds (maceration) has been investigated as a means of reducing the drying time required for alfalfa. Shinners et al. (1987) found that alfalfa dried to 20% moisture in 6 h or less using a field mower macerator prototype. Very severe maceration has increased drying rate by 500% under laboratory conditions (Sundberg and Lundvall [1991], cited by Savoie et al. [1994]) and by 100% under field conditions (Savoie et al. 1993). It has been suggested by Savoie et al. (1994) that severe maceration compared with moderate maceration may result in a marginal increase in wilting rate, but can increase DM loss due to leaf and fine material shattering. Although maceration can increase drying rate, concern has been raised about leaching of plant cell solubles if cut alfalfa is exposed to precipitation (Savoie et al. 1993). Laboratory trials report leaching losses due to precipitation for conventional alfalfa windrows to be 0.1% DM $mm^{-1}$ precipitation compared with 0.3% DM $mm^{-1}$ precipitation for macerated and pressed alfalfa mats (Rotz et al. 1991). Savoie et al. (1993) used simulated rainfall at a rate of 18 mm $h^{-1}$, applied twice during 10-min periods (a total of 6 mm of rain). The two rainfalls were applied at 6 and 24 h post-mowing, respectively, on alfalfa conditioned either with a roller-conditioner or a macerator with press. They found that macerated and pressed alfalfa wilted 87% faster than roller-conditioned alfalfa windrows, using a wind tunnel to simulate good wilting conditions. After simulated rain, the wilting rate of mats was 71% higher than that of windrows.

Initial populations and population changes for epiphytic LAB on wilting alfalfa has been documented (Muck 1989; Lin et al. 1992; Pitt and Muck 1995; Wittenberg 1995). However, only limited information is available regarding the effect of maceration on alfalfa LAB populations (Charmley et al. 1997). The enumeration of bacteria populations, especially LAB in alfalfa is important to understand the fermentation process of alfalfa when ensiled and may have relevance for storage of hay.

Maceration will alter physical properties of alfalfa, influcence field wilting and may improve packing if ensiled (Shinners et al. 1988; Savoie et al. 1994) or baled. Savoie et al. (1994) theorized that when freshly mowed, the forage windrow is typically fluffy and well aerated. Physical conditioning by crushing or maceration can make the alfalfa crumple and become more dense, which may hinder aeration during field wilting. This, however, can be an advantage during ensiling, where increased silage density will preclude air from the mass, increase storage capacity and improve fermentation (Savoie et al. 1994).

A field trial was conducted to monitor the effect of five degrees of maceration at the time of mowing on wilting of alfalfa, wilting rate, nutrient profile and lactic acid population. Compressibility (consolidation) was measured to describe physical differences of alfalfa subjected to five levels of maceration. Mowed alfalfa was subjected to three types of precipitation exposure during drying to determine the effect of rain on field drying characteristics and final nutrient profiles.

## MATERIALS AND METHODS

A 2-ha field having a uniform stand of early-bloom, first-cut alfalfa (*Medicago sativa* L.), was divided into two blocks. Within each block, five 100-m swaths of alfalfa were cut, each assigned to one of five mowing treatments. The five mowing treatments ranged from no maceration to very severe maceration (CONV, LIGHT, LIGHT+, SEVERE, SEVERE+). The CONV treatment was cut with a New Holland 116 haybine and the LIGHT, LIGHT+, SEVERE and SEVERE+ maceration treatments were cut using a pull-type macerator prototype built by the Prairie Agricultural Machinery Institute in Portage la Prairie, MB (PAMI 1994). The four degrees of maceration imposed included: LIGHT using a 1-cm roller spacing and 750/1000 roller rpm speed ratio; LIGHT+ using a 0.75-cm roller spacing and 750/1000 roller rpm speed ratio; SEVERE using a 0.75-cm roller spacing and 750/1500 roller rpm speed ratio; and SEVERE+ for which rollers were set as close together as possible and 750/1500 roller rpm speed ratio.

One quarter of each windrow length was exposed to 2.2 ± 0.4 (SD) cm precipitation at 1.5 h post-mowing (PE), and a second quarter of each windrow was exposed to 2.7 ± 0.4 cm precipitation at 24 h post-mowing (PL), respectively. Precipitation was imposed by sprinkling unchlorinated water on the designated area for a period of 2.3 ± 1.4 min for PE and 3.4 ± 0.6 min for PL. The remainder of the windrow was not exposed to precipitation (0).

Windrows were sampled three times daily for the duration of the wilting trial (51 h) at 0900–1000, 1200–1300 and 1600–1700 h. At each sampling time, nine samples were collected from each windrow: three samples for DM, nutrient, and glucosamine determination and two samples for LAB and TB counts from the windrow section assigned to no precipitation; two samples from each of the PE and PL windrow sections for DM, nutrient, and glucosamine determinations. Windrow sampling stopped once alfalfa DM reached 80%. Samples for LAB and TB counts were collected aseptically and submitted to the laboratory immediately for microbial assessment, and the other seven samples were placed into storage (–20°C) for determination of DM, CP, SN, ADIN, ADF, NDF, soluble carbohydrates, and glucosamine.

Dry matter was determined with a forced-air oven (60°C, 48 h). Crude protein and ADIN were assessed using a Kjeltec 1030 auto analyser (Tecator Inc., Herndon, VI) using Association of Official Analytical Chemists (1990) method no. 984.13; NDF and ADF were assessed using an A200 fibre analyser (Ankom, Fairport, NY). Soluble carbohydrates were assessed by spectrometer according to Slominski et al. (1993) using a Pharmacia Biotech Ultraspec 2000 (Fisher Scientific, Edmonton, AB). Soluble N was assessed using a modified method of Wohlt et al. (1973) as described by Crooker et al. (1978): sufficient sample was taken to provide 25 mg N 100 $mL^{-1}$ Burroughs mineral mixture solution at pH 6.5. The solution and alfalfa sample were incubated and agitated in a water bath at 40°C for 60 min, followed by settling in a rack for 15 min, and filtering. A 50 mL aliquot was taken for N determination, using the Kjeltec 1030 auto analyser. Glucosamine, a measure of fungal biomass, was determined as described by Wittengerg et al. (1989), using a Pharmacia Biotech. Biochrom amino acid analyser (Cambridge, UK).

Lactic acid bacteria were counted by placing 10 g of fresh alfalfa into a sterilized Stomacher disposable plastic bag, and adding 90 mL sterile wash solution made up of 0.1 mL Tween 80 in 100 mL distilled water. The Stomacher bag with contents was placed in a Stomacher 400 lab blender, (Seward Medical, London, UK) set at normal speed for 2 min. One millilitre of the resulting solution was used for serial dilutions, done in duplicate for each alfalfa sample. Plates were prepared by the drop and spread plating technique, using 0.1 mL of the diluted solution per plate, followed by plate incubation at 30°C for 48 h (Muck 1989), using Maltose Rogosa Dextrose agar media (Holley and Millard 1988). Bacteria colonies were counted using an Accu-lite 133-8002 colony counter (Fisher Scientific, Edmonton, AB). Plates with 30 colonies or less or with more than 300 colonies were discarded. Total bacteria were counted using nutrient agar (McFaddin 1985), with sample preparation similar to that for lactic acid bacteria enumeration. For statistical analysis, $\log^{10}$ of colony forming unit (CFU) counts was used.

## Mathematical Calculations

To compare wilting rates among maceration treatments, the wilting coefficient of alfalfa was calculated using a model of Sinners et al. (1987):

$$MR = Mh/Mo = e^{-kt}$$

where $MR$ = moisture ratio, $Mh$ = moisture content of alfalfa at time of sampling (g water $g^{-1}$ DM), $Mo$ = initial alfalfa moisture content (g water $g^{-1}$ DM), $k$ = wilting coefficient, $h^{-1}$, and $t$ = elapsed time between measurements of moisture (h). A moisture ratio was derived for each maceration level, so there were five $k$ values for the five maceration levels for each interval of time during wilting. The wilting coefficient was determined on a series of samples, three samples at each time for swaths not exposed to precipitation, and two samples at each time for swaths exposed to precipitation treatments. Compression tests to compare bulk densities of alfalfa at time of mowing were conducted using a PCV tube with a diameter of 20 cm and a height of 90 cm as described by Savoie et al. (1994). Fresh alfalfa (2.2 kg) was placed into the tube and the length of tube filled was measured. A 47.0 kg plunger was placed on top of the alfalfa and extent of alfalfa compression after 60 s was measured. This load corresponded to a pressure of 14.7 kPa. The volume occupied by the pressed alfalfa was the total cylinder volume minus the cylinder volume above the piston. Bulk density of the compressed alfalfa ($Pf$, kg $m^{-1}$) was calculated by dividing the weight of fresh alfalfa by the final volume (Savoie et al. 1994).

Potential compressibility ($Pf_{max}$) of cut alfalfa was calculated according to Savoie et al. (1994):

$$Pf_{max} = (1 + Md)\, Pd \times Pw \,/\, (Pw + Md \times Pd)$$

where $Pf_{max}$ is the potential or maximum theoretical density of fresh alfalfa which occurs when all air is evacuated ($kg^{-3}$), $Md$ is the moisture content of fresh alfalfa (g water $g^{-1}$ DM), $Pd$ is the intrinsic density of alfalfa DM (1500 kg $m^{-3}$) (Pitt 1983) and $Pw$ is the intrinsic density of water (1000 kg $m^{-3}$).

## Statistical Analysis

Only one value of $k$ for each mowing treatment was generated; therefore, a t-test was used to compare wilting coefficients of alfalfa. Cubic regression equations were developed to determine the time required to reach 45% DM (T45) or 80% DM (T80) for the maceration and precipitation treatments. The T45 and T80 data were analysed using the GLM procedure (SAS Institute, Inc. 1986). A randomized complete block design, five mowing treatments and two blocks, using the general linear model procedure of the SAS Institute, Inc. (1986) was used to compare pre-wilting nutrient profile and bulk density of alfalfa exposed to varying degrees of maceration with no precipitation. The identical design with repeated measures over time was used to compare bacterial population at 0,3 and 24 h post-mowing. The mowing-by-block interaction was used as an error term to test the mowing treatment. A split block design, with five mowing treatments and three precipitation treatments was used for the analysis of nutrient profile of post-wilted alfalfa. The mowing-by-block interaction was used as an error term to test the mowing treatment. A pair-wise mean test of comparison (SAS Institute, Inc. (1986) was used if treatment differences ($P < 0.05$) were observed.

## RESULTS AND DISCUSSION

Daily maximum and minimum temperatures during the 3-d wilting period, from 12 to 14 June 1995 ranged from 29.0 to 32.5°C and from 7.0 to 16.5°C, respectively, with averages of 30.2 and 12.3°C, respectively. Sunshine lasted for 14.7, 7.0, and 9.7 h for 12, 13, and 14 June, respectively. No natural precipitation was detected during those days (Environment Canada, Glenlea Station, MB). Relative humidity was not available at this station.

The CONV treatment, not exposed to precipitation, achieved 45% DM content, a level that is considered favourable for ensiling, at 6.5 h post-mowing (Fig. 1). There was no difference in wilting time between the CONV and the LIGHT mowing treatment. The LIGHT+, SEVERE and SEVERE+ mowing treatments reached 45% DM an average of 61.4% faster ($P < 0.05$) than CONV mowed alfalfa with

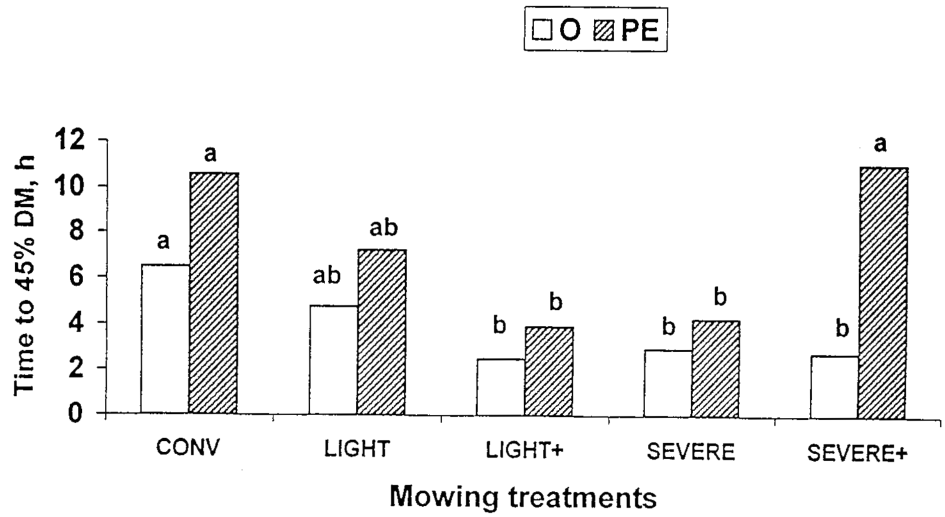


**Fig. 1.** Wilting time (h) to achieve 45% DM of conventionally (CONV) or macerator (LIGHT, LIGHT+, SEVERE, and SEVERE+) mowed alfalfa which was not exposed ( , O) or exposed ( , PE) to precipitation at 1.5 h post-mowing. Pooled standard errors for mowing treatments without precipitation and with precipitation were 0.57 and 0.98, respectively. Columns with different letters are different ($P < 0.05$).

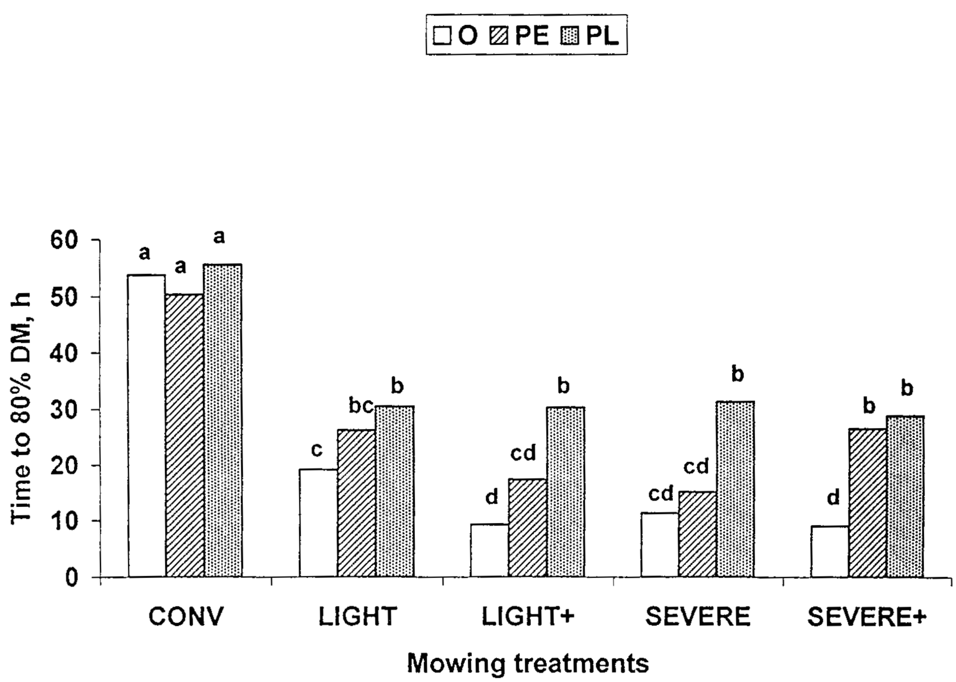


**Fig. 2.** Wilting time (h) to achieve 80% DM of conventionally (CONV) or macerator (LIGHT, LIGHT+, SEVERE, and SEVERE+) harvested alfalfa forage, which was not exposed ( , O) or exposed to precipitation either at 1.5 h ( , PE) or 24 h ( , PL) postcutting. Pooled standard errors for harvest treatments not exposed, exposed at 1.5 h post-cutting and 24 h post-cutting to precipitation were 1.26, 2.19, and 2.19, respectively. Columns with different letters are different ($P < 0.05$).

no rain. Maceration equivalent to that achieved by LIGHT+ or more severe significantly reduced wilting time to reach 45% DM under good wilting conditions.

A 53.7-h wilting time was required for CONV alfalfa to achieve 80% DM content, the minimum acceptable level for storage as hay (Fig. 2). The three most severe maceration levels (LIGHT+, SEVERE, and SEVERE+) reduced ($P < 0.05$) wilting time by 82.7, 78.9, and 83.3%, respectively, relative to CONV under good wilting conditions. Increasing severity of maceration did not further decrease wilting time for SEVERE or SEVERE+ relative to the LIGHT+ treatment. Therefore, with good drying conditions, SEVERE or SEVERE+ maceration may not be warranted in terms of improved wilting times.

**Table 1. Effect of maceration level with or without precipitation on field wilting coefficients ($h^{-1}$) of alfalfa**

| Hours post-cutting | Mowing treatment[z] CONV | LIGHT | LIGHT+ | SEVERE | SEVERE+ | SE |
|---|---|---|---|---|---|---|
| | | | *Without precipitation, n = 6* | | | |
| 0 – 3 | 0.166*b* | 0.171*b* | 0.254*ab* | 0.188*b* | 0.326*a* | 0.06 |
| 3 – 24 | 0.036*b* | 0.078*a* | 0.072*a* | 0.091*a* | 0.106*a* | 0.02 |
| 24 – 51 | 0.022*a* | 0.025*a* | 0.017*a* | 0.003*b* | 0.002*b* | 0.01 |
| | | | *Precipitation at 1.5 h post-cutting, n = 2* | | | |
| 3 – 24 | 0.062*b* | 0.111*a* | 0.113*a* | 0.123*a* | 0.047*b* | 0.03 |
| 24 – 51 | 0.045*a* | 0.026*a* | 0.024*a* | 0.004*b* | 0.006*b* | 0.02 |
| | | | *Precipitation at 24 h post-cutting, n = 2* | | | |
| 24 – 51 | 0.034 | 0.064 | 0.081 | 0.073 | 0.065 | 0.02 |

[z]Harvest treatments included cutting with a mower-conditioner (CONV), or a macerator set to deliver four degrees of maceration.
*a, b* Means within the same row different letters are significantly different ($P < 0.05$).

Öztekin and Özcan (1997) macerated and pressed alfalfa with a 75% initial moisture content and the alfalfa achieved 80% DM in 5 to 6 h. Savoie and Beauregard (1991) under laboratory conditions found that macerated alfalfa pressed into a mat wilted to 80% DM content in 4.7–5.0 h for low-density (0.33 kg DM $m^{-3}$), and in 6.7–7.7 h for high density (0.54 kg DM $m^{-3}$) mats. Formation of a mat by pressing alfalfa materials after maceration can extract a considerable amount of alfalfa juice, while increasing surface area of alfalfa, resulting in a greater evaporation rate relative to macerated but unpressed alfalfa. Wilting rates in our trial were lower than previously reported observations of Shinners et al. (1987), and Savoie and Beauregard (1991) where macerated, pressed alfalfa wilted 200–300% faster than that of conventionally conditioned alfalfa under laboratory conditions.

The CONV alfalfa exposed to precipitation 1.5 h post-mowing required 10.6 h to achieve 45% DM content (Fig. 1). LIGHT+ and SEVERE macerated alfalfa exposed to precipitation 1.5 h post-mowing had a 63.0 and 59.7% shorter wilting time to achieve 45% DM content, respectively, relative to the CONV ($P < 0.05$). To achieve an 80% DM content, the CONV treatment exposed to precipitation 1.5 h post-mowing required 50.4 h (Fig. 2). LIGHT, LIGHT+, SEVERE, and SEVERE+ maceration of alfalfa with the same precipitation exposure decreased the wilting time to reach 80% DM by 47.9, 65.4, 69.9 and 47.4%, respectively, ($P < 0.05$) relative to CONV; LIGHT+ and SEVERE having the shortest wilting times (Fig. 2). These results suggest that excessive maceration of alfalfa at mowing can be detrimental to wilting rate if precipitation occurs shortly after mowing. One possible reason could be that more rain water was absorbed within plant stems as maceration intensity increased. More compacted plant materials in the windrows can hinder good air circulation within the windrow microenvironment and may also have contributed to the longer wilting time when the highest intensity of maceration was used at the time the alfalfa was mowed and the wilting forage was exposed to precipitation.

The CONV alfalfa exposed to precipitation at 24 h post-mowing required significantly more time (55.5 h) to achieve 80% DM content than macerated alfalfa (Fig. 2). There were no differences in wilting time to achieve 80% DM among the four levels of maceration (LIGHT to SEVERE+) when precipitation occurred 24 h post-mowing. LIGHT maceration was considered favourable when field drying conditions were humid with rain during the late phase of wilting.

Interactions occurred between maceration levels and precipitation concerning wilting time to reach 45% and 80% DM (Fig. 1 and 2). On one hand, precipitation exposure at 1.5 h post-mowing resulted in similar wilting time increases (2 to 4 h) to reach 45% DM for the LIGHT, LIGHT+ and SEVERE conditioning treatments relative to alfalfa not exposed to precipitation, but increased wilting time by 8.3 h ($P < 0.05$) in alfalfa subjected to the SEVERE+ mowing treatment (Fig. 1). On the other hand, exposure to precipitation at 24 h post-mowing did not increase wilting time to reach 80% DM in CONV, but increased wilting time for LIGHT, LIGHT+, SEVERE, and SEVERE+ maceration treatments by 11 to 21 h relative to alfalfa not exposed to precipitation (Fig. 2). It has been found by Savoie et al. (1993) that more severely macerated alfalfa absorbed more water than less severely macerated alfalfa, when rewetted with similar precipitation conditions.

Maceration produced the best results for shortening wilting time under good weather or when precipitation occurred shortly after mowing. A reduced field-wilting time with maceration provides producers with more opportunity to plan mowing with short-term weather forecasts, reducing the threat of rain exposure during the latter stages of wilting.

The wilting coefficient during the initial phase (0–3 h) was 96.4% higher ($P < 0.05$) for SEVERE+ ($k = 0.326$ $h^{-1}$) than for the CONV treatment (Table 1). Other maceration levels had wilting coefficients similar to the CONV treatment. Using a wind tunnel, Savoie and Beauregard (1991) found that the wilting coefficient of macerated alfalfa ranged from 0.154 to 0.567 $h^{-1}$ in the initial 22 h post-mowing period. The similarity in wilting coefficients across the CONV, LIGHT, LIGHT+ and SEVERE treatments may be related to windrow characteristics.

Bulk density measured by compression increased as maceration severity increased ($P < 0.05$, Table 2); this might partly explain the phenomenon, as the increased percentage of exposed surface area of the more moderate levels macer-

**Table 2. Effect of maceration on bulk density (kg fresh alfalfa $m^{-3}$) post-mowing, *n* = 2**

| | Mowing treatment[z] | | | | | |
|---|---|---|---|---|---|---|
| Bulk density | CONV | LIGHT | LIGHT+ | SEVERE | SEVERE+ | SE |
| $Pf_{max}$[y] | 1093.2 | 1095.5 | 1094.5 | 1096.6 | 1089.0 | 3.06 |
| $Pf$[x] | 130.1*d* | 145.7*c* | 161.8*b* | 163.0*b* | 192.6*a* | 8.34 |

[z]Mowing treatments included mowing with a mower-conditioner (CONV), or a macerator set to deliver four degrees of maceration.
[y]$Pf_{max}$ theoretical maximum bulk density.
[x]$Pf$ actual bulk density measured by the compression test.
*a*, *b* Means within different letters in the same row are different ($P < 0.05$).

**Table 3. Effect of maceration and precipitation levels at the time of mowing on nutrient profile of alfalfa**

| | Mowing treatment[z] | | | | | | Precipitation type[z] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CONV | LIGHT | LIGHT+ | SEVERE | SEVERE+ | SE | O | PE | PL | SE |
| *At mowing*[y] | | | | | | | | | | |
| CP (g $kg^{-1}$ DM) | 207.9 | 202.9 | 197.6 | 192.8 | 193.7 | 5.3 | – | – | – | – |
| Soluble N (g $kg^{-1}$ TN) | 368.6 | 346.8 | 341.3 | 365.8 | 372.5 | 28.0 | – | – | – | – |
| ADIN (g $kg^{-1}$ TN) | 47.0 | 44.1 | 45.2 | 48.5 | 48.9 | 3.1 | – | – | – | – |
| Soluble sugars (g $kg^{-1}$ DM) | 107.7 | 114.2 | 107.8 | 114.7 | 117.8 | 4.8 | – | – | – | – |
| ADF (g $kg^{-1}$ DM) | 270.0 | 263.5 | 280.1 | 296.4 | 309.7 | 13.5 | – | – | – | – |
| NDF (g $kg^{-1}$ DM) | 356.6 | 346.9 | 367.1 | 384.1 | 368.8 | 19.7 | – | – | – | – |
| Glucosamine (g $kg^{-1}$ DM) | 1.20 | 1.36 | 1.34 | 1.63 | 1.41 | 0.10 | – | – | – | – |
| *Post wilting*[z] | | | | | | | | | | |
| CP (g $kg^{-1}$ DM) | 200.8*a* | 195.5*ab* | 182.7*ab* | 185.1*ab* | 180.7*b* | 4.4 | 189.2 | 190.1 | 186.6 | 3.4 |
| Soluble N (g $kg^{-1}$ TN) | 349.1 | 337.0 | 341.2 | 327.6*a* | 309.9 | 7.7 | 338.9 | 336.1 | 323.9 | 7.6 |
| ADIN (g $kg^{-1}$ TN) | 45.2*bc* | 43.0*c* | 53.5*ab* | 54.8*a* | 50.9*abc* | 2.1 | 47.1 | 49.8 | 51.5 | 1.7 |
| Soluble sugars (g $kg^{-1}$ DM) | 117.1 | 121.1 | 122.9 | 127.5 | 124.0 | 2.8 | 125.6 | 120.5 | 121.5 | 2.2 |
| ADF (g $kg^{-1}$ DM) | 273.5*b* | 276.9*b* | 282.0*ab* | 310.7*a* | 315.7*a* | 7.9 | 295.3 | 290.0 | 290.0 | 6.1 |
| NDF (g $kg^{-1}$ DM) | 335.7*b* | 359.9*b* | 364.5*ab* | 396.6*a* | 397.7*a* | 7.7 | 360.7*B* | 369.3*B* | 382.6*A* | 6.0 |
| Glucosamine (g $kg^{-1}$ DM) | 1.32 | 1.31 | 1.49 | 1.46 | 1.25 | 0.13 | 1.26 | 1.33 | 1.51 | 0.10 |

[z]*n* = 6 for each harvest treatment where CONV represents harvest with a mower-conditioner and LIGHT, LIGHT+, SEVERE, SEVERE+ represent four levels of maceration at mowing.
[y]*n* = 6, 4 and 4 for O, PE and PL, respectively.
*a*, *b* Means in the same rows with different letters are different for mowing treatment ($P < 0.05$).
*A*, *B* Means in the same row with different letters are different for precipitation treatment ($P < 0.05$).

ation resulted in little difference in solar energy absorption relative to CONV treatment during this initial phase of field wilting. Maceration of alfalfa did increase the wilting coefficient from 3 to 24 h of wilting. Maceration potentially resulted in more exposed cell surface area compared with CONV treatment. Shinners et al. (1987) suggested that a greater surface area is exposed to sunlight in macerated alfalfa than conventionally conditioned alfalfa, which would result in more solar energy per unit time being absorbed, thus resulting in a greater water evaporation rate for the former. During the final phase of field wilting, 24–51 h, alfalfa subjected to the most severe maceration treatments had the lowest wilting coefficient because alfalfa moisture content was already low.

When alfalfa was exposed to precipitation at 1.5 h post-mowing, wilting coefficients from 3 to 24 h post-mowing were higher ($P < 0.05$) for SEVERE than for CONV and SEVERE+ (Table 1). Possibly, greater compaction, which may result in poor air circulation between plant materials for SEVERE+, negated the positive impact of maceration in rainy conditions compared with that in good weather conditions. During the final phase of field wilting, SEVERE treatment resulted in the lowest wilting coefficient, which is similar to the value of alfalfa not exposed to precipitation. When alfalfa was exposed to precipitation at 24 h after mowing (PL), there was no effect of maceration on wilting coefficient (Table 1).

Based on the statistical analysis, LIGHT+ maceration level was considered the most favourable relative to other maceration treatments. When there was no rain during field wilting, increasing the intensity of maceration greater than LIGHT+ did not result in a shorter wilting time ($P > 0.05$), while when there was rain during wilting, maceration levels more severe than LIGHT+ had a similar or longer wilting time relative to alfalfa of the same mowing treatment not exposed to precipitation (Figs. 1 and 2, respectively).

Alfalfa nutrient profiles at mowing were similar among mowing treatments (Table 3). Although the field was uniform, based on stage of maturity of the alfalfa, some treatment-by-block interactions were observed immediately post-mowing (data not shown). Lower levels of soluble carbohydrates in alfalfa were detected in block 2 for all maceration treatments, relative to conventionally mowed alfalfa. These differences were not observed in block 1. Higher NDF levels for LIGHT+ and SEVERE maceration treatments of alfalfa also were detected in block 2, while other mowing methods (CONV, LIGHT and SEVERE+) showed no differences in NDF levels between block 1 and 2. Whether this variation is

**Table 4. Lactic acid bacteria (LAB) and total bacteria (TB) counts, $\log_{10}$ CFU $g^{-1}$ DM, during wilting for alfalfa mowed at five levels of maceration ($n$ = 4)**

| | Mowing treatment[z] | | | | | Level of significance[y] |
|---|---|---|---|---|---|---|
| | CONV | LIGHT+ | SEVERE | SEVERE+ | SE | Mowing |
| LAB 0 h | 3.01 | 3.61 | 4.23 | 4.09 | 0.24 | 0.10 |
| LAB 3 h | 3.13 | 4.24 | 4.35 | 4.24 | 0.23 | NS |
| LAB 24 h | 3.51 | 4.59 | 5.06 | 4.51 | 0.28 | 0.08 |
| TB 0 h | 5.03 | 6.10 | 6.24 | 5.97 | 0.39 | NS |
| TB 3 h | 5.87 | 5.90 | 6.45 | 6.46 | 0.33 | NS |
| TB 24 h | 6.15 | 6.56 | 6.59 | 6.53 | 0.35 | NS |

[z]Mowing treatments included cutting with a mower-conditioner (CONV), or a macerator set to deliver four degrees of maceration.
[y]Harvest by block and harvest by time effects were not significant.

inherent to the field or resulting from mowing treatment can not be established in this study.

After wilting, the alfalfa CP concentration was 10% lower ($P < 0.05$) for SEVERE+ than for CONV (Table 3). LIGHT, LIGHT+, and SEVERE maceration of alfalfa had a similar CP concentration relative to CONV. Post-wilting ADF levels were 13.6 and 15.4% higher ($P = 0.05$) for SEVERE and SEVERE+ macerated alfalfa relative to LIGHT and LIGHT+ mowing treatments that did not show significant differences in alfalfa ADF levels relative to CONV. Neutral detergent fibre levels for the SEVERE and SEVERE+ maceration treatments were 18.1 and 18.5% higher ($P < 0.01$) than the CONV treatment. No differences in alfalfa NDF concentration was observed for CONV, LIGHT and LIGHT+ mowing treatments.

Hong et al. (1988) speculated that more leaf shattering in the macerated than conventionally conditioned and higher ADF and NDF concentrations for the macerated alfalfa (Hong et al. 1988a). Petit et al. (1994) also found that when alfalfa was made into hay, the shredded alfalfa tended to contain less CP and more fibre than conventionally mowed alfalfa. In contrast, Chiquette et al. (1994) found no differences in CP, NDF and ADF when timothy hay of nonmacerated and macerated alfalfa were compared. Leaf shedding is a greater problem in legume crops than in grass crops.

Post-wilting concentrations of ADIN, soluble N, and glucosamine were similar among mowing treatments (Table 3). Post-wilting soluble carbohydrate content tended ($P = 0.08$) to be higher for alfalfa mowed with a macerator compared with alfalfa mowed with conventional roller-conditioner, possibly due to reduced plant respiration during the wilting period. A greater release of soluble carbohydrates with maceration may be beneficial for the growth of lactic-acid-forming bacteria required for silage fermentation by converting sugars to lactic acid. Based on post-wilting CP, NDF, ADF, and ADIN concentrations, LIGHT maceration was the most beneficial, because alfalfa subjected to this mowing treatment had similar CP, NDF, and ADF concentrations but did not results in higher ADIN levels relative to CONV alfalfa.

Precipitation had no effect on post-wilting CP, ADIN, ADF and glucosamine concentrations (Table 3). Soluble N decreased by 15 percentage units when alfalfa was exposed to a 2-cm precipitation 24 h after mowing, compared with alfalfa not exposed to precipitation during wilting. Soluble sugars decreased by approximately by 5 percentage units when alfalfa was exposed to precipitation at either 1.5 h or 24 h in the wilting period compared with alfalfa not exposed to precipitation. Neutral detergent fibre content increased by 21.9 g $kg^{-1}$ DM when alfalfa was exposed to precipitation 24 h post-mowing relative to alfalfa not exposed to precipitation, and by 13.3 g $kg^{-1}$ DM when alfalfa was exposed to precipitation 24 h post-mowing relative to alfalfa exposed to precipitation in the early stage of wilting (Table 3). Leaching of soluble cell contents might be responsible for the lower soluble carbohydrates and higher NDF levels in alfalfa exposed to precipitation, especially when precipitation occurred late in the wilting period. A tendency ($P$ = 0.06) toward a higher ADIN content due to precipitation can be partly responsible for the lower soluble N for alfalfa exposed to precipitation as compared with alfalfa not exposed to precipitation. Also, re-wetting of alfalfa increased the moisture content encouraging fungal growth, as indicated by the tendency towards higher glucosamine levels in alfalfa exposed to precipitation ($P = 0.09$).

Lactic acid bacteria tended to increase as a result of maceration ($P = 0.10$, Table 4) at mowing from $10^{3.01}$ CFU $g^{-1}$ DM in conventionally conditioned alfalfa (CONV) to $10^{4.23}$ CFU $g^{-1}$ DM in SEVERE, which was in agreement with observations by Charmley et al. (1997) using a precision-chopped alfalfa. Charmley et al. (1997) found a greater LAB count at ensiling for conventionally conditioned vs. macerated alfalfa ($10^{8.3}$ vs. $10^{6.5}$ CFU $g^{-1}$ fresh alfalfa, respectively). The increase in LAB might be due to increased sugars being released by maceration. Rooke (1990) observed that LAB counts on freshly cut grass ranged from $10^5$ to $10^6$ CFU $g^{-1}$ DM. However, Muck (1989) and Pitt and Muck (1995) observed a much lower bacterial count ($10^2$ CFU $g^{-1}$ DM) at wilting temperatures between 20 and 25°C within 2 h after mowing. At 3 h post-mowing, the LAB count ranged from $10^{3.13}$ in CONV to $10^{4.35}$ CFU $g^{-1}$ DM in SEVERE without significant differences among treatments. At 24 h post-mowing, maceration of alfalfa tended ($P = 0.08$) to increase LAB counts from $10^{3.51}$ for CONV to $10^{5.06}$ CFU $g^{-1}$ DM for SEVERE.

Overall, alfalfa maceration in the current study tended ($P$ = 0.06) to increase LAB counts. As wilting progressed from 0 to 24 h after mowing LAB count also increased ($P < 0.01$).

Muck (1989), using chopped alfalfa, found a similar $10^5$ CFU $g^{-1}$ DM) LAB count at 24 h during wilting. Greater lactic acid bacteria populations can impact fermentation during ensiling, and may also influence microbial succession during silage storage. It has been suggested that a LAB population of at least $10^6$ $g^{-1}$ DM is required in a bacterial inoculant to yield an ideal fermentation profile during ensiling (Henderson and McDonald 1984; Mir et al. 1995). It is important, therefore, to conduct further research related to the effect of alfalfa maceration on LAB population and fermentation profile during ensiling, followed by an evaluation of the quality of the preserved alfalfa and performance of animals fed the ensiled alfalfa.

No differences among mowing treatments of alfalfa were observed for TB counts during the wilting period. Based on LAB and TB counts, SEVERE mowing treatment was recommended, since it tended to increase the LAB count 24 h post-mowing.

The potential or theoretical maximum bulk density of freshly cut alfalfa was similar among maceration levels, ranging from 1089.0 to 1093.2 kg $m^{-3}$, fresh basis (Table 2). This was within the 1056 to 1154 kg $m^{-3}$ range from maximum density reported by Savoie et al. (1994). Wet-basis bulk density increased ($P < 0.05$) with maceration, from 130.1 kg $m^{-3}$ for the CONV treatment to 192.6 kg $m^{-3}$ for SEVERE+ treatment, indicating that the degree of maceration did affect the physical characteristics of the alfalfa. The bulk density values observed for the two most severe conditioning treatments may create inefficiencies in mowing because the additional energy expenditures of mowing did not result in improved wilting times at the field level. Increased bulk density with maceration can increase the capacity of a silo and improve packing at the time of loading, thus reducing the risk of DM loss due to respiration during the early stages of ensiling.

## CONCLUSIONS

Maceration of alfalfa resulted in a shorter wilting time relative to conventionally mowed alfalfa using a roller-conditioner. The advantage of maceration in this field-scale trial was greatest in sunny, good weather conditions. The most severe level of maceration imposed in this trial did hinder wilting rate when there was precipitation. Maceration up to the LIGHT+ level did not result in significant dry matter loss post-wilting. Maceration at the SEVERE level resulted in a tendency toward a higher LAB count, which may be beneficial for later microbial succession during ensiling. This, coupled with increased compressiblity of macerated alfalfa, may have benefits relative to conventionally mowed alfalfa stored as silage.

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