Dry Matter Digestion Kinetics of Two Varieties of Barley Grain Sown with Different Seeding and Nitrogen Fertilization Rates in Four Different Sites Across Canada

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ABSTRACT : Our objective was to determine the differences in the rate and extent of dry matter digestion between barley subjected to differing agronomic variables. Two malting barley varieties, Copeland and Metcalfe were seeded at rates of 200 and 400 plants/m^2. Each of these varieties received nitrogen fertilizer at rates of 0, 30, 60 and 120 kg/ha, resulting in a total of 20 different barley grain samples. Samples were ground through a 6mm screen and approximately 3 g of each weighed into 50 μm Dacron bags and sealed. The bags were incubated in three ruminally cannulated Holstein cattle for periods of 0, 3, 6 and 24 h. Using the data obtained from these incubations, rates of digestion were able to be predicted. The soluble fraction ranged from 0.229-0.327, the slowly degradable fraction ranged from 0.461-0.656, and the undegradable fraction ranged from 0.038-0.299. The rates of digestion ranged from 0.127-0.165 h^{-1} and the effective degradability ranged from 0.527-0.757. At the Canora location, the Copeland samples which received 120 kg/ha of nitrogen fertilizer had a significantly lower (p = 0.013) soluble fraction than the rest of the samples at that location. A significant interaction (p = 0.009) was seen between the seeding rate and nitrogen fertilizer application with samples from the Canora location, as well as significant differences (p = 0.029) between nitrogen application rates in samples from the Indian head location. The rate of digestion of samples from the Indian head location differed (p = 0.020) between the two seeding rates, with samples seeded at 200 seed/m^2 having a slightly higher rate of degradation. Differences in the effective degradability were seen between the different nitrogen application rates with samples from both the Canora and Indian head locations, as well as an (p = 0.004) interaction between the seeding rate and nitrogen fertilizer application rate. Although there was not a clear correlation between the different variables, both nitrogen application and seeding rate did have a significant effect on the rates and extent of digestion across each of the four locations. (**Key Words :** Barley Grain, Digestion Kinetics, Disappearance, *In sacco*)

INTRODUCTION

Barley is a cereal grain which is commonly used in intensive dairy and beef rations for rapid growth and production in Canada. Barley grain consists of 50-60% starch, 80-90% of which is rapidly digested within the rumen (Nocek and Tamminga, 1991). The starch present in barley is a polysaccharide which consists of the polymers amylase and amylopectin. It has a high metabolizable energy content which is provided by a large proportion of rapidly fermentable starch located within the endosperm of the grain kernel. The water requirements of cereal crops such as wheat, corn and barley impact on the ability of the

plant to reach to vegetative stage, required for grain production. The total water usage of barley is significantly lower than the commonly used feed substitutes, wheat and corn. The reduced water requirement of barley is of increasing importance within Australia as drought continues to limit water availability for crop production (McKenzie and Woods, 2009). Barley grain is highly indigestible in its unprocessed form but methods such as grinding, rolling and flaking increase its digestibility throughout the ruminant digestive tract. Grinding is a form of physical processing which breaks down the macrostructure of the barley grain, increasing the surface area available for digestive and microbial enzymes to act and as a result, increasing the rate and extent of grain digestion. The rate, site and extent of digestion differ between grains, cultivars and processing methods due to differences in physical structure, the ratio of surface area to volume (SA:V) and the composition of the

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protein matrix within the endosperm (Stevnebø et al., 2006). These are important considerations when formulating rations because they significantly influence the efficiency of utilisation as well as the substrates formed. A large portion of barley starch is digested within the rumen by microbes to produce volatile fatty acids (VFA) and energy for microbial growth. Rapid rates of rumen fermentation can cause a severe drop in ruminal pH, resulting in ruminal acidosis, reduced feed intake, decreased microbial protein synthesis and a decrease in fibre digestion (Ramsey et al., 2002). Energy utilisation within the small intestine is a result of enzymatic digestion of glucose which is suggested to be more efficient than the rumen due to reduced fermentation, heat losses and methane production (Huhtanen and Sveinbjornsson, 2006). A recent boom in the use of corn starch for ethanol production has placed upward pressure on the price of corn, increasing the demand for cheaper feed alternatives such as barley (Lawrance, 2008). The cost of feed accounts for 55-60% of the cost of production, having a significant impact on the production margins of an enterprise (Murray, 2007).

Differences in barley varieties, environment, nitrogen fertilizer application and seeding rates have an effect on both the yield and chemical composition of the grain produced. They have the potential to alter the starch and protein content of the grain as well as the rate and extent of its digestion (Oscarsson et al., 1998). Knowledge of these parameters can be used to produce grains of the highest nutritional value, specific to animal production industries. The objectives of this study were to evaluate the effects of barley variety, seeding rate, location and differing rates of nitrogen fertilizer application on the rate and extent of ruminal dry matter disappearance.

MATERIALS AND METHODS

Barley samples

Two malting barley (*Hordeum vulgare*) varieties, AC Metcalfe and CDC Copeland, were grown at four sites across western Canada (Canora (SK), Indian Head (SK), Scott (SK), Lethbridge (AB)) in 2007-2008. Both varieties were seeded in April-May (2007) at rates of 200 and 400 seeds/m^2. Nitrogen fertilizer was applied to each cultivar at rates of 0, 30, 60, 90 and 120 kg/ha. Four replicates of each of the 16 treatments (two varieties, two seeding rates and four rates of N fertilization) were grown at each site, totalling 64 plots per site.

Sample preparation

Following harvest, a representative sample of barley grains were ground through a 6 mm screen using a Wiley grinding mill (Arthur H. Thomas Co.). Approximately 3 g DM was weighed into 50×100 mm Dacron bags (pore size 50 μm), sealed using impulse heat, numbered and stored in airtight containers at room temperature prior to the ruminal *in sacco* incubations. Bags were incubated for 0, 3, 6, and 24 h, with triplicate bags at each time for each barley variety. The procedure for incubation (*n* = 4; by location) required triplicate bags for each variety sample (nitrogen fertilization×seeding rate) to be placed in a weighted (350 g) netted bag, so that three lingerie bags per cow were placed in the rumen at the commencement of incubation.

In sacco **incubations**

Animals and diets : Three ruminally cannulated non-lactating Friesian cows were individually housed at the Agriculture and Agri-Food Canada - Lethbridge Research Centre and used for the duration of the incubations. The animals were fed two transition diets over a period of three weeks, before being placed on a mixed ration (60.1% barley grain, 3.7% minerals and vitamins supplement, 36.2% barley silage) on which they remained for the duration of the trial to maintain a similar rumen environment across each of the animals and time points. The animals used in this trial had *ad libitum* access to clean drinking water and were cared for in accordance with the guidelines set by the Canadian Council on Animal Care (1993).

Rumen incubation : The pre-prepared Dacron bags were sorted according to time point, cow and site and placed into larger netted bags, each with a weight to ensure they remained at the bottom of the rumen. Triplicate samples of each of the 64 plots at each location were placed in the rumen and removed after 3, 6, and 24 h. Once removed from the rumen, the bags were rinsed immediately in cold water to remove any external rumen contents and prevent further microbial activity. Bags were stored in a refrigerator until the removal of the final time point. The 0 h bags were not placed in the rumen. These bags were placed in warm water for 10 minutes and stored in a refrigerator until all time points were ready to be placed in a washing machine on a cold water cycle. The cycle was stopped prior to the spin function to prevent damage to the bags. Following the washing procedures, the bags were oven dried (55°C) for 24 h and residues were weighed to obtain disappearance of the dry matter (DM).

Statistical analysis

Data from the *in sacco* incubations was presented in the form of degradation characteristics using a non-linear least-squares procedure (PROC NLIN) of SAS (SAS Inc. 2010) to provide estimates for A, B, C, *k* and the lag time.

Degradation characteristics were analysed using a MIXED procedure of SAS. Data was analysed by variety and by site which was able to be used to determine significant differences between the means of each treatment (seed rate, N fertilization and interaction) and determine the

fractional disappearance rate (k, h^{-1}), lag time (L, hours) and potential degradation (P) according to the formula:

$$P = A+B\times(1-e^{-k(t-L)})$$

where A = soluble fraction (proportion of DM), B = degradable insoluble fraction (proportion of DM) and t is the time in hours.

The effective degradability (ED) was calculated from the kinetic parameters obtained from exponential adjustment assuming a fractional passage rate (k_p) of 0.06 h^{-1}:

$$ED = A+B\times(k/(k+k_p))$$

RESULTS

The dry matter (DM) digestion kinetics have been summarised in Table 1 for barley harvested from the four sites (Canora, Indian Head, Lethbridge and Scott) and two varieties (Copeland and Metcalfe). The "A" fraction (soluble DM) comprised mainly of small particles washed out from within the nylon bags at 0 h. The *in sacco* A fraction varied from 0.229 to 0.316 within the Copeland variety samples. A difference (p = 0.013) was observed between the nitrogen application rates at the Canora location. The Copeland variety which received nitrogen

fertilizer at rates of 60 kg/ha showed a lower soluble fraction (0.229) compared to 0, 90 and 120 kg N/ha treatments. No difference (p≥0.143) was observed in the Metcalfe samples for the soluble fraction which had an average value of 0.248±0.0122. At the Indian Head site the Copeland variety had an average soluble fraction of 0.291 and Metcalfe samples were slightly less with an averaged "A" fraction of 0.279. The soluble DM fraction in Lethbridge for Copeland was numerically higher among sites, but no significant differences or interactions were observed between treatments. At Lethbridge the "A" fraction averaged 0.316 for Copeland samples, whilst the Metcalfe variety averaged 0.310. At Scott no differences or interactions (p≥0.224) were observed and the Copeland and Metcalfe varieties which had average "A" fraction of 0.312 and 0.305, respectively.

The "B" fraction is the slowly degradable portion of the DM. There were no differences (p≥0.096) for seed rate and N fertilization at any of the sites. The readily degradable fraction ranged from 0.466 at Canora to 0.607 at Lethbridge. Numerically the variety Canora had the lowest "B" fraction of all sites averaging 0.466 for the Copeland variety and slightly higher values of 0.476 for Metcalfe variety. At Indian Head, Copeland and Metcalfe had an average readily degradable fraction of 0.534 and 0.520, respectively. At Lethbridge "B" fraction averaged 0.631 and 0.607 for
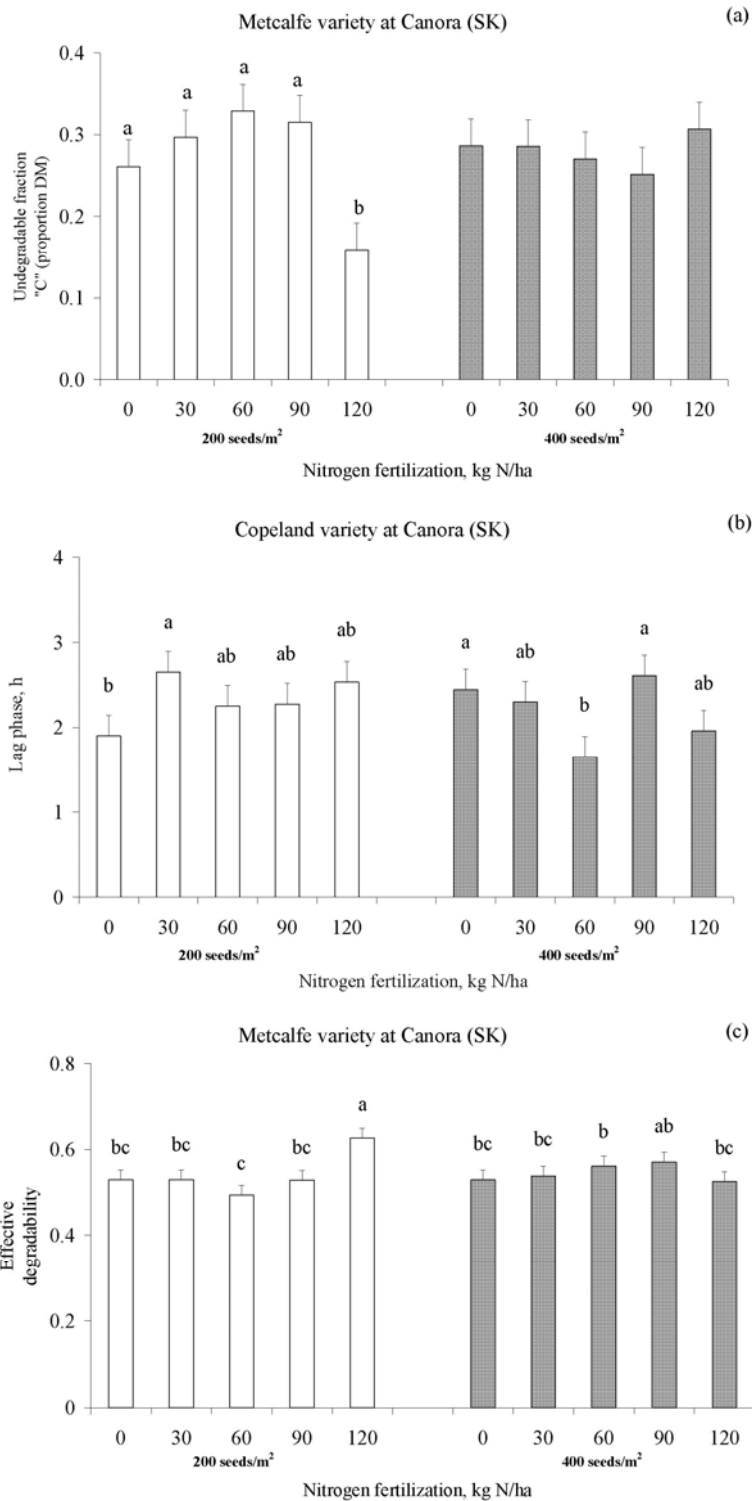
Table 1. Dry matter (DM) degradation characteristics (proportion of the DM) defined as soluble (A), degradable insoluble (B) and undegradable residue (C = 1-A-B) as well as fractional degradation rate (k, h^{-1}), lag time (Lag, h) and effective degradability (ED) which takes into account the effect of passage rate from the rumen for two barley grain varieties (Copeland and Metcalfe) and four sites across Western Canada

Site/variety	A		B		C		k		Lag		ED	
	Copeland	Metcalfe	Copeland	Metcalfe	Copeland	Metcalfe	Copeland	Metcalfe	Copeland	Metcalfe	Copeland	Metcalfe
Canora, SK	0.263	0.248	0.466	0.476	0.271	0.276	0.138	0.139	2.257	2.343	0.552	0.543
Standard error	0.0124	0.0122	0.0232	0.0242	0.0231	0.0233	0.0061	0.0062	0.1711	0.1822	0.0166	0.0162
p-values												
Seed rate	0.808	0.366	0.896	0.408	0.999	0.700	0.454	0.816	0.397	0.631	0.626	0.806
Nitrogen	0.013	0.736	0.525	0.257	0.144	0.289	0.094	0.314	0.183	0.419	0.009	0.184
Seed rate×nitrogen	0.214	0.143	0.827	0.185	0.222	0.009	0.683	0.858	0.048	0.218	0.079	0.004
Indian Head, SK	0.291	0.279	0.534	0.520	0.175	0.201	0.142	0.141	2.018	2.089	0.634	0.607
Standard error	0.0121	0.0119	0.0229	0.0238	0.0212	0.0221	0.0059	0.0061	0.1657	0.1660	0.0147	0.0147
p-values												
Seed rate	0.337	0.280	0.315	0.089	0.590	0.211	0.812	0.020	0.164	0.540	0.894	0.098
Nitrogen	0.836	0.672	0.688	0.096	0.456	0.029	0.106	0.563	0.530	0.820	0.110	0.024
Seed rate×nitrogen	0.943	0.296	0.300	0.159	0.400	0.176	0.189	0.739	0.116	0.626	0.122	0.246
Lethbridge, AB	0.316	0.310	0.631	0.607	0.053	0.082	0.160	0.159	1.696	1.880	0.746	0.722
Standard error	0.0106	0.0109	0.0218	0.0225	0.0216	0.0218	0.0056	0.0056	0.1597	0.1653	0.0170	0.0164
p-values												
Seed rate	0.505	0.154	0.201	0.919	0.333	0.414	0.822	0.447	0.998	0.562	0.399	0.390
Nitrogen	0.588	0.346	0.722	0.319	0.934	0.447	0.084	0.890	0.680	0.166	0.653	0.670
Seed rate×nitrogen	0.682	0.795	0.706	0.929	0.775	0.982	0.059	0.322	0.079	0.652	0.969	0.836
Scott, SK	0.312	0.305	0.591	0.577	0.096	0.118	0.156	0.153	1.705	1.813	0.710	0.688
Standard error	0.0113	0.0115	0.0224	0.0232	0.0211	0.0211	0.0056	0.0058	0.1553	0.1586	0.0152	0.0149
p-values												
Seed rate	0.224	0.884	0.558	0.975	0.976	0.909	0.102	0.279	0.535	0.969	0.627	0.655
Nitrogen	0.369	0.665	0.771	0.925	0.888	0.999	0.304	0.111	0.453	0.865	0.683	0.958
Seed rate×nitrogen	0.504	0.594	0.749	0.799	0.786	0.333	0.215	0.918	0.362	0.919	0.876	0.322

Copeland and Metcalfe varieties while that of Scott samples were slightly less at 0.591 and 0.577.

The "C" fraction of the sample represents the DM proportion of barley remaining following removal of the nylon bags after 24 h. Seed rate×N fertilization interaction (p = 0.009) was observed at the Canora site for the Metcalfe variety (Figure 1a). At the seeding rate of 400 seeds/m² the undegradable fraction ("C") was similar among different

Figure 1. Dry matter (DM) digestion kinetic characteristics affected by seeding rate (seeds/m²) and nitrogen fertilization: undegradable fraction ("C"; proportion in the DM; a) and lag phase (in h; b) for Copeland at Canora (SK) variety and effective degradability (ED) for Metcalfe variety (c).

rates of nitrogen fertilizer. However, at the seeding rate of 200 seeds/m^2 the "C" fraction was smaller at 120 kg N/ha compared to 0, 30, 60 and 90 kg N/ha (p = 0.009). The higher proportion of the DM in the "A" and particularly "B" fractions is assumed to have contributed to the significantly lower undegradable fraction.

At Indian Head the undegradable fraction for Metcalfe variety was smaller (p = 0.029) when nitrogen fertilizer application rates were 30 and 60 kg/ha than other N application rates. No differences in Copeland variety was observed and C fraction across treatments averaged 0.175 at this site.

Both Lethbridge and Scott had numerically lower "C" fractions across all sites, with values of 0.068 and 0.107 respectively. At Lethbridge, Copeland had an average fraction ("C") of 0.053, while the Metcalfe variety averaged 0.083. At Scott, Copeland and Metcalfe averaged 0.096 and 0.118 for the undegradable fraction.

The rate of degradation (*k*) differed (p = 0.020) between the two seeding rates at the Indian Head site. Seeding rate of 400 seeds/m^2 demonstrated a lower degradation rate compared to of 200 seeds/m^2 (0.135 vs. 0.148 h^{-1}, respectively). Data from Lethbridge indicated an interaction between seeding rate and nitrogen application, however it was not substantial enough to be deemed significant (p = 0.059) and had an average degradability of 0.160 h^{-1}. Canora had average rates of degradation of 0.138±0.006 h^{-1} for Copeland and 0.139±0.006 h^{-1} for Metcalfe, and Scott had similar rates of 0.156±0.0056 h^{-1} for Copeland and 0.153±0.0058 h^{-1} for Metcalfe.

Lag phase indicates duration time that the microbes take to adhere to the substrate and for a time at the beginning of the *in sacco* incubation (up to 2-4 h) there is no loss in DM. A significant interaction between seeding rate and nitrogen application rate for the lag phase of the Copeland variety at Canora is illustrated in Figure 1b. At this same location the Metcalfe variety demonstrated no differences between treatments for lag time and averaged of 2.3 h. At Indian Head there was no difference between any of the treatments for lag phase and averaged 2.02 h for Copeland and 2.09 h for Metcalfe. Lethbridge average lag times were 1.7 and 1.9 h for Copeland and Metcalfe, respectively. At Scott, Copeland had an average lag of 1.7 h and Metcalfe averaged of 1.8 h.

Effective degradability (ED) takes into account both extent and rate of digestion, to enable comparison between treatments, and indicate relative nutritive value of these barley varieties. At Canora, ED was affected by nitrogen application (p = 0.009) for the Copeland variety. The highest effective degradability (0.601) was presented at rates of 120 kg N/ha than all other N fertilization rates except for 30 kg N/ha. The effective degradability of the

Metcalfe samples showed a significant interaction (p = 0.004) between seeding rate and nitrogen application rates (Figure 1c). At seeding rates of 200 seeds/m^2, samples that received 120 kg N/ha had a significantly higher effective degradability (0.626) than the remaining four treatments. The lowest degradability (0.493) was seen at 60 kg N/ha, differing significantly from those samples receiving fertilizer at rates of 120 kg N/ha. When seeded at 400 seeds/m^2, the highest effective degradability (0.570) occurred when nitrogen fertilizer was applied at rates of 90 kg N/ha. The extent of effective degradation at this rate did not differ significantly from the remaining treatments which ranged from 0.525-0.570 DM loss.

At Indian Head different levels of nitrogen application rates for the Metcalfe variety affected ED. The effective degradability of samples with 120 kg/ha of nitrogen had a lower (p = 0.024) effective degradability (0.569) to all other treatments except for N application of 90 kg/ha. The Copeland variety had similar ED among N applications or seed rates and averaged 0.634±0.0147; p≥0.110).

At Lethbridge the Copeland variety had an average effective degradability of 0.746, while the Metcalfe variety averaged 0.722. Scott also had no significant differences between treatments and ED averaged 0.710 and 0.688 for the Copeland and Metcalfe varieties, respectively.

DISCUSSION

The ruminal DM data was broken down into the various degradation characteristics. The 0 h time period was used to determine the soluble fraction which was washed out prior to the incubation. The soluble DM fraction of barley is readily degradable by rumen bacteria and is assumed to contribute to a rapid lowering of the rumen pH by providing a large portion of rapidly fermentable carbohydrates, mostly starch (Ghorbani and Hadj-Hussaini, 2002). The DM soluble fraction of all the samples ranged from 0.229-0.327 (Table 1). The lower limit of this range was illustrated when 60 kg/ha of nitrogen was applied to the barley field, appearing lower (p = 0.0131) than all other samples in the Canora group. The difference in the proportion of the soluble fraction is related to a number of factors including bag pore size, particle size of the grain (e.g. preparation before *in sacco* incubation), the ratio of the sample weight: bag surface area and the washing technique (Ghorbani and Hadj-Hussaini, 2002). Since the bag pore size was standardised across the trial, it can be assumed that the differences in the results may be attributed to variations in washing technique and an element of variation in grain particle sizes, resulting in different amounts of small particles being washed out rather than being truly soluble. The soluble fraction ("A") for this study appeared to be smaller than that of similar study by Ramsey et al. (2001)

who had an average washout fraction of 0.544 in an *in sacco* study involving two-row barley varieties. It their study authors analysed the degradability of DM and starch of different barley cultivars ground through a 3 mm screen incubated in 50 μm nylon bags. The proportion of DM soluble fractions in their study ranged from 0.454-0.577 across all varieties. The range of the soluble fractions found in Ramsey et al. (2001) were significantly higher than those found in the current study, but as Azarfar et al. (2007) found fine grinding increased the "A" fraction by either rupturing the cell walls during grinding and hence increasing the release of more soluble nutrients, or breaking particles down to a size whereby they are small enough to be washed out of the bag. The *in sacco* technique is a widely used procedure for estimating the degradation rates of various feedstuffs but it is subject to variability resulting in an overestimation of the soluble fraction of the feedstuff, and an underestimation of the slowly degradable fraction. Reducing the particle size increases the washout fraction, giving an inaccurate representation of the portion which is truly soluble (Huhtanen and Sveinbjornsson, 2006). Boss and Bowman (1996) conducted an *in sacco* study using two barley varieties incubated in 50 μm nylon bags. The proportions of soluble DM fraction obtained in their study ranged from 0.22-0.37, which were similar to the results seen in the current study.

The degradable fraction ("B") is the portion of the grain which is slowly digested within the rumen when allowed sufficient time (Chaves et al., 2006). It is an important source of slowly fermenting starch providing energy for the rumen microbes. In the current study no differences (p>0.05) in the slowly degradable portion were observed between treatments at each site. The average "B" fraction across the locations ranged from 0.466-0.631 (Table 1) which is consistent with the values obtained by Ghorbani and Hadj-Hussaini (2002). These authors performed an *in sacco* study using 50 μm nylon bags and obtained an average "B" fraction across 10 barley cultivars of 0.465. In a similar study by Khorasani et al. (2000), barley was ground into a smaller particle size through a 2-mm screen and incubated in nylon bags with a pore size of 57 μm. These last authors demonstrated an average degradable fraction for DM of 0.455 in an *in sacco* study testing the ruminal degradation of 60 different barley varieties. Huhtanen and Sveinbjornsson (2006) and Ljokjel et al. (2003) concluded from a range of studies that by reducing the particle size of the grain used in the *in sacco* incubation, the soluble fraction is potentially overestimated and the degradable fraction is underestimated. This is potentially the reason to the results seen in the work of Ramsey et al. (2001) who undertook a similar procedure to that of the current study, and observed an average "B" fraction of 0.326 when different barley varieties were ground through a

3 mm screen. A study by Ramsey et al. (2001) looked at the relationships between ruminal DM and starch disappearances of 10 different barley grains when ground through a 3 mm screen and ruminally incubated. From the data obtained they indentified that both the soluble and the slowly degradable DM and starch fractions were significantly correlated. Using this assumption, *in sacco* DM techniques such as the one performed in the current study, can be accurately used to predict the soluble and slowly degradable starch fractions of barley grain. Similar results were found by Philippeau et al. (1999) who found a 0.74 and 0.95 level of correlation between the DM and starch soluble and slowly degradable fractions respectively. The extent of ruminal digestion of barley grain is highly dependant on the degree of kernel damage experienced during grain processing which decreases the particle size and increases the area available for microbial attachment (Dehghan-Banadaky et al., 2007). The indigestible fraction is estimated using the "A" and "B" fractions in the formula C = 1-(A+B). The significantly low indigestible fraction seen at the Canora location was consistent with the higher "A" and "B" fractions in the DM for this treatment. The average range of the treatments was between 0.053-0.276, the upper limit of which differed significantly from the averages observed in similar studies by Ghorbani and Hadj-Hussaini (2002), Ramsey et al. (2001) and Khorasani et al. (2000).

The rate of DM degradation within the rumen is influenced by a number of interactions between the rumen microorganisms and barley kernel tissue. The most important factors influencing the rate of degradation include the level of feed intake, the type of grain fed and the degree of processing (Julliand et al., 2006). Processes such as grinding alter the surface structure of the grain, increasing the surface area available for microbial and enzymatic digestion (Dehghan-Banadaky et al., 2007). The rate at which digestion occurs influences the rate of passage, site of digestion, substrates formed and the efficiency of feed utilization (Offner et al., 2003). Rapid ruminal starch digestion causes the production of VFA for absorption and as a form of energy for microbial protein synthesis. The rate and extent of ruminal digestion is important as a high rate of degradation within the rumen causes a severe drop in pH which can result in ruminal acidosis, a reduction in microbial protein synthesis, fibre digestion and feed intake (McAllister et al., 1990). The efficiency of energy utilization is potentially increased when glucose is absorbed within the small intestine instead of VFA within the rumen due to a reduction in methane and fermentation heat losses, as well as a higher efficiency of ME utilization in the small intestine (SI). An increase in post-ruminal digestion can be achieved through chemical treatment of the grain with formaldehyde (HCHO), which reduces ruminal digestion of

the protein matrix and the starch granules within this matrix (McAllister et al., 1990). This has the potential to reduce the occurrence of digestive disorders such as acidosis, liver abscesses and bloat. The efficiency of digestion within the SI does vary between sources, Nocek and Tamminga (1991) observed a positive correlation between the extent of ruminal and intestinal starch degradability. Limitations to intestinal digestion include the physical starch structure, enzyme capacity and glucose absorption (Reynolds, 2006). A review by Reynolds (2006) identified that post-ruminal infusion of glucose resulted in an increase in milk yield and protein content, but caused a decrease in milk fat and energy concentration as well as a reduction in intake (Reynolds et al., 2001). Increased glucose absorption post-ruminally increases the total glucose supply to the animal, which can be utilized for body tissue energy deposition instead of secreted in the milk in the form of milk fat (Reynolds, 2006). The rates of DM disappearance have been seen to be strongly correlated with the proportions of soluble and slowly degradable fractions (Ramsey et al., 2001). In the current study the difference in the rates of degradation were presented only between the two seed rates of the Metcalfe variety of the Indian Head samples. The rate of degradation was higher for samples planted at 200 seeds/m^2 than those planted at 400 seeds/m^2. A study by O'Donovan et al. (2008) tested the effects of increasing the planting density from 200, 300 and 400 seeds/m^2, in addition to different rates of nitrogen fertilizer application and placement and the effect that they had on crop density, maturity and yield. These authors found that as the seeding rate increased plant density was increased and the days to maturity decreased. This could be a potential cause for the difference in the rate of degradation seen in the Indian Head samples; however, this correlation was not tested in the current trial. The rate of DM degradation ranged from 0.138-0.160 h^{-1} which was much lower than the rates presented by Ramsey et al. (2001) who observed rates of DM disappearance between 0.33-0.58 h^{-1}. Ramsey et al. (2001) ground the barley samples to 3 mm, leaving the grain with a particle size half that of the current study. The rates of digestion obtained in their study are 2-fold that seen when barley was ground through a 6 mm screen, assuming to be due to the difference in particle size and its effects on rates and extent of digestion as demonstrated by Bengochea et al. (2005).

Ramsey et al. (2002) found a positive correlation between the incidence of bloat and liver abscesses in feedlot steers fed 10 different varieties of barley grain and the DM wash out fraction. These authors concluded that rapid rates of ruminal degradation of ground barley would negatively impact steer rate and efficiency of live weight gain due to an increased incidence of bloat and liver abscesses.

The effective degradability is an estimate of the ruminal disappearance of DM at a specific rate using the previously discussed kinetic data. The degradability of the nutrients used within a ration is of importance as they affect the quality and quantity of the nutrients obtained by the animal. Differences in barley cultivar, environment and rates of nitrogen fertilizer application have been reported to have an effect on both the yield and chemical composition of the resulting grain (Conry, 1994; Oscarsson et al., 1998). Oscarsson et al. (1998) conducted a study testing the effects of barley cultivar, nitrogen fertilization rate and environment on yield and grain quality. Within the ten varieties if barley it was found that increasing nitrogen fertilization rates of 45, 90 and 135 kg N/ha had a negative impact on the grain starch content, and increased the crude protein levels within the grain. These authors found that protein and β-glucan were negatively correlated to the starch content, whilst yield and starch content showed a positive correlation. The starch in barley grain represents a large portion of the grain DM and the effective degradability of DM is positively correlated with that of starch (Offner et al., 2003). Differences in starch degradability have been seen in varieties that contain different levels of amylase to amylopectin. High levels of amylase results in more extensive hydrogen bonding, and a subsequent increased resistance to hydrolytic enzymes. In the current study the effective degradability was estimated using a fractional passage rate of 0.06 h^{-1} as suggested for concentrates feeds (Tamminga et al., 1994; Offner and Sauvant, 2004). The ED of the Canora samples showed a higher (p = 0.009) effective degradability (0.601) for Copeland barley with a nitrogen application of 120 kg/ha compared to the rest of the treatments at this location. The high ED of this treatment is most likely correlated with the significantly high soluble fraction caused by particle loss during the washing procedure as discussed by Sanodoval-Castro (1997). A further limitation to the *in sacco* procedure which has been suggested as a cause for inaccurate results is the difference between the microbial population within the nylon bag and that of the surrounding ruminal environment (Offner et al., 2003). Metcalfe samples from the same location displayed an interaction (p = 0.004) between seeding rate and nitrogen application (Figure 1c). Within the Indian Head samples a significantly (p = 0.024) low ED was seen for samples with a rate of 120 kg/ha of nitrogen applied. The effective degradability of samples from Lethbridge and Scott were similar to those of Ghorbani and Hadj-Hussaini (2002) who observed an average ED of 0.781 in a similar study using 10 different barley cultivars. Hart et al. (2008) performed an *in sacco* study using rolled Metcalfe and 5 feed barley cultivars. At the same rate of ruminal passage these authors observed an effective

degradability of 0.356-0.406. The lower ED seen in this study is a result of the degree of processing in each of the procedures. Philippeau et al. (1999) determined the variation in the rate and extent of ruminal starch degradation in 14 different varieties of corn. The trial was an *in sacco* study using ruminally cannulated Jersey cows and identified a strong correlation between DM degradation and starch digestibility. The highest correlation (0.99) was seen between the effective degradability of ruminal DM and starch degradation for corn cultivars (Philippeau et al., 1999). Offner et al. (2003) analysed data from 82 observations using 26 experiments and the regression analysis concluded that starch ED was positively correlated with DM ED. These last authors suggested that this correlation can be used in diet formulations to accurately predict and estimate starch degradation of feedstuffs using *in sacco* procedures and DM digestibility data.

CONCLUSION

This study provided an assessment of the effect that different seeding and nitrogen fertilizer application rates, location and variety have on the *in sacco* kinetics of barley grain. The rates of nitrogen fertilizer application and seeding appeared to have a significant but not consistent effect on *in sacco* DM digestion. The highest levels of significance were seen in the effective degradability at the Canora location, but are most likely due to differences in other fractions caused by limitations within the procedure. Interactions were seen between the seeding and nitrogen application rates for the effective degradability in samples from Canora. From this data it can be concluded that the variables tested did not have a profound and reliable effect on the rates of dry matter digestion within the rumen.

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