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# Energy-dense forages: An Opportunity for the Canadian Beef Production Model

**Clayton Robins**

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NUFFIELD CANADA

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## SCHOLAR PROFILE

This report represents a personal culmination of a journey which began over 25 years ago. After a lifetime of accumulating production and research experience and knowledge, including lessons learned from a mission to Argentina to study the forage-fed beef value chain, I looked to the Nuffield program to pursue answers which have so far eluded the Canadian grass-fed beef industry.

I am fortunate in having had two occupations for most of my adult life that complemented each other very well. As a fourth-generation producer and owner-operator of a mixed farm that is approaching 125 years of Robins' family ownership I have been able to implement new strategies and technologies into our production system, as resources permitted. Concurrently, from 1990-2011, I was employed as a Beef and Forage Researcher with Agriculture and Agri-Food Canada (AAFC) , engaged in investigation of cutting-edge grazing techniques and efforts ranging from cultivar development to greenhouse gas measurement and mitigation strategies. Two major components of this program over that time included development of extended grazing techniques and forage-fed beef production. Owing to the level of innovation and research efforts in these areas, our team was recognized with the Gold Harvest Award in 2009. During this time with AAFC I was able to bring lessons learned from our research efforts home, incorporate and adapt them into our beef and sheep production enterprises, and then observe and bring that knowledge and experience back to the project planning table for future studies. This synergy was mutually beneficial for our farm and the research program, and afforded me the opportunity to consider a very objective, balanced assessment of the true potential of these approaches.

Upon resigning from AAFC to pursue a more rewarding career in positive youth development with the 4-H program, I left with many questions in my mind remaining unanswered. A single slide shown during a presentation to our team in Argentina in 2008, demonstrating the link between animal performance and plant sugar levels, made me realize that we needed to modify our Canadian perspective of forage-feeding streams in feeder and finishing classes of cattle. I recognized that the Nuffield program could provide the means to pursue this knowledge in a way that none of my former colleagues would have the opportunity to, and was very fortunate to be chosen as one of the 2013 Canadian Scholars.

This international journey and the occasion to glean knowledge and data from some of the top minds in the world has truly been a life-changing experience. In the short time that I have engaged in the pursuit of knowledge through this study I have come to understand the complex relationship between soil, plants, animals, and humans at a far higher level and in a context that would have never been possible in prior farming and research careers. Production on our own farm will be greatly enhanced with this knowledge, and I am hopeful for the positive impact that this report may have on the Canadian beef and forage industries. The findings, I believe, are truly significant and I am forever grateful for the opportunity.

# ACKNOWLEDGEMENTS

First and foremost I would like to thank my family for their support, patience and tolerance over the past two years. This study has consumed a significant portion of my life and my thoughts over that time and I cannot express how much your support has helped me see it through to conclusion. To my wife Rebecca for never questioning my decision and for always being there to help me prepare for my time away and to my son Quinn for stepping up to manage the farm in my absence, thank you ever so much. Your support has offered me the confidence to undertake this journey. Also, a big thank you to my parents Brian and Arlene, for always being there to provide a helping hand to Bec and Quinn in my many absences.

Secondly, I need to thank the Board members and staff of the Manitoba 4-H Council for affording me the ability to spend significant time away from the office and for supporting all my efforts over the past two years. Also, to our partners and staff in MAFRD who help deliver the 4-H program in the province, thank you for stepping up to help fill the gaps during my study travel. It will not be forgotten and I am sincerely appreciative of your support.

Thirdly, I would like to thank Nuffield Canada and the members of the 2013 selection committee. I am forever grateful and humbled by your confidence in supporting my pursuit of a concept I was so passionate about, and that I was so convinced was worthy of investigation. You have provided me with the opportunity of a lifetime and no words can do justice to the scope of this experience. Truly, Nuffield must be lived to be believed.

I would also like to thank the many individuals who set time aside in their lives, either in-person, by phone, or by e-mail, in order to assist me in gathering and comprehending the information presented in this report. Without your contribution the many pieces of the puzzle would never have fallen into place. Whether producer, extension agent, or world-renowned scientist I hold all our conversations in great regard and constantly reflect on your generosity and kindness; thank you all. I wish to recognize my Nuffield mentor Ms. Karen Daynard for her sage advice in helping me to better understand the journey which I was about to undertake; and also my peer reviewer Dr. Les Halliday, whose assistance, knowledge and insight at the beginning and the end of this study were invaluable. In addition, I would like to thank my former supervisor, Dr. Shannon Tracey, who followed my journey through its entirety and provided comment on the final draft of the report.

Lastly, but most certainly not least, I must acknowledge my fellow Nuffield Scholars and friends. My journey would not have been complete without the time we spent together, from when we first met at the Contemporary Scholar's Conference to the end of my travels; connecting at times ever so briefly in person, a few longer visits, and sometimes simply over the phone. I am humbled and honoured to know you all and to be a part of such an esteemed group. You are a constant inspiration to me and I am forever grateful for the chance to connect with each and every one of you during my study travel. This truly would not have been the experience of a lifetime without you having been a part of it. I look forward to when next we meet.

# EXECUTIVE SUMMARY

The objective of this Nuffield study was to determine the potential impact of forages with elevated levels of metabolizable energy components on beef production in Canada. Although initially focused on grasses with higher concentrations of water soluble carbohydrates, and the resulting impact on feeder and finishing classes of cattle under grazing, the emphasis quickly shifted toward a more comprehensive approach. It became apparent that a more diverse selection of forages with superior total energy density was the real pursuit, leading to the evolution of the term "energy-dense" forages. There was also clear evidence that the motivation for targeting only feeder and finishing classes of cattle was misguided, and too narrow of scope, to realize the full potential for these forages when incorporated at key stages of the beef production value chain. Several aspects outlining possible impacts of these forages will be examined, based on discussions with industry experts as well as scientific evidence shared and collected from various international research institutions visited during this Nuffield journey.

Owing to scientific evidence of the impact of early life nutrition, as well as data on nutritional and environmental benefits from other jurisdictions already providing energy-dense forages to older classes of cattle, it is not unreasonable to assume the following advances have the potential to be realized in Canadian beef production systems:

- ✓ Increased intake rates and digestive efficiencies, leading to performance improvements in meat, milk and fat production;
- ✓ Increased rumen digestive efficiencies through modification of rumen microbial populations and volatile fatty acid concentrations, resulting in reductions in emissions of volatile nitrogen and methane; i.e. greenhouse gas mitigation; and
- ✓ The development/programming of pre-adipocyte cells in meat tissue of suckling calves, or early onset marbling cell development.

While there is no current evidence available to suggest that energy-dense forages will positively impact concentrations of lipids beneficial for human consumption in adipose (fat) tissues of beef carcasses, ample evidence does exist that demonstrates this result in animals fed concentrate-based, high-energy diets. Should similar levels of sustained metabolizable energy supply be provided to finishing classes of cattle in the form of an energy-dense forage diet, with or without strategic supplementation as necessary, it is not unreasonable to surmise that similar physiological benefits would occur. The concepts of restricted grazing, energetics in beef systems, and the role of genomics in optimizing production efficiencies will also be deliberated, with the incorporation of energy-dense forages at key points in the beef production model taken into consideration. In addition, the model being proposed in this report is founded on the concept of the use of cover crop species blends that have been shown to maintain soil cover and improve soil structure and properties by sequestering carbon; as well as to enhance soil biology. This report will evaluate the comparison of energy-dense forages against conventional Canadian beef production systems related to all these factors.

# DISCLAIMER

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# 1.0 INTRODUCTION

With Canada being well known internationally as a producer of high-quality forages one would expect that, logically, the production of forage-fed beef should be equally as successful. However, due to the short growing season, harsh winters and dominance of perennial forage as a feed source; consistently producing a quality forage-fed beef product has been a challenge. The greatest hurdle to the forage-fed beef enterprise lies in the difficulty in providing an adequate level of diet energy in a forage-fed beef production model, especially in the form of a low-cost forage of consistent feed value. Dietary energy is important in supporting several metabolic processes in ruminants, not the least of which involves the accumulation of body fat in various storage depots. High levels of dietary energy supply provided at key points in a beef production model are critical for achieving acceptable levels of accumulation. Meeting these targeted levels of lipid accretion are necessary to attain desirable carcass grading standards and to supply a retail product that reflects beef consumer preferences.

With respect to this discussion, and the intent of the topic of this study, the focus will be on the region of the Canadian Prairies in the Northern Great Plains of North America. This is the heart of beef production in Canada and the area that faces the both the greatest obstacles and opportunities to providing a low-cost, sustained supply of metabolizable energy to livestock using forages. This is not to say that the region is not capable of producing forages with significant levels of digestible energy; the difficulty lies in the length of time that forages traditionally grown on the Prairies can maintain those levels. At one of the earliest meetings in the course of this investigation I was struck by a comment from Dr. Monica Agnusdei from Balcarce, Argentina; who said: *"Any forage has the potential to be an energy-dense forage."* No truer statement could be conveyed, and forms the basis of the proposed grazing strategy deliberated in this report; that being the utilization of combinations of perennial and annual forage species, provided at appropriate plant stages and at strategic points in the beef production model.

There are two real challenges in Canada with using perennial forages in forage-feeding models for growing and finishing classes of cattle in order to attain high levels of performance. The first is the protein-energy imbalance whereby Canadian forages typically supply digestible protein well in excess of the needs of almost every class of grazing livestock during the growing season; at the expense of other more desirable components in the plant. This challenge is echoed by many graziers around the world so it is not unique to the Canadian Prairie environment. The second is for the inherent need to manage these forages in a manner that allows them to store enough nutrient reserves to mitigate plant injury and/or mortality during severe winter conditions. This is accomplished by either extended periods of rest and/or limiting defoliation during the critical (acclimation) period in the 6-8 weeks prior to a killing frost. By providing for periods of rest and grazing these forages at advanced physiological stages, owing to the length of the rest periods, the digestibility of these forages is greatly diminished. While this management strategy is important for maintaining plant health it is a system best suited for mature animals and not feeder or finishing classes of cattle.

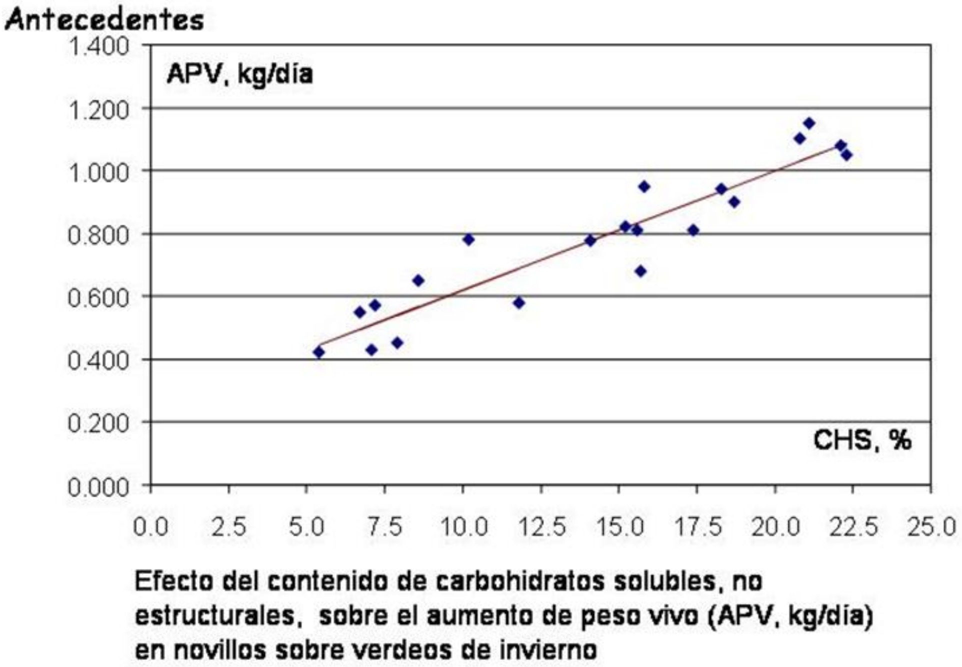
The challenges with incorporating annual forages into this system is that it is necessary to select species that are high-yielding and develop rapidly, owing to the high cost of establishment and the fact that the short growing season only allows for one crop per production cycle. Traditionally, cereals and corn are the crops of choice for this model. Optimal utilization of these species for both yield and quality usually results in mechanical harvesting and storage; in order to capture optimal forage quality and minimize grazing waste. An alternative to this practice, swath-grazing, became very popular across the Canadian Prairie region several years ago. This practice involves the regular production of the cereal crops, mechanical swathing or windrowing, and then leaving the material in the field to be strip-grazed using portable electric fence. There are several advantages to this technique that have been measured scientifically: a) up to $0.50/head/day or higher in reduced feeding costs; b) lower manure handling costs; c) greater nutrient retention in the field; and d) improvements in animal health. However, there is also a significant risk for deterioration of forage quality with material laying exposed to natural elements. Reductions in animal performance, increased forage waste and economic loss are the result when forage quality degrades.

Furthermore, the use of corn and cereals in the feedlot supply chain may come under pressure from two perspectives. Firstly, they may be perceived to be in competition for human consumption as a dietary source of whole grain. This is a debate that will not be addressed in this discussion but is a matter of note to be considered. Secondly and more importantly is the impact on the soil, especially in the case of cereals. Recent research has demonstrated that even under the best soil management practices monoculture short-season crops like cereals are likely neutral at best in terms of sequestering carbon into the soil. Agriculture is at a period in time when the conversation truly needs to be about the regeneration of degraded and infertile soils, as well as about utilizing crop selection and management practices that create net soil carbon storage. Looking at the challenges that lie ahead, conversation about sustainability is not necessarily a sustainable approach, especially if net soil losses are still a risk with current crop production strategies.

Owing to the short growing season and climatic challenges faced by Canadian beef farmers striving to raise and market forage-fed beef, it is apparent that the incorporation of annual forages into a systems-based approach is key to the success of the model. Whether provided under grazing or as stored feed, during and outside the growing season, annual plants offer the best potential for an extended supply of digestible energy in cattle diets. Research and production efforts have been focused in this area in Canada, with some measure of success. However, forage-fed beef production still faces issues in the areas of carcass and eating quality, due to reduced marbling fat content and inconsistent texture as well as considerably longer periods of time on feed than concentrate-fed cattle in feedlot systems. These represent both logistic and economic impediments to the industry that must be overcome to achieve greater market share.

In order to address some of these concerns and to better understand a successful production model a team of researchers and producers, myself included, travelled to Argentina in 2008 to study the entire forage-fed beef value chain. Annual forages comprised a significant component of the Argentine feeding strategy for cattle finishing. However, the approach to forage quality assessment was likely the biggest lesson learned. Graph 1 illustrates the relationship between water soluble carbohydrates (WSC), or simple sugars, and gain of beef cattle.

**Graph 1**. Effect of WSC concentration on steer average daily gain (ADG). Pordomingo, 2008



This single slide changed my perception of forages and immediately directed attention to an entirely new approach; that being how to produce and offer plants with elevated levels of WSC to enhance performance of feeder and finishing classes of beef cattle. I have not had the heart to translate this slide into English owing to the profound effect that it had in coming to this realization. Therefore, to translate, the bottom axis represents plant WSC concentration (percent of DM or dry matter) of cereals being grazed as they advance in physiological maturity to the late milk and early dough stages of kernel development. The side axis represents live weight ADG (average daily gain) of finishing steers in kg/day. Clearly, this is a very impressive and compelling data set that demonstrates a well-correlated and quite linear relationship between the two measured parameters.

It was at this point that I now realize my Nuffield journey truly began.

## *1.1 Objectives of the Study*

In light of the previous discussion that addressed the challenges faced by the forage-fed beef production model on the Canadian Prairies, and in consideration of the impact that plant sugars seemed to have on beef cattle performance; it became apparent that a shift in conventional thinking regarding forage selection and grazing strategies was required.

After some minor experimentation at home with adaptations to the swath-grazing technique, as well as developing numerous hypotheses for improving energy intake into grazing cattle, it became obvious that international expert advice would be necessary to further this strategy. The Nuffield Program turned that dream into a reality and thus began a two-year, eleven-country investigative journey in pursuit of knowledge to seek legitimacy to my suppositions. This journey afforded the privilege of being able to query over 200 experts on these theories, glean data and recommendations, and develop a greater insight into the complexities of the production and utilization of high-energy forages. Early in the study the focus was solely on forages with elevated levels of WSC but it gradually evolved to a greater understanding of the balance of other plant components and the term “energy-dense forage” quickly came to light. Countries visited included: Argentina, Wales, Scotland, Northern Ireland, Republic of Ireland, England, Sweden, Finland, USA, Australia, and New Zealand; as well as consultation with several Canadian experts. As the comprehension of what needed to be achieved and the true potential impact of energy-dense forages became apparent it necessitated meetings and conversations with experts in the fields of: soil agronomy and physiology, plant agronomy and physiology, ruminant nutrition, rumen microbiology, ruminant physiology, genetics, genomics and greenhouse gas mitigation. The findings in this report connect all these disciplines together in a manner that is not often presented.

Their expertise brought the full picture of the pursuit of energy-dense forages into focus; from soil biological health to rumen efficiency to carcass lipid profile and its relation to human health. The production strategy developed in order to provide an in-field forage supply with a sustained delivery of adequate energy, as well as the numerous benefits to the system, will be outlined in this report. While the discussion will focus on a system that is designed for beef production on the Canadian Prairie, information contained within is also applicable to other Canadian environments, as well as to sheep production.

## 1.2 The Canadian Strategy

As mentioned earlier, there is an inherent need to explore opportunities to enhance the productivity of the forage-fed beef model. Based on past experience and the findings from this investigation the strategy being proposed as a potential solution to the challenges faced by the industry is outlined below. It involves a critical shift in conventional thinking as to current views regarding the use of certain species; as well as a change in priorities for forage production and research. Henry Ford was once quoted as saying: *"If I had asked them what they wanted, they would have all said faster horses."* How can anyone argue with the success that came from that philosophy? That being said; in order to initiate positive change unconventional thinking and a new production model are frequently required to effect that change.

Forage-fed beef producers need to consider two key points that form the basis of this report: 1) rethink use of perennial species that can contribute significantly to livestock performance, regardless of longevity potential; and 2) realize that forage quality and livestock performance are the metrics that need to be considered, not yield per unit of land.

- The key to the system is a combination of annual overstory crops and an understory cocktail of 'annual' grasses, legumes, and forbs/herbs.
- All 'annual' crops are to be sown in May, with overstory crop harvest in July, and understory crops allowed to regrow until growth ceases late in the fall.
- Diverse mixes of perennial grasses and legumes are to be rotationally grazed from May to early August, then rested for the remainder of the growing season.
    - Owing to the rest provided during the critical acclimation period, optimal forage quality intake can be targeted with mitigated risk to sward health.
    - Material stockpiled from the last grazing to fall dormancy can be utilized late in the year or be retained for grazing the following spring.
- The overstory crop is to be cut at an immature stage in July, preserved and left in the field as either small square bales or small, individually-wrapped silage or haylage bales.
- Strip-grazing of the stored forage and the high quality regrowth would commence in August and continue until late October or early November, with preserved bales cut open as grazing progresses across the field.
- A diverse mix of select understory crops is critical to realizing the benefits of this model as it is these forages that provide the greatest potential for a sustained, extended supply of metabolizable diet energy to targeted classes of cattle.
    - Utilizing non-traditional perennials that are treated as annuals, in similar fashion to the cover crop concept currently promoted, is the key to such achievement.
    - Also important is the understanding that over-winter mortality will almost exclusively be the norm for the entire populations of these species, and annual re-establishment will be required.

### *1.3 The Canadian Advantage*

While forage production in Canada may seem quite disadvantaged compared to other jurisdictions in the world, the climate does in fact provide some distinct advantages. Although limited by a very short growing season, research outcomes and resultant changes in production practices have afforded producers the ability to extend the grazing of in-field forages to several months of the year. However, there is still opportunity for improvement in this area. The strategy being proposed in this report complements existing management techniques by further exploiting the advantages that the Canadian production environment has to offer in this regard.

Even though long, cold winters demand careful management of perennial forages as compared to other competing production environments they also serve to positively address many issues that are known to be detrimental to forage and beef production in these same countries. Costs for treatment of diseases, pests, and internal parasites are significantly lower for Canadian forage and livestock producers as many of these cycles are broken by the extended periods of intense cold. This allows for the relatively low-cost production, under grazing, of forages that have the potential to be of very high quality. Of additional benefit is the significantly lower requirement for frequent fertilization of grazed forages in the lower-rainfall Canadian climate. Many grazing-prevalent regions in the world are also higher-rainfall environments that are confronted with the necessity of regular applications of supplemental fertility due to leaching. This poses a significant economic and energetic burden on the grazing model, as well as enhances the carbon footprint of the forage-fed production enterprise.

Additional advantages of the Canadian environment over a number of competing jurisdictions are day length and the comparatively cool evenings, owing to geographic location, creating the opportunity for producing forages with highly elevated levels of plant WSCs. In addition to the lengthy photoperiod many regions in Canada are fortunate to experience much higher levels of solar intensity as compared to other countries around the world where conditions are either frequently overcast or fog is often prevalent. This results in a second, distinct prospect for increased rates of photosynthetic plant activity.

The final major advantage to be raised here is in relation to the carbon sequestration potential of the model being proposed. It is a little conflicting to use the word ‘advantage’ in relation to building soil OM (organic matter) because it means that Canadian soils hold this potential only due to long term degradation and diminished nutrient profile. However, such is the case in many of the global soil reserves currently under arable production. The production strategy outlined in this report will establish an annual system that mimics perennial forage swards in terms of total days of plant growth during the season; ideally creating a carbon sink in annual crop land. In addition, there are benefits to perennial forage swards in optimizing their carbon sequestration prospects by providing critical rest periods and enhancing root development and nutrient storage potential.

# 2.0 DISCUSSION AND FINDINGS

## *2.1 Overstory Crop Selection and Management*

As described in section **1.2** the model being proposed involves an overstory cover crop comprised of small grain cereal species as the main component, with the potential for inclusion of legumes as a companion forage. For the purposes of this discussion regarding this production strategy the term overstory crop refers to the cereal crop that is established as an important contributor to both high quality consumable forage yield and also total forage yield under the model outlined in section **1.2**. Traditionally this overstory crop has been denoted as a cover crop when sown as a companion species at the time of establishment of undersown forage species. However, in recent years the term cover crop has taken on an entirely new meaning with the escalating interest in complex species blends designed to augment current mainstream cropping practises as well as to support soil and crop management strategies in organic production. The current terminology as it pertains to the practice of cover crop use is addressed in greater detail in section **2.4**. Not to be confused with the modern definition of the term the cereal companion species utilized under the strategy proposed in this report are characterized as overstory crops.

Production benchmarks for the overstory crop would be targeting seeding in mid to late-May, then cutting and preserving in mid to late-July, with utilization commencing in early August. A minimum 6" cutting height at time of harvest would be recommended in order to enhance forage quality of the cut feed, as well as limit defoliation of the understory crops in order to further their rate of regrowth and production potential. It is necessary for the understory crops to be established at time of seeding of the overstory crops in order for the model to be successful.

The predominant cereal species that would support this strategy are barley, oats, and triticale. All three of these species have been bred and adapted for production in the Northern Great Plains, with specific emphasis at times on use as forages. Cereal rye would not be recommended owing to the risk of allelopathic influence on other plants grown in proximity. Allelopathy is a biological phenomenon by which an organism produces one or more biochemicals that influence the growth, survival, and reproduction of other organisms. Additionally, research has also demonstrated that certain varieties of barley are much more aggressive at the seedling stages; to the point that they are endorsed in systems where they can be used to suppress competition from weeds. These varieties should be avoided. With respect to this it could be suggested that oats and triticale would be the species of choice. Both exhibit slower rates of seedling and tiller development, resulting in a greater period of time for the crop to achieve a closed canopy and thereby ultimately shading understory crops from direct sunlight. With thought to the importance of the understory crops in this model, allowing a greater period of time for establishment before being pressured by reduced exposure to solar energy should enhance survival and productivity of these species. In keeping with that line of thought it would be highly recommended that seeding rates of the overstory cereal crops be reduced by 30-50 percent, thus further reducing competition to the understory seedlings. It is also highly recommended to select cultivars that are both well-adapted for the production region and which also express good resistance packages to crop diseases common to the region. New research is underway in the development of cereal varieties with improved fibre profiles and enhanced digestibility, which would be very advantageous for benefiting livestock performance under this model. These cultivars will most certainly merit consideration as they become available.

Companion legumes could be considered as an addition to the overstory crop. Traditionally forage or field pea cultivars have been selected for this purpose but owing to the intent to repeatedly sow on the same fields over several years it may be that their inclusion is limited due to risk of disease pressure. In order to achieve the full benefit of the model to soil enhancement, and in consideration of the need for fence and water infrastructure to effectively manage the grazing of these forages, the recommendation being brought forward in this report is for long-term inclusion of this practice on degraded or at-risk soils. This will negatively impact the potential for species at greater risk of disease pressure from tight crop selection rotations. With that in mind, fababeans may be the species of choice for this model but their potential under this production strategy remains to be determined. In many jurisdictions around the world fababeans are a common overstory crop in systems similar to this model (from discussion with researchers and producers in the UK, Sweden, and Finland) yet they are not commonly grown in the Canadian Prairie region due to production limitations. However, since they would not be expected to reach full physiological potential under this management scenario, their inclusion is for consideration.

Fertility management will be critical for the success of this strategy. Whether utilizing synthetic or organic fertilizers, or utilizing other means of nutrient import into the fields selected for this grazing system, nutrient balance is well-documented to be very important for plant health and optimal production. Further to the influence of fertility; both over and under-fertilizing, as well as soil nutrient balance, are known to have impacts on plant nutrient composition. With concentrations of digestible plant nutrients being subject to nutrient uptake, soil fertility must be considered as an integral management factor of the model.

It has been explained earlier in this report that the strategy involves the harvest of the overstory crops at an immature stage. This practice has been widely employed in the Northern Great Plains region since the late 1990's utilizing a form of harvest called swath-grazing. This involves windrowing the crops, often cereal monocultures, at a stage when they would normally be cut for dry hay or silage production. This has generally been the milk stage (Zadoks 73, referenced) for oats and soft dough stage (Zadoks 85) for other cereals. Sometime after windrowing the material is strip-grazed with portable electric fences, by various species and classes of livestock, encouraging high levels of utilization and resulting in uniform distribution of residual material across the field. Both of these outcomes are important to the success of the practice. This result is best accomplished by providing enough forage for 1-2 days of utilization at a time and frequent rotation. Research was initiated on this practice by a team at the Agriculture and Agri-Food Canada (AAFC) Brandon Research Centre (BRC) in Manitoba in 1997. Traditionally the strategy was to seed the crop in mid-June, harvest in late-August, then begin grazing in September at a time when perennial pasture yield and quality generally becomes limiting. This has become a very successful strategy in Western Canada for lowering feed costs on cow herds and improving health of weaned calves by reducing time spent in confinement feeding. Significant research efforts in the area are ongoing. One such effort involved the shift of seeding and utilization of the cereal crops to a full month earlier in a production year (Durunna et al, 2014). This provided the opportunity for projected increases in cereal crop yields by allowing for growth and development under more ideal environmental conditions. However the biggest advantage was to allow for utilization of the cereals during the critical acclimation period for perennial forages; thus eliminating grazing and potential injury to these perennial plants during that period when nutrient reserves are being accumulated in their dormancy storage depots. Enhanced plant health, robust root systems, greater over-winter nutrient reserves and the resulting improvements to survivability and longevity are expected gains from this strategy. Anecdotal evidence has revealed increased persistence of species such as legumes or certain desirable grasses and forbs that are most susceptible to winter injury and winterkill in the cold Prairie environment in pastures under good management. This is most evident when extended periods of rest on these swards are provided, especially during the critical acclimation period.

The extension or progression of this strategy that is being recommended in this report is to take the harvest of the overstory crop one step further than a windrow in an effort to preserve the forage quality of the cut material. Research data has clearly demonstrated significant declines in forage quality from environmental impact, especially rainfall events, on material that is left in the swath for extended periods of time. Soluble nutrients, especially plant WSCs, are readily leached from windrowed swaths by precipitation. By preserving and storing the feed in baled form, any WSCs that remain following either Stage 1 drying or fermentation will be maintained as a form of highly utilizable energy for the grazing livestock; as long as further deterioration is limited. Attention must be paid to proper preservation in order to avoid development of moulds or risk of spoilage from environmental impact post-baling. As grazing progresses across the field, these bales are opened up and strings are removed to allow for utilization in combination with the understory regrowth. While having experienced personal success at using small, square bales (35-45 kg) as the storage mechanism (shown in Photo 1, page 10), it was highly recommended that small, round bales of haylage, wrapped in plastic, also be considered for the strategy. Furthermore, regrowth potential of understory crops is hampered by the presence of the windrow; thereby reducing yield of the high quality understory crops.

**Photo 1**. Bale-grazing in oat overstory cover crop and Italian ryegrass understory crop. Rivers, Manitoba 2012

Owing to the high moisture content of the understory forage regrowth the availability of the dry forage may address potential limitations of daily dry matter intake (DMI) that have been known to occur when feed moisture content exceeds 82-83 percent. This theory is supported by many scientists around the world. While not all researchers agree that provision of a dry feed source will improve DMI simply due to management of feed moisture intake, all agree that provision of a secondary feed source will tend to increase total intake. The lower moisture haylage versus wrapped silage bales was the common recommendation from ruminant nutritionists questioned during this study.

Additional recommendations from plant physiologists and agronomists involve the harvest stage of the cereal crop. It was unanimously suggested by all those from whom input was sought that harvest of the overstory crop should occur from late boot stage (Zadoks 45) to heads emerging stage (Zadoks 50), which is much earlier than is currently practiced. The reasons for these recommendations are two-fold. Firstly, in order to preserve a more digestible feed with lower fibre content and, secondly, in order to reduce time of canopy pressure on the understory forages. This will also provide for a longer period of potential regrowth, an important consideration owing to the short Prairie growing season. In appreciation of the recommendation that wrapped haylage (50-70 percent DM) bales be allowed to 'cure' for a period of 14 days before utilization, this also fits well into the production benchmarks of the model, if this is to be the practice of choice for the overstory crop.

However, consideration must be given to the fact that the early harvest stage will provide the opportunity for significant regrowth of the cereal overstory crops, and possibly certain companion legumes. While oats have a tendency to regrow even when harvested at the late milk stage of maturity, and this regrowth can achieve significant yields and reach advanced physiological stages, most cereals do not regrow. For those producers focused on forage-only feeding approaches cereal oat may not be the overstory crop of choice, especially since early harvest stage may often result in regrowth of stems that advance to full kernel development (Zadoks 91-92). It is less likely for cereals like barley and triticale to produce regrowth of stems that achieve physiological maturity; however it may still become an issue for marketers of forage-fed beef. For producers who are not concerned with small amounts of grain intake the potential for kernel development in the cereal regrowth attention must be paid to the stage of development from three perspectives. Firstly, kernel development will result in plants with readily available starch-based energy that can have negative consequences on the rumen. Generally supplementation on grazed systems with concentrate-based diets has not proved advantageous and this may be a concern if a significant amount of grain is on offer. This would most likely not be the case under grazing of annual cereal regrowth but could easily be mitigated to low levels of total DMI by daily rotation if it were of concern. Secondly, metabolizable energy available from these stems would be greatly reduced owing to the prevalence on non-digestible fibres, which would likely result in more refusal and potentially reduced animal performance. In reality, the stems would comprise such a small component of the total DMI that animal performance may not be significantly impacted but post-grazing residues might be higher. Thirdly, from a positive perspective, animals who are being transferred from this grazing system into feedlot for grain-based finishing will be partially transitioned to the change in diet by the exposure to mature kernels, buffering the loss in productivity usually seen in adaptation periods.

While it has been observed that nutrient redistribution of these grazed forages, via manure and urine deposition, is still very desirable in a swath-grazed system it must be noted that provision of the preserved feed may not achieve the same result. As feed is accumulated into baled form nutrients from a large area are resultantly concentrated into the bale. As bale size increases the area of nutrient deposition from animal excretion decreases and surface and soil nutrient concentration is elevated nearer to the point of feeding. This creates a nutrient imbalance across the field and greater risk for nutrient loss from the system. Anecdotally it does not appear that this is a concern when utilizing the small, square bales. If feed is to be preserved as baled haylage then the cost of preservation must be weighed against cost of loss of nutrient redistribution when determining optimal bale size for the system. At this time, no information exists to further expand on this discussion.

Although the concept being introduced in this model is novel to the Canadian Prairies it is a common practice in many European countries. In many cases the overstory cereal crop or crops are often harvested and removed as silage but in some instances these crops are grazed as standing forage. However, utilization rates under grazing may be low owing to trampling losses. Both practices allow for the establishment of the understory crop for future use under grazing in the establishment and subsequent years. The three differences in the Canadian model will be: a) the benefit to leaving the overstory crop in the field as preserved feed (economic, soil-building, nutrient retention and energetics); b) the understory crops will not overwinter in most environments (ergo utilization must be maximized each season and input costs must be minimized as much as possible); and c) the increased energetic efficiencies in the utilization of the in-field forages (to be discussed in more detail in section **2.11**).

## *2.2 Understanding Energy Density in Forages*

Next to water, energy is the most important nutrient required by livestock on a regular basis. Energy supply drives many metabolic processes in ruminants and is derived from the digestion of structural (cell walls) and non-structural (cell contents) carbohydrates, as well as lipids. It is important to understand that the most important end products of the breakdown of carbohydrates in the rumen are volatile fatty acids (VFAs); and that they are the major source of energy for the ruminant (70 percent). With that in mind, and based on the fact that carbohydrates comprise 75 percent of the nutrient composition of dry forages, the greatest potential impact to enhance meta-biological performance and improve rumen function is by increasing the contribution of metabolizable carbohydrates in a forage-based diet.

### 2.2.1 Water Soluble Carbohydrates (WSCs)

Water soluble carbohydrates in plants are the product of photosynthesis, the process of the conversion of solar energy to chemical energy which is then stored in the bonds of simple sugars. While the mechanism of photosynthesis will not be described in this report it will be stated that the process creates a wide range of phytosynthates, compounds produced by the process of photosynthesis, that have important roles in plant health and function. Soluble carbohydrates are perhaps the most fundamental metabolic pool in plants. The organic compounds synthesized as a result of photosynthesis are termed water soluble carbohydrates. They do not have a complex structure and are readily translocated through the plant. Utilized as precursors for numerous compounds, they fulfill a substantial role in higher plant development.

WSCs are comprised of various simple sugars (fructose, glucose, sucrose, etc.), polymerized chains of sugar units called fructans/fructosans in grasses and glucans/glucosans in legumes, as well as pectin, a highly digestible heteropolysaccharide or soluble fibre. While WSCs are found in cell wall contents, pectin comprises part of the cell wall structure, but has the potential to be completely digestible in the rumen, unlike other structural fibres. In all cases, WSC concentration is highly correlated to plant dry matter digestibility (DMD). It has been established that elevated concentrations of water soluble carbohydrates can produce significant positive benefits to rumen function and meta-biological gain. However, according to Dr. Richard Hayes (IBERS), WSC levels in forage need to reach at least 18 percent of the nutrient density (DM basis) in order to elicit a positive impact on livestock meta-biological gain, but even this is no guarantee that benefits will be observed. This performance challenge comes as a result of other influencing factors that will be expanded upon later in the report. As a point of interest the research teams at the Institute of Biological, Environment and Rural Sciences (IBERS) in Wales have set the concentration of 31 percent WSC as a target for their breeding programs, focusing on the advance of plants which they predict to approach optimal ruminal efficiency when grazed.

WSC concentrations in plants are influenced by a number of factors: plant species, plant physiological stage, daylength or time of year, solar intensity, evening respiration rate, plant growth rate, and any plant stressors. Each of these factors, and the degree of their impact, are outlined below.

Plant species has an impact not only on the level of accumulation of WSCs but also the profile of the WSCs. Further to this, recent research from New Zealand has demonstrated that individuals within species can also vary greatly in WSC levels. Physiological stages of plants have a profound impact on WSC concentration in that accelerated growth rates result in high rates of conversion of WSCs to structural fibres as cells divide or grow. When growth rates slow as plants approach physiological maturity WSC levels rise due to increased leaf area for photosynthesis and reduced conversion rates. Daylength also has a significant impact on WSC accumulation owing to the fact that levels increase during the daytime and decrease overnight when the energy from plant sugars is used to fuel respiration. Ergo, production environments further from the equator have a greater propensity to enhance plant WSC accumulation.

As seen in Table 1 solar intensity is also an important factor, and may offset daylength influences in climatic regions prone to such occurrences, since high solar intensity can lead to more rapid accumulations of WSC due to photosynthetic rate exceeding growth rate. Both rate and amount of plant respiration during the evening (a process where sugars are consumed) are a function of two main effects: time and temperature. Canada, with shorter evenings and cooler evening temperatures, is well-suited for the potential accumulation of high levels of WSC in plants possessing such genetic potential; in contrast to other environments in the world.

**Table 1**. Water-soluble carbohydrate concentrations in the herbage of perennial ryegrass after four weeks growth in three different temperature and light intensity regimes. Adapted from Deinum (1966a). (% of dry weight)

| **Day/night temperatures °C** | **Light intensity - cal/cm2/day** | | |
|---|---|---|---|
| | **490** | **350** | **90** |
| 25/20 | 21.2 | 18.8 | 8.2 |
| 20/15 | 26.7 | 21.2 | 7.9 |
| 15/10 | 33.2 | 28.4 | 9.0 |

Plants under stress may bring about elevated levels of WSC as well. The stress could be in any form and can result in growth rates becoming less than the rate of photosynthesis. This is, however, highly variable and dependent on the amount of leaf damage and corresponding plant activity. Lastly, time of year can have a significant effect on WSC levels. Most data demonstrates a great deal of variability in WSC concentrations throughout the course of a growing season, regardless of length of the season. In particular, WSC levels will vary greatly as plants enter into dormancy from nutrient storage triggers like freezing temperatures or waning photoperiod. Once the process of dormancy is initiated energy components like WSCs are translocated to the plant storage depots, which vary greatly from species to species. This process will continue for short periods of time until these storage depots are saturated, depleting leaf-based WSC concentration. Livestock performance gains may be limited for this reason during these periods. At the point of saturation, should growing conditions permit, above-ground WSC levels will greatly elevate as growth has all but ceased yet high rates of photosynthesis can still occur.

WSC concentrations are the most volatile of all the rumen-harvestable energy sources in plants, yet remain the most important. All of the factors outlined above invoke great influence on the concentration of these carbohydrates. In consideration of these factors and their influence on the model being proposed Prairie livestock production is well-positioned to capitalize on the manifestation of enhanced WSC concentrations, especially during the months of August to October. Growing conditions as are experienced in the Canadian Prairie in late summer and early fall are greatly conducive to enhancing WSC accumulation in forages, as evidenced by the following table found in the Chemistry and Biochemistry of Herbage (Smith, 1973).

The data in Table 1 (page 13) are especially related to fructans in grasses, and more so in grass species which are known to accumulate greater levels of fructan, such as ryegrasses. Fructans are polymerized carbohydrate chains, either straight or branched, comprised of fructose sugar units. Fructose is one of the simple sugar monomers (single sugar molecule) produced as an early phytosynthate following photosynthesis. The length of the fructan chain, or degree of polymerization (DP), also has an impact on total plant fructan content; with a resulting influence on animal intake and performance. Generally, longer chain fructans of DP-20 (referring to the number of fructose units) to DP-30 or greater are desirable. Fructan has been shown to increase in plants undergoing either drought or cold stresses. Enhanced fructan accumulation occurs in temperate grasses during cool temperatures, when carbon fixation exceeds plant translocation and utilization. This is due to the fact that fructans accumulate in the vacuole, allowing photosynthesis to continue at cooler temperatures when other storage pools in the plant are saturated. (Chatterton et al, 1988). Fructans are especially important as compared to other sugars owing to their positive impact under grazing due to the way they are degraded in the rumen. This point will be expanded upon later in the report in section **2.3.1**.

As a final generalization regarding plant WSCs, they have been shown to demonstrate very positive benefits in terms of meta-biological gain in ruminants. However, elevated levels of WSCs do not always result in improved livestock performance and results can be inconsistent.

This is, in part, due to the variability in the plant compounds that are replaced as plant WSC concentrations rise. In some cases, proteins decline in order to be replaced by WSC in the nutrient profile. In other cases, WSC concentrations rise as a result of a decline in plant fibre content. Owing to this, it is important to remember that while increases in livestock production (meat, milk, or fat) due to elevated WSC levels in forage can be expected, they are difficult to predict. Consequently, it is important to consider additional sources of forage energy availability.

### 2.2.2 Lipids

The lipids present in forages are predominantly comprised of short-chain omega-3 fats, including alpha-linolenic acid (ALA) or α-linolenic acid. Lipid molecules possess a potential energy supply 2.5 times greater than that of soluble carbohydrate molecules, ergo forages with elevated levels of lipids may be desirable from a ruminant nutrition perspective. Generally, plant lipid content and plant WSC content are negatively correlated, meaning that as the concentration of one increases the other will decrease. However, certain anomalous individual plants have been found within ryegrass lines that do not demonstrate this negative correlation and are being investigated to determine the mechanisms responsible. There is some concern amongst researchers that forages with elevated levels of lipids may result in negative impacts on the accumulation of marbling fat. There is literature to support the suppression of marbling due to increased dietary omega-3 lipids. This suppression comes as a result of displacement of fatty acid deposition into muscle cells versus intramuscular fat cells. However, it is generally agreed upon that only the longer chain omega-3 lipids (discussed in detail in section **2.10**) are prone to affecting this change in accumulation points of fatty acids. Long-chain omega-3's are found in much lower levels in forages than ALA and are essentially just about completely converted in the rumen. Even in forages with enhanced lipid concentration, it is debatable whether the total increase in long-chain omega-3 lipids would result in any measurable impact in carcass quality.

The resulting net benefits to rumen efficiency from high-lipid grasses are currently under evaluation as new cultivars expressing these traits are being developed, although a great deal is known already. Research is ongoing to continue to develop new cultivars of ryegrasses with elevated levels of lipids. In the UK lipid concentrations are generally observed to be in the 2.5 percent (of DM) range and current programs are attempting to produce lines in excess of 4 percent. It is known that lipids are both a high source of available energy and also act as a high efficiency hydrogen sink in the rumen, much more efficient than carbohydrates. In Australia ryegrass lipid levels are very high in the spring (up to 5 percent) but decline to between 3 and 4 percent during the rest of the growing season. With the elevated levels of lipid present in these grazed forages nutritionists express caution against adding fats to supplemental feeds as rumen fermentation of fibre can be impaired when lipid intake exceeds known thresholds of level and content (approximately 5 percent of diet on a DM basis). However, with the elevated concentration of lipids ingested from the forage at intake, it is expected that levels of lipid escaping the rumen intact will increase, leading to enhanced deposition of dietary fats into intramuscular and subcutaneous depots in the animal.

Early research in New Zealand has demonstrated differences in lamb carcass quality due to lipid profile and quantity present in plants under grazing over a range of forage species and at different times of the season. As with protein, lipid content in forages declines with advancing physiological maturity, becoming displaced by an increase in fibre concentration. Therefore, even though lipid content of forages is much more stable than soluble carbohydrates, differences do occur across species, cultivars, stages and times that are known to affect carcass lipid profiles. It remains to be seen whether cultivars with elevated lipid content will express these genetic traits to the same degree in the Canadian production environment, and what impact this might have on livestock performance and carcass quality.

### 2.2.3 Fibre

Digestion of dietary fibre is referred to a 'fermentable metabolizable energy' in ruminants. Decreasing the concentration of indigestible fibre in forages has long been a goal for breeding programs all over the world. Increasing the spread between acid detergent fibre (ADF) content and neutral detergent fibre (NDF) content of forages is an important consideration when trying to provide an energy-dense forage to livestock, especially in terms of the digestible cell wall component of NDF. Researchers with DLF Trifolium, and their partners, have demonstrated up to 30 percent increases in dry matter intake (DMI) due to improvements in digestibility and rate of passage from reductions in concentrations of indigestible plant fibre components. The resulting shifts in rumen volatile fatty acid (VFA) profiles have led to increases in milk production of 6.4 percent and reductions in urine nitrogen excretion (from improved ammonia capture in the rumen) of 4.9 percent when feeding forages with 10 percent improvement in fibre digestibility. There is also a concomitant (associated) benefit to improving plant fibre digestibility as it relates to protein digestive efficiency. Protein available to the ruminant from highly digestible cell fibre/cell wall sources (versus cell content sources) is highly correlated to rumen un-degradable protein (RUP). RUP, or by-pass protein, is that which escapes the rumen intact and is eventually degraded in the small intestine; and is a far more efficient form of protein digestion. Plant breeding efforts are ongoing across the EU to make improvements in forage dNDF (digestible neutral detergent fibre), with the expectation of advances in enhanced protein digestive efficiency as well. Taking everything into consideration it is important to opt for cultivars with these improved-fibre traits, in addition to improved lipid content and elevated WSC concentrations, when determining options for varietal selection. New lines of forage cereals are being developed with improved fibre profiles so these must be considered when evaluating cultivar choices for the overstory crop as they become available. However, no information or data pertaining to these research programs was uncovered during this study. Also of note is that the late-season growth of the forages in this model will tend to be more digestible. The conversion of phytosynthates into fibres generally results in structural carbohydrates with improved digestibility profiles when the transition occurs under cooler temperatures.

## *2.3 Impacts on the Rumen and Livestock Performance*

Providing an energy-dense forage to livestock, versus providing a forage expressing normal levels of metabolizable energy, leads to three major changes in the rumen: a) a decrease in rumen pH; b) a shift in volatile fatty acid (VFA) composition; and c) a shift in microbial populations. All three have the potential to significantly improve ruminal digestive efficiency, from many perspectives, over traditional forage grazing programs in Canada. Extensive investigation has been undertaken, and is ongoing, in the grazing-dominated production systems around the world in order to evaluate the impacts of these higher-energy forages in dairy, sheep, and beef production. While most of the research pertains to dairy and sheep production, owing to the prevalence of these enterprises in those countries, it is considerably applicable to the beef model being proposed in this report. An interesting observation was provided by Dr Jamie Newbold, Ruminant Microbiologist with IBERS in Wales. While the plant breeding efforts of his collaborating colleagues at IBERS focus on elevating plant WSC concentration other subtle, beneficial changes are occurring to plant physical properties. To quote Dr. Newbold's observation: *"Improvements in rumen digestive efficiency are being realized as a consequence of breeding for high sugar grasses, not as a result of it."* What is important to interpret from this statement is that consideration must be given to all components of plant composition that contribute to net available metabolizable energy. Moreover, synergies in whole plant digestibility can be recognized as indirect benefits from a singular breeding and evaluation focus. It is in these indirect benefits that some of the inconsistencies in observed performance improvements under intake of high-WSC grasses may be founded.

### 2.3.1 Decrease in Rumen pH

It has been clearly demonstrated that elevated levels of forage metabolizable energy, particularly in the form of WSCs, result in significant declines in rumen pH levels. The degree of acidity has been shown to approach critical levels but there is overwhelming agreement that energy-dense forages do not readily induce sub-acute ruminal acidosis (SARA). Even though there is evidence that the metabolizable energy provided per kg of DMI almost equals that of feeding small grains like oats and barley, which are known for inducing SARA, acidosis has not been identified in research feeding trials. There are three overlying factors that seem to prevent the onset of SARA as a result of intake of these high energy forages. The first is that, because of simple feed volume, intake may not be as rapid. Secondly, intake of forages requires greater mastication (chewing) for initial processing, thereby increasing salivation and the inclusion of greater levels of saliva in the digesta. Saliva, due to its high pH, acts as a buffer against rumen acidity and therefore contributes to the prevention of the manifestation of SARA. Thirdly, in the case of ryegrasses, the degradation of fructan in the rumen occurs in a manner different than other soluble carbohydrates.

Fructan is the predominant WSC in ryegrasses, and even more so in high-WSC ryegrasses where the fructan is accumulated at proportionally even greater concentrations. It is believed that fructan is degraded in the rumen more like a highly-digestible hemi-cellulose rather than a soluble carbohydrate. What this means is that fructan is not broken down rapidly, ergo does not lead to a rapid release of acids in the rumen and the resultant sudden, significant drop in pH that is associated with SARA; such as known to occur with concentrate-based diets. While many researchers subscribe to the theory that fructans are digested in this manner, research to date has proven unfruitful in determining which microbes are responsible for its degradation. A number of fibrolytic (fibre-digesting) microbes have been evaluated as to their impact on fructans in the rumen but as yet none have been identified. That being said, it is still commonly accepted that fructans are degraded in this manner and will not contribute positively to ruminal acidosis. This is supported by the knowledge that elevated fructose concentrations in feed definitively contribute to ruminal acidosis, yet elevated fructan intake does not, lending credence to the theory that they are degraded by different populations of rumen microflora. Length, or DP, of fructan also has an impact on rapidity of degradation in the rumen as the rate of catalysis (rate of the chemical reaction to degrade the fructan) is affected by the length of the chain. A greater DP, or chain-length, effects an increased time for degradation. As mentioned earlier longer-chain fructans in the forages are more desirable; and this is one of the benefits attributable to that characteristic.

### 2.3.2 Volatile Fatty Acid Profiles

Microbial fermentation breaks carbohydrates down into simple sugars. Rumen microbes use these sugars as an energy source for their own needs as well as to make end products used by the ruminant for meta-biological function and gain. The end products of the microbial fermentation of carbohydrates include the VFAs and gases such as carbon dioxide and methane. As mentioned earlier VFAs are the major source of energy for the ruminant. There are three major VFAs produced by microbial fermentation: acetate (or acetic acid), propionate (or propionic acid), and butyrate (or butyric acid). The ratio of the types of VFAs produced is determined by the type of feed being digested. As they are precursors to several metabolic processes this ratio also determines the course of various metabolic pathways. Volatile fatty acids are absorbed through the walls of the rumen and transported in the blood to the liver, where they are converted to other sources of energy. This energy is used by the animal to perform several critical functions such as: maintenance, activity, milk production, growth (meat and fat), and pregnancy. Understanding the impact of energy-dense forages on the rumen VFA profile is important in understanding the contribution of energy-dense forages to producing desirable metabolites at key points in the beef production model.

Acetate is produced by the fermentation of fibre and thus is normally the dominant VFA in forage-based diets. Generally, high-fibre/low-energy forage diets result in a rumen acetate:propionate ratio of 3.5:1. Acetate is necessary for the production of milk fat so diets low in fibre can result in milk fat depression, which could possibly be a negative consequence for incorporating energy-dense forages into the production model. This is supported by evidence that consistently demonstrates substantial declines in percentage of milk fat when providing grazing dairy cows with grain-based supplements. Propionate is the end product of the fermentation of starches and sugars and is a more efficient energy source for the ruminant. Changes to microbial populations in a propionate-based rumen favour reductions in methane and carbon dioxide production, which translate to lower dietary energy loss. Improving the concentration of propionate in the rumen from 15-25 percent in forage-based diets to 35-45 percent in high-energy diets contributes to increased milk yield and enhanced deposition of body fat. Energy-based diets, as is possible with energy-dense forages, improve the acetate:propionate ratio to 2:1 or lower. In addition, increasing rumen propionate levels augments glucose production in the liver. Adipose (fat) tissue, in particular intramuscular or marbling tissue, requires a glucose-derived fatty acid source. Therefore the impact of energy-dense forage intake should lead to increased potential for marbling. Although not proven yet by science, the concept was supported in discussions with several experts in the field. Butyrate, by far the most minor contributor to the VFA profile in the rumen, can also be slightly increased by diets high in metabolizable carbohydrates. Butyrate contributes to fatty acid synthesis and muscle energy but has a less important role than propionate to elicit benefits from feeding energy-dense forages.

### 2.3.3 Population Shifts in the Rumen Microbial Community

The ruminal microbiome is comprised of four groups of organisms: bacteria, archaebacteria, protozoa, and fungi. All are responsible for some level of fermentation of intake nutrients. In total, over 2000 species of these organisms may exist in the rumen microbial community. Bacteria comprise the greatest population of organisms and thereby have the greatest impact on digestive efficiency. Protozoa, although much smaller in number, are much larger than bacteria (10-100X) in size, and can equal bacterial populations in total mass. Archaebacteria are a collection of microorganisms that includes methanogens and is partially important in the formation of methane from free hydrogen released after the digestion of carbohydrates. Fungi comprise only 5-10 percent of the microbial population in the rumen and contribute to the fermentation of dietary fibre.

There is a big shift in microbial colonization 2-4 hours after the onset of grass digestion. As mentioned previously, intake of energy-dense forages, especially high-WSC grasses, results in lowering of rumen pH levels. This drop in pH effects significant change on the rumen microbial community. One of these changes includes a decline in protozoa. Since the symbiotic relationship of protozoa and archaebacteria are important to the production of methane, increasing rumen acidity results in a reduction in methane emissions. However, there is a trade-off as protozoa are beneficial in digesting cellulosic fibre and a resulting decline in fibre digestion efficiency can occur when rumen pH drops. Rumen microbes that contribute to the increased efficiency of nitrogen capture in the rumen also respond positively to the elevated levels of metabolizable energy from highly digestible forages. Dietary nutrient supply is also essential for propagation of rumen microbe species responsible for the hydrolysis of pectin, a significant source of digestible energy from certain forages. Generally, providing an intake of energy-dense forage to a ruminant causes positive shifts in populations within the rumen microbial community that are beneficial for increased digestive efficiency. In most cases, this effect elicits improvements in live-weight gain, milk yield, milk solids, and/or lipid accretion.

### 2.3.4 Impacts on Protein Synthesis and Nitrogen Recycling

As outlined above, the increase in energy supply to the rumen from energy-dense forages produces an environment that is beneficial to the microbes responsible for improving nitrogen digestive efficiency. These bacteria convert free ammonia, released by the proteolysis (degradation) of rumen degradable protein (RDP), back into protein that can be utilized for meta-biological gain. This process is called microbial protein synthesis (MPS) and has been evidenced to result in significant increases in meat production and milk protein content. If energy is limited, microbes become less efficient at converting ruminal ammonia into protein. Instead, the ammonia passes across the rumen wall and eventually into the liver, where it is converted to urea. Most of the urea is excreted as urine although some is recycled back into the rumen as non-protein nitrogen (NPN) through saliva. It is this recycling that makes it difficult to balance the energy-protein ratio in the rumen, as only intake levels can be estimated. However, data from several institutions supports that microbial protein synthesis is enhanced when the energy:protein ratio is improved. Research from IBERS (Moorby et al, 2013) is demonstrating up to 26 percent reductions in urine-urea concentrations from cattle and sheep fed diets of high-WSC ryegrass versus traditional ryegrass cultivars. Modelling from forage data on the new super high-WSC ryegrasses is predicting the improvements in urea loss to reach 30 percent. Collaborating research groups in IBERS are targeting dietary ratios of 12:1 WSC:N(itrogen) or just under 2:1 WSC:protein. Similarly, researchers in New Zealand, where greater challenges exist to achieve plant-WSC levels as high as in northern hemisphere production environments that are further from the equator, have targeted WSC:protein levels of just over 2:1. Under this scenario, data from Lincoln University in New Zealand (Totty et al, 2013) demonstrates a reduction of urine-excreted urea in the range of 18 percent, as well as improvements in milk yield and protein. These improvements to milk production and quality were echoed by the results from the UK.

However, there is general agreement that although these are realistic target ratios from the perspective of forage production and intake, in terms of rumen efficiency they may not necessarily achieve desired objectives. In some cases protein levels in forages exceed animal demands, and are so high in concentration that even extremely elevated levels of digestible carbohydrates will not result in increased MPS. In these instances no benefit is realized. Such is the case with many Canadian forages where we see elevated levels of protein that are often above requirement for almost all classes of livestock. To compound this, energy supply of Canadian forages is concurrently too deficient for effectively synthesizing free ammonia into protein. Secondly, owing to the unknown contribution of nitrogen cycling back into the rumen via urea in saliva, attempting to balance rumen energy:protein intake ratios may not produce the anticipated result. Clearly though, data does exist that supports positive responses to protein digestive efficiency or nitrogen capture. Choosing plants with the potential for enhanced energy-density and targeting high levels of forage-based energy intake through crop and livestock management is a desirable and achievable goal; even if only limited gains are realized.

In support of this strategy for the Canadian model forage sample data collected at Rivers, Manitoba on October 25, 2014 demonstrates WSC:protein ratios in Italian ryegrass of 2.13:1 and chicory of 1.97:1. In fact, concentrations of WSC and protein in chicory on that date (Table 2) are perfectly aligned with the IBERS ryegrass breeding program targets of 31 percent WSC and 16 percent protein. It is important to additionally note the significantly elevated percentages of WSC concentration expressed by these species in Table 2, which are far superior to traditional forages levels currently utilized in Canadian forage systems. Also of note are the comparably low concentrations of indigestible fibre, expressed as ADF (acid detergent fibre), and the higher concentrations of micro-nutrients in the chicory versus the Italian ryegrass (which will be expanded upon in section **2.4.2**)

**Table 2**. Digestibility of energy-dense forages in late-fall Canadian growing conditions as compared to digestibility equivalents of grain oats and barley. Lardy and Bauer, 1999 and Robins, 2014

| Feed Source | CP % | ADF % | WSC % | TDN % | NE gain Mcal/kg | Ca % | P % | Na % | Mg % | K % |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Oats - grain*** | 13.6 | 14.0 | n/a | 77.0 | 1.22 | 0.01 | 0.41 | 0.02 | 0.16 | 0.51 |
| ***Ryegrass*** | 18.2 | 18.7 | 38.9 | 78.7 | 1.29 | 0.34 | 0.21 | 0.42 | 0.28 | 2.67 |
| ***Chicory*** | 15.9 | 16.6 | 31.2 | 81.9 | 1.35 | 1.42 | 0.23 | 0.62 | 0.48 | 4.24 |
| ***Barley - grain*** | 13.2 | 5.8 | n/a | 88.0 | 1.40 | 0.05 | 0.35 | 0.01 | 0.12 | 0.57 |

### 2.3.5 Livestock Production Benefits of Energy-dense Forages

There is a great deal of data to support stated improvements to animal performance when fed diets of forages with high levels of metabolizable energy. In order to achieve this the focus in the UK has been predominantly on high-WSC perennial ryegrasses, with and without companion clovers. Data from IBERS (Moorby et al, 2006 and British Seed Houses et al, 2012) demonstrates: 6 percent increases in dairy milk production and 16 percent increases in milk protein yield; 20 percent increases in ADG in beef cattle; and 20 percent increases in live weight gains in lambs. To date, substantial improvements to carcass quality have not been seen by feeding high-WSC grass-based pastures. However, significant reductions in time to slaughter have been observed. In contrast to the objectives and strategy of UK researchers much of the effort in Australia and New Zealand emphasizes improving total MegaJoules (MJ) of energy from perennial ryegrass-based systems. This also involves inclusions of herbs such as chicory and plantain in addition to the companion clovers. A New Zealand study (Totty et al, 2013) demonstrated increased milk yields of 12.7 percent, but no improvements to milk solids, in herb-containing mixes versus ryegrass-clover only pastures when provided to dairy cows under grazing. Surprisingly, no impact was observed on milk protein content even though urinary nitrogen excretion was reduced by 18.1 percent. This data supports the concern that energy-dense forages are inconsistent in producing optimal meta-biological performance improvements. However, the reduction in urea excretion through urine did provide environmental benefits to the system that will be expanded upon in section **2.6** later in the report. Lamb data from New Zealand (Kemp et al, 2013 and Somasiri et al, 2013) also supports the previously stated benefits of the herb-based mixes, demonstrating significantly higher gains per hectare even when forage production was lower. Some of this benefit is attributed to the improved energy:protein ratio of the sward due to the comparatively lower protein content of the chicory and plantain.

A point of special interest is that researchers in Wisconsin have ongoing investigations into trying to better understand the relationship of glycogen and rumen microbes. Glycogen is a multi-branched polysaccharide of glucose which serves as a readily available form of energy and is the main form of glucose storage. It is known that fructan and other forms of WSC can be converted to glycogen. Rumen microbes have been shown to store glycogen but it is not yet well understood how and when this energy supply becomes available; nor how this impacts metabolic processes related to lipid accretion and other measurable livestock production parameters. What is known is that this form of energy storage and release is less efficient than other mechanisms owing to the requirement of energy to support the intracellular transfer of the glycogen. It may be that this process is in part responsible for inconsistencies in performance of ruminants being fed high-WSC forages.

It is important to note there are two factors that may negatively impact livestock performance benefits from the incorporation of energy-dense forages into conventional Canadian beef feeding systems. The first is the effect of diet on animal vitamin A levels. Vitamin A is an essential vitamin for several growth processes in ruminants. Grazing cattle are considered to have ample vitamin A stores due to the high intake of carotene found in fresh forages. It is well documented that vitamin A is negatively correlated to the accretion of marbling tissue in cattle. When blood serum concentrations and storage levels of vitamin A in the liver are high marbling is supressed. Studies concluded that stores must be depleted in order to remove the inhibition of vitamin A on adipocyte differentiation in order to increase marbling in beef cattle. It is probable that the replacement of concentrate-based feedlot feeding with the grazing of energy-dense forages toward the end of the finishing period may contribute to lowering marbling scores at slaughter. This can potentially counteract the aforementioned benefits to carcass quality with the intake of highly digestible forages under grazing. The second is the aforementioned contribution of long-chain Omega-3 lipids to the diet in forages with higher lipid content, as discussed in section **2.2.2**. Longer chain fatty acids tend to accumulate more in muscle cells than in adipose tissue, which would detract from lipid accumulation in intramuscular adipocyte cells should they be prevalent in adequate concentration in grazed forages.

## *2.4 Understory Production Benefits and Species Considerations*

Outlined previously, it is important to understand the entire concept of the production and management recommendations for the inclusion of certain forage species that are under-sown in a cereal or cereal-legume crop. The Canadian Prairie environment is challenged by a short growing season and, in addition, soil moisture levels are also often a limiting factor following primary crop production. Other jurisdictions in Canada, and most certainly in other areas around the world, allow for the establishment and adequate growth potential for short-term crops following main crop harvest. Most recently, there has been an up-swell in interest in the use of cover crop mixes for this practice, sown immediately following harvest of shorter term, early-maturing crops; as conditions permit. Leading producers around the world have been incorporating the cover crop concept into their production model for some time. Even, on occasion, as replacement for season-long chemical or tillage fallow. Benefits to soil structure, soil health, available nutrient supply and soil organic matter (SOM) accumulation are well described, although in many cases are anecdotal in nature. These points will be expanded upon later in the report in section **2.7**. The production model being proposed integrates the main elements of the cover crop philosophy, owing to the season-long plant growth and extended ground cover. It provides a distinct advantage over typical monoculture cropping, especially with respect to short-season crops like cereals. The inclusion of understory crops, in particular those that continue to maintain their quality and grow well into the latter part of the growing season, will in fact provide the opportunity for soil regeneration, a superior approach to the current concept of sustainable production.

Efforts have been made to evaluate the cover crop model in Manitoba production systems by researchers at the Brandon Research Centre (BRC) and at the University of Manitoba (Thiessen-Martens and Entz, 2000). Investigators found that timelines were too short and ambient temperature and soil moisture were too limiting to effectively establish and receive benefit from post-cropping seeding of desirable cover crop species, except for a small area of SW Manitoba following harvest of winter cereals. Hence, there is a requirement that any species desired for late-season production following main crop harvest must be under-sown at the time of, or shortly thereafter, sowing of the overstory crop in the spring. From a purely crop production perspective, there is a problem with this strategy as it will likely result in a yield loss in the overstory crop due to competition for nutrients and moisture, as well as the likelihood of restriction of many options for in-crop pest control. It is unlikely that mainstream crop production focused on monoculture cropping and economic yield targets will embrace this strategy; regardless of the long-term benefits being demonstrated. However, this approach will prove successful under a grazing scenario, where producers can accept a slight yield loss of the overstory crop in exchange for the potential of considerably increased yields of total forage due to regrowth of under-sown forages. In 'Systems' research trials at BRC (Legesse et al, 2012) regrowth yields of up to 3-4000 kg/ha were observed in annual ryegrass under-seeded to swath-grazed cereals. This production boost is important in order to offset the annual cost of establishment of these forage mixes. In addition, the high quality of the understory crop, when provided under grazing in addition to the stored overstory crop forage, should result in significant improvements in livestock performance. In the end there will be a compounded economic benefit from both these production gains.

The success of the energy-dense forage beef production model will be realized as a result of the choices and management of understory crop species; and in some cases specific varieties within those species. Following thorough investigation this report will outline the rationale behind the species being recommended, as well as parameters for selecting varieties within those species. In many cases current cover crop practitioners are relying on simple mixes (6-8 species) or complex mixes (15-20 species) in order to achieve desired outcomes, which are mainly focused on soil properties and soil ecology as well as mitigation of erosion and pesticide use. In contrast to those goals the focus of the strategy of selecting species, sub-species and varieties for this model is based on livestock performance parameters, with desired benefits to soil health and soil organisms always an underlying factor. It is important to include grasses, legumes, and other dicotyledonous forbs/herbs in order to realize both improved livestock performance and enhanced soil regeneration. However, it will be important to select key species specific to eliciting positive ruminant digestive efficiencies and physiological responses. The interaction of these species will be targeted for synergistic benefits to both animal and soil. With that in mind, the recommendation from the outcomes of this study suggest one or two grass species, chicory and plantain as herbs/forbs, possibly a brassica, as well as one or two legume species. Although a simple mix in comparison to current recommended cover crop cocktails, the positive results demonstrated should affect a profound improvement to soil over current annual cropping practices, as well as in late-season grazing performance of livestock.

### 2.4.1 Energy-dense Grasses

The predominant grasses with the genetic potential to express significantly elevated levels of digestible energy are the ryegrass (*Lolium*) species. The increase in metabolizable energy derived from ryegrasses comes mainly in the form of WSCs, and in particular fructans, which are regularly significantly higher than in companion or comparative species. Of the differing *Lolium* sub-species, Italian ryegrass (*L. multiflorum/ L. perenne multiflorum*) produces forage with the highest proportions of WSC content. Perennial ryegrass (*L. perenne*), while expressing a measurably lower WSC content, is advantaged over Italian owing to its multi-decade longevity and thus is a dominant forage in many grass-based systems around the world. Italian ryegrass is known to be a relatively short-term forage in these same environments. Hybrid ryegrasses (*L. hybridum*), which are a cross between perennial and Italian cultivars, generally produce greater forage volumes but with a WSC concentration that falls somewhere in the middle of the two parent species. These crosses may contribute well to the model owing to the enhanced growth characteristics from the hybrid vigour. It should be noted that the percentage contribution of each parent to the hybrid cultivar influences WSC accumulation.

However, another hybrid species developed from *Lolium* parentage may in fact be the grass that is best-suited for this model under drier Canadian Prairies environments. Festulolium (*sp. Festulolium*) species are developed by the outcrossing of 4 potential parents: perennial ryegrass or Italian ryegrass as the contributor of *Lolium* germplasm; and either tall fescue (*Festuca arundinacea*) or meadow fescue (*Festuca pratensis*) as the contributor of the fescue germplasm. As with hybrid ryegrasses, genetic potential is expressed based on the percentage contribution of each parent; but more importantly is also dependent on the species of parent. In discussions with several researchers involved in the development and evaluation of festulolium it appears that the hybrid of choice for this model would be a cross between Italian ryegrass and meadow fescue, in terms of WSC production and leaf expression. More importantly so, the preference should be toward cultivars that contain 90-95 percent Italian ryegrass parentage and 5-10 percent meadow fescue parentage. Festulolium hybrids of this origin should tend to produce forage with WSC levels similar to the main parent, develop more extensive root systems than the main parent, and be more efficient at utilizing soil moisture and converting available soil nitrogen to plant growth. Research from Sweden, in environments not too dissimilar to the Canadian Prairie during the growing season, has demonstrated that festulolium tends to establish quicker and exhibits faster rates of regrowth than other forage grasses. Above-ground yield tends to be depressed, as compared to Italian ryegrass, in environments where moisture is not lacking. However, forage growth in drier climates should equal or exceed that of either parent, owing to the deeper rooting potential as a result of the fescue genetics and in part due to hybrid vigour. Italian ryegrass plants will be challenged in low-rainfall jurisdictions or in soils with low water-holding capacity due to the limitations of their shallow root system. The enhanced root development of festulolium versus Italian ryegrass is demonstrated in Photos 2 and 3 (page 26).

The photos displayed represent forage plants after several months of growth and management. Under the model being proposed in this report it remains to be determined as to the differential degree of root production between Italian ryegrass (or other ryegrass species) and festulolium cultivars as annual seedlings in Canadian environments. Demonstration trials of festulolium cultivars in the Eastern Prairie have shown positive results during the establishment year in the past, so it is may be that vigorous root development played a role in this success.

**Photo 2**. Italian ryegrass roots being evaluated in rooting greenhouse at IBERS. Aberystwyth, Wales, 2013

**Photo 3**. Festulolium roots being evaluated in rooting greenhouse at IBERS. Aberystwyth, Wales, 2013

Photo 2 represents typical rooting development of Italian ryegrass plants under normal growing conditions, exhibiting shallow penetration into the soil profile and minimal density. In contrast, the festulolium roots portrayed in Photo 3 demonstrate a completely different growth habit. This particular hybrid in Photo 3 is comprised of 95 percent Italian ryegrass parentage and 5 percent meadow fescue parentage. Fortunately, commercial varieties of festulolium with such ancestry are currently available. As is clearly evidenced by the photo the contribution of the rooting potential of the fescue genetics, combined with the hybrid vigour from the crossing, has resulted in a cultivar that expresses significantly enhanced root development in terms of depth in soil and total density through the profile. This superior rooting capability will buffer against drought-related growth stresses as well as offer greater potential for carbon sequestration, owing to the increased production of structural root mass.

Another important genetic influence to consider is whether ryegrass varieties are diploid or tetraploid. Diploid varieties possess 14 chromosomes in the nucleus whereas tetraploid varieties contain double the content of genetic material in the nucleus with 28 chromosomes. Diploid cultivars are the focus of many breeding programs in the world due to their more basal growth habit versus tetraploids. This is an advantage in high-rainfall environments where ryegrass species, especially perennial ryegrass, dominate all pastoral systems as diploids tend to be more sod-forming than tetraploids. In frequently saturated soils, which do occur in some Canadian environments, this structure better supports the weight of grazing livestock and mitigates pugging or poaching (where the hoof breaks through the sod layer, resulting in injury to plant crowns and long-term sward damage). In high-moisture environments in Canada, diploid species may be preferred and as such producers should seek out varieties of super high-WSC ryegrasses that are commercially available. Generally these will be perennial ryegrass cultivars, owing to the region of development as the major scope of the breeding programs that have advanced these super high-WSC lines is primarily focused on perennial ryegrasses.

It is unlikely that any of the grass species listed in this section will survive and remain productive in the Prairies beyond the establishment year, hence the need for their incorporation into the model of annual re-seeding being proposed. However, there are regions in Canada where multi-year survival will be possible so perennial ryegrass may present a good option for those producers.

In terms of Italian ryegrass cultivars, there are a number of commercial varieties available that are either of diploid of tetraploid genetic base. Tetraploid varieties offer some advantages over the diploids and are best-suited for the purposes outlined in this report. Tetraploid species tend to be more aggressive in the seedling stages and also produce more upright growth, both of which are important factors that contribute positively to their establishment and production as understory crops in this system. Their difference in physiology as compared to diploids also commonly results in higher protein concentrations and lower fibre content. In addition, tetraploids tend to be more efficient at converting sunlight to plant energy via photosynthesis. In simple terms, tetraploids possess twice as much genetic material, resulting in a larger nucleus and hence a larger cell, which contains more chloroplasts and effects greater photosynthetic activity. This is evidenced in the variations in forage colour in breeding plots at the Agri-Food and BioSciences Institute (AFBI) cultivar evaluation center; as seen below in Photo 4.

**Photo 4**. Diploid and tetraploid ryegrass evaluation plots at AFBI. Crossnacreevy, North Ireland, 2013

The plots exhibiting the deeper tones of green are tetraploid varieties, whereas the lighter-coloured plots are diploid ryegrass varieties. At first glance it would appear that Photo 4 is actually a forage fertility trial owing to these variations in leaf colour. However, the distinct differences are solely as a result of genetic background. Regarding additional consideration of the advantages of tetraploid versus diploid it is important to note that most hybrid cultivars of ryegrasses, and of course festulolium, tend to be tetraploid-based owing to the greater ease for crossing. With that in mind, these hybrids should be advantageous to the Canadian production model. In some cases, diploid varieties of ryegrass have been converted to tetraploids and anecdotal information has indicated marked improvements in production metrics. While tetraploids are generally known to have poor grazing tolerance this is not an absolute and large gains have been made in this area through selective breeding. Regardless, when considering annual establishment and no need for overwinter concerns under the energy-dense forage model being proposed, grazing tolerance becomes a non-issue as they will be subject to one-time defoliation only.

### 2.4.2 Chicory

Chicory (*Cichorium intibus*) is a short-lived perennial herb of Mediterranean origin that is cultivated around the world for both human and livestock use. It is generally a summer-active plant but some varieties are known to express some winter-active properties. It is valued for its leafy above-ground growth as both human food and ruminant forage, as well as for its aggressive root system with high concentrations of WSC. These characteristics are clearly evident below.

**Photo 5**. Chicory plant 90 days after establishment. Rivers, Manitoba, Canada, 2014

Chicory forage is readily accessible to grazing animals, owing to the nature of leaf expression as evidenced in Photo 5 (Page 28). However the greatest benefit of the chicory root is in its ability to facture hard soil. As a component in a mixed sward this is highly beneficial to address issues related with soil compaction that have been seen to occur in either poorly-aggregated soils or resulting from equipment and grazing traffic.

Differing from ryegrasses in terms of WSC profile, chicory leaves tend to accumulate high levels of simple sugars, and not polymerized chains of fructans. Although lower in WSC concentration than Italian ryegrass, chicory has often been shown to produce higher levels of WSC in comparison to traditional perennial ryegrass cultivars. Digestive advantages over other species also include: lower total fibre content; a more beneficial ratio of digestible:indigestible fibre; and generally a more desirable energy:protein ratio (as previously discussed in section **2.3.4**). Interestingly, chicory roots can also be harvested for use as a fructan supplement for humans owing to the high degree of accumulation comparable to other species.

Extension information out of the United Kingdom and Australia indicates that chicory is normally very high in metabolizable energy (ME), estimated at 12-13 MegaJoules (MJ)/kg or approximately 80 percent total digestible nutrients (TDN). This is supported by the analysis of forage quality from Canada reported in Table 2 (page 21) in section **2.3.4**. Neutral detergent fibre (NDF) analyses, which can negatively impact total feed intake, demonstrate chicory forage in the range of 18 percent (DM basis), which is very low by most forage standards. Research from several sources indicate that chicory forage has a high voluntary intake compared to other species. This is due, in part, to readily accessible leaf material as mentioned earlier. However, more importantly, it is due to the lower total fibre content and the improved fibre digestibility of the forage. Chicory nutrient profiles contain levels of pectin which are much higher than other companion forages such as ryegrass, although much lower than the contribution of pectin to the total fibre profile in plantain. Pectin, although a structural heteropolysaccharide, is a very readily digestible structural carbohydrate contained in the cell wall. Potentially 100 percent digestible under ideal rumen conditions, it is considered to be an excellent source of digestible plant energy. Hoskin et al (1995) demonstrated that red deer spent significantly less time ruminating (only 12.2 percent of time as compared to ryegrass) when fed a diet of fresh chicory forage, indicating improved fibrolytic digestion in the rumen. The increase in digestive efficiency and resulting reduction in rumination affected a higher rate of passage and greater intake potential.

Chicory has also been shown to be a very efficient scavenger of soil minerals and often results in forage of greater nutrient density than companion species. Whole-plant forage analysis results reported in Table 2 (page 21) section **2.3.4** validate the assertion that chicory forage is more mineral-rich than ryegrass, with 1.5 to 4-fold increases in several of the nutrients measured. Even though it does respond positively to increasing nitrogen (N) supply, research from Australia (Li, 2011) indicates that chicory plants possess a superior ability to scavenge soil mineral nitrogen. As a result companion legumes often fix more atmospheric nitrogen to compensate for the accompanying depletion, leading to greater soil fertility efficiencies. Following sward removal, chicory pastures were also shown to mineralize at a much faster rate than legume (mainly alfalfa) pastures for the first 6 months. How this will contribute to mineral N supply in subsequent years under the model proposed in this report remains to be seen. However, the fact that chicory plants will likely not survive past establishment year should result in improved mineral N supply in successive crops based on this data. Other positive attributes to chicory include the ability to survive up to 14 days of inundation from excessive surface moisture and that it is relatively unaffected by plant pests, especially as compared to other dicotyledonous forage species. Chicory is also a natural anthelmintic, with clear evidence demonstrating significantly reduced faecal egg counts (FEC) in chicory-based versus grass-based pastures in zero-grazing trials (a research method whereby fresh forage is harvested and fed in pens under strict intake evaluation). However, this effect has only been demonstrated in sheep, goats and deer with little evidence to support the benefit to cattle (Marley et al, 2014).

There is conflicting data around the world on the inclusion of chicory in traditional ryegrass or ryegrass-clover pastures. In some environments distinct advantages have not been observed by including chicory at the time of sward establishment. Substantial improvements in terms of forage yield, livestock performance and carcass quality are not often quantified; even though significant differences have been observed in available forage quality. These results have mainly been reported in data from the United Kingdom whereas trials in Australia and New Zealand have shown many positive responses to herb-based pasture mixes containing chicory. The main difference may be due to the inclusion of plantain in herb-mixes in the southern hemisphere versus northern climes, although some studies with chicory-only treatments also presented significant benefits. Data from Kemp and other researchers in New Zealand trials revealed improvements in both forage yield and livestock performance. In fact, livestock performance was so improved in herb-based versus traditional ryegrass-clover pastures that lamb gain per hectare was superior even when forage growth of ryegrass-clover pastures exceeded that of the herb-based pastures.

In short, chicory was strongly recommended by many experts as a valuable inclusion to the understory component of this production system. It is an advantage that the plant will actually not survive past the seedling year in most Canadian situations. One of the challenges with chicory in many environments where it persists as a short-term perennial is its rapid progression to reproductive stages in the years following establishment. Owing to the fact that the growth pattern of chicory does not match well with ryegrass species, it becomes difficult for grazing managers to optimize quality and productivity in these systems. It is for this reason that plantain is the preferred companion forage in these systems. There will be jurisdictions in Canada where this may become an issue should chicory persist past the seedling year. In the Prairies, the plant should remain in a vegetative state following establishment each year, resulting in optimal utilization and anticipated livestock gains under the model being proposed.

### 2.4.3 Plantain

Narrow-leafed plantain (*Plantago lanceolata*), or ribgrass as it is commonly called, is a popular forage species in certain production regions of the world. Not to be confused with broad-leafed plantain (*P. major*), which is common weed in certain environments, narrow-leafed plantain has shown great benefit in herb-based pasture mixes. *P. lanceolata* exhibits a more upright leaf expression than *P. major*, allowing for efficient foraging harvest. The leaves of ribgrass are shaped similarly to those of chicory, in that the narrowest section of the leaf is at the base and then widens further from the crown, enhancing grazing efficiency. Ribgrass, as with chicory, is higher in sugars than other forb species and will be selectively grazed owing to its high palatability. Data from New Zealand indicates that including plantain in a mixed sward can improve intake rates by as much as 30-35 percent over traditional grass-based pastures. This advantage is in part due to the high palatability and ease of intake as a result of leaf shape and placement; but can also be attributed to increased rumen outflow rates because of the high level of digestibility. Ribgrass, like chicory, is comprised of high levels of WSCs and readily digestible fibre. The main difference between the two is that narrow-leafed plantain contains much higher levels of pectin, requiring a good supply of dietary nitrogen to support rumen microbial populations necessary to degrade the pectin.

It is recommended that companion legumes are included in all herb-based pasture mixes containing plantain to ensure an adequate supply of dietary nitrogen. As with chicory, plantain is also nutrient-dense, rich in mineral content and responds well to increasing levels of fertility. Although plantain has a coarse, fibrous root system as compared to chicory, it is still very efficient at scavenging soil minerals. While not as effective at addressing soil compaction, plantain does possess the ability to establish and develop an extensive root system in very hard, low OM, infertile soils, which would be a distinct advantage over other species. It differs from chicory in its ability to rapidly recover from drought-induced partial dormancy but is similar again in that both herbs store more above-ground nitrogen in the form of proteins versus nitrates, mitigating the risk of nitrate accumulation and toxicity concerns in stressed plants. Plantain, like chicory, is not very active for the first 50-60 days following seedling establishment but then begins to grow rapidly. This growth habit makes both species a good fit as understory forages in this model, whereby the overstory crop canopy is recommended for targeted removal around that time.

Narrow-leafed plantain is also a more winter-active plant than chicory, which may result in greater late-season production of high-quality forage. Another big difference between the two species is the presence of active diuretic compounds in plantain that are not found in chicory. These secondary plant compounds encourage greater rates of water intake, resulting in higher kidney weights in slaughter animals and increased rates of urination in animals grazing plantain-based swards. The increase urination rates dilute the concentration of urea in urine patches to the point that urine spots are not often visible in under-fertilized pastures containing plantain, in comparison to traditional grass-based pastures. Research is ongoing to further knowledge of this observation as it relates to the animal, the soil, and environmental influence but it is important to note that to date there have been no impacts to animal health detected. Some of this work involves the feeding of plantain-based silage, both pit-preserved and bale-preserved, as early trials of silage-fed plantain are demonstrating a decrease in urine-urea levels of up to 50 percent.

**Photo 6**. Plantain plant from Agricom plots at the Marshdale Block Farm. Oxford, New Zealand, 2014

It should be noted that both chicory and ribgrass are listed as secondary noxious weeds under the Canadian Weed Act although both are well-accepted forages in many parts of the world and are already found in some parts of the country. It does not appear at this time that this will have a negative impact on the ability to import seed and pursue the inclusion of these herbs/forbs in this grazing strategy. Owing to their tremendous potential to support the model proposed it is hoped that this will not ever be a barrier to their addition in the understory sward.

### 2.4.4 Legumes

The presence of legumes is important in any diverse ecosystem, from their positive impacts due to nitrogen fixation to numerous benefits regarding soil properties that are all very well documented. It is inherently important that a component of the understory plant mix be some form of legume or legumes that are well-adapted to the environment and to the production model. Legumes, while being rapidly degradable, offer less total digestibility than other companion species like the grasses and forbs outlined in this report. As such, and also taking into consideration that legumes often express higher levels of protein in comparison to other digestible plant components, it is recommended that they comprise only a small portion of the understory plant mix. It is likely that 20-25 percent of the species composition, as above-ground biomass, should be sufficient to provide adequate benefit in all areas, including as a source of dietary nitrogen to assist with complete degradation of pectin in the rumen. However, that number remains to be determined under this model in the Canadian production environment.

While red clover is a highly-touted species in many production systems, and the focus of significant research efforts all over the world for agronomic improvements, it does not appear to be a good fit for this production model on the Canadian Prairie. Based on personal experience to date, it has not exhibited the potential to contribute in an effective manner to achieve desired results. Forage agronomists consulted during this investigation supported the concept of annual legumes as a fit to the strategy. Numerous annual legumes have been trialed in varying regions of Canada with mixed results over that time. Some of these different sub-species include crimson clover (*Trifolium incarnatum*), persian clover (*Trifolium resupinatum*), berseem clover (*Trifolium alexandrinum*), arrowleaf clover (*Trifolium vesiculosum*), and balsana clover (*Trifolium michelianum*) to name a few. Of late, some advancements to the balsana sub-species under North American breeding programs would suggest that it is a viable option in environments that are the focus of this report. However, it must be noted that with all these non-traditional legume species sourcing an appropriate, effective supply of inoculant in Canada presents a major challenge to their inclusion in the production system. Without an effective inoculant to ensure nodulation many of the beneficial effects of the legume are lost. Other options include biennial legumes like sweet clover (*Melilotus officinalis*) and hairy vetch (*Vicia villosa*), which would remain vegetative during the establishment year and may actually better serve the model in terms of adaptability. In the case of both the sweet clover and the hairy vetch, establishment and biomass production do not appear to be of concern in most Canadian environments, furthering value to their consideration. An additional advantage to hairy vetch over other legumes is the accessibility of viable inoculants; whereas sweet clover is so widely adapted to the Prairies that an inoculant is likely not even required to achieve nodulation. In contrast, many of the annual clovers listed above can be quite inconsistent in terms of establishment and forage production when growing conditions are less than ideal; especially more so under the pressure of an overstory crop canopy.

### 2.4.5 Brassicas and Other Fodder Options

Various types of brassicas are utilized as forage species in many grazing systems around the world. Examples of these include kale (*Brassica oleracea*), forage rape (*Brassica napus*), and pasja (*Brassica campestris*) which is a bulb-less turnip. Kale-forage rape hybrids are also commonly grown. The leaves of brassica plants are very highly digestible. While only mid-range in WSC concentration they are very low in indigestible fibre content, resulting in an ME of 13-14 MJ/kg or well over 80 percent total digestible nutrients (TDN). However, it is recommended that total intake of these forages be limited to no more than 5-6 kg DMI per day so as not to lead to any metabolic disorders. The brassicas are also more prone to disease pressure and insect damage than other dicotyledonous species like chicory, plantain, and legumes. They also tend to accumulate higher amounts of nitrate in the leaves as compared to other species. With that in mind brassicas are at greater risk of nitrate accumulation under stress-induced growing conditions, thereby resulting in heightened potential for inducing nitrate toxicity in grazing animals. The benefits and risks associated with the inclusion of these species in the understory mix need to be carefully considered against the production environment. These considerations include soil fertility as brassicas tend to perform poorly in terms of biomass accumulation under low fertility environments. In contrast, when subject to adequate to excessive nutrient supply for optimal growth stimulation, brassicas are at greater risk for nitrate accumulation. Fertility balance is critical to the successful inclusion of brassica species in this model.

Other brassicas like true turnips (*Brassica rapa*) and swedes (*Brassica napobrassica*) will not work in this model or in many parts of Canada owing to the length of season required to achieve full economic production potential, as well as the inability to compete with other species. Simply put, they are just not economically or productively viable as an option for production in much of the Prairie environment. It may be that certain regions in Canada can consider them as a grazing option, but the benefits to soil and environment from this model will not be realized. Radish, and in particular tillage radish (*Raphanus sativus*), may be another option as these plants are proving adaptable and viable in many situations as cover crop options to address soil compaction. However, their value as a grazing forage (leaf material and above-ground bulb) is not well documented.

## *2.5 Supplementation*

As discussed earlier the importance for a sustained supply of energy, both in the suckling calf and in feeder/finishing classes of cattle, is an important requirement for efficiencies in the beef production model. While the genetic and production potential for energy-dense forages does exist for adoption into this model, it is critical to accept that forages alone will not meet dietary requirements for desirable performance improvement at all times. Ergo, the necessity for supplementation is a matter that needs to be considered as a support practice for the model. Supplementation can be defined in two ways: true supplementation and substitution. The goal of supplementation should be to provide a secondary feed source that enhances targeted improvements in meta-biological gain. In the case of true supplementation the provision of a secondary feed source triggers additional daily dry matter intake (DMI), ideally resulting in net benefit owing to the additional intake of nutrients. In the case of substitution time spent grazing and DMI from grazed forages is displaced with supplementary feed, which can result in large variations in intake and performance response. In many situations substitution feeding on pasture is practiced to address issues of forage quality that do not support targeted performance levels, or in order to address forage shortfalls (current and future) based on DM plant yield. There has been an enormous amount of research conducted into supplementation strategies in all grazing environments and the approach to supplementation is as varied as the results of animal performance. Outcomes also demonstrate wide variation in economic benefit to the act of supplementation under grazing. While performance enhancements can regularly be observed, often it comes at a cost (including both value of feed and feed delivery) greater than the economic gain of the improved performance. Generally there are other drivers that necessitate the need for supplemental feeding on pasture that overly this financial burden. That is why the need for novel and strategic supplementation strategies to support this model must be considered and investigated.

This report will address supplementation from both perspectives listed above as it pertains to two components of managing rumen intake. Firstly in order to consider issues related to high moisture content of intake forages. Secondly, with the aim to address the need for increased energy supply to the rumen so that targeted performance parameters are met. It will also deal with the approach of supplementation/substitution from a wholly forage-based method to one that incorporates the provision of feedstuffs that do not meet the criteria of a grass-fed beef label.

While there is no consensus on the matter, the majority of the scientific community consulted tend to agree that managing for feed intake moisture level is a critical first step in ensuring desirable DMI and good rumen function. Under grazing, plant moistures can often exceed 82-83 percent moisture at consumption. It is at this point where many scientists and pasture managers agree it is critical to incorporate some form of management strategy (i.e. provision of a fibre source) in order to mitigate performance decline. However there are some experts who have evidence that no impact is observed; but usually in high rainfall, high fertility environments where immature high moisture forage is frequently on offer. This would indicate that the rumen can adapt to these conditions without production losses, but it is likely a factor of time. In situations where plant moisture levels surpass the 82-83 percent threshold for brief periods only, there is likely merit to managing for intake moisture as this change should negatively impact rumen function. Under certain grazing strategies, mainly with perennial forages, this challenge is addressed by ensuring a source of low quality residual standing material carried over from previous grazing events. While this approach works quite well for certain classes of livestock, it will not meet the needs of a program targeting elevated levels of forage energy intake at key points in the beef production cycle. Offering a dry source of high quality feed to animals grazing forages lower than 17-18 percent DM should result in performance benefits, including additional intake. Provided in the correct manner, this practice should result in true supplemental feeding, boosting total feed intake and nutrient capture and translating to real economic gain.

Some researchers have hypothesized that the provision of dry hay is also buffering the pH in the rumen, resulting in a more beneficial rumen VFA profile and enhancing the harvest of plant-based energy from the fibre component of the grazed forages. Under the production model outlined in this report, the provision of dry supplementary feed could be offered in May-Jul when the lush, immature perennial forages being grazed exceed the moisture threshold. It has been surmised that offering this dry feed in a chopped form versus as intact hay might result in better rumen mixing and improve the efficiency of the practice. The act of preserving the overstory crop in-field as either dry small, square hay bales or wrapped haylage bales under Aug-Oct grazing in this mixed species system will also provide such a buffer; should the moisture content of the understory forages approach the critical threshold.

Feeding trials in New Zealand have demonstrated that grazing animals will actively seek out silage and haylage under all grazing conditions, even when fresh pasture is newly provided. Results vary as to whether this is true supplementation or some substitution is occurring but knowing that grazing animals will look to intake of sweet feeds like silage and haylage is an essential point to deliberate when formulating a supplementary feeding strategy. This is especially important when considering round bale haylage as the preserved feed option for the overstory crop. Many dairy operations around the world offer silage as an additional feed source to address pasture moisture concerns when grazed energy supply is deemed adequate; and concentrates or similar feed mixes are added when it is not. In all cases where a feed drier than the grazed forage is to be provided, the resounding recommendation is that it be of the highest quality possible and, where applicable, attempt to balance the energy:protein ratio of the diet. It is also recommended to use a feed source that is not rapidly digested, in order to best complement the highly digestible plant material being consumed under grazing. Concentrate-based feeds were universally not recommended as a supplementary feed source when grazing high-quality, high-moisture forage, owing to their rapid degradation in the rumen and the possibility of inducing sub-acute ruminal acidosis (SARA).

There are a host of products and rations employed around the world to boost energy intake to grazing animals. These include, but are not limited to: small grains; corn; corn gluten; beet or citrus pulp; silages; dry hay; lipids; oils; molasses; various plant products (hulls, pulps, algae, extracts, etc.); products containing sugar; various by-products from other industries (DDG, meals, cakes, etc.); and yeast-based probiotics. There was general agreement that provision of ionophores would be of no benefit to the system. As mentioned earlier, many trials have demonstrated that concentrated-based feed supplementation under grazing offers no real economic benefit. The situations where this practice is implemented usually occur when pasture quality and/or yield is well below animal requirement. In these cases, like maintaining milk production in a dairy operation or in lactating animals facing severe forage shortfalls, the priority is for the preservation of production levels and economics becomes less important.

However, the exception to this may be the development of partial mixed rations (PMRs) at the Ellinbank Dairy Research Centre in Victoria, Australia. After evaluating various supplementation strategies and mixed rations over the years, researchers at Ellinbank discovered that replacing wheat with canola meal in the ration led to many positive benefits. Past efforts with supplementation under grazing led to reductions in milk yield and milk fat content in almost all cases. This is supported by similar research around the world. The Ellinbank PMR consists of ground alfalfa hay, corn silage, ground corn and barley, and canola meal. Feeding the PMR post-milking twice daily has resulted in changes to animal grazing patterns following feeding. Generally, when using concentrate-based feeds, animals feel satiated post-feeding and do not graze for extended periods when turned out after milking and feeding. With the change to a PMR ration it was observed that cows commenced grazing immediately upon turnout. Cows were also observed to graze at the same rate, so grazing behaviour was not impacted in that regard. However, time spent grazing increased significantly, resulting in large increases in DMI. According to Wales et al (2013) the provision of a PMR versus traditional rations stimulated an increase of DMI from 20 to 25 kg/cow/day or from 3.6 to 4.5 percent of body weight. It also resulted in increases of energy-corrected milk yield due to no negative impact on milk fat concentration. The work of Auldist et al (2014) supported these findings.

On a different note, recent research around the world has investigated the use of many sources of feed energy for the purpose of reducing enteric methane emissions. Molasses, essential oils, glycerin, algae (both high in WSC and high in lipid), and sugars have all been investigated, with work ongoing in many Institutions. As an example, an increase in 1 percent dietary fat has been demonstrated to reduce eructated methane by 3 percent. Although methane emissions represent a loss of digested energy from feed intake, reducing enteric methane production does not necessarily translate to observed meta-biological gain in most cases. In addition, methane mitigation and dietary energy supplementation with lipids is limited by the threshold of lipid rumen content before function is impaired. However, providing additional feed energy in these forms may provide dietary benefit as a source of energy to support fat accretion as well as improve nitrogen capture in the rumen. While lipid and sugar-based feed supplements are expensive additions to a ration as compared to starch-based concentrates, there was general agreement that they would affect less negative impact on the rumen than starches when used to supplement high-energy forage grazing. Having said that, some of these additives have demonstrated negative impacts on intake and other performance and quality measurements; whereas others have shown some promise. This is a very new field of research and much remains to be learned.

In summary, supplementing with highly metabolizable and compatible feedstuffs has potential to be of benefit in complementing the grazing of energy-dense forages. In time, research will determine delivery strategies, as well as the cost:benefit analyses of their inclusion in supplementation or substitution diets.

## 2.6 Impacts on Greenhouse Gases (GHGs) and the Carbon Footprint

This section of the report will address all three GHGs that have been identified as responsible for affecting climate change: methane ($CH_4$), nitrous oxide ($N_2O$), and carbon dioxide ($CO_2$). Agriculture has been targeted as a significant contributor to emissions and is the focus of enormous international effort, and disagreement, to quantify its role in global emissions and capture. Animal agriculture in particular has been targeted at various levels as a net emitter of GHGs and, as such, efforts to mitigate emissions are being investigated and enacted by the industry in an effort to curb concerns. Information gathered during this study will examine the potential for energy-dense forages to contribute positively to the mitigation of GHGs and the reduction of the carbon footprints of the current Canadian feedlot and grass-fed beef models.

A recent assessment of the GHG emissions from the Canadian beef production systems currently in place demonstrated that the cow-calf enterprise accounts for 80 percent of the national beef total, with the other 20 percent comprised of feedlot enterprises. This same model predicted total emissions of 22 kg $CO_2$ equivalent per kg of carcass production. American modeling of their beef production systems resulted in emission predictions of 21.7 kg $CO_2$ equivalent per kg of carcass production, not surprising owing to the similarities in our climate and production methods. Comparable results from Ireland, with a greater emphasis on grass and forage-based beef production, predicted a range of 7.6-11.3 kg $CO_2$ equivalent per kg of carcass production. This was based on beef slaughter at younger ages similar to North American systems. However, when the Irish model predicted emissions out to 24-month slaughter times (which is more often the case according to Crosson et al, 2006) the number rose to a range of 25.3-37.7 kg $CO_2$ equivalent per kg of carcass production.

There are two lessons to learn from evaluation of these results: a) higher quality or denser energy pastures have the potential to mitigate $CO_2$ intensity in the cow-calf enterprise, even if instituted for only short periods of time; and b) it is important to reduce time to slaughter in forage-fed beef animals. The authors (Beauchemin et al, 2010) also concluded that feeding grain to ruminants may be a questionable practice in the future due to direct competition for human consumption. This underlines the importance pursuing alternative strategies to the Canadian beef production model, lending credence to the strategy being proposed in this report. The use of energy-dense forages has the potential to significantly reduce enteric methane emissions as compared to traditional forages and grazing strategies. Data from IBERS has clearly shown that the elevated WSC content in the forage elicits a positive response to rumen pH and VFA profiles that translates to 20 percent reductions in enteric methane emissions per unit of feed intake. This figure has been determined in numerous trials using the zero-grazing technique, whereby freshly cut forage is harvested and fed to livestock (sheep and cattle) housed in methane collection chambers. Although animal intakes using the zero-grazing method often realize only 90-95 percent of DMI measured under true grazing conditions, the methodology is an accepted experimental technique.

In that a 20 percent reduction of emissions is an impressive accomplishment, it is important to consider that total DMI often increases under grazing of high-WSC grasses and other energy-dense forages, to the point that total daily animal emissions are reduced to an amount lesser than 20 percent. Having said that, by incorporating energy-dense forages into the Canadian system substantial reductions in total beef emissions can be realized when considering three important factors. Firstly, via the use of these forages in the cow-calf phase of production, when the suckling calf is still on the dam, as outlined earlier in the report. Compared to traditional lower-energy pastures using these forages for three months each year as understory crops in the proposed grazing strategy, in conjunction with provision of the high-quality preserved feed, should measurably reduce methane output from this enterprise model. Owing to the fact that this phase of beef production accounts for 80 percent of the current emission total, this could have a significant effect on that figure.

Secondly, mitigation could be achieved by incorporating this same grazing strategy 12 months later on a feeder/finishing class of cattle. Should there be a continued growing trend toward forage-fed versus concentrate-fed beef, it will be inherently important to utilize energy-dense forages as extensively as possible in order to lessen increases in GHG emissions that would normally result from a shift to higher-fibre diets. As is suggested earlier in this section, it may be that production is driven toward an increasingly forage-based system in the future due to human competition for grain. Subject to that being the case, the use of forages with the potential to significantly reduce methane emissions will be an expectation of the system.

Thirdly, assuming it will be possible to shorten the time to slaughter of forage-fed beef from current standards by utilizing energy-dense forages at key production points, total methane emissions from the system will be reduced. Currently, feedlot animals are slaughtered at a considerably younger age than forage-fed animals. Owing to this, total methane emissions are vastly greater in forage-fed beef due to daily emissions from lower energy diets as well as lifetime emissions due to the extra number of days and months animals are ruminating. If fat accretion later in life can be enhanced by providing energy-dense forages to a cow-calf pair (to be explained in section **2.9**), combined with providing higher energy forage diets later in life to effectively reduce time to slaughter, the result will be a cumulative decrease in total beef systems emissions.

It is important to note that Australian investigators have not been able to show substantive improvements in reducing methane emissions based on current supplemental feeding strategies. With this in mind, providing highly metabolizable forage as the main feed source will be key to reducing emissions, coupled with novel and strategic supplementation strategies as necessary. This assertion is supported by the Australian research, and echoed by efforts in the UK, in affirming that the propionate pathway is the best pathway for reducing enteric methane output. Since energy-dense forage diets have been demonstrated to improve the acetate:propionate VFA ratio in the rumen, this supports their consideration for Canadian production. From discussions with researchers at AgResearch in Palmerston North efforts in New

Zealand have demonstrated that ratios of 2.5:1 down to 2:1 are desirable for effective methane reduction, and that ratios of 2.5:1 or greater result in lesser impact.

The role of energy-dense forages eliciting a positive effect in the rumen in terms of microbial protein conversion was discussed in section **2.3.4** of this report. Expanding on this as it relates to GHG emissions it has also been established that this rumen effect reduces urea excretion via urine, and thus the resultant loss of nitrous oxide from the soil. There is a linear relationship between urea-soil contact and nitrous oxide emissions. As evidenced and modeled by several researchers the shifting of N excretion from urine to feces, and the consequential reduction in urine-urea concentrations, results in subsequent $N_2O$ emissions that are lowered by up to 30 percent. This is a very significant amount and can translate to substantial reductions in total GHG emissions from the beef enterprise. Similarly, soil-applied synthetic urea also demonstrates a linear relationship to $N_2O$ losses from the soil.

Recent work from the Brandon Research Centre (Durunna et al, 2014) discovered that, over time, regular applications of recommended fertilizer resulted in a build-up of nitrogen reserves in the soil under continuous swath-grazing scenarios. After multiple years of fertilizer application, followed by swath-grazing of cereals, it became apparent that issues of excessive nitrogen supply to the crop were occurring. Application of synthetic nitrogen was ceased and for the successive 5 grazing seasons no measurable negative impact on forage yield was observed on monoculture cereals under continuous swath-grazing. Although not an evaluated parameter in the trial, anecdotally it was determined that nitrogen supply was stabilized even under an annual forage grazing system, owing to the fact that little nutrient was being exported. Since the recommendation of this report is for long-term grazing of these preserved overstory and standing understory crops, with the inclusion of legumes; it is reasonable to assume that the need for supplementary sources of nitrogen can be minimalized or negated. This may lead to a reduction in soil nitrous oxide emissions, although it is unknown how much loss occurred from the Brandon pastures in the years when fertilizer was not applied. Regardless, the ability to reduce the need for annual fertilizer application will have a very positive impact on the entire carbon footprint of the model. This is achieved, in part, via reductions in emission equivalents related to the production, transportation and application of the fertilizer. Compared to the traditional feedlot model this is a distinct advantage in terms of the whole-system carbon footprint as grain, forage, and straw supply to commercial feedlot enterprises requires annual fertilizer input to replace exported nutrients.

The final GHG to address is $CO_2$, which is arguably the most important gas to consider in the whole emissions-capture debate when it comes to agriculture as this is the only industry capable of sequestering large amounts of carbon in well-managed soils. Massive amounts of soil carbon have been lost in poorly managed soils through erosion and OM degradation during the short time that tillage has been utilized in the management of the production of food and feed crops. Large tracts of land that should never have been removed from perennial plant cover continue to degrade under annual crop production. Even with the advent of modern technologies that limit or eliminate surface tillage in annual cropping systems recent, ongoing research is indicating that these systems are carbon neutral at best. In fact the production of annual crops in many of these marginal soils may often still be carbon negative, owing to the decline in stored carbon deeper in the soil profile, as well as the limitations to crop growth potential. The practice of annual cropping of short season small grain cereal crops and oilseeds is at best a sustainable model, and in many cases may become completely unsustainable. Therefore, while it can be agreed upon that feedlots themselves are a very efficient entity for the production of beef; the supply chain for grain, forage, and straw sources to the feedlot may not be a viable, long-term sustainable strategy for the Canadian Prairie landscape: either environmentally; economically; or energetically.

The approach being proposed by the model outlined in this report serves to address that challenge. It will be achieved by utilizing a production system that results in active plant growth and root development for upwards of 150 days (versus 70 days in traditional cropping practices) during the months when plant development can potentially occur. The combination of overstory and understory crops closely mimics perennial forage stands, which have been proven to sequester large amounts of soil organic carbon under good management. The picture below, from France, demonstrates the impact of the utilization of cover crops following annual cropping versus the traditional model of idling soils post-harvest until the next season. The image on the left shows soil regeneration via a significant improvement in the OM content in the A horizon in cover-cropped fields, versus the soil from adjacent land where no cover crops were utilized.

**Photo 7**. Comparison of cover crops to common land management practices regarding impact on soil.
Photo from the farm of Frederic Thomas, France, 2013. Courtesy of Mr. Blake Vince, 2013 Nuffield Canada Scholar

This effect is also supported by recent data from the University of Illinois (Olsen et al, 2014) that demonstrated significant improvements to soil organic carbon (SOC) under a 12-year study evaluating the incorporation of cover crop mixes in cropping systems. It can be expected that under grazing, where less carbon is removed from the system as compared to cropping, this impact should be further improved upon. There are hundreds of thousands of acres of marginal soils in the Canadian Prairie region that are currently in arable production that would benefit greatly from the grazing model being proposed in this report. In many cases these soils were low in OM at the time of breaking and have since degraded significantly. It is not uncommon to practice crop production on soils that are well under 2 percent and often under 1 percent OM content. Considering the potential for carbon sequestration on these soils under long-term grazing strategies utilizing full-season annual crop production, carbon capture will represent a significant offset for any GHG emissions from the system. This benefit will be compounded by the long-term impacts to any perennial forage stands (native or tame) that are able to be rested during the critical acclimation period. Improved biodiversity, plant health and corresponding root development, leading to enhanced carbon sequestration, could be realized in rested perennial pastures with this practice.

The utilization of such a model could significantly shift the GHG and carbon footprint of the forage-fed beef model to a much more positive position than is currently estimated under Canadian production. Data collected in Ireland supports this premise. According to Dr. Padraig O'Kiely from Teagasc-Grange housed feeding looks more positive in comparison to grazing, in terms of GHG footprint, when only methane is accounted for. However, under a whole-system analysis, grazing-based management is revealed to be the best strategy. This should be an achievable goal for the Canadian forage-fed beef model as well. It is important to note, though, research has also clearly demonstrated that ceasing management shown to improve SOC and reverting back to previous management practices will effect a rapid decline in the unstable carbon that has been captured. Ergo, long-term commitment to the practice is required for true benefits to soil properties and GHG mitigation.

## *2.7 Benefits to Soil and Impacts of Fertility*

When considering the physiological growth curves of monoculture small grains crops, it becomes apparent that vegetative production is limited to less than half of the Western Canadian growing season period. While most small crop production focuses on achieving maturity within the frost-free period in a given environment; conditions for plant growth and soil microbial activity occur for an extended period on either side of that window. In reality then, the potential for carbon losses from the system are greater than the period of time when growing crops are actively capturing and transitioning carbon into the soil pool. Investigators are now ascertaining that monoculture small crop production is carbon neutral at best, to carbon source, even under the best soil management strategies where tillage has been eliminated. Therefore, at best, the current model for Western Canadian cereal crop production is barely sustainable. In situations where the entire crop is harvested for livestock feed, maximizing organic matter removal from the system, it is very probable that net carbon storage is negative. It is here where the sustainability of the Canadian feedlot model comes into question, with respect to the fact that the supply chain for product to the feedlots is resulting in SOM maintenance only, or possibly the ongoing degradation of soil. At a time of sustainability as the agricultural buzzword, when in fact ecological regeneration should be the focus, alternative approaches to feed and livestock production must be considered. All over the world interest is growing in the incorporation of cover crop mixes into annual cropping systems, owing to the evidence of benefits to several aspects of soil health. These include: increasing soil organic carbon; improved water infiltration; increased water storage capability; increased soil aeration; improved tilth; decreased compaction; enhanced plant available nutrients; and increases in beneficial nematodes. The positive effects of diverse populations of cover crop species have been the topic of numerous publications and assertions in recent years. This topic will not be discussed in depth due to the volume of external information that is available. Suffice it to say, the energy-dense forage production model proposed in this report incorporates the strategy of diverse cover crop use and its returns.

In discussions with Canadian soil experts, and supported by recent data from Illinois, the addition of understory crops into monoculture small grains production, should be an effective carbon sink. Olsen et al (2014) demonstrated that, after 12 years of comparison of the impact of cover crop incorporation into traditional cropping systems, cover crop treatments raised SOC stocks in the tillage zone, subsoil zone, and rooting zone of all tillage treatments. The three tillage treatments evaluated included conventional tillage, zero-tillage (no-till) and moldboard plow. Ergo, the incorporation of cover crops into existing production strategies is universal in enhancing carbon sequestration, as well as all the resulting benefits that come from greater soil organic matter content. However, it is ascertained that this light-fraction carbon is not stable for several years and in that time can also be depleted as rapidly as it is sequestered. Should management practices revert to a system that is not beneficial to carbon sequestration; unstable stored carbon reserves will ultimately decline. Therefore, in order to effectively create an ecologically regenerative annual crop grazing system focused on soil health, it is inherently important to utilize energy-dense forage understory crops as a long-term production strategy. This is especially significant when considering the value of this stored carbon as an offset to GHG emissions from forage-fed beef production.

It is important to understand that the species proposed in this model possess significant potential to contribute to the augmentation of soil carbon content. The utilization of grasses like festulolium, herbs like chicory and plantain, and legumes like sweet clover and hairy vetch offer the prospective for substantial root mass development owing to their aggressive rooting capability.

The structural carbohydrates in the cell wall component of the root tissue generally provides the predominant source of carbon. However, plants like chicory can contain up to 80 percent of total dry weight as inulin. Inulin is a form of fructan, and is the dominant soluble carbohydrate in chicory roots. It has also been demonstrated in chicory that development of the tap root exceeds the biomass of above-ground plant growth during the establishment year (Van den Ende et al, 1996). The propensity for chicory roots to accumulate such high levels of WSC provides a significant secondary source of carbon that can contribute to total sequestration potential. Generally these sugars would act as a source of energy for the initiation of new growth following a period of dormancy. However, owing to the fact that the grasses and herbs being considered for this strategy will succumb to over-winter mortality in the Prairie environment, root-based WSCs will be captured in the soil to potentially contribute to the accumulation of carbon stocks.

Soil fertility is a critical component that affects not only plant growth but also potential WSC accumulation in plant tissue. Evidence is clear that elevated levels of soil nitrogen and potassium supply will negatively impact plant WSC content. However, it is equally critical that macronutrient availability not be a limiting factor; since plant growth, leaf health, and photosynthetic potential can also be negatively impacted when one or more elements are in deficient supply. Anecdotally, improved soil properties and plant available nutrient supply have been promoted to enhance plant WSC accumulation.

With that in mind, over time, improvements to soil structure, OM content and biological diversity from the use of understory energy-dense forage species should result in greater plant metabolizable energy potential. What is especially interesting is the synergistic and cyclical relationship that occurs when optimizing soil fertility and plant WSC concentration. Balanced nutrient supply lends itself to enhancing metabolizable energy, including in the form of plant sugars. As discussed in section **2.3.4** and **2.6**, the intake of forages with high-WSC content facilitate microbial protein synthesis (MPS) and the shift from urea excretion to the feces instead of via urination. The result is the return of a more stable form of nitrogen to the soil, fewer losses as nitrous oxide, and eventually more plant-available nitrogen supply. This, in turn, creates efficiencies in nitrogen uptake and reduces the need for supplemental or applied nitrogen sources. The energetic benefits to this increased efficiency will be expanded upon in section **2.11**. Coming full circle, a balanced supply of plant available nitrogen achieved by this nutrient cycling optimizes forage growth and furthers the potential for plant WSC accumulation, which then results in improved MPS and more stable urea excretion; and so on.

The incorporation of such a production strategy into degraded or low-OM soils, as is being proposed in this model, will warrant the investigation of the impact of applied fertility and fertility management in the short-term. This is especially true when in consideration of soils that have been mined, without adequate replenishment, of various macro- and micro-nutrient elements. It is really unknown at this time what the effects of application of the various micro-nutrients to

Canadian soils (either in organic or synthetic form) will have on plant WSC content and other factors that contribute to improved digestibility. When considering the potential impact of increasing the energy density of grazed forages to Canadian livestock, it becomes evident that scientific investigation into the soil-plant interaction based on nutrient balance is warranted.

## *2.8 The Concept of Restricted Grazing*

It has been documented that livestock commit a significant portion of their diurnal grazing time to a period of a few hours either side of sunrise each day. However, it is at this same time of day when plant WSC content is at its lowest as a result of respiration. Respiration in plants is the chemical reaction that converts glucose and oxygen to carbon dioxide and water, releasing energy in the process. The metabolism of these phytosynthates into energy used by the plant for growth, reproduction and other critical life processes is as important to cell growth and development as photosynthesis. If a targeted intake of an energy-dense forage is a grazing objective then understanding the relationship of plant WSC content in relation to the cycle of photosynthesis and respiration may be an important consideration.

Fulkerson et al (1998) demonstrated that time of pasture grazing influenced the ratio of non-structural carbohydrate to degradable intake protein ratio (NSC:DIP). With water soluble carbohydrates comprising over 90 percent of NSC, this assessment serves as a similar expression regarding the importance of the relationship of plant energy and protein content as was discussed in section **2.3.4** of this report. It was also shown by Fulkerson et al that daily plant WSC concentration increases at a rate of 0.5 percent of total plant dry matter for each hour of unimpeded sunshine, culminating in a WSC content 70 percent higher in late afternoon than in early morning. With that in mind, restricting grazing access during the time of the day when plant WSC levels are at their lowest should maximize digestible forage intake by only allowing grazing of plants with greater WSC levels. The potential paybacks to the elevation of WSC content have already been conferred in this report. It is expected that managing grazing access to periods of the day when photosynthetic activity and WSC accumulation are greatest should cause said benefits. The efforts of Trevaskis et al (2001) support this concept by stating "*This magnitude of change in WSC content of pasture should affect microbial activity in the rumen of dairy cattle grazing such pasture*". While results vary, the majority of data generally corroborates this conclusion. Australian studies have demonstrated increases in milk production from afternoon (AM) versus morning (PM) grazing when these times represented the major diurnal grazing events. Livestock performance improvement from PM versus AM grazing, as a result of increased WSC content, has also been proven by research efforts with dairy herds in Wales and in forage-fed beef streams in Argentina. In some cases milk protein content in UK dairy herds was also increased.

However, in other trials it was observed that improvements in dairy herd performance were not necessarily due to increases in plant WSC concentration. While Trevaskis et al (2004) showed significant digestive benefits to feeding dairy cows their daily allocation in the afternoon; no direct production benefits were achieved as a consequence of improved digestive efficiencies due to the increase in WSC content. Results indicated that microbial protein synthesis was not a limiting factor for milk yield and milk solid content in the control treatments; therefore improvements in intake energy:protein ratios did not affect meta-biological gain directly. Daily milk production was shown to increase in cows grazing Italian ryegrass in afternoon versus morning however this was due to an increase in total daily intake, an additional 2.6 kg/cow/day in the PM group, owing to enhanced palatability and digestibility. This observation is consistent with increase intake rates recorded in UK data comparing high-WSC ryegrasses to conventional ryegrass varieties.

The work of Trevaskis et al also revealed that 70 percent of daily pasture forage intake will occur within the first 3 to 4.5 hours of a fresh allocation, and that there were differences in animal behaviour between herds on morning and afternoon allocations. This data is supported by work in Ireland (Teagasc, Moorepark) and in New Zealand (Massey University) that determined 90 to 100 percent of total daily DMI from grazing can be achieved in two four-hour grazing periods, one following each daily milking regime. Researchers with INTA in Balcarce, Argentina are also employing a grazing strategy whereby fresh forage access is limited to only 4 to 8 hours per day. This strategy is part of a systems-based research effort utilizing annuals and perennials to achieve forage-based finished animals. In order to limit plant injury from livestock traffic during freezing evening temperatures during their winter grazing period cattle are confined from early evening until noon or early afternoon. During confinement stock are fed forage and forage-grain based supplements, in some cases approaching one percent of total body weight as DMI, when grazing intakes were low due to slow plant winter growth rates. However, grazing of high quality forage material is still the main intake goal so optimizing forage utilization under these conditions is critical to the strategy. Producers in this region of Argentina are also employing the same practice in their operations. Although it was unclear as to the amount of performance gains attributable to this approach, elevated WSC levels were being targeted in an effort to enhance biological performance even though potential for high WSC accumulation in plants is limited in the Argentine winter environment.

Hence, it is worthy of consideration for grazing access to be restricted as a management tool in controlling intake of forages with enhanced energy density. Under Canadian production this would likely represent a grazing period from noon to early evening in order to maximize intake of higher-WSC forage material; potentially optimizing rumen function and meta-biological gain. This, of course, would require a supplemental feed supply during confinement but experience indicates that animals will adapt their feeding behaviour to focus on the majority of intake occurring during the grazing period, self-minimizing consumption of supplemental feed. However, certain factors need to be taken into consideration as to the merit of this approach. First of all is the ease of access to confinement facilities in a grazing system where water and a readily replenish-able supplemental feed reservoir can be provided. Secondly, it could be ascertained that the greatest benefits to this approach should be realized when sunlight hours are shortest and conversely when evenings are hottest.

However, it may be that restricted grazing during these periods of the Canadian growing season might not achieve the expected benefits. Short days and long evenings may not necessarily bring about impediments to optimizing WSC intake. Even though daylength and potential for maximum WSC accumulation are related to total photosynthetic activity, it may be that WSC levels do not decline as drastically during the evening during these parts of the year, owing to the cool evening temperatures that inhibit plant respiration rates. This is evidenced in certain parts of New Zealand, especially the South Island, where no benefit is being measured between major grazing events later in the day versus earlier under such conditions. Since plant WSC content is already high in the morning due to slow rates of respiration, significant elevations in WSC intensities are not being realized throughout the day. It is probable that similar results could be expected in spring and fall in the Canadian environment. It would be anticipated for the greatest benefit to occur during the months when evening temperatures are elevated to the point where respiration rates are being maximized. Even with a short light restriction period during these times, high respiration rates, coupled with a much longer photoperiod, large variations in plant WSC concentrations will be realized between early morning and peak accumulations in the afternoon. When considering the tendency for animals to limit movement and feed intake during the hottest parts of the day, it may be that target intake rates may not be reached on days of elevated temperature and high solar intensity. Therefore, performance may actually be impacted negatively with this approach. It may be that the most opportune time to employ the practice of restricted grazing would be for a period of time in late spring or early summer when the protein:energy imbalance in immature perennial forages is at its greatest.

As with many of the points being brought forward in this report, only scientific investigation will determine the true potential for this approach in the Canadian production model.

## *2.9 The Impacts of Diet Energy during Early-life Nutrition*

This section of the report will examine research results in the area of production impacts from a sustained supply of adequate to superior dietary energy in young cattle, from early embryonic stages through the months prior to weaning.

Several American trials have focused on dietary impacts in early-weaned calves as they relate to performance and carcass quality measurements. Myers et al (1999) proved that early-weaned calves (100 days of age) fed concentrate diets increased the percentage of steers grading Average or Choice by more than 40 percent when compared to normal-weaned calves (200 days of age). Fluharty et al (2000) supported these findings by establishing that body weights and body conditions scores were improved in early-weaned (EW) calves fed high-energy diets, and that part of the increase in ADG for the EW group was due to accelerated fat accretion. Additional investigations by Schoonmaker et al (2001) demonstrated that early-weaned calves were younger at final slaughter and were rated higher in taste panel evaluation for tenderness and juiciness versus normal-weaned calves. Even though quality grade was not impacted by weaning treatment in these trials *longissimus* muscle fat percentage was 2.7-fold greater for EW steers. Assumptions were made that intramuscular fat deposition may have been initiated at a younger age. Conversely, an experiment by Schoonmaker et al (2004) revealed that high-quality forage-based diets fed to early-weaned calves from a period of days 119 to 259 of age resulted in the opposite effect. In this study the forage-fed calves demonstrated greater muscle tenderness but a lesser *longissimus* muscle area at slaughter. While no differences in marbling score were reported in the Schoonmaker trial, ether-extracted lipid from the *longissimus* muscle showed significantly higher concentrations in the forage-fed treatment animals as opposed to those from the two concentrate-based diet treatments. This is supported in part by the work of Greenwood et al in Australia where the only positive effects observed in pre-weaning diet manipulation of calves were as a result of forage-based diets with improved protein and energy levels. However, the impact in these trials was observed only in relation to subcutaneous fat content and benefits were negligible. In addition, the Australian trials were conducted on calves pre-weaning and not early-weaned so comparisons may be difficult. Australian research into post-weaning energy supplementation provided no significant positive affects for lipid accretion as observed at slaughter.

It is important to note that there is general agreement regarding the provision of a high-energy diet to calves between 110 to 200 days of age as often resulting in early marbling cell development. This physiological response is also referred to as adipocyte (fat) cell programming or the establishment of pre-adipocyte cells. Pre-adipocyte cells are formed by the differentiation (modification) of stems cells and can be stimulated to become true adipocyte cells later in life. Once adipocyte cell formation occurs they differ from other mammalian cells in that they do not turnover, i.e. die and become replaced. This is an important factor to consider when assessing the impact that early development of adipocyte cells in intramuscular tissue can have on carcass lipid expression. However, this effect has mainly been observed post-natally in early-weaned calves. The question remains as to whether this same result can be achieved at this stage of development with a sustained supply of energy to a calf that is still nursing its mother. It also is to be determined whether the effect can be realized by providing energy-dense forages to the cow-calf pair under grazing.

While no evidence exists to date about this potential, trials are underway to investigate the possibility of high-energy forage diets in early-life nutrition of calves. Some of these trials include evaluating marbling potential in beef cattle and others involve enhanced neo-natal milk intake followed by dietary forage quality evaluation to determine impact on later life performance in dairy calves.

In all cases these investigations involve artificially-reared, early-weaned calves and not suckling calves. In discussions with experts in several fields during this study there was also general agreement as to the potential for grazed energy-dense forages to initiate pre-adipocyte cell development. The concept of the positive effect for this response in pre-weaned calves from a sustained supply of highly metabolizable forage-based energy was strongly supported, although as yet remains unproven. The expected benefit to adipocyte cell initiation in calves between 110 and 200 days of age would come from two dietary sources. Firstly, would be from the daily grazing intake of these calves. Secondly would be from the augmentation of milk production from the dam as a result of her intake of these same forages. A great deal of evidence exists regarding the intake of highly metabolizable forage that ascertains increases in milk production and increases in concentrations of milk solids, although in most cases the latter is mostly protein. While it is difficult to elicit elevations of milkfat percentage through diet manipulation overall increases in milk production will allow for greater daily calf intake of milkfat by volume. The end result is an increase in total milkfat consumption, providing a good source of dietary energy for the suckling calf. Researchers agree that total nutrient influx is critical for the stimulation of the programming of adipocyte cell formation. In theory, the combination of increased milk consumption and intake of energy-dense forages should stimulate the desired response. However, it may be that provision of supplemental feed is necessary when energy supply requirements are not adequate.

The discussion in this section has so far focused on “developmental genetic potential” versus “epigenetic potential” (discussed in detail in section **2.12**) in terms of influence on biological performance resulting from enriched dietary energy supply. Recent work has demonstrated the effect of nutrient restriction in fetal programming; resulting in measurable differences in muscle development, adipogenesis (lipid accretion) and other traits, especially at later stages of gestation. Fetal programming is the concept that a maternal stimulus or insult during a critical stage in fetal development can result in long-term effects on the performance of the offspring. Fetal programming is not the same as but is sometimes linked to epigenetic influence, which will also be addressed later in section **2.12**. Summers and Funston (2013) cite a figure from Du et al (2010) to support a paper presented to The Range Beef Cow Symposium XXIII, shown here as Figure 1. However, it must be noted that a review of similar evaluations conducted in Australia (Greenwood and Bell, 2014) reported no demonstrable changes to carcass quality due to restriction of maternal nutrition. Progeny impacts in Australian trial animals were limited to only growth-related factors in the form of changes to birth weight and end slaughter weight. No significant physiological impacts were identified.

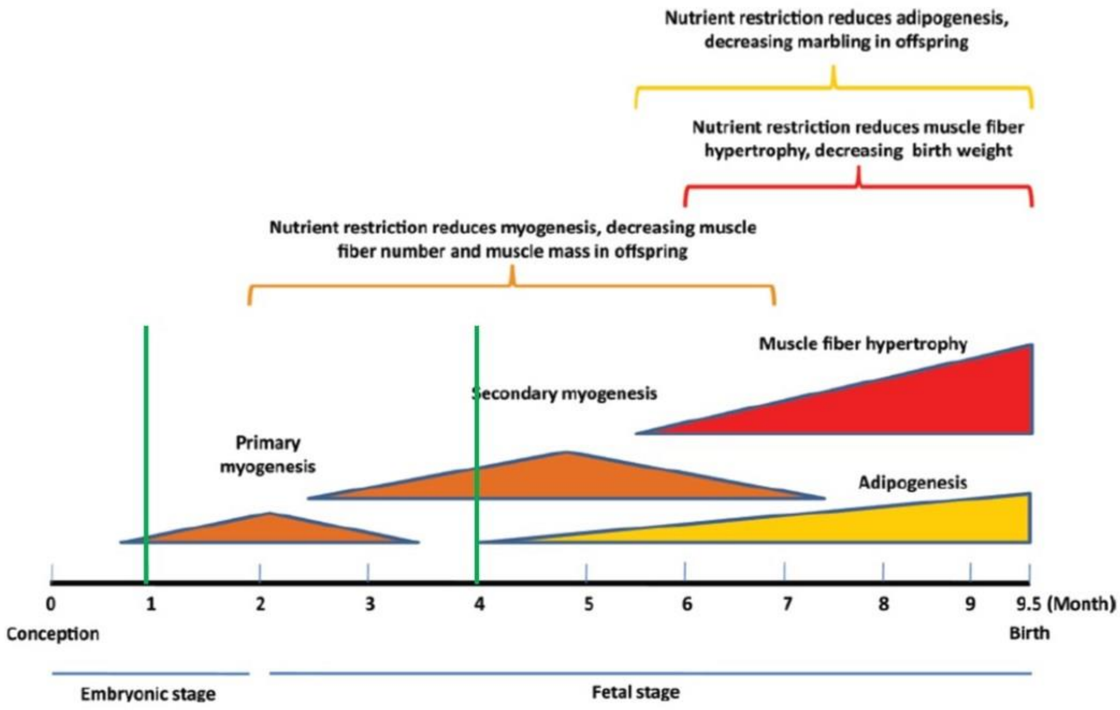
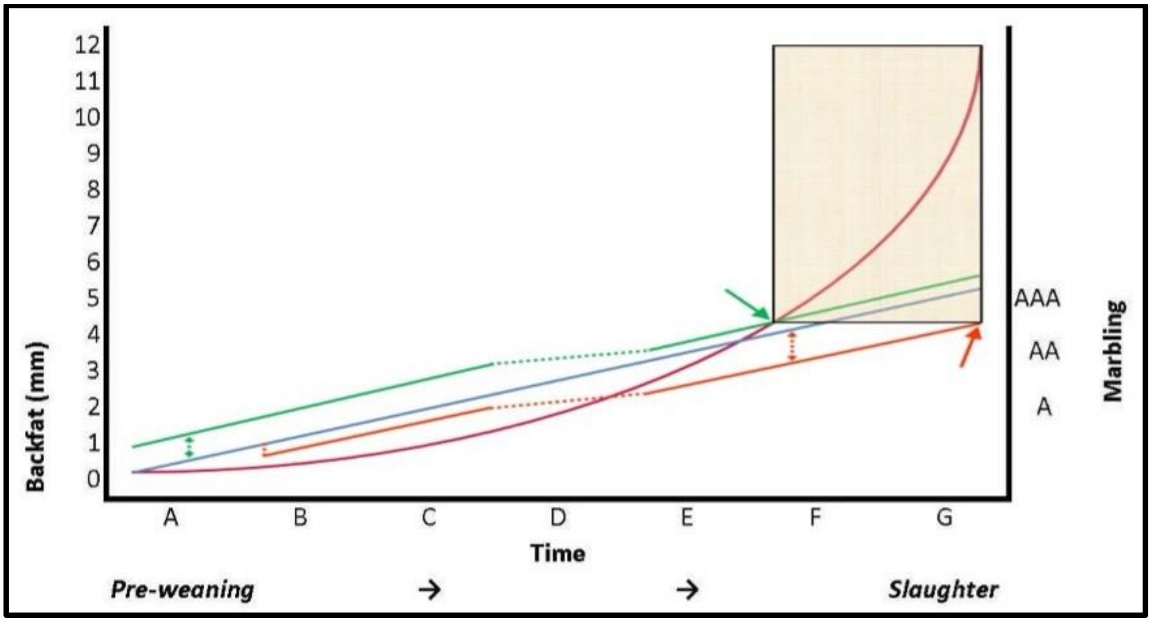


**Figure 1**: Effects of maternal nutrition on bovine fetal muscle development and adipogenesis, from Du et al (2010)

The results of Du et al (2010) indicate that the greatest impact to fetal programming comes from nutrient restriction, rather than elevated nutrient supply, as long as all nutritional requirements of the dam and fetus are being met. With that in mind, there is less effect to be expected from the feeding of energy dense forages versus traditional models in terms of benefit to the fetus from a couple of perspectives. Under the model being proposed the supply of these forages is intended for cows with suckling calves between the ages of 110 to 200 days. The vertical green lines have been added to the graph to represent the stage of the embryo and fetus at that time of lactation. As is evidenced by the figure, the opportunity for impact on fetal development programming is more likely to occur at later stages of development. Additionally, it is unlikely that any positive benefits to the fetus are to be realized by supplying excess energy to the dam as most impacts being reported, physiological or genetic, are due to nutrient restriction. The timing of availability of energy-dense forages for grazing of spring and summer-calving herds in the Canadian production environment is likely to result in negligible impact on embryonic and fetal development. Exceptions to this would be in cases where normal forage supply would be severely nutrient-deficient, or in the case of fall-calving herds where grazing would occur at a time when developmental nutrient demand is highest and restrictions may result in greater negative impacts to the fetus. Regardless, Figure 1 reinforces the need for adequate nutrient supply, including energy, for producers in forage-fed beef production enterprises; as diet energy can become a performance-limiting factor when forage supply is marginal or quality is poor.

In order to exemplify the benefits to the Canadian beef production model by achieving early onset marbling cell development the following figure has been prepared to describe the impact potential. Owing to the importance of marbling in regard to consumer preferences for North American beef consumption, emphasis needs to be placed on the ability for forages to result in superior intramuscular (IM) lipid content than is often currently attained. Higher carcass marbling scores are difficult to achieve using forage-based diets, especially in animals of younger ages. Even in concentrate-based feedlot systems it is difficult to succeed in obtaining desired marbling grades without the accumulation of excessive amounts of subcutaneous (SQ) fat, which are routinely trimmed prior to retail packaging. The notion of establishing marbling potential early in life, and the resulting benefits to the entire beef production process, is outlined below; with special thanks to Dr. Henry Zerby from Ohio State University for offering up this graphic representation of fat deposit progressions in beef cattle:

**Graph 2**: Comparison of rates and responses of subcutaneous (SQ) and intramuscular (IM) fat deposition in beef cattle as influenced by external factors. Zerby, 2014



It is important to understand that Graph 2 is not a true, scaled representation of the adipogenesis cycle of calf, feeder and finishing classes of cattle. Rather it is a conceptual illustration of the relationship of lipid accretion to time and management. The curved magenta-coloured line represents the deposition of SQ fat or backfat based on provision of a high-energy diet at later stages of life prior to slaughter. The accretion (deposition) of SQ fat is a curved line, depicting the potential for compensatory and accelerated rates of deposition that are governed by a number of factors. The straight blue line denotes accumulation of marbling tissue under ideal circumstances. IM fat deposition differs from SQ in that there is no potential for compensatory accumulation, and that once an opportunity is lost to promote the accrual of lipid tissue in IM adipocyte cells it is foregone permanently. It is also important to realize that the two metabolic pathways for deposition of lipids in SQ and IM cells are separate and unrelated, a fact that is often misunderstood. The orange line signifies a more normal course for the accumulation of marbling tissue. The solid line segments constitute normal rates of deposition whereas the dotted portions of the line express negative impacts on accrual rate due to physiological stresses to the animal. The first dotted line demonstrates a sudden, short-term drop in marbling rate that occurs as a result of a shock to the calf development such as that at weaning. The second more gradual decline in accumulation rate exemplifies a period of restricted performance as is seen in the backgrounding phase of beef production. The end result is a significant decrease in the rate and total accretion of IM adipose tissue, as evidenced by the orange dotted arrow. The solid orange arrow depicts the target point for the majority of Canadian carcass production; high proportions of carcasses grading AA to AAA with accumulations of 10-12 mm of backfat. The green line represents the potential to improve IM marbling content by initiating the programming of adipocyte cell development early in life. As is demonstrated with the dotted green arrow, marbling rate and accumulation prospects are markedly increased when this physiological response is activated. The entire line is moved up on the graph in respect to the rate of SQ fat accretion. On this line the stress effect from weaning has been eliminated owing to consideration of the two-stage, no-stress weaning technique promoted by the University of Saskatchewan.

Even with the decline in accumulation rates owing to a backgrounding phase, represented by the dotted segment of the line, desirable levels of IM marbling content will be realized much earlier in the life of the growing animal. This opportunity is portrayed by the solid green arrow where, in theory, optimum levels of adipose tissue in the *longissimus* muscle can be achieved at younger ages and at substantially lower accumulations of subcutaneous fat deposition. The final feeding stages in a finishing phase of beef production are generally the most inefficient and expensive in terms of cost per rate of gain. The potential to eliminate or limit this portion of the feeding stream may offer significant economic, environmental, and energetic benefits to the beef production model. The difference between the proposed model incorporating enhanced marbling using energy-dense forages (or other means) and the traditional model is depicted by the shaded box on the upper right portion of the graph. This concept could have profound, far-reaching implications for Canadian beef production.

## *2.10 Carcass Quality Benefits and Lipid Profiles*

The discussion on lipids so far in this report has focused on the potential impact of energy-dense forages in relation to accumulation of adipose tissue prior to slaughter. This section of the report will delve deeper into the nutritional aspect that may be realized due to the possibility of this influence. While there is no data to currently support some of the hypotheses that will be raised, the opportunity for improved carcass quality and beneficial lipid content utilizing highly metabolizable forages has not been dismissed by experts and deserves valid consideration. There have been many carcass quality comparisons of mainstream grain-based versus grass-based finishing systems in North America. There are also many lipid-based health claims by proponents of the grass-fed beef brand that need to be carefully considered. This discussion will incorporate current scientific knowledge regarding lipid accumulation and lipid profiles of adipose beef tissue. In addition it will extrapolate the potential for energy-dense forages to affect superior positive benefits relating to lipids, over traditional forage-fed beef production, owing to physiological enhancements previously outlined.

It has already been discussed that traditional forage-fed beef tend to possess lower concentrations of total lipids versus concentrate-fed cattle carcasses. Generally the greatest decline in beef carcass fat content is seen in relation to the accretion of subcutaneous fat. However, it is well established that significant differences in intramuscular fat concentration (usually measured in the *longissimus dorsi* muscle) exist between forage-fed and grain-fed beef animals at similar points of slaughter. The presence of marbling fat tends to be diminished in forage-fed beef carcasses, as supported by Faucitano et al (2014).

The potential for elevated levels of total lipid content under intake of energy-dense forages contrasted with traditional forage feeding has also been previously addressed in this report. This is important point to consider as forage-fed beef does contain lipids that have been shown to offer some measure of benefit to human health when consumed, although in most cases levels are negligible and true health-value claims cannot be made.

The following is an examination of fatty acids in beef presented in a review paper by Van Elswyck and McNeill (2014) that provides a very balanced explanation of lipid concentrations in American retail beef products and their respective importance to human health. It begins with a discussion of the polyunsaturated fatty acids (PUFA) that are dominant in American carcasses. PUFA are a group of essential lipids represented by omega-3, omega-6, omega-9, and conjugated fatty acids that are both beneficial and detrimental to human health. Forms and concentrations of particular fatty acids in this group, by dietary source, determine their role in human metabolism and physiology. In terms of beef, they represent only around 5 percent of the total lipid profile and, of this, the omega-6 acids are the predominant group, comprising 85 percent of total PUFA profile in grain-fed beef. The percentage of omega-6 is significantly reduced in grass-fed beef comparisons. This is generally accepted to be of greater advantage for human consumption even though total intake levels are still very low; and particularly in grass-fed beef where total meat lipid content is lower.

In regards to omega-3 fatty acids in forage-fed beef, small increases in the short-chain omega-3 fatty acid (alpha-linolenic acid or ALA) are realized, with estimated mg/100 g beef amounts ranging from 16-26 mg ALA in various lean cuts for forage-fed versus 4–13 mg/100g ALA in grain-fed beef. In terms of the longer-chain omega-3 fatty acids (n-3 LCPUFA) such as eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA), and docosahexaenoic acid (DHA), only slight increases have been detected in forage-fed beef. The medical community have determined that the contribution of ALA to cardiovascular health is debatable. However, scientific evidence regarding the role of n-3 LCPUFA in the prevention of heart disease is convincing. Owing to the importance of n-3 LCPUFA for human cardiovascular health, recommendations from around the world are for a minimum of 250mg EPA+DHA/day. Based on US data it appears that both grain-fed and forage-fed beef contribute n-3 LCPUFA to daily intake targets, ranging from 2–19mg per 100g and 5–33mg per 100g, respectively. These levels represent mainly EPA and DPA as DHA concentrations in beef, whether grain-fed or forage-fed, are nominal. EPA, and especially DHA, intake have been associated with improved cardiovascular health. However, little is known about the contribution to health benefits of DPA alone or EPA+DPA. Generally there is an inherent inability to accumulate significant amounts of n-3 LCPUFA in beef. For this reason, elevated levels of omega-3 in forage-fed beef are not considered to provide noticeable health benefits.

Considering conjugated linoleic acid (CLA), which is the subject of much debate as to perceived human health benefits, it has been shown to double in concentration in forage-fed beef versus grain-fed beef. However, again due to the lower fat content of forage-fed beef, total CLA intake per dietary serving is essentially identical and provides at best a minor contribution to any health benefits. Should energy-dense forage diets stimulate a large increase in carcass lipid content (both IM and SQ), it may be that CLA levels are significantly elevated. However, whether that translates to a level of enhanced dietary intake that provides a human nutritional benefit is unlikely. Current levels of intake from 100g serving of grain-fed or grass-fed beef equate to approximately only 20mg of total isomers of CLA, whereas expert recommendations for daily intake requirements are up to 3g per day or greater.

In terms of cholesterol content of beef from forage-fed versus grass-fed beef only one study demonstrated any significant reduction in cholesterol concentration, with most results indicating no significant differences due to feeding regime. It is apparent that neither feeding strategy will provide any legitimate impact over the other.

Saturated fatty acids (SFA) are present in the range of 36-38 percent of the total fat content in beef, of which stearic acid tends to represent approximately one-third of the total SFA. When described on a percentage basis, American studies have consistently reported increases in total saturated fat deposition in forage-fed beef when compared to grain-fed carcass cuts. However, again owing to significantly lower total fat content in forage-fed beef, intake amounts of saturated fats responsible for elevating human cholesterol levels are also lower, reduced by up to 1.4 g per 100g of steak. This is again a positive benefit from current forage-fed beef lipid profiles that may be impacted, negatively or positively, by the incorporation of energy-dense forages into the grass-fed beef model, should it result in a rise in meat lipid concentrations. United States (US) data also shows that forage-fed beef tends to provide a greater amount of saturated fatty acid in the form of stearic acid over grain-fed beef. Stearic acid has been shown to be neutral in regard to its effect on human plasma LDL (low-density lipid) cholesterol, in contrast to other saturated fats which have been confirmed by many world health organizations as cholesterol-raising. On the down side stearic acid, when compared to its de-saturated derivative oleic acid, has a much higher melting point and has been shown to result in negative consumer responses to meat texture and preference when levels are elevated.

Oleic acid is a monounsaturated fatty acid (MUFA), derived from the desaturation of stearic acid by the stearoyl-CoA desaturase (SCD) enzyme, and represents 90 percent of the MUFA present in beef. Researchers have known for decades that oleic acid has positive health benefits, such as reducing LDL-cholesterol (the bad cholesterol) and perhaps increasing HDL-cholesterol (the good cholesterol), when consumed in adequate amounts in a daily diet. According to studies conducted by the Department of Animal Science at Texas A&M University (Adams et al, 2010) ground beef from grass-fed cattle fed to hypercholesterolemic men decreased HDL-cholesterol in test subjects. Conversely, in men with normal cholesterol levels, only ground beef from grain-fed cattle increased HDL-cholesterol. Neither ground beef type elicited any effect on LDL-cholesterol in both test groups. The observation of the elevation of HDL-cholesterol from the consumption of high-MUFA (grain-fed) as opposed to low-MUFA (forage-fed) ground beef is supported by Gilmore et al (2011). Research from Adams et al (2010) also demonstrated an increase in HDL-cholesterol in mildly hypercholesterolemic men after a 5-week consumption period of high-MUFA hamburgers when compared to similar consumption of high-SFA hamburgers, validating the benefit to elevated oleic acid levels in beef. According to data from Steve Smith (2014) forage-feeding of beef cattle during the finishing phase definitely does not increase oleic acid concentrations as compared with grain-feeding. Smith et al (2009) demonstrated that high-concentrate diets stimulate the activity of the SCD enzyme, which is responsible for the conversion of saturated fatty acids to their de-saturated counterparts (e.g. stearic acid to oleic acid). Also, the feeding of a high-energy, starch-based diet causes a depression in ruminal pH, which decreases those populations of ruminal microorganisms responsible for the isomerization and hydrogenation of polyunsaturated fatty acids (PUFA). The net effect of elevated SCD activity in marbling adipose tissue and depressed ruminal isomerization/hydrogenation of dietary PUFA is a resulting large increase in MUFA concentrations in beef over time. Conversely, forage-feeding has been shown to depress both the accumulation of marbling tissue and SCD activity. Although pasture feeding increases the relative proportion of n-3 PUFA in beef, it also decreases the total amount of lipid. To summarize, pasture feeding increases n-3 PUFA by only milligram amounts in beef, but decreases MUFA by gram quantities. Thus, this fat is harder and may be less healthful than beef from concentrate-fed cattle.

Under current forage-fed beef production systems pasture and hay feeding have been shown to strongly depress SCD expression in several studies, resulting in an elevation of SFA in beef and depressions in marbling scores. According to the Smith et al (2009) manuscript regarding a trial evaluating animals at 12 months of age fed a corn-based diet for 4 months versus grazing of native pasture for 4 months it was found that the concentration of stearic acid was lower, and oleic acid concentration was incidentally higher, in the marbling adipose tissue of the steers on the corn-based diet. SCD gene expression was virtually undetectable in adipose tissue in trial calves at weaning stage and in the pasture-fed steer treatment, but was highly expressed in adipose tissue of the corn-fed steers. Differences in SCD activity between corn-fed and pasture-fed steers clearly contributed to differences in beef fatty acid composition. This is summarily supported in the review paper by Van Elswyck and McNiell (2014) that lists beef as a primary source of MUFA in the US diet, with one of the most common sources of MUFA being in the form of oleic acid. Data concludes that forage-fed cattle produce beef with 30–70 percent less MUFA when compared to beef from grain-finished cattle. The reduction in total MUFA is estimated to be as much as 1.8g less MUFA per 100g beef in US forage-fed beef as compared to grain-finished beef.

The role of MUFA in cardiovascular health is well documented. Recent expert reports rate the evidence as "convincing/strong" that substitution of dietary MUFA for cholesterol-raising saturated fatty acids reduces LDL-cholesterol levels and lowers risk of type II diabetes and cardiovascular disease. Results from recent studies (Adams et al, 2010 and Gilmore et al, 2011) suggest that the higher MUFA content of grain-finished beef may be important for increasing plasma HDL cholesterol among beef consumers. Conversely, exclusive grass-feeding could shift the MUFA:SFA ratio of beef in a manner that significantly lowers HDL, increases triglycerides, and increases the density of LDL particles among consumers of grass-fed beef.

It has been established that energy-dense forage intake has the potential to impact rumen activity and other biological processes similarly to concentrate-based diets of similar energy intake. Therefore, it begs the question as to whether these same forages can affect an increase in SCD activity and result in comparable lipid profiles that are proven to be beneficial to human health. To date, little investigation has been undertaken to ascertain this possibility. Grazing trials in Ireland utilizing high-WSC grasses versus conventional grasses found no difference in carcass quality/fatness after a whole grazing season. However, it must be noted that in this study the range in sugar content between conventional and high-WSC was quite small and far less than initially targeted. Unfortunately lipid profile was not measured so it is unknown if the variances in forage energy intake had any effect on constituents of the adipose tissue.

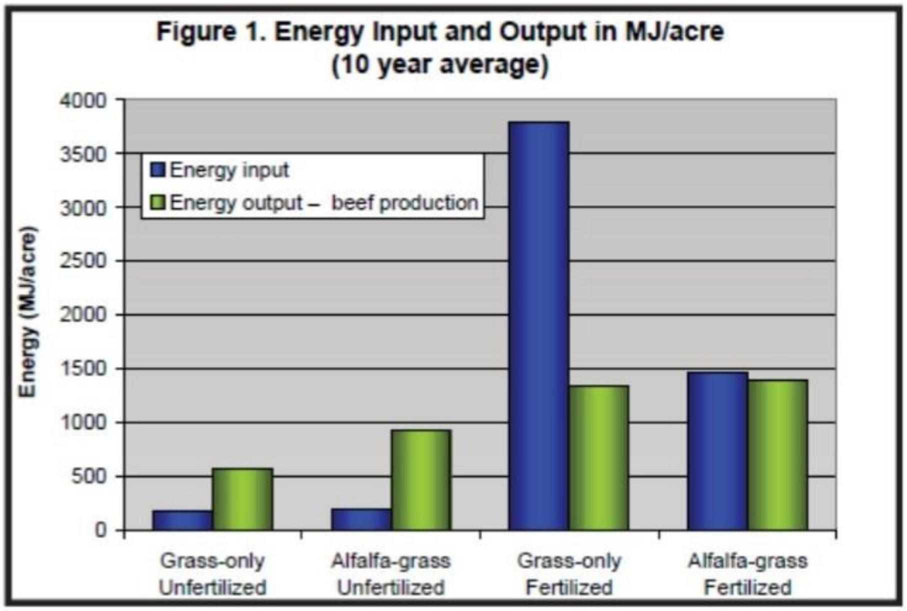
In order to address this gap in knowledge investigators in Australia and New Zealand have recently entered in trials evaluating the potential of energy-dense forages. Both countries are evaluating traditional pastures containing ryegrass and white clover mixes, but are focused on optimizing metabolizable energy intake, including the incorporation of chicory and/or plantain in these blends at establishment. The efforts in Australia are to increase IM lipid content in lambs while studies in New Zealand are attempting to determine if programming of IM adipocyte cells can be activated on young weaned calves; using these blends of highly digestible forages. Trials are to include rigorous carcass evaluation and researchers are hopeful to stimulate the same responses as observed with early-weaned calves fed high-energy grain diets in previous studies. It is expected that supporting experiments will be also initiated in the near future.

It should also be noted that age of animal and breed type can specifically affect the concentration of MUFA in beef cattle by impacting SCD gene expression and activity (Smith et al, 2009). Generally, the greatest MUFA:SFA ratio was observed in the oldest cattle under trial. Supported by several studies it is now well understood that there is a general elevation of MUFA and resultant depression of SFA in total adipose tissue lipids in beef cattle with increasing time on a grain-based, feedlot diet. Forage-fed beef are often slaughtered at an older age than concentrate-fed cattle. Since it is a function of time, deliberation of the incorporation of energy-dense forages (potentially with supplementation) into final feeding stages of greater-aged calves would suggest that it is not unreasonable to surmise that positive shifts in the MUFA:SFA ratio can be realized under the model proposed in this report.

## *2.11 Energetics*

One of the components of current agricultural production systems that does not receive enough attention is that of energetics; the comparison of energy input to energy output as it relates to production efficiencies. Economics, environmental impact, carbon footprint and greenhouse gas emissions are the parameters frequently quantified to assess sustainability. However, should energy prices increase significantly in the future, either due to supply challenges or other economic drivers, many agricultural models will be under great pressure to remain viable. Data from an early study at the Brandon Research Centre is presented below to emphasize the consideration of energetic efficiency in Canadian beef production.

**Graph 3**: Estimated energy input and output of four pastures systems under rotational grazing. Scott et al, 2008

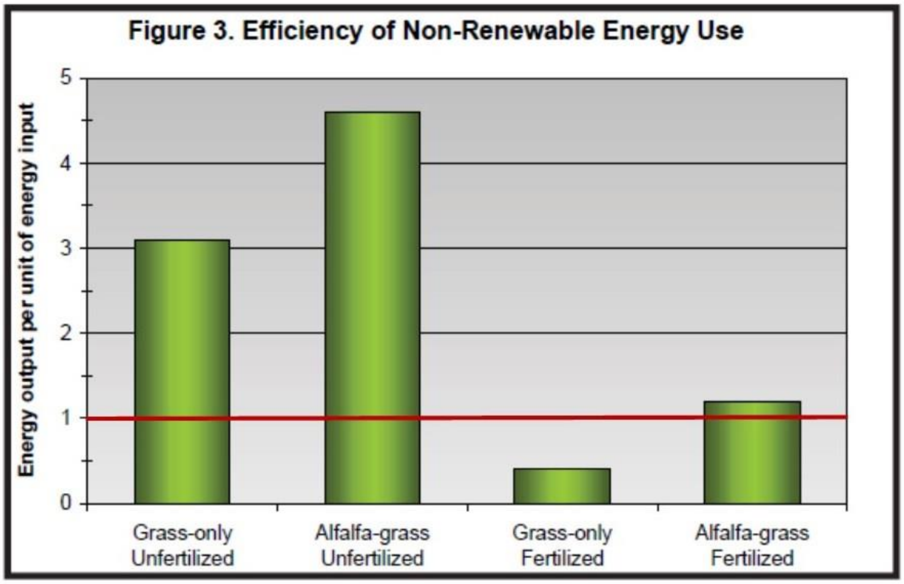


As mentioned in section **2.6** the ability for fertility capture under annual crop grazing was inadvertently discovered during long-term swath-grazing trials at the Brandon Research Centre (BRC). Nitrogen supply appeared to stabilize after 5-6 years of repeated application of synthetic fertilizer, to the point that no observed yield or forage quality reduction occurred in 5 seasons subsequent to the last application. The information presented in Graph 3, courtesy of an extension bulletin by Scott et al (2008) and based on data from Khakbazan et al (2009), demonstrates the differences in energy input and energy output from a previous, long-term grazing trial at BRC. The trial, conducted from 1995 to 2004, involved 4 main pasture treatments as outlined on the bottom axis. Unfertilized treatments received no application of synthetic fertilizer while fertilized treatments received annual spring applications based on full soil test recommendations from field samples collected the fall previous. Spring fertilizer application rates, based on N-P-K-S, were 99-26-23-7 and 32-30-20-11 for the grass and alfalfa-grass treatments respectively, averaged across all treatment years. Under both fertility treatments, pure grass (*Bromus riparius*) pastures and grass-legume pastures, containing 30 percent alfalfa (*Medicago sativa*) at time of seeding, were established at the start of the trial. All pastures were rotationally grazed with uniform exit grazing residues in each paddock being the management target, regardless of total forage production at entry across the four treatments and two replicates. This was achieved by adjusting stocking rate in each paddock twice weekly for the life of the trial.

Energy inputs for the trial included: fuel and lubricants, machinery, fertilizer, pesticides, and amortized infrastructure. Energy was reported as MJ/ha (MegaJoules per hectare) and was averaged over the 10 years of the study. Energy input into each system is represented by the blue bars on the graph. It is important to note that the only real difference between the fertility treatments, regardless of whether pure grass or grass-legume pasture, was the application of commercial synthetic fertilizer. As is clearly evidenced by the data, applied fertilizer constitutes the most significant component of energy input into a commercial grazing enterprise should it be a management consideration. Fertilizer, especially N fertilizer, accounts for a large amount of the total non-renewable energy input. Fertilizer was responsible for 93 percent of the total energy input for fertilized grass-only pastures and 75 percent for fertilized alfalfa-grass pastures. Therefore, removing the need for nitrogen fertilizer from beef forage production systems will become increasingly important as ongoing energy inputs become challenging.

Although several beef performance parameters were measured throughout the trial, the data reported in Graph 3 (page 57) represents calories of beef production in MJ/ha equivalents. As is demonstrated by the green bars, beef production (or in this case beef energy output), increased by both the inclusion of a legume component and by the application of fertilizer. However, in the case of fertilizer, additional output was much lower than the input required to achieve the extra production. The difference is more evidently displayed in Graph 4 on page 59.

**Graph 4**: Estimate energy efficiency of four pasture systems under rotational grazing, Scott et al, 2008



The above graph denotes the efficiency of energy input, whereby the ratio of energy input to energy output is demonstrated by the treatment bars. With 1:1 being energy equilibrium (represented by the red horizontal line), whereby each unit of energy inputted into the production system yields an identical unit of output, it is obvious that displacing the requirement for supplemental fertility is tantamount to achieving energetic efficiency. Even with significant improvement in livestock performance in a fertilized alfalfa-grass pasture over an unfertilized alfalfa-grass pasture, there is barely any benefit realized as energy output increases per unit of input. In comparison, the inclusion of alfalfa (or other legumes) in a grass-based system, without added fertilizer, reveals the greatest efficiency of all systems; achieving an output in excess of 4.5X greater for every unit of energy input. While an unfertilized grass-based system still attains demonstrable energetic efficiency, total beef production is much lower. Under perennial forage production this represents sustainability in many circumstances, and most certainly under good grazing management. However, owing to much lower overall productivity and significantly lower energetic efficiency than legume-containing pastures, long-term economic viability may be of concern. This will be dependent on additional expenses that are not related to energetic input and therefore were not included in this analysis.

Clearly, the application of fertility to a monoculture grass-based pasture is completely unsustainable from an energy perspective, with a input:output ratio of approximately 0.4:1. It is also questionable as to whether this is a sustainable model in annual feed and forage systems. Considering the inherent requirement for annual fertilizer input into annual crops for the supply of grain, forage, and straw into Canadian feedlots, the long-term sustainability and viability of this strategy, from an energetic perspective, must be challenged and alternative options explored.

The model being proposed in this report, due to limited nutrient removal and enhancements in soil physical and biological properties, has the potential to reduce energy input into beef feeding strategies in a very significant manner. In addition, should it be that the use of such a model, or a derivative of, can enhance marbling cell development in young animals further benefits will be realized. Reducing time to slaughter, as has been outlined earlier, will provide many advantages over current models. When considering the amount of energy input (feed, fuel and lubricants, machinery, infrastructure, hydro, etc.) that is required for the final stages of current beef finishing practices, any decrease in days on feed will translate to additional declines in total energy input.

In summary, the beef industry in general needs to place greater consideration on its energy footprint in order to better position itself against both rises in energy costs and potential criticism for inefficiencies that may exist.

## *2.12 Genomics*

There is an ever-growing body of knowledge regarding genetic and genomic influence in all areas of agriculture. While genetics is the study of heredity, genomics is defined as the study of genes and their functions. The main difference between genomics and genetics is that genetics scrutinizes the functioning and composition of the single gene whereas genomics addresses all genes and their inter-relationships in order to identify their combined influence on the growth and development of the organism. This discussion will be prefaced by a quote from Dr. Jamie Newbold, Ruminant Microbiologist with IBERS, whose current efforts are to map the genome of all rumen microbial species. In conversation with Dr. Newbold regarding the importance of grasping the greater concept of genetic contribution as it relates to beef production efficiencies, he stated: *"There are three genomes we need to understand; the genome of the plant, the genome of the animal, and the genome of the bugs in the rumen."* This was made in reference to understanding the complex relationship of: a) trait-specific animal genetic potential; b) contribution of forage quality to meta-biological gain as it relates to trait-specific breeding efforts; and c) influence of genetics and environment on rumen microflora. While animal and plant evaluations, selection, and management have benefited greatly from concerted effort and scientific knowledge of genetic potential in these fields there is not yet consensus regarding genetic influence over rumen microbial populations. That being said, there are a number of experts in the world who believe very strongly that the microbial community in the rumen is influenced far more greatly by host and maternal genetic expression than is currently accepted.

Benson et al (2010) concluded that gut microbiota can be understood as a complex, polygenic trait that is influenced both by host genomic loci (the specific location of a gene on a strand of DNA) and environmental factors. Their findings led to the summation that host genetic control was likely to be implicated in colonization of organisms important for ruminal fermentation. Weimer et al (2010) supported the theory of genetic influence on rumen microbial populations with a trial that suggested ruminal BCC (bacterial community composition) displays substantial host specificity. They determined that BCC could re-establish itself with varying successes when challenged with a microbial community optimally adapted to the rumen conditions of a different host animal. This was evaluated by swapping rumen contents in trial cows. Results were, however, inconsistent. Research from Herd et al (2014) in Australia, who have been investigating genetic influence on methane production in cattle systems, have concluded that there is some level of genetic control over methane emissions in beef cattle. Their data demonstrates enough genetic variation in methane emission traits such that the potential exists to reduce methane emissions in beef cattle through selective breeding. They have determined that genetic influence on the rumen microflora responsible for methane production (archaebacteria and protozoa) is a medium heritability trait. Since they have concluded that methane production is a heritable trait this demonstrates that there must be some intrinsic control over rumen microbial populations; at least in relation to those organisms involved in the production of enteric methane. Other work in Australia involves metagenomics, or the science of using sequencing techniques to study the microbial community as a whole in an effort to better understand which microbes dominate the rumen under certain diets and what they are doing. Although heavily focused on methane, these trials complement the broader efforts of other researchers in this field.

Investigators who support the notion of rumen microbial genetic control subscribe to the theory that influence occurs across stages of early life in young ruminants. Firstly is epigenetics, which represents genetic changes that can occur in utero to the fetus or in early post-partum calves due to nutritional and/or environmental influences. While these influences do not affect changes to the DNA sequence itself, external stimuli can impact proteins attached to the codons in the DNA sequence, thereby manipulating gene expression. Epigenetics can best be described as the study of heritable changes in gene expression that occur without a change in the genetic sequence. Ergo, the impact of nutrition and environment at a very early age can influence an animal's ability to express its true genetic potential. This effect is termed fetal programming or metabolic imprinting. Evidence of this is limited in beef cattle and was discussed briefly in section **2.9**. Under current Canadian production systems the model being proposed in this report is unlikely to provide significant influence in this area owing to the stage of gestation when energy-dense forages would be grazed.

The second opportunity exists between days 120 and 200 days of age in a young calf's life and is more applicable to the energy-dense forage grazing model. One investigator expressed confidence in that there were two finite periods during this time, between days 120-150 and days 180-200, when the potential for influence was greatest. Although evidence was not provided to support this assertion, it seemed clear their efforts demonstrated proof of concept. Other researchers were of the opinion that this physiological response could as yet not be so accurately determined. Regardless, data does exist that supports the principle of the impact of sustained energy intake on intramuscular fat deposition later in life at this early stage of development. In support of the discussion of this manifestation in section **2.9** recent research efforts from Gotoh and associates in Japan (2008) showed increases in IM fat content in *longissimus* muscles of cattle in separate trials. Elevated energy intake in calves up to 10 months of age resulted in IM fat percentage increases in these same animals at 26 months of age. This study demonstrated an increase to 10.3 percent versus 6.2 percent for the control group while a second in 2012 showed an increase to 13.2 percent from 9.4 percent in the control group. However, it is imperative to point out that these improvements were only observed in Wagyu cattle and not in the Holstein calves involved in the trials. No positive effect was seen in the Holstein calves, indicating an influence of breed. In relation to genomics and early adipocyte cell development, it is evident that animals must first possess the genetic potential for this to occur, and then be provided the appropriate environment for that genetic potential to be expressed. Similar distinctions will also exist for individuals within breed.

Moreover, it is important to realize that the same variability exists within the plant kingdom as well as the animal kingdom. Research in New Zealand has discovered 2 to 3-fold differences in WSC concentrations in plants within a standard population, as well as fructan levels up to 2X higher than the population median within varieties.

Additional observations from the Japanese trial in 2008 also support the influence of genetics on metabolic processes. The study refers specifically to the establishment of the pre-adipocyte cells that develop under the provision of elevated dietary energy early in life. As mentioned earlier pre-adipocyte cells are formed at the initial stage of differentiation from stem cells, and then differentiate again into true adipocyte cells and begin to accumulate lipids. Their results showed not only an effect on total lipid accretion later in life, but also in adipocyte cell diameter in energy-fed calves versus the control group. This increase in cell diameter was evident at 10 months and at 22 months of age, indicating very early influence in animals genetically pre-disposed to exhibit enhanced marbling potential. Overall growth and meat quantity, not just quality, were also markedly greater in the early-energy-fed groups, which was likewise attributed to the stimulus on genetic expression.

In addition, the expression of several genes related to intra-muscular adipogenesis (marbling potential) were measured to be significantly elevated in the high-energy-intake calves as compared to the control group in the study. This set included the SCD (stearoyl-CoA desaturase) gene, which is involved in the production of the SCD enzyme responsible for the desaturation of stearic to oleic acid. This is not surprising as there have been beef cattle genetic markers identified that result in deposition of softer fats like oleic acid. It is important to note that these markers were first identified in Wagyu cattle. As discussed earlier in section **2.10** the shift to more oleic acid in the lipid profile of forage-fed beef would be a measureable and significant improvement to eating quality and health benefits. Since it appears possible to enhance SCD gene expression and ultimately SCD enzyme activity with grain-based, high-energy early nutrition, it raises the question as to whether the intake of energy-dense forages can achieve the same result.

There is also some evidence that diets fed in utero and in early ruminal development do have impact on potential rumen efficiencies later in life. With respect to ruminal development in early post-natal and pre-weaning calves there are a number of researchers listed in this report who support the theory of early nutritional influence having lasting influence on BCC (bacterial community composition). Rumen development, to a certain extent, occurs as immunological responses to external stimuli. As one scientist commented, there is an education period for the immune system and rumen microflora are developed based on an immunological response. Some experts agree that the rumen can be 'coached' or 'conditioned' early in life to possibly develop desirable populations of rumen microflora for improvements in digestive efficiency later on. However, at this time, the theory is not broadly supported by scientific evidence and other experts question the claim. There is general agreement that genetics do have influence on the rumen microbial community, just a lack of consensus as to the degree of impact.

Should early life feeding of energy-dense diets in under 200-day calves truly incite positive genetic influence, then the resulting benefits discussed in this report could have profound implications for the Canadian beef industry. Furthermore, one scientist surmised that if these positive physiological responses could be effectively elicited through grazing of energy-dense forage at key developmental points then the retention of breeding stock benefiting from these impacts would have long-term consequences to herd performance over generations. The ability of energy-dense forages to succeed in achieving results in the area of lipid accretion still needs to be scientifically determined, as little effort has been made to date in this field of research.

# 3.0 CONCLUSION

As a result of the opportunity provided by the Nuffield program a significant amount of evidence has been provided in this report. This information has been brought forward as a combination of: a) personal knowledge; b) observations and discussions with international experts; and c) the collection of scientific and extension literature imparted to the author throughout the journey. Collectively, it supports the need for the consideration of viewing forages from a completely different perspective than is the current standard in the Canadian forage and beef industries. While a number of the concepts addressed can be backed by existing scientific knowledge and practical experience, it is as yet unknown whether similar observations are attainable in the Canadian environment. Furthermore a number of theories are raised that, although supported by experts in principle, are very early in investigatory stages or have yet to be entered into trial. Regardless, the findings of this report provide a compelling argument as to why alternative strategies must be explored. Moreover, there is real potential for specific forages, incorporated at key points in the beef production cycle, to have profound implications in everything from soil regeneration to digestive efficiency to the carbon footprint of the entire model. The point must be made that the Canadian beef and forage industries have nothing really to lose by trying. To quote Edwards et al (2007) from a review paper assessing the potential for high-WSC grasses to influence red meat production in New Zealand, "*Available evidence reveals substantial variation in livestock production responses, but the effect has never been negative*." Owing to the greater potential for WSC accumulation in the Canadian climate over the New Zealand environment it would suggest that there will be an even greater propensity for meta-biological gain to be realized by Canadian producers. Again, and this cannot be stressed enough, there is no risk in attempting to incorporate energy-dense forage production into our current systems.

Many statements have been made recently about the need for agriculture to become more bio-rational. The forage and grazing sector is well-positioned to address this philosophy from a sustainability/regenerative perspective, owing to the ability of the industry to incorporate diverse plant ecologies into production models. Shifting from monoculture agriculture and lending greater consideration to the biological benefits of mixes of diverse species contributing to the entire ecosystem and biome may become a critical component of livestock production in the future. In many production environments around the world there is a strong focus to enhance the contribution of forages in regards to beneficial influences on dairy and red meat production. There is a great deal of commonality in these regions regarding research priorities. These priorities include: a) increasing the nutritive value of forages without sacrificing yield; b) increasing the use of tetraploid cultivars; c) increasing the utilization of nutrient-dense, non-traditional species; d) the use of alternative species to rest and maintain health of principal grazing systems at appropriate times; and e) maintaining or increasing agricultural production (milk, meat, fat) while at the same time reducing environmental impact. The concept of integrating energy-dense forage grazing into current Canadian beef production enterprises addresses all of these priorities.

In addition, the strategy proposed in this report exemplifies almost every criteria agreed upon in the Global Round Table for Sustainable Beef Definition Document that was released in 2014. The model that has been outlined, and variations in adaptation approaches thereof, will serve to meet or exceed 28 out of the 30 production-based Criteria listed under the 5 Principles identified in the document. This may become an important consideration for determining research and production priorities for the Canadian beef and forage sectors if future policies dictates that criteria targets are to be met.

Only time will tell as to the effect of the inclusion of energy-dense forage intake into traditional beef production strategies in Canada.

## 4.0 RECOMMENDATIONS

The recommendation is most certainly for the consideration of a new approach to the utilization of annual forage systems in Canadian beef production. This will involve a multi-crop approach incorporating specific species capable of providing a highly metabolizable form of intake energy to ruminants under Canadian environmental conditions.

A prudent course of action, from the Canadian forage and ruminant sectors, would be to begin evaluation of the key points raised in this report that have the potential for significant implications toward improving current beef production strategies. Initially collaborative efforts between research and extension agencies, as well as producers and industry consultants, would be well-served to assess the production potential, including metabolizable energy components, of the plant species highlighted in throughout this report. Results from these studies, should they validate the hypothesis that these species are able to provide an enhanced supply of forage dietary energy, would then support proceeding to livestock-based evaluations. The findings from those investigations, ideally in a variety of production environments, would be useful in designing regionalized management strategies and production models that incorporate the use of these forages at the key production points outlined during this discussion. Comprehensive, multi-disciplinary studies would need to be initiated in order to evaluate both production and physiological responses related to the intake of these forages. Robust investigative techniques will be required to truly determine, for the classes of cattle previously described, if the opportunities put forward in this report can be realized.

It is hoped that the findings from this Nuffield study and the information presented in the resulting report provides the necessary incentive for such a course of action.

To end with a quote: “***Energy-dense forages have the potential for significant benefits to several aspects of the Canadian beef production model; when incorporated at key production points and true genetic potentials are realized***.” (But only if the right people ask the right questions, then pursue investigation to determine what those answers might be.)

# 5.0 GLOSSARY

AAFC – Agriculture and Agri-Food Canada
ADG – average daily gain
ADF – acid detergent fibre
ALA – alpha linolenic acid or α-linolenic acid
AFBI – Agri-Food and Biosciences Institute (N. Ireland)
BCC – bacterial community composition
BRC – Brandon Research Centre (Canada)
CLA – conjugated linoleic acid
CP – crude protein
CSIRO – Commonwealth Industrial and Scientific Research Organization (Australia)
DEPI – Department of Environment and Primary Industries (Australia)
DP – degree of polymerization
DHA – docosahexaenoic acid
DIP – degradable intake protein
DM(I) – dry matter (intake)
DNA – deoxyribonucleic acid
DPA – docosapentaenoic acid
EBLEX – English Beef and Lamb Executive Ltd. (UK)
EW – early-weaned
EPA – eicosapentaenoic acid
GMO – genetically modified organisms
GHG – greenhouse gases
HDL – high density lipids
IBERS – Institute of Biological, Environment and Rural Sciences
INTA – Instituto Nacional de Tecnología Agropecuaria (Argentina)
IM – intramuscular
LCPUFA – long-chain poly-unsaturated fatty acids
LDL – low density lipids
LFA - Lesaffre Feed Additives (France)
MLA – Meat and Livestock Agency (Australia)
ME – metabolizable energy
MJ - megajoules
MPS – microbial protein synthesis
MTT – Maa-ja elintarviketalouden tutkimuskeskus (Finland)
MUFA – mono-unsaturated fatty acids
N - nitrogen
NLMP – National Livestock Methane Program (Australia)

NDF – neutral detergent fibre
NPN – non-protein nitrogen
NSC – non-structural carbohydrates
(O)DMD – (organic) dry matter digestibility
PMR – partial mixed rations
PUFA – poly-unsaturated fatty acids
SARA – sub-acute ruminal acidosis
SLU - Sveriges lantbruksuniversitets (Sweden)
(S)OM – (soil) organic matter
SRUC – Scotland’s Rural College (UK)
SCD – stearoyl-CoA desaturase (enzyme) or Δ-9 desaturase enzyme
SQ - subcutaneous
TDN – total digestible nutrients
US – United States
USDA – United States Department of Agriculture (USA)
VFA – volatile fatty acids
WSC(s) – water soluble carbohydrate(s)

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# 7.0 APPENDICES

## *7.1 Expert Contacts*

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