PACIFIC NORTHWEST ANIMAL NUTRITION CONFERENCE

2025

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Heat stress effects on the dry cow and her calf; evidence to support cooling cows throughout the lactation cycle.

(This is an updated version of an article presented at the Southern Brazil Dairy Symposium in 2021)

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As ambient temperatures continue to rise globally and warm weather extends for more of the year, impacts of heat stress on the dairy cow become a greater threat to health and productivity. Historically, heat stress abatement has been focused on the lactating cow with good reason. Heat stress during lactation reduces milk yield, alters composition, lowers dry matter intake and adversely impacts health and reproduction. While sub-tropical areas such as the southeastern US are subject to heat stress much of the year, heat stress is often ignored in more temperate regions, yet those locations can experience significant periods of high temperature and humidity in the summer. Heat abatement involves actively cooling cows, usually through application of water via soakers and air movement using fans to dry the hide and remove heat as the water evaporates. A focus on the productive portion of the herd is logical, but there is increasing evidence that ignoring heat stress of the dry cow will lead to negative outcomes on productivity, health and even the offspring of those cows.

We have now completed extensive studies examining the impact of dry period cooling on various aspects of productivity and health. The basic design for those studies involves housing the animals in typical sand-bedded freestall barn with water soakers over the feed bunks. Those soakers cycle on automatically when temperatures exceed 70 ^{o}F for 1 min and off for 4 minutes. Fans, which come on at 72 ^{o}F, are placed over the stalls provide air movement to promote evaporation of the water from the cows backs and sides, thus cooling the animals effectively even in a humid environment. This active cooling system allows cows to maintain a constant body temperature and avoid heat stress. To initiate our heat stress treatment we simply shut off the fans and soakers to those groups of animals. Core body temperature increases by 0.8 to 1.2 ^{o}F in the absence of cooling, and that increment is maintained for the entire dry period in our study model. All cows are cooled after parturition, and all other management is the same before and after the dry period except for cooling.

Using this system we have answered a number of questions related to the impact of dry period heat stress on production and health. For example, heat stressed dry cows consume less feed than cooled herdmates, and they calve 3-4 days earlier. Both of these observations suggest a significant negative impact of heat stress on metabolism and placental function, which may explain the observed lower yield in the next lactation. However, metabolic variables such as circulating insulin, glucose and free fatty acid concentrations do not differ between cooled and heat stressed dry cows despite a 10% reduction in dry matter intake. Mammary growth is lower in heat stressed dry cows, likely as a result of altered endocrine status and the reduction in total gestation length and thus duration of mammary regeneration. Although the lower DMI with dry period heat stress partially explains the poorer performance in the next lactation, the physiological impacts on placental function and mammary growth are the primary factors in lower yield.

Late gestation heat stress also alters immune status of cows both directly in the dry period and indirectly during the next lactation. Cooled dry cows have greater leukocyte proliferation relative to heat stressed dry cows, and the antibody response to an antigen is lower in cows that are heat stressed when dry. These results indicate that heat stress has a direct, depressive effect on immune status relative to active cooling. After calving, despite being actively cooled, cows that were heat stressed when dry have lower innate immunity ass indicated by lower circulating neutrophil concentrations in early lactation and altered neutrophil gene expression consistent with poorer ability to detect and eliminate pathogens. In fact, cows that were heat stressed when dry had lower phagocytic action and oxidative burst capacity than cooled dry cows, even though the heat stress ended at calving. Collectively these observations support the idea that immune status is improved with dry period cooling.

Given the results summarized above, other questions arise with regard to actual application of dry period cooling. For example, do cows require cooling for the entire dry period? Do late gestation heifers, about to calve for the first time, require cooling? Does dry period cooling improve disease and other performance indicators such as reproduction? In a recent study we cooled cows for the initial half of the dry period, the second half, or the entire dry period and compared their productivity to a group that were heat stressed the entire dry period. Compared with cooling the entire dry period, cows that were heat stressed in the first or second half of the dry period had lower yields in the next lactation, essentially the same as cows that were heat stressed for the entire dry period. Our interpretation of those results is that any heat stress during late gestation is detrimental to future productivity. As for late gestation heifers, we compared cooling for the final 60 days of pregnancy to heat stress, and found that the cooled heifers made more milk in their first lactation than the heifers that were heat stressed, similar to reposes observed in older cows. Finally, in a field study we compared records of cows that were dry in the summer with those dry in the winter months on a large commercial dairy in Florida. Cows that were dry in the summer had greater incidence of mastitis, retained placenta and respiratory disease, and made less milk than herdmates dry in the winter. Cows dry in the summer also took 5 days longer to become pregnant relative to winter dry cows, indicating that being cool when dry improves health and reproductive performance as well as milk yield.

Heat stress in late gestation profoundly influences the cow, but also has significant negative implications for the developing fetus, both early in life and at maturity. Calves born to cows that are heat stressed are born at lower weights, wean at lighter weights, and have poorer passive transfer from colostrum than those born to cooled dams. The drag on growth persists through puberty as calves heat stressed in utero are lighter and shorter at 1 year of age. They also tend to leave the herd sooner than their herdmates from cooled dams. Ultimately, the calves from heat stressed dams produce less milk in their first lactation and that reduced productivity extends to their second and third lactation as well. Heat stress in utero causes fetal programming impacts beyond the lower productivity described above. The calves born to heat stressed dams have reduced survival when compared to calves from cooled dams; cooled calves are in the herd an extra 350 days versus the heat stressed calves. And the heat stressed calves pass along the poorer performance to their offspring, with their calves being less likely to remain in the herd than those from cooled dams.

If these limitations on productivity and health were carried through at the herd level, one might expect an effect of birth season on longevity and performance, and indeed that occurs. We analyzed records from commercial herds in Florida and California across multiple years, and identified cows that remained in the herd for five or more lactations. A clear pattern emerged to indicate that heifers born in the cooler months of the year had a greater likelihood to survive to the 5th lactation or beyond. When the reasons cows left the herd were examined it was also clear that the normal issues of mastitis, reproductive competence and feet and leg problems explained the exit of cows across the board; it's just that those problems occurred more frequently in the animals born in the summer versus the winter and led to shorter herd lifespan.

Our most recent efforts have focused on the impact of heat stress on placental function under heat stress, as that organ is the nexus for effects on the dam and developing fetus. Whereas the primary function of the placenta is to provide nutrients and gas exchange from the maternal side to the fetus, it also serves as to exchange heat with the fetus and the dam and as a source of hormones that impact the dam, particularly those associated with mammary development in late gestation. Concentrations of progesterone and estrogens are reduced with heat stress in late gestation, as are other pregnancy specific hormones that may affect mammary growth. Another hallmark of placental dysfunction is apparent at calving, as the number of placentomes (as indicated by cotyledon number) are reduced by half with heat stress relative to cooling. These structural changes in the placentas of heat stressed dams likely limit the capacity for nutrient and gas exchange, and along with the shorter time in utero for calves from those heat stressed mothers may drive the lower growth observed at birth and beyond.

The studies described in this paper strongly support the idea that dry cows require cooling, for the entire dry period, in order to maximize performance and health in the next lactation. We have estimated that lack of cooling of dry cows costs the US dairy industry approximately USD$ 800 million annually when only the effects on the cows are considered. A more recent study included the effects of in utero heat stress on calf loss and decreased survival and that increases the estimated losses to over USD$ 1 billion annually. Therefore, the effects of heat stress in late gestation need to be considered and managed to improve the health and performance of the cow and calf, which should realize a significant improvement in the financial status of the farm as well.

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Behind the Scenes of the Inland PNW Pasture Calendar
What were we thinking? Why?

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Grasslands are a biome of grasses and forbs adapted to conditions between wet forests and dry deserts, found on all continents except Antarctica, and represent about 40 % of Earth's land surface. In North America, our grasslands are referred to as "prairies", which are temperate, typically drier than surrounding areas with cold winters and hot summers. Tropical grasslands have distinct wet and dry seasons while being warm year-round. Each of the 50 states has some type of prairie composition, ranging from the short-grass prairie to the tall grass prairie to the dry grassland steppe in Alaska and northern Canada to the subtropical dry prairie in Florida. One common characteristic of all grasslands is their creation and maintenance with natural wildfires or domestic, prescribed fires. Depending on location, environmental factors and adapted species, fires may naturally or prescribed burned every few years, to five – 10 years, or up to 40 years in North America. Wildland fires have a rejuvenating effect because most species are perennial with deep root systems and higher in sugar concentration than many other plants. Thus, they have reserves of energy stored in crown (stubble) and roots for rejuvenation. Fire, overgrazing, tillage, replanting introduced species, are some of the disturbance factors imposed naturally or by design on North American grasslands.

The Inland Pacific Northwest Pasture Calendar (PNW Bulletin 708), the 'Calendar', is designed for the Inland region of Idaho, Oregon and Washington, to recognize the importance of native rangelands and introduced tamegrass pastures for "… environmental sustainability while providing animal products and higher quality of life for those who live there", page 4. The Calendar is a joint Extension and USDA-NRCS effort from all three states. A USDA-WSARE grant supported this endeavor throughout, even though COVID-19 changed timelines and educational outreach plans. The intended audience for the Calendar includes, but not limited to: regional livestock producers and ranchers, hay producers, animal nutritionists, crop consultants, wildlife conservationists, NRCS agents, Extension faculty and anyone else interested in range and pastures. The basis of this Calendar is its predecessor PNW Bulletin 699, The Western Oregon and Washington Pasture Calendar (2017). The scientific foundation principles do not change but changing environmental conditions and stress factors, altered and expanded some component constituents and timing when growth or other events would occur.

The Calendar is composed of eight Introduction Chapters and 18 Appendix Chapters. The eight introduction chapters provide the scientific foundation of perennial cool-season grass growth and development we found and confirmed from research conducted by Irene Stuckey "Seasonal Growth of Grass Roots" in American Journal of Botany, 1941. She compared grass root growth and shedding of 11 perennial cool-season grass species and varieties during spring, summer and autumn growth periods. She did not investigate what these grasses did during winter dormancy. We confirmed her results for about half of her test species, plus other perennial cool-season grasses adapted and grown in PNW pastures, that she had not evaluated. That was our contribution to better understanding the below ground cycle of these plants, setting up the full development of the Calendar. To complement the below ground root growth – shedding cycle, as shown as Figure 1, page 10 We also overlayed typical above ground growth from well managed pastures in the PNW. We recognize that overgrazing reduces stand vigor, plant and soil health, productivity, weed invasion, nutrient imbalances and quality losses. The overarching goal is to minimize overgrazing, promoting productive and sustainable range, dryland tame, irrigated and sub irrigated pastures in the Inland region.

The principles supporting the Calendar involve recognizing how and when pasture grasses grow within the different NRCS Major Land Resource Areas (MLRA's) in USDA Agriculture Handbook 296. Within the Handbook, each MLRA contains the following information: Area Identified, Physiography, Geology, Climate, Water, Soils, Biological Resources and Land Use. The Calendar MLRA discussion was adapted and expanded to: Natural Features, Environmental Factors, and Challenges (Introduction Chapter 4). The Calendar recognizes the challenges the target audience faces and provides some management insights to address those in relationship to environments, pastures and grazing. The Inland region encompasses 13 MLRA's with two (MLRA 9 and 43-44) shared among the three states. Idaho and Oregon share MLRA's 10, 11 and 25. Oregon and Washington share MLRA's 6, 7 and 8. Washington has five MLRA's (6, 7, 8, 9, and 43-44) while Idaho has seven MLRA's 9, 10, 11, 12, 13, 25 and 43-44) and Oregon has all 13 MLRA's (6, 7, 8, 9, 10, 11, 12, 13, 21, 23, 24, 25 and 43-44) (Introduction Chapter 7). We combined MLRA 43 and 44 because these represent the mountainous regions and valleys, which provide special characteristics and challenges. State maps highlighting MLRA's are depicted in Introduction Chapter 5.

Introduction Chapter 6 presents ten Growth Periods of grass root and above ground growth, starting with semi-dormancy, which occurs during the summer heat when roots are shedding, and above ground growth is nil. From mid-August through September, new apical meristem growth and first generation of roots are initiated and steady regrowth occurs with shortening daylengths and cooling autumn temperatures. Following the fall flush growth, growth declines as soil temperatures decrease to 41^0 F the transition into winter dormancy, Growth Period 4 when all active plant growth stops and root shedding occurs. Only spring or fall seeded perennial grasses, during the first winter dormancy period, do not shed roots, as roots will retain white coloration then. In future Growth Period 4 cycles, root shedding will occur. Post winter dormancy soil temperatures warm to 41^0 F when Growth Periods 5a and 5b initiate new spring root and above ground growth. This is when the second generation of root growth occurs. Rapid pasture growth follows as 6a and 6b, when cool soils transition into warmer soils with maximum daily growth and spring flush occurs. It should be noted that few to no new apical meristem development occurs during 5 and 6 Growth Periods but builds pasture stands and yields based on tiller development in the fall and how these were managed from Growth Period 2 through 4. As the flush ends, pasture grasses transition again into a slowing growth period because roots are about to transition into shedding rather than growth. Once roots transition into shedding, which occurs during Growth Periods 8, 9 and 10, above ground growth greatly reduces but under irrigation will likely not reach full summer dormancy. Lower than recommended grass stubble heights will increase soil temperatures from 10 to 20^0 F higher than when a canopy of leaves covers and protects the soil surface. Through managing pastures, based on the principles presented in the 18 Appendix Chapters, pasture will easily transition in Growth Period 1 and 2, will rejuvenate for another productive cycle again.

Chapter 7 presents the Growth Period responses for each MLRA within each state. Each bi-weekly period provides the growth and development of 'average or dryland' and 'optimal or irrigated'. These values should be considered an average within an MLRA and microclimates within maybe different by plus or minus one Growth Period on any calendar date period.

Finally, Chapter 8 presents the ‘essentials’, specific topics included are: What is the grass doing? Environmental effects. Management needed, and Things to avoid. This section provides an overall summary of the Calendar basics and recommendations that should be useful to anyone in the target audience and others.

The 18 Appendix Chapters are designed to provide greater details regarding pasture integration (chapters 1 and 2), agronomy focused (chapters 3 – 6), animal science focused (chapters 7 – 11) and systems focused (12 – 18). There were 20 co-authors, collaborators, colleagues, who spent countless hours, days, weeks, months and years developing the Calendar. We are all helpful this publication will support sustainable pastures, for many decades, in the Inland PNW region. Good Luck.

Appendix Chapter 10: How grazers change the pasture environment

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This paper is an authorized reprint of Appendix Chapter 10 from PNW 708 Inland Pacific Northwest Pasture Calendar, Washington State University, Oregon State University, and University of Idaho

There is a truism for pasture and grazing management, "You get what you manage for." If you overstock or more likely allow continuous grazing, you will shift plant composition and form to grazing-resistant individual plants and species. Understocking or grazing with low stock density can create patch grazing patterns with some plants grazed too close and often, and some areas and plants that are not grazed. Sowing a pasture with the "best variety of grass" doesn't ensure long-term success. Although using good genetic resources is recommended, they will be overcome by poor grazing management in a few years. A pasture that resembles a golf green before seeding with a best new variety will still look like a golf green later if management does not change.

The converse can also happen. When good grazing management was applied on a previously continuously grazed pasture, we observed an obvious shift in plant composition from Kentucky bluegrass to orchard grass, meadow brome, tall fescue, and several legumes over three years. These more desirable species and plants existed in the pasture composition but were unable to be productive, with significantly reduced vigor. When plants were allowed to recover photosynthetic capacity from rest and buildup of carbohydrate reserves in the stubble and crown, plant vigor improved.

Different species require different stubble heights or residual—remaining vegetation after grazing—to 1) maintain photosynthetic capacity, 2) allow the growing point, apical meristem, to continue tiller extension, and 3) extend root growth. For example, perennial ryegrass will maintain only three leaves and is resistant to grazing, so the recommendation is to begin grazing at the 3-leaf stage on the majority of tillers. In contrast, smooth bromegrass will maintain many leaves and the recommendation is for longer rest between grazing events. On timothy at heading, 18 leaves have been counted per tiller prior to hay harvesting. Orchard grass is intermediate, but the leaves of this bunch grass stand erect and require a 4 to 5-inch stubble height to capture enough photosynthetically active light (figure 1) to remain vigorous.

Good grazing management positively impacts plant vigor. Vigorous plants will have deeper and more abundant roots. This results in more efficient water and nutrient uptake, and more effective photosynthesis. Better grazing management results in better pore space and water infiltration, more carbon sequestration, and improvement in other soil properties.

Grazing animals exert pressure on the ground comparable to crop tillage with agricultural machinery. The soil under pasture can be compacted and there is little opportunity to mitigate poor soil physical conditions through tillage. Hence, it is important to understand the effects of grazing on physical soil properties and how this affects pasture growth and composition.

Grazing wet pastures will cause soils to be compacted to some extent, even those managed to minimize soil physical degradation. However, the magnitude of this compaction is usually small, and limited to the upper 2-6 inches of the soil. Compaction to greater depth, and other negative changes in physical soil properties, are more likely in recently tilled, wet soils.

Grazers affect how plants grow, and plant response to defoliation affects how grazers graze. There is variation in chemical composition and thus nutrient concentration within the vertical distribution of forage available to grazers. The proportion of leaf material decreases, and the proportion of stem and dead material increases resulting in reduced nutrient concentration as the animal grazes progressively down through the sward. Grazing modifies plant morphology and chemical composition. Repeated defoliations of the same area will result in a reduction of bite mass, intake rate, and crude protein and sugar content, but an increase in structural carbohydrate content of the material ingested. Thus, increased grazing time and decreased bite mass common on short swards as compared with taller swards, as well as increased rumen fill and increased amounts of energy gained from rumen fermentation end products, were found after longer regrowth of pasture (Chilibroste et al., 2000).

Performance of high-producing livestock, such as lactating dairy cows or finishing cattle, can be limited by forage intake. Forage intake is primarily a function of biting rate, grazing time, and dry matter (DM) intake rate:

> Forage intake = biting rate (bites/minute) x grazing time (minutes/day) x intake rate (grams DM/bite)

Cows work hard seven days a week, 365 days a year. Their survival depends on it. They also belong to the cow union, however, and will not graze more than about 12 hours per day! They must also have time to ruminate or “chew their cud,” meaning they regurgitate their food and chew it again.

There is also a limit to how many bites animals can take per minute. High-producing dairy cows may have biting rates of up to 60 bites per minute (40,000 bites per day), while low-producing cows may take only about 25,000 bites per day.

With limited grazing time and bites per minute, animals must maximize the amount of intake per bite. If they do not get enough sustenance in 12 hours, they will lose weight or exhibit decreases in production. Sward height and mass affect bite size and intake rate. A pasture must have at least 2,000 pounds of forage DM available for an animal to realize 100 percent of its intake potential (figure 2). Thus, managing pastures to maintain proper sward height and density can influence grazing behavior for optimal intake.

Your goal for grazing animals is to optimize intake. Several animal and pasture factors influence intake rates. As a manager, you can manipulate these factors to improve intake. Keep the following factors for bite size and sward characteristics in mind (Crane et. al. 2010):

Bite size:

- Bite size (ounces of forage dry matter per bite) has a greater influence on intake than does bite rate or grazing time.
- Bite size increases with forage quality and leaf density.
- At a feeding station, cattle graze in horizons from the top of the sward to the soil surface. Higher horizons provide deeper, heavier bites.

Sward characteristics:

- Optimal intake on pastures is often limited by herbage height (low vertical density). As sward height decreases, bite size declines and grazing time must increase. Conversely, intake on rangelands is limited by herbage density (low horizontal density).
- On grazed pastures, bite size and intake generally increase with forage abundance and height. However, animal gain has not been shown to necessarily increase with the height of grass. Digestibility often decreases as forage height increases. Additionally, lodging and trampling are more likely to occur and may decrease access to leaves of forage plants.
- The presence and accessibility of leaf material are both important factors in forage quality. For example, switchgrass has a lower proportion of leaves to stems than bermudagrass, but it produces better cattle gains because leaves are more accessible (taller).
- Large herbivores are at a disadvantage when grazing short swards because each bite represents a smaller portion of daily requirements.
- Animal diets are higher in quality than the overall quality of the pasture because animals can select leaves over stems and live portions of plants over dead portions.
- Cattle will select “normal” over lodged swards, but it is possible to maintain intake rates on lodged swards.

Good grazing management will improve livestock productivity as measured by average daily gain or milk production. For example, Abrahamse et al. (2008) confirmed that increased pasture allocation frequency from once every 4 days to once a day improved milk production in grazing dairy cows, especially when the amount of pasture availability was high. This was mainly the result of a change in grazing behavior, resulting in an increase in pasture dry matter intake. Concentrations of crude protein and sugars decline with each day in the same pasture as livestock selectively graze the most desirable plants first, while concentrations of neutral detergent fiber and lignin increased each day of continuous pasture grazing.

Summary

Good grazing management affects plant species abundance, plant vigor and growth characteristics of pasture plants. Good grazing management maintains plant vigor, which results in deeper and more abundant roots. This results in more efficient water and nutrient uptake, and more effective photosynthesis. Better grazing management results in better soil pore spaces and water infiltration, more carbon sequestration, and improvement in other soil properties. These practices influence how grazers affect the environment.

Intensive management and rotational grazing systems can optimize production per livestock unit and per acre. Intensive grazing management allows for abundant forage or pasture height which affects bite size, the major factor controlling pasture intake. If a grazing manager allows livestock to regraze a pasture or overconsume the forage by continuous stocking, as pasture height decreases:

A. Bite size decreases
B. Biting rate increases
C. Grazing time must increase

Although forage dry matter intake can be maintained temporarily by the grazer adjusting with the above rates in B and C, there are physical limits to these relationships and soon animal production becomes limited. Grazing animals don't plan for the next days feed, they just eat the best feed available until it is gone. Grazing managers should plan for the grazers and allocate forage to them for optimal livestock production.

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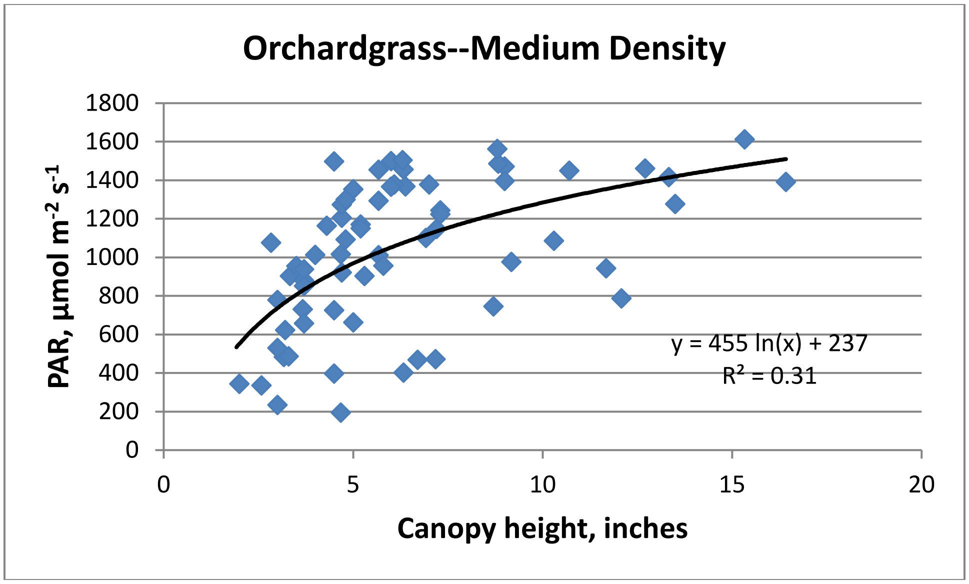

Figure 1. Photosynthetically active radiation (PAR) intercepted by Dactylis glomerata canopies as a function of canopy (sward) height in medium canopy densities across 2 growing seasons and 2 sites in south-central Idaho (Shewmaker and Hooper 2013).

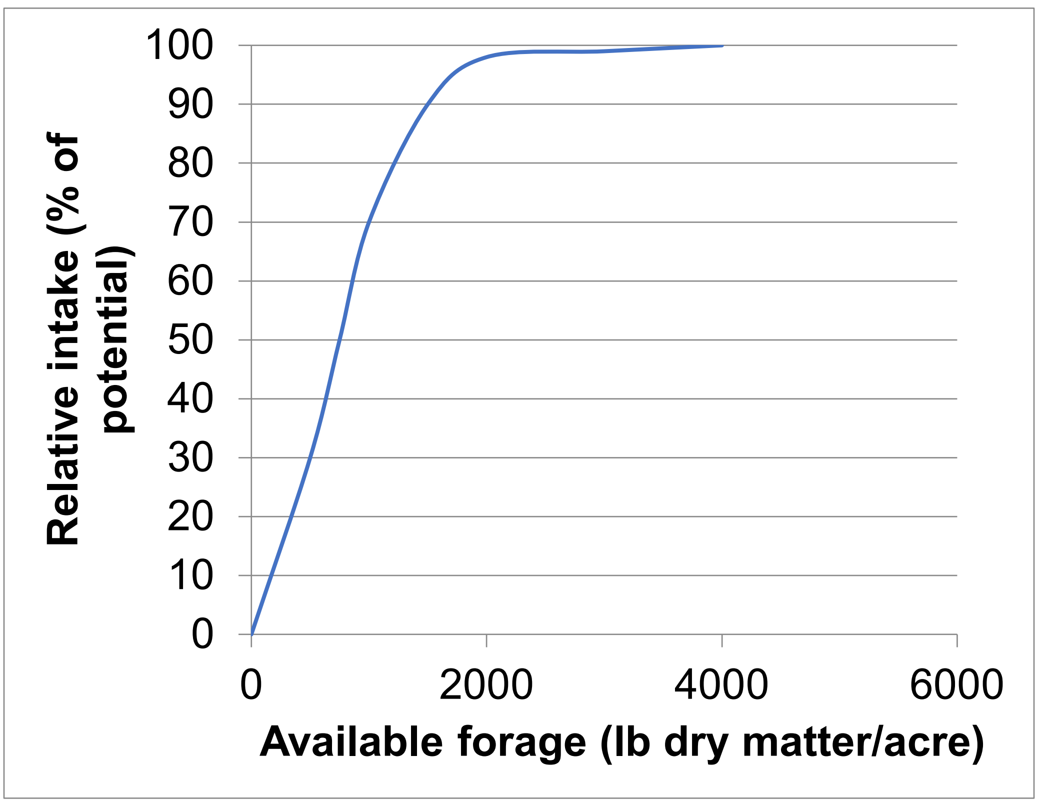

Figure 2. Availability of forage affects animal dry matter intake. (Adapted from Martz, Tate, and Gerrish. 1999. Meeting nutritional needs of livestock from pasture. In Gerrish, J. and C. Roberts, eds. Missouri Grazing Manual. MU Extension, University of Missouri-Columbia)

Matching Pasture Production and Animal Demands

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Inland Pacific Northwest Pasture Calendar, Appendix Chapter 1, reprinted by permission of Washington State University Extension

Introduction

The amount and quality of forage produced by pastures changes throughout the year due to seasonal differences in temperature and moisture, and physiological changes that occur in maturing forage plants. Forage production often does not line up with animal feed requirements throughout the year. This paper will cover how the production and quality of different types of forage plants change over the year and how you can better match animal demand and plant production.

Forage Production

Plant growth requires the availability of moisture, heat, and sunlight. These resources tend to change over the seasons. In many locations around the globe including the intermountain west, moisture tends to be scarce when heat and sunlight is plentiful and vice versa. Different groups of forage plants have developed different adaptations and strategies to manage limited resources. These different strategies result in different seasonal patterns of growth for cool-season vs. warm-season species, grasses vs. legumes, and annuals vs. perennials. Adjusting the amounts of these different types of forages on the farm can help achieve forage production that is better matched to animal demand (Figure 1).

Cool-season species are adapted to grow well when temperatures are low, but water is plentiful and can be used efficiently. Higher temperatures increase evapotranspiration rates so a plant has to use more water to grow. Cool season perennial grasses can begin growing when temperatures are around 41 °F (4.4 °C) and are most productive when temperatures are between 60 °F (15.6 °C) and 80 ° F (26.7 °C). These grasses grow fastest when temperatures warm up in the spring. When temperatures peak in the summer, cool-season grasses are adapted to go dormant to survive limited water avail- ability. Even with irrigation, growth will slow during what is often referred to as the “summer slump.” Production increases again when temperatures begin to cool in the fall.

Cool-season winter annuals primarily grow in the fall and spring, but compared to cool season perennials, the growth of annuals is shifted more toward the winter. This means they can be used to provide extra forage early in the spring and later in the fall, extending the grazing season and reducing the need for hay.

Perennial legumes have deep tap roots that help them reach water stored deep in the soil profile, so they can maintain higher growth rates during the heat of the summer. Legumes such as clover and alfalfa tend to prefer warmer temperatures than cool season grasses. Legume growth follows a pattern that is similar to cool season grasses, but it begins later in the spring, ends earlier in the fall, and is more uniform throughout the summer, with a smaller drop in production in the heat of the summer.

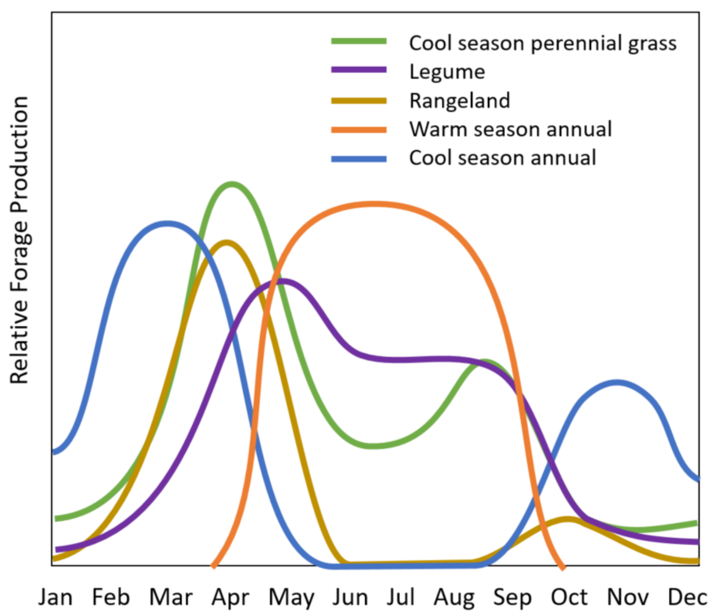

Figure 1. Seasonal variation in forage production for groups of forages. Different types of forages are productive at different times of the year.

Warm season species have adaptations that allow them to use water more efficiently during the summer. This allows them to take advantage of warm temperatures and abundant sunlight during mid-summer. Growing some warm season forages can help ensure that plenty of forage is available during the summer when cool season forages decline in productivity.

Rangelands are a source of forage for many livestock producers in the inland Pacific Northwest. Range adapted plant species often have a cool season growth strategy that allows them to utilize water from winter precipitation as the weather warms in the spring. In many areas, spring growth has largely completed by June because the plants run out of water. Fall forage production is dependent on precipitation and is often minimal. While forage production on the range occurs during a short time period, this forage is often utilized over a more extended period.

Forage Quality

Forage quality depends on several interacting factors including temperature, forage maturity and leaf to stem ratio. Because forage quality declines as plants grow and mature (Figure 2), producers must balance trade-offs between forage yield and quality. Management factors including the timing and height of cutting or grazing can be used to help maintain more consistent forage quality.

Temperature is the most consistent factor controlling forage quality. During the high temperatures of midsummer, forage quality declines along with productivity of cool season perennial grasses and legumes during the "summer slump". While quality changes in response to temperature occur within species, warm season species generally have lower quality than cool season species.

The tissues of forage plants differ in their forage quality. Leaves, where photosynthesis takes place, are generally high in protein because the machinery for photosynthesis is high in protein. Stems are low protein and high in fiber to fill their role in structurally supporting the leaves (Figure 3). Because of these differences, a leafy plant will have higher quality than a stemmy plant.

The ratio of leaves and stems changes as plants grow and mature (Figure 3). During initial growth or regrowth, leaves are preferentially produced so that the plant can photosynthesize. Next, the plant begins to produce stems to hold new leaves above the canopy. Eventually, leaf production begins to level off once the plant has a full canopy because higher, newer leaves will shade lower, older leaves, causing older leaves to die. Perennial ryegrass, for example, will have at most three leaves per stem. The timing of these changes differs between species. Cool season grasses will have about 50 % leaves and 50 % stems at the boot stage, while this will occur at the bud stage for legumes.

Both leaf and stem tissues decrease in quality as they mature due to changes cell wall composition. Cell contents are highly digestible and largely made up of non-structural carbohydrates, as well as fats and proteins. Cell walls are structural and made up of slowly digestible and indigestible compounds such as cellulose, hemi- cellulose and lignin. Primary cell walls form when cells first develop, but secondary cell walls form after the cell has grown to its final size and begins to mature. When secondary cell walls form, the amount of indigestible material accumulates including increased lignin in legumes and increased silica in cool season grasses (Figure 4). The quality of forages declines as they mature, but yield increases because the forage is growing.

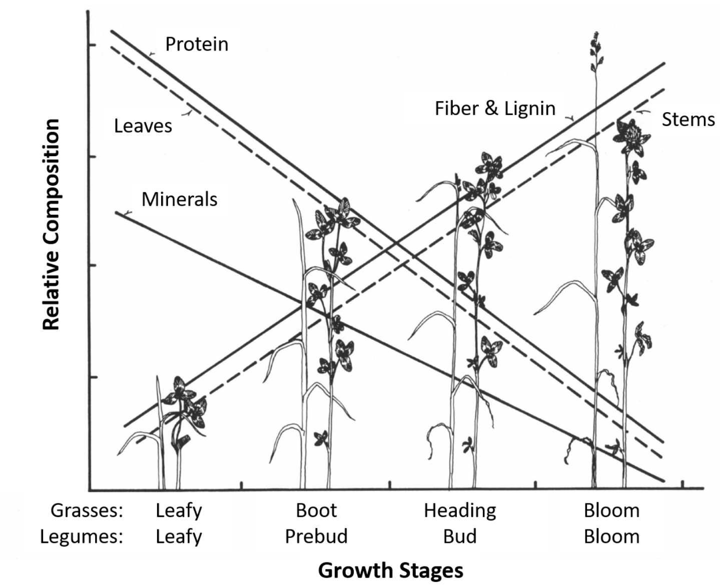

Figure 2. Relationships between forage maturity and quality. Source: Virginia Cooperative Extension, published in Blaser, R., R.C. Hammes, Jr., J.P. Fontenot, H.T. Bryant, C.E. Polan, D.D. Wolf, F.S. McClaugherty, R.G. Klein, and J.S. Moore. 1986. Forage–animal management systems. Virginia Polytechnic Institute, Bulletin 86-7.

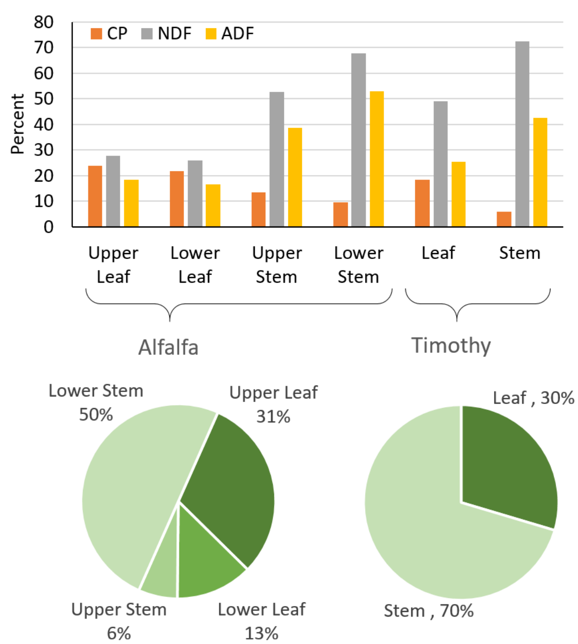

Figure 3. Distribution of forage quality throughout the plant. Top: Crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) percentages for leaves and stems. Bottom: Relative contribution of leaves and stems to whole plant biomass. Alfalfa was separated into upper (last five internodes of each stem) and lower portions before leaves and stems were separated. Source: Collins, M. 1988. Composition and fibre digestion in morphological components of an alfalfa-timothy sward. Anim. Feed Sci. Tech. 19:135–143.

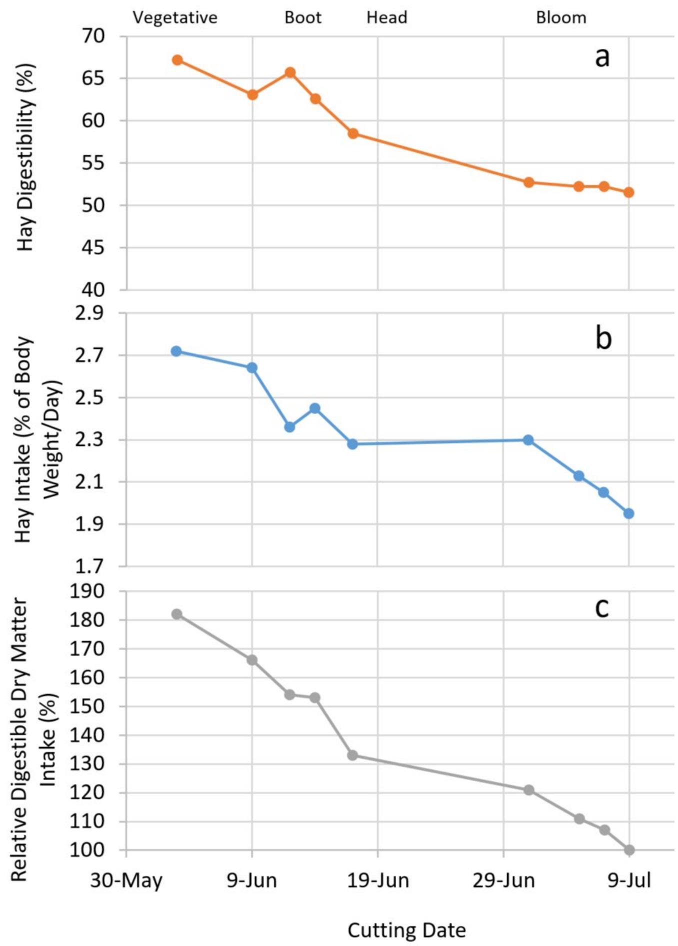

Figure 4. Hay digestibility (a), intake (b) and the relative intake of digestible dry matter (c) for grass hay harvested at nine different cutting dates spanning the vegetative stage to late bloom. Source: Stone, J.B., G.W. Trimberger, C.E. Henderson, J.T. Reid, K.L. Turk, J.K. Loosli. 1960. Forage Intake and Efficiency of Feed Utilization in Dairy Cattle. J. Dairy Sci. 43(9):1275-1281. https://www.sciencedirect.com/science/article/pii/ S0022030260903143?via%3Dihub

Successful forage producers find a balance between yield and quality that meets the needs of their operations while also maintaining the health of their plants. The best time to graze or harvest is generally when the forage has reached a peak growth rate, but before it shifts to reproductive growth. When pastures are grazed, it works well to have a target maximum height when grazing is started, and a target minimum height when animals are moved to another paddock. The target heights will depend on species, but for many species grazing should start at 8 to 10 inches and stop at 4 inches (Table 1). When harvesting hay, the best balance between yield and quality is when grasses are in the boot stage, and legumes are in the late bud stage. Forage quality is unevenly distributed throughout the plant: the tops of plants are primarily high-quality leaves, while the lower portions of the plants are mostly fibrous stems (Figure 3). Cutting or grazing height will affect the quality and yield of forages. Raising the cutting height for hay will lower yield, but increase quality because more low quality forage is left in the field. Animals that are allowed to selectively graze in a field or paddock over several days will consume the highest quality forage first. Over time, the quality of forage consumed will decrease until the animals are moved to a new paddock. Fluctuations in forage quality can influence animal performance and can be seen in fluctuations in milk production in dairy cattle. Animals will consume more uniform amounts and quality of forage if they are in a paddock for a shorter period of time.

Table 1. When to begin and end grazing based on forage plant height.

	Forage height, inches (cm)	
Species	Begin Grazing	End Grazing
Tall growing cool season grasses and tall growing legumes	8 – 10 (20 – 25)	4 (10 cm)
Ryegrasses	6 – 8 (15 – 20 cm)	2 (5 cm)
Short growing cool season grasses and legumes	4 – 6 (10 – 15 cm)	2 (5 cm)
Warm season grasses	12 - 14 (30 – 35 cm)	4 – 6 (10 – 15 cm)
Cereals	8 – 12 (20 – 30 cm)	3 – 4 (7.5 – 10 cm)

Adapted from Undersander, D., B. Albert, D. Cosgrove, D. Johnson, and P. Peterson, (2002). Pastures for Profit: A guide to rotational grazing (A3529). Cooperative extension publishing. https://learningstore.extension. wisc.edu/products/pastures-for-profit-a-guide-to-rotational-grazing-p96

Perhaps the most important factor in achieving success in utilizing improved pastures is the thought process by which grazing/feeding programs are developed. The following are some key points to consider: In achieving optimum productivity (with grazing animals) in forage-based systems, producers of the major ruminant species all have the same general goals geared toward profitability: 1) feed economically; 2) reduce reproductive failure; and 3) keep the livestock healthy. The goals are straight forward, but each has unique animal demands attached to it. To realize success in productivity, producers have at their disposal best management practices and technologies that can assist in supporting their goals. While the major ruminant species, cattle [beef and dairy], as well as small ruminants [sheep and goats] generally respond similarly to management strategies, it is essential to apply the technologies as appropriate to the various classes of animals (age, maturity, physiological status, time in the production cycle) as a subgroup within each species to match the nutrient requirements to the nutrient availability of the pasture at various times throughout the production cycle.

Recently, producers have become aware of the fact that providing nutrients to pregnant females at strategic times during gestation can influence productivity of the offspring after birth. This concept called epigenetics or commonly referred to as "fetal programming" has been shown to influence productivity later in life of both male and female offspring. Figure 5 shows the times in gestation during which key development of economically associated traits occur and it is apparent that maternal nutrition can affect muscle and fat development that in turn play an important role in both yield and quality of beef.

Another key element when determining if the nutrient demands of a ruminant are being met by the available forage is the recognition that in essence ruminant feeding programs are geared toward providing nutrition to the rumen microbes that in turn provide nutrition to the animal (i.e. energy and microbial protein). Meeting the rumen microbe's requirement for protein and energy will ensure adequate delivery of nutrients to the host (i.e. cow, sheep, goat). Likewise, correcting for nutritional imbalances at the rumen microbe level is essential for optimum productivity.

When the nutrient requirements of grazing livestock exceed the available nutrients in the pasture, *supplementation* may be indicated. Supplementation is essentially a way to correct for nutritional imbalances. That is, provision of feed in addition to the available forage for grazing or harvested feed to correct for nutritional deficiencies. As noted previously, these deficiencies can be microbial or otherwise deficiencies to the host animal directly. It is important to note that the provision of supplemental feed may correct for the imbalances directly. For example, a pasture that provides inadequate energy for livestock may be supplemented with feed rich in energy such as corn, barley, or other grain. Alternatively, one can provide supplemental feed to enhance the utilization of the base forage. An example of this would be the provision of limited amounts of ruminally degradable protein (RDP) to very low-quality forages in the winter. The provision of the RDP stimulates the work of the rumen microbial populations and in many cases increases intake and digestion of the base forage thereby delivering more energy to the animal. Figure 6 shows the relationship between season and the energy requirements of spring calving beef cows and appropriate times to consider supplementation to achieve production goals. Fall and winter supplementation are classic times to provide the additional nutrients. It is also notable that due to less-than-optimal management such as soil fertility, grazing strategies, and water availability, supplementation may be indicated during other parts of the year and different times in the production cycle (Figure 6).

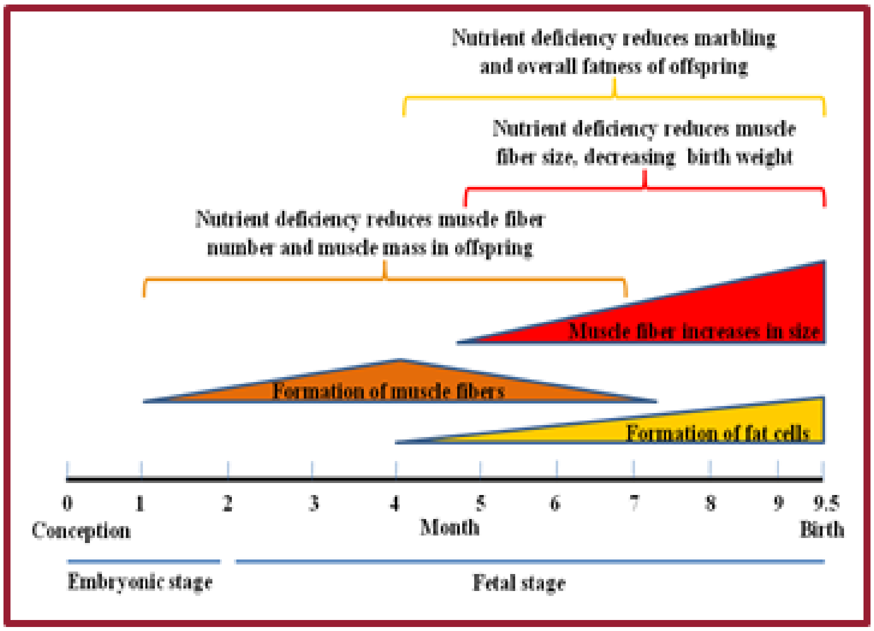

Figure 5. Nutrition of the pregnant cow: Mid-gestation is important for muscle fiber formation and late-gestation accounts for much of the increase in muscle fiber size. Mid-to late-gestation is critical for muscle fiber formation and growth, and late gestation is important for marbling development (Du et al., 2010).

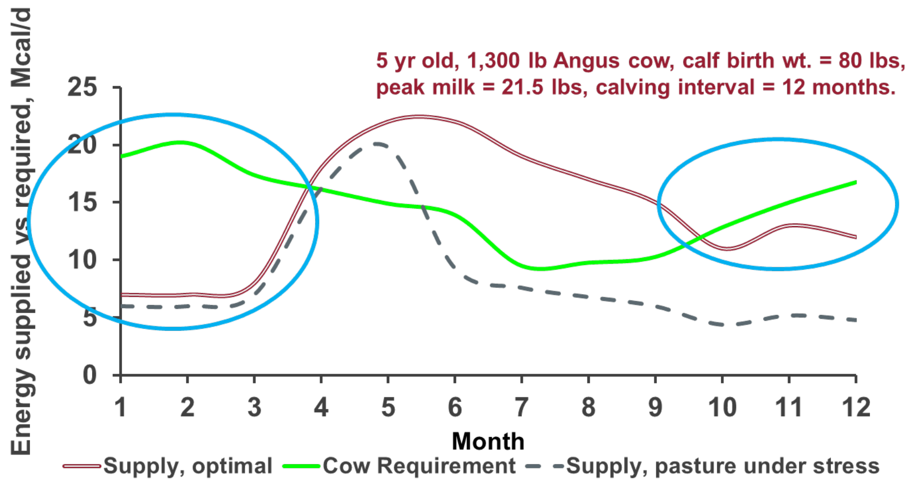

Figure 6. Matching the available forage energy resources to the nutrient requirements of spring-calving beef cows. The maroon- colored series shows the energy supply when management (i.e. fertilization, grazing, water supply) are optimal whereas the black-dashed series shows the potential reduction in nutrient supply when the pasture is under stress from less-than-optimal management. The blue circles depict the likely occurrences when the nutrient requirements exceed nutrient supply at which time supplementation may be indicated. This does not necessarily mean feeding extra energy at times encompassed in the blue circles. Also note that under stressful, less than optimal management conditions, that nutrient supply is less than the nutrient requirements for a significant part of the year. (Adapted from Marston, personal communication 2004).

Low quality forages present both a challenge and an opportunity for producers. The challenge is that in general they are typically not meeting the protein and energy requirements of the livestock. The opportunity is that ruminant livestock can economically utilize low quality forages in a very efficient way if adequately supplemented. An example of this scenario would be grazing or stockpiling of pastures that have reached vegetative maturity. While the pasture may have provided good dry matter yield, it may be low or defi- cient in crude protein. This is particularly common in fall and winter pastures. Protein is usually the first-limiting nutrient in low quality forages, defined as forages with < 7 % crude protein. Not all full vegetative, mature pastures are this low in quality, this is particularly true of cool season grass species in the Pacific Northwest.
The concept of the first-limiting nutrient means that if the first-limiting nutrient is not present in sufficient amounts in the forage, maximum productivity cannot be achieved even if all other nutrients are present to meet their requirements.

Producers often ask why livestock are more productive on high quality pastures or forages than when grazing low quality forages or crop residues? The answer to that question is based in “utilization” of the forage. Each forage is unique in chemical composition, and it is the chemical composition that defines the quality for the forage. It is essential to measure the forage quality of your pasture/forage by chemical analyses at various times throughout the growing season. Where the potential need for supplementation is concerned: "you don't know what you need until you know what you have." Forages are utilized to different extents based on the chemical composition. Young and immature plants are less fibrous and much more easily digestible. In general, young grasses are higher in protein as well. As grasses mature moving toward vegetative maturity, they also tend to accumulate anti-quality components such as silica, and phenolic compounds such as lignin all of which can chemically and physically inhibit degradation by rumen microbes leading to lower utilization and less energy delivered to the animal.

Supplementation of protein to livestock grazing or otherwise utilizing low quality forages has been shown to be very efficient (Llewellyn et al., 2006). The provision of limited amounts of RDP can unlock the energy in the base forage. Where improved pastures are concerned, what type of supplements can be used to provide supplemental protein? In the PNW, the classic protein supplement is alfalfa hay. Provision of alfalfa hay alone to ruminants overfeeds protein and is wasteful. However, when fed in limited amounts in conjunction with a low-quality hay or pasture, it is a great protein supplement. Likewise, other readily available feeds in the PNW can serve in the role as protein supplement, such as canola meal and dried distiller's grains. Each can be fed to address protein deficiencies of late-season pastures and can usually be purchased for a reasonable price as this is written. Molasses-based supplements such as blocks, and lick wheel tanks can serve the same purpose as the hand fed supplements when forage quality needs to be addressed.

Finally, in some cases protein in the forage is adequate, but energy is deficient. In this circumstance an "energy supplement" may be indicated. It is also important to note that protein supplements can be mixed with energy supplements to balance for both protein and energy. Energy supplements can be found in several forms, but grains such as corn, barley, and triticale are typical energy supplements commonly used in the Pacific Northwest. An interesting dynamic in the use of energy supplements is that while they provide additional calories, they also reduce the efficiency of supplementation. In other words, they sometimes depress utilization of the base pasture/ forage rather than only unlocking the potential of the forage and cause the energy feed to "substitute" for the forage. However, this dynamic can be used as a tool when wanting to extend the pasture resource or to increase stocking rate.

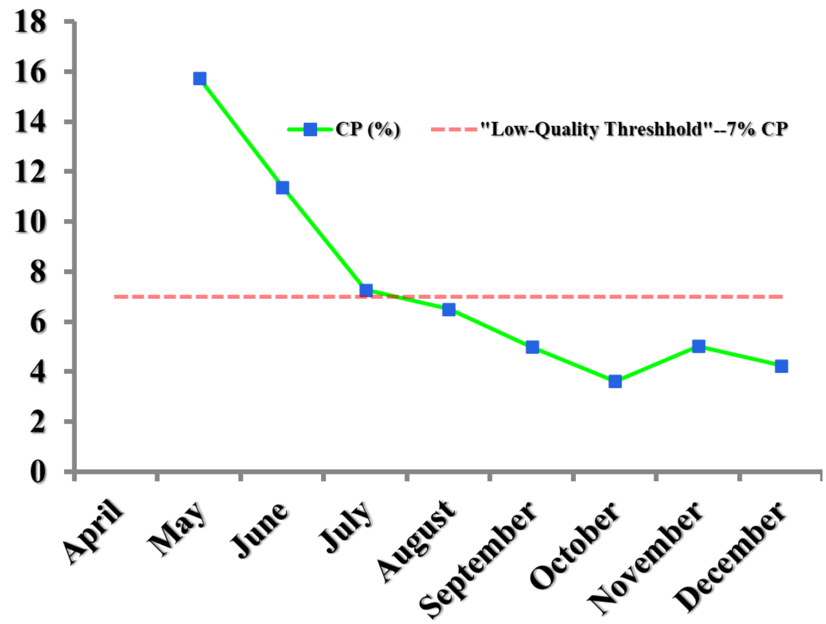

Figure 7. Seasonal changes in crude protein (CP; %) content of Bluebunch Wheatgrass across two years (1992 and 1993). Adapted from Ganskopp and Bohnert, 2001.

Managing pastures in the Northwestern United States requires an inexorable link between matching the nutrient requirements of livestock with the available forage, using techniques and technologies to increase forage utilization (getting the most out of the available forage), and managing in a way that is consistent with maintaining healthy forage resources into perpetuity (i.e. sustainability). Using beef cows as an example: Figure 7 depicts the seasonal changes in crude protein during the grazing season, (the dashed red line denotes 7% crude protein, below which is considered to be of low quality. During those periods forage quality may be low (i.e. crude protein content less than 7%) and cows may benefit from supplemental protein to satisfy the rumen microbes needs for nitrogen and thereby unlock more potential energy from the available forage as a result of increases in forage intake and/or digestion. Using Bluebunch Wheatgrass as an example, a significant portion of the grazing season is characterized by only modest forage quality (less than 7% CP). For spring calving cows in the third trimester of gestation, nutrient demand is low (pasture Growth Periods 3a, 3b, and 4). In fact, during this stage in the cows' production cycle, it is possible to realize very efficient body weight and body condition score gains when supplemented appropriately with protein (Llewellyn et al., 2006), even though the availability of protein in pastures during this period is typically deficient (Figure 7). Another key point is that for spring calving cows, forage quality is at optimum when calves are young and the cows' demand for protein are greatest with cows in early lactation (matching Growth Periods 6a and 6b). Shifting calving season to fall may have benefits for marketing, conserved forage and labor availability, or other reasons that apply to individual and unique operations. However, cows producing winter calves (i.e. born in November—

January) will have the greatest demand for nutrients during pasture Growth Periods 4, 5a, and 5b requiring significant amounts of supplemental feeds for the cows and later for the calves until weaning. Upon weaning, forage availability for fall calves should be adequate in pasture Growth Periods 6a and 6b.

There is a temptation to "turn out" onto pastures too early (pasture Growth Periods 5a and 5b). This is especially true when supplemental winter and spring feed is expensive. However, the long-term implications may be costlier than otherwise expected: Reduction in total forage production for the grazing season; Potential for the detrimental effects of infestation of winter annuals in the pastures; Reduction in the animal carrying capacity; and finally, the cost of rehabilitation of those pastures to reestablish the favorable forage species. Time and patience are key to managing pastures. Allowing sufficient time for soils to warm and forages to establish new and viable root systems and have sufficient top growth (pasture Growth Periods 6a and 6b) will go a long way in achieving healthy and sustainable forages.

Meeting animal demands requires careful assessment (through observation and forage testing) of the amount and quality of available nutrients and then to match those resources to the nutrient requirements of the species and class of livestock utilizing the pasture. In doing so, optimum productivity can be achieved.

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Understanding the Importance of Dietary Fats in Liquid Feeds for Calves

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Milk composition in mammals has likely evolved under evolutionary pressure to ensure the survival and optimal growth of offspring, who depend exclusively on milk during the early stages of life (Davis et al., 1994). These evolutionary adaptations have resulted in milk compositions that meets the specific nutritional requirements of neonates, addressing factors such as growth rate, body composition, and environmental conditions. In the dairy industry, calves are separated from the dam shortly after birth and half of calves are fed milk replacer (**MR**) or a combination of whole milk (**WM**) and MR. While substantial advances have been made in calf nutrition, MR formulations still differ significantly from WM in several key aspects, most notably in fat content, which is typically only half of that found in bovine WM (Wilms et al., 2022). This is counterintuitive as the logical starting point for creating a MR for any species would be to mimic the composition of its natural milk. As a result, nutrient imbalances in MR formulations may disrupt metabolic homeostasis, emphasizing the need to establish nutritional boundaries to support optimal calf development and health.

I) Implications of feeding milk replacers low in fat to calves

Feeding MR with a high fat content increased body fat in calves (Tikofsky et al., 2001). Likewise, a higher nutrient intake from enhanced plane of nutrition allows adipocyte to increase fat stores (Leal et al., 2018). Low-fat MR formulations are common due to the inclusion of dairy industry by-products and are often fed under the assumption that higher fat intake might impair mammary gland development. While fat accumulation in the mammary glands during the post-weaning phase has been linked to reduced milk production (Sejrsen and Purup, 1997; Van Amburgh et al., 2019), there is currently no evidence to suggest that fat deposition in the mammary glands during the pre-weaning phase negatively affects future milk production. In fact, a higher plane of nutrition during the pre-weaning phase has been associated with an increase in mammary parenchyma mass, which may contribute to improved future milk yield (Geiger, 2019). In a study by Soberon and Van Amburgh (2017), calves fed an enhanced plane of nutrition during the pre-weaning phase exhibited not only superior growth, but also increased development of the mammary gland, along with other organs such as the liver, kidneys, and parenchyma. In the same study, the gene expression profile across different tissues, including fat, liver, bone marrow, muscle, pancreas, and mammary gland, highlighted significant differences (Leal et al., 2018; Hare et al., 2019). This shows the need to take a whole-body approach when evaluating dairy calf development rather than solely focusing on mammary development. Calves fed enhanced plane of nutrition gained more fat, with gene expression suggesting increased fat deposition (Leal et al., 2018). In adipose tissues, the gene expression profile indicated a shift toward beige adipocytes (Leal et al., 2018), which is considered more metabolically favorable than white fat, as beige adipocytes are associated with improved energy regulation and health outcomes (Cannon and Nedergaard, 2004). The question of the ideal fat percentage for young calves remains unclear, especially in relation to its importance in calf development and future productivity.

Calves are born with limited fat reserves with only about 3% of their BW as fat (McCance and Widdowson, 1977). Newborn calves rely on lipids and lactose from colostrum and WM to maintain body temperature and build energy stores. Body fat primarily serves as an energy reserve (Cahill, 1982; Norgan, 1997), and the accumulation of fat after birth prepares the animal for future energy challenges. The advantage of using triglycerides (**TG**) as energy storage rather than polysaccharides (glycogen) is due to the reduction level of carbon atoms of FA than those of carbohydrates (Nelson et al., 2008), allowing for more energy to be stored per molecule. In human infants, fat deposition supports the transition from breast milk to solid foods and aids the shift from maternal to endogenous immune protection (Kuzawa, 1998). Fat stores are mobilized during infections suggesting a link between nutritional status to disease outcomes in infants (Kuzawa, 1998). A parallel can be drawn with the early life of a calf, which is marked by numerous stressors, including separation from the dam shortly after birth and the frequent challenge of inadequate colostrum management leading to a dip in immunity during the second week of life. Additionally, calves are often fed low milk volumes (8-10% of birth BW as volume fed; 4-6 litres) (Leal et al., 2021), which is far below the 10-12 litres they would naturally consume when nursing from the dam (Reinhardt and Reinhardt, 1981). These factors likely contribute to the high morbidity observed during the second week of life (Urie et al., 2018). Moreover, many calves are weaned as early as 6-8 weeks of age, though naturally, they would remain with the dam for up to 10 months (Hall, 1979; Reinhardt and Reinhardt, 1981). These disruptions create significant challenges to calf health and may help explain why higher fat intake in liquid feeds was associated with reduced preweaning mortality (Urie et al., 2018). In addition, increasing the energy density of MR by supplementing fat allows calves to maintain BW gain during cold temperatures (Jaster et al., 1992). Calves fed MR high in fat also experience lower morbidity, with improved fecal scores (Amado et al., 2019) and reduced need for medical treatments (Berends et al., 2020). Thus, increasing fat content in MR not only supports energy needs but also enhances overall calf health and development, helping calves to better cope with the challenges of early life in modern dairy production systems.

An imbalanced nutrient profile in MR during early life can negatively affect calf metabolic health, potentially disrupting long-term metabolic homeostasis. Prolonged feeding of MR high in lactose (up to 55% DM) impaired glucose homeostasis and insulin sensitivity in veal calves (Hugi et al., 1997). While high-lactose MR reduced insulin sensitivity of calves in some studies, others found no significant differences (Stahel et al., 2019), suggesting that factors like feeding duration, lactose inclusion levels in MR, and plane of nutrition impact glucose-insulin metabolism. Likewise, calves fed MR high in protein required more insulin secretion after a meal compared to those on high-fat diets (Wilms et al., 2024a). This aligns with the higher serum insulin-like growth factor I (**IGF-I**) of calves fed MR high in proteins compared with MR high in fat (Bartlett et al., 2006; Wilms et al., 2022). High protein intake from infant formula increased the concentration of insulin-releasing amino acids, which stimulate the secretion of insulin and IGF-1 (Luque et al., 2015). This promotes accelerated growth during infancy (Koletzko et al., 2005), but also raises the risk of obesity and metabolic disorders later in life (Michaelsen and Greer, 2014). However, the long-term impact of early insulin and IGF-1 dynamics on the metabolic health of replacement heifers remains unclear. Since milk facilitates biochemical signaling between mother and offspring, it is crucial to carefully consider the metabolic signals transmitted to calves, particularly when feeding MR with significant macronutrient imbalances compared to WM.

II) Fat composition in milk replacer impacts lipid metabolism

Bovine milk fat exhibits unique complexity, containing over 400 different fatty acids (**FA**). The natural FA profile of WM, which shifts over the course of lactation, likely supports the evolving developmental needs of the calf. Fat plays a crucial role in the nutrition of calves, serving as a highly concentrated source of energy and providing essential FA critical for organ development, immune system development, metabolic regulation, and overall health. Yet, competition with the food industry limits the availability of milk fat for use in MR formulation, leading to reliance on alternative fat sources derived from vegetable or animal sources. These alternatives, while effective in providing energy and supporting growth, do not replicate the full nutritional profile of milk fat (Figure 1). Diarrhea in calves has been observed when the fat composition of MR significantly deviates from that of bovine milk fat (Jenkins et al., 1985,1988).

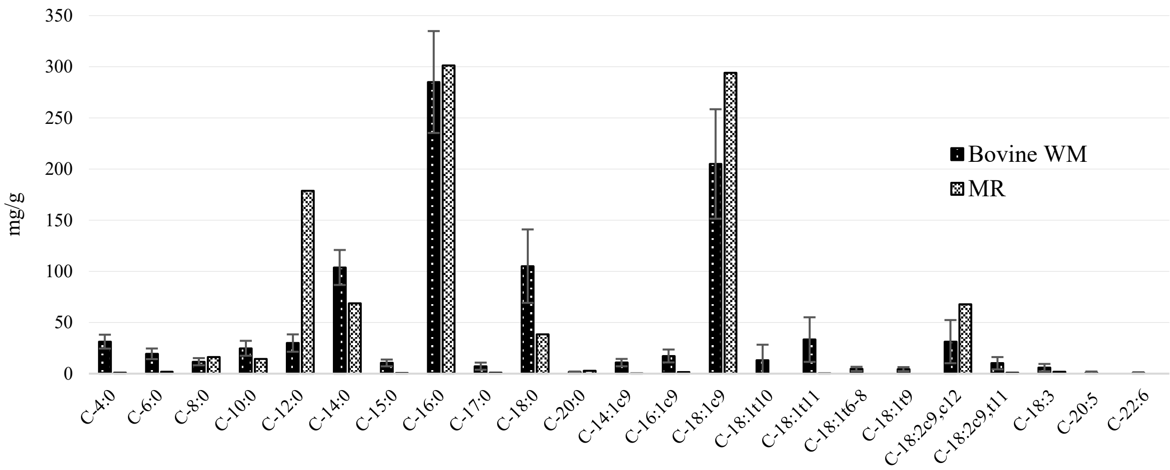

Figure 1. Fatty acid profile of bovine WM (Moate et al., 2007) and a MR containing 65% palm and 35% coconut fats.

Formulating the FA profile (and TG structure) of MR to more closely resemble that of bovine milk fat—by incorporating dairy cream—produced significant benefits, including increased voluntary MR intake in an ad libitum system, which led to enhanced preweaning growth (Wilms et al., 2024b). In contrast, in that same study, calves fed MR containing vegetable fats from rapeseed and coconut exhibited lower preweaning feed efficiency, along with reduced MR intake and preweaning growth (Wilms et al., 2024b). In addition, calves fed MR with rapeseed and palm fats had elevated plasma cholesterol compared to calves fed a MR with lard and dairy cream (Leite et al., 2024; Wilms et al., 2024b) (Figure 2). Notably, Wilms et al. (2024b) reported a shift from a high proportion of high-density lipoprotein (**HDL**) cholesterol, known as "good" cholesterol, to a higher proportion of low-density lipoprotein (**LDL**) cholesterol, often referred to as "bad" cholesterol, in calves fed ad libitum. A study by McNamara et al. (1987) showed that the quality of dietary fat is a more crucial factor in determining plasma cholesterol than dietary cholesterol intake. Indeed, cholesterol synthesis has a significantly greater impact on circulating cholesterol than intestinal absorption of cholesterol. It has been suggested that high cholesterol concentrations in calves fed MR with vegetable fats is related to high levels of polyunsaturated FA in rapeseed oil and to differences in C16:0 positioning on the glycerol backbone between palm oil and animal fats (Leite et al., 2024; Wilms et al., 2024b). Differences in total cholesterol concentration diminished during the weaning transition, suggesting that shifts in blood lipid profiles in response to animal or vegetable fat sources during early life are transient. Nevertheless, it remains unclear whether variations in fat composition and imbalances in lipid metabolism may have long-term consequences for the health and production of future dairy cows.

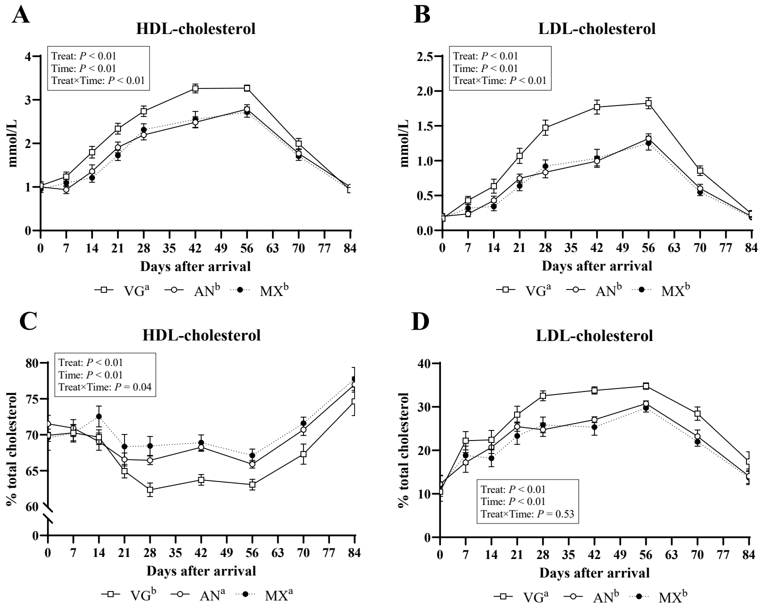

Figure 2. Plasma HDL-cholesterol (A) and LDL-cholesterol (B), as well as the proportion of HDL-cholesterol (C) and LDL-cholesterol (D) on total cholesterol (Wilms et al., 2024b). Treatments included an MR with only vegetable fats (VG, 80% rapeseed and 20% coconut fats, n = 19), an MR with only animal fats (AN, 65% lard and 35% dairy cream, n = 20), and an MR with a mix of 80% lard and 20% coconut fat (MX, n = 20). Means with a different superscript (a, b) in the figure legend are significantly different throughout the study period. Error bars indicate SEM.

III) Restoring butyric acid in milk replacer to promote health and growth

Formulating the FA profile of MR to more closely resemble that of milk fat by incorporating dairy cream has demonstrated significant benefits (Wilms et al., 2024b). However, adding dairy cream to MR formulations is not commercially viable due to its high cost. The positive effects of dairy cream may be partly due to the presence of short-chain FA and medium-chain FA, specifically butyric acid (**C4:0**) and caproic acid (**C6:0**), which are natural components of mammalian milk, but absent in MR. Butyric acid plays a crucial role in promoting gut development and metabolic regulation (Guilloteau et al., 2010). Although C6:0 has received less attention, experiments by Aurousseau et al., (1984, 1988) showed that calves and lambs fed MR with a blend of tallow and coconut fats, along with tricaproin, had higher growth rates and feed efficiencies. Incorporating tributyrin and tricaproin into MR enhanced digestive health, leading to better fecal scores and improved apparent total-tract fat digestibility (Wilms, 2024). These improvements may also be linked to enhanced ileal development and a healthier gut microbiota (Liu et al., 2022; Wilms, 2024). Additionally, tributyrin in MR seemed to promote rumen development in 5-week-old calves (Wilms, 2024), a key factor in the successful transition from a milk to solid feed. Remarkably, enhanced rumen development was observed in calves fed MR with tributyrin and tricaproin although solid feed was not available (Wilms, 2024). This early development likely enabled the calves to consume more starter feed at weaning, resulting in improved growth performance (Figure 3). This suggests that tributyrin and possibly tricaproin play a systemic role in gastrointestinal maturation, as MR bypasses the rumen and is directed to the abomasum through the closure of the esophageal groove. Facilitating the weaning transition through enhanced rumen development reduces stress, a major welfare concern for calves. Conflicting findings between studies regarding growth performance may be related to different MR feeding regimes, the type and method of C4:0 supplementation, the timing of C4:0 introduction, the time of treatment exposure, and the C4:0 inclusion levels in MR. Differences in growth may only become apparent during the late weaning and early post-weaning phases. In a study by Wilms (2024) where calves were fed ad libitum, calf health was also improved, with a 50% reduction in treatment days for illness when tributyrin and tricaproin were included in MR. Improvements in health are likely due to reduced diarrhea severity, stronger gut development, and a smoother weaning transition, all contributing to more resilient calves.

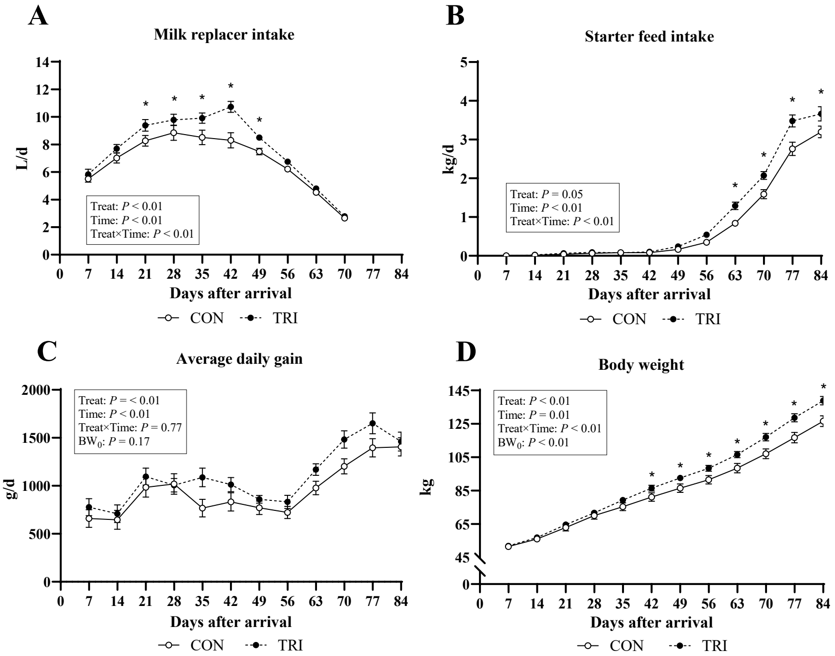

Figure 3. Intakes of milk replacer (A), starter feed (B), and growth (C: ADG, D: BW) in calves (Wilms, 2024b). Milk replacer (13.5% solids) was fed ad libitum from arrival to 42 d after arrival, weaning took place between d 43-70 after arrival, and from d 71-84, calves were fed exclusively solid feeds. Treatments included an MR with vegetable fats (palm, coconut, and linseed, CON, n = 22) and a MR with the same fat blend to which tributyrin and tricaproin were incorporated (TRI, n = 24).

Calves fed MR with tributyrin and tricaproin required significantly less insulin to regulate postprandial blood glucose compared to those fed MR with dairy cream (**MF**) or a control diet, suggesting enhanced insulin sensitivity (Wilms, 2024) (Figure 5). The role of butyric acid in enhancing insulin-glucose metabolism has also drawn attention in human nutrition, particularly for its potential therapeutic benefits in managing diabetes and metabolic syndromes (van Deuren et al., 2022). Furthermore, calves fed TRI displayed lower postprandial TG than those fed a control MR. Calves fed TRI also had lower plasma cholesterol and non-esterified FA concentrations (Wilms, 2024). This was also observed within rodent models and individuals with metabolic syndrome suggesting improved lipid metabolism and liver function (van Deuren et al., 2022). However, while these so called "enhanced lipid markers" are beneficial in humans suffering from metabolic disorders associated with obesity, their relevance to young calves remains uncertain.

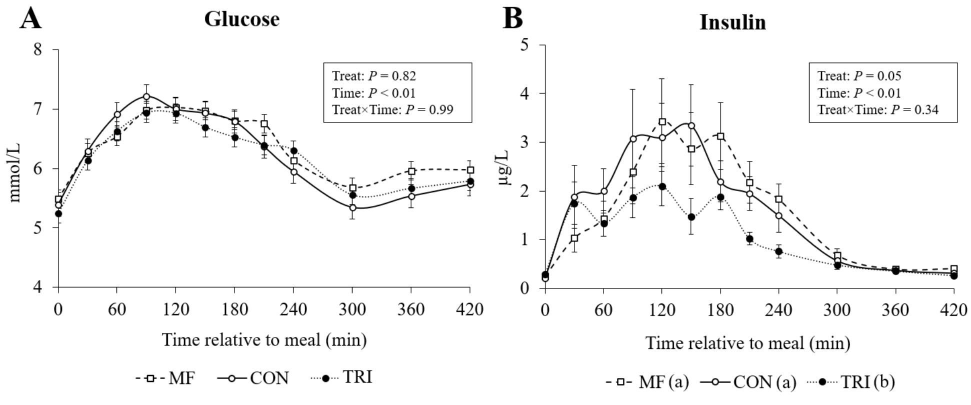

Figure 4. Postprandial glucose (A) and insulin dynamics (B) in calves. Treatments (n = 15 per treatment group) included an MR with dairy cream (MF), an MR with a blend of vegetable oils (palm, coconut, and linseed, CON), and an MR with the same oil blend than CON to which tributyrin and tricaproin were incorporated (TRI). [a,b]Means with a different superscript in the legend are significantly different ($P \leq 0.05$).

Conclusion

Taken together, these findings highlight the critical importance of dietary fats in calf nutrition. Higher fat intake from liquid feed is beneficial for calves as it allows them to build energy stores that can be mobilized during energetic challenges (e.g. low nutrient intake, weaning) and diseases. This likely explains the lower morbidity and mortality in calves fed high fat liquid feeds. When considering fat composition, MR formulations often rely on vegetable or animal fats, which differ from bovine milk fat in terms of FA profile and TG structure. Balancing individual FA by incorporating tributyrin and tricaproin into MR improved digestive health. In addition, tributyrin in MR enhanced rumen development allowing for a substantial increase in starter feed intake, which likely reduces weaning stress. In conclusion, increasing fat inclusion in MR and carefully balancing fat composition to closely resemble WM led to substantial improvements in calf welfare while supporting optimal growth.

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Pasture Economics: Managing for pasture and animal production while mitigating risk

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Introduction

Pasture economics is a challenging measurement because of a variety of stochastic variables, such as temperature and precipitation, that play a vital role in production, as well as plant heterogeneity complicating our evaluation of growth rates. Spatially, there are also vast differences in pasture types and quality – ranging from irrigated pasture with heavy legume components to native rangelands. The economic potential of pasture comes largely from its ability to create forage for livestock – and proper management is essential to keep this forage resource viable over time without the need for costly inputs.

To understand the basics of pasture economics I will first overview the forage production functions and show how pasture regrowth contributes to economic success. The importance of stocking rates and measuring pasture yield will follow, along with a how grazing systems can help to optimize resource use. Finally, I will discuss livestock sale considerations and the various insurance products that are available to help livestock producers mitigate their risk.

Pasture Management and Livestock Economics

The growth of most living things follows a sigmoid-shaped growth curve – growth is rapid when we are young and slows substantially at some point, which we refer to as maturity (Voisin, 1959). Humans, cattle, and plants all follow the same patterns, albeit on different timelines. In economics we think "on the margin" – is next unit of output less than, equal to, or greater than the previous unit. In pastures, unless irrigated, the inputs are largely stochastic, such as temperature and precipitation. However, early in the growth cycle, there is substantially more output for each unit of input and, unlike in animal agriculture, taking advantage of the rapid growth rate is more valuable than waiting for a final mature product.

Grazing forage during the growing season gives the added benefit of regrowth. As long as enough biomass is left over to allow for adequate photosynthetic activity, a grazed plant will continue to grow given the proper inputs (water and light). This is where stocking rate becomes very important. Stocking rate is the number of animal units in a given area for a specific length of time. The rule of thumb for calculating the proper stocking rate is "take half, leave half"; the "take half" refers to the forage biomass that the livestock eat and trample/defecate on not exceeding 50% of total available forage biomass. The amount eaten versus destroyed depends on grazing efficiency, which is typically a function of time spent in a pasture or paddock.

Increasing grazing efficiency and maximizing regrowth potential will result in more pounds of livestock gain coming off a pasture. Accurately estimating the amount of forage available in the pasture can be done in several ways; the most accurate would be the clip-and-weigh sampling method (Ogle and Brazee, 2009) however this method is time consuming and removes forage from the pasture, so the clipping information collected can be calibrated to a grazing stick (Bauman, 2021) for easier future measurements. Once proper stocking rate is calculated, grazing efficiency and maximizing regrowth potential can both be improved by subdividing a pasture with electric fencing and moving animals through sub-pastures in an organized rotation. This first increases grazing efficiency by giving the livestock less forage selection, so they have less ability to roam the pasture for their preferred plants; animals are incentivized to eat what is available to fill their rumens when they otherwise may have passed over. The shortened time component also contributes to decreases in wasted forage; it is more likely that when the animal urinates or defecates, the ground on which it lands has already been grazed, thus not wasting potential forage. Grazing efficiency is positively correlated with stocking density, or the number of animal units within an area of land at a single moment in time, therefore the smaller the pastures and quicker the rotation, the higher the efficiency, but also, the higher the infrastructure and labor input costs. Producers should determine what kind of rotation works best for their operation.

In irrigated pasture systems, rotational grazing often leads to adequate forage regrowth to allow a second grazing within each pasture. In rangeland systems it still increases the grazing efficiency, but returning to already grazed pastures is not typically advised; instead the rotation has the potential to contribute to future rangeland health and increased productivity by allowing a longer rest period. It is important to note that overgrazing leads to decreased pasture productivity for multiple years, especially in low input systems like rangelands where irrigation, seeding, and fertilization are inefficient.

There are several ways in which stocking rate can be used to calculate the value of production for a pasture. Pasture can be leased using a fixed rate per animal (Equation 1), pasture value can be calculated by weighing animals before turning them into a pasture and again when removed and the market value of that gain can be calculated as the value (Equation 2), or the value can be determined by the sale value of calves plus the avoided cost of feeding the dam hay or in a drylot setting (Equation 3) (Neibergs and Westerhold, 2024).

$$Pasture\ revenue = Stocking\ rate * pasture\ rent\frac{\$}{AUM} * \#\ of\ months \qquad \text{Eq. 1}$$

$$Pasture\ revenue = Stocking\ rate * lbs\ of\ gain\ on\ pasture * Market\frac{\$}{lb} \qquad \text{Eq. 2}$$

$$Pasture\ revenue = Stocking\ rate\ of\ dams * \left(calf\ weights * Market\frac{\$}{lb}\right) + avoided\ dam\ feed\ costs \qquad \text{Eq. 3}$$

Pasture rental rates (in Eq. 1) can be charged a variety of ways, with price per animal unit month (AUM) or animal unit day (AUD) being the most common; other ways include price per acre or price per animal. Pasture rent also varies by land type and services offered. Irrigated pasture where the landlord maintains fencing and water infrastructure would be leased for a premium, while native rangeland with no services offered would be priced at a basic rate (Rimbey *et al.*, 2014).

Pasture is typically thought of as a feed resource only during its active growing season, however, stockpiling forage for winter grazing reduces the amount of feed that needs to be purchased or set aside for winter months. Winter feeding of livestock is the single largest expense for livestock producers. Stockpiling lower quality feed in the pasture can reduce total feed costs while also increasing the value obtained from pasture.

When pasture value is determined by weights and market value of livestock (as in Eqs. 2 and 3) there is large variation in both intra- and inter-year values. Intra-year valuation differences result from seasonal changes in demand. Demand is typically highest in the early summer, however in much of the country feeder cattle are sold in October – after the growing season ends. At this time, due to typical supply and demand economics, the price for feeder cattle is at its seasonal lowest. There are potential benefits to selling cattle earlier than the typical October date to take advantage of higher prices, while also 'banking' the forage that would have been grazed for winter use, thus saving on winter feed costs (Baldwin *et al.*, 2022) Inter-year cattle prices fluctuate substantially, with historic price highs seen in 2014-15 and currently in 2023-24. Immediately after the 2014-15 highs, came very low prices in 2016; when pasture value is determined by the sale prices of livestock it devalues the pasture, but in terms of leases it can help mitigate some of the downside risk.

Concerns may arise about the economic losses associated with selling cattle at an earlier date due to the lower weights going to market. Though there would be some profit loss, it would be partially alleviated by the existence of the price slide. The price slide is a phenomenon where lower weight cattle sell for a slightly higher price than their heavier counterparts. This 'slide' is steeper and likely to reward sellers of lower weight cattle when corn prices are low. Similarly, the slide is less steep when corn prices are higher and the cost of putting weight on a steer in the feedlot is higher. Further analysis should be done to determine when selling early and grass banking are most economical, but low corn prices and high hay prices could both be potential indicators.

Insurance and Risk Mitigation Tools

Proper pasture management helps mitigate production risk, however there are still some risks that cannot be perfectly managed for. Drought and livestock market declines are two such risks. Luckily for producers, there are insurance programs aimed at alleviating the consequences of these problems. Two insurance programs offered by the USDA Risk Management Agency (RMA) are Pasture, Range, and Forage (PRF) and Livestock Risk Protection (LRP). PRF was introduced as a pilot program in 2007 to insure pasture or hay ground losses due to below-average precipitation. LRP was established in 2003, however recent changes to the program have increased its popularity. LRP was created to insure producers against declines in market prices. Insurance programs are designed such that producers pay a premium to receive a specified level of coverage; if losses meet or exceed that level, the producer receives an indemnity payment to compensate for the losses. Disaster relief is not an insurance program, but it is another way producers can receive compensation for losses. One specific program for pasture is the Livestock Forage Program (LFP) which provides assistance payments in the event of severe drought or wildfire on grazing lands.

The PRF insurance program is a subsidized insurance based on a rainfall index; each rainfall index covers a 17 x 17-mile grid, which is equivalent to a 0.25-degree change in longitude and latitude. Coverage levels range in 5% increments from 70% to 90% of normal historical precipitation, measured by NOAA since 1948. 70 and 75% coverage are subsidized at 59% of the premium, 80 and 85% at 55% of the premium, and 90% at 51% of the premium. Finally, there are 11 2-month intervals, of which a producer must choose at least two non-overlapping intervals. The intervals are January-February, February-March, March-April, April-May, May-June, June-July, July-August, August-September, September-October, October-November, and November-December.

If a producer leases or owns pasture within one of the 17 x 17-mile grids, they may insure that pasture as either pasture or hay ground, not both. If they insure their acreage for two interval periods at an 85% coverage level, they would need to purchase that coverage by December 1 of the previous year, but they would not need to pay their 45% share of the subsidized premium until September 1 of the following year, after their covered period. If rainfall within either or both of the covered periods was less than 85% of the historical average, then the premium would come out of the indemnity payment paid to the producer.

The LRP insurance program is also subsidized and protects producers from declines in livestock market prices; this program is available for beef and dairy cattle and swine. Coverage can be purchased for 70 to 100% of the expected price at the end of the coverage period, based on futures market pricing. There is not upside risk to this program, if cattle sell for a higher price than a producer insures for, they only have to pay their premium. The length of coverage options ranges from 13 to 52 weeks, in 4- to 5-week gaps and there a two insured weight ranges, 100-599 lbs and 600-1,000 lbs. Coverage can be purchased for cattle ranging from unborn calves to fed cattle, and the same cattle can be covered up to three times in their lives, as long as ownership is retained. Similar to PRF, premium payments are due one month after the end of the insured period.

Finally, the LFP disaster relief program was created to compensate wildfire- or drought-related pasture losses up to 60% of the monthly feed costs incurred due to the disaster. The program is administered through local Farm Service Agency (FSA) offices and relief is tiered by drought intensity. If a county is in a D2 intensity drought for at least 8 weeks, assistance is equal to a one month of payment, a D3 intensity drought for 4 weeks equals 4 monthly payments, and a D4 intensity drought is automatically eligible for 4 monthly payments. If D4 intensity drought persists for over 4 weeks, 5 monthly payments of assistance are paid. If drought forced the sale of livestock in two years prior to the current production year, that producer may still receive

80% of eligible payments. To receive benefits from this program, enrollment within 30 days of qualifying drought conditions at a local FSA office is required.

Conclusion

Proper pasture management is the first step to improving or maintaining the economic value of pasture. Implementing a grazing rotation can yield higher forage returns or provide an alternative to purchased winter feed. Keeping the forage resource healthy over the long term can result in more consistent livestock gains and delayed response to drought conditions. If drought conditions do arise, insurance and disaster relief are options to mitigate losses, and if pasture value is tied to the sale of livestock, there are insurance options to mitigate those losses as well.

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Is there a relationship between residual feed intake and weather resilience?

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Abstract

Extreme temperature fluctuations might have a profound impact on livestock welfare and productivity. Heat stress (**HS**) occurs when external temperatures rise beyond an animal's ability to dissipate body heat effectively. Under HS conditions, cattle typically reduce feed intake to lower metabolic heat production, seek shade, and increase rest periods. Conversely, cold stress (**CS**) arises when ambient temperatures drop below the animal's thermoneutral zone, causing a decline in body temperature. In response, cattle increase feed intake, seek shelter, and activate mechanisms to generate heat and maintain homeostasis. With projections forecasting more extreme temperature fluctuations, the challenges to animal welfare and productivity are expected to escalate, underscoring the critical need to prioritize the selection of weather-resilient livestock.

Residual feed intake (**RFI**) is a widely recognized metric for evaluating feed efficiency across various livestock species. Animals with a negative RFI are considered more feed-efficient, as they consume less feed to achieve the same level of production compared to their counterparts with a positive RFI value, that require more feed to reach equivalent performance. Residual feed intake is calculated by subtracting the expected feed intake from the actual feed intake, using data such as daily feed intake, average daily weight gain, mean body weight, and metabolic weight. Based on the results, animals can be classified as either high-RFI or low-RFI. Five major physiological processes are likely to contribute to variation in RFI, which include feed intake and digestion, metabolism (anabolism and catabolism), physical activity, and thermoregulation. It is estimated that heat production from metabolic processes and physical activity explains 73% of the variation in RFI in cattle, which could directly impact how animals respond to weather conditions. In this proceeding, we will explore how RFI influences cattle responses to both hot and cold environments and how genetic selection based on RFI could be a strategy to improve weather resilience in livestock.

Introduction

In recent years, there has been a significant intensification of extreme temperatures, with projections indicating a global temperature increase of 2.4 to 6.4°C by the end of this century (Nardone et al., 2010). In Canada, such changes have already resulted in extreme weather events. For instance, during the summer of 2021, temperatures soared to 49.6°C in British Columbia, exacerbating drought conditions in the region (WMO, 2021). Simultaneously, due to global warming, the Arctic region has experienced significant melting processes (Zhang et al., 2020), resulting in increased occurrences of cold spells and heavy snowfalls in regions geographically close to the Arctic, such as Canada. This melting contributes to the loss of grounded ice sheet mass in Greenland, which is projected to raise sea levels significantly over the next several decades to centuries (Smith et al., 2020). Additionally, this reduction in ice mass may accelerate airflow velocities, resulting in substantial shifts in global weather patterns (Morard et al., 2010). During the winter months, higher wind speeds can amplify windchill effects, leading to further decreases in surface temperatures in exposed areas (Shitzer and Tikuisis, 2012). These shifting dynamics underscore the critical need for strategies to mitigate the impacts of extreme weather on ecosystems, including livestock welfare and productivity.

The Government of Canada operates numerous meteorological stations to monitor weather conditions across the country, providing public access to this information at no cost (Alberta Climate Information Service [https://acis.alberta.ca/acis/]). From this source, data from 2007 to 2023 at Kinsella in the province of Alberta in Western Canada was analyzed. During the summer, the highest recorded temperatures were 31.3°C, 32.3°C, and 32.7°C, while the lowest winter temperatures were -37.7°C, -36.9°C, and -41.6°C, corresponding to the periods 2007–2012, 2013–2018, and 2019–2023, respectively. Notably, summer temperatures have increased by 1.4°C over the past eighteen years, while winter temperatures have dropped by 4.6°C in the last twelve years, suggesting a trend toward both extremes. This information could serve as an important alert for cattle producers in backgrounding, feedlots, and cow-calf operations across Canada.

Extreme variations in weather have the potential to impact cattle physiology and overall well-being, ultimately affecting animal productivity. Heat stress (**HS**) is characterized by elevated external temperatures that impose a greater heat load on cattle while simultaneously reducing their capability to dissipate body heat (Lees et al., 2019). The physiological changes associated with HS include a decrease in feed intake to mitigate metabolic heat generated during digestion (Collier et al., 2012), increased reliance on shade, and an increase in the duration of lying time in areas with reduced solar radiation exposure (Silva et al., 2021). Additionally, heat stress (HS) can weaken the immune response, as demonstrated by reduced lymphocyte counts after three hours of continuous in vitro exposure to 45°C, along with impaired growth performance in cattle (Nonaka et al., 2007). On the contrary, cold stress (**CS**) occurs when external environmental conditions are extremely cold, and an animal's body is unable to generate sufficient heat to maintain normal body temperature (Roland et al., 2016), leading to hypothermia. This response involves a combination of metabolic and physical adaptations, including increased food intake to meet elevated energy demands (Young, 1983) and a heightened need for shelter to mitigate the effects of wind chill and precipitation (Fogsgaard et al., 2018). Furthermore, cold exposure activates the sympathetic nervous system (Kozyreva et al., 2015), triggering the release of catecholamines, which may suppress immune function (Madden et al., 2003).

Various models have been developed to assess environmental conditions impacting cattle under both hot and cold temperatures. These include the Temperature-Humidity Index (Thom, 1959; NRC, 1971), Black Globe-Humidity Index (Buffington et al., 1981), Heat Load Index (Gaughan et al., 2003, 2008), Adjusted Temperature-Humidity Index (Mader et al., 2006), Comprehensive Climate Index (Mader et al., 2010), and the Index of Thermal Stress for Cows (Da Silva et al., 2014). A more detailed version with equations was previously reported by Herbut et al. in 2018.

Residual feed intake

Beef cattle with a negative residual feed intake (**RFI**) value consume less feed than expected to meet their physiological needs, indicating greater efficiency compared to animals that require more feed to achieve the same production levels (Koch et al., 1963). These animals achieve specific production goals while consuming less feed, demonstrating improved biological or cellular efficiency (Richardson et al., 2004; Herd and Arthur, 2009). As a result, selecting for more efficient beef heifers based on RFI has become increasingly important in breeding programs over the years. Five major physiological processes contributing to variation in RFI variations are feed intake, digestion, metabolism (anabolism and catabolism), physical activity, and thermoregulation. Cattle classified as more efficient achieve the energy requirements for physiological processes more effectively, converting less feed into more body weight and obtaining more nutrients from the same quantity of feed (Castro Bulle et al., 2007). Moreover, more feed-efficient animals demonstrate a comparatively reduced environmental impact, as they produce fewer greenhouse gas emissions from enteric fermentation and manure (Haugen-Kozyra, 2021).

The RFI metric is calculated by subtracting the expected feed intake required for livestock growth and maintenance from the actual feed intake (Arthur et al., 2001; Basarab et al., 2003), which provides insights into how efficiently an animal utilizes the feed it consumes. Studies by Hoque et al. (2009) and Seabury et al. (2017) have shown that RFI's genetic potential has a heritability ranging from moderate (0.21) to high (0.60). This highlights that genetic factors play a significant role in determining an animal's feed efficiency, making RFI a valuable tool for cattle producers in breeding genetically feed-efficient offspring (Herd et al., 1997).

Estimating RFI in beef cattle involves a series of detailed steps. First, individual measurements of daily feed intake and average daily gain (ADG) are collected. Next, a linear regression model is used to predict the expected dry matter intake (DMI) for each animal. This prediction is based on factors such as body weight, average daily gain (ADG), and, in some cases, additional parameters like final ultrasound rib fat thickness (FUFAT). The RFI corrected for FUFAT (RFIf) is then calculated by determining the difference between the animal's observed daily DMI and the expected DMI predicted by the regression model using its intercept and coefficients. This correction accounts for variations in body composition, particularly differences in fat and protein, which influence energy demands. Animals are subsequently categorized as either high or low efficiency based on their RFI values. High RFI indicates less efficient animals that consume more feed than expected for maintenance and growth, whereas low RFI values signify more efficient animals that meet their physiological requirements with reduced feed intake. By incorporating RFIf into evaluations, the accuracy of feed efficiency assessments is improved, offering valuable insights into an animal's metabolic performance while accounting for body composition differences. This refined approach aids cattle producers in identifying and selecting more efficient animals for breeding and management programs.

Residual feed intake as an alternative for extreme environment

Extreme weather conditions, such as heat or cold, influence the productivity of beef cattle raised on pasture (Toghiani et al., 2020) and possibly has a greater impact in less efficient animals. Changes in feed intake, feed efficiency, and performance are associated with seasonal changes in environmental and climatic conditions with those variations being caused by differences in individual adaptation and efficiency of energy utilization (Mujibi et al., 2010). Environmental stress (cold or heat stress) occurs when air temperature deviates from the animal's thermoneutral zone, affecting production or causing discomfort (Webster, 1983). Still, cold susceptibility depends upon specific housing and pen conditions, breed type, nutrition, time after feeding, thermal adaptation, and behavior (Young, 1981). The increased energy requirements for beef cattle associated with thermoregulation during cold and heat extremes suggests that environmental conditions are worthy of consideration when evaluating RFI (Thompson et al., 2018). There is still a lack of research focused on the evaluation of the interaction between cattle feed efficiency in forage-based systems and environment, specifically during the winter season. Such information is necessary to understand the impacts of environment in animal health and production to support more sustainable beef production.

In the ongoing effort to improve livestock efficiency and reduce the environmental footprint to enhance sustainability, studies on RFI have shown promising results not only in improving sustainability but also potential for enhanced weather resilience. We have previously demonstrated that Bos-indicus influenced replacement beef heifers previously classified as thermotolerant based on multiple vaginal temperature measurements collected throughout the summer in Florida had decreased RFI when measured in the fall, indicating the potential of more heat tolerant heifers to be more feed efficient (Silva et al., 2022). Research on Angus steers selected for divergent RFI revealed that heat production from metabolic processes and physical activity accounted for 73% of the variation in RFI (Herd and Arthur, 2009). Animals with higher body temperatures, all else being equal (e.g., feed intake), allocate a greater proportion of feed energy to metabolic heat production rather than productivity. This shift in energy utilization reduces production efficiency, as less energy is directed toward growth or other productive functions (Hill and Wall, 2017). Sprinkle et al. (2019) observed that on cooler days (maximum temperature of 23°C), inefficient cows grazed 1.5 hours longer than efficient cows. However, on hotter days (maximum temperature of 30°C), inefficient cows reduced grazing by 2 hours compared with their efficient counterparts. Authors argue that less efficient cows would be expected to have greater appetite than efficient ones to compensate for increased energy requirements and should increase daily grazing time when conditions are favorable. Yet, greater appetites are accompanied by larger gastrointestinal tracts (Sprinkle et al., 2000), increasing metabolic heat load and reducing heat tolerance. Furthermore, efficient cows exhibited compensatory behavior when compared to less efficient cows following extended periods with elevated summer temperatures. This compensatory behavior enabled these efficient cows to access more difficult terrain and distribute more evenly on rangeland during extended time periods with elevated summertime temperatures. These studies demonstrated a greater energy demand associated with activities in less efficient animals and probably lower thermotolerance capacity in less efficient animals. Richardson et al. (2001) identified a positive correlation between RFI and daily activity, showing that less efficient cattle required approximately 5% more feed energy intake due to their higher activity levels compared with more efficient cattle. Additionally, more efficient animals have lower energy requirements for maintenance (Herd et al., 2003) and produce less metabolic heat as a result of reduced energy waste during digestion (Sainz et al., 2016).

On the contrary, in non-ruminants, Schmitt et al. (2021) reported that new-born piglets classified as less feed efficient had more difficulties to maintain body temperature by displaying lower ear tip temperatures than more feed efficient cohorts. It was concluded that more efficient piglets can better adjust body temperature when required during stressful conditions. Our research demonstrated that less efficient beef heifers exhibited higher plasma leptin concentrations and lower rumen temperatures during winter compared to their more feed-efficient counterparts (Londono-Mendez et al., 2024a). These findings suggest potential thermogenic activity and an increased susceptibility to cold stress in less feed-efficient heifers. Additionally, in first-calf heifers, our group observed that RFI influenced both physiological responses (such as changes in body temperature) and behavioral activity. Less efficient animals displayed a greater number of steps, more standing time, and less lying time during the hottest hours of the day, highlighting a greater sensitivity to environmental stress. These patterns collectively favored the more feed-efficient first-calf beef heifers (Londono-Mendez et al., 2024b).

Selection of cattle based on RFI may promote thermotolerance capacities, as more efficient animals tend to have smaller visceral organs, including the liver (Zhang et al., 2017). This suggests that more feed-efficient cattle generally exhibit relatively lower liver weights compared to their less efficient counterparts (Basarab et al., 2003). Moreover, it is well established that the liver can be approximately 1°C warmer than other core tissues (Sessler, 2005), potentially contributing to an increased heat load under HS conditions in less efficient animals. A smaller liver size in more efficient animals may therefore enhance thermoregulation under extreme heat, providing them with a physiological advantage in maintaining productivity and well-being in hot environments. Furthermore, Llonch et al. (2016) assessed cortisol levels following stress-inducing events, such as transportation, and found notable differences in cortisol responses among cattle with varying RFI levels. These findings suggest that cattle with more efficient metabolism may have improved stress tolerance, which could positively impact their overall feed efficiency. However, the association between feed efficiency and thermotolerance has not been thoroughly explored (Silva et al., 2022), especially during both cold and hot conditions.

Conclusions

Residual feed intake represents a promising avenue for improving both feed efficiency and thermotolerance in beef cattle, offering potential solutions to mitigate the challenges posed by extreme environmental conditions. The intricate relationship between feed efficiency and environmental stress highlights the importance of selecting animals with superior metabolic and thermoregulatory capacities. More feed-efficient cattle demonstrate advantages such as reduced energy requirements for maintenance, better control of stress responses, and lower metabolic heat production, contributing to enhanced weather tolerance. These attributes position RFI as a valuable tool for not only enhancing cattle productivity and reducing the environmental footprint of beef production but also improving animal welfare in the face of challenging climatic conditions. However, further research is needed to fully understand the interaction between RFI, environmental stressors, and long-term cattle performance, particularly in forage-based systems during winter. Such insights will play a critical role in developing sustainable breeding programs that align with the industry's goal of producing resilient and efficient animals capable of thriving in diverse and extreme environments.

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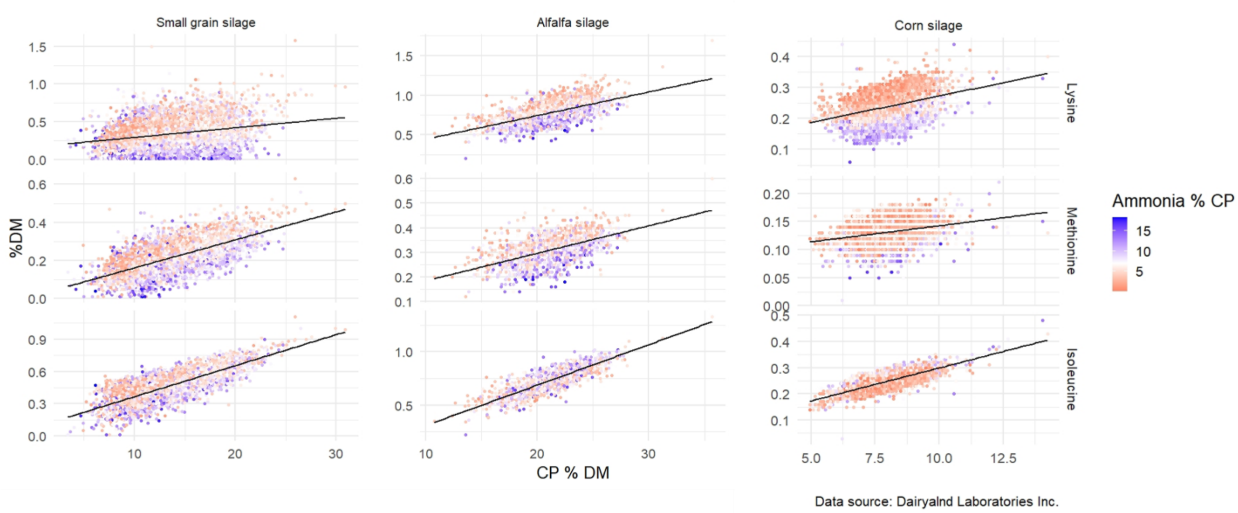
Are Poor fermentations Degrading Silage Amino Acids?

DAIRYLAND
Laboratories, Inc.

Over the first year of including amino acids in NIR packages for silages, we've observed these trends:

- Silages with high ammonia (or soluble protein) consistently contain lower amino acid levels
- Some amino acids are impacted more than others



What might be causing these trends?
It looks like amino acids are being deaminated due to poor or extended fermentation during ensiling. As bacteria and fungi break down proteins, deamination results in ammonia production (raising ammonia while lowering amino acids). Clostridium species are especially known for their proteolytic and deaminating activities.

But why are some amino acids being degraded more than others? Lysine has a unique structure with a side chain amino group, which could make it more susceptible to deamination. Methionine and cysteine are unique in that they contain a sulfur atom, which can cause them to be targeted preferentially by bacteria and fungi. In contrast, isoleucine, leucine, and valine are branch chain amino acids with more hydrophobic side chains, which could make them less susceptible to microbial attack.

Are Poor fermentations Degrading Silage Amino Acids?

DAIRYLAND
Laboratories, Inc.

How much does this matter?
In this example diet, moving the silages' amino acids and ammonia from a standard deviation on one side of average to the other changed CNCPS predictions of MP allowable milk 2 lbs, MP supply 44 grams, lysine supply 5 grams, and methionine supply 1 gram.

Feed	Lbs/day DM
Corn silage	15
Alfalfa silage	15
HMSC	10
Protein/mineral mix	10
Total	50

Parameter	1 SD high	1 SD low	Difference
ME allowable milk	83.2	83.1	0.1
MP allowable milk	83.6	81.5	2.1
MP Supply (g)	2518.8	2474.7	44.1
Lys (g)	171.7	166.4	5.3
Met (g)	54.0	52.7	1.3
His (g)	74.8	71.9	2.9

Within this "normal range" of silage qualities the magnitude of impact isn't severe, but silage quality is not evenly distributed, and the long tail of poorer fermentations can get ugly. How much MP is truly being lost in those small grain silages where ammonia runs over 30% of CP and lysine approaches 0? or those butyric haylages where ammonia averages 20% of CP?

NIR measurements of lysine, methionine, histidine, leucine, and isoleucine are included in Dairyland's CNCPS and NASEM Complete packages for all forages and several non-forage ingredients. Combined with XML imports, these impacts of fermentation quality on amino acid concentrations are accounted for in most formulation software by default.