IMPROVEMENT OF ALFALFA FORAGE QUALITY BY MACERATION AT HARVEST

A Thesis

Submitted to

The Faculty Of Graduate Studies

The University of Manitoba

by

Suwarno

In Partial Fulfilment of the

Requirements of the Degree of

Doctor of Philosophy

Department of Animal Science

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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ABSTRACT

A series of trials were conducted to evaluate benefits of alfalfa maceration at the time of cutting on wilting, storage and feed characteristics under prairie conditions. Early bloom alfalfa was harvested with either a conventional roller-conditioner (CONV) or a macerator with four degrees of maceration (LIGHT, LIGHT+, SEVERE and SEVERE+). Maceration of alfalfa from LIGHT+ to SEVERE reached an 80% DM during wilting in 9 - 11 h, relative to CONV, which reached the same DM content in 54 h. Exposure to 2 cm precipitation shortly after cutting and maceration resulted in 24.2 to 26.8 h shorter wilting time relative to conventionally-conditioned alfalfa. Lactic acid bacteria population of alfalfa tended to be higher with maceration at 0 - 1 h post-cutting ($P = 0.10$).

Alfalfa harvested with a macerator had a lower ($P < 0.05$) CP content at the time of baling. Macerated alfalfa conserved as silage had more colony forming units (cfu, $P < 0.05$) of lactic acid-producing bacteria at the initial day of ensiling. At day 80 of storage, macerated alfalfa conserved as hay had a higher content of soluble carbohydrates ($P < 0.05$) and a tendency toward a lower glucosamine content ($P = 0.07$) compared to alfalfa harvested with a conventional mower-conditioner. The benefits of maceration in this study appeared to be related to the shortening of wilting time and increasing the quality of conserved alfalfa as silage or hay compared to conventionally conditioned alfalfa. Decreased in CP at post-harvest was not followed with a significant increase in fibre content.

Dry matter intake for steers fed SEVERE hay tended ($P = 0.08$) to be lower and ADF and

NDF digestibilities were 22.0 and 16.7% lower ($P < 0.05$) compared to CONV hay. Dry matter and CP digestibilities were 8.1 and 32.4% higher, respectively, ($P < 0.05$) for steers fed the SEVERE hay compared to those fed CONV hay.

Beef calves consumed 13% more DM of silage made from the macerated alfalfa compared to those fed CONV silage or hay and achieved 22.7% greater average daily gain (ADG) at the initial 21 day growing trial ($P < 0.05$) but overall ADG was unaffected by treatment. Holstein cows were used in an early lactation trial and fed silage-based TMR's which contained either CONV or SEVERE alfalfa with similar level of concentrate, 58 and 59%, DM basis, respectively. Daily DMI, milk yield and milk composition were not affected by alfalfa harvest treatment. Cows fed the TMR containing macerated alfalfa had a greater ($P < 0.05$) ADG and tended to achieve a better body condition score (BCS) at the end of 14 week lactation trial.

Dedication

To my mother, Disah M; my wife, Rahayu Ningsih; my sons, Panji E. Y. and Rizki D. Y. Without their support, understanding and patience during my leave, I would not have completed this duty.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my advisor, Dr. K. M. Wittenberg for her guidance, support, and patience throughout this program. Sincere appreciation and thanks are forwarded to the committee members of this program, Drs. J. R. Ingalls, W. P. McCaughey, and S. R. Smith for their suggestions and encouragements during the committee meetings. To Dr. H. V. Petit, the external examiner, appreciation is forwarded for her thorough review of my thesis.

Appreciation is also extended to Drs. G. H. Crow and L. Onischuk for their statistical advice, to Drs. Mostaghi-Nia and B. Slominski, to Mr. P. Mills and Mrs. J. Haines for sample analyses, and to the staff of Glenlea Reseach Station and Animal Science Research Unit for their field assistance.

Financial support for this program was provided by the cooperative project between the Ministry of Education and Culture of the Republic of Indonesia and the Asian Development Bank (ADB), which was managed by the World University Service of Canada (WUSC) as its trustee. The research was funded by the Federal Government Energy Research and Development Program. Use of the macerator prototype was provided by the Prairie Agriculture Machinery Institute (PAMI).

FOREWORD

The research conducted for the purpose of this Ph. D. program has been written as the following three manuscripts. At this time two manuscripts have been submitted to the Canadian Journal of Animal Science.

1. Comparative characteristics during wilting for alfalfa harvested by maceration vs. a conventional roller-conditioner: submitted (Can. J. Anim. Sci.).
2. Alfalfa maceration: Impact on storage characteristics and feed value when fed to beef cattle.
3. Performance of lactating dairy cows fed macerated alfalfa conserved as silage and hay: submitted (Can. J. Anim. Sci.).

ABBREVIATIONS

ADF	Acid detergent fiber
ADFD	ADF digestibility
ADIN	Acid detergent insoluble nitrogen
BCS	Body condition score
BW	Body weight
ADG	Average daily gain
CFU	Colony forming unit
CP	Crude protein
CPD	Crude protein digestibility
DM	Dry matter
DMD	Dry matter digestibility
DMI	Dry matter intake
FCM	Fat corrected milk
GE	Gross energy
GLM	General linear model
Inwt.	Initial weight
LAB	Lactic acid bacteria
N	Nitrogen
NDF	Neutral detergent fiber
NDFD	NDF digestibility

NDIN Neutral detergent insoluble nitrogen

NE_L Net energy for lactation

Precip. Precipitation

Sol. Soluble

TB Total bacteria

TMR Total mixed ration

TN Total nitrogen

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INTRODUCTION

Forages are a key ingredient in the production of milk and meat from ruminant livestock (Schimdt et al. 1988). Continuous availability of good quality forages, therefore, is important to maintain year round productivity and reproduction of the animals. Production systems where the growing season is short, for example Canada, have been developed so that animals depend almost entirely on conserved forages for their diet. The technology of forage preservation primarily as hay and silage in these countries, therefore, has received substantial attention.

Making silage and hay requires that after cutting, forage be dried to an appropriate moisture level before being stored and fed. Forage drying is usually conducted on the field in swaths or windrows. The drying time to achieve a desired moisture content primarily depends on weather conditions, which requires that farmers should know beforehand the weather conditions during forage drying. It has been reported by Hayhoe and Jackson (1974) that in eastern Canada, drying time of the cut forage to achieve 20% moisture ranged from 3 to 18 days, depending on the length of day light, precipitation, relative humidity and wind.

Plant cells continue to respire until the forage material drops below 40% moisture, using available carbohydrates that will be converted to water and carbon dioxide and causing losses of forage DM. Some species of detrimental microbes also can grow on the plant cell surface during drying, the extent of which depends partly on the water and carbohydrate availability, causing further DM loss during forage drying. Also, precipitation during drying, especially with high intensity and long duration can cause leaching of cell solubles. High

relative humidity (RH) can cause further DM loss through facilitating mold growth during the prolonged drying time. Every effort, therefore, should be made to shorten drying time in order to minimize field drying DM loss.

Cutting and laying the cut forage in wide swaths or windrows, raking, tedding, crimping, addition of water absorbing agents such as $CaCO_3$, and physical conditioning have been used to shorten forage drying time with various success. Addition of chemicals and physical conditioning have been reported to shorten drying time by 39 to 79% compared to forage cut and wilted without conditioning, depending partly on the density of forage on the field and weather conditions (Clark et al. 1989; Rotz et al. 1984).

From the 1980's until recently a physical super-conditioning process known as forage maceration was developed in order to dramatically reduce forage drying time. Maceration splits the stem longitudinally into several pieces, allowing more cell surface area to be exposed to the outside environment and, therefore, can increase drying rate. Savoie et al. (1993) observed that macerated forage had a 110 % greater drying rate relative to conventionally conditioned forage. According to Charmley et al. (1997) the increase in cell surface area exposed due to maceration can increase lactic acid bacteria attachment to the plant cells during ensiling, facilitating the production of lactic acid required to preserve the forage. Shinners et al. (1987) and Savoie et al. (1992) suggested that macerated forage can be packed more densely than the unmacerated, conventionally conditioned forage, thus increasing the capacity of silos and facilitating the anaerobic conditions required for making a good quality silage.

There are few reports evaluating maceration technology under conditions typical of

Prairie Canada and Central USA, where harvest conditions are more condusive to hay and silage harvest than in the eastern parts of North America. Also, limited information is available regarding field scale trials where amount and timing of precipitation is considered. Little information is available on storage characteristics of macerated forage conserved as hay or silage at DM levels more typical of Prairie Canada or central USA, at 80% DM for hay and at 45 - 55% DM for silage. As well, limited information using macerated forage fed to cattle is available (Chiquette et al. 1994). For example, the published literature has not included use of macerated forage in dairy cattle diets. Therefore, the objectives of our studies were to investigate the effect of field scale forage maceration on drying time under the North America Prairie, drier climatic conditions. Effects of maceration on post-storage nutrient characteristics of silage and hay, fermentation characteristics of silage, and on the feeding performance when the silage and hay were fed to dairy or beef cattle, were also examined.

LITERATURE REVIEW

HAY AND SILAGE PRODUCTION AND USE IN CANADA

Canada is the second largest country in the world, stretching 5,500 km east to west, 4600 km south to north, and covering approximately 10 million km^2. However, only 10% of that vast area of land is inhabited (McCartney and Horton, 1997), and only 5% (45 million ha) of the Canadian land base forms a grassland biome, on which most of the cattle grazing in Canada takes place. The majority of harvested forage, dehydrated alfalfa and forage seed crops are grown in western Canada (McCartney and Horton, 1997). The four provinces of western Canada also have 82% of the nation's cultivated pasture and 64% of the nation's forage crop area.

Forage production is the foundation of Canada's beef and dairy industries. Canadian forage resources include native rangelands and cultivated crops. The forage resources used for livestock grazing and production of forage crops covers 36 million ha or 3.6% of Canada's land base which include 72% native range (26 million ha), 11% cultivated pasture (4 million ha) and 17% forage crops (6 million ha) (Statistics Canada, 1996, adapted by McCartney and Horton, 1997). In 1996, the total land area for growing corn for silage was 191,359 ha, and for tame hay production was 6,210,871 ha (Statistics Canada 1997). It has been estimated that two thirds of the feed protein for ruminants in Canada comes from hay, grazing of forages and fodder corn production (McQueen and Buchanan Smith 1993). The long, cold winter, typical of the Canadian climate dictates that feeding livestock with

preserved forages from October to May is the first choice (McCartney and Horton, 1997) with many intensive operations relying on year round supplies of conserved forages.

Forage species used in Canada are widely adapted to the various climatic regions. The important cultivated forage species include alfalfa (*Medicago sativa* L.), red, white, and alsike clovers (*Trifolium pratense* L., *T. repens* L., and *T. hybridum* L.), bird's-foot trefoil (*Lotus corniculatus* L.), smooth bromegrass (*Bromus inermis* Leyss.), creeping red fescue (*Festuca rubra* L.), timothy (*Phleum pratense* L.), orchard grass (*Dactylis glomerata* L.) and crested wheatgrass (*Agropyron cristatum* L. and *A. desertorum* (Fisch. exLink) Schult). These crops may be grown in rotation with cereal and oilseed crops, but primarily are grown on soils not suitable for annual crop production (McCartney and Horton, 1997). These grass and legume forage crops can yield as much as 4 tonnes of DM ha^{-1} $year^{-1}$ on productive lands of western Canada to 8 - 10 tonnes DM ha^{-1} $year^{-1}$ from corn in southern regions of eastern Canada (McCartney and Horton, 1997).

Annual tonnage of Canadian conserved forages equal approximately 43 million tonnes DM year (McQueen and Buchanan-Smith 1993). These conserved forages consists of whole plant corn, cereal grain, grass, and legumes (McCartney and Horton, 1997). Common ways that forage is conserved include small rectangular bales, medium and large square bales, round bale hay and long fiber or chopped silage that is stored in horizontal or upright silos. Frequent rainfall and high humidity, weather conditions unfavourable for hay making, has led to wilted silage, 55-65% forage moisture, production as the preferred form of conserved forage in eastern Canada. Meanwhile in western regions, especially on the prairie provinces of Canada, hot and relatively lower humidity during summer has led to preservation of forage

primarily for hay production. Trends towards increased specialization and size of cattle operations has resulted in increased use of silage as compared to dried forage across Canada. The value of forage conserved as hay and silage accounts for 40 - 60% the value of feed grain crops (McQueen and Buchanan-Smith 1993). Less than 15% of forage produced by the farmers is being sold (McCartney and Horton 1997).

Double-density compressed hay, with overall processing capacity over 300,000 tonnes is targeted for the export market. Pure timothy hay is the standard for this industry. Alfalfa, alfalfa/timothy, and oat hay may also be compressed. Hay processing plants exist in several provinces across Canada, but most of the densified hay is produced in Alberta (McCartney and Horton 1997). High quality baled hay is typically harvested in conventional small square bales. This hay is baled under 14% moisture content to avoid condensation and molding during transit in shipping containers.

Over 90% of the compressed hay produced in Canada is exported, mainly to Japan. In 1996, Canada exported over 100,000 tonnes of compressed hay to countries in Asia, Europe and Americas, with an estimated value of over $26 million. Another $10 million worth of hay was shipped from Canada to the US, most of which is as a standard density in round or square bales (McCartney and Horton 1997). Other processed forage products for export market are cubed and ground, pelleted alfalfa. In 1994 and 1995, Canada produced 750,000 metric tonnes of alfalfa pellets and cubes, 60% of which was produced in Alberta with more than 80% of the remaining of this product was produced in Saskatchewan (McCartney and Horton, 1997). With 85 to 90% of these processed forage being marketed to Asia, Canada is the largest world exporter of alfalfa pellets and second only to the US as

the largest world exporter of alfalfa cubes (McCartney and Horton, 1997).

IMPORTANCE OF HAY AND SILAGE IN RUMINANT AND EQUINE RATIONS

A major constituent in ruminant diets is forages (Schmidt et al. 1988). With the help of rumen microflora, plant fiber can be digested into more available carbohydrates such as starch, fructose, glucose, and galactose and volatile fatty acids; primarily acetic, propionic, and butyric acids. Hindgut fermentators, such as horses, also can digest plant fiber as an energy source.

Inventory of ruminants and equines in Canada

The 1996 census documented the following numbers of ruminant animals in Canada: 1,227,732 dairy cows; 4,680,585 beef cows ; 2,285,988 heifers; 290,975 bulls; 1,734,113 steers; 4,673,641 calves; 864,850 sheep and lambs ; 125,819 goats; 45,437 bisons; 69,883 deer and elk; 8,669 lamas and alpacas (Statistics Canada 1997). The number of horses are 443,889 head (Statistics Canada 1997).

Percent of dietary energy from forage

Ruminant animals have a unique ability to thrive on a wide range of diets. It is feasible to feed dairy or beef cattle 100% of their nutrient requirements as grass and conserved forage, or conversely, to feed only by-products and concentrates if none of their requirements can be met by grassland. In the United Kingdom, about 50-75% of the annual energy requirements for dairy cattle are contributed by grassland and forage (Leaver, 1988), while

in western European countries and North America, grazed grass also supplies from 60 to 80% of annual nutrient intake of 50 million suckler cows (Petit et al. 1992).

In general, beef cattle operations are more dependant on pasture lands as compared to dairy cattle. Because of differences in the nature and nutrient contents of their primary product, the ME energy requirements between beef and dairy cattle are also different, 15% more for dairy than beef (Ferrell and Jenkins 1984; Petit et al.1992). The proportion of forage included in ruminant diets generally depends on age, body weight and physiological status of the animal and the quality of dietary forage. For grazing ruminants, the ME energy for walking distance should also be considered.

Although lactating dairy cows are being fed higher levels of concentrates, forages still play an important role in supplying energy and protein, because there is a lower cost of producing nutrients from forage than from concentrate, and the importance of forage inclusion in the ration to prevent low-fat milk production and digestive disturbances (Schmidt et al. 1988). It has been suggested that a high-quality silage fed as the sole dietary ingredient can support energy for maintenance and 20 kg milk d^{-1} (Schmidt et al. 1988). Therefore, concentrates should be included in high-production dairy cow diets (Schmidt et al. 1988).

Increases in milk yield have been mainly produced from increased concentrate input, therefore, the contribution of grass and conserved forage as a proportion of the metabolizable energy requirements of the cow has been reduced from 64.6% in 1976 to 60.5% in 1980 (Leaver 1988). Although increasing concentrates in the diet can increase dietary DMI (Kalscheur et al. 1997) and milk production, the practice also increases feeding costs and tends to require a higher level of animal management, therefore, only a proportion of dairy

farmers will successfully practice such systems. Another alternative would be to limit the use of concentrates when ration balancing and to place a greater emphasis on high quality pasture and conserved forage production (Leaver 1988).

For moderate quality forage, maximum ME intake is achieved at about 30% forage in total dietary DM, but with high quality forage the maximum ME intake is achieved at about 55% forage in total dietary DMI (Schmidt et al. 1988). It is important, therefore, to have a high quality forage to increase the contribution of forage to the energy supply.

It has been calculated that if a cow was targeted to produce 4000 kg milk $year^{-1}$, a diet of solely grass forage was adequate (100% ME was supplied by forage), and if a cow was targeted to produce 7000 kg milk $year^{-1}$, 46 % of the ME requirement should be supplied by forage (Leaver1988). According to Schmidt et al. (1988) forage feeding to lactating dairy should not be less than 40% of total DMI. Lower than this level, factors other than physical capacity control consumption of feed and no further improvement in digestibility occurs (Schmidt et al. 1988). If the forage portion of the diet is too low, dietary fiber content decreases, resulting in less chewing and salivation, lowering the buffering capacity in the rumen, with the result of decreasing the ratio of acetic to propionic acid production. Because acetic acid is a precursor of fatty acid that is important in the formation of triglyceride, lowering acetic acid in the rumen as a result of low forage inclusion in the diet, will also decrease the percentage of milk fat. Current consumer preference toward a low-fat and high-protein milk leads to the attempts of increasing the production of high-protein milk through feeding manipulations.

Beef cows winter grazed on the sandhills range near Whitman, Nebraska, on a 100%

grass with CP content of 5.0% (DM basis) were reported to loose up to 24.5 kg. Supplementation with either 2.2 kg cow^{-1} d^{-1} grass hay containing 15.5% CP content or 1.2 kg cow^{-1} d^{-1} concentrate containing 36% CP, or combination of hay and concentrate fed on alternate days resulted in an increase of 3 to 53 kg BW $winter^{-1}$ in a similar area (Villalobos et al. 1997).

The results of the mentioned trials indicated that in order to reap more benefit from forage energy utilization, high quality forage should be used in rations. Low quality forage can be used but should be supplemented with higher percentage of concentrate, to produce a higher yield of milk or meat. Very low proportion of forage in diets, less than 1.5% BW, may cause a decrease in dietary DMI and digestive upset (Schmidt et al. 1988).

Horses by instinct are forage consumers. Horses have the ability to digest fiber about two-thirds as efficiently as cows (Cunha 1991). It has been suggested that horse rations contain at least 1.0% of BW as forage DM, with a minimum of 0.5% BW. As with ruminants, forages supply horses with energy, proteins, vitamins and minerals, and can prevent digestive upsets (Cunha 1991). Forages used in horse rations are generally in the form of hay, although silage and haylage have been used (Pilliner 1992).

As with ruminants, the inclusion of forage in equine diets depends on the horse's age, and for mature horses depends primarily on work load. For example, nursing foals of 3 months require only 20% of dietary dry matter (air dry basis) as forage DM (Cunha 1991; Pilliner 1992), mature horses, for maintenance require 80 to 100% (1.5 - 2.0% body weight) dietary DM from forage. The light working horses require 75% and the hard working horses require 40% their energy requirements from forages.

As mentioned above, increasing the percentage of forage can improve the economics of milk production. However, when the price of concentrates are relatively low, moderate or poor quality forage can be fed to animals. Increasing the amount of concentrates in poor or moderate quality forage based diets have been shown to increase DMI until rumen fill becomes a limiting factor, but the increase in DMI is marginal with high quality forages.

HARVEST TECHNOLOGY CURRENTLY BEING USED FOR HAY AND SILAGE PRODUCTION

Process of hay or silage harvest

In 1996, farm activities in Canada utilized (in thousands) 137,346 swathers, 96,554 less-than-90 kg balers, 63,304 90.8 kg-or-more balers, and 28,609 forage harvesters (Statistics Canada, 1997). Other equipment used in forage harvest includes mowers, rakes and tedders.

Crops for silage and hay usually are harvested at the late vegetative or early reproductive (10% bloom or 10% head emergences in legumes and grasses, respectively) stage. The choice of harvest at a certain growth stage is a compromise between quantity (nutrient yield) and quality (DM yield ha^{-1}) and other factors such as animal acceptance. The harvested forage is dried, usually as swathes or windrows, as quickly as possible to achieve a moisture content appropriate for silage (55-75% moisture) or hay production. The dried forage for hay production was baled as small rectangular (36 X 46 X 46 cm/variable), large round (100-170 X 100-180 cm) bales, large rectangular (122 X 122 X 200-280 cm) bales, as stacks (260-750 X 210-360 X 240-520 cm), or processed as cubes (4 X 4 X 5 cm) and

pellets (0.5 X 2.5 X 2.5-4.5 cm). The densities range from 160 for small-rectangular bales to 550 kg m^{-3} for large rectangular bales (Nash 1978; Larsen and Rider 1985) for hay. For silage, the forage is usually chopped or baled as large round bales prior to ensiling.

Cutting generally is considered as the main sources of mechanical DM loss, although crop factor such as plant maturity can have an impact as well. It has been found (McDonald and Clark 1987) that mature plants are more brittle than immature plants, therefore, the former is more susceptible to DM mechanical loss than is the latter. Type and speed of mower during cutting may negatively affect DM loss due to leaf shattering (McDonald and Clark, 1987). McDonald and Clark (1987) reported a slightly higher DM loss with a rotary mower than with a cutter-bar mower with a speed of 6.4 km h^{-1}, but when travel speed was increased by 50%, DM loss was increased for the cutter-bar mower but not for the rotary mower. Svensson (1978) noted that DM losses were 5-20% for cutter-bar mower, 5-25% for rotary mower, and 15-40% for a flail-type mower at a speed of 6.1 km h^{-1}.

Conditioning is the mechanical or chemical treatment of forage to increase the rate of moisture evaporation from the cut plant (Klinner and Shepperson, 1975). Mechanical conditioning reduces cuticular resistance to water loss by crushing or crimping (Greenhill, 1959), which is accomplished at the same time as mowing, often using the same machine. The process of propelling the conditioned forage backwards from the rollers, such that it strikes the apron and is shaped into a windrow by adjustable baffles, produces an open and airy structure, which minimizes boundary layer resistance (McDonald and Clark, 1987). The machine used for conditioning is termed a mower-conditioner or haybine. Crushing is a process by which plant material is pulled through a pair of solid, high-speed, metal or rubber

rollers, often of an intermeshing herringbone design which split or damage stems longitudinally. Under a good drying condition, conditioning may increase wilting rate by as much as over 100%, with a lesser effect under a less favorable weather condition (Savoie et al. 1993). Mechanical conditioning has been reported to increase leaching losses if the cut forage is subjected to rainfall during the wilting cycle (Savoie et al. 1993).

Forage subjected to conditioning also tends to have more ADF after wilting (Savoie et al. 1992), however, respiration loss was less (2.7%) for the macerated forage than for mower-conditioned forage (6.8%). Savoie et al (1993) observed that conventionally harvested alfalfa hay without rain experienced total field losses of DM of 18%, compared to only 13% of total losses for the macerated, pressed mat under similar conditions, after 24 h of wilting. In another study, Savoie et al. (1994) found that the mechanical DM losses due to mowing, conditioning, and baling as large round bales for silage (predominantly 80%, orchardgrass) ranged from 1.9 to 5.0% with an average of 3.4%. Baling the forages at 6.7 km h^{-1} resulted in lower DM losses, 3.1%, as compared to baling at 3.4 km h^{-1}, 3.6%. Very severe maceration resulted in slightly (0.5%) higher DM losses due to mowing, conditioning, and baling, 3.6%, as compared to that of mower-conditioned forage, 3.1% (Savoie et al., 1994).

A crimper is a machine similar to roller-conditioner with open rather than solid rollers that break the stem laterally. Abrasion occurs when rollers with unequal tufted brush speed were exposed to the harvested forage, causing the waxy cuticle of stems and leaves to be modified or damaged, but the stems were not split open (McDonald and Clark, 1987). Recently, a super conditioner or macerator has been introduced (Ajibola et al. 1980; Shinners,

et al. 1987, Koegel et al. 1988; Hong et al. 1988; Savoie et al., 1992; Savoie and Beauregard 1991; Koegel et al., 1992). A small-scale (1.2-m wide mower) macerator prototype (Koegel et al. 1988) has been successfully used in the field with alfalfa drying to 80% DM in 6 h or less (Shinners et al. 1987). This machine consisted of a mower, two series of macerating rollers, and a belt press to compress the mashed forage and the formation of a thin mat that is laid on the stubble for drying (Savoie and Beauregard 1991). Another design of macerator was described by Shinners et al. (1987) which consisted of a major toothed cylinder with several counter-rotating rollers around half of the major cylinder circumference. A difference in the peripheral speeds of the cylinder and the rollers causes the plant material to be macerated or shredded along its stems

Most windrows produced by mowers or mower-conditioner are compact and lumpy. Windrow resistance to wilting is the initial limiting factor for rapid wilting. Tedding of this windrow at the early period of wilting increases wilting rate up to a DM content of 50%. Subsequent raking and turning further increase drying rate (Nash, 1978). Damaged/fractured stems after mechanical conditioning makes the windrow denser, requiring tedding to ensure air circulation in and around the windrow. Frequent disturbance by tedding and raking ensures maximal ventilation, especially to the innermost and underlying parts of the windrow (Clark and McDonald, 1977).

Tedders are used early in the wilting period, when the forage is moist and relatively insensitive to agitation, and rakers are used late in the wilting periods, for the drier materials. The two most common types of rakes are the side-delivery rake and the finger-wheel rake. The conventional side-delivery rake uses an angled, tine-spring tooth beater, oriented parallel

to the ground, to gather or turn the windrow. The finger-wheel rake consists of several large, ground-driven spring-toothed wheels, oriented perpendicular to the ground, which roll the hay to one side to form a windrow. Raking may result in DM loss, with the magnitude depending on the type of rake, the forage moisture content at raking, and the yield and composition of the hay (McDonald and Clark, 1987).

When forage DM content on the field has reached 80 to more than 85%, depending on the size of bales, the forage is ready for baling. The types of balers include small, medium and large rectangular balers and large round balers. In order to minimize mold growth and temperature increase during storage, the increase in bale sizes should be followed with the increase in DM concentration of forages being baled.

Forage packaging as hay.

The various large bale packages have become increasingly popular because they substitute mechanical energy for human labour and labour efficiency with an average handling rate of 2.5 to 5.6 tons man-hour^{-1} (Heslop and Bilanski, 1986) and are considered to be cost effective (McDonald and Clark, 1987). Because the size and weight of the various large package systems imply complementary investment in specialized equipment to retrieve the bales from the field to the feeding areas, the choice between making small relative to big bales depends partly on the size of farm (financial aspects). The ease of handling (baling, transportation, storage) and quality (nutrient and DM retention after handling and storage and animal performance) should be taken into account as well.

Rectangular and square bales are vulnerable to weathering and leaching losses,

therefore requiring cover for storage, but they do allow for easiness in transportation and feeding, either mechanically or manually (Larsen and Rider, 1985). For storage and transportation purposes, rectangular bales are generally more suitable for space utilization efficiency and easiness of piling and sealing, relative to round bales.

Conventional baling incurs DM losses ranging from 3 to 8%, while losses associated with baling as large round bales ranging from 1 to 15% (MacDonald and Clark, 1987). Nash (1978) found that leaf shattering of alfalfa, even under favorable conditions, accounted for losses of 15% of total crop weight, up to 30-45% of total weight under poor conditions, due to baling.

Overall, DM losses for small rectangular bale hays includes 17.4-32.6% harvest loss, 3.6-4.0% storage loss, 5.2% feeding loss, with total losses ranging from 20.4 to 41.8% with an average of 34.0%, depending partly on precipitation during wilting. Barn wilting of similar bales resulted in lower total DM losses, 20.4%, particularly due to less harvest and storage losses as compared to field wilted hay (Schmidt et al. 1988).

Large bale, field-cured hay has 25.0, 14.2, and 15.3% harvest, storage, and feeding losses, respectively, with total losses of 54.5%. Acid treatment of similarly baled hay has 15.0, 10.7, and 5.5% harvest, storage, and feeding losses, respectively, with a total DM losses of 31.2% (Schmidt et al. 1988).

Long fibre vs chopped fibre silage.

Chopped silage production has long been practised all over the world. The forage, wilted or not, is chopped, packed and sealed in tower, bunker, or pit pile silos. In recent

decades, long fiber silage has been introduced. In this system, forage is baled at 35 to 45 % forage DM as big bales (800-900 kg $bale^{-1}$). The bales are then placed in plastic tubes, sealed, and stored on the ground or floor until ready for feeding. Stretch wrappers for individual or collective bales of silage have also been developed recently.

The advantages of chopped silage includes improved compactness, therefore, enhancing anaerobic conditions; greater release of soluble carbohydrates for fermentation; greater possibility for microbial attachment $unit^{-1}$ weight of forage DM due to greater surface area and a faster decrease in pH, compared to long fiber, baled silage. The disadvantages of chopped silage systems include the requirements for costly silos; a greater number of operations from cutting to feeding; greater effluent (cell soluble content) losses, and occasionally produces hazardous compounds such as nitrous oxide gas (Morrison 1959), requiring more careful handling during unloading. Moreover, chopped silage is not suitable for long distance transportation, while large, individual silage bales can be made (cut, wilted, baled and wrapped) on the field, at a location close to the feeding area, or transported as a sale commodity.

Difficulties in creating ideal conditions for fermentation, include low bulk density and low available soluble carbohydrate levels at the initial stage of ensiling for long fiber, large round bale silage may be overcome with maceration of forage prior to ensiling (Shinners et al. 1988) because bale bulk density increases from 170 (mower-conditioner) to 208 kg DM m^{-3} (mower-macerator). Use of silage preservatives such as a combination of formic acid and lactic acid bacteria (LAB) inoculant (Jonsson et al. 1990); LAB inoculant (Mir et al. 1995); ammoniation and LAB inoculant (Bates et al. 1989), have been documented, however,

results have not been consistent.

Silage has 2.0-11.5, 10.1-21.2, and 11.0% harvest, storage, and feeding DM losses, respectively, with total DM losses from 26.1 to 34.2%, depending partly on forage DM content at ensiling. In general, lower DM content at ensiling results in lower harvest DM losses but higher storage and total losses compared to that for higher forage DM contents (Umana et al. 1991). Addition of a combination of microbial inoculant and molasses to grass silage further enhanced quality of both direct cut and wilted forage (Umana et al. 1991).

FORAGE HARVESTING GOALS

The goals for forage harvested as hay or silage for animal feed include high yield, high nutrient content, low mold growth and high LAB counts for silage, more efficient storage and feeding, efficient labour and fuel, and efficient packaging as baled hay or processed forage such as hay cubes and hay pellets for sale purposes. Good regrowth for the harvested plant also should be taken into account.

Standing, living plants have a high moisture content and are resistant to physical and chemical disturbances, and maintain relatively small numbers of microbes on plant surfaces (Muck 1989). Some time after cutting, the plant cells are still respiring until forage DM content achieves 60% (McDonald and Clark, 1987), which lowers forage soluble carbohydrate contents. The forage DM losses due to plant and microbial respiration during field wilting can be as low as 2-8% under good drying conditions but may increase to 16% under poor conditions (Klinner and Shepperson, 1975). Resistance of plant cells to

environmental disturbances also decrease due to deteriorating cell membranes and walls some time after cutting. Rainfall that occurs during wilting may cause loss of cell solubles due to leaching especially when rainfall is intense and/or prolonged . Extended wilting time may also increase DM loss due to respiration. During the breakdown of plant cell structure after cutting, some of soluble cell contents leaches out and becomes available to bacteria attached to plant stems and leaves which stimulates their growth.

During wilting, especially in good weather conditions, leaves generally dry faster than stems, and therefore, are more susceptible to leaf shattering due to tedding, raking, or baling, primarily if forage has been very dry. Attempts to minimize DM losses during harvest, therefore, should be borne in mind, relating to the potential DM loss during that period of time.

Minimize loss in nutrient content of standing crop

Klinner and Shepperson (1975) reported that losses of DM and nutrient content during drying and baling depend on the type of mower used for cutting, on the post-cutting or conditioning treatment, on timing and method of raking and tedding, and on the type of balers and forage moisture content at harvest. With well adjusted cutter bar and rotary disc mowers, DM losses during mowing and conditioning range from 1 to 5% (Koegel et al. 1985; Savoie 1988; Shinners et al. 1991). With flail-type mowing machines, losses of DM are much larger, between 6 and 11% (Rotz and Sprott 1984; Shinners et al. 1991).

Further DM losses after cutting include losses due to respiration (5-10%), raking (3-6%), tedding (1-2%), and baling (2-10%). The extent of these DM losses depend partly on

crop moisture content and swath density (Rotz and Abrams 1988). To minimize DM loss during and immediately after harvest due to leaf shattering and respiration, cutting at a good weather condition and conditioning forage to hasten the wilting rate are worth considering.

Successful drying to 80% DM with low ambient RH will result in good quality hay during storage with leafy, green colour and low mold growth while being free of dustiness and astringent odour. Hay baled with excess moisture content due to unfavourable weather during harvest usually succumbs to molding during storage and colour deteriorates to gray or brown (McDonald and Clark, 1987). Therefore, rapid drying is important to minimize DM loss during wilting.

Rate of water loss during field wilting of cut forage typically declines exponentially, so that each additional percentage drop in moisture content requires progressively more time as the moisture content decreases (Robertson 1983; Hale 1986, Wilkinson 1981; Wilkins 1988). Nash (1978) categorized the wilting interval of forage into 3 phases: a short, initial phase; a second, longer phase; and a final phase when moisture content reaches about 45%. This wilting pattern interval is caused, in part, by the closure of stomata and an increase in osmolarity as forage decreases in moisture content. When stomata close, water evapo-transpiration must go through the plant cuticle which has 10 times more resistance to water than the stomata (Wilkins 1988).

A short drying time is critical to make quality hay, because a wilted crop is more vulnerable to rain damage than when wet (Wilkins 1988; Waldo and Jorgensen 1981), because rain results in greater leaching of plant solubles, which may cause molding (Hill 1976). This leaching due to unfavourable weather at drying not only reduces DM yield, but

also reduces digestibility of the conserved forage (McDonald and Clark, 1987). Plant and microbial respiration during field wilting can reduce forage DM yield by 2-8% under good weather conditions and by up to 16% (twice as much) under poor drying conditions (Klinner and Shepperson, 1975). When drying is delayed by extremely wet and humid conditions, as much as 30% of initial DM can be lost due to respiration (Rees 1982). In alfalfa, respiration loss under poor weather conditions may reach a maximum of 4% of DM day^{-1}, independent of plant maturity (MacDonald and Clark 1987; Kennelly and Baars 1990).

A decrease in digestible DM by 8 percentage units has been reported in 21 comparisons where rain exposed field-cured grass hay was compared to that not exposed to rain (Wilkinson 1981). Nash (1978) reported a decrease in digestible organic matter by 5 percentage units or more when forage was exposed to modest rainfall during drying. Dry matter intake was reduced by 5 and 20 g kg^{-1} $BW^{0.75}$ and DM digestibility was reduced by 4 and 8.8 percentage units, respectively, when forage was exposed to 25 and 38 mm rainfall, compared to forage not exposed to precipitation (Milligan et al. 1981, unpublished data, in MacDonald and Clark, 1987). Simulated rainfall of 2.5 cm applied after 24 h of field wilting increased mean DM loss from 8.1 % for the unwetted forage to 17 % in alfalfa and to 25.8 % DM loss in red clover cut at first flower. Rainfall of 4.1 cm over a 4-day period increased mean DM loss from 10.5 % (control) to 43.4 %, with a concomitant reduction in in vitro DM digestibility from 66.4 to 48.1 %. Due to the risks of DM losses during forage wilting through respiration, leaching, and molding when wilting time is extended, several methods to reduce wilting time such as raking, tedding and conditioning have been studied.

To achieve the goal of minimizing nutrient loss of the harvested forage, wilting forage

in as short a period as possible to minimize respiration loss is preferable.

Minimize mold growth

Excessive growth of fungi and mold on preserved forage is not desirable since mold and fungi are potential micotoxin producers, and may modify the market-value of hay if a visible mold is detected in a hay-lot. These microflora can grow on a growing plant, during field wilting and during storage of the preserved forage (Wittenberg et al. 1994). According to Wittenberg et al. (1994) the surface of living plants are generally inhabited with epiphytic micro-organisms, predominantly bacteria, that can help protect the plant from fungal invasion, and yeast that can protect the plant from the effects of visible light. Linn et al. (1992) reported high numbers of mold and yeasts on living plants, 10^6 to 10^7 cfu g^{-1}, based on the field data. Freshly cut forage is further contaminated with soil and airborne fungi (Wittenberg et al. 1994). Wittenberg et al. (1994) observed that during wilting, alfalfa forage in their University of Manitoba trials was contaminated by several genera and species including *Absidia, Acremonium, Alternaria, Aspergillus glaucus, Cladosporium cladosporoides, Fusarium, Phoma leveillei* and unidentified yeast. The species and numbers of microflora found during wilting can be affected by the microbial population present at cutting, the extent of plant damage, mixing at cutting, plant maturity, temperature, and moisture (Wittenberg et al. 1994).

Humid or high RH conditions are generally more favorable for mold growth. The goal would be to minimize mold growth in preserved forage during storage by the addition of antifungal agents and by preserving the forage in low moisture conditions such as hay,

dehydrated forage, and pellets. Ideal storage conditions including low RH , good ventilation and rodent proofing for hay; and oxygen and leak proofing for silage, should be maintained to maintain the quality of forage being stored.

High lactic acid bacteria counts for silage production

In living plants, the number of lactic acid-producing bacteria generally is low (150-200 cfu g^{-1} fresh forage, Muck 1989), and increases after cutting, depending on the availability of non-structural carbohydrates. However, the LAB on the plant is usually a mixture of heterofermentative and homofermentative species, which are not only producing lactic acid, but other less desirable compounds such as acetic acid. Maceration to some extent can increase the LAB population during wilting (Charmley et al. 1997), but not lactic acid production during ensiling. Some studies have attempted to improve fermentation characteristics of forage by inoculating forages with microbial preparations at cutting (Umana et al. 1991) or by wilting the forage to some degree before ensiling (Nicholson et al. 1992). Chopping the forage before ensiling, to some extent, has been found to improve silage quality by lowering CP degradation, butyric acid content and clostridia count and increasing LAB count (Nicholson et al. 1992). It has been suggested that for rapid pH decline during ensiling, a LAB count of at least 10^8 g^{-1} forage DM is required (Pitt et al. 1985).

Because of the importance of maintaining a high LAB count to produce lactic acid to levels sufficient enough to preserve forage, it is worthwhile conducting attempts to maximize LAB growth during ensiling for example by addition of available carbohydrate to forages low in soluble carbohydrate levels, by excluding oxygen from the silo to the extent possible, or by

inoculating the plant with LAB inoculations.

Efficient storage and feeding

In the countries with long winters such as Canada, the storage of preserved forage (hay and silage) is very important. Although concentrates can be fed during winter, they are more expensive than forage per unit energy or protein weight, also high quality forage is a more preferable feed during this season. In practise, small or large rectangular hay bales would be most efficient for storage due to their cube shape which would increase the holding capacity of a shed or storage room. In addition, rectangular bales are more easily transported to the feeding area. For silage, large bales have been increasing in popularity among farmers in the last decade due to ease of handling and relatively lower cost of production compared to chopped silage. The choice of shape and size of bales may depend partly on the size of farm. Therefore, efficiently of storing and feeding harvested forage with minimum handling and minimum dry matter loss in storage and minimum plant shattering during transportation and feeding is important.

Labour and fuel efficiency

Intense mechanical conditioning of forage during cutting substantially increases fuel costs, and has a marginal benefit in improving forage quality or minimizing DM loss (Savoie et al. 1992). Therefore, a compromise between increase in fuel and labour costs with the impact in benefit of forage quantity and quality is a worthwhile study.

Savoie et al. (1992) found a similar wilting time to reach 80% DM, approximately 6.6

h and 10.0 h for alfalfa forage under 0.35 and 0.52 kg DM m^{-2} mat density, either passed once or twice through 6 macerating rollers of a stationary macerator. Doubling compression pressure from 138 to 276 kPa only had a marginal decrease in wilting time to 80% DM (7.5 vs 6 h and 11.5 vs 9.5 h for light and heavy density mat, respectively (Savoie et al. 1992). In another trial, Savoie and Beauregard (1991) observed that increasing compression pressure from 140 to 280 kPa resulted in similar wilting time to reach 80% DM, which led them to conclude that the low, 140 kPA, pressure was preferable due to less power to run the compression belts. Agbossamey et al. (1998) noted that when forage was passed through two steel-knurled rolls once up to seven times, fresh density of alfalfa and timothy increased (139 to 331 and 189 to 428 m^{-3}, respectively,). However, increasing compression pressure from 1750 to 3500 Newton resulted in similar fresh density for the two forage species. Increasing intensity of maceration from one up to seven passes through the macerator resulted in a linear increase in NDF, ADF, and a linear decrease in NPN content in hay and silage and an increase in soluble CP fraction of those forages (Agbossamey et al. 1998). These trials suggest that increasing pressure of the rollers or belt beyond a certain level substantially increases fuel and labour costs and time spent, but does not show any other major benefit. Therefore, research is needed to improve labour and fuel efficiency while harvesting forage.

Packaging of forage for sale purposes

As has been described previously, small, double-compressed rectangular bales are more suitable for long-range destination transport, such as for over-seas export market. For short and medium-range transport, larger bales, rectangular or round, can be considered as

long as this sale is still feasible or profitable.

Tyrchniewicz and Prentice (1992) observed that southeastern parts of the US such as Florida may be a potential market for hays. According to their survey results, large bales of hay made of forage containing high CP levels (20%) and low ADF level (25%) were more preferable than the reverse. The cost of transporting hay can be reduced by increasing density of hay through dehydration and compaction. Although dehydration can sanitize the hay, it costs more relative to compaction per unit weight of hay. Compacted hay usually is more desirable and is priced higher than dehydrated hay. Compaction, cubing and pelleting enable shippers to load the full weight limit of 40 foot ISO containers. Truck weight restrictions of the US interstate highway system permit a maximum of 21 t, enabling shippers to transport the hay in 48 foot trailers. When hay is not compacted only 15 t can be shipped in the same truck (Tyrchniewicz and Prentice, 1992). For the US destination, the hay is usually not compacted due to cost and benefit considerations. For a distance up to 2500 miles, the maximum bale size limit to be transported is 20.4 cm X 20.4 cm X 135 cm square bales on a maximum truck size of 53 foot dry vans. For a distance of up to 800 miles, round bale hay can be transported using flat deck trailers.

Hay is also transported using intermodal transport systems (trailers, railways and ships) for overseas destinations, primarily to Asia (Japan) and Europe. The size of compressed square bales that can be transported for overseas destinations is 20.4 cm X 20.4 cm X 102.2 cm with a maximum load weight of 25 tonnes truck^{-1} (Tyrchniewicz and Prentice, 1992).

The goal of forage harvest for packaging and sale purposes requires that the forage

be dried to a level (less than 20% DM) that can prevent mold growth and discolouration (browning) and be compacted or pressed to increase transportation capacity.

TECHNOLOGY ASSOCIATED WITH RAPID DRYING OF HARVESTED FORAGE

Cutting system

Forecasted weather conditions should be considered before cutting to minimize DM losses during wilting, because cutting without knowing the weather forecast increases the risk of increasing DM field losses due to precipitation. Forage should be cut to leave stubble which will ensure good aeration below and within windrows during drying. In addition, stubble that is too short can result in less carbohydrate reserve for regrowth. It has been shown that cutting and laying the forage on the field as wide swaths is preferable to dense windrows to facilitate wilting.

Conditioning system

Clark et al. (1989) found that K_2CO_3 accelerated drying to 80% DM in alfalfa, sainfoin, alsike clover, sweet clover, and red clover from 44-50, 52, 58, 72, and 88 h to 22-25, 26, 38, 30 and 50 h, respectively, compared to mechanical conditioning. When pure alfalfa stands were cut and mechanically or chemically conditioned, DM content after 74 h of wilting were similar compared to the unconditioned forage (82.9 and 83.3 vs 80.2%, respectively). However, mechanical or chemical conditioning significantly increased wilting rate when bromegrass-alfalfa mixture were observed at 70, 100, and 149 h during wilting

period (Clark et al. 1989), indicating that more ventilation probably develops within the windrow when legume was mixed with less lumpy materials such as grass, resulting in increasing wilting rate. Combining both mechanical and chemical conditioning resulted in a further enhancement of the wilting rate, especially for the legume-grass forage. Poor weather conditions and heavy windrows lessened the positive impact of either conditioning treatment. At the lower level of solar radiation, K_2CO_3 was slightly more effective in high (70%) than in low (45%) humidity (Clark et al. 1989). Higher wilting rates in alfalfa were reported by Hong et al. (1988b), when conditioned with K_2CO_3 or KOH, but only K_2CO_3 improved digestibility of alfalfa. Untreated alfalfa forage reached 60 and 80% DM content in 14.8 and 109.4 h, compared to 8 and 46 to 47 h for forage conditioned with KOH and K_2CO_3, respectively (Hong et al. 1988b). Under laboratory conditions, KOH and K_2CO_3 has been reported to be more beneficial as compared to potassium sulfates and potassium chloride to shorten wilting time of alfalfa to reach 33% moisture content, dry basis, by 68% and 70%, respectively (Meredith and Warboys, 1993). Under field conditions, the effectiveness of K_2CO_3 decreases, but can be improved by better ventilation of swaths (Meredith and Warboys, 1993).

Legumes have been found to be more responsive than grasses to chemical drying agents. The drying agents can disrupt or decrease cuticle blockage of water evaporation from plant material. Jones (1991) found that application of potassium carbonate to alfalfa and white clover , 2%, w/w, under laboratory conditions, decreased wilting time to reach 50% DM, wet basis, by 66 and 33%, respectively, but the salt did not decrease wilting time when applied to six species of grasses. Bigger size and thicker cuticle of legume stems as compared

to grasses may have resulted for the legume to be more responsive to chemical drying agents.

Oellermann et al. (1989) found an increase in wilting rate from 0.40 (control) to 0.48% moisture h^{-1} in alfalfa treated with Na_2-K_2CO_3-citrate. Dairy cattle fed the treated forage yielded 0.5 kg d^{-1} more milk relative to the controls (Oellermann et al. 1989) because of a higher energy content in the treated forage as compared to control. Meredith and Warboys (1993) treated alfalfa with several carbonate salts and hydroxides containing potassium, sodium or lithium under laboratory conditions. They found that from the ranges of potassium salts in their study, only potassium hydroxide and potassium carbonate were effective in reducing drying time to reach 25% moisture, from the initial moisture content of 75% (wet basis). Potassium hydroxide and potassium carbonate reduced drying time by 68 and 65-76%, respectively, compared to untreated alfalfa. The untreated control reached 25% moisture content in 63 h, as compared to 20 and 22 h for the potassium hydroxide and potassium carbonate treated forage, respectively. Under good weather conditions, however, the effectiveness of these treatments were greatly reduced, primarily in the late stages of wilting. The control reached a 25% moisture content in 75 h, compared to 69 and 73 h for aqueous and emulsified potassium carbonate treated alfalfa forages, respectively.

The function of the salts is partly to disrupt the plant cuticle and to absorb the physically bound water which escapes from the plant material. In humid conditions, water evaporation from plant materials is relatively slow, partly due to humid environment surrounding the plant materials. The absorption of water from the micro environment surrounding plant materials by the chemicals can decrease the humidity of this environment. As a result, water can escape easier from the plant material when salts are added as compared

to reverse. In contrast, under good weather conditions, water can evaporate from the plant more quickly than in a more humid conditions. The water vapor that escapes from plant materials can leave the swath micro environment. This low micro environment humidity, in turn, facilitates to increase water evaporation rate. Therefore, application of a drying agent to plant materials in good weather conditions may decrease the effectiveness of these chemicals as compared to application in bad weather conditions. When forage has been too dry, most of the physically bound water in plant cells has been evaporated, causing the chemical effectiveness in facilitating water evaporation to be reduced dramatically.

Several of the chemical conditioning studies described above suggested that potassium carbonate and potassium hydroxide were the most effective in enhancing wilting rate. Combinations of mechanical and chemical conditioning can further enhance wilting rate compared to either treatment alone. Chemical conditioning is less effective if applied in good weather conditions or late in the wilting period. Grasses are less responsive to chemical conditioning than legumes.

Savoie et al (1993) found that wilting rate in alfalfa and timothy windrows can be increased with maceration: by 54% under rainy conditions and 87% under good weather conditions in alfalfa; and by 87% in rainy conditions and 135% under good weather conditions in timothy. Macerated forages, laid in mats, experienced less respiration losses compared to conditioned forage laid in windrows (2.7% vs 6.8% of forage DM, respectively) under good weather conditions. However, the reverse was true in rainy conditions, 8.5% for timothy and 19,7% for alfalfa mats, respectively, compared to 7.4% for timothy and 13.0% of forage DM for alfalfa windrows, respectively. Savoie and Beauregard (1991) reported that thin mats of

alfalfa and timothy (0.55 kg DM m^{-2}) wilted 199% faster, and thick (1.14 kg DM m^{-2}) mats wilted 62% faster than conditioned forage in windrows under controlled environmental conditions. Oztekin and Ozcan (1997) in a field drying of alfalfa under good weather conditions found that maceration achieved 80% DM in approximately 6 days which was in agreement with the finding of Savoie et al. (1992) that macerated-pressed alfalfa achieved 80% DM within 6 to 12 h under controlled weather conditions. Forage with severe (14 shearing rollers) maceration and high pressure (280 kPa) only resulted in a marginal increase in wilting rate relative to less severe (7 shearing rollers) with low (140 kPa) pressure (Savoie et al. 1992).

These studies suggest that forage maceration at cutting can increase wilting rate dramatically, primarily in good wilting conditions. Dry matter loss due to respiration during wilting is reduced by maceration in good weather conditions, and the reverse is true under rainy conditions. It is important to determine the minimum degree of maceration necessary as this is related to increased fuel cost and the benefit of increasing wilting rates.

Raking and tedding

Tedders and rakes are used to open up the windrow, which promotes drying by increasing air flow and enhancing penetration of radiant energy into the windrow (Nash, 1978). A properly made windrow has the small stems, quick-drying, leafy portions of the plant surrounded by the coarse stems, slow-drying part of the plant. This arrangement of plant tissue to the surrounding environment encourages a more uniform drying of the hay crop materials. Proper and careful raking can contribute to the ideal windrow architecture

(Macdonald and Clark, 1987).

Grasses are less vulnerable to leaf loss during drying than legumes, thus can tolerate greater manipulation during the drying cycle (Nash, 1978). Dry matter loss in alfalfa between cutting and baling as hay, subjected to four post-cutting treatments was 38.9%, but only 19.1% for grass hay under similar treatments (Wilkinson, 1981). Tedding on the same day as cutting resulted in lower DM loss and faster wilting than did tedding 1-2 days after cutting (Murdock and Bare, 1963) and tedding was most beneficial to wilting if carried out when time forage DM content had reached the range of 33-50%. Tedding is more beneficial to immature than mature crops because immature crops contain more leaves and therefore tend to pack down, to a greater degree than mature crops (Wilman and Owen, 1982).

Raking at 85-90 % forage DM reduced yield and nutritional value by 25 and 30%, respectively, relative to raking at 50-60 % forage DM. Low yielding crops raked at a low moisture content are more vulnerable to raking losses (Dobie et al. 1963). Raking and tedding operations could result in 50% DM loss as leaf material in alfalfa and timothy after 52.5 h of field drying (Alli et al. 1985). According to McGechan (1988), mechanical operation in grass causes 1% losses of DM per mechanical treatment when forage contained lower (below 50%) DM concentration. The losses increase dramatically when the forage contained higher (more than 60%) DM concentration and is exposed to the same treatment. Based on those findings, it is worthwhile to rake and ted forage more often when moisture content is still high to maximize wilting rate and minimize DM loss due to leaf shattering.

Ideal situation for rapid field wilting of cut forage

The ideal condition for wilting forage is bright sunshine, moderate temperature with low humidity and a little wind. If the temperature is too hot, differences in physical structure between leaf and stem will cause leaves to become very dry while stems are still relatively wet, causing DM loss from leaves at the time of baling.

Sunlight intensity may have the greatest influence on both alfalfa and grass wilting rates. Also, potential evapo-transpiration or vapor pressure deficit, soil moisture, and windrow density are important factors affecting wilting rates (Rotz and Chen, 1985; Savoie and Mailhot, 1986). Time of harvesting can also affect wilting rate. In Guelph, (43 $^{\circ}$ N), the probability of making dry hay in 4 days or less varied from 50% in early June to 60% in late July, down to 5% in early September. Hayhoe and Jackson (1974) studied wilting time of mixed alfalfa (25%) and timothy (75%), at Nappan, Nova Scotia. With 7-8 h sunlight d^{-1}, wilting time to reach 80% DM ranged from 2 to 5 d, depending on temperature, wind, and precipitation, which determine drying index. When sunlight was only 3.05 h d^{-1} the number of days required to wilt forage increased to 18 (Hayhoe and Jackson, 1974). Relative humidity has an important effect on wilting time. The RH gradient that influences water loss from wilting hay is within the windrow, close to the plant tissue (Clark and McDonald 1977). Due to hygroscopic characteristics of hay materials, the RH also affects the equilibrium moisture content. At 80% RH, hay will reach an equilibrium moisture content with its environment at 22% DM content, and at 60% RH the equilibrium moisture content of hay is approximately 13% (Nash 1978). Immature plants have the potential to absorb more dew at night relative to mature plants (Wilman and Owen 1982).

In summary, cutting the forage in good weather condition would be recommended.

However if cutting cannot be delayed due to advancing plant maturity, cutting in less favourable weather conditions can be conducted using chemical or mechanical conditioning or with the used of barn drying.

STORAGE OF HIGH MOISTURE HAY

Hay making requires that forage be wilted to achieve at least 80% DM content before baling (Robertson, 1983; Wilkinson, 1981). However, the disadvantage of wilting to 80% DM content prevails: the drier the forage the more susceptible it is to DM loss due to mechanical (raking, tedding, baling) operation to facilitate drying, or to rain exposure (McGechan 1988). Therefore, some studies have attempted to bale hay at lower DM content, by adding additives such as antifungal agents.

Barn drying of hay is less dependent on weather. Heating during storage is caused by microbial respiration and can be reduced by barn drying (Klinner and Shepperson, 1975). Damp bales (65 - 75% DM) are transported to the destined barn or shed for artificial drying using a ventilated heater. Heat generated during plant and microbial respiration can save 15-75% fuel energy, but this comes at the expense of lowering nutrient content, especially soluble carbohydrates of the forage (Wood and Parker 1971). Barn drying can be done with heated forced air, a few degrees above ambient temperature using a fan. Forage dries progressively beginning from the source of air, moving outward from this source. The drier is designed so that molding and deterioration of hay does not occur by blowing the air throughout the forage area evenly or by arranging the bales in such a way to ensure even distribution of the blowing

air and smooth air circulation, so that variation in drying rate of forage within and between bales can be decreased to a minimum level (Wilkins, 1988). This drying system can dry hay in 3-4 weeks (Wilkins, 1988), and is more effective when humidity of the environment is low (Schmidt et al. 1988). Barn drying can minimize storage losses, based on a report of Klinner and Shepperson (1975) that post-storage digestibility of barn-dried grass hay was 69.9%, as compared to 64.7% for the same grass, field-dried hay. Based on data collected from several experimental farms Culpin (1962), noted that the reduction of swath and in-store DM loss due to barn drying may increase the total yield of hay by 7 to 18%, depending on the season and the effectiveness of the swath treatment. The disadvantage of barn drying, aside from a greater fuel cost relative to field drying, is when the DM content in particular area of forage in the bales is different with the other, which can cause pockets of mold in the wetter parts.

EFFECT OF FORAGE FORM ON INTAKE AND DIGESTION

Dry matter intake and digestibility as linked to the rate of passage

Factors that regulate DMI by ruminants are complex and not fully understood. Previous research has established relationships between dietary energy concentration and DMI by beef cattle based on the concept that consumption of less digestible, low energy (high-fiber) diets is controlled by physical factors such as rumen fill and digesta passage, whereas consumption of highly digestible, high energy (often low-fiber, high-concentrate) diets is controlled by the animal's energy demands and by metabolic factors (NRC, 1989).

Cell wall concentration and digestibility limit the potential DMI and energy availability of forage crops in beef and dairy cattle (Jung and Allen, 1995). Lignin is the key element that

limits digestibility and the extent of this limitation is related to the cross-linkage of lignin and cell wall polysaccharides by ferulic acid bridges (Jung and Allen 1995). Cell wall affects intake by contributing to rumen fill. Waldo et al. (1972), using data collected over a 20-year period, developed a model relating DMI, DM digestibility, passage and rumen fill of fibrous materials concluded that cell wall concentration and rate of passage are the most critical parameters determining rumen fill. They assumed that the weight of fiber residues in the reticulo-rumen is an important determinant of rumen fill and is dependent upon the amount of fiber consumed per unit time, the fraction of fiber that is potentially digestible and indigestible, the rate of digestion and the rate of passage of the fibrous materials.

A general conclusion was that DMI usually decreases with increasing fiber and lignin content of the diet. The extent of the decrease depends partly on the amount of fiber consumed per unit time, the digestible and indigestible fractions and rate of digestion and passage of the dietary DM. Increases in DMI per unit time generally are followed by an increase in passage rate and a concomitant decrease in rumen retention time with a resulting decreased apparent digestibility of the fibrous material being consumed.

Legumes vs grasses

At the same stage of maturity, legumes generally have higher concentration of CP and lignin and lower concentration of cell wall carbohydrates compared to grasses (Stefanon et al. 1996). Feed intake and digestibility are usually greater for legumes than for grasses, probably because of lower cell wall content of legumes (Cecava 1995). Holden et al. (1994) showed that diets containing different sources of fiber (alfalfa vs orchard grass) and similar

NDF content (42%) had a similar dietary passage rate.

Stefanon et al. (1996) compared the nutrient values of alfalfa and bromegrass hays cut at 5 growth stages each, from vegetative to reproductive (to early bloom in alfalfa and to full head for bromegrass, respectively). The NDF contents from vegetative to generative stages were 19 to 43% for alfalfa and 42 to 58% for bromegrass, respectively. When both forages were dried in an oven, ground and used as substrates for a 48 h in vitro ruminal digestion, alfalfa had a lower acetate to propionate ratio (2.2) as compared to brome hay (3.2). In vitro NDF digestibility was higher in both the vegetative (77.2%) and the reproductive stage (72.7%) for bromegrass than for alfalfa 73.2% and 49.6%, respectively.

Khorasani et al. (1996) fed lactating Holstein cows with TMR containing 50:50, forage (silage) : concentrate ratio, with dietary NDF contents from 32.2 to 37.9%. Cows fed TMR containing alfalfa or barley silages as the dietary forage had a greater DMI, 19.6 and 18.6 kg d^{-1}, compared to those for cows fed a TMR containing oat or triticale silages, 16.7 and 17.2 kg d^{-1}, respectively. Although total tract NDF digestibility was similar between the TMR containing legume or grasses, cows fed alfalfa had a higher rate of NDF digestion and lower rumen turnover rate compared to oat or triticale. The TMR containing alfalfa resulted in higher ruminal total volatile fatty acids (VFA) and acetic to propionic acid ratio compared to the TMR containing triticale. Milk yield (30.2 to 31.6 kg d^{-1}) was similar among dietary treatments, which resulted in a greater feed efficiency of the TMR containing triticale silage for milk production. Lower lignin content in alfalfa as compared to barley might be partly responsible for the higher rate of NDF digestion in alfalfa.

Weiss (1995) fed lactating dairy cows a silage-based TMR with either alfalfa (late bud

to early bloom stages) or orchardgrass (vegetative stage) with low NDF, low rumen escape protein concentrate or high NDF, high rumen escape protein concentrate. Digestibility of NDF tended to be lower and digestibility of N was higher for alfalfa-TMR diet than that containing orchardgrass silage. Forage species did not affect DMI, milk yield and composition, but gain was higher in cows receiving TMR containing alfalfa silage (0.18 vs 0.03 kg d^{-1}, respectively. Higher CP and limiting amino acid concentrations in alfalfa as compared to orchardgrass could have been partly responsible for the greater response in gain for cows fed TMR containing alfalfa silage than cows fed the diet containing orchardgrass silage.

Vanzant et al. (1996) studied in situ and in vivo digestibilities of alfalfa hay (16.4 % CP) and tall grass prairie hay (5.5% CP). They found that apparent total tract DM digestibility of alfalfa hay was 25% higher than that of prairie hay, and true ruminal DM digestibility was 34% higher for alfalfa hay as well. No difference in passage rate between the two forages was detected. Higher CP and lower NDF contents in alfalfa hay as compared to tall grass prairie hay can influence differences in these results.

Beef steers with an initial BW of 252 kg were fed either fresh fescue grass, a mixture of fescue grass-red clover, or fescue grass-alfalfa in stock-piled grazing, or fed fescue grass hay, fescue grass silage, or orchardgrass-alfalfa hay in the barn (Allen et al. 1992). They found that DMI was similar between animals fed the mixture of fresh or grass hay-alfalfa, but that DMI was lower when grass (fescue) was fed alone or in combination with red clover. Higher CP contents in grass-alfalfa compared to grass-alone might be partly responsible for the higher DMI in the grass-alfalfa combination. Higher DMI in steers fed the grass-alfalfa

combination resulted in a higher ADG (0.50 kg d^{-1}) compared to steers fed fescue alone (0.34, 0.18, and 0.07 kg d^{-1} for steers fed fresh, hay, and silage, respectively). Crude protein digestibility was highest for grass-alfalfa (63 and 67 % for fescue-alfalfa and orchardgrass-alfalfa, respectively), and lowest for fescue-red clover, 49.1%. There were no differences in DM and ADF digestibility among diets of different species and grass-legume mixtures. Vanzant and Cochran (1994) reported a linear increase in passage rate of indigestible ADF with increased alfalfa hay supplementation to beef cattle fed tallgrass prairie hay, which resulted in a decrease in dietary NDF concentration. Voluntary DMI was increased with increasing alfalfa supplementation in this study.

These results may suggest that although individual species of forages may differ significantly in nutrient profile and may reflect differences in animal response if fed as the sole dietary ingredient; inclusion of the same forages with concentrates in a TMR can result in a different perspective depending partly on dietary NDF and NDIN, non-structural carbohydrates, CP, and ruminal escape protein contents of the diets.

Stage of growth of forage

Total tract DM digestibility decreases from 82.2% in the vegetative stage to 51.1% at the full head stage of *Phalaris tuberosa* (Merchen and Bourquin, 1994). De Boever et al. (1993) compared the effect of physical structure of perennial ryegrass on nutrient composition, chewing behaviour, and DMI in cattle. They found that chewing index increased as NDF content of the grass increased. Lignin, ADF, NDF, and cellulose increased with advanced growth stage. Dry matter intake tended to be lower when growth stage

advanced from head emergence to full head and was significantly lower with advancing growth stage from vegetative to full head. Nelson and Satter (1992) failed to show differences in DMI due to forage maturity when lactating dairy cows were fed alfalfa silage or hay at either early bud or early flower growth stages as a TMR (60:40 forage to concentrate ratio, DM basis). Although higher NDF concentrations of hay made from the older plant materials could occur as compared to hay made from the younger plant materials, this difference might be smaller as compared to that in silage, due partly to less cell soluble effluent being leached during hay storage as compared to that in silage.

In general, advancing forage maturity decreases DMI, increases chewing activity and decreases DM digestibility.

Silage vs. hay

Brouk and Belyea (1993) studied the response of cows fed unchopped, chopped, or reconstituted alfalfa hay or long silage as the sole diet. They observed that silage had higher NDF, ADF and ADIN contents compared to hay (49.9%, 39.3%, DM basis, and 12.7% TN vs 46.5%, 34.8%, DM basis, and 6.7% TN, respectively). They found that cows spent more time eating long hay compared to silage (463 vs 348 min d^{-1}) and spent more time chewing $unit^{-1}$ of DM or NDF when eating hay than when eating silage. Digestiblities of DM and N were lower for silage than for hay. The fact that alfalfa silage in their study contained greater concentration of NDF may contribute to lower DM digestibility. They speculated that lower N digestibility could have been related to higher portion of silage N to be bound to cell wall fraction in silage compared to hay. Cows fed silage excreted about 60 g d^{-1} more fecal N than

cows fed hays. Greater leaching of cell solubles in silage compared to hay in the Brouk and Belyea's (1993) study might have caused a greater fiber content in silage.

Beauchemin et al. (1997) observed that alfalfa hay contained lower CP and soluble CP and higher NDF and ADIN contents than alfalfa silage of the same stage of growth, possibly due to exposure to 11 mm precipitation during the 6-day wilting period. Cubing had no effect on ADIN content in hay but increased ADIN content in silage, indicating that high temperature associated with cubing may cause some heat damage of forage CP in the silage. Effective in sacco CP degradabilities were 69 and 87% for hay and silage, respectively. Inclusion of hay or silage up to 45% of dietary DM in TMRs of lactating dairy cows fed ad libitum intake resulted in no differences in milk yield and ADG between the two conservation methods. However, protein content of milk was higher for cows fed the hay diets than for cows fed the silage diets, and butterfat content was similar for both groups. Dry matter intake was greater for hay-based than silage-based diets (Beauchemin et al. 1997). Cows fed silage diets had fewer chews d^{-1} compared to those fed hay diets. The hay-TMR diets had lower energy for lactation as compared to the silage-TMRS, possibly forcing the cows to consume more DM from the hay-TMR diets than the silage-TMRs in order to produce a similar quantities of milk for both diets. The higher protein content in milk of cows fed TMR containing hay might suggest that rumen escape protein was higher in hay compared to that in silage.

Nelson and Satter (1992) fed cows diets containing either alfalfa hay or silage (60 : 40, forage to concentrate ratio, DM basis). Cows fed the hay-based diet consumed 2.25 kg more daily DM than cows fed silage-based diets. Rumen retention time was 6.3 h longer for

cows fed alfalfa hay than for those fed alfalfa silage. Masticated and rumen samples from cows fed hay showed a greater percentage of DM as particles greater than 9.5 mm in length than those from cows fed silage diet. In situ DM disappearance rates were 15% and 9.5% h^{-1}, respectively, for silage and hay. Zero hour disappearance of DM from dacron bags was greater for silage than hay. Gross feed efficiency was found greater for silage than hay diets. Wattiaux et al. (1991) observed that alfalfa hay had a higher digestible DM pool than alfalfa silage, 39 vs 34%, respectively, and a higher digestible NDF pool, 52 vs 44%, respectively. Digestion rates of DM and NDF were similar between hay and silage.

These results suggest that the quality of conserved forages is not only affected by conservation methods but also by external factors during harvest, storage and feeding.

Chopped vs. long fiber silage

De Boever et al. (1993) fed maize silage harvested at milk to hard dough dent stages, chopped at 4, 8, and 16 mm theoretical length, on an ad-libitum basis, supplemented with 2 kg of SBM cow^{-1}. Eating, ruminating, and chewing increased, respectively, from 16.5 to 25.3, 34.0 to 50.2, and 50.8 to 75.5 min kg^{-1} of DMI with increased chopping length. The ruminating and chewing index decreased as maturity of maize crop increased. It has been shown by Deswysen and Ellis (1988) that the increase in time spent eating, ruminating, and masticating with longer chops was related to the decrease in fecal output of NDF, suggesting that longer eating, ruminating, and masticating can result in greater NDF digestibility probably through greater reduction in dietary particle size during those activities.

De Boever et al. (1993) observed that the chewing index decreased when grass was

chopped to 24 mm compared to unchopped silage. Direct cut, long fiber silage tended to contain higher fiber compared to wilted, chopped silage, maybe attributed to cell contents being lost or used up during fermentation in the former mentioned silages (De Boever et al. 1993). By contrast, Brouk and Belyea (1993) observed that coarse chopping had no effect on chewing activity. Digestibilities of DM, N, and fiber were not affected by chopping or rewetting of hay (Brouk and Belyea, 1993).

Mooney and Allen (1997) fed dairy cows TMRs containing either long-chop, 9.5 mm, or short-chop, 4.8 mm theoretical length, cut at late bud to early flowering alfalfa silage and fed with or without whole linted cottonseed (WLC). The forage to concentrate ratio was 55 : 45 and 41 : 59 without and with WLC, respectively. Length of cut did not affect milk yield and composition or cow's ADG. Long cut alfalfa silage resulted in lower DMI and NDFI . Long chop alfalfa was consumed more slowly, required more eating time and greater number of chews $unit^{-1}$ of DMI, and increased daily rumination time $unit^{-1}$ DMI.

Fischer et al. (1994) fed multiparous and primiparous dairy cows with corn silage-based (21.5 % in the diet, DM basis) TMR containing either long (9.5 mm) or short (4.6 cm) cut alfalfa silage (46% in diet, DM basis), with or without the addition of 3 kg of long alfalfa-grass hay. Shorter alfalfa silage enhanced DMI but lowered 4% fat corrected milk for multiparous cows, and depressed fat test for multiparous and primiparous cows. Addition of hay enhanced rumination time for the short cut silage TMR, but tended to reduce rumination for the long-silage TMR. Addition of hay resulted in a greater DMI and lower ruminal pH without affecting milk yield. Length of chop did not affect ruminal VFA concentrations.

Prigge et al. (1993) found that when fistulated steers were fed 100% orchardgrass or

switchgrass in the form of long (intact form of small rectangular bales) or short (ground to pass a 2-cm screen) fiber hay resulted in a higher DMI for orchardgrass than for switchgrass (11.7 vs 10.4 kg d^{-1}, respectively).

In general, based on these studies, the temporary conclusion is that a shorter chop of silage length can result in higher DMI and similar or lower milk yield and milk fat test.

Chopping of hay

The purpose of chopping hay is to ease management of feeding systems, to lower feed-out waste, and to decrease labour inputs (Belyea et al. 1985). These authors suggested that physical form of forage may affect forage utilization and animal performance. O'Dell et al. (1968) observed that cows consumed less DM of ground, pelleted alfalfa and produced less milk relative to those fed long or ground but not pelleted alfalfa.

Belyea et al. (1985) compared digestibility and energy utilization in dairy heifers fed alfalfa hay at maintenance or ad libitum level, either chopped in a hammer mill (2.54-cm diameter opening) or as long hay. Ad libitum intake resulted in lower DM, 56 vs 58%, NDF, 45 vs 58, and ADF, 45 vs 52%, digestibilities as compared to maintenance intake. No effect of chopping on DMI, 5.4 vs 5.5 kg d^{-1}, respectively, was observed. Digestibilities of DM, NDF, ADF, and cellulose were 7 to 10 percentage units lower when heifers were fed the chopped alfalfa hay relative to those fed long alfalfa hay. Intake of ME was approximately 2 Mcal d^{-1} less for heifers fed chopped hay. Heat production was similar between the two physical forms of hay, resulting in a lower energy balance for heifers receiving the chopped hay. The researchers speculated that lower digestibility for the chopped hay compared to the

long hay was probably associated with a faster passage rate for the chopped hay.

Rogers et al. (1985) fed lactating dairy cows a TMR containing 54% of either long, or chopped, 1.3 cm, alfalfa hay at ad libitum levels. The hays were fed separately from the concentrate portion. Sodium bicarbonate was either not added or added at 3.0% of the dietary concentrate portion to manipulate rumen pH. Feed intake, milk yield and composition, rumen pH and molar percentages of rumen VFA were similar among the four dietary treatments. Digestion of nutrients was lower for diets containing the chopped alfalfa hay compared to those containing long hay, which was not related to passage rate as chopping did not affect passage rate of dietary digesta from the rumen. Sodium bicarbonate increased water intake and tended to improve nutrient digestion.

Rearte et al. (1985) supplemented grazing dairy cows on grass and clover pasture with either concentrate at 1 kg per 3 kg of 4% fat corrected milk (FCM), concentrate at 1 kg per 2.7 kg of 4% FCM plus 10% chopped hay, or concentrate at 1 kg per 3 kg of 4% FCM plus 1 kg long hay cow^{-1} daily. The concentrate allowance was reduced by 0.36 kg d^{-1} to adjust for lower milk production during period 2, which again was reduced by similar amount during period 3. Cows on the chopped hay treatment ate 1.1 kg more concentrate than those fed the other diets. Chopping of hay had no effect on milk production, milk fat, milk protein percentages, ruminal pH, and molar percentages of VFA. Body weight change ranged from -0.10 (long hay) to 0.10 kg (chopped hay) cow^{-1} d^{-1}, but was similar among dietary treatments. No digestibility or passage rate data are available for this study. These studies suggest that chopping of hay does not always result in a higher DMI. Lower digestibility due to chopping of hay can be related to faster passage rate.

Grinding

Grinding is the process of reducing particle size of forage by grinding through a mill with screen sizes ranging from 1.0 to 20 mm diameter. The forages are generally partly dried prior to grinding. Grinding makes the forage becomes easier to handle, and is expected to enhance diet or forage DMI and digestibility. However, grinding may also result in less chewing and mastication. This may result in lower salivation and lower rumen buffering capacity. Grinding can enhance rumen passage rate with the result of shortening fermentation time and lowering digestibility, as compared to those in forage without grinding. The ground forage can further be processed through pressing as cubes or pellets, in which form the processed forage can be sold worldwide.

Bowman and Firkins (1996) found that species of forage and grinding affect particle size reduction in the rumen. They used gammagrass (GG), orchardgrass (OG), and red clover (RC), either ground through a 5-mm (L) or 2-mm mesh (S) and incubated for 3, 6, 12, 24, 36, 48, and 72 h in the rumen. Initially, GG had 10.2% greater proportion of DM as particles greater than 300 μm than did OG and RC. Long forages had 7.5% greater proportion of DM as 300μm or larger particles than S forages. Mean particle size decreased with increased time of incubation. Long forages exhibited a greater ($P < .10$) reduction in mean particle size (527μm in 60 h) than did S forages (372 μm in 60 h).

Prigge et al. (1993) examined the effect of forage species (orchardgrass, OG vs switchgrass, SG, hays) and particle size (long vs ground, 2-cm screen) on the rate of passage of digesta from the reticulo-rumen of steers. Particle size of ruminal digesta and feces determined by wet sieving was greater ($P <.05$) for OG and long hay diets than for SG and

ground hay diets. Particle sizes of digesta collected from the anterior dorsal and anterior ventral sac of the rumen and from the reticulum were similar. Ruminal concentrations of 1 mm nylon particles tended ($P < .11$) to be greater in the lower strata of the reticulo-rumen at 12 and 24 h after dosing. Passage rate of the 1 mm nylon particles from the reticulo-rumen was greater for animals fed the OG diets, whereas for the 5 mm nylon particle, the reverse was true. Particle size of the diets did not affect passage rate of digesta, although it affected particle size of the ruminal and fecal samples.

Bourquin et al. (1994) fed steers mixed diets comprised of OG hay high (HF, 92% dietary DM) or low (LF, 60% dietary) forage portion, as either ground (G) or long (L) forms. Diurnal pH variation was greater in steers fed G compared to those fed L forms.

Lintzenich et al. (1995) fed fistulated Angus X Hereford steers in an enclosed barn with an average temperature of 14 ^{o}C to evaluate the effect of three methods of forage processing. Forage processing included pelleting of alfalfa without dehydration; pelleting of ground, 9.5 mm screen, dehydrated alfalfa; and long alfalfa hay. The processed forages were fed as supplements, at a rate of 0.5% BW to supplement blue-stem range forage based diets. Supplementation with dehydrated pellet tended to increase bluestem OM intake, dietary OM intake, and ruminal OM fill. This study concluded that intake of low quality forages (2.8% CP) increased with high quality, 20-21% CP, forage supplementation, and that processing of high-quality forage in general had little impact on forage utilization by the animal, findings similar to those of Hannah et al. (1991).

Del Cutro et al. (1990) fed three kinds of supplements, soybean meal and grain sorghum, long-stem alfalfa hay, and dehydrated alfalfa pellets to canulated steers grazing

dormant native range. Supplement feeding was designed to attain a similar daily CP and ME intakes. Digestibility of NDF was lower, 45.8%, for steers fed dehydrated alfalfa pellets than for those fed long-stem alfalfa hay, 52.6%. Rumen indigestible ADF fill and rumen DM fill (5.31 and 6.76 kg, respectively) at 0 h and 5 h post-supplement feeding was greatest for steers fed dehydrated alfalfa pellets than those fed SBM/SG or control diet. Cows on similar pasture fed the dehy-alfalfa pellet supplement resulted in a greater initial 84-d cumulative BW (18.7 kg) than those supplemented with concentrate or alfalfa-hay (2.1 and -3.4 kg, respectively). The benefit of dehy-alfalfa pellets diminished over a 265 day feeding trial (Del Cutro et al. 1990). Whether rumen metabolites (especially acetate to propionate ratio) affect forage DMI, is still open to question based on these studies. This study confirmed the results of other two studies mentioned above that supplementation of low-quality, low CP forage with high-quality forage enhanced forage DMI, and that processing high-quality forage by grinding had little effect on animal performance.

Rewetting or reconstitution of hay

The purpose of rewetting or reconstitution of hay prior to feeding is to increase the specific gravity of hay by absorption of water between the air pockets of the plant tissues (Stetter Neel et al. 1995). Rewetting of hay may also influence post-masticated or post-ruminated forage particle size, based on a report by Brouk and Belyea (1993). They observed that alfalfa silage with lower DM content resulted in a greater chewing activity and greater digesta particle size as compared to hay of the same species and maturity. Therefore, it is hypothesized that by rewetting hay, digesta particle size of the hay will be coarser than the

unwetted hay, with the result of decreasing degradation and passage rates. Greater specific gravity of particles in the rumen has been suggested by several researchers to increase ruminal passage rate of the digesta (Kaske and Engelhardt, 1990). It implies, therefore, that rewetting of hay on one hand, may delay outflow from the rumen due to coarser particle size, and on the other hand, may cause an increase in rumen passage rate due to a higher specific gravity relative to unwetted hay.

Stetter Neel et al. (1995) reconstituted ground (3 cm screen) alfalfa and timothy hay to achieve a targeted 35% DM content and fed them to beef steers. They observed a tendency toward a decreasing proportion of digesta with specific gravity of 1.1 to 1.2 and a tendency toward an increasing proportion of digesta with a specific gravity of more than 1.2, as compared to digesta for hay not exposed to reconstitution. Dry matter intake was held constant between treatments. Apparent DM digestibility was not affected by reconstitution, a finding similar to that of Brouk and Belyea (1993) for reconstituted or not reconstituted alfalfa hay fed to dry dairy cows. Apparent NDF and ADF digestibilities were greater for reconstituted alfalfa hay, but were not affected by reconstitution in the case of timothy. Reconstitution decreased ruminal passage rate for timothy hay, but no influence of reconstitution on passage rate was observed for alfalfa hay. The ruminal DM pool (rumen fill) tended to increase as a result of reconstitution. Stetter Neel et al. (1995) also showed that inert particles with a specific gravity of 1.32 units passed from the rumen at a faster rate with reconstituted alfalfa hay than with dry alfalfa hay but at a slower rate for reconstituted timothy than for the dry timothy hay. Differences in cell wall characteristics between legumes (lower concentration but more lignified) and grasses (higher concentration with a greater

potentially digestible fraction) may contribute to this phenomenon.

The results of these studies suggest that passage rate may increase with reconstitution of hay, but digestibility of DM may or may not be affected by reconstitution, depending on the characteristics of the cell walls of the forage in question.

Heating of hay

Heat treatment has been reported to have a positive impact on digestibility, especially for post-ruminal digestion of crude protein (Yang et al. 1993; Broderick et al. 1993). When alfalfa hay was heated at 100 to 110 °C for 47 min, net ruminal escape CP, estimated in-vitro, was 50% compared to only 29% for untreated hay (Broderick et al. 1993). Yang et al. (1993) observed that net escape CP of shredded and unshredded hay was increased from 21.0 and 25.4% (for unheated-unshredded and unheated-shredded, respectively) to 43 - 45 % for unshredded and 54 - 55% for shredded when both forages were heated for 0.5 h, 1 h, and 2 h, respectively.

Heating resulted in an increased ADIN content from 4.6% (unheated) to 15.3% TN (Broderick, 1993) and from 5.5 to 17.4 % (Yang et al. 1993), and NDF was increased from 43 to 53% DM (Broderick et al. 1993). Yang et al. (1993) also found that wet-heating with steam resulted in a greater increase in ADIN and NDF contents relative to dry-heating in oven (16.8 vs 10.8%, and 50.4 vs 54.8% respectively), and wet-heating of hay was more detrimental to shredded forage in term of increasing ADIN con tent.

Lactating dairy cows fed a mixed-diet containing 81% of either unheated or heated hay (with 18% corn and 0.7% urea) showed no differences in DMI , milk fat content, and fat

yield (Broderick et al. 1993). Apparent DM digestibility was lower (53.8 vs 61.2%) and NDF digestibility was higher (51.6 vs 44.2%) for cows fed diet containing heated compared to unheated alfalfa hay. Digestibility of DM, ruminal pH, ruminal ammonia and branched-chain VFA were lower for cows fed a diet with heated than unheated hay (Broderick et al. 1993). The diets that contained heated hay had lower DM digestibility (60.6 vs 62.2 to 62.7%, $P < 0.05$) and ADF digestibility (39.5 vs 43.0 to 44.9%) compared to the other diets (Broderick et al. 1993). In vitro degradation rate of the diet was consistently decreased by heating from 0.193 h^{-1} (unheated) up to 0.031 h^{-1} (heated at 160 ^{o} C) (Yang et al. 1993).

Maceration of forages during harvest

Hong et al. (1988) fed macerated hay to sheep and lactating goats. Maceration increased DMI, NDFD and ADFD (1.22 vs 1.15 kg d^{-1}, 48.5 vs 43.0%, and 50.2 vs 46.0% for shredded and unshredded, respectively). Fat corrected milk yield and CP content of milk were increased in goats fed the macerated alfalfa hay (3.7 vs 3.3 kg d^{-1}, and 3.0 vs 2.93% for shredded and unshredded, respectively). Rumen retention time, hindgut retention time and total retention time of DM were not affected by maceration. Petit et al. (1994) reported that maceration increased DM intake and DM, ADF, NDF, GE, and N digestibility of alfalfa hay fed to sheep. Also, maceration increased the potentially degradable fraction of DM and ADF of timothy and alfalfa hays. However, maceration of timothy decreased total tract DM, OM, ADF, NDF, and CP digestibility in beef steers (Chiquette et al. 1994). Rumen disappearance studies have shown that macerated timothy contained a greater portion of rapidly degradable DM (12.5 vs 10.9%) and a lower portion of potentially but slowly degradable DM (61.6 vs

77.9%). Rate of DM disappearance was higher for the macerated (.034 h^{-1}) compared to unmacerated forage (.020 h^{-1}) (Chiquette et al. (1994). Hong (1988) found no effect of maceration on alfalfa as hay in terms of rumen rate of passage of the forage. Charmley et al. (1997) found no effect of alfalfa maceration on silage DMI (31.3 vs 33.6 g kg^{-1} when control and macerated forage were compared) or on forage DM, OM, N, and GE digestibility when 3-mo stored silage was fed to sheep. Variability in the effects of maceration on DMI and nutrient digestibility among those studies could have been related to differences in the severity of maceration, preservation methods and species of forages and animals being fed. There are few reports in the literature describing the effects of hay maceration on the performance of beef or dairy cattle.

Chemical treatments of forages

Chemicals, such as sodium hydroxide, ammonia, and potassium carbonate have been studied as a forage additives to improve forage feeding quality. Sodium and potassium hydroxide and ammonia have also been used for high fiber forages such as barley straw to increase fiber digestibility. Potassium carbonate is used to enhance forage wilting rate. Rode et al. (1997) reported benefits when ammonia was used to treat barley straw fed to Holstein steers. Diets containing ammonia-treated straw were more digestible than diets containing untreated straw which resulted in higher DMI and ADG. Fondevilla et al. (1993) treated barley straw with anhydrous ammonia at a rate of 30 g kg^{-1} straw DM in a covered stack and allowed for 28 days before sampling and feeding to sheep. No effect of treatment on ruminal pH and VFA was detected, except for a higher butyric acid for sheep fed the

treated straw. However, treated straw fed as the sole diet resulted in a greater DMI (692 g d^{-1}, compared to untreated, chopped straw, 507 g d^{-1}). An in situ trial suggested that the treated straw resulted in greater DM disappearance rates. These results might be expected, because alkali (sodium hydroxide) treatments have been shown to convert lignin into more degradable fractions (Akin and Hartley, 1992; Jung et al. 1992).

TECHNIQUES USED TO MEASURE THE EFFECT OF PROCESSING ON TRAITS THAT AFFECT FORAGE UTILIZATION BY THE ANIMAL

Formulating rations to achieve optimum feed utilization cannot rely on feedstuffs nutrient density only, because the chemical form of the nutrient affects availability. Chemical conversion of a specific nutrient, for instance protein, may be required to optimize rumen microbial utilization and post ruminal digestion and absorption of amino acids (Nocek 1988, Michalet-Doreau and Ould-Bah, 1992).

Attempts have been made to determine the percentage of specific nutrients, such as CP, that are readily or unreadily digestible in the rumen in a variety of feedstuffs. For this purpose, the in situ or in sacco nylon bag technique has been developed (Nocek, 1988, Wilkerson et al. 1995, Vanzant et al. 1998). A known weight of ground feedstuffs is placed into nylon bags that are inserted into the rumen of canulated ruminants, generally cattle. Bags are incubated in the rumen for different time intervals usually from 0 to 48 h or longer. By measuring the amount of a specific nutrient before and after incubation at each incubation time, the percent disappearance of that nutrient for a given time interval can be determined.

The in situ technique allows intimate contact of the test feed with the ruminal environment (Nocek et al. 1988), is one means of obtaining input for diet evaluation models (Vanzant et al. 1998), and is a relatively inexpensive and a quick means to quantify ruminally degraded protein, fiber and/or fats in feedstuffs (Wilkerson et al. 1995). The in situ technique that has been used for the last 20 years (Vanzant et al. 1998) has received extensive evaluation (Nocek, 1988).

The bags and contents used in in situ studies generally are unfermentable, and are not exposed to mastication or rumination. Microbial fermentation of a test feed is the only means by which particle reduction occurs (Nocek, 1988). In general, longer and coarser materials are associated with slower rates of digestion and greater variations of disappearance results among sample bags. However, finely ground materials are subject to greater mechanical loss from the bags, resulting sometimes in unrealistically rapid rates of digestion but variation is less compared to those of longer and coarser material (Nocek, 1988). Grinding of forages increases surface area per unit weight of sample for microbial attachment, and resulted in increased digestion rate and decreased variability of results between bags (Nocek, 1988, Vanzant et al. 1998).

After reviewing the results of various studies, Nocek (1988) and Vanzant et al. (1998) concluded that for hay and silage, recommended particle size to be incubated is 5 mm, recommended sample to bag surface ratio is 10-20 mg cm^{-2}, and recommended bag porosity is 40-60 μm. Diet of the animals used should meet the energy requirement, with dietary forage inclusion of 60-70% DM (Vanzant et al. 1998), and should contain the feedstuffs being tested (Nocek 1988). Nocek (1988) suggested that bags be soaked in water or buffer prior

to ruminal incubation, and be inserted in sequence and removed all at once.

Digestion and rate of passage trials

Ruminal cell wall digestibility is determined by the indigestible fiber fraction, rate of digestion of the potentially digestible fiber fraction and by the residence time of feed particles in the rumen (Jung and Allen, 1995). The longer particulate matter stays in the rumen or the slower the passage of that matter from the rumen, the higher the probability that particulate matter will be more completely digested.

Rate of passage is an important determinant of the space occupying characteristics, therefore, it is worthwhile to examine limitations of the passage rate from the rumen through particle size reduction. Plant factors that affect rate of passage include those that affect particle size reduction through chewing (lignin and NDF contents) and those that affect particle size buoyancy in the rumen. Particle size buoyancy in the rumen is affected by the ability of particulate matter to produce and retain gas, which is related to plant anatomy and rate of digestion of the plant tissue (Jung and Allen, 1995).

It has been established that reduction of feed particles after mastication and rumination takes place primarily in the rumen, with little reduction in particle size taking place post ruminally (Deswysen and Pond 1989; Jung and Allen, 1995). Poppi et al. (1981) and Uden and Van Soest (1982) found that particulate size in feces is smaller than that in feed being consumed. Lechner-Doll et al. (1991) observed that passage rate of feed from the rumen increases exponentially with the decrease in particle size due to chewing. Dietary particle size did not affect passage rate of digesta from the reticulo-rumen. Particle size of the ruminal

digesta and feces determined by wet sieving was greater for orchardgrass than switchgrass hay and was greater for long as compared to short hay, which suggested that lignin content in switchgrass was probably higher as compared to orchardgrass, and that chewing of finer dietary particle size probably resulted in more severe reduction in particle size of the ingested diet. Although both species of forage were sieved through an identical screen size, 2-cm, the particle size of the orchardgrass hay was bigger, 2.73 cm, than switchgrass, 2.14 cm.

EXPERIMENTAL OBJECTIVES

To our knowledge, there is no published information regarding field scale forage maceration on the prairie regions of North America, typified by drier climatic conditions during forage growth and harvest. Information regarding the optimum degree of forage maceration is also limited. Several studies on the effects of forage maceration on DMI, dietary nutrient digestibilities and animal performance responses have shown inconsistent results.

Therefore, the overall objective of these studies was to determine the effect of field scale maceration under North American prairie conditions, under both good and unfavorable weather conditions; on the nutrient characteristics of the resulting alfalfa forage; and beef and dairy cattle performance. A comparison of the current results to previous studies will be used to identify beneficial and detrimental factors that may emerge due to maceration, and which may have accounted for variation in results reported in the literature to date.

The specific objectives were to determine if field scale maceration of forage has a positive impact on post-wilting and post-storage nutrient profiles of alfalfa forage preserved

either as silage or hay when compared to conserved alfalfa forage harvested by a conventional roller-conditioner. Feeding these conserved forages to beef or dairy cattle would further reveal if forage maceration could improve animal performance. Recommendations to producers can also be proposed based on the results of this study.

MANUSCRIPT I

COMPARATIVE CHARACTERISTICS DURING WILTING FOR ALFALFA HARVESTED BY MACERATION VS. A CONVENTIONAL ROLLER-CONDITIONER

ABSTRACT

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 harvest. Early bloom alfalfa was harvested with either a roller-conditioner (CONV) or a macerator set to deliver four degrees of maceration during forage harvest: LIGHT, LIGHT+, SEVERE, and SEVERE+, respectively. Macerated forage reached 80% dry matter in 9 - 11 h compared to forage harvested by roller-conditioner which required 54 h. The most rapid wilting rates were associated with LIGHT+, SEVERE, and SEVERE+ maceration treatments when forage was not exposed to precipitation. The wilting coefficient in the first 24 h was increased by more than 100% for SEVERE treatment compared to forage harvested using conventional roller-conditioner in alfalfa forage that was not exposed to precipitation. Precipitation at 1.5 h post-cutting increased wilting time by up to 8.3 h to achieve 45% DM, and by 17.5 h to achieve 80% DM in the SEVERE+ maceration treatment relative to forage from the same harvest treatment that was not exposed to precipitation. Precipitation at 24 h post-cutting increased wilting time to reach 80% DM by 11 h for LIGHT maceration to 21 h for LIGHT+ maceration, relative to forage of the same harvest treatments not exposed to precipitation. Maceration of forage resulted in a 24.2 to 26.8 h shorter wilting time relative to the conventional roller-conditioner treatment when forages were exposed to precipitation at 24 h post-cutting. The SEVERE and SEVERE+ maceration treatments of harvest resulted in higher ($P < 0.01$) NDF and tended ($P= 0.09$) to increase forage ADF levels post-wilting. Overall, the lactic acid bacteria population on forage tended to be higher ($P < 0.07$) with

maceration compared to conventionally conditioned forage. The wilting study implied that LIGHT+ maceration would be recommended since no further enhancement in wilting rate was achieved when targeting either 45% or 80% DM when the intensity of macerations was increased.

Keywords: Alfalfa, maceration, precipitation, wilting time, bacteria, nutrient profile, compressibility.

INTRODUCTION

Conventional methods of forage harvest with cutting equipment utilising rollers or crimpers and leaving the forage in wide swaths on the field requires three to four days of drying to reach an 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 have been made by conditioning the forage during mowing or harvest. Rotz and Sprott (1984) found that field wilting time was decreased by 34% when alfalfa was conditioned using a flail conditioner relative to unconditioned or lightly brushed forage. Klinner (1975) found a 40 to 60% increase in wilting rate using a high friction brush conditioner in low yielding grass. However, the wilting rate was increased only by 20% when the conditioner was applied to heavy yielding grass.

In the last decade, longitudinal splitting and crushing of the plant stem by running cut plant material through a series of serrated steel rollers rotating at differential speeds (maceration) has been investigated as a means of reducing drying time required for alfalfa forage (Shinners et al. 1987). Shinners et al. (1987) found that alfalfa dried to 20% moisture in six hours or less using a field mower macerator prototype. Very severe maceration has increased drying rate by over 100% under field conditions (Savoie et al. 1993). It has been suggested by Savoie et al. (1994) that severe compared to moderate maceration may result in a marginal increase in wilting rate but can increase DM loss due to leaf and fine material

shattering. Hong et al. (1988), for example, stated that shredding of alfalfa forage tended to increase NDF levels of hay relative to non-shredded hay of the forage.

Initial populations and population changes for epiphytic lactic acid bacteria (LAB) on wilting alfalfa forage has been documented (Lin et al. 1992; Muck 1989; Pitt and Muck 1995; Wittenberg 1995), however, only limited information is available regarding the effect of maceration on forage LAB populations (Charmley et al. 1997). The enumeration of bacteria populations, especially LAB in forage is important to the fermentation process of forage when ensiled and may have relevance for storage of hay. More information about the nutritional and microbial characteristics of macerated forage during and post-wilting is required to predict quality changes of the resulting silage or hay.

Although maceration can increase drying rate, concern has been raised about leaching of plant cell solubles if cut forage 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 to 0.3% DM mm^{-1} precipitation for macerated and pressed alfalfa forage, respectively. With an increase in fibre content after rainfall due to leaching (Rotz et al. 1991). Savoie et al. (1993) used simulated rainfall at a rate of 18 mm h^{-1}, applied six times at 3 mm 10 min^{-1}, beginning at 6 and 24 h post-cutting, respectively, on alfalfa forage harvested 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. They also found that ADF levels were considerably higher after rainfall and wilting relative to the fresh crop values for both harvest

treatments.

Forage maceration will alter physical properties of the harvested forage, which influence field wilting and may improve packing if ensiled (Shinners et al. 1988; Savoie et al. 1994) or bale density in hay production. Savoie et al. (1994) has attempted to quantitatively describe the degree of maceration by measuring bulk density of forage immediately after cutting. Savoie et al. (1994) theorized that when fresh forage is mowed, it is typically fluffy and well aerated. Physical conditioning by crushing or maceration can make the forage crumple and become more dense, which may hinder aeration during field wilting. This can, however, be an advantage. Under its own weight or pressure ensiled, macerated forage becomes more dense (Savoie et al. 1994).

A field trial was conducted to monitor the effect of five degrees of maceration at the time of harvest on field wilting of alfalfa, drying rate, nutrient profile and lactic acid population. Compressibility (consolidation) was measured to compare forage treatments with results of other maceration trials. Harvested forage was subjected to three types of precipitation exposure during drying to determine the effect of rain on field drying characteristics and final nutrient profiles of alfalfa.

MATERIALS AND METHODS

A two ha field, at Glenlea Research Station, having a relatively 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 harvest treatments. The

five harvest treatments included a New Holland 116 haybine (CONV) and 4 degrees of maceration using a pull type macerator prototype built by the Prairie Agricultural Machinery Institute in Portage la Prairie, MB. The four degrees of maceration imposed included: LIGHT using a 1-cm roller spacing and 750/1000 rpm roller speed; LIGHT+ using a 0.75-cm roller spacing and 750/1000 rpm roller speed; SEVERE using a 0.75-cm roller spacing and 750/1500 rpm roller speed; and SEVERE+ for which rollers were set as close together as possible and 750/1500 rpm roller speed.

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

Windrows were sampled 3 times daily for the duration of the wilting trial (51 h) at 9:00-10:00, 12:00-13:00 and 16:00-17:00 h. At each sampling time, nine samples were collected from each windrow : three samples for dry matter (DM) and nutrient determination and two samples for lactic acid bacteria (LAB) and total bacteria (TB) counts from the section assigned to no precipitation; two samples from each of P and PP for DM and nutrient determinations. Windrow sampling stopped once forage DM reached 80%. Samples for LAB and TB counts were collected aseptically and submitted to the lab immediately for microbial assessment, and the other seven samples were placed into storage (-20 ^{o}C) for determination of DM, crude protein (CP), soluble nitrogen (SN), acid detergent insoluble nitrogen (ADIN), acid detergent fibre (ADF), neutral detergent fibre (NDF), soluble

carbohydrates, and glucosamine.

Dry matter was determined with a forced air oven (60 ^{o}C, 48 h). Crude protein and ADIN were assessed using a Kjeltec 1030 auto analyser (Tecator Inc, Herndon, Virginia) using AOAC (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, Alberta. 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 forage sample were incubated and agitated in a water bath at 40 ^{o}C for 60 minutes, followed with settling in a rack for 15 minutes, 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 Wittenberg et al. (1989), using a Pharmacia Biotech., Biochrom amino acid analyser (Cambridge, England).

To compare wilting rates among maceration treatments, wilting coefficients of forages were calculated using a model of Shinners et al. (1987):

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

MR = moisture ratio, Mh = moisture content of forage at time of sampling (g water g^{-1} DM), Mo = initial forage 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. Wilting coefficient was determined on a series of samples, 3 samples

at each time for swaths not exposed to precipitation, and 2 samples at each time for swaths exposed to precipitation treatments.

Lactic acid bacteria enumeration was conducted by placing 10 g of fresh alfalfa forage into a sterilized Stomacher disposable plastic bag, adding 90 ml sterile wash solution made up of 0.1 ml Tween 80 in 100 ml distilled water. The macher bag with contents was placed in a Stomacher blender (Stomacher 400 lab blender, Seward Medical, London, England) at normal speed for two minutes. One ml of the resulting solution was used for serial dilutions, done in duplicate for each forage sample. Plates were prepared by drop and spread plating technique, using 0.1 ml of the diluted solution petri plate^{-1}, followed by plate incubation at 30 ^{o}C for 48 h (Muck 1989), using Maltose Rogose Dextrose agar media (Holley and Millard 1988). Bacteria colonies were counted using an Accu-lite 133-8002 colony counter, Fisher Scientific, Edmonton, Alberta. Plates with 30 colonies or less or with more than 300 colonies were discarded. Total bacteria enumeration was conducted using nutrient agar (McFaddin 1985), with sample preparation similar to that for lactic acid bacteria enumeration. For statistical analysis, log10 of colony forming unit (CFU) counts was used.

Compression tests to compare bulk densities of forage at time of cutting 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 forage (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 forage and extent of forage compression after 60 seconds was measured. The volume occupied by the pressed forage was the total cylinder volume minus the cylinder volume above the piston. Bulk density of fresh forage (Pf, kg m^{-3}) was calculated by dividing the weight of fresh forage under 47 kg

pressure by the volume of pressed forage (Savoie et al. 1994).

Potential compressibility (Pfmax) of cut forage was calculated according to Savoie et al. (1994):

$$Pfmax = (1 + Md)\ Pd\ Pw / (Pw + Md\ Pd), \text{ where;}$$

Pfmax is the potential or maximum theoretical density of fresh forage which occurs when all air is evacuated (kg m^{-3}). Md is the moisture content of fresh forage (g water g^{-1} DM). Pd is the intrinsic density of forage 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 harvest treatment was generated, therefore, a t-test was used to compare wilting coefficients of forage. 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, 1986). A randomized complete block design using the general linear model procedure of the Statistical Analysis System (SAS, 1986) was used to compare pre-wilting nutrient profile and bulk density of forage exposed to varying degrees of maceration with no precipitation and the identical design but with repeated measures over time was used to compare bacterial population at 0, 3 and 24 h post-cutting. The harvest by block interaction was used as an error term to test the harvest treatment. A split block design, with 5 harvest methods and 3 precipitation treatments was used for the analysis of nutrient profile of post-wilted forage. The harvest by block interaction was used as an error term to test the harvest

treatment. A pair-wise mean test of comparison (SAS, 1986) was used if treatment differences ($P < 0.05$) were observed.

RESULTS AND DISCUSSION

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

The moisture content of forage samples taken immediately post-cutting ranged from 72.3 to 75.0%. Savoie et al. (1994) reported higher initial moisture, 82.2 - 83.0%, for an Eastern Canadian trial with late-bud stage alfalfa. In another trial, alfalfa harvested at mid-bloom to full-bloom stage contained 69.1% moisture immediately after mowing (Savoie and Beauregard, 1991). Alfalfa in our study was at the early-bloom stage, an intermediate stage of growth compared to those of Savoie et al. (1994) and Savoie and Beauregard (1991). Differences in the growth stage, management, and environmental conditions can contribute to differences in moisture content of forage at the time of harvest.

The CONV treatment, not exposed to precipitation, achieved 45% DM content, a level that is considered favourable for ensiling, at 6.5 h post-cutting (Figure 1). There was no difference in wilting time between the CONV and the LIGHT harvest treatment. The

LIGHT+, SEVERE and SEVERE+ harvest treatments had similar wilting times to achieve 45% DM and reached 45% DM in average of 61.4% faster ($P < 0.05$) than CONV harvested forage with no rain. On the basis of statistical results, maceration equivalent to that achieved by LIGHT+ or more severe significantly reduced wilting time to reach 45% DM under good wilting conditions.

To achieve 80% DM content, the minimum acceptable level for storage as hay, CONV treatment not exposed to precipitation required 53.7 h (Figure 2). Maceration reduced wilting time ($P < 0.05$) with the three most severe levels (LIGHT+, SEVERE, and SEVERE+) requiring 82.7, 78.9, and 83.3% less wilting time, respectively, relative to CONV under good wilting conditions. There were no improvements of decreasing wilting time for SEVERE or SEVERE+ relative to LIGHT+. The three most severe maceration levels were considered favourable to wilt alfalfa forage to 80% DM under good wilting conditions.

Slightly shorter wilting times, 5 to 6 h, to achieve 80% DM content were obtained by Oztekin and Ozcan (1997) when they macerated and pressed alfalfa of about 75% initial moisture content. Savoie and Beauregard (1991) under laboratory conditions found that macerated mat alfalfa forage 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 forage materials after maceration can extract a considerable amount of forage juice, while increasing surface area of forage, resulting in a greater evaporation rate relative to macerated but unpressed forage. Wilting rates in our trial were slightly lower than previously reported observations of Shinners et al. (1987), and Savoie and Beauregard (1991) where macerated, matted alfalfa forage dried 200-300% faster than that of conventionally harvested

alfalfa. Shinners et al. (1987) and Savoie and Beauregard (1991) in their studies pressed the forage and placed it on trays, conditions more conducive to rapid drying. Therefore, with good drying conditions the extra energy costs associated with SEVERE or SEVERE+ maceration may not be warranted in terms of improved wilting times.

The CONV harvested forage exposed to precipitation 1.5 h post-cutting required 10.6 h to achieve 45% DM content (Figure 1). LIGHT+ and SEVERE macerated forage exposed to precipitation 1.5 h post cutting had a 63.0 and 59.7% lower wilting time to achieve 45% DM content, respectively, relative to the CONV ($P < 0.05$). The CONV, LIGHT, and SEVERE+ treatments exposed to precipitation shortly after cutting had similar wilting times to achieve 45% DM. To achieve an 80% DM content, the CONV treatment exposed to precipitation 1.5 h post-cutting required 50.4 h (Figure 2). LIGHT, LIGHT+, SEVERE, and SEVERE+ maceration of forage 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. Under precipitation exposed at 1.5 h post-cutting, LIGHT+ and SEVERE showed the shortest wilting time (15 h) to achieve 80% DM than other harvest treatments (Figure 2). These results suggest that excessive maceration of forage at harvest can be detrimental to wilting rate if precipitation occurs shortly after cutting. One possibly reason could have been more rain water being absorbed within plant stems with the increase in maceration intensity. More lumpy plant materials that can hinder good air circulation within the micro environment surrounding plant materials is another reason for the lack of shortening wilting time when macerated forage with high intensity of maceration was exposed to precipitation.

The CONV harvested forage exposed to precipitation at 24 h post-cutting required

significantly more time (55.5 h to achieve 80% DM content) than macerated alfalfa (Figure 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-cutting. 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 (Figures 1 and 2). Precipitation exposure at 1.5 h post-cutting resulted in similar wilting times to reach 45% DM for the LIGHT, LIGHT+ and SEVERE harvest treatments, but increased wilting time by 8.3 h ($P < 0.05$) in forage subjected to the CONV and SEVERE+ harvest treatment. Alfalfa subjected to SEVERE harvest treatment behaved like other maceration treatments when not exposed to precipitation (Figure 1). Similarly, exposure to precipitation at 24 h post-cutting did not increase wilting time to reach 80% DM in CONV, but increased wilting time for LIGHT, LIGHT+, SEVERE, and SEVERE+ maceration treatments by approximately 11 to 21 h relative to forage not exposed to precipitation (Figure 2). It has been found by Savoie et al. (1993) that more severely macerated forage absorbed more water relative to less severely macerated forage, when they were rewetted with similar precipitation conditions.

Under field conditions in this current study, maceration of forage produced the best results for shortening wilting time under good weather conditions or when precipitation occurs shortly after cutting. Reduced field wilting time with maceration provides producers with more opportunity to time harvest with short term weather forecasts, reducing the threat of rain exposure during the latter stages of wilting.

The wilting coefficient during the initial phase of wilting (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 similar wilting coefficients to the CONV treatment. Using a wind tunnel, Savoie and Beauregard (1991) found that k of macerated alfalfa ranged from 0.154 to 0.567 h^{-1} in the initial 22 h post-cutting period. The similarity in wilting coefficients across the CONV, LIGHT, LIGHT+ and SEVERE treatments may be related to windrow characteristics.

In fact, bulk density ($P < 0.05$, Table 2) was intermediate for LIGHT to SEVERE treatments with a higher value for SEVERE+. Maceration of forage did increase the wilting coefficient from 3-24 h of wilting. Maceration resulted in more exposed cell surface area compared to CONV treatment. Shinners et al. (1987) suggested that greater surface area exposed to sunlight in macerated forage than conventionally conditioned forage would result in more solar energy unit $time^{-1}$ 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 forage moisture content was already low.

Wilting coefficients from 3 to 24 h post-cutting were higher ($P < 0.05$) for SEVERE than for CONV and SEVERE+ when alfalfa was exposed to precipitation at 1.5 h post cutting (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 condition compared to 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 during the same phase of wilting period. When alfalfa was exposed to precipitation at 24 h after cutting (PP), 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 to be 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 forage of the same harvest treatment not exposed to precipitation (Figure 1 and 2, respectively).

The potential or theoretical maximum bulk density of freshly cut forage was similar among maceration levels (Table 2), which is within the 1056 to 1154 kg m^{-3} range for maximum density reported by Savoie et al. (1994). Wet basis bulk density increased ($P < 0.05$) with maceration, from 130.1 for the CONV treatment to 192.6 kg m^{-3} for the SEVERE+ treatment, indicating that degree of maceration did affect physical characteristics of the forage. The high bulk density values observed for the 2 most severe harvest treatments may create inefficiencies in harvest because the additional energy expenditures of harvest 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 early stages of ensiling.

Forage nutrient profiles at cutting were similar among harvest 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-cutting (data not shown). Lower levels of soluble carbohydrates in alfalfa were detected in block 2 for all maceration treatments, relative to conventionally harvested forage. These differences was not observed in block 1. Higher NDF levels for LIGHT+ and SEVERE maceration treatments of alfalfa forage also were detected in block 2, while other harvest methods (CONV, LIGHT and SEVERE+) showed no differences in NDF levels between block 1 and 2. Whether this variation is inherent to the field or resulting from harvest treatment can not be established in this study

After wilting, the alfalfa CP concentration was lower (20.1 g kg^{-1} DM) ($P < 0.05$) for SEVERE+ than for CONV (Table 3). LIGHT, LIGHT+, and SEVERE maceration of forage had a similar CP concentration relative to CONV. Post-wilting ADF levels were 37.2 and 42.2 g kg^{-1} DM or tended to be 13.6 and 15.4% higher ($P = 0.09$) for SEVERE and SEVERE+ macerated forage relative to LIGHT and LIGHT+ harvest treatments that did not show significant differences in forage ADF levels relative to CONV. Neutral detergent fiber levels for the SEVERE and SEVERE+ maceration treatments were 60.9 and 62.9 g kg^{-1} DM or 18.1 and 18.5% higher ($P < 0.01$) than the CONV treatment. No differences in forage NDF concentration was observed for CONV, LIGHT and LIGHT+ harvest treatments.

Hong et al. (1988a) speculated that more leaf shattering in the macerated forage than conventionally conditioned alfalfa occurred when baling alfalfa at 80% DM content. This may result in a lower CP content and a higher ADF and NDF concentrations for the macerated forage (Hong et al. 1988a). Petit et al. (1994) also found that when alfalfa forage was made into hay, the shredded forage tended to contain less CP and more fibre than conventionally harvested forage. In contrast, Chiquette et al. (1994) found no differences in CP, NDF and

ADF when timothy hay of nonmacerated and macerated forage 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 harvest treatments (Table 3). Post-wilting soluble carbohydrate content tended ($P = 0.08$) to be higher for forage harvested with macerator compared to forage harvested with conventional roller-conditioner, possibly due to reduced plant respiration during 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 these sugars to lactic acid. Based on post-wilting CP, NDF, ADF, and ADIN concentrations, LIGHT maceration was the most beneficial, because forage subjected to this harvest treatment had similar CP, NDF, and ADF concentrations but did not result in higher ADIN levels relative to CONV forage.

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 cutting, compared to alfalfa not exposed to precipitation during wilting. Soluble sugars decreased by approximately 5 percentage units when forage was exposed to precipitation at either 1.5 h or 24 h in the wilting period compared to forage not exposed to precipitation. Neutral detergent fiber content increased by 21.9 g kg^{-1} DM when alfalfa was exposed to precipitation 24 h post-cutting relative to alfalfa not exposed to precipitation, and by 13.3 g kg^{-1} DM when alfalfa was exposed to precipitation 24 h post-cutting 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 to alfalfa not exposed to precipitation.

Lactic acid bacteria increased as a result of maceration ($P = 0.05$, Table 4) at cutting from $10^{3.01}$ cfu g^{-1} DM in conventionally conditioned alfalfa (CONV) to $10^{4.09}$ cfu g^{-1} DM in SEVERE+ macerated alfalfa. The higher LAB count for the SEVERE+ macerated alfalfa than CONV might be due to increased sugars being released by maceration. Rooke (1990) observed that LAB counts on freshly cut alfalfa forage 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 the wilting temperatures between 20 and 25 ^{o}C within 2 hours after mowing. At three and 24 h post-cutting, the LAB count ranged from $10^{3.13}$ in CONV to $10^{5.06}$ cfu g^{-1} DM in SEVERE without significant differences among treatments.

Overall, forage maceration in the current study tended ($P = 0.07$) to increase LAB counts, and prolonged time after cutting from 0 to 24 h resulted in an increase ($P < 0.01$) LAB count. Muck (1989) using chopped alfalfa forage, 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 (Mir et al. 1995, Henderson and McDonald, 1984). It is important, therefore, to conduct further research related to the effect of forage maceration on LAB population and fermentation profile during

ensiling, followed with the evaluation of quality of the preserved forage and animal performance fed the ensiled forage.

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

CONCLUSIONS

Maceration of alfalfa resulted in a shorter wilting time relative to conventionally harvested alfalfa using a roller-conditioner. The advantage of maceration in this field scale trial was greatest in sunny, good weather conditions; LIGHT+, SEVERE, and SEVERE+ maceration treatment of alfalfa achieved 45% DM in 61,4, 54.5, and 57.4% less time, respectively, relative to conventionally harvested alfalfa, and achieved 80% DM in approximately 82.7, 78.9, and 83.3 % less time relative to conventionally harvested alfalfa.

Precipitation at 1.5 h post-cutting still resulted in approximately 63.0 and 59.7% less wilting time for LIGHT+ and SEVERE maceration, respectively, relative to CONV, to reach 45% DM. Precipitation at 1.5 h post-cutting resulted in 47.9, 65,4, 69.9, and 47.7% less time for LIGHT, LIGHT+, SEVERE, and SEVERE+, respectively, to achieve 80% DM relative to conventionally conditioned alfalfa. Precipitation at 24 h post-cutting resulted in 45.1 to 48.3% less wilting time in all maceration treatments of alfalfa to achieve 80% DM relative to CONV.

Maceration did not result in significant leaf or juice loss at the time of cutting, based

on the nutrient profile of alfalfa sampled at harvest. Post-wilting CP content of alfalfa subjected to the most severe maceration treatment was lower relative to conventionally conditioned and other levels of macerations, while NDF content was higher in the two most severe levels of maceration relative to those of other harvest treatments. There was no effect of harvest treatment on soluble N, ADF, and glucosamine concentrations of the post-wilted alfalfa. Precipitation decreased alfalfa soluble N and soluble carbohydrates and increased NDF level, and tended to increase ADIN level. Lactic acid bacteria population in alfalfa increased with maceration immediately after cutting. This, coupled with increased compressibility of macerated alfalfa may have positive benefits relative to conventionally harvested alfalfa stored as hay or silage.

ACKNOWLEDGEMENTS

The authors appreciate the assistance of Drs. G. H. Crow and L. Onischuk for their statistical suggestions. Appreciation is also forwarded to the technical and Glenlea Research Station staff for their laboratory and field assistance. This project was financially funded by the Federal Government Energy Research and Development Program. Use of macerator was provided by the Prairie Agriculture Machinery Institute (PAMI).

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

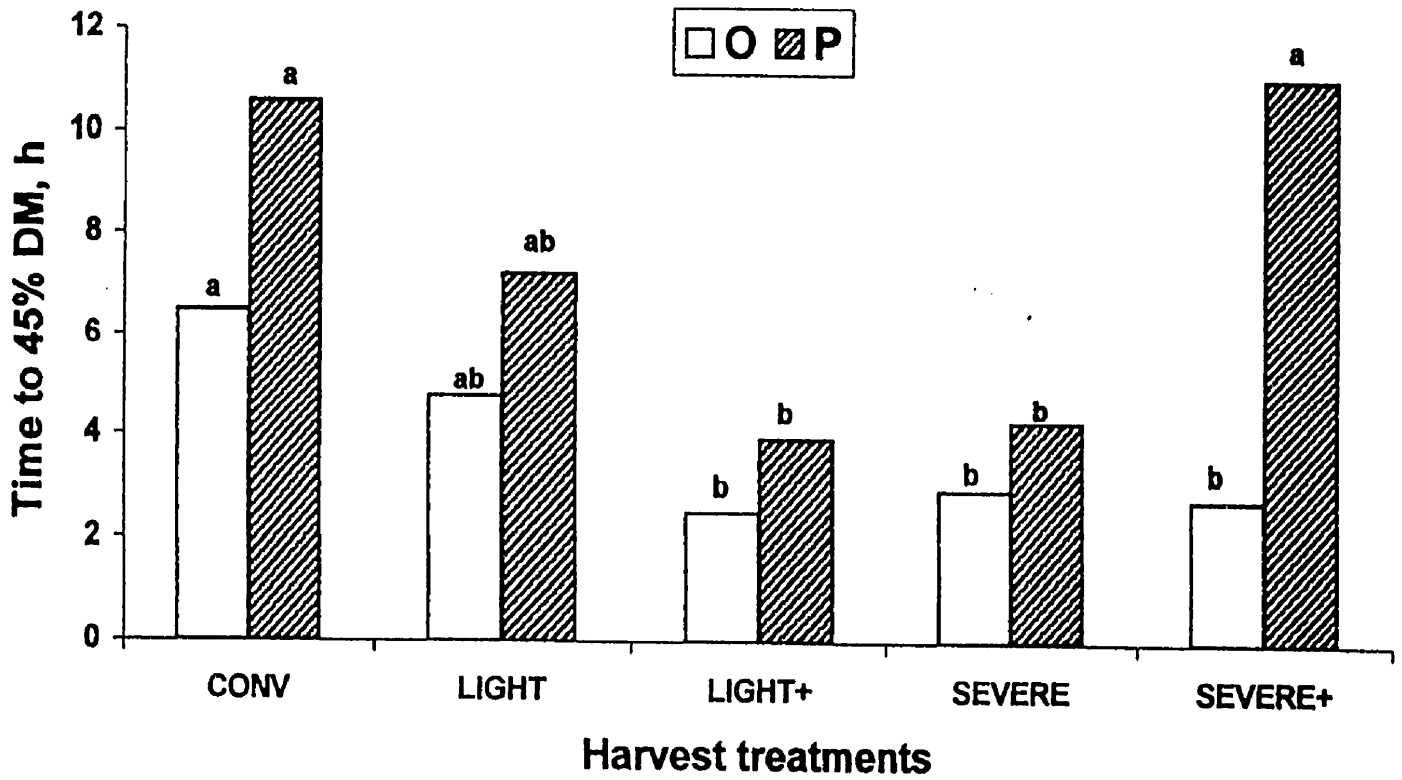

O P
Time to 45% DM, h
12
10
8
6
4
2
0
a
a
ab
ab
b
b
b
b
b
a
CONV
LIGHT
LIGHT+
SEVERE
SEVERE+
Harvest treatments

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

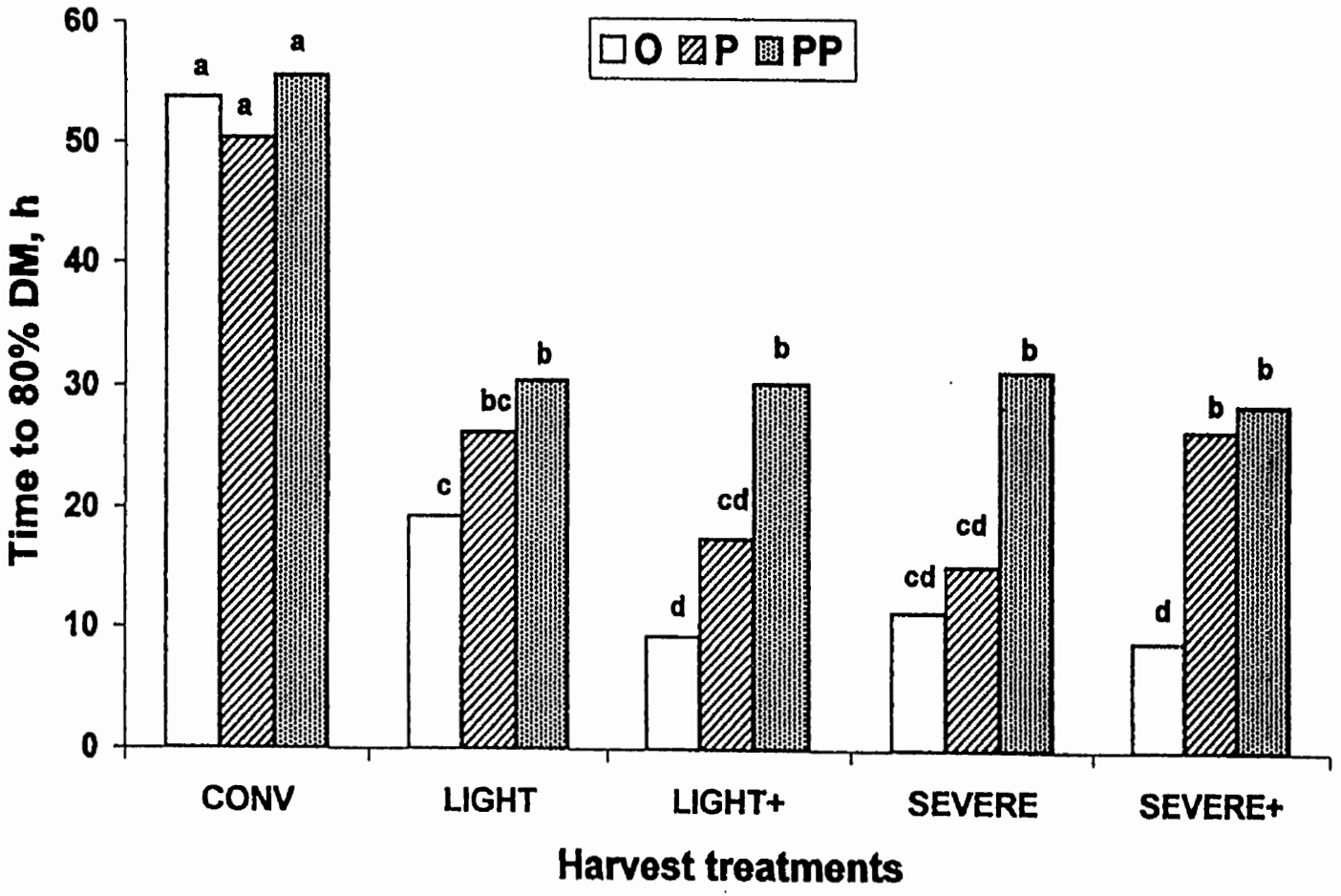

O P PP
Time to 80% DM, h
60
50
40
30
20
10
0
a
a
a
c
bc
b
d
cd
b
cd
cd
b
d
b
b
CONV
LIGHT
LIGHT+
SEVERE
SEVERE+
Harvest treatments

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

Hours post cutting	Harvest treatment[z]					
	CONV	LIGHT	LIGHT+	SEVERE	SEVERE+	SE
	---------- Without precipitation, n = 6 ----------					
0 - 3	0.166 b	0.171 b	0.236 ab	0.188 b	0.326 a	0.06
3 - 24	0.036 b	0.078 a	0.076 a	0.090 a	0.106 a	0.02
24 - 51	0.022 a	0.025 a	0.014 a	0.003 b	0.002 b	0.01
	--------- Precipitation at 1.5 h post-cutting, n = 2 ----------					
3 - 24	0.062 b	0.111ab	0.113 ab	0.123 a	0.078 b	0.02
24 - 51	0.033 ab	0.031 ab	0.027 ab	0.007 b	0.052 a	0.01
	---------- Precipitation at 24 h post-cutting, n = 2 ----------					
24 - 51	0.059	0.086	0.021	0.085	0.058	0.07

a, b Means within the same row with different letter are different, $P < 0.05$.

[z] Harvest treatments included cutting with a mower-conditioner (CONV), or a macerator set to deliver four degrees of maceration.

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

	Harvest treatment[Z]					
Bulk density	CONV	LIGHT	LIGHT+	SEVERE	SEVERE+	SE
Pfmax [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] Harvest treatments included cutting with a mower-conditioner (CONV), or a macerator set to deliver four degrees of maceration.

[Y] Pfmax: theoretical maximum bulk density.

[X] Pf: actual bulk density under 47 kg pressure.

a, b Means with different letters in the same row are different, $P < 0.05$.

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

	Harvest treatment[Z]						Precipitation type			
	CONV	LIGHT	LIGHT+	SEVERE	SEVERE+	SE	O	P	PP	SE
At cutting[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	200.8a	195.5ab	182.7ab	185.1ab	180.7b	3.5	190.0	189.2	183.6	2.0
Soluble N,g kg^{-1} TN	349.1	337.0	341.2	327.6	309.9	7.7	338.9 a	336.1 a	323.9 b	7.6
ADIN, g kg^{-1} TN	45.2	43.0	53.5	54.8	50.9	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 a	120.5 b	121.5 ab	2.2
ADF, g kg^{-1} DM	273.5	276.9	282.0	310.7	315.7	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 harvest.

[Y] n = 6, 4 and 4 for O, P and PP respectively.

a, b Means within the same row with different letters are different, $P < 0.05$.

Table 4. Lactic acid bacteria (LAB) and total bacteria (TB) counts, log10 cfu g^{-1} DM, during wilting for alfalfa harvested at 5 levels of maceration, n = 4.

	Harvest treatment[z]					Level of significance
	CONV	LIGHT+	SEVERE	SEVERE+	SE	Harvest
LAB 0h	3.01b	3.61ab	4.23 a	4.09 a	0.24	0.05
LAB 3h	3.13	4.24	4.35	4.24	0.23	ns
LAB 24h	3.51	4.59	5.06	4.51	0.28	ns
TB 0h	5.03	6.10	6.24	5.97	0.39	ns
TB 3h	5.87	5.90	6.45	6.46	0.33	ns
TB 24h	6.15	6.56	6.59	6.53	0.35	ns

[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 with different letters are different, $P < 0.05$.

MANUSCRIPT II

ALFALFA MACERATION: IMPACT ON STORAGE CHARACTERISTICS AND FEED VALUE WHEN FED TO BEEF CATTLE

ABSTRACT

A series of trials were conducted to investigate the effect of alfalfa maceration at time of harvest on silage and hay storage, and feeding characteristics. A 40 ha field of 1st cut, early bloom alfalfa was divided into 4 uniform blocks. Each block was harvested simultaneously, either with a roller-conditioner or with a macerator for both silage and hay trials. The silage trial was conducted using two cutting treatments: roller-conditioner (CONV) and a macerator with the roller spacing and roller rpm speed ratio set at 0.75 cm and 750/1500, respectively (SEVERE). Alfalfa was wilted to 45% DM, baled as large round bales and ensiled in a white polyethylene tube for 62 d. The hay trial was conducted using three harvest treatments: roller-conditioner (CONV) and maceration with the roller spacing and roller rpm speed ratio set at 0.75 cm and 750/1000 (LIGHT+) and at 0.75 cm and 750/1500 (SEVERE), respectively. Alfalfa was wilted to 80% DM, baled as large round bales and stored for 80 d. The silage and hay were fed to beef cattle in digestibility and growing trials. Alfalfa harvested by the macerator had a lower CP and higher ADIN ($P < 0.05\%$) at ensiling and post-ensiling. Alfalfa NDF, ADF and soluble carbohydrates at ensiling were similar across harvest treatments. However, soluble N was lower and NDIN and soluble carbohydrates were higher for macerated relative to roller-conditioned alfalfa post-ensiling ($P < 0.05$). Alfalfa baled as hay had lower CP levels for macerated relative to CONV. No differences in hay NDF, ADF, ADIN, soluble N and glucosamine levels were observed between the three harvest treatments at the time of baling despite a 2 day delay in wilting for CONV harvested alfalfa. Dry matter intake tended ($P = 0.08$) to be lower, and CP and DM digestibilities were 32.4 and 8.1% higher ($P < 0.05$) for steers fed macerated relative to roller-conditioned hay, respectively.

However, digestibility of hay NDF and ADF were 22.0 and 16.7 % lower ($P < 0.05$) for steers fed macerated relative to roller-conditioned hay. Maceration increased post-ensiling soluble carbohydrate levels and reduced ethanol and isobutyric acid concentrations for ensiled alfalfa and increased post-storage soluble carbohydrate levels with a tendency toward lower glucosamine concentration for hay. Beef calves fed SEVERE silage in a feeding trial consumed 13% more DM and achieved 22.7% greater ADG compared to those fed CONV silage or hay in the initial 21 d. The beneficial effect of alfalfa maceration on DMI and ADG was not apparent over the 78 d feeding period.

Keywords: alfalfa, roller-conditioner, maceration, silage, hay, storage, intake, digestibility, gain.

INTRODUCTION

Alfalfa harvested using superconditioning or maceration has been found to increase wilting rate by over 100% (Savoie et al. 1993, Savoie and Beauregard, 1991) relative to alfalfa harvested by a mower-conditioner. Rapid field wilting of the macerated forage is targeted to decrease field dry matter (DM) loss due to respiration, and to increase opportunities to bale the resulting hay within 24 h post-cutting.

One possible benefit of the more rapid wilting of alfalfa for silage making includes better silage fermentation by preserving water soluble carbohydrates (Charmley and Veira 1990 a,b). Faster wilting of the macerated alfalfa compared to conventionally conditioned alfalfa can also decrease weather risk during wilting. Forage maceration decreases the rigidity of forage stems, thus facilitates alfalfa compaction and increases bulk density (Savoie et al. 1993). Therefore, alfalfa maceration assures anaerobic conditions required for ideal silage fermentation. Bruising and laceration of stems and leaves with maceration can increase plant surface area which may result in a greater bacterial attachment and more release of soluble sugars, the major substrate for lactic acid forming bacteria (Charmley et al. 1997; Savoie et al. 1996).

Few field scale trials have been conducted to determine the effects of alfalfa maceration on post-storage nutrient profiles of hay and silage and on animal performance. Hong et al. (1988a) and Petit et al. (1994) observed that macerated alfalfa hay tended to contain lower CP and higher NDF and ADF levels than conventionally conditioned alfalfa hay. Savoie et al. (1996) found that maceration did not affect silage CP and acid content, but increased NDF and ADF content when an 85% orchard grass : 20% white clover, DM basis,

alfalfa was baled at 26% DM as large bale silage. Using precision chopped alfalfa silage, Charmley et al. (1997) observed that maceration decreased pH and increased LAB population in the first six days of ensiling, but not thereafter, during a 70 day ensiling trial.

Alfalfa hay when macerated and fed to lambs had a higher DM, gross energy, acid detergent fibre (ADF), neutral detergent fiber (NDF) and nitrogen (N) digestibility as compared to hay harvested by a mower-conditioner (Petit et al. 1994). In contrast, Chiquette et al. (1994) using timothy hay fed to steers found that maceration had no effect on DMI and CP digestibility, but decreased organic matter, NDF, and ADF digestibilities. Mertens and Hintz (1991), cited by Koegel et al. (1992), using alfalfa hay fed to sheep during a 2-week trial found that maceration of alfalfa increased DMI by 14.0% and body weight (BW) gain by 23.5%, respectively, but had no effect on feed conversion. None of these trials evaluated the effects of macerated alfalfa fed to cattle.

Therefore, the purpose of this study was to conduct field scale trials to establish the potential benefits of maceration when producing long fiber alfalfa silage in large bales, and to compare wilting, nutrient and storage characteristics of alfalfa harvested by a roller-conditioner and macerator for big bale hay production. The second objective was to compare the effect of physical conditioning of alfalfa at harvest on DMI, nutrient digestibility, and performance responses of growing beef cattle.

MATERIALS AND METHODS

Field condition and cutting treatments.

A 40-ha field of first cut alfalfa at the early bloom stage was divided into six sections. Two sections were randomly assigned to be harvested with a roller-conditioner (CONV) (New Holland model 489, New Holland, PA); the remaining four sections were assigned to be simultaneously harvested by a prototype macerator (Prairie Agricultural Machinery Institute, PAMI, MB) set at 0.75 cm roller space, 750/1000 rpm roller speeds ratio (LIGHT+) or at 0.75 cm roller space, 750/1500 rpm roller speeds ratio (SEVERE). All swaths were cut in an east - west swath direction. During wilting, grab samples were taken randomly at 3-h intervals during the daylight hours to determine DM concentration.

Silage trial

Once alfalfa DM content averaged 45%, half of the alfalfa in each of the CONV and SEVERE field sections was baled using a New Holland baler (New Holland, model 640, New Holland, PA), with a weight of approximately 800- 900 kg $bale^{-1}$. Bales were then placed into 0.6 mm white plastic tubes with a diameter of approximately 1.4 m, and 23 m long (Richard Prairie Welding, Rosemary, AB) within 1 - 2 h after baling. A total of 34 and 24 bales were ensiled for CONV and SEVERE silage, respectively. Three bales per harvest treatment were core sampled on the day of baling (d 0) and on d 2, 4, 7, 15, 22 and 62 of storage. A 300 g sample of forage was taken from each bale using Penn State core samplers and was frozen (-20 ^{o}C) for subsequent nutrient and fermentation profile and LAB determinations. To

minimize adverse effect of sampling, the core sampling site was flushed with CO_2 gas following sampling and the core sample holes was sealed immediately there after. To sample alfalfa for LAB determination, core samplers were disinfected by dipping in alcohol (70%, v/v) solution between samplings. Samples for LAB determination were immediately processed.

Core samples from day 0 and day 62 were used to determine DM and nutrient (CP, NDF, ADF, soluble sugars, soluble N, ADIN, and NDIN) concentrations and fermentation (pH, ethanol, lactic, acetic, propionic, butyric, and isobutyric acids concentrations) profiles. Core samples from d 0, 2, 4, 7, 15 and 22 were used to do lactic acid bacteria (LAB) counts.

Hay trial

The remainder of the field was baled using the same baler. There were three cutting treatments: CONV, LIGHT+, and SEVERE. The CONV conditioned alfalfa was baled at a lower DM content (63.1%) because heavy rain was forecast. The LIGHT+ and SEVERE swaths were baled when alfalfa DM content was approximately 80%, to yield 400-500 kg hay bales. . Bales were placed in a pole shed for storage. Seven bales per treatment were core sampled 24 h post-baling (day 0) and after 80 days in storage (d 80) for DM, nutrient (CP, ADF, NDF, soluble sugars, soluble N, ADIN) and glucosamine determinations. Samples were frozen until ready for laboratory analysis, as described in silage trial.

Digestibility trial

The dietary treatments were alfalfa hay harvested with a roller-conditioner (CONV-

hay) or with a macerator (SEVERE-hay). Hay was chopped to 2-3 cm length using a New Holland 900 bale processor (New Holland, PA). Four steers with an initial weight of 344.8 ± 4.4 kg were used in a two period cross-over study. Each period consisted of a 7-day adjustment to diet, 7-day intake data collection, 2-day adjustment to 90% of voluntary DMI and a 7-day digestion data collection. Feed offered during the initial 14 days of each period allowed a minimum of 1 kg weighback. Fresh water and cobalt iodized salt were offered on free choice basis. Animals also received 50 g of a 1 : 1 calcium : phosphorus mineral mix with trace minerals (Hi C-n- Z , Feed Rite, Winnipeg, MB) daily. Feed offered and weighbacks were measured daily and sampled during the 7-day intake and 7-day digestion data collection periods.

Total fecal collection was measured during the digestibility trial. Representative samples of feces (10% of total feces) were collected during the digestion trial. Samples of feed, weighback and feces were frozen -20 ^{o}C, until ready for DM and nutrient determination. Apparent total tract digestibility was measured as:

100*(DM or nutrient weight in feed consumed - DM or nutrient weight in feces)/DM or nutrient weight in feed consumed.

Growing trial.

CONV and SEVERE silage from the silage trial was chopped to a 2-3 cm length and fed to weaned calves in a 78-d feeding trial (October 24, 1995 to January 9, 1996). A third dietary treatment was chopped alfalfa hay from the hay trial. Thirty-four Simmental cross calves, 17 males and 17 females (272.0 ± 4.9 kg BW) were allocated to the three dietary treatments.

One male and one female calf was allocated on the basis of body weight to each of 17 pens, 6 pens each for the silage treatments, and 5 pens for the hay treatment. Animals were offered 100% alfalfa diets with 50 g 1:1 mineral mix $head^{-1}$ d^{-1} top dressed daily. A cobalt iodized salt block and fresh water were available at all times. Animals were given a vitamin A and D injection at the start of feeding trial.

Animals were fed on an ad libitum basis, with feed offered adjusted to obtain a weighback of approximately 2 kg pen^{-1} d^{-1}. Weighbacks were collected and sampled on a weekly basis. Feed samples were collected on a daily basis and composited for each week. Samples of feed and weighback were frozen (-20 ^{o}C) until ready for DM and nutrient analyzes. Body weight measurements were taken on two consecutive days at the start and end of the feeding trial and at three week intervals during the trial. Animal trials were conducted in accordance with the guidelines stipulated by the Canadian Council of Animal Care (1993).

Dry matter and nutrient determination.

Dry matter of alfalfa was determined with a forced air oven (60 ^{o}C, 48 h). Crude protein and ADIN were assessed using a Kjeltec 1030 auto analyzer (Tecator Inc, Herndon, VI), using AOAC (1990) method no. 984.13. Neutral detergent fiber and ADF were assessed using an A200 fibre analyzer (Ankom, Fairport, NY). Soluble carbohydrates were assessed by a spectrometer (Pharmacia Biotech Ultraspec 2000, Fisher Scientific, Edmonton, AL) using a method described by Slominski et al. (1993). 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 at pH 6.5. The solution and alfalfa

sample were incubated and agitated in a water bath at 40 °C for 60 minutes, followed with settling in a rack for 15 minutes, and filtering. A 50 ml aliquot was taken for N determination, using the Kjeltec 1030 auto analyzer. Glucosamine, a measure of fungal biomass, was determined as described by Wittenberg et al. (1989), using a 4151-alpha plus amino acid analyzer (Pharmacia Biotech/Biochrom, Cambridge, England).

Silage pH was determined using an Accument pH meter (model 810, Fisher Scientific, Nepean, ON). Silage ethanol and lactic acid concentrations were determined as described, respectively, by Gutman and Wahlefeld (1974) and Gawehn and Bergmeyer (1974). Volatile fatty acids were determined according to Di Corcia and Samperi (1974), using a gas-liquid chromatography (Hewlett Packard model no.5840A, Fisher Scientific, Edmonton, Alberta). Lactic acid bacteria (LAB) enumeration of the sampled alfalfa was conducted as previously described (Suwarno et al. 1999, Manuscript 1).

Statistical analysis.

Dry matter, nutrient profiles and fermentation characteristics for silage trial were analyzed as a split-plot with repeated measures over days (Steel and Torrie, 1980). The main plot was harvest treatment with three bales as replicates in each of two treatments (CONV and SEVERE) for the silage trial. The effect of harvest treatment was tested using bale within treatment as the error term. The sub-plot had measurements taken on d 0 and d 62 of ensiling. The effect of day and the interaction of harvest treatment with day was tested using bale within treatment by day as an error term.

Dry matter and nutrient profiles for the hay trial were analyzed using a split-plot

design with 3 harvest treatments as the main-plot with four bales for each treatment as replicate. The sub-plot had measurements taken on d 0 and d 80 of storage. The effect of harvest treatment was tested using bale within treatment as an error term.

Digestibility trial data were analyzed using a 2 X 2 Latin square design (2 treatments and 2 periods) which had 2 sets of steers as replicates using common time periods. The Trt*Steers*Period(square) was used as its error term. The DMI and feed efficiency data for the growing trial were determined on a pen basis, using a GLM procedure (SAS 1986). Initial body weight was added to the model as a covariate in all cases. To analyze ADG among treatments in the growing trial, individual data of animal weight gain was used.

When treatment differences ($P < 0.05$) were observed, means were compared using the Bonferroni test (Steel and Torrie 1980). All statistical analyzes were conducted using the Statistical Analysis Systems (SAS, 1986).

RESULTS AND DISCUSSION

Harvest conditions and schedule

Alfalfa was cut at approximately 9:00 AM, June 19, 1995, with maximum and minimum temperatures of 33.5 and 18.0 °C, respectively, without precipitation but with haze conditions before noon. Maximum and minimum temperatures for the following three days averaged 31.7 and 18.3 °C, respectively. Total precipitation during the wilting period from rain and dew events was 10.4 mm.

Silage trial.

The macerated alfalfa (SEVERE) was baled on the day of cutting, starting at 16:00 h with bale wrapping starting at 18:00 PM. The CONV harvested alfalfa was baled and wrapped the following day, June 20, starting at 16:00 h, with bale wrapping at 18:30 h.

More rapid field wilting of the macerated alfalfa resulted in a silage that averaged 10 percentage units higher DM content ($P < 0.05$) compared to alfalfa harvested with roller-conditioner (Table 5). In both cases baling had been initiated when wilted alfalfa was 45% DM based on spot checks of the field. Similar results were observed by Charmley et al. (1997) when they targeted to wilt a roller-conditioner vs. macerator harvested alfalfa to 35% DM.

Alfalfa CP content in our study was 1.0 percentage unit lower, DM basis, and ADIN content was 0.8 percentage unit higher, total N basis, with maceration vs. roller-conditioner at the time of ensiling. This lower CP content with maceration is consistent with the results from hay trials by Hong et al. (1988a) and Petit et al. (1994) for legumes, and Chiquette et al. (1994) for grasses. Hong et al. (1988a) assumed that leaf shattering of macerated alfalfa at the time of baling may be responsible for this phenomenon. Given the high moisture content at baling in this trial, leaf shattering losses are not likely to have occurred to the extent that would be expected for drier alfalfa baled as hay.

After being ensiled for 62 d, alfalfa CP and soluble N content were 1.5 and 18.0 percentage units lower; and NDIN and soluble carbohydrates were 6.0 and 2.4 percentage units higher, respectively, with maceration. Crude protein ($P = 0.05$), NDF, ADF, soluble N, NDIN, and ADIN concentrations increased ($P < 0.01$) during 62 days ensiling (Table 5).

The soluble carbohydrate content of CONV silage decreased during the 62-d storage by 2.9 percentage units but not for SEVERE silage (Table 5). A possible explanation for this interaction was a greater amount of soluble carbohydrate being used for microbial growth in CONV during 62-d ensiling relative to SEVERE alfalfa as suggested by fermentation acid profile (Table 5) and the pattern of LAB counts during day 2 to day 15 ensiling period (Table 6). A greater increase of soluble N in CONV alfalfa during 62-d ensiling compared to that of SEVERE alfalfa was detected, indicating a greater proportion of CP in CONV being converted to NPN than for SEVERE (Table 5). While NDIN for CONV silage remained relatively similar during 62 d ensiling, it increased in SEVERE silage by 5.9 percentage units from day of ensiling to 62 d ensiling.

Alfalfa LAB counts tended to be higher in SEVERE than CONV alfalfa on the day of wrapping ($P = 0.06$, Table 6). Maceration results in more plant cell surface area being exposed relative to conventionally conditioned alfalfa, which may result in more opportunity for bacteria attachment to the plant. In addition, the cell contents exposed with maceration can be used by the attached micro flora as an energy source. This, combined with the higher forage DM content, may have resulted in the tendency toward a higher LAB population on the macerated alfalfa on the day of ensiling. Similar findings were observed by Charmley et al. (1997) for chopped silage: 6.51 vs. 8.30 $\log^{10}$ cfu g^{-1} fresh Alfalfa for control and macerated silage, respectively. A recommended level of 10^8 cfu g^{-1} is required for an immediate decrease in silage pH (Pitt et al. 1985).

The reverse was observed from d 2 up to d 15 post-ensiling (Table 6). Higher moisture content of CONV vs SEVERE at the time of baling may have resulted in greater

LAB populations for CONV than SEVERE during day 2 to day 15 ensiling (Nicholson et al. 1992; Charmley et al. 1997). At 15-d ensiling, no further microbial growth was detected in either harvest treatment, as indicated with no differences in LAB population between d 15 with d 22. Charmley et al. (1997) found that the growth of LAB was inhibited or halted at d 9 ensiling under a 4.9 - 5.5 pH range.

Alfalfa has a high buffering capacity, which may account for the marginal decrease in pH from 5.8 immediately after wrapping to 5.4 at 62-d ensiling (Table 5). Post-storage lactic acid content in the current study was not affected by harvest treatment, 27.0 and 15.3 g kg^{-1} DM for CONV and SEVERE silage, however, levels were low compared to wilted, chopped alfalfa silage (Charmley et al. 1997). A greater ethanol content at 62 d of post-ensiling indicated that yeast activity was greater in the CONV compared to SEVERE silage. Savoie et al. (1996) found that alfalfa maceration resulted in similar production of ethanol and acids compared to conditioned alfalfa in chopped silage systems. Differences in the silage lactic acid concentrations in the current study are consistent with trends towards increased silage lactic acid levels as ensiling DM decreases from 50% to 40% (Mir et al. 1995; Nicholson et al. 1992). Higher levels of ethanol and acids at 62 d ensiling in CONV compared to SEVERE silage in our study was probably due to greater microbial activity in the CONV than SEVERE during ensiling period, as indicated by reduced soluble carbohydrate concentration post-storage for CONV.

Macerated silage was inferior to CONV silage in terms of CP, soluble N, and NDIN contents at 62 d ensiling. The reverse was true when considering the soluble carbohydrate and ethanol levels at feed out. Similar levels of soluble carbohydrate pre and post-ensiling

for SEVERE silage and lower levels of LAB counts during 22 days of ensiling for SEVERE silage relative to CONV silage indicated that something interfered with fermentation of the macerated silage. Based on fermentation profile, maceration of alfalfa at the time of cutting did not improve fermentation of alfalfa when ensiled in big bales.

Hay trial

Harvested alfalfa in the swath was sampled periodically to achieve a targeted level of 80% DM at which time sampling was terminated and the alfalfa was baled. This was achieved the day after cutting for the LIGHT+ (June 20 at 11:30 h) and SEVERE (June 20 at 16:20 h) treatments. After 2.3 days of wilting the CONV alfalfa had not yet reached the target DM content, but baling was initiated (June 21 at 16:30 h) to avoid forecasted heavy rains. Differences in DM content of baled hay between the two maceration treatments reflect differences in field wilting rates once baling was initiated (Table 7).

Alfalfa CP content was lower with maceration and NDF, ADF, soluble N and ADIN contents at baling were similar among CONV, LIGHT+, and SEVERE harvest treatments. Alfalfa soluble carbohydrate content was higher ($P < 0.05$) on the day of baling with maceration relative to conventionally harvested alfalfa, possibly related to an extended period of respiration during field wilting for the CONV compared to LIGHT+ and SEVERE. Glucosamine levels were similar among the three harvest treatments at baling, an indication that the release of cell contents due to maceration did not encourage increased fungal growth while the alfalfa material was wilting, relative to conventionally harvested alfalfa. The pre-storage nutrient profile of macerated vs. roller-conditioned alfalfa baled at 45% or 80% DM

showed a very similar pattern (Table 5 and 7, respectively).

Alfalfa CP content was lower ($P < 0.05$) with maceration and NDF and soluble N contents between treatments were similar ($P > 0.05$) after hay had been stored for 80 days (Table 7). Concentrations of NDF increased for CONV and LIGHT+ after being stored for 80 d, but not for SEVERE hay. Concentrations of ADF increased for CONV but remained similar for LIGHT+ and SEVERE with 80 d storage (interaction effect). Higher moisture content at baling might have caused greater usage of cell solubles by storage microbes in CONV hay compared to LIGHT+ and SEVERE during early stage of storage. The higher alfalfa ADIN ($P < 0.05$) on the CONV hay as compared to LIGHT+ and SEVERE hay, was an indication of more heating during CONV hay storage (Undi and Wittenberg 1996; Yang et al. 1993). Glucosamine content for CONV increased by 100% indicating storage fungal growth but it did not increase for LIGHT+ and SEVERE during 80-d storage.

The longer time to achieve 80% DM in CONV compared to LIGHT+ and SEVERE alfalfa hay increased the risk of precipitation exposure or storage molding with the consequence of lower hay quality due to lower post-storage soluble carbohydrate levels and higher glucosamine levels. Therefore, maceration of forage at mowing is recommended for hay production.

Digestibility trial

The forage used in this trial was chopped (2 -3 cm long) CONV and SEVERE hay from the hay trial. The dietary hay had been in storage for approximately 6.5 mo (June 22, 1995 - January 16, 1996) when the digestibility trial began. Hay nutrient profiles were

analyzed based on daily samples. The CONV hay had higher CP, NDIN and ADIN and lower NDF and ADF contents.

Alfalfa DMI, as percent BW, tended ($P = 0.08$) to be higher for animals were fed the CONV hay compared to the SEVERE hay (Table 8). Ruminant DMI is affected by physical (rumen fill) and physiological (satiety) factors. If the cell wall content is high, rumen fill dominates as a factor that limits intake, and limits DMI (Jung and Allen, 1995). The quality of dietary hay in this trial was of average, therefore, rumen fill is still a factor that limits intake.

Apparent DM digestibility and CP digestibility were 4.5 and 17.3 percentage units higher, respectively, and NDF and ADF digestibility were 12.0 and 9.1 percentage units lower respectively, in animals fed SEVERE hay ($P < 0.05$, Table 8). It appears that the effect of maceration was not mitigated by coarse chopping of the alfalfa prior to feeding. The differences observed may be an effect of harvest treatment or related to heating during storage of the CONV hay (Broderick et al. 1993). Lower DM digestibility for CONV vs SEVERE hay in the current study could have been related to lower ruminal microbial attachment for CONV than SEVERE, because CONV hay resulted in less surface area being exposed to ruminal environment than SEVERE, although surface area was not measured in this study, or to lower soluble carbohydrate levels for CONV hay. Soluble carbohydrates are important for the initial growth of rumen bacteria colonizing forage materials. Higher fiber digestibility for CONV vs SEVERE hay in the current study could have been related to a slower the ruminal passage rate for CONV than SEVERE hay, although passage rate was not measured in this study. Hong et al. (1988a) found similar DM and CP digestibility when they

compared conventionally conditioned vs macerated alfalfa hay fed as hay to sheep. Petit et al. (1994) found an increase in DM, NDF, and ADF digestibility with maceration in timothy and alfalfa hay fed to sheep as a sole diet ingredients. In contrast, Chiquette et al. (1994) found a decrease in DM, ADF, and NDF digestibility with maceration when timothy hay was fed to steers as the sole diet. It appears that factors other than alfalfa maceration alone, such as species of forage, storage temperature and species of animal, may influence impact of harvest treatment on nutrient digestibility.

Growing trial.

Alfalfa treatments fed to the beef animals reflect alfalfa cut on the same day, but subjected to three different harvest and storage systems. Alfalfa CP content was lower for the SEVERE silage and hay treatments relative to CONV silage, and the NDF content was higher in hay as compared to the silage treatments ($P < 0.05$, Table 9). No differences were observed in ADF and ADIN content among the three treatments. The average temperatures during the initial 3 weeks, the next 3 weeks, and thereafter until the end of the 78 d growing trial (October 24 to November 13, 1995; November 14 to December 4; and December 5 to January 9, 1996) were -5.4 ± 7.6, -10.3 ± 5.4, and -17.4 ± 6.6 ^{o}C, respectively.

Calf DMI and ADG were 0.3 % BW and 0.2 kg d^{-1} higher, respectively, for calves fed SEVERE silage compared to calves fed CONV silage or hay in the initial 21 days of the trial (Table 9). No differences in feed conversion ratio among the three groups of treatments were observed. The positive impact of alfalfa maceration on DMI and ADG was still apparent ($P < 0.05$) for next the 21 d feeding period. The advantages initially observed for the SEVERE

silage was not carried on throughout the 78 d growing trial (Table 9).

Using chopped alfalfa silage fed to sheep, Charmley et al. (1997) observed that maceration did not affect DMI (3.1 vs 3.4% BW for control and macerated, respectively). However, Petit et al. (1994) found a tendency ($P = 0.09$) toward an increase in DMI with maceration by 8.7 and 7.5%, respectively, when macerated and non-macerated timothy or alfalfa hay were fed to sheep. In the current study, the growing trial was initiated in the fall (October 24, 1995) and ended in the middle of winter, January 9, 1995. The negation of the beneficial effect of alfalfa maceration occurred from day 42 until the end of the 78 d growing trial. During the last 5 weeks of growing trial, animals were exposed to colder environmental conditions as compared to the earlier period in this study. This allows a greater portion of heat increment associated with feed digestion to be used to maintain body temperature, possibly increasing the efficiency of utilizing heat generated during digestion. Also, during the cold weather, animals tend to eat more relative to those in warmer conditions (Delfino and Mathison, 1991) possibly resulting in an increased passage rate of the digesta (Kennedy et al. 1986). According to Kennedy et al. (1986), intake by sheep fed chopped alfalfa hay ad libitum for the last 10 d of 46-d cold (0 to -5 ^{o}C) ambient temperatures increased by approximately 13% compared to sheep at 20-25 ^{o}C ambient temperatures. In this case animal appetite did increase compared to that in warmer conditions.

CONCLUSIONS

Maceration did not improve the fermentation characteristics of alfalfa ensiled as long fiber in large round bales. Alfalfa maceration had a positive impact on the quality of alfalfa hay by increasing soluble carbohydrate content and decreasing glucosamine content compared to those of conventionally conditioned hay. Maceration levels of alfalfa up to SEVERE in this study did not cause any significant pre- and post-storage DM losses.

More severely macerated hay was superior to roller-conditioned hay as indicated by lower ADIN and NDIN, and higher DM and CP digestibility, but not when DMI, ADF and NDF digestibility were taken into account. Beef cattle fed the macerated alfalfa silage had greater DMI and ADG as compared to those fed the conventionally conditioned silage or hay in the initial 6 weeks of feeding. Beneficial effects of alfalfa maceration were not evident for the remainder of the trial.

ACKNOWLEDGMENT

The authors appreciate the assistance of Drs. G. H. Crow and L. Onischuck for their statistical suggestions. Appreciation is also forwarded to the technical and Glenlea Research Station staff for their laboratory and field assistance. This project was financially funded by the. Federal Government Energy Research and Development Program. Use of macerator was provided by the Prairie Agricultural Machinery Institute (PAMI).

Table 5. Nutrient and fermentation profiles of alfalfa harvested with a roller conditioner (CONV) vs. macerator (SEVERE) and ensiled as large round bales, n = 3.

	At ensiling		62 d post-ensiling			Significance		
Harvest treatment (Trt)	CONV	SEVERE	CONV	SEVERE	SE	Trt	Day	Trt * Day
Nutrient profile								
% DM	39.0 b	49.2 a	40.7 b	48.0 a	1.5	0.05	NS	NS
CP, g kg^{-1} DM	170.6 a	160.2 b	177.5 a	162.9 b	2.3	0.01	0.06	NS
NDF, g kg^{-1} DM	420.9 b	425.7 b	443.0 a	460.0 a	4.7	0.09	0.01	NS
ADF, g kg^{-1} DM	347.5 b	352.9 b	386.1 a	385.0 a	6.3	NS	0.01	NS
Soluble N, g kg^{-1} Total N	433.3 c	393.8 c	714.4 a	534.2 b	15.2	0.01	0.01	0.01
NDIN, g kg^{-1} Total N	52.3 b	66.2 b	65.3 b	124.8 a	4.5	0.01	0.01	0.01
ADIN, g kg^{-1} Total N	44.8 c	52.5 b	55.0 b	59.0 a	1.6	0.05	0.01	NS
Soluble carbohydrates, mg g^{-1} DM	75. 9 a	72.5 a	47.1 b	71.1 a	3.7	0.05	0.01	0.01
Fermentation profile								
pH	5.9 a	5.8 a	5.4 b	5.5 b	0.1	NS	0.01	NS
Ethanol, g kg^{-1} DM	0.43 c	0.28 c	2.73 a	1.11 b	0.19	0.05	0.01	0.05
Lactic acid, g kg^{-1} DM	0.52 b	0.01 b	27.02 a	15.27 a	2.73	NS	0.01	0.09
Acetic acid, g kg^{-1} DM	11.42	9.02	14.03	11.19	0.97	NS	0.08	NS
Propionic acid, g kg^{-1} DM	0.05	0.04	0.32	0.11	0.06	NS	0.05	NS
Butyric acid, g kg^{-1} DM	0.00	0.00	0.29	0.14	0.08	NS	0.06	NS
Isobutyric acid, g kg^{-1} DM	0.03 c	0.00 c	1.72 a	0.43 b	0.04	0.05	0.01	0.01

a, b, c Means in the same rows with different letters are different, $P < 0.05$.

Table 6. Lactic acid bacteria population, log^{10} colony forming unit (cfu) g^{-1} fresh basis, of alfalfa harvested with a roller conditioner (CONV) vs macerator (SEVERE) and ensiled as large round bales, n = 3.

	Harvest treatments			
Day ensiled	CONV	SEVERE	SE	Significance
0	6.2	6.6	0.1	.06
2	7.5 a	6.0 b	0.2	.01
4	7.4	6.8	0.2	.06
7	7.4 a	6.7 b	0.1	.01
15	7.5	7.0	0.2	.06
22	7.2	7.0	0.1	.14

a, b Means in the same rows with different letters are different, $P < 0.05$.

Table 7. Nutrient profile of alfalfa harvested with a roller-conditioner (CONV) vs macerator (LIGHT+ and SEVERE) and baled as hay in large round bales, n = 4.

	At baling			At 80 day storage						
Harvest treatment (Trt)	CONV	LIGHT+	SEVERE	CONV	LIGHT+	SEVERE	SE	Trt	Day	Trt*Day
Days wilting	2.3	1.1	1.3							
% DM	63.2 c	79.8 b	86.6 a	85.3 a	84.1 a	87.0 a	1.1	0.01	0.01	0.01
CP, g kg^{-1} DM	189.7 a	179.6 b	175.1 b	193.7 a	179.2 b	172.8 b	3.2	0.02	NS	NS
NDF, g kg^{-1} DM	416.5 b	433.1 b	425.5 b	511.6 a	496.3 a	443.8 ab	9.2	NS	0.01	0.01
ADF, g kg^{-1} DM	334.5 c	340.1 bc	339.3 c	396.5 a	367.8 ab	342.3 c	9.1	NS	0.01	0.01
Sol N, g kg^{-1} Total N	327.4 a	292.3 ab	342.1 a	273.3 c	212.2 c	275.0 bc	14.3	0.05	0.01	NS
ADIN, g kg^{-1} Total N	62.2 b	60.7 b	58.4 b	116.4 a	72.0 b	61.5 b	6.2	0.01	0.01	0.01
Sol. carbohydrates, mg g^{-1} DM	70.1 bc	79.2 ab	84.6 a	48.5 d	59.4 cd	79.0 ab	3.1	0.01	0.01	0.05
Glucosamine, g kg^{-1} DM	0.7 b	0.8 b	0.8 b	1.7 a	1.0 ab	1.0 ab	0.1	0.01	0.01	0.01

a, b, c Means in the same row with different letters are different, $P < 0.05$.

Table 8. Effect of harvest methods on nutrient profile, dry matter intake and nutrient digestibility of alfalfa hay fed to beef steers. n =4

	Harvest treatment			Significance[z]	
	CONV	SEVERE	SE	Harvest	Period
Nutrient profile					
% DM	88.1	92.2	2.8	NS	NS
CP, g kg^{-1} DM	187.8 a	167.5 b	2.8	0.05	NS
ADIN, g kg^{-1} Total N	151.5 a	60.8 b	5.2	0.05	NS
NDIN, g kg^{-1} Total N	399.6 a	129.7 b	3.4	0.05	NS
NDF, g kg^{-1} DM	526.3 a	454.9 b	5.5	0.05	NS
ADF, g kg^{-1} DM	427.5 a	370.1 b	5.3	0.05	NS
Soluble carbohydrates, mg g^{-1} DM	54.3	77.8	0.8	NS	NS
DMI and nutrient digestibility					
DMI, kg d^{-1}	10.7	10.0	0.14	0.07	NS
DMI, % BW	3.04	2.82	0.04	0.08	NS
Apparent digestibility, %					
DM	55.0 b	59.5 a	0.6	0.05	NS
CP	53.6 b	70.9 a	1.1	0.01	.06
NDF	54.4 a	42.4 b	1.4	0.05	NS
ADF	54.4 a	45.3 b	1.5	0.05	NS

[z] NS, not significance, $P > 0.05$.

a, b Means in the same rows with different letters are different, $P < 0.05$

Table 9. Effect of harvest and storage treatments on nutrient profile and dry matter intake, body weight gain and feed conversion when alfalfa was fed to Simmental cross cattle in a 78-d growing trial.

	Harvest treatments			
	CONV Silage	SEVERE Silage	Hay[z]	SE
Nutrient profile				
% DM	43.7 c	56.9 b	85.6 a	1.1
CP, g kg^{-1} DM	181.2 a	167.8 b	161.6 b	3.1
NDF, g kg^{-1} DM	481.8 b	498.3 b	543.1 a	7.5
ADF, g kg^{-1} DM	384.3	392.6	400.7	6.9
ADIN, g kg^{-1} Total N	71.0	75.8	83.8	4.4
Animal performance				
Number of pens	6	6	5	
Initial weight, kg	274.1	275.0	268.9	4.9
Final weight, kg	341.5	351.4	341.8	7.0
Initial 21 days				
DMI, kg d^{-1}	7.0 b	7.9 a	7.1 b	0.1
DMI, % body weight	2.5 b	2.8 a	2.5 b	0.0
ADG, kg d^{-1}	0.9 b	1.1 a	1.1 a	0.1
Feed conversion	8.1	7.7	6.5	0.5
Overall				
DMI, kg d^{-1}	8.5	9.1	8.8	0.2
DMI, % body weight	2.8	2.9	2.8	0.1
ADG, kg d^{-1}	0.9	1.0	1.0	0.1
Feed conversion	9.6	9.1	9.0	0.4

[z] Hay fed to cattle was from the same field as silages.
Harvest equipment for the hay included both roller-conditioner and macerator.
a, b Means in the same rows with different letters are different, $P < 0.05$.

MANUSCRIPT III

PERFORMANCE OF LACTATING DAIRY COWS FED MACERATED ALFALFA CONSERVED AS SILAGE AND HAY

ABSTRACT

An experiment was conducted to determine the effect of forage maceration at harvest on silage characteristics and on lactation performance of Holstein cows. In a field study, either a roller conditioner or a prototype forage macerator manufactured by PAMI were used to cut a 25 ha field of alfalfa. The harvested forage was wilted and preserved as silage or hay. Maceration of alfalfa resulted in lower crude protein concentration of fresh forage. Silage volatile fatty acid and ethanol concentration and hay and silage nutrient profile were not affected by harvest methods. Thirty four Holstein cows (602.9 ± 3.4 kg) in early lactation were used in a 14-week lactation study. The cows were fed two dietary treatments in the form of a TMR; one which contained roller-conditioner-harvested alfalfa silage and hay and the other TMR contained macerator-harvested alfalfa silage and hay. Feed, weighbacks and milk were sampled weekly. Daily DMI (21.6 ± 0.5 kg) was not affected by harvest method. Daily milk yield (38.7 ± 0.3 kg) and milk composition were not affected by dietary treatment during the 14-week lactation trial, however, cows fed the macerated forage as part of a total mixed ration had a 0.23 kg greater daily body weight gain ($P < 0.05$). Dietary energy input and energy output (total energy in milk, maintenance and body weight change) were not affected by dietary treatment, however, energy retained in body weight gain was greater ($P<0.05$) in cows fed a TMR containing the macerated alfalfa.

Key words: alfalfa, maceration, milk yield, body weight, forage energy.

INTRODUCTION

Alfalfa is one of the most important species grown in North America, in part because of consistent high yields of crude protein (CP) and energy per unit land area. Harvest of alfalfa for storage as silage or hay requires that the crop be field wilted to achieve the desired moisture content. Precipitation or high humidity during wilting can reduce forage quality due to extended plant respiration, bacterial growth, and leaching. Delaying harvest until the weather is favourable for wilting is not helpful because there is a decline in forage quality related to maturing of the plant. A better harvest strategy would be to shorten drying time.

Mechanical as well as chemical attempts have been made to increase drying rate. In the last decade, maceration or longitudinal breaking of the plant stem has received increased attention. Tests under the humid conditions of eastern Canada suggest that field wilting time can be cut in half by macerating forage at harvest, reducing risk associated with respiration loss (Savoie et al. 1993) and potentially increasing the soluble carbohydrate fraction of the forage. Increased forage soluble carbohydrate concentration in silage is related to high levels of lactic acid production and successful fermentation. Muck et al. (1989) identified an increase in lactic acid bacteria population at early stages of ensiling when forage was harvested with a mower- macerator compared to that harvested with mower-conditioner.

The effect of forage maceration on animal performance is not well documented. Koegel et al. (1990) estimated that maceration could increase the energy value of forage by 11% for dairy cows, however, a production trial run with late lactation cows showed higher body weight gain and no change in milk production for macerated relative to conventional

alfalfa forage. On the other hand, a trial with dairy goats resulted in a 12% increase in milk production when macerated alfalfa hay was compared with conventional alfalfa hay (Hong et al. 1988a). Therefore, the objective of this study was to evaluate the response of lactating cows fed early bloom alfalfa harvested using either a macerator or a conventional mower-conditioner and conserved as silage or hay.

MATERIALS AND METHODS

Forage treatments.

A uniform 25 ha alfalfa field at 0 -10% bloom was divided into 4 sections. Field sections were randomly allocated for harvest using either a macerator prototype manufactured by the Prairie Agriculture Machinery Institute (PAMI), Portage La Prairie, MB (Macerated) or a New Holland 116 haybine with a roller conditioner (Roller-conditioner). Harvest was conducted simultaneously. There were 2 periods of harvest; 1st cut was conducted on June 23rd and 24th, and 2nd cut was conducted on August 2nd, 3rd and 4th, 1994. The harvested forage was wilted to reach 45% DM, chopped and loaded into 2 identical 140 t tower silos, with one silo designated for macerated forage and the other for conventionally harvested forage. A second field containing 2nd cut alfalfa forage was divided into 4 blocks, two of each were assigned to harvest using a macerator and two using the haybine. This forage was wilted to 85% DM and baled as hay for the production trial.

Four marked burlap bags containing known amounts of harvested alfalfa were placed in each of two levels (level 1 and 2) of the silo as 1st cut forage was blown into the silo. Similarly, four marked burlap bags were placed at 2 levels (level 3 and 4) at the time silos

were filled with 2nd cut forage. As silos were unloaded during the feeding trial, burlap bags were retrieved, weighed and sub sampled to determine DM retention, nutrient composition, final pH and VFA concentrations. The sub samples were oven dried (60 ^{o}C, 48 h) for DM determination and ground with a Willey Mill fitted with a 1-mm screen for nutrient analysis. Only the intact burlap bags recovered during unloading were used.

Animals and feeding

Thirty four animals including 14 primiparous and 20 multiparous Holstein cows were assigned to one of two dietary treatments. One multiparous cow was removed during the first week of the trial due to mastitis, resulting in 33 animals being used for data collection and statistical analysis. Animals were assigned on the basis of number of lactations (first, second and mature), and previous lactation performance. Feeding of the silage and hay treatments started 2 weeks prior to calving. Data collection was initiated on the second Saturday after calving and continued for 14 weeks.

Long hay and silage were fed as part of a total mixed ration (TMR), which included a concentrate, a protein supplement, and whole sunflower seeds. Long hay, fed separately at 2 kg head^{-1} d^{-1} and the TMR were fed once a day. The TMR including the 2 kg hay was formulated to contain 1.73 Mcal NE_L kg^{-1} DM, with other nutrient parameters meeting production parameters for a 625-kg cow producing 40 L milk d^{-1} at 3.60% fat (NRC, 1989). Actual TMR formulations were revised on a weekly basis, to account for actual silage DM and averaged a 42 : 58 forage to concentrate ratio, DM basis.

Animal body weight (BW) and body condition scores (BCS) were determined at the

time data collection was initiated and every four weeks thereafter until animals went off test. Milk yield was monitored daily and milk composition over a 24 h period was assessed on a weekly basis. Feed offered and weighbacks were weighed daily with the amount of feed offered targeted to allow a minimum weighback of 2 kg.

Sampling and nutrient analysis

Silage and concentrate samples from the production trial were taken on a weekly basis and stored (-20^{o} C). These samples were composited to represent 5 week intervals during the trial. Composites were dried using a forced air oven (60 ^{o}C, 48 h).

Silage ethanol, VFA and lactic acid were determined as outlined by Di Corcia and Samperi (1974) using gas chromatography, and silage pH measurement was conducted using an Accument pH meter (model 810, Fisher Scientific, Nepean, ON).

Hay was core sampled prior to feeding. All analyses for hay DM and nutrient composition were conducted on these core samples. Samples were dried and ground with a Willey mill to pass through a 1-mm screen for nutrient analysis. Nutrient analyses included neutral detergent fibre (NDF) and acid detergent fiber (ADF) according to Goering and Van Soest (1970) and acid detergent insoluble nitrogen (ADIN) and crude protein (CP) using Kjeldahl N according to the Association of Official American Chemists (AOAC, 1990 method no. 984.13). Calcium (Ca), phosphorus (P), potassium (K) and magnesium (Mg), were determined after dry ashing forage samples at 550^{o}C for 12 h, followed with determination using a flame atomic absorption spectroscopy (AA/E spectrophotometric model 551: Instruments Laboratory Inc., Willmington, MA). Soluble carbohydrate was determined

according to Slominski et al. (1993).

Milk fat, protein and solid-non-fat concentrations were determined by infrared spectroscopy using an infrared analyser (Milk-O-Scan 203B type 17920 A-SN, Foss Electric, Hillerod, Denmark). Dietary energy density and energy status of cows were estimated using the methods of NRC (1989) and Tyrell and Reid (1965).

Statistical analysis

Data collected from burlap bags placed into the silos was analysed as a split-split-plot design. The main plot was harvest treatment (Roller-conditioner and Macerated), the sub-plot was harvest period (1st cut and 2nd cut) the sub-sub-plot was level in the silo (levels 1, 2, 3 and 4) with burlap bags as the experimental units.

Nutrient composition of the diets was analysed using a general linear model (GLM) procedures (SAS, 1986) with harvest treatments as the source of variation and periods of feeding (5 weeks period^{-1}) as replicates. All other data were analyzed as a split-plot design, with harvest treatment and parity as the main-plot (2 x 2 factorial) using cow within harvest by parity as the error term, and week of lactation as the sub-plot, using general linear model (GLM) procedures of SAS (1986). The Bonferoni difference technique was used to compare least square means when treatment differences were observed. Levels of significance were determined at $P < 0.05$ and trends at $P < 0.10$ unless indicated otherwise.

RESULTS AND DISCUSSIONS

Silage trial

Crude protein concentration of the macerated alfalfa was lower than alfalfa harvested with the roller-conditioner at ensiling (Table 10). No differences due to harvest method were observed for fiber constituents in fresh alfalfa. Cutting height for the macerator prototype and haybine were similar. Greater leaf shedding for the maceration compared with the roller-conditioner treatment during cutting might be responsible for the lower CP content in macerated alfalfa.

Post-storage nutrient profiles and nutrient retention data retrieved from burlap bags were similar between macerated and conventionally harvested alfalfa silage (Table 10). The actual differences in CP content observed pre-ensiling was still evident post-ensiling, however, a reduced number of observations due to removal of data because of damaged burlap bags may have affected the ability to detect significant differences.

Final pH, volatile fatty acids (VFA) and ethanol levels of ensiled alfalfa retrieved from burlap bags were similar for macerated vs roller-conditioner harvested alfalfa (Table 10). The profile of the fermentation products of these silages indicate that a good fermentation occurred in both silos. The pH of both silages was higher than optimum, however, this is related to the high buffering capacity of alfalfa.

Lactation study

Alfalfa was harvested close to the optimum stage of growth for alfalfa production, based on

nutritional consideration. The nutrient profile of silages retrieved from the silos and hay used in the feeding trial were similar for the two harvest procedures used (Table 12). Alfalfa quality in this trial was typical of an early bloom alfalfa under good harvesting and storage conditions. Experimental diets were formulated to be iso caloric on the basis of estimated alfalfa NE_L (NRC, 1989) with an actual alfalfa to concentrate ratio of 42 : 58, DM basis (Table 11). The actual dietary nutrient profile was slightly lower in calculated energy density (1.63-1.67 Mcal kg^{-1} DM) compared to the desired formulation (1.73 Mcal kg^{-1} DM), however, diets were isocaloric.

Dry matter intake (DMI) was 21.6 ± 0.5 kg without any differences being observed between treatments (Table 13). Similar results were found by Hong et al. (1988a) for lactating goats fed a TMR with macerated or conventionally harvested, chopped alfalfa hay, and by Chiquette et al. (1994) using steers fed macerated or conventionally harvested timothy hay that was chopped prior to feeding. Sheep fed chopped macerated alfalfa (Hong et al. 1988a, Petit et al. 1994) tended ($P < 0.10$) to eat more feed relative to their counterparts fed conventionally harvested alfalfa, probably due to faster ruminal dietary rate of passage or greater degradation rate for the TMR containing macerated alfalfa than that containing conventionally harvested alfalfa. Alfalfa hays used by Hong et al. (1988a) and Petit et al. (1994) were similar in NDF (41.6-48.6 %) and ADF (33.0-38.7%) content relative to the current trial. The fact that lactating cows also were consuming a high proportion of concentrate in the current trial may have masked potential differences due to maceration. Differences in the alfalfa types also may have influenced results. Hong et al.(1988a) and Petit et al. (1994) used hay whereas the current trial used mostly silage. Dry matter intake was

lower ($P < 0.01$) for primiparous cows relative to multiparous cows. This was as expected, because rumen capacity and potential milk production of multiparous cows are greater relative to those of primiparous cows.

Milk and 4% FCM production were high in this study, but not affected by alfalfa harvest method (Table 14). Lactating goats fed a TMR containing a 60:40 ratio, DM basis, of chopped, macerated alfalfa hay and concentrate (Hong et al. 1988a) tended to yield more 4% FCM, and lactating cows fed macerated alfalfa silage in a TMR (Mertens and Hintz 1990 as cited by Koegel et al. 1992) had similar milk yields relative to cows fed conventionally harvested alfalfa in the lactation ration. Milk constituent levels were not affected by harvest method of the alfalfa fed to lactating cows (Table 14).

Although DMI and 4% FCM was similar between treatments, animals fed the TMR with macerated alfalfa gained more weight than those fed the TMR with conventionally harvested alfalfa (Table 13), resulting in a higher final weight. These results suggest that the TMR containing macerated alfalfa was more efficiently used for BW gain relative to that of the control diet. Koegel et al. (1992) cited the findings of Mertens and Hintz, that growing sheep gained more weight when they were fed macerated alfalfa silage ($P < 0.06$) relative to control.

Overall, body condition score (BCS) tended ($P = 0.07$) to be higher for cows fed the macerated diet (Table 13). Multiparous cows fed macerated diets had higher ($P < 0.05$) BCS for the last 10 weeks of the lactation trial than cows fed the control diets (Figure 3). Both multiparous groups of cows lost body condition during the first four weeks of the lactation trial, however, the cows fed a TMR containing the roller-conditioner harvested alfalfa showed

a greater decrease in BCS during that period relative to cows fed a TMR containing macerated alfalfa. The body weight of cows fed a TMR containing roller-conditioner harvested alfalfa during that period decreased 38.4 kg as compared to a 6.3 kg decrease in BW over the same period of time for cows fed a TMR containing the macerated alfalfa. The decrease in both BW and BCS in multiparous cows on both diets during the initial weeks of lactation is related to a greater energy output in the form of milk, relative to energy consumed. The energy shortage is supplied by body fat mobilization. This situation did not happen in primiparous cows because milk production was not great enough to cause a negative energy balance. At the end of the trial (week 14 post-partum), cows receiving a TMR containing the macerated alfalfa almost recovered their BCS (3.1) while in the same period, cows fed a TMR containing the roller-conditioner harvested alfalfa were still well below their initial BCS. The better BCS for cows fed a TMR containing the macerated alfalfa at week 14 post-partum coupled with similar production levels suggests that alfalfa maceration has benefits to early lactating cows.

Animals consumed a similar amount of energy (35.4 and 35.3 Mcal d^{-1} respectively, Table 15) from both dietary treatments over the course of the 14-week lactation trial. Similar production of milk and milk constituents by both groups of animals resulted in no differences in milk energy output between the two dietary treatments. Energy for maintenance was not significantly affected by treatment. However, animals fed the TMR containing macerated alfalfa gained more weight as indicated by a greater energy output for BW change. Calculated total energy outputs (sum of energy in milk, maintenance and BW change) were not significantly affected by harvest methods. Higher conversion of feed energy to body mass

for the lactation ration containing macerated alfalfa relative to control maybe partly due to a greater NDF digestibility (Hong et al. 1988a), greater soluble fraction or increased degradability (Chiquette et al. 1994) in the macerated alfalfa.

CONCLUSIONS

Maceration resulted in no change in silage nutrient composition at the time of feeding. Feeding macerated silage and hay to lactating cows did not affect DMI, milk production and milk composition, however maceration resulted in higher daily body weight gain in the initial 14-week of lactation.

ACKNOWLEDGEMENTS.

The authors would like to thank Drs. G. Crow and L. Onischuk for their statistical help. Use of the macerator through cooperation with Prairie Agricultural Machinery Institute, Portage la Prairie, MB, is appreciated. Financial support for the project is provided by the Federal Government Energy Research and Development Program.

Table 10. Pre-ensiling and post-ensiling alfalfa quality and silage characteristics for roller-conditioner vs roller-macerator harvested alfalfa placed into tower silos.

	Roller-conditioner	Macerator	SE
Nutrient content			
Pre ensiling			
No. of bags	16	16	
DM, %	46.4	46.0	1.8
CP, g kg^{-1} DM	197 a	191 b	2.0
ADF, g kg^{-1} DM	326	346	3.1
NDF, g kg^{-1} DM	416	411	3.0
Post ensiling			
No. of bags	7	13	
DM, %	45.7	40.3	2.7
CP, g kg^{-1} DM	216	201	4.0
ADF, g kg^{-1} DM	357	383	15.0
NDF, g kg^{-1} DM	444	477	13.0
DM retention[z], %	87.0	90.6	2.5
CP retention[z], %	91.6	98.7	3.9
Silage characteristics			
pH	5.00	4.76	0.18
Lactic acid, mg g^{-1} DM	42.83	58.59	20.64
Acetic acid, mg g^{-1} DM	12.42	31.04	4.74
Propionic acid, mg g^{-1} DM	0.96	1.16	1.04
Butyric acid, mg g^{-1} DM	3.73	1.86	4.10
Ethanol, mg g^{-1}DM	1.10	2.49	1.26

a, b Means within the same row with different letters are different, $P < 0.05$

[z] % DM retention = (weight out / weight in) x 100.

Table 11. Post-storage nutrient composition of alfalfa silage and hay harvested using either a roller conditioner or a macerator and fed to lactating dairy cows

	Silage[Z]			Hay[Y]		
	Roller-conditioner	Macerator	SE	Roller-conditioner	Macerator	SE
DM, %	49.5	48.2	1.6	86.8	87.0	-
Composition, DM basis						
CP, g kg^{-1}	196.1	199.1	3.7	195.1	193.6	14.4
ADIN, mg g^{-1} total N	74.8	85.1	1.5	48.2	42.9	1.2
NDF, g kg^{-1}	458.1	461.4	16.5	407.5	400.4	12.7
ADF, g kg^{-1}	376.0	371.0	6.8	305.8	296.3	9.4
Soluble carbohydrate, mg g^{-1}	33.8	32.6	5.6	84.2	90.2	4.4
NE_L, Mcal kg^{-1} [X]	1.23	1.25	-	1.41	1.43	-
P, g kg^{-1}	3.20	3.14	0.08	2.10	2.20	0.34
Ca, g kg^{-1}	20.3	18.7	0.2	17.0	17.12	1.46
K, g kg^{-1} [W]	26.0	26.0	-	21.0	21.0	-
Mg, g kg^{-1} [W]	2.60	2.80	-	2.90	2.80	-

[Z] Based on composite samples of silage fed during the lactation trial.
[Y] Based on composite of core samples taken from bales fed during the lactation trial.
[X] Calculated according to NRC, 1989.
[W] Samples composited prior to analysis.

Table 12. Formulation and nutrient composition of diets fed to lactating cows

	Roller conditioner	Macerated
Diet ingredients, g kg^{-1} DM		
Alfalfa silage	343.6	325.7
16% concentrate[Z]	514.4	530.5
Protein supplement[Y]	40.7	41.3
Whole sunflower seeds	22.0	22.3
Alfalfa hay, long	79.3	80.2
Alfalfa:concentrate ratio, DM basis	42:58	41:59
Nutrient composition, DM basis		
CP, g kg^{-1}	192.0	191.0
NDF, g kg^{-1}	303.0	307.0
ADF, g kg^{-1}	202.0	203.0
NE_L ,Mcal kg^{-1} [X]	1.63	1.67
Ca, g kg^{-1}	14.3	14.0
P, g kg^{-1}	5.8	5.7
K, g kg^{-1}	15.4	15.6
Mg, g kg^{-1}	2.6	2.6

Z Concentrate mix consisted of (as fed basis) 52.9% steamed rolled barley and 10.0% steam rolled corn, 11.0% wheat shorts, 9.0% canola meal, 3.5% distilled grains, 2.6% soybean meal, 2.0% meat meal, 1.0% blood meal, 2.0% wheat, 0.8% Co-I salt, 0.7% dynamate (Pitman Moore Inc., Oakville, ON, Canada; contained guaranted analysis of 22% S, 18% K, and 11% Mg), 0.6% limestone, 0.8% dicalcium phosphate, 1.0% micropremix, 2.0% tallow, and 0.2% mold inhibitor.

Y Protein supplement consisted of (as fed basis) 42.0 % distilled dried grains, 7.0% fish meal, 22.8% canola meal, 20.0% soybean meal, 3.0% beet molasses, 0.3% niacin, and 5.0% sodium bicarbonate

X Calculated NE_L (NRC, 1989).

Table 13. Post-partum intake, body weight (BW), and body condition score (BCS) of lactating dairy cows fed alfalfa silage and hay harvested using a macerator vs a roller conditioner as parts of TMR.

	Harvest methods			Level of significance[z]		
	Roller-conditioner	Macerator	SE	Harvest	Lactation	Interaction
n	16	17				
DMI						
kg d^{-1}	21.7	21.4	0.5	0.01	ns	ns
%BW	3.46	3.45	0.11	ns	ns	ns
Body weight						
Final, kg	619.6 b	641.5 a	10.7	0.01	ns	ns
Change, kg d^{-1}	0.17 b	0.40 a	0.07	0.05	ns	ns
BCS[y]						
Mean, unit	2.80	2.94	0.05	ns	0.04	ns
Change, unit d^{-1}	-0.02	-0.001	0.006	0.07	ns	ns

[z] Probability associated with an effect.

[y] Body condition scores were estimated based on score 1-5, 1 is thinnest or severe under conditioning and 5 is fattest or severe over conditioning (Edmonson et al. 1989).

Table 14. Milk yield and composition of Holstein cows fed a total mixed ration containing alfalfa harvested with a roller conditioner or a macerator.

	Harvest method (Trt)			Level of significance[z]		
	Roller-conditioner	Macerator	SE	Parity	Trt*Parity	Trt*time
Yield, kg d^{-1}						
Milk	38.8	38.5	0.3	0.01	ns	ns
4% FCM[y] 0	31.8	31.8	0.1	0.01	ns	ns
Butterfat	1.08	1.09	0.06	0.01	ns	ns
Protein	1.17	1.19	0.03	0.01	ns	ns
Solids non-fat	3.34	3.38	0.09	0.01	ns	ns
Composition, %						
Butterfat	2.78	2.84	0.14	ns	ns	ns
Protein0	3.04	3.09	0.04	0.01	ns	ns
Solid non fat	8.62	8.76	0.07	0.05	ns	ns

[z] Probability associated with an effect

[y] 4% FCM (fat corrected milk), based on definition of NRC, 1989. Calculated with an equation:
4% FCM= (0.4) (kg of milk) + (15) (kg of milk fat).

Table 15. Post-partum energy status of Holstein cows as influenced by harvest method of alfalfa.

	Harvest method (Trt)			Level of significance[Z]		
	Roller-conditioner	Macerator	SE	Parity	Trt*Parity	Trt*time
Energy input [Z]						
Total, Mcal NE_L d^{-1}	35.37	35.31	0.72	0.01	ns	ns
Energy output, Mcal NE_L d^{-1}						
Milk[Y]	24.43	24.49	0.76	0.01	ns	ns
Maintenance[X]	9.76	9.90	0.13	0.01	ns	0.06
BW change [X]	0.93 b	2.08 a	0.36	0.002	ns	ns
Total	35.13	36.48	0.84	0.01	ns	ns
Dietary energy density, Mcal NE_L kg^{-1} DM						
Estimated, [Z]	1.63	1.65	-	-	-	-
Calculated, [W]	1.66	1.74	0.04	ns	ns	ns

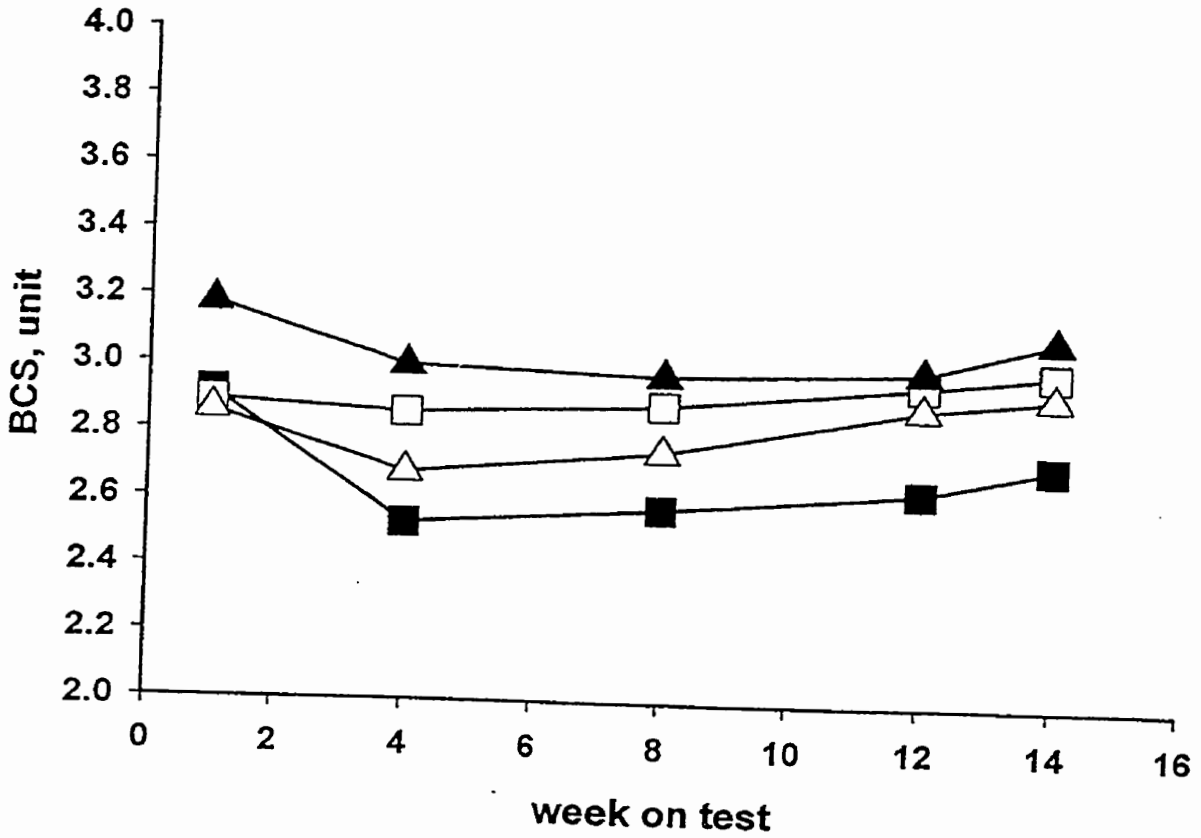
[Z] Estimated from NRC (1989) values; based on feedstuff composition in diets and energy values contained in each feedstuffs in question and amount of diets consumed.

[Y] Calculated from daily protein yield (P, g kg^{-1}) and butterfat yield (BF, g kg^{-1}) of milk (Tyrell and Reid, 1965); Energy in milk (MJ kg^{-1}) = 0.0376(BF) + 0.0209(P) + 0.948. Joule is converted to calorie in this table.

[X] Energy for maintenance and BW change were calculated based on BW and daily BW change respectively (NRC, 1989, table 6.3: energy for maintenance= ($BW^{0.75}$) x 0.08, and energy for BW change was either -4.92 Mcal kg^{-1} BW loss or +5.12 Mcal kg^{-1} BW gain.

[W] Calculated from total energy output and DMI; Energy density=Total Energy output/DMI.

Figure 3. Body condition scores (BCS) of multiparous and primiparous cows in response to experimental diets during a 14-week lactation trial (■ : roller conditioner-multiparous, ▲: macerated-multiparous, □: roller conditioner-primiparous, △: macerated-primiparous. Pooled SE=0.07).


4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
BCS, unit
0
2
4
6
8
10
12
14
16
week on test

GENERAL DISCUSSION

Effect of maceration on wilting time and bulk density

Alfalfa forage in an early bloom stage was cut at a uniform height (approximately 6-7 cm above the soil level) at an average of 72% moisture content. To wilt to 45% DM, alfalfa subjected to a roller-conditioner required 6.5 h under good prairie weather conditions. Four intensity levels of forage maceration resulted in an average of 61.4% less time, or 2.5 h to achieve 45% DM content (Figure 1, Manuscript I). However, when weather conditions were cloudy (haze) during wilting, alfalfa subjected to roller-conditioner required more than 31 h whereas alfalfa subjected to maceration (SEVERE) required only 7 h to achieve 45% DM. (Manuscript II).

To achieve 80% DM, a level that is considered safe for hay making, the conventionally harvested forage in our study required approximately 54 h under good weather conditions (Manuscript I). Maceration resulted in an average of 80% less drying time (10 h) to achieve 80% DM under similar conditions. Cloudy weather conditions during wilting (Manuscript II) resulted in longer wilting time; ranging from more than 55.5 h for alfalfa subjected to roller-conditioner to 26.5 h for alfalfa subjected to LIGHT+ maceration and 31.3 h for alfalfa subjected to SEVERE maceration, respectively. When macerated alfalfa forage was pressed, the forage dried in 5-6 h, under good weather conditions (Oztekin and Ozkan, 1997), and in 5 to 8 h under controlled environmental conditions, depending upon mat density (Savoie and Beauregard, 1991).

Precipitation either at early or late stages of wilting will increase wilting time,

especially for the most severely macerated forage (Savoie et al., 1993). Relative to unexposed forage, 2 cm precipitation at 1.5 h post-cutting on conventionally conditioned forage increased wilting time by 4 h to achieve 45% DM. None the less, the average wilting time was 60% lower for macerated alfalfa compared to conventionally conditioned alfalfa exposed to precipitation shortly after mowing (Figures 1 and 2, Manuscript I).

Macerated alfalfa exposed to 2 cm precipitation at either 1.5 or 24 h post-cutting during wilting could reach an 80% DM content in 18 to 28 h, respectively, compared to about 50 to 54 h for the conventionally conditioned alfalfa under similar wilting conditions (Figure 2, Manuscript I). These results suggested that the influence of maceration on shortening wilting time is greater when weather is more conducive for wilting (eg. Canadian prairies) than in more humid and higher rainfall environments (eg. Maritimes and Coastal Canada).

Macerated alfalfa in our study had a greater bulk density relative to conventionally conditioned alfalfa at the time of harvest, with density increasing with the intensity of maceration. This may have a positive impact on ensiling, because the macerated forage can be packed more densely in the silo, increasing storage capacity of silo and facilitating anaerobic conditions, thus enhancing anaerobic lactic acid producing bacteria growth. However, excessive maceration can make the swaths or windrows become more densely packed due to the shredding of stems which may reduce air circulation within plant material. Less air circulation within the swaths or windrows can depress wilting rate especially when the forage is exposed to rain. Therefore, excessive maceration can reduce the benefit of maceration by extending wilting time (Manuscript I).

Effect of maceration and precipitation on post-wilting (pre-baling and post-baling) alfalfa nutrient profile.

Although field operations were targeted to achieve similar post-wilting DM contents at baling (45% for forage baled as silage and 80% for forage baled as hay) the macerated forage had a greater DM content at sampling time post-baling. Higher wilting rate at time of baling for macerated alfalfa could have caused this phenomenon. Therefore, at the commercial level, producers must match the time of cutting as closely as possible with wilting and baling rates, so that the macerated forage is not too dry when baled.

The post-wilting nutrient profile in our study showed that alfalfa CP content was lower with maceration. There might be more leaf shattering when samples were taken from SEVERE+ compared to other treatments, because SEVERE+ wilted much more quickly than CONV. The leaves for SEVERE+ maceration might have been too dry compared to its stems when alfalfa achieved 80% DM, causing much easier for the leaves to shattering compared to CONV. The post-wilting NDF content were not affected by maceration, when two levels of maceration, CONV and SEVERE, were compared (Manuscript II, silage and hay; Manuscript III, silage). The exception was found in Manuscript I: NDF levels were higher for SEVERE and SEVERE+ maceration compared to other mowing treatments (CONV, LIGHT, and LIGHT+). This fact was possibly due to more leave shattering for the two most intense maceration levels than other treatments. This phenomenon was in agreement with the findings of Hong et al. (1988a) and Petit et

al. (1994). Hong et al. (1988a) explained that the increase in NDF with maceration was due to more leaf shattering for the macerated forage relative to conventionally conditioned forage. The ADF content, with the exception of the hay trial which was lower for SEVERE vs CONV in Manuscript II, was not affected by maceration. Post-wilting soluble N and glucosamine contents were not affected by maceration. Soluble carbohydrates, except for hay, Manuscript II, in which post-baling soluble carbohydrate content was higher with maceration, was similar among mowing treatments. The speculation was that maceration of alfalfa for hay might have resulted in a lower respiration activity during wilting to 80% DM under cloudy condition compared to that for CONV hay treatment (Manuscript II).

Precipitation, especially when occurring late during the wilting period, increased forage NDF, and tended to increase glucosamine contents (Table 3, Manuscript I). The increased NDF and decreased cell solubles could be explained, in part, by leaching of cell solubles due to precipitation, and the increase in glucosamine could be due to prolonged exposure to high relative humidity (RH), a condition favourable for mold growth, during the time following precipitation.

Effect of maceration on post-ensiling and post-storage nutrient profile of alfalfa

Consistent with previous findings, post-ensilage and post-storage alfalfa CP content in our study (except for chopped silage, which was similar, Manuscript III) was lower for macerated than for conventionally harvested alfalfa. The NDF contents were similar for alfalfa harvested with a mower-macerator to conventionally harvested forage. The post-

ensiled and storage ADF contents (except for hay trial, which was lower for SEVERE vs CONV, Manuscript II) were also not affected by maceration. Post-ensiled ADIN content was higher for macerated than conventionally-conditioned alfalfa silage, but the reverse was true for hay (Manuscript II). Differences in DM content at ensiling between conventionally-conditioned vs macerated alfalfa could interfere with harvest treatment in affecting ADIN content of the alfalfa being preserved.

More heating during storage, possibly due to lower DM content at baling, might have occurred for conventionally-conditioned alfalfa compared to that for macerated alfalfa hay, causing more N to be bound to the cell wall fraction in the former compared to that in the later (Broderick et al. 1993).

Post-ensiled CP and soluble N were 1.5 and 18.0 percentage units lower for macerated compared to conventionally conditioned alfalfa hay. Maceration of alfalfa conserved as hay resulted in 6.0 and 2.4 percentage points higher NDIN and soluble carbohydrates, respectively. This suggested that maceration of forage can result in a greater rumen escape of N (Agbossamey et al.1998) and greater availability of sugars for fermentation during ensiling. Macerated alfalfa silage and hay had more post-ensilage and post-storage soluble carbohydrate content and tended to contain a lower glucosamine content compared to conditioned alfalfa hay at 80 d after storage (Manuscript II). This suggested that some time, possibly at the early stage of silage and hay storage, the higher moisture level of the conventionally-conditioned forage facilitated mold growth, using up soluble carbohydrates and resulting in a greater depletion of the sugars in the conventionally conditioned than in macerated alfalfa.

Although LAB count was higher for SEVERE+ compared to CONV at 0 h post-cutting, these values were similar among harvest treatments from $10^{3.51}$ (CONV) to $10^{4.51}$ cfu g^{-1} DM (SEVERE+), at 24 h post-cutting (Table 4, Manuscript I). The lactic acid producing bacteria population of the macerated alfalfa in our study was below the recommended 10^6 cfu g^{-1} DM for forage inoculation, to support an ideal condition for fermentation (Mir et al. 1995; Henderson and McDonald, 1984). However, the tendency toward the positive impact of maceration on increasing LAB count disappeared during ensiling (Table 6, Manuscript II), probably due to differences in alfalfa DM content at baling that could interfere with maceration effect.

Lactic acid-producing bacteria (LAB) numbers tended to be greater ($10^{6.6}$ vs $10^{6.2}$) cfu g^{-1} DM) at the start of ensiling, tended to be lower during ensiling, and were similar by 22 d ensiling for macerated, relative to conventionally-conditioned alfalfa. Charmley et al. (1997) found a similar result with the current study using a precision chopped, macerated alfalfa silage placed in glass jars during 70 d ensiling. A greater cell surface area and available carbohydrates due to maceration on the initial day of ensiling, might have caused a greater attachment and growth of the microbes on the cell surface of the macerated forage. relative to conventionally-conditioned hay. However, as time progressed, sugars in the macerated forage may have become more depleted than the conventionally-conditioned forage, resulting in slower LAB growth in the macerated relative to the conventionally-conditioned forage.

The similarity of LAB counts between CONV vs SEVERE silage post-ensilage was illustrated with similarity in post-ensiled pH and acid contents between the two mowing

treatments. However, one (Manuscript II) out of two trials (Manuscripts II and III) in the current study showed a lower ethanol content for the macerated compared to conventionally-conditioned alfalfa, indicating that lower activity of yeast might have occurred in the macerated vs conventionally-conditioned alfalfa (Manuscript II).

Effect of maceration on DMI, total tract digestibility and performances in beef and dairy cattle

Macerated hay, as the sole feed in a digestibility study was similar in CP, ADF and NDF content, and lower in ADIN content than conventionally-conditioned forage. Dry matter intake in our study tended (10.8 vs. 10.0 kg d^{-1}) to be lower for macerated relative to conventionally-conditioned hay. Trials conducted by Petit et al. (1994) using timothy or alfalfa hay fed to sheep; Chiquette et al. (1994) using timothy hay fed to steers; Hong et al. (1988a) using alfalfa hay fed to sheep or alfalfa hay at 60% dietary DM in a TMR fed to lactating goats; and Petit et al. (1997) using timothy hay fed ad libitum to sheep as a supplement to concentrate, resulted in different responses for DMI. Three trials, one timothy and two alfalfa hays (Petit et al. 1994; Hong et al. 1988a), out of nine, showed a greater DMI due to maceration, 6.1 to 8.4% increases, for sheep fed macerated vs. conventionally conditioned hays. Four, two timothy (Petit et al. 1997; Chiquette et al. 1994) and two alfalfa trials with forage fed alone or as part of a TMR (Hong et al. 1988a) out of nine trials showed no effect of forage maceration on DMI. One trial out of nine using alfalfa hay fed to goats (Hong et al. 1988a) showed a tendency ($P = 0.10$) toward an increase in DMI as a result of forage maceration, and one trial using alfalfa hay fed to

steers (the current study) out of nine showed a tendency ($P = 0.08$) toward a decrease in dietary DMI due to forage maceration. Factors other than forage maceration such as severity of maceration, chop length, forage species and kind of diet, experimental animals and storage conditions of the conserved forage may have influenced the results. For instance, matted, macerated timothy hay fed to sheep resulted in a 8.4% increase in DMI for sheep (Petit et al. 1994), but no response when macerated timothy hay fed to steers was not matted (Chiquette et al. 1994), or when macerated timothy hay was fed as a part of a TMR diet for sheep (Petit et al. 1997). This phenomenon was also observed in alfalfa hay, which showed a positive response on DMI with maceration when fed alone (Petit et al. 1994; Hong et al. 1988a), but no response when the macerated forage was fed as a part of TMR (Hong et al. 1988; Petit et al. 1997).

Dry matter and CP digestibility were 8 and 32% higher (59 vs. 55 %, and 53 vs. 70 % , $P < 0.05$), but ADF and NDF digestibility were 22% lower (53 vs 43 and 50 vs. 40 %) for macerated vs. conditioned hay in the current study, respectively. Three out of six studies showed that maceration of alfalfa hay fed as a sole diet to sheep (Petit et al. 1994); silage fed to sheep (Mertens and Hintz 1990, cited by Koegel et al. 1992) or timothy hay fed to sheep (Petit et al. 1994) also resulted in 11.7, 15.9, and 6.8% higher DMD, respectively. Hong et al. (1988a) using alfalfa hay fed alone to sheep noted that maceration did not affect DMD, while Chiquette et al. (1994) using timothy hay fed to steers observed a 1.2% lower DMD. All the mentioned studies used mower-conditioned forages as a control. Differences in the type of macerator and conditioner, species of forages and animals, and growth stage of plants used and methods of forage wilting, may

partly have influenced the variation of the results. For instance, Petit et al. (1994) used a younger growth stage, 10% head emergence, of timothy pressed the macerated forage to form a mat, and wilted the forage partly on field and partly in barn using a forced air flow, whereas Chiquette et al. (1994) did not use the making or barn wilting processes. Hong et al. (1988a) used alfalfa of a younger, late bud to first flower, growth stage relative to the growth stage of alfalfa used in the study conducted by Petit et al. (1994), 10% bloom, or in the current study, early flower. Comparison of the results in dry matter digestibility of Hong et al. (1988a) to that of Petit et al. (1994) or the current study suggests that maceration of younger stage of growth within the interval of late vegetative (first bud to early bloom) may have resulted in a lower improvement in dry matter digestibility compared to maceration of alfalfa forage at the older stage. However, since there were differences in the macerators, conditioners and wilting conditions among the three studies, the effect of forage maceration at different growth stages on DMD requires further research. Whether lower dry matter digestibility for the macerated timothy hay as compared to conventionally conditioned hay in the results of Chiquette et al. (1994) study relative to the reverse results for the study of Petit et al. (1994) was due partly to plant maturity is also still open to question since other factors (animal species and wilting method differences) were involved. Comparisons of the increase in dry matter digestibility due to forage maceration in Mertens and Hintz's (1990) study to that of Petit et al. (1994) study may suggest that forage maceration conserved as silage is probably more beneficial in improving dry matter digestibility compared to that of hay.

Differences in maceration intensity among trials may also affect differences in

digestibility results by influencing rumen environment. More severely macerated forage causes the plant material, especially the more lignified parts such as stems to be extensively shredded or broken down, compared to conventionally conditioned or lightly macerated forage. It has been observed that differences in physical form of forage can affect salivation through differences in chewing activity during eating and ruminating. It is possible that the intensity of maceration was negatively related with chewing activity and saliva production. A decrease in saliva production with increasing maceration severity can lower rumen pH to a level that is more conducive for the growth of non- cellulolytic rumen bacteria. This condition can negate the positive impact of maceration on digestibility due to greater surface area of the macerated forage compared to conventionally conditioned or lightly macerated forage. Therefore, very severe maceration of forage may not have a beneficial effect on forage DM digestion, although very severe maceration can have beneficial effect in enhancing DMI.

A higher ADIN content in the conventionally-conditioned hay, maybe due to heating, can contribute to lower total tract CP digestibility. Forage maceration did not affect forage CP digestibility of alfalfa hay (Hong et al. 1988a) or timothy hay Chiquette et al. (1994) fed alone to steers, or in timothy hay fed as part of a TMR to sheep (Petit et al. 1997).

Lower ADF and NDF digestibilities of macerated alfalfa hay could possibly be related to differences in the passage rate (retention time) of the hay from the rumen. Broderick et al. (1993) observed that cows fed a TMR containing heated alfalfa hay had a lower dietary DM digestibility and higher dietary NDF digestibility compared to those

fed a TMR containing unheated alfalfa hay, a finding similar to our results. A 13 percentage unit higher NDF content was identified due to heating (Broderick et al. 1993), which might have caused lower DM digestibility for the heated compared to unheated dietary hay. It was possible that CONV hay in our study had a higher storage temperature compared to macerated hay, as indicated by the higher ADIN and NDIN contents in the CONV hay.

Four out of six studies showed that maceration of forage in which the forage was conserved as hay and fed to sheep, resulted in an increase in CP digestibility, by 13 to 35%. Older stage of plant growth seemed to result in a greater increases CP digestibility due to maceration. Two out of the six studies, Chiquette et al. (1994) and the current study, showed that forage maceration decreased NDF digestibility by 2.2 and 22.1%, respectively, when timothy or alfalfa hay fed alone to steers. Factors other than maceration may be implicated by the results of these studies.

In the initial 21 d of the feeding trial, beef calves fed macerated silage consumed greater DM and gained more relative to those fed the conventionally-conditioned silage or hay. In the interval of 3 - 6 week period during the growing trial, feed was more efficiently used for gain compared to conditioned silage. However, the beneficial effects of forage maceration in increasing DMI and BWG disappeared thereafter in a of 78 d feeding trial.

Primiparous and multiparous Holstein cows fed a TMR containing macerated alfalfa silage and hay in a 14-week early lactation trial showed similar dietary DMI, high but similar daily milk yield (39 kg cow^{-1}) compared to cows fed TMR containing alfalfa

forage harvested with a mower-conditioner. Cows fed a TMR containing macerated alfalfa, however, had greater body weight gain and a tendency toward a greater body condition score (BCS) at the end of the trial. The silage-based diets were formulated to contain similar nutrient profiles, with a forage : concentrate ratio of 42 : 58, DM basis. This suggested that the TMR containing macerated forage was more efficiently used for producing body weight (fat and lean) compared to a TMR containing mower-conditioned forage. At the end of the feeding trial, cows fed the TMR containing macerated forage had a BCS close to the initial BCS of 3.2, while those fed the other TMR were still well below that point. The results of our study was similar with those of Mertens and Hintz (1990, as cited by Koegel et al. 1992), that sheep fed the macerated alfalfa silage gained more BW compared to those fed the not-macerated alfalfa silage.

As severity of maceration may explain variation among studies, it is difficult to compare the results among studies, since the severity of maceration may vary from one study to another. Therefore, it is important to develop a valid measure to compare the severity of forage maceration, to ease comparison of results among studies. One of the possible means of comparing the severity of maceration is a compression test to measure bulk density of the fresh cut forage. Compression tests in the current study suggested that the degree of maceration correlated well with fresh bulk density. It seems worthwhile to include compression test results in the study of forage maceration.

Based on the inconsistent results in the current growing and digestibility studies, further studies are still required to establish the feed value of macerated alfalfa for the ruminants.

CONCLUSIONS

Under good weather in dry-climate, North American prairie conditions, maceration of alfalfa up to LIGHT+ was reasonable and can be recommended to shorten wilting time When precipitation occurred during wilting, the beneficial effect of maceration to shorten wilting time, especially with greater intensity, decreased. Alfalfa maceration did not result in significant leaf and juice losses at time of cutting, based on the nutrient profile of forage sampled immediately after harvest and post-storage. The macerated forage showed greater fresh bulk density, a suggestion that the forage can be packed more densely in silo at the time of loading compared to that of conventionally conditioned forage.

Alfalfa maceration had a marginal, positive effect on improving round bale silage quality as indicated with improvement of post-ensilage soluble carbohydrate levels and a decrease in post-ensilage ethanol content for macerated vs conventionally conditioned alfalfa silage. This positive effect of maceration was indicated in the initial 6-week of growing trial.

Alfalfa maceration had a marginal impact on round bale hay quality as indicated by higher post-storage soluble carbohydrate levels and lower ADIN levels.

Beef calves fed severely macerated alfalfa had a better performance in the initial 42-day of a growing trial. The beneficial effect of maceration disappeared after 42 d during a 78-d feeding trial. Beef steers fed severely macerated alfalfa hay tended to have

lower DMI, ADF, and NDF digestibilities compared to those fed the conventionally conditioned hay. However, DM and CP digestibilities were higher for steers fed the macerated alfalfa hay as the sole diet.

Dairy cows fed TMR containing macerated silage and hay produced similar milk yield and milk composition, relative to those fed TMR containing conventionally conditioned silage and hay. However, feeding macerated alfalfa to lactation dairy cows as part of TMR can be recommended to minimize a decrease in body weight loss and BCS loss during lactation period.

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APPENDIXES

Appendix I.1 T. tests for comparing effect of maceration level on field wilting coefficients, k: $t_{[0.05 \text{ with } 41, 57, \text{ and } 96 \text{ df, respectively}]}$ (t values = 1.68, 1.67, and 1.66, respectively) for 0-3, 3-24, and 24-51 h post-cutting for forage not exposed to precipitation; $t_{[0.05 \text{ with } 16 \text{ and } 41 \text{ df, respectively}]}$ (t values = 1.75 and 1.68) for 3-24 and 24-51 h post-cutting for forage exposed to precipitation 1.5 h post-cutting; and $t_{[0.05, \text{ with } 19 \text{ df}]}$ (t value = 1.73) for 24-51 h post-cutting for forage exposed to precipitation 24 h post-cutting.

	Without precipitation				t cal
Treatment comparison	kx	ky	Sx	Sy	$(kx-ky)/Sqrt(Sx^2 + Sy^2)$
			0 - 3 h post-cutting		
CONV vs LIGHT	0.166	0.171	0.042	0.042	0.084
CONV vs LIGHT+	0.166	0.236	0.042	0.048	1.098
CONV vs SEVERE	0.166	0.188	0.042	0.046	0.353
CONV vs SEVERE+	0.166	0.326	0.042	0.052	2.394*
LIGHT vs LIGHT+	0.171	0.236	0.042	0.048	1.019
LIGHT vs SEVERE	0.171	0.188	0.042	0.046	0.273
LIGHT vs SEVERE+	0.171	0.326	0.042	0.052	2.319*
LIGHT+ vs SEVERE	0.236	0.188	0.048	0.046	0.722
LIGHT+ vs SEVERE+	0.236	0.326	0.048	0.052	1.272
SEVERE vs SEVERE+	0.188	0.326	0.046	0.052	1.806*

		3-24 h post-cutting			
CONV vs LIGHT	0.036	0.078	0.012	0.012	2.475*
CONV vs LIGHT+	0.036	0.076	0.012	0.013	2.261*
CONV vs SEVERE	0.036	0.090	0.012	0.018	2.496*
CONV vs SEVERE+	0.036	0.106	0.012	0.016	3.500*
LIGHT vs LIGHT+	0.078	0.076	0.012	0.013	0.113
LIGHT vs SEVERE	0.078	0.090	0.012	0.018	0.555
LIGHT vs SEVERE+	0.078	0.106	0.012	0.016	1.400
LIGHT+ vs SEVERE	0.076	0.090	0.013	0.018	0.631
LIGHT+ vs SEVERE+	0.076	0.106	0.013	0.016	1.455
SEVERE vs SEVERE+	0.090	0.106	0.018	0.016	0.664

		24-51 h post-cutting			
CONV vs LIGHT	0.022	0.025	0.005	0.005	0.424
CONV vs LIGHT+	0.022	0.014	0.005	0.006	1.024
CONV vs SEVERE	0.022	0.003	0.005	0.007	2.209*
CONV vs SEVERE+	0.022	0.002	0.005	0.008	2.120*
LIGHT vs LIGHT+	0.025	0.014	0.005	0.006	1.408
LIGHT vs SEVERE	0.025	0.003	0.005	0.007	2.557*
LIGHT vs SEVERE+	0.025	0.002	0.005	0.008	2.438*
LIGHT+ vs SEVERE	0.014	0.003	0.006	0.007	1.193
LIGHT +vs SEVERE+	0.014	0.002	0.006	0.008	1.200
SEVERE vs SEVERE+	0.003	0.002	0.007	0.008	0.094

		Precipitation at 1.5 h post-cutting			
		3 - 24 h post-cutting			
CONV vs LIGHT	0.062	0.111	0.022	0.022	1.575
CONV vs LIGHT+	0.062	0.113	0.022	0.022	1.639
CONV vs SEVERE	0.062	0.123	0.022	0.022	2.194*
CONV vs SEVERE+	0.062	0.078	0.022	0.017	0.575
LIGHT vs LIGHT+	0.111	0.113	0.022	0.017	0.064
LIGHT vs SEVERE	0.111	0.123	0.022	0.022	0.432
LIGHT vs SEVERE+	0.111	0.076	0.022	0.017	1.187
LIGHT+ vs SEVERE	0.113	0.123	0.022	0.017	0.360
LIGHT+ vs SEVERE+	0.113	0.078	0.022	0.017	1.259
SEVERE vs SEVERE+	0.123	0.078	0.017	0.017	1.871*

		24 - 51 h post-cutting			
CONV vs LIGHT	0.033	0.031	0.012	0.012	0.118
CONV vs LIGHT+	0.033	0.027	0.012	0.012	0.354
CONV vs SEVERE	0.033	0.007	0.012	0.012	1.532
CONV vs SEVERE+	0.033	0.052	0.012	0.014	1.030
LIGHT vs LIGHT+	0.031	0.027	0.012	0.012	0.236
LIGHT vs SEVERE	0.031	0.007	0.012	0.014	1.414
LIGHT vs SEVERE+	0.031	0.052	0.012	0.014	1.139
LIGHT vs SEVERE	0.027	0.007	0.012	0.012	1.179
LIGHT vs SEVERE+	0.027	0.052	0.012	0.014	1.356
SEVERE vs SEVERE+	0.007	0.052	0.012	0.014	2.440*

	Precipitation at 24 h post-cutting				
	24 - 51 h post-cutting				
CONV vs LIGHT	0.059	0.086	0.066	0.066	0.289
CONV vs LIGHT+	0.059	0.021	0.066	0.066	0.407
CONV vs SEVERE	0.059	0.085	0.066	0.066	0.279
CONV vs SEVERE+	0.059	0.058	0.066	0.066	0.011
LIGHT vs LIGHT+	0.086	0.021	0.066	0.066	0.696
LIGHT vs SEVERE	0.086	0.085	0.066	0.066	0.011
LIGHT vs SEVERE+	0.086	0.058	0.066	0.066	0.300
LIGHT+ vs SEVERE	0.021	0.085	0.066	0.066	0.686
LIGHT+ vs SEVERE+	0.021	0.058	0.066	0.066	0.396
SEVERE vs SEVERE+	0.085	0.058	0.066	0.066	0.289

Appendix I.2. Analysis of variance of bulk density of alfalfa forage immediately after cutting

Dependent variable: Pfmax

Source	DF	SS	MS	F value	P > F
Trt	4	139.4980	34.8745	.93	.526
Block	1	124.0020	124.0020	3.32	.143
Trt*Block	4	149.6080	37.4020	4.06	.033
Error	10	92.2200			

Dependent variable: Pf.

Trt	4	8640.6642	2160.1661	7.76	.05
Block	1	0.49298	0.4930	0.11	.75
Trt*Block	4	1113.6156	4.4350		
Error	10	44.3501			

Appendix I. 3. Anova of post-wilting nutrient profile of alfalfa forage harvested at 5 levels of maceration exposed or not exposed to precipitation.

Dependent variable CP.

Source	DF	SS	MS	F value	P > F
Trt.	4	22.5958	5.6490	6.98	0.05
Block	1	0.0804	0.0804	0.21	0.65
Trt. * Block	4	3.2393	0.8098	2.09	0.137
Precip.	2	1.1380	0.5690	0.26	0.264
Precip * Trt.	8	9.2835	1.1604	2.99	0.035
Precip.*Trt.*Block	10	13.7132	1.3713	3.53	0.016
Error	14	5.4356			

Dependent variable: Soluble N.

Trt	4	54.3723	13.5931	1.82	0.29
Block	1	0.9957	0.9957	0.13	0.73
Trt*Block	4	29.8513	7.4628	4.24	0.05
Precip	2	16.6834	8.3417	0.03	0.05
Trt*Precip	8	55.0318	6.8790	0.01	0.05
Trt*Block*Precip	9	57.3192	6.3688	3.62	0.05
Error	13	22.8945	1.7611		

Dependent variable: ADIN

Source	DF	SS	MS	F value	P > F
Trt	4	8.1026	2.0256	3.54	0.12
Block	1	0.0057	0.0057	0.01	0.92
Trt*Block	4	2.2884	0.5721	1.79	0.19
Precip	2	2.2555	1.1278	0.06	0.06
Trt*precip	8	4.2346	0.5293	0.20	0.20
Trt*Block*Precip	7	3.2026	0.4575	0.27	0.27
Error	14	4.4723	0.3195		

Dependent variable: Soluble sugars

Trt	4	423.0125	105.7531	4.88	0.08
Block	1	205.4531	205.4531	9.49	0.04
Trt*block	4	86.6189	21.6547	1.25	0.34
Precip	2	158.6495	79.3247	4.58	0.03
Trt*Precip	8	368.0785	46.0098	2.66	0.06
Trt*Block*Precip	10	598.8110	59.8811	3.46	0.05
Error	13	225.2764			

Dependent variable: ADF

Source	DF	SS	MS	F value	P > F
Trt	4	121.1665	30.2916	4.31	0.09
Block	1	32.2547	32.2547	4.59	0.10
Trt*Block	4	28.0841	7.0210	2.76	0.07
Precip	2	2.2820	1.1410	0.45	0.65
Trt*Precip	8	27.2561	3.4070	1.34	0.30
Trt*Block*Precip	10	20.9474	2.0947	0.82	0.61
Error	14	35.5962			

Dependent variable: NDF

Trt	4	208.6375	52.15938	21.11	0.01
Block	1	55.0808	55.0808	22.29	0.01
Trt*Block	4	9.8842	2.4710	0.65	0.64
Precip	2	38.7934	19.3967	5.08	0.05
Trt*Precip	8	52.5239	6.5655	1.72	0.18
Trt*Block*Precip	10	29.3795	2.9380	0.77	0.66
Error	14	53.4584			

Dependent variable: Glucosamine

Trt	4	0.3220	0.0805	1.06	0.48
Block	1	1.0584	1.0584	13.94	0.05
Trt*Block	4	0.3036	0.3036	1.23	0.34
Precip	2	0.4008	0.4008	0.07	0.07
Trt*Precip	8	0.4876	0.0610	0.49	0.49
Trt*Precip*Block	10	1.0165	0.1017	1.65	0.20
Error	13	0.8007			

Appendix L4. Lactic acid bacteria and total bacteria counts for alfalfa forage during wilting harvested at 4 levels of maceration.

Dependent variable: LAB, at 0 h post-cutting

Source	DF	SS	MS	Fcal	P > Ftable
Trt	3	6.0856	2.0285	21.59	0.05
Block	1	0.0326	0.0326	0.35	0.60
Trt*Block	3	0.2819	0.0940	0.37	0.77
Error	22	5.5476	0.2522		

Deependent variable: LAB, 3 h post-cutting.

Trt	3	1.6490	0.5497	1.88	0.31
Block	1	1.0464	1.0464	3.58	0.15
Trt*Block	3	0.8767	0.2922	2.85	0.06
Error	22	2.2524			

Deependent variable: LAB, 24 h post-cutting

Trt	3	5.0415	1.6805	2.69	0.21
Block	1	1.3822	1.3822	2.21	0.23
Trt*Block	3	1.8763	0.6254	5.24	0.01
Error	24	2.8665	0.1194		

Deependent variable: TB, 0 h post-cutting

Trt	3	3.5602	1.1867	1.46	0.38
Block	1	0.2509	0.2509	0.31	0.62
Trt*Block	3	2.4412	0.8137	2.44	0.09
Error	22	7.3408	0.3337		

Deependent variable: TB, 3 h post-cutting

Source	DF	SS	MS	F value	P > F
Trt	3	0.1524	0.0508	0.06	0.98
Block	1	0.0254	0.0254	0.03	0.87
Trt*Block	3	2.5169	0.8390	5.81	0.01
Error	21	3.0315	0.1444		

Deependent variable: TB, 24 h post-cutting

Trt	3	0.0330	0.0110	0.01	1.00
Block	1	1.0781	1.0781	0.63	0.48
Trt*Block	3	5.1072	1.7024	19.86	0.01
Error	24	2.0570	0.0857		

Overall Anova of LAB and TB counts, repeated measure over time.

Deependent variable: LAB

Trt	3	11.2310	3.7437	6.90	0.07
Block	1	0.0031	0.0031	0.01	0.94
Trt*Block	3	1.6270	0.5423	3.46	0.05
Time	2	1.5555	0.7777	4.96	0.01
Trt*Time	6	0.8188	0.1365	0.87	0.52
Trt*Block*Time	8	3.6788	0.4599	2.93	0.01
Error	68	10.6665	0.1569		

Dependent variable: TB

Source	DF	SS	MS	F value	P > F
Trt	3	1.8051	0.6017	2.67	0.22
Block	1	0.5933	0.5933	2.64	0.20
Trt*Block	3	0.6751	0.2250	1.21	0.31
Time	2	1.7263	0.8632	4.65	0.05
Trt*Time	6	1.9529	0.3255	1.75	0.12
Trt*Block*Time	8	8.9691	1.1211	6.04	0.01
Error	67	12.4293	0.1855		

Appendix II. 1. Anova of nutrient and fermentation profiles of round bale silage at two harvest (Trt) methods

Dependent variable: DM

Source	DF	SS	MS	Fcal	P > F
Trt	1	230.8176	230.8176	13.70	0.05
Bale (Trt)	4	67.3879	16.8470	2.42	0.21
Day	1	0.2491	0.2491	0.04	0.85
Trt*Day	1	6.0620	6.0620	0.87	0.40
Error	4	27.8650	6.9663		

Dependent variable: CP

Trt	1	977.5277	977.5277	.55.24	.01
Bale (Trt)	16	283.1454	17.6966	1.07	0.46
Day	1	3496.5929	3496.5929	210.85	.01
Trt*Day	1	389.4884	389.4884	23.49	.01
Error	14	232.1683	16.5834		

Dependent variable: NDF

Trt	1	10.0306	10.0306	3.30	0.09
Bale (Trt)	15	48.6817	3.0423	1.51	0.21
Day	1	67.2355	67.2355	33.42	0.01
Trt*Day	1	3.0990	3.0990	1.54	0.23
Error	15	30.1780			

Dependent variable: ADF

Source	DF	SS	MS	F value	P > F
Trt	1	0.3787	0.3787	0.21	0.66
Bale (Trt)	16	29.4154	1.8385	0.51	0.90
Day	1	98.6023	98.6023	27.56	0.01
Trt*Day	1	0.8213	0.8213	0.23	0.64
Error	14	50.0834	3.5773		

Dependent variable: Soluble N

Trt	1	977.5277	977.5277	55.24	0.01
Bale (Trt)	16	283.1454	17.6966	1.07	0.46
Day	1	3496.5929	3496.5929	210.85	0.01
Trt*Day	1	389.4884	389.4884	23.49	0.01
Error	14	232.1683	16.5835		

Dependent variable: NDIN

Trt	1	88.9923	88.9933	105.43	0.01
Bale (Trt)	16	13.5050	0.8441	0.93	0.56
Day	1	83.0286	83.0286	91.86	0.01
Trt*Day	1	33.6002	33.6002	37.17	0.01
Error	11	9.9423	0.9038		

Dependent variable: ADIN

Source	DF	SS	MS	F value	P > F
Trt	1	2.8143	2.8143	7.82	0.05
Bale (Trt)	16	5.7560	0.3597	1.98	0.1023
Day	1	5.5430	5.5430	30.56	0.01
Trt*Day	1	0.2746	0.2746	1.51	0.24
Error	14	2.5391	0.1814		

Dependent variable: soluble carbohydrates

Trt	1	904.0087	904.0087	5.93	0.05
Bale (Trt)	16	2441.0601	152.5663	1.52	0.21
Day	1	1941.5180	1941.5180	19.29	0.01
Trt*Day	1	1599.8210	1599.8210	15.89	0.01
Error	15	1509.9307	100.6620		

Dependent variable: pH

Trt	1	0.0016	0.0016	0.40	0.56
Bale (Trt)	4	0.0161	0.0040	10.52	0.05
Day	1	0.5376	0.5376	1402.52	0.01
Trt*Day	1	0.0040	0.0040	10.52	0.05
Error	4	0.0015	0.0004		

Dependent variable: Ethanol

Source	DF	SS	MS	F value	P > F
Trt	1	2.3640	2.3640	42.32	0.01
Bale (Trt)	4	0.2234	0.0559	0.54	0.72
Day	1	7.3688	71.3688	71.36	0.01
Trt*Day	1	1.6371	1.6371	15.85	0.02
Error	4	0.4130	0.1033		

Dependent variable: Lactic acid

Trt	1	112.5454	112.5454	4.92	0.09
Bale (Trt)	4	91.4395	22.8599	1.02	0.49
Day	1	1307.7997	1307.7997	58.57	0.01
Trt*Day	1	94.5412	94.5412	4.23	0.11
Error	4	89.3093	22.3273		

Deependent variable: Acetic acid

Trt	1	20.6132	20.6132	2.22	0.21
Bale (trt)	4	37.1121	9.2781	3.26	0.14
Day	1	17.0737	17.0737	6.00	0.08
Trt*Day	1	0.1496	0.1496	0.05	0.83
Error	4	11.3840	2.8460		

Dependent variable: Propionic acid

Source	DF	SS	MS	F value	P > F
Trt	1	0.0362	.0362	2.45	0.19
Bale (trt)	4	0.0592	0.0148	1.39	0.38
Day	1	0.0856	0.0856	8.02	0.05
Trt*Day	1	0.0289	0.0289	2.71	0.18
Error	4	0.0427	0.0107		

Dependent variable: Butyric acid

Trt	1	0.0154	0.0154	0.83	0.42
Bale (Trt)	4	0.0743	0.0186	1.00	0.50
Day	1	0.1364	0.1364	7.35	0.06
Trt*Day	1	0.0153	0.0153	0.83	0.41
Error	4	0.0743	0.0186		

Dependent variable: Isobutyric acid

Trt	1	1.3084	1.3084	142.43	0.01
Bale (Trt)	4	0.0367	0.0092	2.31	0.22
Day	1	3.3649	3.3649	845.59	0.01
Trt*Day	1	1.2063	1.2063	303.15	0.01
Error	4	0.0159	0.0040		

Appendix II. 2. Anova of post-wilting hay nutrient profile

Dependent variable: DM

Source	DF	SS	MS	F value	P > F
Trt	2	566.4212	283.2106	69.44	0.01
Bale(Trt)	9	36.7049	4.0783	1.37	0.34
Day	1	433.0907	433.0907	145.07	0.01
Trt*Day	2	491.8876	245.9438	82.38	0.01
Error	8	23.8831	2.9854		

Dependent variable: CP

Trt	2	16.53711	8.26855	6.86	0.02
Bale(Trt)	8	9.6406	1.2051	2.51	0.05
Day	1	0.0122	0.0122	0.03	0.88
Trt*Day	2	0.5750	0.2875	0.60	0.56
Error	18	8.6439	0.4802		

Dependent variable: NDF

Source	DF	SS	MS	F value	P > F
Trt	2	55.0483	27.5241	2.15	0.18
Bale(Trt)	8	102.4449	12.8056	3.18	0.05
Day	1	274.6444	274.6444	68.18	0.01
Trt*Day	2	80.6384	40.3192	10.01	0.01
Error	18	72.5064	4.0281		

Dependent variable: ADF

Trt	2	28.4016	14.2008	2.18	0.18
Bale (Trt)	8	52.1267	6.5158	1.96	0.12
Day	1	69.4227	69.4227	20.84	0.01
Trt*Day	2	42.6188	21.3094	6.40	0.01
Error	16	53.2924	3.3308		

Dependent variable: Soluble N

Source	DF	SS	MS	F value	P > F
Trt	2	170.0171	85.0085	7.67	.05
Bale (Trt)	8	88.6578	11.0822	1.13	0.39
Day	1	357.5562	357.5562	36.46	0.01
Trt*Day	2	9.1523	4.5761	0.47	0.63
Error	18	176.5328	9.8074		

Dependent variable: ADIN

Trt	2	45.6036	22.8018	9.81	0.01
Bale (Trt)	8	18.6031	2.3254	1.51	0.23
Day	1	38.0728	38.0728	24.75	0.01
Trt*Day	2	37.7777	18.8889	12.28	0.01
error	16	24.6171	1.5386		

Dependent variable: Soluble carbohydrates

Source	DF	SS	MS	F value	P > F
Trt	2	2502.1323	1251.0662	26.04	0.01
Bale (Trt)	8	384.2785	48.0348	1.08	0.42
Day	1	1953.5990	1953.5990	43.87	0.01
Trt*Day	2	400.3140	200.1570	4.50	0.05
Error	18	801.4843	44.5269		

Dependent variable: Glucosamine

Trt	2	0.6872	0.3436	10.23	0.01
Bale (Trt)	13	0.4367	0.336	0.74	0.70
Day	1	1.4866	1.4866	32.93	0.01
Trt*Day	2	1.2181	0.6090	13.49	0.01
Error	13	0.5869	0.0451		

Appendix II. 3. Anova of beef calf performances for the 78-d growing trial.

Dependent variable: initial 21-d DMI, kg d^{-1}

Source	DF	SS	MS	F value	P > F
Trt	2	2.6816	1.3408	19.30	0.01
Inwt	1	1.3185	1.3185	18.98	0.01
Error	13	0.9032	0.0695		

Dependent variable: initial 21-d DMI, % BW

Trt	2	0.000031	0.000015	19.02	0.01
Inwt	1	0.000002	0.0000022	2.68	0.13
Error	13	0.000010	0.0000008		

Dependent variable: initial 21-d FCR

Trt	2	7.5686	3.7843	3.43	0.06
Inwt	1	5.5240	5.5240	5.01	0.04
Error	13	14.3361	1.1028		
Total	16	25.5670			

Dependent variable: Initial 21-d ADG

Trt	2	0.3633	0.1816	4.30	0.05
Inwt	1	0.6749	0.6749	15.97	0.01
Error	30	1.2678	0.0423		

Dependent variable: overall DMI, kg d^{-1}

Source	DF	SS	MS	F value	P > F
Trt	2	0.9415	0.4707	2.48	0.12
Inwt	1	2.3968	2.3968	12.61	0.01
Error	13	2.4704	0.1900		

Dependent variable: overall DMI, % BW

Trt	2	0.0000052	0.000003	1.80	0.20
Inwt	1	0.0000004	0.0000004	0.28	0.60
Error	13	0.00002			

Dependent variable: overall FCR

Trt	2	1.3710	0.6855	1.10	0.36
Inwt	1	0.1360	0.1360	0.22	0.65
Error	13	8.1336	0.6257		

Dependent variable: overall ADG

Trt	2	0.0879	0.439	2.21	0.13
Inwt	1	0.0892	0.0892	4.49	0.5
Error	30	0.5961	0.0199		

Appendix II. 4. Anova for steer performances in the digestibility study.

Deependent variable: DMI, kg d^{-1}

Source	DF	SS	MS	F value	P > F
Sq	1	0.0850	0.0850	0.20	0.65
Trt	1	6.9910	6.9910	12.88	0.08
Per	1	15.9895	15.9895	29.46	0.05
Steer (Sq)	2	7.7537	3.8769	9.35	0.01
Trt*Steer*Per (Sq)	2	1.0856	0.5428	1.31	0.28
Error	44	18.2811	0.4155		

Dependent variable: DMI, % BW

Sq	1	0.0404	0.0404	1.25	0.27
Trt	1	0.6398	0.6398	10.85	0.08
Per	1	0.4153	0.4153	7.61	0.11
Steer (Sq)	2	0.3020	0.1510	4.65	0.05
Trt*Sterr*Per (Sq)	2	0.1179	0.0590	1.82	0.17
Error	44	1.4289	0.0325		

Dependent variable: DMD

Source	DF	SS	MS	F value	P > F
Square	1	3.6782	3.6782	0.50	0.48
Trt	1	255.9982	255.9982	21.58	0.05
Trt*Square	1	270.3624	270.3624	21.58	0.05
Period	1	3.8544	3.8544	0.53	0.47
Steer (Sq)	2	83.1714	41.5857	3.99	0.05
Trt*Steer*Per (Sq)	2	23.7203	11.8602	1.14	0.33
Error	44	456.2334	10.3689		

Dependent variable: CPD

Sq	1	0.000073	0.000073	0.00	0.999
Trt	1	3515.0818	3515.0818	172.50	0.01
Per	1	305.2803	305.2803	15.40	0.06
Steer (Sq)	2	204.1702	102.0851	3.93	0.05
Trt*Steer*Per (Sq)	2	40.7552	20.3776	0.78	0.46
Error	40	1024.8628	25.6216		

Dependent variable: NDFD

Source	DF	SS	MS	F value	P > F
Sq	1	0.8234	0.8234	0.02	0.89
Trt	1	1546.3750	1546.3750	43.47	0.05
Per	1	1.7701	1.7701	0.05	0.84
Steer (Sq)	2	283.7194	141.8597	3.21	0.052
Trt*Steer*Per (Sq)	2	71.1462	35.5131	0.81	0.45
Error	38	1635.4910	43.0392		

Dependent variable: ADFD

Source	DF	SS	MS	F value	P > F
Sq	1	0.9986	0.9986	0.02	0.88
Trt	1	843.8617	843.8617	48.34	0.05
Per	1	108.3335	108.3335	6.21	0.13
Steer (Sq)	2	256.5098	128.2549	3.18	0.53
Trt*Steer*Per (Sq)	2	34.0606	17.0303	0.41	0.67
Error	37	1490.1961	40.2756		

Appendix III. 1. Anova of feed DMI, BW and BCS for dairy cows in lactation study

Dependent variable: DMI, kg week^{-1}

Source	DF	SS	MS	F value	P > F
Trt	1	439.6789	439.6789	0.08	0.78
Parity	1	81200.1603	81200.1603	14.91	0.01
Trt*Par	1	6000.4010	6000.4010	1.10	0.30
Cow (Trt*Parity)	29	157940.4547	5446.2226	25.12	0.01
Week	13	107897.3241	8299.7942	38.28	0.01
Trt*Week	13	3305.2988	254.2538	1.17	0.30
Parity*week	13	1339.8957	103.0689	0.48	0.94
Trt*Parity*Week	13	3831.7310	294.7485	1.36	0.18
Error	377	81731.6369			

Dependent variable: BW

Trt	1	6046.4926	6046.4926	0.67	0.42
Parity	1	225482.8395	225482.8395	25.05	0.01
Trt*parity	1	739.1146	739.1146	0.08	0.78
Cow (Trt*Parity)	29	260986.7540	8999.5432	24.66	0.01
Period	4	32315.5579	8078.8895	22.14	0.01
Trt*Period	4	2865.6661	716.4165	1.96	0.10
Parity*Period	4	7278.3758	1819.5939	4.99	0.01
Trt*Parity*Period	4	1649.3593	412.3398	1.13	0.35
Error	116	42332.7913	364.9379		

Dependent variable: BCS

Source	DF	SS	MS	F value	P > F
Trt	1	0.7858	0.7858	3.40	0.08
Parity	1	0.0020	0.0020	0.01	0.93
Trt*Parity	1	2.442	2.442	9.72	0.01
Cow (Trt*Parity)	29	6.6956	0.2309	7.32	0.01
Period	4	0.9161	0.2290	7.26	0.01
Trt*Period	4	0.0099	0.0025	0.08	0.99
Parity*Period	4	0.3658	0.0915	2.90	0.05
Trt*Parity*Period	4	0.1401	0.0350	1.11	0.36
Error	116	3.6597	0.0315		

Appendix III. 3. Anova of milk production and composition for cows in lactation study

Dependent variable: Milk production, kg d^{-1}

Source	DF	SS	MS	F value	P > F
Trt	1	10.4964	10.4964	0.04	0.85
Parity	1	18631.7066	16831.7066		0.01
Trt*Parity	1	447.8732	447.8732	1.58	0.22
Cow (Trt*Parity)	29	8244.6179	284.2972	38.70	0.01
Week	13	541.1476	41.6267	5.67	0.01
Trt*Week	13	73.7755	5.6750	0.77	0.69
Parity*week	13	190.1831	14.6295	1.99	0.05
Trt*Parity*Week	13	80.3014	6.1770	0.84	0.62
Error	377	2769.1997			

Dependent variable: 4% FCM, kg d^{-1}

Trt	1	0.0637	0.0637	0.00	0.99
Parity	1	11405.4430	11405.4430	42.20	0.01
Trt*Parity	1	43.0052	43.0052	0.16	0.69
Cow (Trt*Parity)	29	7837.3581	270.2537	18.79	0.01
Week	13	104.0880	8.0068	0.56	0.89
Trt*Week	13	146.9879	11.3068	0.79	0.68
Parity*Week	13	401.6007	30.8924	2.15	0.05
Trt*Parity*Week	13	143.2313	11.0178	0.77	0.69
Error	366	5263.8012			

Dependent variable: Butterfat, kg d^{-1}

Source	DF	SS	MS	F value	P > F
Trt	1	0.0119	0.0119	0.02	0.90
Parity	1	11.8062	11.8062	17.35	0.01
Trt*Parity	1	0.0220	0.0220	0.03	0.86
Cow (Trt*Parity)	29	19.7332	0.6805	14.19	0.01
Week	13	0.9139	0.0703	1.47	0.13
Trt*Week	13	0.4431	0.0341	0.71	0.75
Parity*Week	13	1.1390	0.0876	1.83	0.05
Trt*Parity*Week	13	0.4919	0.0378	0.79	0.67
Error	366	17.5511	0.0480		

Dependent variable: Butterfat, % in milk.

Trt	1	0.4174	0.4174	0.10	0.75
Parity	1	1.0055	1.0055	0.24	0.62
Trt*Parity	1	3.5199	3.5199	0.86	0.36
Cow (Trt*Parity)	29	119.0433	4.1049	14.60	0.01
Week	13	14.6641	1.1280	4.01	0.01
Trt*Week	13	2.5671	0.1975	0.70	0.76
Parity*Week	13	4.8548	0.3734	1.33	0.19
Trt*Parity*Week	13	3.3005	0.2539	0.90	0.55
Error	366	102.9391	0.2813		

Dependent variable: Milk protein, kg d^{-1}

Source	DF	SS	MS	F value	P > F
Trt	1	0.0227	0.0227	0.11	0.74
Parity	1	11.7090	11.7090	57.04	0.01
Trt*Parity	1	0.1679	0.1679	0.82	0.37
Cow (Trt*Parity)	29	5.9535	0.2053	17.36	0.01
Week	13	0.2016	0.0155	1.31	0.20
Trt*Week	13	0.1105	0.0085	0.72	0.75
Parity*Week	13	0.1705	0.0131	1.11	0.35
Trt*Parity*Week	13	0.0768	0.0059	0.50	0.92
Error	377	4.4595			

Dependent variable: Milk protein, % in milk.

Trt	1	0.2625	0.2625	0.60	0.45
Parity	1	4.0992	4.0992	9.32	0.01
Trt*Parity	1	0.1416	0.1416	0.32	0.57
Cow (Trt*Parity)	29	12.7541	0.4398	22.48	0.01
Week	13	0.8497	0.0654	3.34	0.01
Trt*Week	13	0.3846	0.0296	1.51	0.11
Parity*Week	13	0.3214	0.0247	1.26	0.23
Trt*Parity*Week	13	0.4516	0.0347	1.78	0.05
Error	377	7.3746	0.0196		

Dependent variable: Milk SNF, kg d^{-1}

Source	DF	SS	MS	F value	P > F
Trt	1	0.1498	0.1498	0.08	0.79
Parity	1	121.7518	121.7518	61.17	0.01
Trt*Parity	1	1.4815	1.4815	0.74	0.40
Cow (Trt*Parity)	29	57.7213	1.9904	21.63	0.01
Week	13	2.1401	0.1646	1.79	0.05
Trt*Week	13	0.7159	0.0551	0.60	0.86
Parity*Week	13	1.4346	0.1104	1.20	0.28
Trt*Parity*Week	13	0.6578	0.0506	0.55	0.89
Error	377	34.6916	0.0920		

Dependent variable: Milk SNF, % in milk

Trt	1	2.2893	2.2893	2.08	0.16
Parity	1	6.3678	6.3678	5.79	0.05
Trt*Parity	1	1.3533	1.3533	1.23	0.28
Cow (Trt*Parity)	29	31.8898	1.0996	39.06	0.01
Week	13	0.7687	0.0592	2.10	0.01
Trt*Week	13	0.5012	0.0386	1.37	0.05
Parity*Week	13	0.3942	0.0303	1.08	0.17
Trt*Parity*Week	13	0.1687	0.0130	0.46	0.38
Error	377	10.6148	0.0282		

Appendix III. 4. Anova of daily energy status for dairy cows used in the lactation study.

Dependent variable: Energy input, Mcal.

Source	DF	SS	MS	F value	P > F
Trt	1	0.5091	0.5091	0.02	0.92
Parity	1	496.7320	496.732	34.08	0.01
Trt*Parity	1	29.2385	29.2385	2.01	0.16
Error	52	758.0057	14.5770		

Dependent variable: Energy in milk, Mcal.

Trt	1	0.2730	0.2730	0.05	0.85
Parity	1	919.1071	919.1071	1075.1	0.01
Trt*parity	1	5.0100	5.0100	5.86	0.05
Error	52	44.4545	0.8549		

Dependent variable: Energy for maintenance, Mcal.

Trt	1	0.2289	0.2289	3.79	0.30
Parity	1	10.8768	10.8768	179.91	0.05
Trt*Parity	1	0.0605	0.0605	1.87	0.18
Error	52	1.6796	0.0323		

Dependent variable: Energy for BW change, Mcal.

Trt	1	9.4711	9.4711	3.64	0.05
Parity	1	37.5724	37.5724	5.01	0.05
Trt*Parity	1	2.6015	2.6015	0.35	0.56
Error	52	390.1886	7.5036		

Dependent variable: Total energy output, Mcal

Source	DF	SS	MS	F value	P > F
Trt	1	1.8981	1.8981	1.25	0.46
Parity	1	986.9162	986.9162	651.55	0.05
Trt*Parity	1	1.5147	1.5147	0.53	0.47
Total	52	149.9527	2.8837		

Dependent variable: Dietary energy density, Mcal kg^{-1} DM.

Trt	1	0.0112	0.0112	0.20	0.73
Parity	1	0.1077	0.1077	1.97	0.39
Trt*Parity	1	0.0546	0.0546	2.29	0.14
Error	52	1.2416	0.0239		