Characterization of First Cut Alfalfa Grass Silage Management Practice on Canadian Dairy Farms and Their Impact on Silage Quality.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
ALFA	Alfalfa
ADF	Acid Detergent Fiber
ADIN	Acid Detergent Insoluble Nitrogen
ATL	Atlantic Region
25^{th}	Twenty Fifth percentile
75^{th}	Seventy Fifth percentile
AB	Alberta
ALFA-GR	Alfalfa-Grass
AM	Ante meridiem (before midday)
AOAC	Association of Official Analytical Chemistry
BC	British Columbia
CHO	Carbohydrate
CP	Crude Protein
CTL	Central Region
DDM	Digestible Dry Matter
DM	Dry Matter
DMI	Dry Matter Intake
GRS	Grass
g	Gram
GC	Gas Chromatography
IVDMD	*In-vitro* dry matter digestibility
KG	Kilogram
Max	Maximum
MB	Manitoba
Min	Minimum
NB	New Brunswick
NDF	Neutral Detergent Fiber
NFC	Non-Forage Carbohydrate
NDIN	Neutral Detergent Insoluble Nitrogen
NIR	Near Infrared Reflectance Spectrometry
NL	Newfoundland and Labrador
NRC	National Research Council
NS	Nova Scotia
NSC	Non-Structural Carbohydrate
ON	Ontario
P	p-value
PEI	Prince Edward Island
pH	Power of hydrogen
PM	Post meridiem (after midday)
PRA	Prairie Region
QU	Quebec
R^2	Coefficient of Determination
RFQ	Relative Forage Quality
RFV	Relative Feed Value

RMSE	Root Mean Square Error
SAS	Statistical analysis software
SE	Standard Error
SK	Saskatchewan
TDN	Total Digestible Nutrient
Vol_{GAS48}	*In vitro* Cumulative Gas Production
WK	Weeks
WSC	Water Soluble Carbohydrate

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ABSTRACT

Characterization of First Cut Alfalfa Grass Silage Management Practices on Canadian Dairy Farms and Their Impact on Silage Quality

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This study was conducted to compare silage management practices on Canadian dairy farms and evaluate their impact on the quality of first cut alfalfa grass silages. In manuscript 1, n=288 responses were collected in the British Columbia (n=21), Prairie (n=32), Central (n=218), and Atlantic (n=17) regions from an online survey distributed in 2020. Forage type *($p<0.0001$),* silo type *($p<0.0001$),* and wilting method *($p<0.0001$)* were the most significantly different among regions. Alfalfa-grass was the most common forage type reported in the Central (93.0%), Atlantic (88.2%), and Prairie (68.8%) regions whereas grass was more common in British Columbia (66.7%). Use of all silo types were reported in the Prairies, Central, and Atlantic regions while only bunkers (52.4%) and baleage (28.6%) were reported in British Columbia. The Central region had the highest response rate for towers (37.2%). Majority of respondents in the Central (78.9%), Prairie (75.9%), Atlantic (71.0%), and British Columbia (55.0%) regions reported wilting forages in windrows. However British Columbia had a sufficient response rate for the use of a tedder (45.0%), which corresponds with the regions high response rate for grass.

In manuscript 2, (n=186) first cut alfalfa, alfalfa-grass, and grass silage samples were collected from British Columbia (n=15), Prairies (n=55), Central (n=34), and Atlantic (n=82) regions. Relative Feed Value (RFV) and Relative Forage Quality (RFQ) were developed to have similar index scales where the minimum value of 125 is recommended for lactating dairy cows. When forages were evaluated with RFV only alfalfa (136.34) met the minimum

recommendations. Evaluating forages with RFQ saw all forages meet the minimum recommendation with alfalfa averaging (163.92), alfalfa-grass (158.53), and grass (146.42). The average IVDMD values for alfalfa (66.68 %DM), alfalfa-grass (62.95 %DM), and grass (57.19 %DM) were in line with previous studies, however Vol_{GAS48} averages could not be compared to other studies. This study concluded that (i) there is a large variation in silage quality across Canada, (ii) region and forage type influence quality among other silage management factors (iii) measured estimates such IVDMD and Vol_{GAS48} need further research to standardize the protocol for industry use.

FOREWARD

This thesis is written in manuscript style, with each manuscript having its own abstract, introduction, materials and methods, results, discussion, and conclusion. There is also a general introduction, literature review, discussion, and conclusion, followed by the literature cited. None of the manuscripts have been submitted for publication at the time of thesis completion.

CONTRIBUTION OF AUTHORS

Manuscript I: Characterization of Alfalfa Grass Silage Management Practices on Canadian Dairy Farms.

C.J. Plett: Conducted field research, sample and statistical analysis, writing of original draft and editing of manuscripts; N. McLean: Principal Investigator, sample analysis, reviewing, and editing of manuscripts; C. Lafrenière: conducted field research, sample analysis; S. Bittman: conducted field research; K.H. Ominski: Supervision, reviewing and editing of manuscripts; J.C. Plaizier: Supervision, conceptualization, statistical analysis, reviewing and editing.

Manuscript II: Effects of On-Farm Silage Production Practices on the Quality of Alfalfa Grass Silages Across Canadian Dairy Farms.

C.J. Plett: Conducted field research, sample and statistical analysis, writing of original draft and editing of manuscripts; N. McLean: Principal Investigator, sample analysis, reviewing, and editing of manuscripts; C. Lafrenière: conducted field research, sample analysis; S. Bittman: conducted field research; K.H. Ominski: Supervision, reviewing and editing of manuscripts; J.C. Plaizier: Supervision, conceptualization, statistical analysis, reviewing and editing.

1. GENERAL INTRODUCTION

The goal of ensiling forage is to preserve and store the original nutrient content of the plant by creating an anaerobic environment that allows for bacteria to ferment the plants' sugars into acids that help lower pH (Charmley, 2001; Borreani and Tabacco, 2006; Muck et al, 2015). Although silage making began more than 3000 years ago, its adoption into modern farming practices has increased dramatically only within the last century (Bernardes et al, 2018). This increase in silage making has largely been due to the mechanization of forage harvest equipment and the increasing demand for forage as cattle numbers continue to grow on farms (Wilkinson et al, 2003). Today, silage making is a well-established practice in Europe and North America and is often the primary forage preservation method used on dairy and beef feedlot operations (Muck et al, 2015; Bernardes et al, 2018). Advantages of making silage over dry hay include the ability to conserve large amounts of forage in a short period of time, ability for mechanization on both large and small farms, less weather dependency, and reduced leaf shattering (Charmley, 2001; Borreani and Tabacco, 2006; Coblentz and Akin, 2018). In colder climates, the advantages of silage making are well suited for the short growing season (Charmley, 2001; Bernardes et al, 2018). However, one of the major disadvantages of silage making is the nutritive value of forage is reduced through the ensiling process (Charmley, 2001). Therefore, producers must make informed silage management decisions to help limit this loss of nutrients.

Dry matter (DM) loss is inevitable during the silage making process. However, under good management it could be limited to approximately 15% or less, but under poor management, DM losses could be upwards of 30% or higher (Borreani et al, 2018; OMAFRA, 2022). Therefore, producers have many silage management factors and options to consider. In the pre-ensiling stage producers make decisions regarding the forage type grown, maturity of forage at cutting, cutting height, use of mower-conditioners, moisture content prior to harvest, use of silage additives, and baler chopping systems (Bernardes et al, 2018; Borreani et al, 2018). Producers also make decisions regarding the use of the kind of silo being used, e.g., horizontal silos (bunkers and drive over piles), tower silos (top and bottom unloading), and baleage (Bernardes et al, 2018; Borreani et al, 2018). Finally, in the feed out phase, producers must consider silage removal rate, face management, and feed bunk management (Bernardes et al, 2018; Borreani et al, 2018). While producers have control over many of the silage management factors, they have limited control over many factors including regional climate and soil conditions (Alberta, 2009; Bernardes et al, 2018; OMAFRA, 2022).

Silage management decisions should be focused on making high quality silage. For many producers, evaluating the quality of silage is based on its nutritive value, such as its crude protein (CP) content, or quality indices like relative feed value (RFV) and relative forage quality (RFQ); (Charmley, 2001; Jeranyama and Garcia, 2004). RFV and RFQ are calculated based on the neutral detergent fiber (NDF), acid detergent fiber (ADF), and total digestible nutrients (TDN) of the silage, and, therefore, better reflect the maturity at harvest rather than its *in vivo* potential for the animal (Jeranyama and Garcia, 2004). In research laboratories, analyses such as *in vitro* cumulative gas production and *in vitro* dry matter digestibility (IVDMD), are used to evaluate potential ruminal fermentation and total tract digestibility, respectively (Buxton et al, 2003). These *in vitro* methods provide a better estimation of how the silage will be utilized by the animal. By understanding how quality indices are determined and how they are affected by silage management factors, producers can make informed decisions to enhance the quality of their silages. The goals of this study are to characterize and compare silage management practices of first cut alfalfa, alfalfa-grass, and grass silages across and within different Canadian regions; evaluate quality using various parameters (RFV, RFQ, IVDMD, Vol_{GAS48}, pH); determine effects of silage management practices on forage quality parameters; and develop recommendations for best management practices for growing and ensiling first cut perennial forages in different Canadian regions.

2. LITERATURE REVIEW

2.1 Forages in Canada

Perennial GRS and legume species commonly found across Canada include timothy (*Phleum pratense L.*), perennial ryegrass (*Lolium perenne L.*), orchardgrass (*Dactylis glomerata L.*), red clover (*Trifolium pratense L.*), an ALFA (*Medicago sativa L*) (Thompson, 2013; Bernardes et al, 2018; Belanger et al, 2020). In the most recent Canadian Agriculture census, 3 million hectares were reported being under production ALFA and ALFA mixtures and 2.1 million hectares as tame hay and fodder (Statistics Canada, 2022). The census also indicated that majority (73%) of ALFA production occurs within the PRA provinces (Statistics Canada, 2022). ALFA is sensitive of acidic (pH<6.5) and poor draining soils (OMAFRA, 2022). Therefore, the PRA region is ideal for ALFA production due the semi-arid climate and chernozemic soils which are rich in soil organic matter and neutral in acidity (Pennock et al, 2011). Areas of the BC interior also share similar climate and soil conditions as the PRA making ALFA production possible (Pennock et al, 2011). However, for most of BC, CTL (ON and QU), and ATL Canada increased precipitation and humidity is experienced due to the proximity of the oceans and Great Lakes (Pennock et al, 2011; Sanborn et al, 2011; Thomspon, 2013). These regions also tend to have acidic soils because of the predominate podzolic soil order (Sanborn et al, 2011; Pennock et al, 2011; Thomspon, 2013). Peterson and Waldern (1977), demonstrated the acidity of soil in the lower Fraser Valley in their survey of 65 dairy farms who reported an average soil pH of 5.99. However eastern Canada and parts of BC have been successful in turning these soils into viable farmland through drainage and liming (Sanborn et al, 2011). In ATL Canada, ALFA is now one of the highest yielding perennial forages within the region (Perennia, 2021). In eastern Canada, ALFA is also often grown as a mixture with increased use of at least one GRS species, which is most commonly timothy (Belanger et al, 2020). In BC, orchardgrass has been reported by previous dairy farm studies (Peterson and Waldern, 1977; Von Keyserlingk et al, 1996; Zebarth et al, 2001; Smith et al, 2011;Thompson, 2013) as a common monoculture crop or as a mixture with ALFA. Unlike ALFA, perennial GRS have a higher tolerance to acidic and poor draining soils (Alberta, 2009; Perennia, 2021; OMAFRA, 2022). For example, ALFA can tolerate 1 to 2 WK of poor draining soil while timothy can tolerate 6 WK or more (OMAFRA, 2022).

2.1.1 Forage Chemical Composition and Impact of Maturity

In the Canadian dairy industry, ALFA is considered an important forage (Ren et al, 2021). It is known for having a high nutrient content, digestibility, high yields, and can fix its own nitrogen due to the plants' symbiotic relationship with Rhizobia bacteria within the root nodules (Aponte et al, 2019; Guo et al, 2019; NRC, 2021; Ren et al, 2021). The nutrient profile of ALFA is typically characterized by high CP ranging from 20-22% DM, and a moderate fiber content with NDF ranging from 38-43% DM, and ADF ranging from 30-33 % DM. (NRC, 2021). For *in vitro* dry matter digestibility (IVDMD), ALFA-based forages ranged from 47.52 to 79.69% DM (Holden, 1999; Mabjeesh et al, 1999; Brons and Plaizier, 2008, Plaizier and Li, 2013).

Perennial GRS do not have the same high nutrient content as ALFA-based forages as CP is lower (12-14% DM) and fiber content is significantly higher (NDF 55-63% DM, ADF 38-45% DM) (NRC, 2021). However, due to GRS having lower lignin content (~5.8% DM) compared to ALFA (~6.5-8% DM), the fiber tends to be more digestible (Moore and Undersander, 2001; NRC, 2021). This was observed in a study conducted by Lauzon et al (2019), where IVDMD was reported higher for GRS on each of the three experimental plots. In Normandin, St-

Augustin, and Ste-Anne QU, ALFA had IVDMD of 76.5%, 72.9%, and 72.6% DM respectively (Lauzon et al, 2019). Within those same locations timothy reported IVDMD was 82.9%, 78.6%, and 81.7% DM respectively (Lauzon et al, 2019). When neutral detergent fiber digestibility (NDFD) was evaluated by Aponte et al, (2019), monoculture GRS were found to average significantly higher NDFD at 583 g kg^{-1} DM compared to ALFA monocultures that averaged 462 g kg^{-1} DM.

Planting ALFA with at least one GRS species is a common practice seen across Canada (Foster et al, 2013; Thompson, 2013, Pomerleau-Lacasse et al, 2018; Belanger et al, 2020). The benefits of growing binary mixtures include increased DM yield while reducing weed invasion with little to no impact on digestibility (Pomerleau-Lacasse et al, 2013; Belanger et al, 2014; Belanger et al, 2020). There is no standard nutrient profile for ALFA-GR as the percentage of GRS in the stand will impact the CP and fiber content. However, ALFA-GR generally have slightly lower CP values and slightly higher fiber content compared to ALFA monocultures (NRC, 2021). Aponte et al, (2019) observed that ALFA-GR in its' third production year averaged 198 g kg^{-1} in CP which was lower than AFLA monoculture stands (226 g kg^{-1}) but higher than GRS monocultures that averaged (140 g kg^{-1}). When NDFD was compared between ALFA-GR and ALFA monocultures in its' third year they only differed by +27 g kg^{-1} for ALFA-GR mixtures (Aponte et al, 2019)

Forages intended for lactating dairy cows should be of high quality and sufficient yield (Ball et al, 2001; Belanger et al, 2020). Maturity has the greatest influence on forage quality as a result of the leaf:stem ratio decreasing and cell wall content increasing (Ball et al, 2001;Yari et al, 2012; Guo et al, 2019; NRC, 2021). The impact of maturity was well demonstrated in Yar et al, (2012) study that looked at the botanical and chemical composition of fresh alfalfa cut at early bud, late bud, and early flowering stage. In the study, the leaf: stem ratio (0.55 to 0.37) and CP (220 to 162 g kg^{-1} DM) simultaneously decreased while DM (210 to 3170 g kg^{-1} DM) and fiber (ADF: 355 to 430 g kg^{-1} DM; NDF 425 to 491 g kg^{-1} DM) increased with maturity (Yari et al, 2012). Similar patterns were observed by Guo et al, (2019), where ALFA CP decreased from 216 to 196 g kg^{-1} DM and NDF increased from 301 to 351 g kg^{-1} DM from budding stage to full flower. Therefore, ALFA should be harvested between the early bud and early flower stage (Lauzon et al, 2019; Belanger et al, 2020). GRS should be harvested between the boot and early heading stage (Lauzon et al, 2019). Harvesting ALFA-GR is more complicated as GRS will have a higher fiber content than ALFA at the same stage of maturity, therefore harvest should be based off the maturity stage of the ALFA within the stand (MSU, 2011).

2.2 Silage Making Process

The process of making silage can be divided into two general categories, pre-ensiling (aerobic phase) and ensiling (anaerobic phase; Alberta, 2004). The pre-ensiling phase is primarily focused on limiting field respiration and harvesting sufficient DM yield. This typically includes the mowing, harvesting, and the filling of the silo. Plant respiration occurs in the presence of oxygen and continues after the forage is mowed for several hours (PENN State, 2004). However, if poorly packed plant respiration can continue after the silo has been sealed. When oxygen is present, plant enzymes (such as protease) continue to function and naturally occurring plant bacteria start to multiply (Alberta, 2004; PENN State, 2004). During these processes valuable carbohydrates within the plant are consumed while: carbon dioxide, water, and heat are produced (Alberta, 2004; PENN State, 2004). The ensiling phase of silage making typically refers to the fermentation process that occurs after the silo has been sealed. When ensiling forage such as ALFA and or GRS, the four phases of fermentation typically occur over the course of 21 days but may be prolonged depending on the buffering capacity of the forage: i) plant respiration ii) acetic acid production iii) initial lactic acid production iv) peak lactic acid production and storage (PENN State,2004). As previously mentioned, plant respiration begins on the field and continues until the silo is packed and sealed. Once oxygen is eliminated, acetic acid bacteria convert carbohydrates into acetic acid which lowers the pH from 6 to 5 which limits proteolysis (PENN State, 2004). Acetic acid production is approximated to lasts 1 to 2 days as the bacteria is intolerant of acidic environments (PENN State, 2004). The acidity within the forage brought on by the acetic acid therefore enhances the growth of lactic acid bacteria (LAB) as carbohydrates are continuously converted into lactic acid, acetic acid, ethanol, mannitol, and carbon dioxide (PENN State, 2004). Lactic acid production peaks around day 7 of ensiling and lasts for two WK (PENN State, 2004). At the end of this period all bacterial growth stops including LAB due to the low pH (PENN State, 2004). So long as sufficient acid production has occurred and oxygen remains excluded from the silo, silage should remain stable (Kung Jr, 2010).

2.2.1 Mowing

To limit DM loss due to field respiration, forages are typically wilted until they reach a targeted moisture content. It is generally recommended that producers mow forages late morning to maximize the drying period during the day and limit the overall wilting period (PENN State, 2004; Tremblay et al, 2014). However, the time at which producers start mowing their fields is influenced by day-to-day farm operations. Therefore, fields may be mowed at different times throughout the day. Previous forage studies (Morin et al, 2011; Morin et al, 2012; Trembley et al, 2014) have shown that forages mowed in the PM have a higher concentration of nonstructural carbohydrates (NSC) than forage cut in the AM. This is due to photosynthate production exceeding the plants utilization of carbohydrates Morin et al, (2011) and Trembley et al, (2014). This is significant as NSC in forages are readily available as an energy source for the rumen (NRC, 2021). Morin et al, (2011) and Morin et al, (2012), determined that the maximum NSC content occurs 11 to 13 hours after sunrise. Though NSC accumulates throughout the day, they can be lost to plant respiration or inclement weather (i.e., rain) overnight (PENN State, 2004). Tremblay et al, (2014), also determined that the benefit to PM cutting was often not maintained through the fermentation process of silage. Therefore, producers should focus on management practices that reduce the wilting period so forages can be ensiled faster.

In recent decades the practice of intensive mechanical conditioning, also known as maceration, has been used to decrease the field wilting duration and improve the ensiling process (Ouellet, et al, 2006; Borreani et al, 2018). Mower-conditioners essentially macerate the forage by cracking and crushing the forage stems to help moisture escape (Muck et al, 2003; Borreani et al, 2018; OMAFRA, 2022). Borreani et al, (1999) determined forages mowed with a conditioner had a wilting period 30 to 45% shorter than unconditioned forage. Depending on drying conditions, this means ensiling the same day or at least the following morning is possible Borreani et al, (1999). This is particularly important in humid climates like ON where heavy dew can prolong wilting (OMAFRA, 2022). However, forage type must be considered when deciding to use a mower-conditioner. GRS can handle more severe maceration from the use of impeller conditioners (e.g., steel flails) unlike ALFA (Borreani et al, 2018). Extensive maceration from impeller conditioners can decrease the CP in ALFA up to 20% because of leaf shattering (Borreani et al, 1999). Therefore, it is recommended that impeller conditioners be used on GRS while ALFA be macerated with intermeshing rollers (Borreani et al, 1999; Borreani et al, 2018).

By leaving longer stems, air can move under the swath to aid in wilting. However, cutting heights are typically based on forage type, nutritional goals of the farm, and topography (rocks, mole hills, etc) of the field. In general, forages should not be cut lower than 5 to 7 cm. Lower cutting heights increase the risk of soil contaminating the forage with bacteria such as *Clostridia* (OMAFRA, 2022). *Clostridial* contamination from soil can increase the risk of *Clostridial* fermentation or diseases such as black leg (King Jr, 2010). A sign that cutting height was too low is an increase in the forages' ash content (OMAFRA, 2022). For ALFA and GRS, ash content is typically 8% and 6%, respectively, therefore higher concentrations indicate potential contamination (Undersander, 2016). The general cutting height recommendation for GRS and ALFA is 10 cm and 7-10 cm, respectively (PENN State, 2004; Alberta, 2009; Jones and Tracy, 2018; OMAFRA, 2022).

2.2.2 Harvesting and Storing

Forages should be harvested once they have reached their targeted moisture content which is determined by silo type. Recommended moisture content of forages stored in horizontal silos is 65-70%, conventional silos (top unloading) 60-65%, oxygen limiting (bottom unloading) 40-55%, and baleage 50-60% (Alberta, 2004). Having the correct moisture content is important to maximize nutrient yield per hectare, minimize DM lost on the field (leaf shattering) and within the silo (effluent), and ensure a good packing density and adequate fermentation (PENN State, 2004). Valuable water-soluble carbohydrates are lost when the wilting period is prolonged. Therefore, anaerobic bacteria do not have enough substrate for sufficient lactic acid production to lower pH resulting in restrictive fermentation (Alberta, 2004; PENN State, 2004, Kung Jr, 2010). When acid production is insufficient silage becomes unstable when exposed to oxygen and secondary microbial growth can occur (King Jr, 2010). To ensure sufficient acid production, silage additives such as inoculant are commonly used (Filya et al, 2017; Muck et al, 2018). Inoculants typically are selected strains of homofermentative lactic acid bacteria (LAB) and have been known to decrease pH faster, lower final pH, increase lactate: acetate ratios, lower ethanol, and ammonia nitrogen (Filya et al, 2017). In recent years, heterofermentative LAB species, *Lactobacillus buchneri*, has gained popularity as it promotes aerobic stability of the forage once the silo is open (Borreani et al, 2018). Inoculants should be used on the crop they are intended for, with application rates, storage, re-hydration, application, and handling followed according to the label (OMAFRA, 2022). Failure to do so can impede the interaction between the crop and inoculant and results may not be noticed until the silo is opened.

The purpose of the silo is to aid in eliminating and maintaining the exclusion of oxygen. They should provide sufficient volume for storage, be complementary to the farms' overall feeding operation, as well as economical (Alberta, 2004; Holmes, 2009). Baleage is a common storage choice among small and medium sized farms due to economic advantages such as lower fixed operating costs, less specialized equipment, equipment can be used for dry or silage bales, no physical storage structure is required therefore, in theory limitless storage capacity, low risk for effluent, and market potential (Coblentz and Akins, 2018). Although there are many advantages to baleage, there are few major disadvantages. The first being restrictive fermentation. In baleage, restrictive fermentation is brought on through the combination of low moisture content and longer forage particles. As forage is rolled rather than precision chopped air exclusion is difficult and LAB are not able to efficiently access plant sugars needed for acetic and lactic acid (Borreani and Tabacco, 2006; Coblentz et al, 2016; Coblentz and Akins, 2018). To shorten the length of forage particles and improve bale density many modern silage balers now come with the option of a chopping system. Borreani and Tabacco, (2006) evaluated the effects of chopping systems on ALFA baleage and found the percentage of stems <10 cm increased from 14 to 38% and bale density increased by 4%. However, there was no significant improvement in silage fermentation (Borreani and Tabacco, 2006). Similar results were also seen in a study conducted by Muller, (2009) who looked at chopped vs un-chopped GRS silage baleage for horses. Though silage fermentation may not be improved, chopping systems do reduce forage particle size and improved bale density anywhere from 4 to 15% (Coblentz and Akins, 2018). Layers of polyethylene (PE) stretch film are also a consideration when making baleage. One layer of PE is about 25 μm thick and when stretched to 55% allows oxygen to permeate 0.775 to 0.981 cm^3 cm^{-2} d^{-1}. In a recent review on baled silage technology Coblentz and Akins, (2018) were reviewed various studies on ideal number of PE layers. Most studies concluded two layers was not sufficient as bale temperatures rose regardless of moisture and forage stems punctured through the PE (Coblentz and Akins, 2018). Four layers of PE was the minimum recommendation in most studies to achieve anaerobiosis for silage fermentation. However, more layers may be needed for extended storage (Coblentz and Akins, 2018). This is due to the increase in risk of internal and external punctures from stems, vermin, or during handing (Coblentz and Akins, 2018).

On larger farms, horizontal silos such as bunkers and drive over piles are commonly used to meet their storage demands (Luchini et al, 1997; Wilkinson et al, 2003). When determining the size of a horizontal silo, the feed out rate must be considered. Wide and tall silos have lower feed out rates for a given volume than narrow and short silos Holmes, (2009) Feed out rate will vary by season, as feed should be removed approximately 1 meter per day in the winter and 1.5-2.1 meters per day during the summer (Bernardes et al, 2018). The recommended width of a horizontal silo can be determined by dividing the volume of feed required per day by the silo's height multiplied by the daily removal rate (Holmes, 2009). Filling methods for horizontal silos include full height where silo height is maintained as length increases, full length where length is maintained while height increases and progressive wedge where loads are added with a slope of 20 to 30°C as length and height increase simultaneously (Ruppel et al, 1995). The final goal at the end of filling and packing the silo is to have a packing density of 705 kg m^{-3} (Bernardes et al, 2018; Borreani et al, 2018). In a survey conducted by Muck and Holmes, (2000), packing density was found to be strongly correlated with DM content, packing time per ton, tractor weight, and how thin loads were spread out.

Once the silo is full, it must be sealed immediately to prevent oxygen from penetrating into the silo. Sealing horizonal silos with PE films is the most common strategy (Parra et al, 2021). PE film used in horizonal silos ranges from 120 to 200 µm which is considerably thicker than PE used for baleage (Parra et al, 2021). Bolsen et al, (1993), determined that ALFA experienced a DM loss of 78.8% when a bunker was uncovered compared to only 7.2% when PE was used. To ensure PE stays in place, it needs to be weighed down. Common materials used include tires, tire sidewalls, gravel filled bags, loose soil/sand/gravel/ or other organic materials (Borreani et al, 2018).

Top and bottom unloading silos can be ideal for small to medium size farms feeding ~150 tonnes of DM annually (OMAFRA, 2022). No packing or sealing is required therefore labour is minimal compared to other silos. Under well managed towers (i.e., correct moisture, rapid filling, etc), DM losses can be as low as 5-10% as there is little to no loss from effluent or the top surface of the silo (OMAFRA, 2022).

Silo type can also influence nutrient quality. Previous studies have found that silages from bunkers tend to have higher NDF, ADF, ADIN, and lower RFV compared to silages from towers (Luchini et al, 1997; Muck et al, 2015). As larger bunkers are usually used on bigger farms, there tends to be a larger variation in forage maturity because of the larger numbers of hectare harvested (Luchini et al, 1997). Several studies have shown that CP was not significantly different between bunkers and towers (Janicki and Stallings, 1987; Luchini et al, 1997; Muck et al, 2015). However, it should be noted that in previous studies that evaluated the effect of silo type on forage quality, the only controlled factor within the study was the silo and other management factors were not considered. Therefore, more extensive research correlating management factors with silo types is needed.

2.*3 Silage Quality Parameters*

2.3.1 Relative Feed Value vs Relative Forage Quality

Relative feed value (RFV) was developed in the late 70's by the Hay Marketing Task Force of the American Forage and Grassland Council to rank and compare the quality of forages, set prices, and educate people on forage quality (Moore and Undersander, 2001). The index was developed using legume forages with intake responses of lactating dairy cows (Jeranyama and Garcia, 2004). Digestible dry matter (DDM) and dry matter intake (DMI) potential for ALFA are estimated from ADF and NDF respectively (Jeranyama and Garcia, 2004). DDM and DMI are then multiplied together and divided by 1.29 so that when ALFA is at full bloom RFV is 100

(Jeranyama and Garcia, 2004). At full bloom the index assumes ALFA has 41% ADF and 53% NDF (Jeranyama and Garcia, 2004). The equations for RFV are as follows:

$$1.)\ Digesible\ Dry\ Matter\ (DDM) = 88.9 - (0.779 * \%\ ADF)$$

$$2.)\ Dry\ Matter\ Intake\ (DMI)(\%\ Body\ Weight) = \frac{120}{\%\ NDF}$$

$$3.)\ Relative\ Feed\ Value\ (RFV) = \frac{(DDM * DMI)}{1.29}$$

RFV is greatly influenced by the fiber content of the forage as NDF and ADF are the only two lab values used within the equations. Therefore, as a forage stand matures RFV will decrease due to the increase in fiber content. However, caution must be taken when evaluating GRS-based forages as the naturally occurring higher fiber content penalizes the GRS and results in low RFV. For example, budding ALFA ADF is 30% DM and NDF is 40% DM resulting in an RFV 152 while GRS at a similar maturity stage has an ADF of 35% DM and NDF of 63% DM resulting in a significantly lower RFV of 91 (Jeranyama and Garcia, 2004). Aside from only using ADF and NDF lab values, RFV is also limited by assuming DDM and DMI is constant for all forages, does not account for CP or digestibility, and cannot be used in ration formulation (Jeranyama and Garcia, 2004).

To improve the ability to evaluate forage quality across forage types, researchers at the University of Wisconsin developed the relative forage quality index. This index was designed to improve among the faults of RFV by deriving intake and TDN from fiber digestibility using laboratory values (Jeranyama and Garcia, 2004).

The equations for RFQ are as follows:

1. $Total\ Digestible\ Nutrients\ (TDN, \%DM) = (NFC * 0.98) + (CP + 0.93) + (FA * 0.97 * 2.25) + \left(NDFn * \left(\frac{NDFD}{100}\right)\right) - 7$

CP= crude protein (%DM)	NDFCP= neutral detergent fiber crude protein
EE= ether extract (%DM)	NDFn=nitrogen free NDF
FA= fatty acids (%DM)	NDFD= 48-hour in-vitro NDF digestibility (%NDF)
NDF= neutral detergent fiber (%DM)	NFC= non fibrous carbohydrates (%DM)

2. $Dry\ Matter\ Intake\ (DMI, \%BW) = \left(\frac{120}{NDF}\right) + (NDFD - 45) * \left(\frac{0.374}{1350}\right) * 100$

3. $Relative\ Forage\ Quality\ (RFQ) = \frac{(DMI, \%BW) * (TDN, \%DM)}{1.23}$

The RFQ equation was developed to provide more accurate estimates of forage quality while having a similar index to RFV to make management decisions easier for those accustomed to the old index. Therefore, the recommended RFV and RFQ for lactating dairy cows are the same. For lactating dairy cattle forages should have a minimum RFV/RFQ of 125 but forage is considered of milking quality at 140 or higher (Undersander et al, 2011).

2.3.2 In vitro dry matter digestibility and in vitro cumulative gas production

Since the 1960's *in vitro* dry matter digestibility has become a standard research laboratory procedure in evaluating and comparing ruminant feeds (Cherney and Cherney, 2003). The initial *in vitro* digestion protocol was developed by Tilley and Terry, (1963) and has since been modified for improved efficiency using the Ankom Daisy^{II} incubator (Cherney and Cherney et al, 2003; Tasson et al, 2020). *In vitro* dry matter digestibility (IVDMD) has been found to be highly correlated with *in vivo* studies where forage digestibility was evaluated, therefore, it has been extensively used to analyze feeds (Holden, 1999). When using the Ankom Daisy^{II}, inoculum is the greatest source of variation within the fermentation system (Tasson et al, 2020). The purpose of the inoculum is to mimic an environment representative of the rumen. In a study conducted by Holden, (1999), two donor diets (diet ; grass, diet 2; TMR) were tested with various feeds to determine how IVDMD was impacted. The study found that six out of the ten feeds were affected with feed inoculated with rumen fluid from the TMR donor diet averaging significantly higher IVDMD compared to feed inoculated with rumen fluid with the grass diet (Holden, 1999). However, Holden, (1999) findings were not replicated in other studies (Mabjeesh et al, 2000; King and Plaizier, 2006) that evaluated donor diets and inoculum sources. Mabjeesh et al, (2000) evaluated feeds using inoculum from Holsteins and Merino rams and found no significant effect on the IVDMD. King and Plaizier, (2006) had similar findings to Mabjeesh et al, (2000) when evaluating rumen fluid from steers on hay diets vs cows on a TMR and determined there was no significant effect on IVDMD. Shewmaker et al, (2009), evaluated that 75-83% DM for 48 HR IVDMD was optimal for ALFA. These values were observed in studies where ALFA and ALFA-GR were harvested at early flower and GRS at early heading (Kozelov et al, 2008; Belanger et al, 2014; Lauzon et al, 2019). In these studies where maturity was controlled, IVDMD ranged from (76.5 to 87.4% DM) for ALFA, (85.2 to 86.9% DM) for ALFA-GR, and (82.9 to 88.5% DM) for GRS (Kozelov et al, 2008; Belanger et al, 2014; Lauzon et al, 2019). In studies where maturity was unknown, IVDMD values were reported significantly lower (Holden, 1999; Mabjeesh et al, 2000; Brons and Plaizier, 2008; Plaizier and Li, 2013). When maturity of the forage was unknown ALFA had IVDMD values from (53.6 to 59.89% DM), (47.52 to 70.7% DM) for ALFA-GR, and (51.22 to 58.5% DM) for GRS (Holden, 1999; Mabjeesh et al, 2000; Brons and Plaizier, 2008; Plaizier and Li, 2013).

In vitro gas production has also been used since the 1960's to evaluate forages. However, due to the sensitivity of gas production systems to buffers, rumen inoculum, and handing of inoculum, repeatability of experiments is difficult (Cherney and Cherney, 2003). For example, Plaizier and Li, (2013) observed that ALFA/GRS forage resulted in a cumulative gas production of 161 mL g^{-1} which was significantly higher than the Vol_{GAS48} previously reported by Kozelov et al, (2008) who reported 52 mL g^{-1}. Interpretation of results can become difficult as well when silages have a large range in chemical composition resulting in different gas yields (Cherney and Cherney, 2003). There is no standardization of the cumulative gas production procedure, therefore gas production values should only be compared within a study.

2.3.3 Silage pH

The purpose of measuring silage pH is to give an indication of the fermentation process that occurred within the silo. Freshly cut forage typically has a pH of 5-6 then decreases to 3.6-4.5 depending on the type of crop (Kung Jr, 2010). For ALFA, ALFA-GR, and GRS silages, pH can range from 4.0 to 5.5 (Kung Jr, 2010). A final pH for silage is considered high when it exceeds 5.5 (PENN State, 2004; Kung Jr, 2010). In general, the more legume content a forage has the higher the buffering capacity (Kung Jr, 2010). The higher the buffering capacity the more acid will be required to reduce the pH (Kung Jr, 2010). High silage pH may also be caused by high (>45-50% DM) or low (<30% DM) DM content (PENN State, 2004; Kung Jr, 2010). When forages are ensiled with low DM content, clostridial fermentation can occur (Kung Jr, 2010). Clostridial fermentation is caused by the spore-forming bacteria, *Clostridia* (PENN State, 2004). There are many species of *Clostridia*, but they are typically found in manure and the soil (PENN State, 2004). As *Clostridia* begin to multiply, they consume the plants' proteins, remaining carbohydrates, and any organic acids from the previous fermentation stage (PENN State, 2004). The breakdown of plant protein can result in non-protein nitrogen compounds like putrescine and cadaverine, which are known for their unpleasant odor (PENN State, 2004). Butyric acid can be a product of clostridial fermentation via the breakdown of lactic acid and sugars (PENN State, 2004). Silage with butyric acid tends to be sour smelling and decreases feed intake (PENN State, 2004).

Ensiling dry forage (>45-50%DM) often results in restrictive fermentation which occurs when the production of fermentation acids (acetic and lactic acid) is insufficient (King Jr, 2010). This insufficient production of acid means that secondary microbial growth is possible once silage is exposed to oxygen (Kung Jr, 2010). High pH due to restricted fermentation is often observed in baleage (Coblentz et al, 2016). Therefore, when evaluating silage pH, silo type should be considered as well as the overall forage analysis including volatile fatty acid (VFA) content.

2.4 Summary

In summary, ALFA and GRS species are grown across Canada as monocultures or as mixtures such as ALFA timothy and or ALFA orchardgrass. Forages intended for lactating dairy cows should be harvested between early budding through early flowering for ALFA and GRS should be harvested between the boot and early heading stage, and ALFA-GRS mixtures should be harvested based off the maturity of the ALFA. The process of making silage can be divided into anaerobic and aerobic phases. During the aerobic phase the goal is to limit plant respiration via wilting. To speed up the wilting process producers should mow forages to take advantage of drying conditions during the day. Mower-conditioners can be used to speed up wilting, however, impeller conditioners (steel flails) should not be used on ALFA to avoid leaf loss. The targeted moisture content of the forage should be appropriate for the silo it is being stored in. The anaerobic phase occurs once the silo is sealed, and fermentation can begin. To aid in the fermentation process when moisture content is too low or a lack of carbohydrates, inoculants can be used. Overall, there is no significant difference in nutritional content of silages stored in various silos . However, many of the previous studies did not consider multiple silage management factors. Evaluating forages can be complex as different parameters provide a different assessment of quality. RFV and RFQ are commonly used in industry, but better reflect maturity of the forage at cutting compared to its *in vivo* potential. Silage pH should not be used on its own as an indicator of quality but used conductively with the forage analysis to interpret its meaning. Vol_{GAS48} and IVDMD measure the potential ruminal fermentation and total tract digestibility of the forage.

3. RESEARCH HYPOTHESES AND OBJECTIVES

3.1 Hypotheses

1. Forage types grown for silage on Canadian dairy farms will differ among four Canadian regions; BC, PRA (AB, SK, MB), CTL (ON, QU), and ATL (PEI, NS, NB, NL)
2. Silage quality will be impacted by controllable and uncontrollable management factors.
3. Best management practices for silage production will differ among Canadian regions because of different silo and forage types among other silage management factors.
4. Region as well as management practices affect the quality of first cut ALFA, ALFA-GR, and GRS silage.
5. Silage quality parameters such as *in- vitro* dry matter digestibility (IVDMD), *in-vitro* cumulative gas production, relative feed value (RFV) and relative forage quality (RFQ), and silage acidity (pH) provide different assessments of the quality of first cut silages from different perennial forages.

3.2 Research Objectives

The overall objectives of this study were: i) characterize and compare silage management practices of first cut ALFA, ALFA-GR, and GRS silages across and within different Canadian regions; ii) evaluate first cut ALFA, ALFA-GR, and GRS silages using various silage quality parameters (RFV, RFQ, IVDMD, Vol_{GAS48}, pH) iii) determine effects of silage management practices on silage quality parameters; iv.) develop recommendations for best management practices for growing and ensiling first cut perennial forages in different Canadian regions.

4. MANUSCRIPT 1

Characterization of Alfalfa Grass Silage Management Practices on Canadian Dairy Farms

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4.1 ABSTRACT

To obtain an overview of the forage types grown and silage management practices on dairy farms across Canada, an online survey was developed by researchers at the University of Manitoba and then distributed to Canadian dairy farmers through provincial milk boards. Responses were collected from (BC, n=21), (PRA, n=32), (CTL, n=218), and (ATL, n=17). Responses were analyzed using PROC Freq with chi-square analysis to determine regional differences for forage type, silo type, tower type, cutting time, cutting height, conditioner use, wilting method, inoculant use, baler knives, additional packing weight, oxygen barrier use, and the number of plastic layers used on baleage. Alfalfa-grass mixed (AG) stands were the most common forage in CTL (93.0%), ATL (88.2%), and PRA (68.8%), whereas in BC, gras (GRS) was the most common (66.7%). Alfalfa (ALFA) monoculture stands were only reported in PRA (28.1%) and CTL (5.6%). Use of all silo types were reported in all regions, except in BC, which only reported bunkers (52.4%) and baleage (28.6%). Bunkers (31.3%) were the most common in PRA, followed by baleage (28.1%), piles (18.8%), tower silos (6.3%), while 9.3% indicated use of other silos such as Ag bags and 6.2% indicated Don't know. Tower silos (37.2%), were the most common silo in CTL, followed by bunkers (33.9%), baleage (22.0%), and piles (1.8%), while 2.3% indicated using other silos such as Ag bags, and 2.8% indicated Don't know. Bunkers (29.4%) and baleage (29.4%) were equally reported in ATL, followed by tower silos 17.7%, and piles (11.8%), and 11.7% indicated Don't know. Windrows were the most common wilting method in BC (55.0%), PRA (45.0%), CTL (77.1%), and ATL (71.0%). In BC, (45.0%) and ATL (17.7%), had the highest response rates for tedder usage. "No wilting" was only reported in PRA (10.3%), CTL (14.7%) and ATL (11.8%). The majority of respondents in BC (55%), CTL (58.3%), ATL (64.7%) indicated using inoculant, except for in PRA where only

44.8% indicated inoculant use. The majority of respondents in BC (72.7%), PRA (50.0%), CTL (81.1%) that used bunkers and piles, added weight to packing equipment, except for ATL where only 33.3% added weight. The majority of respondents in PRA (62.5%), CTL (78.7%), ATL (100%) also indicated using an oxygen barrier, except for BC that only indicated 18.2%. The main regional differences were seen for forage type and silo type. Climate and soil type determine what type of forage is best suited for a region. Therefore, in regions like BC that experience acidic soils and higher precipitation, perennial grasses are recommended whereas alfalfa is better suited in the PRA due to the pH neutral soil and semi-arid climate. The silo used on farm must meet the storage capacity needs of the farm therefore larger farms tend to make use of horizonal silos while small to medium farms make use of towers and baleage. This is why more tower silos are reported in CTL and ATL as milking herds in eastern Canada tend to be smaller than western herds. Overall, the respondents within this survey appear to follow recommendations for forages according to their region and recommendations specific to the silo being used.

4.2 INTRODUCTION

In the Canadian dairy industry, ALFA (*Medicago sativa L*) is considered an important forage crop due to its high nutrient content, high digestibility, and high yields (Yar et al, 2012; Ren et al, 2021). According to the 2021 Canadian Agriculture Census, over 3 million hectares of ALFA and ALFA mixed stands were grown, accounting for 8.1% of total field and hay crops in Canada (Statistics Canada, 2022). Due to the short growing season, producers must manage fields and harvest systems to obtain a sufficient yield to feed throughout the winter-feeding period (Charmley, 2001).

Preserving forage through an ensiling process has many advantages including reduced wilting periods, a reduced risk of inclement weather impacting the forage, an improved legume leaf retention, suitability for mechanization on both small- and large-scale operations, and ability to ensile large amounts of forage quickly (Coblentz et al, 2016; Borreani et al, 2018). Throughout the ensiling process there are many controllable and uncontrollable factors that can impact quality. Uncontrollable factors such as climate and soil conditions vary across the country and are the main factors that determine whether a forage is suitable to grow within a region (Alberta, 2009; OMAFRA, 2022). This can be observed within the data of the recent Canadian Agriculture Census where the PRA made up 73% ALFA and ALFA mixture production, ON and QU 21%, BC 5%, and ATL Canada 1% (Statistics Canada, 2022).

Controllable factors include cutting time, cutting height, use of a mower-conditioner, wilting method, and use of an inoculant (Borreani et al, 2018). Factors related to silo type can also be controlled. For example, if ensiling in a horizontal silo, producers can decide if they will add additional weight to the packing equipment or utilize an oxygen barrier (Borreani et al, 2018). If the producer is making baleage management decisions can be made on the use of baler knives and how many layers of plastic will be used on bales (Borreani et al, 2018).

Current forage guides provide recommendations for various forage types grown across Canada, as well as general silage management recommendations (Alberta, 2004; Alberta, 2009; Perennia, 2021; OMAFRA, 2022). However, to our knowledge there are currently no studies and or surveys that have focused and reported on silage management practices for first cut alfalfa, alfalfa-grass mixed, and grass silage on Canadian dairy farms. Therefore, the objective of this study was to characterize and compare management practices related to first cut alfalfa, grass, and alfalfa grass mixed silage across different regions in Canada.

4.3 MATERIALS AND METHODS

4.3.1 Online Silage Survey

An online silage survey was developed during the summers of 2019 and 2020 by researchers at the University of Manitoba with input from Canadian dairy producers. A weblink to the survey was created both in English and French on the SurveyMonkey (SurveyMonkey, 1999-2023 Momentive) online platform, and contained questions related to general farm characteristics and silage management practices. The online survey was designed to be completed within 20 minutes or less and was tested with dairy producers in Manitoba for feedback. The survey contained two qualifying questions that asked (1) the type of forage grown (ALFA, ALFA-GR, GRS) in 2020, and (2) the silo type used, (bunkers, drive over piles, wrapped bales, or upright silos), in 2020. If the producer selected “No” or “Don’t Know”, to either question, they were disqualified from the survey. Researchers involved in the national study collaborated with provincial dairy farmers organizations to distribute the survey link to Canadian dairy producers via monthly newsletters, emails, and texts. The weblink to the survey was open to producers from October 2020 through March 2021. Incomplete surveys or disqualified surveys were removed from the data set. In total n=288 complete surveys were collected. Responses were categorized into four regions: (BC, n=21), (PRA n=32), (CTL, n=218), and (ATL, n=17).

4.3.2 Statistical Analysis

Proc Univariate in SAS 9.4 (SAS Institute Inc. 2022) was used to determine descriptive statistics regional milking herd size, perennial hectares, and total cultivated hectares of each region as well as the milking herd size and perennial hectares of each storage system. PROC FREQ with chi-square analysis in SAS 9.4 (SAS Institute Inc. 2022) was conducted to determine regional differences in silage management practices for forage type, storage system, tower type, cutting time, cutting height, conditioner use, wilting method, inoculant use, use of baler knives, added weight during packing, use of oxygen limiting barrier, and layers of plastic used on baleage. Survey responses were expressed both as a number and a percentage of the total responses for each region. Significance was considered at $p<0.05$.

4.4 RESULTS

Table 4.1. Descriptive Statistics on Regional Farm Size

Region	Factor	N[a]	Mean	SD[b]	Min[c]	25 perc[d]	Median[e]	75 perc[f]	Max[g]
BC	Cows Milked	19	127	63	30	85	123	160	300
	Perennial Hectares	21	45	19	8	30	45	61	81
	Total Hectares	21	76	40	28	42	73	81	182
PRA	Cows Milked	32	193	196	33	88	119	215	1000
	Perennial Hectares	31	144	157	22	65	113	142	809
	Total Hectares	31	702	1299	36	12	283	647	6880
CTL	Cows Milked	218	94	73	21	55	72	109	500
	Perennial Hectares	218	55	40	5	30	42	64	243
	Total Hectares	217	202	196	9	81	142	243	1920
ATL	Cows Milked	17	146	91	42	70	123	280	320
	Perennial Hectares	17	144	76	40	81	146	202	273
	Total Hectares	17	223	128	61	121	202	364	405

[a]N=number of samples
[b]SD= standard deviation
[c]Min=minimum value
[d]25 perc= 25% of samples below this value
[e]Median=50% of samples below this value
[f]75 perc=75% of samples below this value
[g]Max= maximum value

Table 4.2. Descriptive Statistics of Silo Type and Associated Milking Herd Size and Perennial Hectares Harvested

Silo	Metric	N[a]	Mean	SD[b]	Min[c]	25 perc[d]	Median[e]	75 perc[f]	Max[g]
Bunker	Cows Milked	100	168	134	38	98	130	290	1000
	Perennial Hectares	100	76	62	5	36	56	85	324
Pile	Cows Milked	12	140	76	55	85	117	187	315
	Perennial Hectares	12	132	136	22	45	11	154	526
Tower	Cows Milked	86	66	26	27	50	63	80	160
	Perennial Hectares	86	45	28	10	26	34	55	146
Baleage	Cows Milked	66	69	33	21	50	60	85	165
	Perennial Hectares	68	147	110	30	77	111	172	500

[a]N=number of samples
[b]SD= standard deviation
[c]Min=minimum value
[d]25 perc= 25% of samples below this value
[e]Median=50% of samples below this value
[f]75 perc=75% of samples below this value
[g]Max= maximum value

Table 4.3. Survey Responses for Forage Type and Silo Type,

	Regions										
	All responses		BC		PRA		CTL		ATL		
Survey questions and responses	N[a]	%[b]	N[c]	%[d]	N[c]	%[d]	N[c]	%[d]	N[c]	%[d]	*P-Value*
Forage Type											
ALFA	21	7.4	-	-	9	28.1	12	5.6	-	-	<0.0001
ALFA-GR	244	85.6	7	33.3	22	68.8	200	93.0	15	88.2	
GRS	20	7.0	14	66.7	1	3.1	3	1.4	2	11.8	
Silo Type											
Bunker	100	34.7	11	52.4	10	31.3	74	33.9	5	29.4	<0.0001
Drive over pile	12	4.2	-	0	6	18.8	4	1.8	2	11.8	
Tower	86	29.9	-	0	2	6.3	81	37.2	3	17.7	
Baleage	68	23.6	6	28.6	9	28.1	48	22.0	5	29.4	
Other (Ag bag, etc.)	9	3.1	1	4.8	3	9.3	5	2.3	-	0	
Unknown	13	4.5	3	14.2	2	6.2	6	2.8	2	11.7	
Tower Silo											
Conventional	69	81.2	-	0	-	0	66	82.5	3	100	0.0090
Oxygen limiting	16	18.8	-	0	2	100	14	17.5	-	-	

[a]N = total number of survey responses from all participants
[b]%= percentage of survey responses from all participants
[c]N= total number of survey response from all participants within the region
[d]%= percentage of survey responses from all participants within the region

Table 4.4. Survey Reponses Relating To Cutting Management

	Regions										
	All responses		BC		PRA		CTL		ATL		
Survey questions and responses	N[a]	%[b]	N[c]	%[d]	N[c]	%[d]	N[c]	%[d]	N[c]	%[d]	*P*-Value
Preferred Cutting Time											
AM	195	69.6	13	65	19	65.5	151	70.6	12	70.6	0.8384
PM	65	23.2	6	30	6	20.7	50	23.4	3	17.7	
No preferred time	17	6.1	1	5	3	10.3	11	5.1	2	11.8	
Don't know	3	1.1	0	0	1	3.5	2	0.9	0	0	
Cutting Height											
<5 cm	25	8.9	5	25.0	2	6.9	16	7.3	2	11.8	0.4682
5-10 cm	199	71.1	11	55.0	23	79.3	154	70.6	11	64.7	
>10 cm	55	19.6	4	20.0	4	13.8	43	19.7	4	23.5	
Don't know	1	0.4	0	0.0	0	0	5	2.3	0	0.0	
Conditioner Used											
No	80	28.6	2	10	12	41.4	59	27.1	7	41.2	0.2152
Yes	186	70	18	90	17	58.6	151	69.3	10	58.8	
Don't know	4	1.4	0	0	0	0	8	3.7	0	0	
Are Forages Wilted											
No	37	13.2	0	0	3	10.3	32	14.7	2	11.8	<0.0001
Yes, in windrows	213	76.1	11	55.0	22	75.9	168	77.1	12	71.0	
Yes, with tedding	24	8.6	9	45.0	1	3.5	11	5.0	3	17.7	
Don't know	6	2.1	0	0	3	10.3	7	3.2	0	0	

[a]N = total number of survey responses from all participants
[b]%= percentage of survey responses from all participants
[c]N= total number of survey response from all participants within the region
[d]%= percentage of survey responses from all participants within the region

Table 4.5. Survey Responses Relating To Harvest and Ensiling Management

			Regions								
	All responses		BC		PRA		CTL		ATL		
Survey questions and responses	N[a]	%[b]	N[c]	%[d]	N[c]	%[d]	N[c]	%[d]	N[c]	%[d]	*P*-Value
Inoculant Used											
No	117	40.6	9	45	16	55.2	87	39.9	5	29.4	0.0050
Yes	162	56.3	11	55	13	44.8	127	58.3	11	64.7	
Don’t know	9	3.1	0	0	0	0	4	1.8	1	5.9	
Baler Knives											
No	18	27.7	0	0	5	55.6	12	26.7	1	20	0.1136
Yes	47	72.3	6	100	4	44.4	33	73.3	4	80	
Additional Packing Weight											
No	28	26.2	3	27.3	7	43.7	14	18.9	4	66.7	0.0140
Yes	78	72.9	8	72.7	8	50.0	60	81.1	2	33.3	
Don’t know	1	0.9	0	0	1	6.3	0	0	0	0	
Oxygen Barrier											
No	28	26.2	8	72.7	6	37.5	14	18.9	0	0	0.0010
Yes	77	72.0	2	18.2	10	62.5	59	79.7	6	100	
Don’t know	2	1.8	1	9.1	0	0	1	1.4	0	0	
Wrapping Layers											
<4	5	7.8	0	0	0	0	3	6.8	2	40	0.0772
4-6	17	26.6	2	33.3	2	22.2	12	27.3	1	20	
7-10	20	31.3	1	16.7	2	22.2	16	36.4	1	20	
>10	9	14.1	2	33.3	0	0	7	15.9	0	0	
Don’t Know	13	20.3	1	16.7	5	55.6	6	13.6	1	20	

[a]N = total number of survey responses from all participants
[b]%= percentage of survey responses from all participants
[c]N= total number of survey response from all participants within the region
[d]%= percentage of survey responses from all participants within the region

4.5 DISCUSSION

4.5.1 Pre-Ensiling Management

To our best knowledge there are no reports regarding the management of first cut perennial silage on Canadian dairy farms. In line with our hypothesis, forage types grown on Canadian dairy farms differed among Canadian regions (Table 4.5). For monoculture GRS stands, the highest response rate was 66.7% by respondents in the BC region. Respondents in the PRA, CTL, and ATL regions only reported 3.1%, 1.4%, and 11.8% production of monoculture GRS stands respectively. Previous forage and dairy farm studies in BC have reported orchardgrass *(Dactylis glomerta L.)* as a common monoculture or mixed with ALFA (Peterson and Waldern, 1977; Von Keyserlingk et al, 1996; Zebarth et al, 2001; Smith et al, 2011; Thompson, 2013). Perennial GRS have a higher tolerance of acidic soil (pH<6.5) and excessive soil moisture compared to ALFA (Alberta, 2009; Perennia, 2021; OMAFRA, 2022). Acidity of the soil in BC has been demonstrated by Peterson and Waldern (1977), who reported an average soil pH of 5.99 on 65 dairy farms in the lower Fraser Valley. In more recent studies, lower soil pH (5.6) values have been reported for forage plot test sites, including those at Agriculture and Agri-Food Canada in Agassiz BC (Belanger et al, 2020). Due to the acidic soils which are associated with agriculture land in BC and ATL Canada, perennial GRS are better suited for forage production intended for livestock use in this region (Sanborn et al, 2011). For ALFA monoculture stands, BC and the ATL region had no survey responses. However, these survey responses are just representative of the respondents who answered the survey, as it is well documented that ALFA production does occur in BC and ATL Canada (Penncock et al, 2011; Pennia, 2021). PRA and CTL regions reported growing monoculture ALFA at 28.1% and 5.6%

respectively. The majority of respondents in the PRA (68.8%), CTL (93%), and ATL (83.2%) regions indicated growing ALFA-GR mixed stands while only 33.3% of BC respondents reported growing ALFA-GR mixed stands. In BC, ALFA-GR mixtures are often orchardgrass and ALFA while in eastern Canada ALFA and timothy mixtures are common (Zebarth et al, 2001; Thompson, 2013). Over the past decade, Canadian forage studies have focused on the benefits of ALFA-GR mixtures over ALFA and GRS monocultures (Aponte et al, 2019; Belanger et al, 2014, Belanger et al, 2020; Pomerleau-Lacasse et al, 2018). Studies have found that when ALFA is grown with at least one GRS, DM yield increases, weed invasion decreases, and the need for nitrogen inputs decreases (Aponte et al, 2019; Belanger et al, 2014, Belanger et al, 2020). While there are limited surveys and studies regarding forage types grown on Canadian dairy farms, there are studies and surveys that have examined the composition of lactating cow rations on Canadian dairy farms (Plaizier et al, 2004, Sheppard et al, 2011, Gee et al, 2021). Since most Canadian dairy farms produce their own forages, the composition of the ingredients of the lactation diets gives a good indication of the types of forages being grown on farm. A nutritional management survey conducted on 40 Manitoba dairy farms in 2004 by Plaizier et al (2004) found that 75% of dairy farms in Manitoba used AFLA and mixed haylages, while only 5% used GRS silage in their lactation cow rations. These percentages were higher than those reported by Gee et al, (2021) who surveyed feeding practices on dairy farms in western Canada and Ontario. In the survey of Gee et al, (2021), 18.6% of respondents indicated using GRS haylage, 34.8% utilized legume haylage, and 41.6% reported using mixed haylage in their lactation cow rations. For BC and PRA regions in Gee et al, (2021), GRS haylage use was reported at 26.3% which was higher than legume and mixed haylage which were reported at 21.3%. (Gee et al, 2021). For Ontario farms, Gee et al, (2021) reported that, legume, mixed, and grass haylage were utilized by 45%, 48%, and 13.3% of respondents respectively. In the ATL region, Sheppard et al, (2011) reported that the average lactation ration contained 27% low legume silage (<25% legume content), 16% high legume silage (>25% legume content), 18% low legume hay, 10% corn silage, 8% grain, 7% high legume hay, 6% pasture, 6% other ingredients, and 3% cereal silage. The high percentage of mixed silage/haylage used within Canadian lactation cow rations (Plaizier et al, 2004; Sheppard et al, 2011; Gee et al, 2021) corresponds with the our survey responses for ALFA-GR mixed stands in the PRA, CTL, and ATL regions, while the use of GRS silage/haylage (Sheppard et al, 2011; Gee et al, 2021) in western Canada corresponds to the survey responses for monoculture GRS stands in BC.

Once forages reach the desired maturity for cutting, producers must make decisions regarding the time of cutting, cutting height, conditioner use, and whether forages are directly cut or wilted. The time of cutting has become an area of interest for dairy producers due to the accumulation of NSC in the forage that occurs during the day (Britto et al, 2008; Morin et al, 2011; Morin et al, 2012, Tremblay et al, 2014; Borreani et al, 2018). These NSC act as an energy source that is readily available to rumen bacteria (NRC, 2001) with maximum concentrations occurring 11 to 13 hours after sunrise (Morin et al, 2011). Increased forage NSC contents have been found to increase DM intake (DMI) (Burns et al, 2005; Britto et al, 2008) and milk yield Britto et al, (2008). However, Tremblay et al, (2014) found that NSC concentrations in afternoon cut ALFA were not maintained throughout the silage fermentation process, unless the NSC concentration was greater than >10 g NSC kg^{-1} DM). Afternoon cutting also prolongs plant respiration, thereby expending accumulated NSC and increases the risk of nutrient leaching (PENN State, 2004; Alberta, 2009; Kung Jr et al, 2010, Kung Jr et al, 2010; OMAFRA, 2022). Therefore, it has been recommended that producers cut in the AM to maximize the drying period during the day (PENN State, 2004; Alberta, 2009, OMAFRA 2022). In our survey, cutting time was not significantly different among the regions as 65%, 65.5%, 70.6%, and 70.6% of respondents respectively from BC, PRA, CTL, and ATL, indicated cutting in the morning. This indicates that majority of dairy producers are maximizing the drying period during the day. For the 30% respondents in BC, 20.7% in PRA, 23.4% in CTL, and 17.7% in the ATL region that indicated cutting in the PM, there is an increased risk of weather exposure and loss of accumulated NSC.

Recommended cutting heights are often based on forage type and the nutritive goals of the farm. Lower cutting heights (less than 5 cm) are associated with higher yields, but the nutritive value decreases as the leaf: stem ratio of the cut decreases (PENN State, 2004; Jones and Tracy, 2017). The recommended cutting heights for GRS and ALFA are 10 cm and 7-10 cm, respectively (PENN State, 2004, Alberta, 2009; Jones and Tracy, 2017, OMAFRA, 2022). Cutting height was not significantly different among the regions, as the majority (BC 55%, PRA 79.3%, CTL 72.0%, and ATL 64.7%) of respondents indicated cutting forages between 5-10 cm, which agrees with current recommendations. The respondents that indicated cutting at <5 cm (BC 25.0%, PRA 6.9%, CTL 7.5%, and ATL 11.8%) can expect higher yields, although nutritive value of their silage could be compromised. The respondents that indicated cutting at >10 cm (BC 20.0%, PRA 13.8%, CTL 20.1%, and ATL 23.5%) may obtain lower yields but higher nutritive value of their silages.

Intensive mechanical conditioning or maceration is a method used in forage conservation to accelerate the wilting process (Oullet et al, 2006). This is achieved by using a mower conditioner that cracks or crimps the plant stems to help with moisture evaporation. Mower conditioners are often recommended, as they accelerate the wilting process, and limit nutrient and energy losses due to plant respiration and allow for target moistures to be reached faster (Alberta, 2009; Borreani et al, 2018; Haselman et al, 2021; OMAFRA, 2022). In our survey, the use of conditioners was not significantly different among the regions, with a majority of respondents indicating that a conditioner was used at the time of cutting (BC 90%, PRA 58.6%, CTL 70.6%, and ATL 58.8%). This indicates that respondents follow current recommendations. For the respondents that indicated not using a conditioner at harvest (BC 10%, PRA 41.4%, CTL 27.6%, and ATL 41.2%), it is possible that these respondents want to avoid or reduce leaf shattering that is often associated with conditioner use (Borreani et al, 2018; Haselman et al, 2021).

It is recommended for forages to be wilted in wide windrows to target moisture levels for the intended silo, unless direct cutting of the forages in occurring (Ownes et al, 2002; Alberta, 2009; Kung Jr, 2010; Kung Jr et al, 2010; Borreani et al, 2018, OMAFRA, 2022). Recommended moisture levels are 65-70% MC for horizonal silos, 60-65% MC for conventional concrete tower silos, 40-55% MC for oxygen limiting tower silos, and 50-60% MC for wrapped bales (PENN State, 2004). In our study, there was a significant difference among the regions regarding wilting methods. BC was the only region that had no responses for direct cutting compared to the response rates of 10.3%, 15%, 11.8%, in the PRA, CTL, and ATL region, respectively. The majority of respondents across all regions in BC 55.0%, PRA 75.9%, CTL 78.9%, and ATL 71% wilted their forages in windrows. The remaining respondents indicated wilting their forages in windrows, followed by tedding. BC had the highest response rate for tedder use (45%), while the PRA, CTL, and ATL regions had response rates of 3.5%, 5.1%, and 17.7%, respectively. Tedding is a common practice in grass production systems, so the higher response rate in BC and ATL regions correspond with the higher GRS monoculture stands indicated in these regions (Table 4.2).

4.5.2 Harvest and Ensiling Management

Inoculants are recommended to help improve fermentation and aerobic stability of silage, once the silo is open (Muck et al, 2018; OMAFRA, 2022). Lactobacillus Bacteria (LAB) strains are the most commonly used homofermenter, because they only produce lactic acid and help to rapidly decrease silage pH (Muck et al, 2018; OMAFRA, 2022). In recent years *Lentilactobacillus buchneri* (formerly *Lactobacillus buchneri*), a heterofermenter, that produces both lactic and acetic acid (Buxton et al, 2003; Muck et al, 2018; OMAFRA, 2022), has also been used. The benefit of acetic acid is that it supresses yeast and mould better than lactic acid, and slows down heat production upon opening the silo, thereby were enhancing aerobic stability, and keeping the silage's face fresh longer (OMAFRA, 2022). There was a significant difference seen among the regions for inoculant use. The majority of BC 55%, CTL 59.4%, and ATL 64.7% respondents indicated using inoculant during harvest which is in line with current recommendations (OMAFRA, 2022). The PRA region was the only region with the highest response rate for no inoculant (55.2%). While inoculants have been proven to aid fermentation, the benefits of the product are not always noticed at the farm level (OMAFRA, 2022). This may be a determining factor for a producer, as inoculant is an added expense (Muck et al, 2018; OMAFRA, 2022). As observed in the survey, there were substantial response rates for "no inoculant" (BC 45%, PRA 55.2%, CTL 40.7%, and ATL 29.4%).

Silos used on farm must fit into the entire feeding operation of the farm. For tower silos, the CTL region had the highest response rate, with 37.2%, followed by the ATL region with

17.7%, and the PRA region with a 6.3% response rate. BC had no respondents indicating the use of tower silos. Tower silos are divided into two categories, i.e., “conventional or concrete” which are typically described as top-unloading silos and “oxygen limiting” which are bottom unloading silos. In the survey, 82.5% of the tower silos in the CTL region were conventional towers and 17.5% were oxygen limiting towers. In the ATL region, 100% of the tower silos were concrete, while 100% of the tower silos in the PRA region were oxygen limiting. Since top unloading silos are not completely sealed, like bottom unloading silos, GRS and ALFA should be conserved at high moisture contents (55-65%MC) (Wilkinson et al, 2003). A wet silage prevents air from being trapped among the forage particles and reduces the risk of silo fires (Wilkinson et al, 2003). In oxygen limiting silos, silages can be drier (40-50%MC), which prevents the forage from caking and losing its ability to flow in the silo as well as reduces the risk of effluent damaging the unloader and conveyors (Wilkinson et al, 2003). The high response rate for tower silos in the CTL region are in line with historical reports and previous tower silo studies conducted during the 70s, 80s, and 90s (Bozozuk, 1976; Morin and Bozozuk, 1983; Negi et al, 1990; I.S.A, 2020). In Canada, the first records of concrete tower silos being built were in the early 1900’s with majority being in eastern Canada (I.S.A, 2020). By 1974, there were about 3000 tower silos within ON and QU, and in 1978, there were 9,430 tower silos reported in QU only (Bozozuk, 1976; Morin and Bozozuk, 1983). In the mid to late 1980’s the use of oxygen limiting silos increased, as the bottom unloading silos provided a fully automated feed handling system and eliminated the need to climb the silo to service the unloader (Negi et al, 1990). Another benefit of the oxygen limiting silos was the “first in-first out” feature, which benefitted farms that harvested two or three cuts during the growing season (Negi et al, 1990). In the 1990’s herd sizes began to increase, which decreased the demand for tower silos in

Canada, as producers switched to horizontal silos like bunkers and piles to meet their silage storage needs (Wilkinson et al, 2003). From 1974 to 1990, the average milking herd size went from 30 to 41 cows in the CTL region, 22 to 39 cows in the ATL region, 13 to 42 cows in the PRA region, and 48 to 75 cows in the BC region (CDIC, 2023). By 2020, the average milking herd size had more than doubled in the CTL, ATL, PRA, and BC regions, averaging 84, 102, 159, and 176 cows respectively (CDIC, 2023). Respondents of our survey averaged milking herd sizes of 10, 44, and 34 cows more than these averages for CTL, ATL, and PRA respectively. Respondents from BC had 49 cows less than the averages reported by the Canadian Dairy Information Center (CDIC) for 2020. The association between milking herd size and choice of silos is demonstrated in TABLE 4.3. Farms with tower silos had a herd average of 66 cows, whereas bunkers and piles had herd averages of 168 and 140 cows, respectively. Respondents that reported using tower silos also averaged 45 hectares per farm for perennial silage while farms using bunkers and piles averaged 76 and 132 hectares for perennial silage per farm, respectively.

Bunkers and piles are the least expensive to construct, and are well suited for larger farms, as seen in (Table 4.3) (Alberta, 2003; Alberta, 2009; OMFARA, 2022). The highest response rate for bunkers was in BC with 52.4%, followed by the PRA 31.5%, CTL 33.9%, and 29.4% in the ATL region. Bunkers can be built for increased storage capacity to meet the large tonnage needed by larger farms. For example, a bunker with the dimensions, 3 m high, 28 m wide, and 60 m long, has the capacity to hold 5,845 tonnes of silage at 60% moisture (Alberta, 2004). This is more than double the storage capacity of a large concrete tower silo with the dimensions (9.1 m diameter x 30.5 m height), that can only hold 1’692 tonnes of silage at 60% moisture (OMAFRA, 2022). The response rate for piles was the highest in the PRA region at

18.8%, followed by 11.8% in the ATL region, and 1.8% in the CTL region, but no responses in BC. Piles are a cost-effective method to store silages, as no physical structures, such as side walls, are required (Alberta, 2004; Alberta, 2009). It is recommended that silages are only stored in piles after permanent silos are filled and more storage is required or as interim storage while silos are being built (Alberta, 2004). The lack of side walls can result in large surface areas that are exposed to oxygen and weather, which can increase the risk of spoilage (Alberta, 2004; OMAFRA, 2022).

Additional weight can be added to packing equipment for bunkers and piles, to help reach targeted packing densities. There was a difference among the regions for additional weight on packing equipment. In BC 72.7% of respondents indicated adding weight to packing equipment, while 27.3% did not. In the PRA region, 50.0% of respondents indicated additional weight, while 43.8% did not. In the CTL region, 81.1% of respondents indicated adding weight to packing equipment, while 18.9% did not. In ATL the majority (66.7%) of respondents indicated not adding additional weight to packing equipment.

In addition to plastic film for covering, oxygen barriers can be added to bunkers and piles as additional measure to keep oxygen out of the silo. In the survey there were differences among the regions for oxygen barrier use. The majority of respondents in the PRA 62.5%, CTL 79.7%, and ATL 100% regions indicated using an oxygen barrier, while in BC only 18.2% of respondent indicated using an oxygen limiting barrier. These results indicate that most producers ensiling forage in bunkers and piles are following the recommendations for additional weight during packing and use of oxygen barriers (Alberta, 2004; Alberta, 2009; OMAFRA, 2022).

Wrapped bales can be a cost-effective storage option for small to medium size farms (Coblentz et al, 2016). Wrapped bales made up less than a third of the silos used in each region, i.e., 28.0% BC, 28.1% in PRA, 22% in CTL, and 29.4% in the ATL region. Fermentation is often restricted in wrapped bales as forage particles are not finely chopped like forage stored in bunkers, piles, or tower silos, therefore lactic acid-producing bacteria have limited access to fermentation substrates (sugars) (Borreani and Tabacco, 2006). To reduce forage particle size within the bale, baler knives can be added to baling equipment. In this survey, the use of baler knives did not differ significantly among the regions. The majority of respondents in, BC 100%, CTL 73.3%, and ATL 80% regions, indicated using baler knives, except for the PRA region (44.4%). It is recommended that bales are wrapped with a minimum of 4 layers (Hancock and Collins, 2006; OMAFRA, 2022). In our survey, 31.3% of respondents indicated using 7-10 layers, 26.6% indicated using 4-6 layers, 14.1% indicated wrapping more than 10 layers, and 7.8% indicated using less than 4 layers for the wrapping of bales. These results indicate that the majority of producers ensiling forage as baleage are wrapping bales with the minimum of 4 layers and or exceeding this recommendation (Hancock and Collins, 2006; OMAFRA, 2022).

4.6 CONCLUSION

Data presented here provides an overview on the current forage types being grown and silage management practices being used on Canadian dairy farms. Significant differences were seen among the regions were for forage type (p<0.0001), storage system (p<0.0001), and wilting methods (p<0.0001). Climate and soil types vary across the country, and the forage types grown in each region are in line with the different recommendations for the regions. Silos used on farms corresponded with milking herd size with smaller farms using tower silos and larger farms using horizontal silos. Wilting forages in windrows was the most common method utilized among the regions. However, there were a substantial number of responses for wilting forages utilizing a tedder, particularly in BC and the ATL region who also had the highest response rates for GRS. The PRA, CTL, and ATL region also had a substantial number of responses for “No Wilting”. The majority of respondents of the survey are following recommendations by cutting forages between 5-10 cm with mower conditioners, maximizing use of drying conditions by cutting in the morning, and wilting forages in windrows. During harvest, majority of respondents are using inoculants, except for the Prairie region. where majority indicated not using inoculants. The majority of producers ensiling forage in horizonal silos are following the recommendations for achieving the required packing density by adding weight to packing equipment. A majority of responders ensiling forage in horizonal silos are also utilizing oxygen barriers to help limit oxygen infiltration. The majority of responders ensiling forage in wrapped bales are using baler knives during harvest and wrap bales with 7-10 layers of plastic which exceeds the recommended minimum of 4 layers Overall, the respondents within this survey appear to follow recommendations for silage production according to their region and recommendations specific to the silo being used.

5. MANUSCRIPT 2

Effects of On-Farm Silage Production Practices on the Quality of Alfalfa Grass Silages Across Canadian Dairy Farms

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5.1 ABSTRACT

The objectives of this study were to assess forage quality of first cut ALFA, ALFA-GR, and GRS silages using various quality parameters and determine the effects of region and silage production management practices on forage quality. Between 2018 – 2020, (n=186) first cut ALFA, ALFA-GR, and GRS silage samples were collected from (BC, n=15), (PRA, n=55), (CTL, n=34), and (ATL, n=82) regions. Silage quality was assessed with proximate analysis and near infrared reflectance spectroscopy (NIR), relative feed value (RFV), relative forage quality (RFQ), 48 hour *in vitro* dry matter digestibility (IVDMD) (ANKOM DAISY^{II} Incubator), 48 hour *in vitro* cumulative gas production (ANKOM RF Gas Production System), and silage acidity (Accument AB15 benchtop pH meter). Descriptive statistics were determined using PROC UNIVARIATE. PROC GLM was conducted using quality parameters as dependent variables (RFV, RFQ, IVDMD, Vol_{GAS48}, pH) and survey responses as independent variables. Effects and interactions within models were reported significant when $p<0.05$ and trends $0.05<p<0.10$ were discussed. When silages were evaluated using RFV, ALFA averaged (136.34) which meet the minimum RFV (125) recommendation for lactating dairy cows whereas ALFA-GR (109.83) and GRS (98.68) did not. Evaluating silages with RFQ improved their quality estimation and the average RFQ of ALFA (163.92), ALFA-GR (158.53), and GRS (146.42) met the minimum RFQ (125) recommendation. The ALFA samples tended to have a higher pH (4.86) than ALFA-GR (4.50), and GRS (4.79). Higher pH for GRS samples could be attributed to higher DM content at time of ensiling. The IVDMD values for ALFA (66.68% DM), ALFA-GR (62.95% DM), and GRS (57.19% DM) were in line with previous IVDMD studies. Vol_{GAS48} averages could not be compared to other studies, due to the lack of a standardized laboratory procedure, ALFA (104.89 mL g^{-1}), ALFA-GR (103.85 mL g^{-1}), GRS (57.19 mL g^{-1}). Currently

there is no industry standard using IVDMD or Vol_{GAS48} to categorize forages as good or poor. Region and forage type were the two most significant factors that had an effect within every model. The ALFA silage tended to have the highest estimates of forage quality, but regions never ranked in the same order. Forages cut with mower-conditioners tended to have lower Vol_{GAS48} and IVDMD. Inoculated forages had lower pH values and higher IVDMD compared to non-inoculated forages. This study concluded that (i) there is a large variation within silage quality across Canada, (ii) RFV should not be used to evaluated forages other than ALFA and (iii) measured estimates such IVDMD and Vol_{GAS48} need further research to standardize good vs poor forage as the models are influenced by multiple silage management factors with regional interactions.

5.2 INTRODUCTION

In the Canadian dairy industry, ALFA (*Medicago sativa L.*) is an important forage crop with Canada growing over 3 million hectares of ALFA and ALFA mixtures (Statistics Canada, 2022). Advantages of ALFA include its high nutrient content, digestibility, and high yield capability (Pomerleu-Lacasse et al, 2019; Belanger et al, 2020; Ren et al, 2021). While ALFA and ALFA mixtures can be found across Canada, the majority (73%) of its production occurs within the PRA region (AB SK, MB) (Ren et al, 2019; Statistics Canada, 2022). The predominant chernozemic soils of the PRA and pockets of the BC interior are rich in soil organic matter, neutral in acidity, and tend to only have brief saturation periods during the spring making for ideal ALFA growing conditions (Pennock et al, 2011). For the majority of BC, CTL, and ATL regions, soils tend to be more acidic because of podzolic soils and experience greater precipitation compared to PRA (Lavkulick et al, 2011; Sanborn et al, 2011). Through drainage and liming, soil can be amended to improve growing conditions for ALFA (Pennock et al, 2011). However, unlike ALFA, some perennial GRS and other legumes are better adapted to saturated soils and low soil pH (OMAFRA, 2022). In BC, it is a common practice to grow orchardgrass (*Dactylis glomerata*) as a monoculture or mixed with ALFA (Thompson, 2013) and in eastern Canada ALFA is often mixed with timothy (*Phleum pratense*) (Belanger et al, 2020). The difference in forage type production is also reflected in the most recent Canadian Agriculture Census. The CTL region makes up 33% of the "all other tame hay and fodder crops" production compared to 21% of ALFA and ALFA mixtures (Statistics Canada, 2022). While BC makes up 8% of tame hay production vs 5% of ALFA production and ATL Canada made up 6% tame hay production compared to only 1% ALFA production (Statistics Canada, 2022).

When harvesting forages intended for lactating dairy cattle, the goal is to optimize forage quality with sufficient yield (Belanger et al, 2020). It is well known that maturity negatively impacts forage quality as the leaf to stem ratio decreases and stem cell content increases (Guo et al, 2019). Therefore, monoculture ALFA stands should be harvested between the early bud through early bloom stage (Belanger et al, 2020). Monoculture GRS stands should be harvested between the boot stage and early heading stage (Lauzon et al, 2019). Harvesting ALFA-GR mixtures tend to be more complicated as GRS has higher fiber content than ALFA when cut at the same maturity stage (MSU, 2011). Therefore, it is generally recommended to harvest mixed stands based on the maturity of the ALFA (MSU, 2011). While maturity plays a significant role in forage quality, silage management factors also play a significant role. Two common silage management practices often discussed are the use of mower conditioners and silage inoculants. The benefits of mower conditioners are that they crush and crack the stems of the forage to help speed up the wilting process and stop plant respiration (Borreani et al, 2018). However, conditioners may also be a source of DM loss due to leaf shattering, particularly if the conditioner is too severe for the forage being cut. Borreani et al, (1999), found that intermeshing rubber rollers were better suited for ALFA than impeller conditioners which were better suited for Italian ryegrass. Silage inoculants are another silage management practice that may be used to help rapidly decrease the silage pH. Controlled laboratory studies using mini silos have shown the benefits of inoculating forages prior to ensiling (Filya et al, 2007). But with variation in forage moisture content, natural plant bacteria populations, silo types, and handling practices of inoculant, the benefits are not always observed at the farm level (OMAFRA, 2022). Therefore, producers may opt to not use inoculant and not incur the additional cost (OMAFRA,2022).

Forage quality can ultimately be defined as the forage's potential to produce a desired animal response such as kg's of milk. However, an animal's response to a forage is generally not known prior to the feeding or purchase of a forage. Therefore, quality parameters or quality indices exist to help evaluate forage potential. When evaluating and comparing quality indices it is important to understand (i) what is being assessed in the forage (ii) is the index measured or estimated and (iii) is the index forage type specific. A standard forage analysis provides the nutritive feed value of the forage and what is potentially available to the animal. These are generally conducted via proximate analysis or NIR methods. Proximate analysis methods measure the nutrients using various analysis while NIR provides calculated estimates of the nutrient profile via calibrations. However, the nutrient profile is often not enough to evaluate and compare forages as similar nutrient profiles tend to perform differently as digestibility varies. In the past, RFV was commonly used to evaluate and compare forage quality/performance for legume-based forages like ALFA (Jeranyama and Garcia, 2004). This was calculated by using the plants' ADF and NDF to estimate DDM and DMI, respectively (Moore and Undersander, 2001). Unfortunately, the higher fiber content in GRS resulted in lower RFV and could not compare forage quality across different forage types. The RFV equation was later improved upon to consider more nutrient coefficients and become known as RFQ (Moore and Undersander, 2001). By incorporating multiple nutrient coefficients into the equation legume-based forages and GRS can be compared without being penalized due to natural occurring plant characteristics like fiber or CP. While RFV and RFQ can be a quick way for producers to evaluate their forages, the indices are a better reflection of the forage's maturity at harvest. Analysis like IVDMD or Vol_{GAS48} are better indicators of forage quality as they mimic total tract digestion and ruminal fermentation. However, even though *in vitro* analysis is a better representation of the forages potential the procedures are time consuming and expensive for most commercial labs due to the rumen fluid requirement.

To our knowledge there is limited literature that evaluates the quality of first cut perennial silage on Canadian dairy farms and the impact of region and silage management practices. Therefore, the objectives of this study are to: (i) evaluate forage quality of first cut ALFA, ALFA-GR, and GRS silage using RFV, RFQ, IVDMD, Vol_{GAS48}, and silage pH; and (ii) determine the impact of region and silage management practices on the quality of first cut perennial silage.

5.3 MATERIALS AND METHODS

5.3.1 Silage Sample Collection

Between 2018–2020, (n=186) 1 kg samples of first cut ALFA, ALFA-GR, and GRS silage samples were collected in the late summer and winter months from BC (n=15), PRA (n=55), CTL(n=34), and ATL (n=82). Samples were collected from bunkers, driver over piles, towers, and wrapped bales following the sampling protocols described in Valacta, (2017). A STAR Universal Forage Sampler (Star Quality Samplers Inc. Irricana AB Canada) and a Dewalt 20V power drill were used to collected samples from bunkers, drive over piles, and wrapped bales. Samples from tower silos were collected at the time of feeding on farm. Samples were stored in an insulated cooler with ice between farms and then placed in -20 ºC freezer. A 600 g subsample of the silage was collected and sent to l'Université du Québec en Abitibi-Témiscamingue (UQAT) (QU, Canada) for silage acidity and a forage analysis using NIR. A 100 g subsample of the silage was sent to Central Testing Laboratory (Winnipeg, MB Canada) for a forage analysis using AOAC methods. Remaining silage samples were stored at the University of Manitoba in a -20 ^oC freezer.

5.3.2 In-person Silage Survey

An in-person silage survey was development in 2019 by the researchers at the University of Manitoba with inputs from other collaborators as well as local dairy producers and industry professionals. The survey contained questions related to general farm characteristics and silage management practices as well as specific management questions related to the silage sample collected on farm. The survey was tested with local dairy producers prior to administering on farm. The survey was then administered in-person during the farm visits, over the phone, or via email. A copy of the survey is included in the appendix of this thesis.

5.3.3 Proximate Analysis

Silage samples were analyzed at Central Laboratory Testing (Winnipeg, MB, Canada) for CP (AOAC method 990.03), ADF and NDF were determined using the A2000 Ankom Fiber Analyzer with method 12 and 13, respectively as described by Ankom Technologies (Ankom, 2017a; Ankom, 2017b). Chemical composition results from proximate analysis allowed for RFV to be calculated. Relative feed value (RFV) was determined using the equations below (Jeranyama and Garcia, 2004):

$$Digestible\ Dry\ Matter\ (DDM) = 88.9 - (0.779 * \%ADF)$$

$$Dry\ Matter\ Intake\ (DMI, \%BW) = \frac{120}{\%NDF}$$

$$Relative\ Feed\ Value = \frac{(DDM * DMI)}{1.29}$$

5.3.4 Near Infrared Reflectance Spectrometry

The NIR analysis was contracted out to Dairyland Laboratory (UCAT) and Cumberland Valley Analytical Services (Waynesboro, PA). Frozen silages samples were thawed at room temperature for two hours before DM and NIR analysis. Dry matter analysis was conducted by drying forages at 60ºC for 4 hours using methods 2.2.1.1 or 2.2.1.2 of the National Forage Testing Association (NFTA, 1993). These methods were conducted to allow grinding and scanning of samples, while keeping as many volatile products as possible in the samples. Samples were ground using a 1 mm sieve with the Cyclotec CT-293 (Foss, Eden Prairie, Minnesota, USA), and subsequently inserted and compressed into a cell to a thickness of 1.5-2.0 cm. Scanning was conducted using a NIR DS 2500 (Foss, Eden Prairie, Minnesota, USA) and sent to Cumberland Valley Analytical Services (Waynesboro, PA) and Dairyland Labortory Inc. (UQAT) to predict the nutritional attributes according to the botanical composition of the sample. Final analytical DM analysis was conducted by drying at 105˚C. CP, ADF and NDF determined from the NIRS analysis were used to determine legume content using the equation below from Allard et al (2001). Silage samples were considered grass when legume content was less than 25%, mixed when legume content of 25.01-49.99%, and as legume samples when legume content was greater than 50%.

$$\%legume = 119.265\left(\frac{CP}{ADF}\right) + 352.415\left(\frac{ADF}{NDF}\right) - 238.685$$

NIRS forage analysis also reported relative forage quality (RFQ) values.

5.3.5 In-*Vitro* Dry Matter Digestibility

Dry ground silage samples were weighed out to 0.5g ±0.02g into F57 Ankom filter bags that had been rinsed in acetone, air dried, labeled with a solvent-resistant marker, and subsequently heat sealed. Duplicate samples were then placed into one of four rotation digestion vessels of the AKOM Daisy^{II} Incubator with a 4:1 ratio of rumen buffer (1600ml) and rumen fluid (400ml) and left to incubate for 48 hours at 39˚C. Rumen buffer was made up the morning of the experiment according to Dept of Animal Science Method DAISY^{II}, (2021). Two liters of rumen fluid were collected from two rumen fistulated lactating Holstein cows at the Glenlea Research Dairy Barn (Glenlea, MB) prior to morning feeding (Dept of Animal Science Method: DAISYII, 2021). Then the rumen fluid was filtered through cheesecloth and purged under constant CO_2 in a preheated water bath set at 39 ˚C before filling digestion vessels. The ANKOM DAISY^{II} digestion jars were warmed in an incubator at 39 ˚C prior to being filled with rumen buffer and rumen fluid. Jars were purged with CO_2 for 60s before and after being filled with rumen buffer and rumen fluid to eliminate oxygen in the head space of the jar. After 48 hours, incubation was terminated, and samples were removed, and triple rinsed with reserved osmosis water (RO) and analyzed with an NDF ending using the ANKOM DELTA Fiber Analyzer under method 15 by Ankom Technologies (Ankom Technology, Macedon, New York). Samples were then dried overnight in an oven at 102˚C and weighed back the next morning. *In-vitro* dry matter digestibility (IVDMD) was calculated using the following equations below.

<u>*In-vitro* Dry Matter Digestibility:</u>

$$Empy\ bag\ weight, grams\ (g) = W_1$$

$$Sample\ weight, grams\ (g) = W_2$$

$$Post\ In\ vitro\ weight, grams\ (g) = W_3 = W_1 + W_2$$

$$Remaining\ sample\ weight, grams\ (g) = W_4 = W_3 - W_1$$

$$Dry\ matter\ content, \% = W_5$$

$$Corrected\ Sample\ Weight, grams\ (g) = W_6 = \frac{(W_2 * W_5)}{100}$$

$$IVDMD, (\%) = W_1 = \left(\frac{(W_6 - W_4)}{W_6}\right) * 100$$

5.3.6 *In-vitro* Cumulative Gas Production

On day 1 of trial, dry ground silage samples were weighed out to 1.00 g in triplicate into F57 Ankom filter bags that had been rinsed in acetone, dried, labeled with solvent-resistant marker, heat sealed, and then randomly assigned modules within the same water bath. Solutions were made up according to the Dept of Animal Science Method: Gas Production, (2020) and stored in a 4 °C refrigerator. On day 2 of trial, inoculum was prepared for 42 jars according to Dept of Animal Science Method: Gas Production, (2020) then moved to a preheated water bath set at 39ºC and purged under constant CO_2 with an overhead mixer. The reducing solution was made up the morning of the experiment according to Dept of Animal Science Method: Gas Production, (2020) and then placed in pre-heated water bath at 39 ºC. Rumen fluid was collected the morning of the experiment from two rumen fistulated lactating Holstein cows at Glenlea Research Dairy Barn (Glenlea, MB) prior to morning feeding Dept of Animal Science Method: DAISY^{II}, (2021). Rumen fluid was filtered and prep in lab the same as Dept of Animal Science Method: DAISY^{II}, (2021). Rumen fluid, inoculum, and reducing solution were then combined while being purged under constant CO_2. Gas production jars were purged for 60 s with CO_2 before filling with 125 mL of inoculum and rumen fluid mixture. Jars were then purged for an additional 5 s after filling to eliminate oxygen in the jars' head space. Modules were then screwed onto the filled jars and placed in one of two water baths that had been set to 39 ºC. The ANKOM RF Gas Production software (Ankom Technology, Macedon, New York) was opened on computer to ensure all modules started at the same pressure, and subsequently, the "recording interval" was set to 1 min. The "live interval" was set to 10 s and the global pressure was set at 1 PSI. The pressure was recorded for 15-30 min to ensure modules were gradually increasing in pressure. After a 15-30 min "live interval", this was changed to 60 s. The jars were then shaken every 3 hr between 8:00 am and 4:30 pm for 48 hr. On day 4 of the procedure, the experiment was terminated. The cumulative gas production of the samples was converted from psi to mL/g^{-1} using the equations set out by ANKOM^{RF} Gas Production System Operators Manual (ANKOM Technologies, 2022). These equations are as follows:

'Ideal" Gas Law

$$n = p * \left(\frac{V}{R * T}\right)$$

n= gas produced in moles (mol)

p = pressure in kilopascal (kPa)

V= head-space volume in glass bottle in liters (L)

T= temperature in kelvin (K)

R = gas constant (8.314472 L·kPa·K^{-1} ·mol^{-1})

Gas Produced

$$gas\ produced\ (ml/g^{-1}) = n * 22.4\frac{L}{mol} * 1000\frac{ml}{L}$$

5.3.7 Silage Acidity and Dry Matter

Silage acidity was measured using a benchtop pH meter (Accument AB15, Fisher Scientific, Toronto, ON, Canada) at UQAT, (QU, Canada). To determine DM an extraction of water with anhydrous methanol (Methyl alcohol Chromar, VWR, Mississauga, ON) was performed according to Petit et al, (1997), using 20 g of silage and 150 mL of anhydrous methanol. The water content was determined by gas chromatography, using an Agilent 7890A/5975C (Mississauga, ON, Canada) chromatograph equipped with a 60-m DB-WAX capillary column (i.e., 0.25 mm; film thickness, 0.25 µm; Agilent J&W 122-7063UI), a 5 m-guard column HYDROGUARD FS, (i.e., 0.25 mm; Restek, 20429) and a mass spectrometer detector. At the time of the sample injection the column, temperature was 70°C for 1 min, then ramped at 70°C min^{-1} until 240°C and maintained for 3 min. At the end, the apparatus was purged during 8 min at 240°C. The inlet, detector and quadrupole temperatures were 250°C, 230°C and 150°C, respectively. The split ratio was 100:1, and the flow rate of the helium carrier gas was 1.5 mL min^{-1}.

5.3.8 Statistical Analysis

5.3.8.1 Descriptive Statistics

Forages were sorted by forage type (ALFA, ALFA-GR, GRS). PROC UNIVARIATE in SAS 9.4 (SAS Institute Inc. 2022) was used to determine mean, standard deviation, minimum, 25th percentile, median, 75th percentile, and maximum for CP, NDF, ADF, IVDMD, Vol_{GAS48}, RFV, RFQ, pH, and DM.

5.3.8.2 Forage Quality Models

PROC GLM in SAS 9.4 (SAS Institute Inc. 2022) was conducted where forage quality parameters (IVDMD, Vol_{GAS48}, RFV, RFQ, and pH) were dependent variables and survey responses were independent variables (region, forage type, silo, cutting height, conditioner use, inoculant use). Stepwise removal was used within the models to where the independent variables had a p-value <0.25. Effects and interactions were considered significant at p<0.05 and trends (p>0.05 <0.1) were discussed. The full model:

$$Y_{ijklmn(ixj)(ixk)(ixl)(ixm)(ixn)(kxn)} = \mu + h_i + +h_j + h_k + h_l + h_m + h_n + h_i x h_j + h_i x h_k + h_i x h_l + h_i x h_m + h_i x h_n + h_k x h_n + e_{ijklmn(ixj)(ixk)(ixl)(ixm)(ixn)(kxn)}$$

Where $Y_{jklmn(ixj)(ixk)(ixl)(ixm)(ixn)(kxn)}$= observations of dependent variables, μ =overall mean, h_i = effect of region (BC, Pr, Ct, Atl), h_j=effect of forage type (alfalfa, alfalfa-grass, grass), h_k= effect of silo type, h_l= effect of cutting height (<5 cm, 5-10cm, >10cm, unknown), h_m= effect of conditioner use (no, yes, unknown), h_n=effect of inoculant use (no, yes, unknown), $h_i x h_j$= interaction effect of region and forage type, $h_i x h_k$= interaction effect of region and silo type, $h_i x h_l$= interaction effect of region and cutting height, $h_i x h_m$=interaction effect of region and conditioner use, $h_i x h_n$= interaction effect of region and inoculant use, $h_k x h_n$=interaction effect of silo type and inoculant use, $e_{ijklmn(ixj)(ixk)(ixl)(ixm)(ixn)(kxn)}$= residuals

5.4 RESULT

TABLE 5.1. Descriptive Statistics of *In- Vitro* Dry Matter Digestibility (IVDMD), *In-Vitro* Cumulative Gas Production (VolGas48), Chemical Composition, pH, Dry Matter (DM), and Legume Content of First Cut Alfalfa, Alfalfa-Grass Mix Silage

Forage Type	Parameter	N[a]	Mean	SD[b]	Min[c]	25 perc[d]	Median[e]	75 perc[f]	Max[g]
G	IVDMD (%DM)	20	57.19	6.71	45.25	52.45	57.24	62.67	70.35
	Vol_{GAS48} (mL g^{-1})	19	102.16	17.55	68.29	89.50	101.50	116.75	128.17
	CP (%DM)	19	12.06	1.95	9.26	10.27	12.24	13.56	15.20
	NDF (%DM)	19	57.40	4.88	48.21	54.20	57.48	60.08	65.21
	ADF (%DM)	19	36.78	3.83	29.44	33.33	36.55	40.36	43.19
	RFV	19	98.68	12.73	80	87	98	112	120
	RFQ	14	146.42	29.1	94.70	120.00	142.75	169.00	192.0
	pH	20	4.79	0.67	3.85	4.28	4.53	5.30	6.09
	%DM	20	50.30	13.21	21.36	38.87	48.55	63.77	69.0
	Legume content	20	16.26	6.47	2.86	12.78	17.55	21.01	21.66
AG	IVDMD	41	62.95	5.68	51.97	58.70	62.54	66.75	75.71
	Vol_{GAS48} (mL g^{-1})	39	103.85	14.91	69.57	92.59	103.15	114.12	137.54
	CP	40	14.72	1.64	11.27	13.54	14.95	15.7	17.80
	NDF	40	52.65	4.14	42.77	50.92	52.87	55.15	61.69
	ADF	40	35.01	3.37	27.41	32.89	35.46	36.70	44.94
	RFV	40	109.83	13.01	89.0	100.5	108.5	114.5	143
	RFQ	25	158.54	28.24	93.2	143.0	157.1	185.5	209.0
	pH	41	4.50	0.62	3.70	4.11	4.28	4.76	6.52
	%DM	41	46.37	9.48	21.22	41.19	46.94	52.58	61.64
	Legume Content	41	37.71	7.83	25.22	30.60	38.14	44.16	49.94
A	IVDMD	108	66.68	5.05	54.20	62.98	66.35	70.53	79.69
	Vol_{GAS48} (mL g^{-1})	101	104.89	14.44	53.23	99.16	108.48	113.18	141.45
	CP	104	19.49	2.56	11.70	17.88	19.87	20.84	25.99
	NDF	104	43.86	4.85	32.91	40.86	44.08	47.10	56.51
	ADF	104	32.91	3.87	25.02	29.98	32.96	35.56	41.86
	RFV	104	136.31	20.51	95.00	122.5	133.0	145.5	192.0
	RFQ	64	163.92	35.26	99.00	136.50	155.25	184.65	246.00
	pH	108	4.86	0.55	3.80	4.45	4.81	5.81	6.75
	%DM	108	51.78	10.87	25.04	45.15	50.65	58.84	77.64
	Legume Content	108	88.38	15.96	50.50	74.13	100	100	100

[a]N=number of samples
[b]SD= standard deviation
[c]Min=minimum value
[d]25 perc= 25% of samples below this value
[e]Median=50% of samples below this value
[f]75 perc=75% of samples below this value
[g]Max= maximum value

TABLE 5.2. Relationship Between Effects of Silage Management Factors (Region, Silo, Forage, Cutting Height, Conditioner Use, and Inoculant Use) on *In vitro* dry matter digestibility (IVDMD) (%DM). Only significant (P<0.05) and trending (0.05<P<0.10) estimates are shown.

Independent Variable	Level	Estimate	SE	R^2	RMSE	P Value
-	Mean	64.65	-	0.52	4.70	-
Region	CTL	67.85[a]	0.90			0.0003
	BC	59.55[b]	0.71			
	ATL	55.47[c]	0.81			
	PRA	52.75[d]	1.02			
Forage Type*	ALFA	66.68[a]	1.08			<0.0001
	ALFA-GR	62.95[b]	1.24			
	GRS	57.19[c]	1.40			
Region x Forage Type						0.0296
Region	Forage Type					
ATL	ALFA	69.04[a]	0.91			<0.0001
	ALFA-GR	63.38[b]	0.94			
	GRS	58.03[c]	1.32			
CTL	ALFA	66.82	1.10			NS
	ALFA-GR	65.72	2.86			
	GRS	60.17	3.57			
PRA	ALFA	65.81[a]	4.37			<0.0001
	GRS	45.25[b]	0.70			
BC	ALFA	58.94[a]	2.51			0.0402
	ALFA-GR	58.12[a]	2.43			
	GRS	53.91[b]	1.79			
Region x Conditioner Use						0.0011
Region	Conditioner Used					
ATL	No	67.24[a]	1.13			0.0051
	Unknown	63.81[b]	0.89			
	Yes	63.13[b]	2.94			
CTL	No	70.57[x]	3.39			0.0898
	Yes	65.86[y]	1.34			
	Unknown	65.00[y]	2.22			
PRA	Yes	66.10[a]	0.97			0.0386
	No	64.35[b]	0.56			
	Unknown	61.81[c]	1.14			

BC	Unknown	58.32	2.04	0.0189
	Yes	57.38	2.94	
Region x Inoculant Use				0.0187
Region	Inoculant Use			
ATL	Yes	65.32[a]	6.38	0.0309
	No	64.56[a]	7.16	
	Unknown	53.06[b]	3.71	
CTL	Unknown	64.99[y]	2.22	0.0881
	Yes	70.57[x]	3.39	
	No	65.85[y]	1.34	
PRA	No	65.86	0.97	NS
	Yes	64.36	1.62	
	Unknown**	62.29	-	
BC	Yes	58.39	2.07	NS
	Unknown	57.84	2.93	
	No	57.04	2.75	

[a,b,c] Means with different superscripts were significantly different (P < 0.05)
[x,y] Means with different superscripts tend to differ (0.05< P < 0.10)
* Estimate determined by Proc Means sorted by forage type; standard error (SE) calculated from standard deviation (SE=SD/SQRT(n))
**Only 1 sample
NS: not significant

TABLE 5.3. Relationship Between Effects of Silage Management Factors (Region, Silo Type, Forage Type, Cutting Height, Conditioner Use, and Inoculant Use) and *In vitro* Cumulative Gas Production (VOL_{GAS48}) Only significant (P<0.05) and trending (0.05<P<0.10) estimates are shown.

Independent Variable	Variable	Estimate	SE	R^2	RMSE	P Value
-	Mean	104.31		0.48	11.30	-
Region	PRA	109.93^{a}	1.45			<0.0001
	CTL	98.98^{c}	2.56			
	ATL	105.19^{b}	1.71			
	BC	77.87^{d}	3.55			
Silo*	Baleage	110.84^{a}	2.03			0.0008
	Tower	106.16^{b}	2.05			
	Pile	102.30^{b}	3.34			
	Bunker	95.82^{c}	1.93			
Forage*	ALFA	104.89^{a}	1.08			0.0247
	ALFA-GR	103.85^{ab}	2.39			
	GRS	102.16^{b}	1.12			
Conditioner Use*	No	110.83^{a}	2.20			0.0174
	Yes	102.23^{b}	1.41			
	Unknown	94.30^{c}	3.82			
Region x Forage Type						0.0167
Region	Forage Type					
ATL	ALFA	113.14^{x}	2.22			0.0735
	GRS	108.49^{y}	3.09			
	ALFA-GR	107.38^{y}	2.26			
CTL	ALFA-GR	108.65^{a}	7.16			0.0354
	ALFA	96.03^{b}	5.88			
	GRS	89.50^{b}	16.01			
PRA	ALFA	105.70^{a}	1.44			0.0057
	GRS**	79.52^{b}	-			
BC	ALFA-GR	83.33^{a}	4.34			0.0100
	ALFA	72.41^{b}	5.31			
	GRS	72.35^{b}	7.52			

[a,b,c] Means with different superscripts were significantly different (P < 0.05)
[x,y] Means with different superscripts tend to differ (0.05< P < 0.10)
* Estimate determined by Proc Means sorted by forage type; standard error (SE) calculated from standard deviation (SE=SD/SQRT(n))
**Only 1 sample
NS: not significant

TABLE 5.4 Relationship Between Relative Feed Value (RFV) and Relative Forage Quality (RFQ) and Silage Management Factors (Region, Silo type, Forage Type, Cutting Height, Conditioner Use, and Inoculant Use). Only significant (P<0.05) trending (0.05<P<0.10) estimates are shown

Independent Variable	Variable	Estimate	SE	R^2	RMSE	P Value
-	Mean	125.42	-	0.40	18.18	-
(RFV) Forage	ALFA	136.31[a]	1.78			<0.0001
	ALFA-GR	109.83[b]	2.87			
	GRS	98.68[b]	4.17			
-	Mean	160.24		0.49	25.46	-
(RFQ)Region	BC	187.98[a]	8.31			<0.0001
	ATL	157.80[b]	9.60			
	PRA	99.46[c]	11.19			
	CTL	72.55[c]	27.07			
(RFQ)Forage*	ALFA	163.92[a]	5.64			<0.0001
	ALFA-GR	158.54[a]	4.50			
	GRS	146.42[b]	8.01			
(RFQ)Region x Silo						0.0070
Region	Silo					
ATL	Baleage	167.21	8.88			NS
	Bunker	155.88	9.92			
	Tower	150.65	9.33			
CTL	Tower	167.95	14.60			NS
	Baleage	141.18	14.32			
	Bunker	134.70	10.33			
	Pile**	115.40	-			
PRA	Baleage	167.89[a]	10.06			0.0364
	Tower	165.76[a]	10.05			
	Bunker	151.23[ab]	9.89			
	Pile	142.31[b]	4.98			
BC	Bunker**	200.83	5.35			NS

[a,b,c] Means with different superscripts were significantly different (P < 0.05)
[x,y] Means with different superscripts tend to differ (0.05< P < 0.10)
* Estimate determined by Proc Means sorted by forage type; standard error (SE) calculated from standard deviation (SE=SD/SQRT(n))
**Only 1 sample
NS: not significant

TABLE 5.5 Relationship Between Silage Management Factors (Region, Silo type, Forage Type, Cutting Height, Conditioner Use, and Inoculant Use) and Silage pH. Only significant (P<0.05) and trending (0.05<P<0.10) estimates are shown.

Dependent Variable	Independent Variable	Variable	Estimate	SE	R^2	RMSE	P Value
pH	-	Mean	4.77		0.56	0.413	-
	Region	PRA	4.91[a]	0.17			<0.0001
		CTL	4.68[a]	0.19			
		BC	4.22[b]	0.22			
		ATL	4.18[b]	0.19			
	Silo x Inoculant Use						<0.0001
	Silo	Inoculant Used					
	Tower	No	4.53	0.10			NS
		Yes	4.39	0.08			
		Unknown	4.33	0.21			
	Bunker	No	4.78	0.15			NS
		Yes	4.56	0.10			
		Unknown	4.40	0.20			
	Baleage	Unknown	5.38[ab]	0.00			0.0241
		No	5.33[a]	0.10			
		Yes	4.87[b]	0.15			
	Pile	No	4.97	0.11			NS
		Yes	4.87	0.09			

[a,b,c] estimates with same letters are not significantly different
NS: not significant

5.5 DISCUSSION

5.5.1 Forage Quality Assessment

Evaluating forage quality is complicated by the multitude of quality parameters used in this evaluation and the different assessments of quality that they provide. Of these measures, RFV, RFQ, and pH are commonly used in the dairy industry while IVDMD and Vol_{GAS48} are currently only used in research settings. Therefore, it is important to understand how these quality parameters are determined and which of them provides the best indicator of forage quality and potential animal performance.

The RFV and RFQ are two of the most common parameters used in industry to assess forage quality. The RFV was developed in the 1970's by the Hay Marketing Task Forace of American Forage and Grassland Council for legume-based forages with intake data from lactating dairy cows (Undersander and Moore, 2001). It is a unitless measure, where an RFV of 100 represents ALFA at full bloom. Hence, using this parameter, producers learned to associate decreasing RFV with increasing maturity (Jeranyama and Garcia, 2004). However, the use of the RFV is limited, as it only considers the NDF and ADF contents of the forage. Therefore, ALFA-GR and GRS are penalized for their higher fiber content, however unlike ALFA, the fiber in GRS is more digestible due to lower lignin content (Jeranyama and Garcia, 2004; Undersander and Moore, 2001). As seen among the silage samples of our study, the GRS silage samples were 13.54% higher in NDF and 3.87% higher in ADF compared to ALFA silage samples, which resulted in a lower RFV of GRS silage samples. The use of ADF and NDF not only has a limitation for comparing forage types, but when forages have the same fiber content, they are ranked the same in quality even though digestibility may vary. To accommodate such differences in fiber content and digestibility, the RFQ was developed. The RFQ equation utilizes total digestible nutrients (TDN), so nutrients like CP, ether extract, and digestibility estimates like NDF digestibility (NDFd) are considered (Undersander and Moore, 2001). The RFQ of forages is typically higher than its RFV as observed in our study, ALFA samples averaged an RFV of 136.31 and a RFQ of 163.92. This was also seen among the GRS (RFV: 98.68; RFQ: 146.42), and ALFA-GR (RFV: 109.83; RFQ: 158.54). Understander et al, (2011) recommended feeding forages with an RFV/RFQ of 140 or higher for dairy cattle in their first trimester and feeding forages with a minimum RFQ/RFV of 125 for dairy cattle in their last 200 days of lactation. In our study, 50% of the alfalfa silage samples had an RFV of 133.0 or higher, however, only 25% of alfalfa samples had an RFV greater than 145.5 with the maximum RFV at 192. For ALFA-GR and GRS, RFV was relatively low as expected with 75% of ALFA-GR and GRS having an RFV lower than 114.5 and 112 respectively. By using RFV, majority of the ALFA-GR and GRS silages in this study would be better suited for dry cows or heifers (Undersander et al, 2011). When forages were evaluated with RFQ, all forages ranked higher in quality, as 75% of ALFA and ALFA-GR and 50% of GRS silage samples met the minimum RFQ for lactating dairy cows. With, 50% of ALFA, 75% of ALFA-GR, and 50% of GRS silages having a RFQ of 150 or higher (USDA, Unknown; UCD, 2007; Undersander et al, 2011). Therefore, when two forages have the same fiber values or if the forage type is not known, RFQ should be used to assess forage quality.

Since the 1960's, IVDMD and Vol_{GAS48} have been used to evaluate the quality of ruminant feeds (Wilkinson et al, 2003). Total tract digestibility is reflected in IVDMD measurements with optimal IVDMD values suggested between 75 to 83% DM (Shewmaker et al, 2009). This was demonstrated by studies in which ALFA was harvested at the early flowering stage and GRS was harvested at the early heading stage (Kozelov et al, 2008; Belanger, et al, 2014; Lauzon et al, 2019), In these studies, IVDMD were in the range of 76.5 to 88.5% DM (Kozelov et al, 2008; Belanger, et al, 2014; Lauzon et al, 2019). Only the top 25% of ALFA samples in our study had IVDMD values comparable to these studies, as our IVDMD values ranged from 70.53 to 79.69% DM. The IVDMD of 75% of the ALFA silage samples, and all the ALFA-GR and GRS silage samples were comparable to values reported by Holden, (1999), Mabjeesh et al, (1999), Brons and Plaizier, (2008) and Plaizier and Li, (2013). In these studies, IVDMD ranged from 47.52 to 70.7% DM, which is comparable to the IVDMD ranges seen in TABLE 5.1 (Holden, 1999; Mabjeesh et al, 1999; Brons and Plaizier, 2008; Plaizier and Li, 2013). Rumen fermentation is reflected in Vol_{GAS48} (Buxton et al, 2003). The Vol_{GAS48} values of our study were lower than those reported by Plaizier and Li, (2008), but they were higher than values observed by Tunkala et al, (2022). It is difficult to compare Vol_{GAS48} across studies, as different methodologies were used (Tunkala et al, 2022). Standardization of this technique is difficult, as the result of the analysis is highly sensitive to differences in buffers, rumen inoculum, and the handling of rumen inoculum post collection and gas production equipment (Wilkinson et al, 2003). Therefore, Vol_{GAS48} values of the forages can be compared within our study, but not to other studies.

pH measures the acidity of the silage and indicates if adequate fermentation and preservation occurred. For ALFA, ALFA-GRS, and GRS silages, acceptable final pH values can range from 4.0 to 5.5 (PENN State, 2004; Kung Jr, 2010). pH values greater than 5.5 are considered high and can result from things such as higher legume content and increased DM (Kung Jr, 2010). In TABLE 5.1, it was observed that 75% of all GRS and ALFA-GRS samples respectively had a pH of 5.30 and 4.76 or lower, while 50% of ALFA samples had a pH 4.81 or lower. The DM content of 25% of the GRS samples ranged from 63.7 to 69.0% DM, which could have contributed to their high pH values.

5.5.2 Region and Silage Management Factors

It was hypothesized that region and silage management factors would affect the quality of first cut ALFA, ALFA-GRS, GRS silage. The two most influential of these factors were region and forage type. Region influenced every parameter of silage quality, except for RFV which was only affected by forage type. Forage type influenced every parameter, except for silage pH. This was unexpected, as the legume content in ALFA-based forages tends to increase its buffering capacity, challenging the pH reduction (Kung Jr, 2010). Region and forage type are closely linked, as climate and soil conditions determine the type of forage that is best grown in a region (Alberta, 2009; OMAFRA, 2022). In the BC, CTL, and ATL regions, high precipitation, and acidic soils are common (Sanborn et al, 2011). Therefore, producers in these regions opt for perennial GRS stands and ALFA-GR, as perennial GRS have a higher tolerance to acidic and saturated soils (Thompson, 2013; OMARFA, 2022). In the PRA region and parts of the BC interior, growing conditions are best suited for ALFA. This is due to the soil being relatively neutral in soil pH, a high soil organic matter, content, a semi-arid climate, and soil saturation typically occurring for only brief periods in spring (Pennock et al, 2011). Even though ALFA, ALFA-GR, and GRS silages are found across Canada, they do not all perform similarly. As observed in our study, regions were never ranked the same for all of silage quality parameters. However, silages were always ranked high to low as ALFA, ALFA-GR, and GRS for RFV, RFQ, IVDMD, and Vol_{GAS48}. The ranking of ALFA was expected as it has the highest nutrient contents and digestibility (Guo et al, 2019; NRC, 2021; Ren, 2021). When evaluating silage quality based on IVDMD, the interaction between region and forage type was consistently significant, but ALFA had the highest values among the three forage types in each region. Despite this, IVDMD differed within forage types across the regions. For example, ALFA silage in the ATL region had the highest IVDMD of 69.04% compared to ALFA in BC that had an IVDMD of only 59.94%. The GRS silages were ranked lowest for IVDMD across regions. The Vol_{GAS4} of silage samples also differed among regions. In the ATL and PRA regions, based on Vol_{GAS48} silages ranked from highest to lowest as ALFA, ALFA-GR, and GRS. In the CTL and BC regions, ALFA-GR silage had the highest Vol_{GAS48} values followed by ALFA, and GRS silages. Although ALFA-GR silage ranked highest in Vol_{GAS48} in the CTL and BC regions, ALFA silage in the ATL and PRA regions had higher Vol_{GAS48} values, indicating that ALFA had the higher silage quality.

Although producers have limited control over their farm location or forage varieties best suited to them, they do have control over decisions at harvest, such as the use of conditioners and inoculants. At the time of harvest, producers may use conditioners that crack and crush forage stems to help reduce wilting time (Agbossamey et al, 1998; PENN State, 2004; Kokko et al, 2013; OMAFRA, 2022). However, if the conditioning is too severe, this can lead to DM loss due to leaf shattering (Borreani et al, 2018; OMAFRA, 2022). In our study, conditioner use affected Vol_{GAS48} and IVDMD, with lower Vol_{GAS48}. A similar effect was seen in the effect of the region x conditioner use interaction on IVDMD. Regions that utilized conditioners had lower IVDMD, except for the PRA region, where the use of a conditioner increased the IVDMD. Conditioners are recommended to help reduce the wilting time, particularly in humid regions like the CTL region, where heavy dews result in longer wilting requirements (OMAFRA, 2022). However, our results indicate that conditioner use reduced IVDMD. This suggests that conditioned forages may have experienced too much leaf loss, conditioned forages were exposed to inclement weather, resulting in nutrient leaching or perhaps poor management of the conditioner (i.e., impeller conditioner use on ALFA instead of rubber rollers). In the BC region, all participants indicated “yes” or “unknown” for conditioner. Hence, there was no data for “non-conditioned” samples.

Inoculants are among the most used forms of silage additives and have been known to decrease pH during ensiling (Filya et al, 2007; Kung Jr, 2010). For silage pH, there was an interaction between silo type and inoculant use. Also, for IVDMD, there was an interaction between region and inoculant use. Baleage tends to have higher pH, compared to other silages, as the DM content at harvest is higher and forage particles are longer compared to other silages, resulting in restrictive fermentation (Coblentz et al, 2016). Inoculated forages had higher IVDMD, except in the PRA region, where inoculated forages had lower IVDMD. Factors that can impact the success of inoculants Lactic Acid Bacteria (LAB) population, carbohydrate availability, legume content, DM content, forage variety, and type of inoculant used (Filya et al, 2007). This could explain why there was no difference in pH between inoculated and non-inoculated silages in bunker and tower silos and in piles, and why the inoculated silages from the PRA region had a comparatively lower IVDMD. When the benefits of inoculants are not observed, producers may opt to not utilize them, as their use involves a significant cost (OMAFRA, 2022). Based on our results, it is recommended to use an inoculant specific to the forage type, as inoculated samples consistently had lower silage pH.

5.6 CONCLUSION

Evaluating first cut silage samples using different forage quality parameters demonstrated in a large variation in forage quality within and across forage types. Decreased RFV and RFQ are associated with increasing maturity and decreased forage quality. The RFV was developed to evaluate and compare legume-based forages. Therefore, majority of ALFA samples met the minimum RFV recommendations for lactating dairy cows, but ALFA-GR and GRS samples did not. When these forages were evaluated using RFQ, 50% of ALFA samples, 75% of ALFA-GR samples, and 50% of GRS samples had an RFQ of 150 or higher, indicating that forage was of "good" quality. The RFQ includes TDN in its equation. Hence, differences in CP and NDFd in the forage are accounted for, thereby making RFQ more accurate than RFV. For the quality assessment of these silages. If forages have the same fiber content and RFV, they will be ranked the same in terms of quality, even though digestibility is likely to differ. For haylage, pH below 5.5 is considered acceptable, though the lower the pH the most acid was produced during fermentation (PENN State, 2004; Kung Jr, 2010). In our study, 75% of all ALFA-GR and GRS samples had acceptable final pH values below 4.76 and 5.30 respectively and 50% of ALFA had final pH values of 4.81 or lower. A higher silage pH was correlated with higher legume and DM content. The IVDMD results were in line with previous IVDMD studies. Currently there is no classification system that associates IVDMD values with poor, average, or good quality forage like that of RFQ. Hence, it is difficult to define good vs poor silage quality based on this measure. Like IVDMD, $VolGAS_{48}$ also does not have an industry standard that can be used for ranking forage quality of silages. Thus, the IVDMD and Vol_{GAS48} of silage samples could only be compared with other silage samples within our study.

Region and forage type were the most significant factors that affected the quality of ALFA, ALFA-GR, and GRS silages. Region and forage type are closely linked, as climate and soil conditions determine the type of forage that is suitable within a region (Alberta, 2004). Producers have limited control over the location of their farm and the forage varieties available and most suited to them. Therefore, the only recommendations to improve RFV or RFQ is to cut forages earlier as they parameters are influenced by maturity at cutting. It is recommended that conditioners are used to decrease the wilting time, particularly in humid regions, like the CTL region. However, our study showed that the use of a conditioner did not improve Vol_{GAS48} and IVDMD in silages, except for in the PRA region. Therefore, conditioned silages from the CTL and ATL regions may have had extensive leaf loss, conditioned forages may have been exposed to inclement weather during wilting and experienced increased nutrient leaching, or the conditioner was not appropriate for the type of forage being cut. Our study supported the recommendation of inoculating forages prior to ensiling, as inoculated samples had a lower final pH in all silo types, with baleage having a significantly reduced pH when inoculated. The use of inoculants also improved IVDMD across all regions except for in the PRA region.

Of all the silage quality parameters, IVDMD and Vol_{GAS48} were most affected by silage management factors and regional interactions. However due to the sensitivity of Vol_{GAS48} to differences in equipment and inoculum, as well as lack of a standard laboratory protocol, it is difficult to compare Vol_{GAS48} of forages to other studies. The lack of standard laboratory protocol currently also makes it difficult to compare Vol_{GAS48} across labs. Unlike IVDMD and Vol_{GAS48}, RFV and RFQ are routinely used by the industry. However, they are only calculated measures based on results from proximate forage analysis. Therefore, they are mostly affected by forage type and maturity at harvest. Silage pH is commonly determined and indicates if restrictive or clostridial fermentation took place. However, pH alone does not comprehensively measure how the silage will perform within the animal. Therefore, IVDMD is most representative of the forage’s potential, as it is a measured parameter of total tract digestibility. By considering IVDMD, all nutrients are included in the assessment, and quality is not based on a nutrient that is solely influenced by forage type such as high fiber in GRS or high CP in ALFA.

Before IVDMD can be used as a standard for evaluating ruminant feeds, more work needs to be done to standardize its procedure, and values for various forage types at different maturity stages and how these correlates to animal performance.

6. GENERAL DISCUSSION

In Canada, ensiling forage is the primary preservation method for perennial forages used on Canadian dairy farms (Charmley, 2001). However, there is limited Canadian literature that has evaluated the quality of these silages, and the effects of silage management practices currently used on Canadian dairy farms. Many Canadian provinces have forage guides (Alberta, 2009; Perennia, 2021; OMAFRA, 2022) with recommendations for making silage. However, much of the literature is based on research from regions with different climates, soils, and forage varieties. The Canadian growing season is comparatively short, and forages make up 50 to 70% of a lactation cow diet Duniere et al, (2013), therefore, understanding the effect of silage management practices and being able to identify good quality forage is important for the Canadian dairy industry.

Forage quality has been associated with the forage nutritive content. However, this is a limited view of forage quality as additional characteristics of the forage, such as palatability, intake, anti-nutritional factors, and digestibility, must be considered in assessing silage quality. Over the decades, researchers have continued to develop forage quality indices to aid producers and their animal nutritionists in evaluating and comparing forages. Forage quality indices that are commonly used in the dairy industry, such as RFV and RFQ, were developed to demonstrate the impact maturity has on forage quality (Moore and Undersander, 2001). However, RFV does not accurately compare different forage types nor differentiate forages with the same fiber content. The RFQ is an improvement over the RFV, due to the inclusion of TDN in the calculation (Jeranyama and Garcia, 2004). As a result, GRS silages rank higher under RFQ than under RFV. More accurate quality measures, like IVDMD and Vol_{GAS48}, have been used in research to evaluate ruminant forages (Wilkinson et al, 2003). However, due to the need for rumen fluid, high costs and time requirements, these indexes are yet to be used routinely by commercial laboratories. Therefore, most producers still resort to the forage's nutrient contents, like CP or RFV/RFQ for their forage analysis, and as a method of evaluating and comparing the forage quality of feed sources (Charmley, 2001).

The research conducted in this study: i) compared and characterized silage management practices of first cut ALFA, ALFA-GR, GRS silages across and within different Canadian regions via a survey; ii) evaluated the quality of first cut ALFA, ALFA-GR, GRS silages using various silage quality parameters, including RFV, RFQ, IVDMD, Vol_{GAS48}, and pH; iii) determined the effects of silage management practices on various forage quality parameters; and iv) developed recommendations for best management practices for growing and ensiling first cut perennial forages in different Canadian regions.

6.1 Characterization of Silage Management Practices and Their Impact on Perennial Silage Quality

Chapter 4 supported our first hypothesis that forage types grown for silage as well as silage management practices used on Canadian dairy farms would differ among regions. In previous Canadian dairy surveys (Plaizier et al, 2004; Sheppard et al, 2011; Gee et al, 2021) the focus has been on whole rations rather than their components, and often excluded responses from ATL Canada and combined responses from BC and the PRA to form "Western Canada". This made it difficult to make accurate comparisons between our study and previous research, as much data had to be inferred. For example, in MB only 5% of producers used GRS silage, but 75% of producers used ALFA/ALFA-mixed silage. Hence, it could be inferred then that GRS silage is not commonly produced by MB dairy farmers (Plaizier et al, 2004). Therefore, a high response to ALFA forage grown in the PRA in our study would be in line with responses from previous studies. In Chapter 4, forage type was differed across regions. This was supported by Chapter 5, as region and forage type influenced all measures of forage quality. This was expected, as climate and soil conditions influence the type of forage that can be grown in a region (AB Forage Guide, 2009; OMAFRA, 2022). The majority of respondents in Chapter 4 confirmed they were following the current literature and forage guide recommendations on mower-conditioners and inoculants. However, in Chapter 5, conditioner use reduced IVDMD and Vol_{GAS48} of forages across all regions, with the exception of in the PRA, where IVDMD was improved by conditioner use. With regards to inoculants, inoculated forages had improved IVDMD across all regions and silage pH was lower across all silo types. The biggest regional difference for inoculants was seen in the PRA, in both Chapters 4 and 5. In Chapter 4, the majority of respondents from PRA did not use inoculants, and in Chapter 5 inoculant use was found to improve IVDMD in the forages in this region, unlike the other regions.

In Chapter 5, forages were evaluated using RFV, RFQ, IVDMD, Vol_{GAS48}, and pH. As hypothesized, this resulted in a large variation in silage quality within and among regions. The large variation within regions may have limited the number of significant differences among regions. Despite this, region and silage management practices affected silage quality parameters. The RFV was only affected by forage type, while other quality parameters were affected by management factors, as well as by interactions between region and silage management factors. The IVDMD had more significant regional x silage management interactions, including interactions between region x forage type, region x conditioner use, and region x inoculant use. The Vol_{GAS48} was also affected by several silage management factors, including region, silo type, forage type, and conditioner use, but regional x forage type was the only significant interaction.

The significant region x forage type interaction was expected, as demonstrated in chapters 4 and 5, forage types grown for silage differ across Canadian regions. Hence, regional recommendations for improving forage quality should be made when evaluating forages with IVDMD. For producers in ATL, the use of mower-conditioners decreased IVDMD, while the use of inoculants improved IVDMD. In the CTL region, mower-conditioners tended to decrease IVDMD, while the use of inoculants tended to increase IVDMD. In the PRA, mower-conditioners improved IVDMD, but inoculants did not. In BC, all producers surveyed reported using conditioners, which could be inferred as a majority of producers are using conditioners. This was also reported in Chapter 4. In BC, higher IVDMD was observed in inoculated forage.

6.2 Research Impact on Industry

This study is the first large scale silage quality study on dairy farms to be conducted in Canada. Therefore, its results will provide the Canadian dairy industry with an overview of current silage management practices, and how they affect forage quality. The evaluation of forages using different quality parameters demonstrates the large variation of forage quality in Canada. It also demonstrates that the quality of forages can be ranked higher or lower depending on the index used for tis evaluation.

Unlike for RFV, RFQ, and pH, there are no industry standards for IVDMD and Vol_{GAS48}. Currently, IVDMD and Vol_{GAS48} are not available for routine forage analysis for producers. However, before these analyses become routine or adapted to NIR, they will need to be standardized. Then equations can be developed to translate *in vitro* values into *in viv*o estimates and ultimately NIR calibrations.

6.3 Future Research

It is evident that there is more research required to fully understand the effects of current silage management practices in Canada on first cut perennial silages. The current study demonstrated that forage type and silo type differ among regions indicating the need for the individual study of regions. Larger sample sizes are required particularly for the CTL region, as 80% of Canadian dairy farmers are in ON and QU. In future studies producers should participate over several years, to make comparisons between years more accurate. Since the goal of ensiling is to preserve as much of the forages original nutritive value, fresh forage samples should be collected prior to ensiling. This will help determine dry matter changes found in the fermented samples. The collection of bagged silage samples should also be considered, as it is becoming a common storage method.

Before IVDMD and Vol_{GAS48} can be effectively used within industry as silage quality parameters, a larger data set of various forage types cut at specific maturity stages over consecutive cuts over several years need to be collected. By having larger and more accurate data sets, equations can be developed to translate *in vitro* responses to estimate *in vivo* responses in animals.

7. GENERAL CONCLUSION

This thesis provides an overview of current silage management practices used on Canadian dairy farms for perennial forage, how they differ regionally, and how they impact forage quality. In Chapter 4, via an online survey, it was observed that silage management practices differ regionally with forage type and storage systems being the most significantly different. This was expected as climate and soil conditions directly impact the growing conditions suitable for specific forages (Alberta, 2004). Storage systems used on farm often correlate with farm size, with smaller farms making use of baleage and tower silos (OMAFRA, 2022). Western Canadian dairy farms tend to be larger than eastern dairy farms therefore, the lack or absence of tower silos in the PRA and BC was expected. However, overall, the online survey indicated that forages being grown were in accordance with regional growing conditions and producers were following silage management practices recommendations specific to their storage systems.

Chapter 5 reflected similar findings to Chapter 4 in that region and forage type had significant effect on forage quality models. However, in Chapter 5 there was a larger variation in forage types found in each region as a result of calculated legume content from a physical sample. Chapter 5 indicated that there is a large variation in first cut silage quality across Canadian dairy farms. The large range in RFV and RFQ indicates maturity varied among farms and higher pH values are often a result of increased DM which is also a reflection of maturity at harvest. Not having an industry standard for IVDMD and Vol_{GAS48} makes officially ranking the samples into quality categories difficult. However, the quality models indicate that IVDMD and Vol_{GAS48} are impacted by forage type and regional interactions. Therefore, further research into standardizing these parameters would be viable to the dairy industry as another way to evaluate forage quality.

8. APPENDIX

8.1 IN-PERSON SILAGE SURVEY

General Farm Characterization

1. Is your farm **[SELECT ONE ONLY]**

☐ 1 Organic
☐ 2 Conventional

2. What is the physical land location of the farm?
   ____**[RECORD ADDRESS OF FARM]**

3. What is the physical land location of the field sampled and distance from the farm (if known)?

   Physical Land Location: ______________________**[RECORD ADDRESS OF FIELD]**

   Distance from Farm in km: _____________________

4. Milk Production

Milking System	# of Milkings per Day	# of Cows Being Milked	Milk Shipped per day (liters)	Normal Fat Test	Normal Protein Test

5. Did your farm purchase forage in the past 12 months? **[SELECT ONE ONLY]**

☐ 1 No
☐ 2 Yes: **[IF YES]**: What % of your forages is purchased: ______________________________ %

6. How many cultivated hectares were allocated to annual and perennial silage crops?

a. Perennials		b. Annuals	
Crop	Hectares	Crop	Hectares

7. How often do you rotate your perennial silage crop stands? If this differs for different crops, please provide different times for the different perennial forage crops.

______________________________frequency of rotating silage crop stands **[IN YEARS]**

8. Is the forage fed to dry cows stored separately from the forage fed to the milking cows? **SELECT ONE ONLY**

☐ 1 No
☐ 2 Yes

9. Does perennial forage fed to dry cows come from different fields vs forage fed to milking cows?

☐ 1 No
☐ 2 Yes: **IF YES**, how is it managed differently?

____

____

10. a. Do you have a soil nutrient management plan? **[SELECT ONE ONLY]**

☐ 1 No
☐ 2 Yes

10 b. How often do you soil test: **[SELECT ONE ONLY]**

☐ 1 every year
☐ 2 every two years
☐ 3 every three years
☐ 4 less frequently than every three years
☐ 5 Never
☐ 8 Don't know

11. Are you able to provide us a copy of the soil analysis for the field sampled? **[SELECT ONE ONLY]**

☐ 1 No
☐ 2 Yes

12. What type of storage facilities do you use on the farm? **[SELECT ALL THAT APPLY]**

- ☐ 1 Bunker
- ☐ 2 Drive over pile
- ☐ 3 Tower silo
- ☐ 4 Bales
- ☐ 9 Other: **SPECIFY: ________________**

Field Sampled

Seeding

13. What type of perennial silage was seeded?

a. Alfalfa			b. Grass			
Variety	Seed Rate	Year Seeded	Species	Variety	Seed Rate	Year Seeded

14. What type of seeding equipment was used to seed the sampled forage?

____

8☐ Don't know

15. What was the percentage of legumes, grasses, and weeds in the foraged sampled**? [RECORD**

%s, TOTAL SHOULD BE

100%]

Legumes %	Grass %	Weeds%

☐ 8 Don't know

16. Are you able to provide us a copy of previous forage analysis of the field being tested?

[SELECT ONE ONLY]

- ☐ 1 No
- ☐ 2 Yes

17. Were there any signs of the following on the sampled forage at harvest? **[SELECT ALL THAT APPLY]**

	1	Leaf disease
	2	Insect damage
	3	Winter kill
	4	Frost damage
	5	Drought
	6	No damage
	8	Don't know
	9	Other: **SPECIFY:** ___________________________

Soil and Fertilization

---

18. Describe the soil the of the sampled field: **[SELECT ONE ONLY]**

	1	Sandy
	2	Loam
	3	Clay
	4	Silt
	8	Don't know
	9	Other: **SPECIFY:** ______________________

19. What is soil pH and when did you last apply lime to the sampled field.

______________soil pH

______________last applied lime **RECORD DATE**

☐ 98 Don't know

20. What type of drainage do you have on the field sampled?

	1	Tile drainage
	2	Drainage ditches
	3	None
	8	Don't know

21. Did you apply commercial fertilizer, manure, or both to the sampled field? **[SELECT ONE ONLY]**

	1	Commercial Fertilizer
	2	Manure
	3	Both
	4	Other (like compost) SPECIFY: ______________________________
	5	None
	8	Don't know

22. **[ASK IF COMMERCIAL FERTILIZER IN Q.21]** Provide the following details for the commercial fertilizer on the field sampled.

1 NPK composition (ex. 40-0-0): ____________________

2 Rate of application: ______________________________

3 Timing: ____**RECORD DATE**

☐ 8 Don't know

23. **[ASK IF MANURE IN Q.21]** If manure fertilizer, check all that apply for the field sampled Species used: **[SELECT ALL THAT APPLY]**

	1	Cattle slurry
	2	Cattle solid

	3	Swine slurry
	4	Poultry litter
	8	Don't know
	9	Other: **SPECIFY:** ________________________________

24. Method of application **[SELECT ALL THAT APPLY]**

	1	Broadcast
	2	Surface banding
	3	Irrigation
	4	Injection
	8	Don't know
	9	Other: **SPECIFY:** ________________________________

25.Rate of application**: [SELECT ONE AND COMPLETE]**

☐ ________tonnes/ha

~or~

☐ ________litres /ha

~or~

☐ ________gallons per acre.

Timing: ____**RECORD DATE**

26.Are you able to provide us with a manure analysis report? **[SELECT ALL THAT APPLY]**

☐ 1 No

☐ 2 Yes

Harvest

27. What was the start date of harvest for the field sampled?

Mowing

_______________________**RECORD DATE**

☐ 8 Don't know

28. Do you…**SELECT ONE ONLY**

☐ 1 Harvest your own silage
☐ 2 Custom harvest
☐ 3 Combination of both
☐ 8 Don't know

29. What type of mower and conditioner/crimper equipment is used?

Width of Header	Mower Type	Conditioner/Crimper Used

☐ 8 Don't know

30. What time of day did you start mowing and chopping the field sampled?

[SELECT ONE ONLY]

Mowing			**Chopping**		
	1	Morning		1	Morning
	2	Mid morning		2	Mid morning
	3	Afternoon		3	Afternoon
	4	Late afternoon		4	Late afternoon
	5	Evening		5	Evening
	8	Don't know		8	Don't know

31. What is your average cutting height for first cut alfalfa mix silage? **[SELECT ONE ONLY]**

☐ <2 inches

☐ 1 2-4 inches

☐ 2 >4 inches

☐ 8 Don't know

32. Was the crop wilted? **[SELECT ONE ONLY]**

	1	No
	2	Yes, in windrows
	3	Yes, with tedding
	8	Don't know

33. [**ASK IF CROP WAS TEDDED IN Q32]** How many teddings occurred on field sampled?

________________________# of teddings

☐ 98 Don't know

34. What were the weather conditions while the crop was down? [**SELECT ALL THAT APPLY]**

	1	Rain
	2	Sun
	3	Wind
	4	Overcast
	8	Don't Know
	9	Other: **Specify:** ________________________

35.At what stage did you harvest your silage crop? **SELECT**

ONLY ONE

Alfalfa, most plants were at:	Grass:
☐ 1 Early bud ☐ 2 Mid bud ☐ 3 Early flower ☐ 4 Mid flower ☐ 5 Late flower ☐ 8 Don't know	☐ 1 Pre-heading ☐ 2 Early Heading ☐ 3 Mid Heading ☐ 4 Anthesis ☐ 5 After Anthesis ☐ 8 Don't know

Silage inoculants and enzymes

36.Were inoculants and enzymes added? **[SELECT ONE ONLY]**

☐ 1 No

☐ 2 Yes

IF YES:

Location of application	Product name and manufacturer	Application Rate, if different from manufacturer's recommendation
a. Forage Harvester		
b. Storage Facility		

37. On average how many cuts do you get off the sampled field and how long do you wait between cuts?

1 Average # of cuts: ____________________

2 Length between cuts: __________________**[SPECIFY # OF DAYS]**

☐ 8 Don't know

38. What was your theoretical chop length? _______inches ~or~ _________cm

☐ 98 Don't know

39. How is silage moved from the field to the storage facility? **SELECT ONE ONLY**

☐ 1 Truck – drive beside harvester
☐ 2 High dump to truck
☐ 3 High dump to tractor wagon/trailer
☐ 8 Don't know
☐ 9 Other: **[SPECIFY:** ______________________________

40. What are the dimensions and materials of your bunker?

1 Width: ____________
2 Length: ____________
3 Height: ____________
4 Material: _____________
☐ 8 Don't know

41. What method do you use when filling your bunker? **SELECT ONE ONLY**

☐ 1 Progressive Wedge: Feed is added at a 20-30-degree angle and height and length are increased simultaneously
☐ 2 Full Height: The height of the storage facility is maintained while length is increased.
☐ 3 Full Length: The length of the storage facility is maintained while height is increased
☐ 8 Don't know
☐ 9 Other: **SPECIFY:** ________________________

42. What type of equipment is used to fill and pack your bunker?

____

98 Don't know

43. What is the wheel set up of your filling and packing equipment? **SELECT ALL THAT APPLY**

☐ 1 2-wheel drive
☐ 2 Front wheel assist
☐ 3 4-wheel drive
☐ 4 Duals
☐ 8 Don't know

44. Do you add weight to your equipment?

☐ 1 No
☐ 2 Yes: **IF YES**, how much is added: _______________kg ~or~ ___________lbs

45. Describe the method you use to compact your silage.

____

____

____

☐ 98 Don't know

46. How many tonnes of silage per load ____________and how many minutes between loads

____________?

☐ 98 Don't know

47. How long does packing continue each day after the last load of forage is unloaded?

_______________________________hours

☐ 98 Don't know

48. How many tonnes of forage do you ensile per day?

_______________________________tonnes of forage

☐ 98 Don't know

49. How much time elapsed between the first load of forage and covering of the bunker? **[SELECT ONE ONLY]**

	1	Less than 1 day
	2	At least 1 day but less than 2 days
	3	At least 2 days but less than 3 days
	4	3 days or more
	8	Don't know

50. Do you use plastic to cover your silage? **[SELECT ONE ONLY]**

☐ 1 No: **IF NO**, what are you using? ______________________________

☐ 2 Yes: **IF YES**, what is the thickness of the plastic? _____________mm

51. Do you use an oxygen barrier? **SELECT ONE ONLY**

☐ 1 No

☐ 2 Yes

52. **[ASK IF YES IN Q50]** How are you keeping your plastic in place? **[SELECT ALL THAT APPLY]**

☐ 1 Tires

☐ 2 Bales

☐ 3 Waste Feed

☐ 4 Soil

☐ 8 Don't know

☐ 9 Other: **SPECIFY: _________________**

53. [**ASK IF YES IN Q.50]** How often is plastic checked for holes and repaired?
SELECT ONE ONLY

☐ 1 Daily
☐ 2 Couple times a week
☐ 3 Weekly
☐ 4 Less often than once per week
☐ 5 Never
☐ 8 Don't know

54. Was the sample collected from an opened bunker? **SELECT ONE ONLY**

☐ 1 No
☐ 2 Yes

55. What date did you cover the bunker (for first cut silage)?

______________________**RECORD DATE**

☐ 8 Don't know

56. At what rate are you removing the face of the bunker? ______inches per day ~or~ ____cm per day)

☐ 98 Don't know

57. a. How do you deface your bunker?

____

☐ 8 Don't know

57.b. How long does the face of the bunker stay exposed?
______________________________hours

☐ 8 Don't know

57.c. Is the face re-covered after silage is removed?

☐ 1 No
☐ 2 Yes
☐ 8 Don't know

58. When opening your bunker did you notice any form of the following **[SELECT ALL THAT APPLY]**

	1	Heating
	2	Effluent
	3	Smell of spoilage
	4	Observed spoilage in pockets or the surface
	5	No spoilage
	8	Don't know

59. If signs of heating were noticed when opening the bunker did they last longer than 1 hour?

[SELECT ONE ONLY]

☐ 1 No
☐ 2 Yes
☐ 8 Don't know

If Silage Sample Was Taken from a Drive Over Pile

---

60. What was your theoretical chop length? ________inches ~or~ ________cm

☐ 98 Don't know

61. How is silage moved from the field to the drive over pile? **SELECT ONE ONLY**

☐ 1 Truck – drive beside harvester
☐ 2 High dump to truck
☐ 3 High dump to tractor wagon/trailer
☐ 8 Don't know
☐ 9 Other: **[SPECIFY: ________________________________**

62. What are the dimensions of the pile?

1 Width: _____________

2 Length: _____________

3 Height: _____________

☐ 8 Don't know

63. What is the base of the drive over pile? [**SELECT ONE ONLY]**

☐ 1 Concrete

☐ 2 Dirt

☐ 8 Don't know

64. What method do you use when filling your drive over pile? **SELECT ONE ONLY**

☐ 1 Progressive Wedge: Feed is added at a 20-30-degree angle and height and length are increased simultaneously

☐ 2 Full Height: The height of the storage facility is maintained while length is increased.

☐ 3 Full Length: The length of the storage facility is maintained while height is increased

8 Don't know

☐ 9 Other: **SPECIFY:** _________________________

65. What type of equipment is used to fill and pack your drive over pile?

____

☐ 98 Don't know

66. What is the wheel set up of your filling and packing equipment? **SELECT ALL THAT APPLY**

☐ 1 2-wheel drive

☐ 2 Front wheel assist

☐ 3 4-wheel drive

☐ 4 Duals

☐ 8 Don't know

67. Do you add weight to your equipment?

☐ 1 No

☐ 2 Yes: **IF YES**, how much is added: ______________kg ~or~ ___________lbs
☐ 8 Don't know

68. Describe the method you use to compact your silage.

____

☐ 98 Don't know

69. How much time per tonne of silage is spent compacting the silage on the drive over pile?

How many tonnes ______________with each load of feed
_________________________and how many minutes between loads
_____________________________?

☐ 98 Don't know

70. How long does packing continue each day after the last load of feeds is unloaded?

____________________________hours
☐ 98 Don't know

71. How many tonnes of forage do you ensile per day?
____________________________tonnes of forage
☐ 98 Don't know

72. How much time elapsed between the first load of forage and covering of the pile? **[SELECT**

	1	Less than 1 day
	2	At least 1 day but less than 2 days

	3	At least 2 days but less than 3 days
	4	3 days or more
	8	Don't know

73. Do you use plastic to cover your silage? **[SELECT ONE ONLY]**

☐ 1 No: **IF NO**, what are you using? ______________________________

☐ 2 Yes: **IF YES**, what is the thickness of the plastic? ______________mm

74. Do you use an oxygen barrier? **[SELECT ONE ONLY]**

☐ 1 No

☐ 2 Yes

75. **[ASK IF YES IN Q73]** How are you keeping your plastic in place? **[SELECT ALL THAT APPLY]**

☐ 1 Tires

☐ 2 Bales

☐ 3 Waste Feed

☐ 4 Soil

☐ 8 Don't know

☐ 9 Other: **SPECIFY:** __________________

76. **[ASK IF YES IN Q73]** How often is plastic checked for holes and repaired? **SELECT ONE ONLY**

☐ 1 Daily

☐ 2 Couple times a week

☐ 3 Weekly

☐ 4 Less often than once per week

☐ 5 Never

☐ 8 Don't know

77. Was the sample collected from an open drive over pile? **SELECT ONE ONLY**

☐ 1 No

☐ 2 Yes

78. What date did you cover the drive over pile for first cut silage?

______________________**RECORD DATE**

☐ 8 Don't know

79. At what rate are you removing the face of the drive over pile? ________inches per day ~or~

_________cm per day

☐ 98 Don't know

80. a. How do you deface your drive over pile?

____

☐ 98 Don't know

80.b. How long does the face of the drive over pile stay exposed?

______________________________hours

☐ 8 Don't know

80.c. Is the face re-covered after silage is removed?

☐ 1 No

☐ 2 Yes

☐ 8 Don't know

81. When opening your drive over pile did you notice any form of the following **[SELECT ALL THAT APPLY]**

	1	Heating
	2	Effluent
	3	Smell of spoilage
	4	Observed spoilage in pockets or the surface

	5	No spoilage
	8	Don't know

82. If signs of heating (steam) were noticed when opening the pile did they last longer than 1 hour?

☐ 1 No
☐ 2 Yes
☐ 8 Don't know

If Sample Was Taken from a Tower Silo

---

83. What is the dimension of your silo?

a. Diameter: _________feet ~or~ _______meters
b. Height: _________feet ~or~ _________meters
☐ 8 Don't know

84. What is the material of your silo? **[SELECT ONE ONLY]**

☐ 1 Concrete
☐ 2 Steel

85. How is silage moved from the field to the drive over pile? **SELECT ONE ONLY**

☐ 4 Truck – drive beside harvester
☐ 5 High dump to truck
☐ 6 High dump to tractor wagon/trailer
☐ 10 Don't know
☐ 11 Other: **[SPECIFY: ______________________________**

86. What type of equipment do you use to fill your silo?

____

☐ 8 Don't know

87. How many tonnes on average do you add per day?

____________________________tonnes

☐ 98 Don't know

88. Do you close your silo at night in the middle of harvest? **[SELECT ONE ONLY]**

☐ 1 No

☐ 2 Yes

☐ 8 Don't know

89. How much time elapsed between the first load of first cut forage and closing the silo after harvest? **[SELECT ONE ONLY]**

☐ 1 Less than 1 day

☐ 2 At least 1 day but less than 2 days

☐ 3 At least two days but less than 3 days

☐ 4 3 days or more

☐ 8 Don't know

90. What date did you close the silo after first cut was done?

____________________________**RECORD DATE**

☐ 98 Don't know

91. At what rate, on average, do you feed out your silage? (________kg/day)

☐ 98 Don't know

92. When you opened your tower did you notice any form of the following? **SELECT ALL THAT APPLY**

	1	Heating
	2	Effluent
	3	Smell of spoilage
	4	Observed spoilage in pockets or the surface
	5	No spoilage
	8	Don't know

93. If signs of heating (steam) were noticed when opening the tower did they last longer than 1 hour?

[SELECT ONE ONLY]

- ☐ 1 No
- ☐ 2 Yes
- ☐ 8 Don't know

If Sample Was Taken from a Silage Bale

94. What are the dimension and weight of each bale?

1 Height: __________feet ~or~ ________meters_

2 Width: __________feet ~or~ ________meters_

3 Weight: __________lbs ~or~ ________kg_

☐ 98 Don't know

95. What type of equipment is used for…

1 Baling: ________________________________

2 Wrapping: ______________________________

☐ 7 Don't know

96. How are bales moved from the field to wrapping site? **SELECT ONE ONLY**

- ☐ 8 Flat deck
- ☐ 9 Bale rack
- ☐ 10 Just a tractor and bale fork
- ☐ 12 Don't know
- ☐ 13 Other: **[SPECIFY:** ________________________________

97. Are there knives in the round baler? **[SELECT ONE ONLY]**

- ☐ 1 No
- ☐ 2 Yes
- ☐ 8 Don't know

98. How long, on average between baling and wrapping? **[SELECT ONE ONLY]**

☐ 1 Less than 8 hours
☐ 2 At least 8 hours and less than 12 hours
☐ 3 At least 12 hours and less than 24 hours
☐ 4 24 hours or more

99. How many bales, on average, do you wrap per day?

________# of bales

98 Don't know

100. Are bales wrapped... **[SELECT ONE ONLY]**

☐ 1 Individually
☐ 2 Tube
☐ 3 Stacked
☐ 8 Don't know

101. Are bales kept: [**SELECT ONE ONLY]**

☐ 1 In the open: on field
☐ 2 In the open: on concrete
☐ 3 Under roof: on field
☐ 4 Under roof: on concrete
☐ 8 Don't know

102. What is the thickness of the plastic used to wrap the bales? (mm)

____________mm ☐ 98 Don't know

103. How many layers of plastic are used per bale?

____

☐ 98 Don't know

104. How often is plastic checked for holes and repaired? [**SELECT ONE ONLY]**

☐ a. Daily
☐ b. Couple times a week
☐ c. Weekly
☐ d. Less often than once per week
☐ e. Never

105. How long did you wait before feeding out your silage bales?

______________# of days

☐ 98 Don't know

106. At what rate, on average, do you feed out your bales (bales per day)?

____________________bales/day

☐ 98 Don't know

107. When you opened your bales did you notice any form of the following? **SELECT ALL THAT APPLY**

	1	Heating
	2	Effluent
	3	Smell of spoilage
	4	Observed spoilage in pockets or the surface
	5	No spoilage
	8	Don't know

108. If signs of heating (steam) were noticed when opening your bales did they last longer than 1 hour?

☐ 1 No
☐ 2 Yes
☐ 7 Don't know

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